Engineer On a Disk

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1. TABLE OF CONTENTS

2. INTRODUCTION

This section contains adminstrative materials from some of the courses I have taught before. This includes syllabi, lab guides, etc. The courses that begin with ’EGR’ have been taught at Grand Valley, all other courses have been taught elsewhere.

EGR 209 - STATICS AND MECHANICS OF MATERIALS

3. BASIC STATICS

3.1 PHILOSOPHY

• The only way to learn statics is by solving problems.

3.2 RESOURCES

1. Read the textbook chapters as indicated, and try suggested problems, they should serve as a reasonable approach to the topic.
2. Compare your solutions (after they are completed) to other students.
3. When stuck, ask the professor detailed questions. Points 2 and 3 will help you learn to overcome problems yourself, instead of depending upon others.
4. It is not recommended until all else fails, but books may be found in the library or purchased. If you decide to use another source, read a few problems in any book you are considering to make sure they suit your style.

3.2.1 Bibliography

Bedford, A., Fowler, W., “Engineering Mechanics Statics”, Addison-Wesley Publishing Co., Inc., 1995.

Beer, F.P., Johnston, E.R., Statics & Mechanics of Materials, McGraw-Hill, 1992.

Gere, J.M., Timoshenko, S.P., Mechanics of Materials, fourth edition, PWS Publishing, 1997.

Hibbeler, R.C., Engineering Mechanics: Statics and Dynamics, 6th edition, MacMillan Publishing Co., New York, USA, 1992.

Pytel, A., Kiusalaas, J., Engineering Mechanics; Statics and Dynamics, Harper Collins, 1994.

Sousta-Little, R.W., Inman, D.J., Engineering Mechanics; Statics, Prentice-Hall, 1997.

3.3 ASSIGNED HOMEWORK

- The assignments are to be done INDIVIDUALLY from beginning to end. My experience shows that study groups are of great help, and will help a student get by many small problems quickly. But students who never do any problems individually (i.e., assignments) always do poorly when they must solve problems themselves on exams.

- Stassen's Ten Commandments for Assigned Calculations

The following format requirements must be met before an assignment will be accepted or given credit.

1. The problem must be clearly identified at the top left of the page. The name of the author must be placed at the upper right-hand corner of the front page.
2. All calculations must be shown and a clear "heading" must be given with each step of the calculations.
3. All units must be attended to properly in balanced equations. Answers without units are not valid, except 0, variables, or unitless values such as ratios.
4. Where applicable, references must be given for all uncommon relationships or empirical values obtained from textbooks.
5. Clear diagrams must be provided where necessary.
6. Do not use unnecessary terms like "I" or verbose terms such as "to find", etc. It is expected that proper and concise statements are made where needed.
7. At the conclusion of each problem the final result must be clearly summarized and indicated.
8. Where necessary a conclusion should be drawn or a final comment made. Sometimes a recommendation is necessary and should be included in the report.
9. Reports must be written on one side of letter size paper. Only in the case of graphic solutions can "odd" paper sizes be used, but these must be folded to size.
10. Calculations should progress in a logical and sequential manner to the final result.

**** NOTE: A good maxim for overall appearance is that the work should be ready for typing, or done in a package such as mathcad.

3.3.1 EGR 209 Textbook Problems

- The list below should be final for fall 1998 (any corrections will be announced during class).

Book	Read Sec.	Description	Problems Suggested	Required
SLI	1.1-1.6	Definitions, units	1-9	
SLI	2.1-2.3	Forces & vectors	2, 4, 13	15(WM), 16(MC)
SLI	2.4-2.5	3D Forces	48, 51, 55	
SLI	2.6-2.7	Matrices/equations	67, 70	64 (MC)
SLI	2.8	Dot Product	78, 84	93(use fig 2-92) (MC)
SLI	2.9-2.10	Particles	105, 110	108(WM), 113(MC)
SLI	2.11	Springs and indet.	114, 115	115(WM)

GT	1.1-1.2	Axial Stress	2-1,2-2,2-5	
GT	1.3-1.5	Stress/Strain	3-4,3-6,4-1,5-6	
GT	1.6	Shear Stress	6-2,6-10	8-4(MC)
GT	2.1-2.3	Axial Strain	2-1,2-13,3-8	3-10(MC)
GT	2.4	Indeterminate Probs		
GT	2.6	Oblique Stress Planes	6-10	6-18(MC)
SLI	3.1-3.2	Scalar Moments	6, 9	
SLI	3.3	Vector Moments		
SLI	3.4-3.5	Moment About Point	26, 38	
SLI	3.6	Moment About Line	57	
SLI	3.7	Couples	64	68(MC)
SLI	3.8	Moving Forces	74	
SLI	3.9-10	Moving Forces	83	82(WM pin at corner)
GT	3.1-3.4	Torsional Deflection	3-4, 4-7	3-11(MC)
GT	3.5-3.6	Torsion Strains	5-5	5-6(MC)
SLI	4.1-4.3	Center of Mass	5, 18	
SLI	4.4	Pappus and Guldinus	26	
SLI	4.5	Composite Bodies	41, 48	38(WM)
SLI	4.6	Distributed Loads	52, 59	50(MC)
SLI	5.1-5.4	Rigid Bodies	6, 9, 10	
SLI	5.5	2D Equilibrium	13, 20	43(MC), 43(WM)
SLI	5.6-5.7	3D Equilibrium	69, 80	
GT	1.7-1.8	Design and Safety		
GT	2.9	Cyclic Loading		
GT	2.10	Stress Concentration	10-6, 10-7	10-9(MC)
GT	3.7	Torsional Power Shafts	7-6	7-7(MC)
GT	3.11	Torsional Stress Conc.	11-4	11-5(MC)
SLI	6.1-6.5	Method of Joints	7, 16	8(MC), 8(WM)
SLI	6.6	Method of Sections	32, 48	47(MC)
SLI	6.8-6.9	Method of Members	81, 92	94(MC)
SLI	7.1-7.2	Internal Forces	4, 17	
SLI	7.3-7.4	PVM Diagrams	21, 22	33(MC)
SLI	9.1-9.4	Second Moments	1, 8	
SLI	9.5-9.6	Parallel Axis/Gyration	22, 29	
SLI	9.7	Composite Areas	37	43(MC)
GT	5.1-5.6	Beam Design	4-4, 5-8	4-6(MC), 5-17(MC)
GT	5.8	Transverse Loading	8-3	8-10(MC)
SLI	8.1-8.2	Friction	11, 51	58(MC), 58(WM)
SLI	8.3	Wedges	73, 84	
SLI	8.5	Belts	108	

3.3.2 EGR 210 Textbook Problems

• This is the final problem list for Fall 1998

Book	Sections	Description	Problems
TG	1.1-1.6	Stress/Strain	Suggested: 2-1,2-2,2-5,3-4,3-6,
			Suggested: 4-1,5-6,6-2,6-10
			Required: 8-5(mathcad)
TG	2.1-2.3	Axial Strain	Suggested: 2-1,2-13,3-8
			Required: 3-10(mathcad)
TG	2.6	Oblique Stress Planes	Suggested: 6-10
			Required: 6-18(mathcad)
TG	2.9	Cyclic Loading	Suggested:
			Required:
TG	2.10	Stress Concentration	Suggested: 10-6, 10-7
			Required: 10-9(mathcad)
TG	3.1-3.4	Torsional Deflection	Suggested: 3-4, 4-7
			Required: 3-11(mathcad)
TG	3.5-3.6	Torsion Strains	Suggested: 5-5
			Required: 5-6(mathcad)
TG	3.7	Torsional Power Shafts	Suggested: 7-6
			Required: 7-7(mathcad)
TG	3.11	Torsional Stress Conc.	Suggested: 11-4
			Required: 11-5(mathcad)
TG	4.1-4	PVM Review	Suggested:
			Required:
TG	5.1-5.6	Beam Design	Suggested: 4-4, 5-8
			Required: 4-6(mathcad), 5-17(mathcad)
TG	5.8	Transverse Loading	Suggested: 8-3
			Required: 8-10(mathcad)

3.4 BRIDGE BUILDING COMPETITION

Objective: To use simple materials to construct a bridge with the highest strength to weight ratio.

Scope:

1. Students will be expected to build a prototype as well as a final bridge design.
2. Students will be expected to produce a report explaining their design strategy.

Rules:

A list of acceptable materials and the official rules will be provided in class.

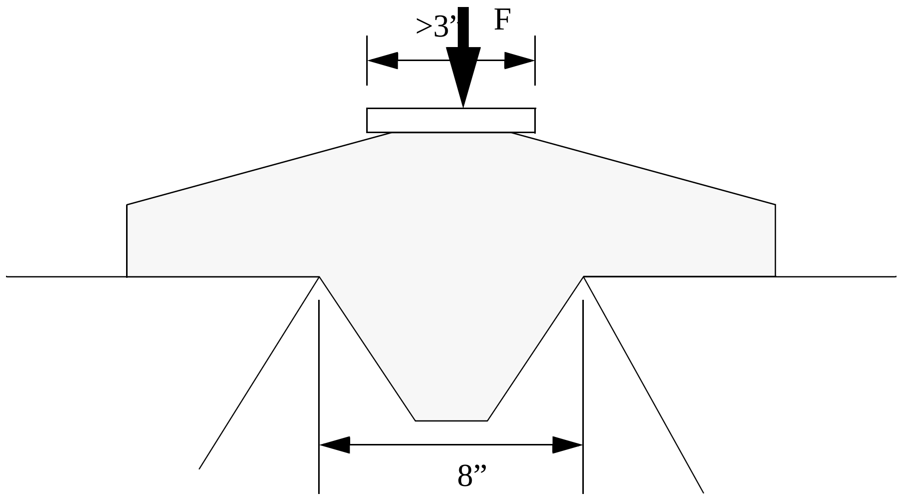
Evaluation:

1. All bridges will be checked for conformance to rules.
2. A ratio of failure load to the weight of the bridge will be used to judge performance.

3. Grading will be based on the report.

The Test Stand:

The bridge will be mounted between two 1”x6” bars approximately 8” apart.



The bridge will be loaded on the upper surface until failure by a ram that is between 2 to 3 inches wide and long. The top loading area must be no larger than 3 inches by 3 inches at the center of the bridge.

A computerized testing machine will be used to load the bridges and produce stress-displacement graphs. The bridges will be loaded until failure. Failure will be measured using engineering judgement. A catastrophic failure will be complete and self evident. A graceful failure will be when the structure is still standing, but will evidently failure. A ratio of failure load to weight ratio of the bridge will be used to rank the performance.

Hints:

1. Heavy is not necessarily better (an ant would outperform a human with the strength to weight ratio.
2. Triangles form stable supports in a solid structures. You should be able to identify a visible path for the force to flow to the ground.
3. Try building prototypes first to test the structure.
4. Consider various beam types. Most bridges that win have beams made of special beam sections.
5. Buckling will be a major concern. The buckling load calculation can be found in the textbook. Basically in compression, beams should be shorter, or have stabilizing (zero force) members, or be made thicker.
6. One of the most common points of failure is joints in tension. These require more care in design and construction.
7. Careful construction will increase the strength. When loaded the geometry of the bridge will change. Small distortions will become a source of failure.

3.5 BEAM BUILDING PROJECT

Details will be provided in lectures.

3.6 INTERNET RESOURCES

3.7 How to Send and Receive email

1. You will need your user name and password to access your e-mail account.
   Username - Usually first six letters of your last name and the first letter of your first name.
   Examples: John Farris ---> farrisj
   Ron Smith ---> smithr
   Lefty Moskowitz ---> moskowl
   Password - Your student number, usually your social security number
   If you do not know your pass word type "reset" at the login prompt and follow the instructions. Your pin is the four numbers representing the month and day of your birthday. For example if you were born on September 18 your PIN is 0918.

2. Open Netscape Communicator by double clicking on the Netscape Communicator Icon on the desktop.

3. Input User information into Netscape Communicator.
   A. Under the Edit pull down menu select Preferences.
   B. A pop up window will appear and with a sub menu titled Category. Single click on the "+" sign to the left of the Mail & Groups category. This will reveal more choices.
   C. Single click on the Mail Server sub group and input boxes will appear to the right.
   D. Enter the information below in the correct box.
      Mail server user Name: Your River user Name
      Out Going Mail server: river.it.gvsu.edu
      Incoming Mail server: river.it.gvsu.edu
      Note: "Leave messages on server after retrieval" box should be checked.
      E. Single Click on the Identity sub category under the mail and groups category. Enter your name and email address in the appropriate box. Your e-mail address is your river user name followed by "@river.it.gvsu.edu"
      F. Click on the OK button at the bottom of the pop up window to close the window.

4. Viewing incoming e-mail and sending e-mail.
   A. Under the Communicator pull down menu choose Messenger Mailbox. This will bring up a new widow that displays your messages. To read a message simply click on the message.

B. To send a message select New Message under the Message pull down menu and fill in form.
C. Send a message to the lab instructor to show mastery of the e-mail system

3.7.1 How to Browse the Web

1. Open Netscape Communicator by double clicking on the Netscape Communicator Icon on the desktop. The Icon is shown below.

2. The Location shown at the top of the page is the name and location of the file displayed. use the mouse and the keyboard to enter in the locations and files listed below to explore other internet sites.
   http://engineer.gvsu.edu - Information about the engineering program at GVSU.
   http://patent.womplex.ibm.com - Patent information.
   http://www.evworld.com/ - Information about electric vehicles.
   http://www.sdp-si.com - Information about standard mechanical parts. Order a catalog here.
   http://bignerds.com/ - student site
   yahoo.com - search site.
   http://www.mmsonline.com/ - Modern machine shop magazine.

3.7.2 How to Download Files from the Web

1. Downloading pictures or images from the internet.
   A. Pictures or images can be saved to incorporate them into documents or your own web page. To save an image simply position the cursor over the information and click the right mouse button. This will cause a pop-up menu to appear. Click on the Save Image as... button. Another dialogue box will appear. Specify the name of the file you would like to save the image as and its location in the pop up menu. Finally click on the Save button. Do not forget the name and location of the file!!!!!

2. Downloading files from the internet.
   A. Some links on web pages are files that require your computer to have software loaded to view the files. The web browser will ask what software you would like to use to open the file or where you would like to save the file. For security reasons always save the file before running the file. As an example go to the site http://www.engineer.gvsu.edu/faculty/default.htm and click on John Farris, then click on EGR 101 Information and finally on Download Border. Try to save this file to your floppy disc.

3.7.3 How to Store Files on river and Publish a Web Site

3.7.3.1 - Overview

When you register for classes the computer administers give you 5 megabytes of storage space on the river web server. You can store files, back up files, share files with colleagues and publish your web page in this space. By placing files in your "public_html" directory on river, you can publish them to the world. If your river user name is "smithm", then your web pages will be found on the web at **www2.gvsu.edu/~smithm**. For example, if you put a file "homework1.htm" in your public_html directory, then you can view it from your browser (e.g., Netscape) at www2.gvsu.edu/~smithm/homework1.htm.

If no file is specified, the browser will attempt to display the file "Welcome.html" from your public_html directory. Because of this, people usually name their Home Page file "Welcome.html".(note capitalization) If Welcome.html does not exist a list of files in the public_html directory is displayed.

You publish web documents by transferring them to your river account using FTP. FTP stands for "File Transfer Protocol", a standardized way that has evolved for one machine to send files to another. The steps to do this are described below.

3.7.3.2 - Setting disc space on the river server (this step is only done once!!!!)

A. Double click on the river Icon to connect to river.
B. Enter your river user name and pass word.
C. Enter "Z" to access the Unix shell.
D. Type "makeweb" at the Unix prompt. This command creates your public_html directory.
E. Type "exit" to leave the Unix shell and type "exit again to leave river.

3.7.3.3 - Transferring files with FTP

Once *public_html* is created, use an FTP program to transfer files from your local machine to river. You should have an FTP (Windows) program somewhere on your machine if you are a PC user. Use the FTP program to transfer your web page document from your local directory to your *public_html* directory on *river.it.gvsu.edu*(the remote directory). One easy to use FTP program is WS_FTP 95 LE. It is already installed on the computers in all GVSU computer labs.

3.7.3.4 - Using WS_FTP 95 LE

A. Double click on the "WS_ftp 95 LE" Icon on the desktop.

B. Enter the information below except your river pass word. The program will prompt you for the password. If you enter your password at the prompt, the program will remember your password and it will be available to subsequent users.

Host Name/Address: **river.it.gvsu.edu**

Host type: **Automatic Detect**

User ID: **(your river username)**

Password: **(your river password)**

C. After a successful connection is made a window divided into two sections will appear. The left side shows the contents of your local machine and the right side shows the contents of the river machine. To transfer a file to your public_html directory on river:

In the right side window click on the public_html folder. This will direct the files transferred into your public_html folder.

Highlight the files you want to transfer in the left hand window and then click on the right facing arrow key between the windows to initiate the transfer. The file will appear in the right hand side window when the transfer is complete.

Files can be downloaded from your river space to your local machine by highlighting the file in the right side window and clicking on the arrow that points toward the left.

3.7.3.5 - Creating an html file

A. Downloading template

The easiest way to create a home page or html document is to modifying an existing one. A simple template can be found by going to the site http://www.engineer.gvsu.edu/faculty/default.htm, clicking on John Farris, then clicking on EGR 101 Information and finally on View, edit and download web page template. This will bring up a simple, generic web page that you can customize.

B. Modifying template

To modify the template go under the File pull down menu and select the Edit Page option. This will launch Netscape composer program which will allow you to modify the page. Before modifying the page you must save the file to the hard drive or floppy drive of your local machine. This is done by selecting the Save As... option under the File pull down menu. Be sure to enter a file destination on your local machine!!!!

After the file has been saved the text can be modified much like the way text in a word processor is modified. Practice modifying text by customizing the header. Save the file after each modification.

C. Adding a picture to your web page

To insert a picture:

Position the cursor where you want to add the picture To insert a picture:
1. Position the cursor where you want to add the picture
2. Click on the Insert pull down menu and select Image.
3. Enter the file name of the image you would like to insert.
4. Click on the OK button. Note the picture may not appear on your page. Do not panic yet.

D. Adding a link

A link is simply some text that will display cause your browser to jump to another web page or file when the text is clicked upon. To insert a link:
1. Highlight the text that you want to include in the link
2. Click on the Insert pull down menu and select Link.
3. Enter the file name or web address of the link you would like to insert.
4. Click on the OK button.

E. Adding an e-mail link

A mail link is link that allows people to send you e-mail. To modify the e-mail link on the bottom of the page:
1. Right click on the "E-MAIL ADDRESS" text.
2. Select Link Properties.
3. Enter your e-mail address after "mailto:". For example my link reads mailto:farrisj@gvsu.edu.
4. Click on the OK button.

3.7.3.6 - Publishing Your Web Page

To publish your web page so that others may view it follow the following steps:
1. Save the file you are modifying on your local machine as Welcome.html. The w must be capitalized.
2. FTP the Welcome.html file to your Public_html directory using directions presented earlier
3. FTP any image or other files that are referenced by your Welcome.html file to your Public_html directory. If this is not done the pictures or other files will not be displayed.
4. To check your web page, open Netscape communicator and type in the address of your web page. You may need to click on the Reload button at the top of the window to get the most recent copy of your Welcom.html file to be displayed.

3.7.3.7 - Glossary

Browser: A Browser is the software that lets the user access web pages on the internet. Examples of browsers are Netscape and Microsoft Internet Explorer.

FTP: File Transfer Protocol, a protocol computers use to transfer pretty much any type of file to one another.

HTML: HyperText Markup Language, a language that is used to create web pages. From Netscape, you can view the actual HTML file that is used to create the web page you see by choosing "View" and then "Source". For more information, see "A Beginner's Guide to HTML".

HTTP: HyperText Transfer Protocol, a protocol web servers (such as www2.gvsu.edu)and browsers (such as Netscape) use to transfer web documents.

URL: Uniform Resource Locator, an addressing system that allows you to uniquely address a file on the internet. Assumes addresses are of the form *protocol://server/path/filename*. An example is *http://www2.gvsu.edu/~stuindex/users.html*.This indicates we are addressing a web document (*http://*) that is on the server called *www2.gvsu.edu*. The file on that server can be found down the path called *~stuindex* (a weird UNIX way of naming a path, or series of folders), and the name of the file is *users.html*.

Web Server: A machine on the internet that is able to publish web documents. decision

3.8 CREATING WEB PAGES

• The instructions below should help with the general procedure of creating a web page. Additional help can be obtained from the course instructor, or from the lab assistants in Henry Hall.

• The general steps are,

1. Get a computer account on 'claymore.engineer.gvsu.edu' from Prof. Jack. This account will have a prototype web page that you can edit.
2. Go to a laboratory (HRY 113 or EC 616), or home computer and run 'Netscape Gold'. Go to 'claymore.engineer.gvsu.edu' and look for your account under 'students'. You should be able to find a page that starts with 'YOUR_NAME_GOES_HERE'.
3. In Netscape (with your home page showing), select 'edit' from the tool bar, or under 'file' select 'edit' or 'edit page'. You will be asked if you want to save the page. Create a 'temp' directory on the computer. This directory will be used to temporarily hold your web page files. Make sure that the files will be saved in the 'temp' directory, and then 'save' the files. An editor will start on the screen.
5. The editor behaves much like Microsoft Word, with some subtle differences. At this point add your name, and change your email address to your river account.
6. To upload the changes you have made to the website, under 'file' select 'publish'. You will need to indicate the destination as 'ftp://claymore.engineer.gvsu.edu/home/YOUR_NAME/public_html'. You will also need to enter your user name and your password (DO NOT SAVE THE PASSWORD - SOMEBODY ELSE CAN GET ACCESS TO YOUR ACCOUNT). You should see a message that indicates files are being uploaded successfully.
7. Use Netscape, not the editor, to see if the changes have occurred. Your changes may not show up on the browser. This is because Netscape does not reload pages every

time to look at them. Pages are stored for up to 1 month, and reused when you look at them. There are two ways to update the screen before this time click on the reload button.

8. Next we will links to your home page. First, run Mathcad, and create a simple file, and then save it in the same folder/directory you saved. Use a file name that is all lower case such as ‘test.mcd’ - any upper case letters cause problems in Windows 95.
9. Get your home page back in the Netscape editor. Someplace type the word ‘GVSU’. Use the mouse to select what you just typed, and then click on the link button. For the link name enter ‘http://www.gvsu.edu’, and apply the change. This will now be a link to the Grand Valley home page. For your mathcad file type something like ‘Mathcad file’, highlight it, and add a link to ‘test.mcd’. This link will connect to your Mathcad file.
10. Publish the file, but this time click the option ‘include all files in folder’.
11. Test the page.

• Some tips are,
  - Windows will not allow multiple applications to open the same file at the same time. If you seem to be having trouble opening a file, make sure it is not open in another application.
  - As you add other files to your homepage, put them in the ‘temp’ directory. This will make all of the procedures simpler.
  - Try to make your web pages small, and link them together. This will decrease download time and make browsers happier.
  - Avoid using excessive images. Anything over 10K will make it very slow downloading over modem. Anything over 100K makes modem downloading painfully slow.
  - When putting images on the web page use ‘jpg’ for photographic images, and ‘gif’ for line images. ‘jpg’ images can be compressed more than ‘gif’, but lines will become blurred.
  - To link to other files or web pages there will be a ‘link’ command. If you want to add a file that is in your ‘temp’ directory, just put the name of the file in the ‘URL’ field.
  - Watch upper/lower case. This is a major cause of web page problems.

3.9 STATICS REVIEW TOPICS

Forces
- 2D
  - cartesian
  - polar
  - concurrent/coplanar/parallel
- 3D
  - right hand axes and position rotations about axis
  - direction cosines
  - projected

        - cartesian
    - Topics
        - resultants
        - forces with magnitude and unit vector
        - projecting forces with dot/scalar products
        - angles between forces with dot products
        - two force members
- Moments
    - Calculating
        - shortest distance
        - perpendicular components
        - cross/vector product
    - Couples
        - movability
        - equivalent force couple pairs
- Equilibrium
    - Particle
        - concurrent forces/parallel forces
        - force triangles
    - Rigid bodies
        - free body diagrams
        - action/reaction
        - supports, decomposition, and indeterminate problems
        - pulleys/springs/rollers
        - sum of forces/moments
    - Method of members
- Trusses
    - Supports/tension/compression
    - Zero force members
    - Method of joints
    - Method of sections
- Friction
    - Dry friction/dynamic friction
    - Slip/tip
    - Wedges
    - Belts
- Mass properties
    - Center of mass/gravity/centroids
    - Centroids
        - integration
        - composite bodies
    - Second Moment of Inertia
        - integration
        - parallel axis theorem
        - composite bodies
        - polar moments of inertia

Internal forces

Shear force and bending moments

PVM diagrams

EGR 209 - SOLID MECHANICS
PADNOS SCHOOL OF ENGINEERING
GRAND VALLEY STATE UNIVERSITY

COURSE OUTLINE
FALL SEMESTER 1999

OBJECTIVE:

There are three objectives for this course. First it is important that you master the content of this course as this is the foundation for engineering analysis as well as almost all of the mechanical engineering courses that follow. Second, it is important that you master the engineering approach to problem solving. Finally, you will be expected to develop critical thinking skills by applying concepts learned in class to mechanical systems.

INSTRUCTOR:

Dr. John Farris
Assistant Professor, School of Engineering
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Phone: 336-7267
email: farrisj@gvsu.edu
www: http://claymore.engineer.gvsu.edu

CLASS TIMES:

SEC A: M, T, W, F, 8-9am, PAD 168
SEC B: M, W, 10-11am, F, 9-11am, MAK 2341

OFFICE HOURS:

Monday 1:00-3:00
Tuesday 9:00-11:00
Thursday 11:00-12:00

TEXTS:

Engineering Mechanics; Statics (with Mathcad supplement), by R. W. Soutas-Little and D.J. Inman, Prentice Hall
Mechanics of Materials, by J.M. Gere and S.P. Timoshenko, PWS Publishing
EGR 209/210 -Statics and Solid Mechanics Lecture Notes, by H. Jack

PREREQUISITES:

EGR 209 students must have taken Physics 230 and Math 202

EXAMS:

There will be a final exam. There will also be two midterm tests, each one hour in duration. All students will be expected to write tests at the scheduled time, make-up tests will be given only in the most extreme circumstances at the discretion of the instructor.

ANALYSIS PROJECT:

Within the first few lectures a project topic will be chosen. The selected mechanical structure will be analyzed over the term as relevant material is covered. Segments of the report will be judged acceptable (100%)/not-acceptable(0%). In the event a portion of the work is not acceptable, there will be a single chance to correct it. As with the work of a Professional Engineer, at any time your work may be reviewed, and the grade changed. The project will be kept up to date by adding to relevant web pages. The work will be done in groups of three students.

HOMEWORK:

You will not be able to learn this material if you do not do problems. To encourage you to do homework in a professional manner, random samples of the assignments will be collected and graded. This homework may be collected as soon as the next class after introduction, and when collected it is due immediately. All homework solutions should be logical, concise, clear, and readable.In general the following rules should be observed,

- Do all work on engineering computation paper, or on Mathcad.
- Multiple page solutions should be stapled and given page numbers.
- At the top of the page indicate your name, the date the work was done, and the course number.
- Each problem should begin with a brief problem statement (do not copy out the question).
- Free body diagrams will be required for most solutions, and should appear before the calculations.
- The problem solution should be concise, logical, clear, neat, and correct.
- The final answer should be clearly indicated with a box, or leader lines.
- Mathcad solutions should be done entirely within Mathcad (i.e., not with a calculator or scrap paper)

GRADING:

The grade for this course will be determined as follows:

Exam(s)	65%
Analysis Project	15%
Homework	20%

TENTATIVE SCHEDULE:

Dates	Lec.#	Topic
08/30	1	Course overview - introduction to statics
	2	Force scalars and vectors
	3	Vector addition and subtraction
	4	Particle equilibrium and force triangles
09/08	5	Projected forces with unit vectors and dot products
	6	3D force vectors
09/13	7	3D particle equilibrium
	8	Equilibrium and free body diagrams
	9	Mechanical components
	10	Axial and shear stress
09/20	11	Analysis of stress in rigid bodies

	12	Oblique and generalized stress
	13	Strain and Failure
	14	Shear strain
09/27		Review
		Review
		Midterm #1
	15	Moments using components
10/04	16	Moments using cross products
	17	Equilibrium of moments
	18	3D Moments
	19	Torsion
10/11	20	Introduction to mass properties
	21	Centroids using integration
	22	Centroids using composite sections
	23	Parallel axis theorem
10/18	24	Moments and Forces on 3D objects
	25	Equilibrium of Rigid Bodies
	26	Stress failure
	27	Loading and Factor of Safety
10/25	28	Strain failure
		Review
		Midterm #2
	29	Introduction to Truss Analysis and Project
11/01	30	Method of members for machine frames
	31	Method of sections
	32	Method of joints
	33	Review of Trusses and Frames
11/08	34	Internal forces in members and beams
	35	Simple bending and shear
	36	P, V, M diagrams
	37	Normal, shear and bearing stress
11/15	38	Moments of inertia
	39	Pure bending
	40	Transverse Loading
	41	Introduction to friction
11/22	42	Wedge friction
	43	Belt friction
		Review
		Review
11/29		Bridge Testing
		Review
12/06		Review
		Review

FINAL EXAMINATION (Section A - Mon., 13, Dec., 1999, 8-10am)
(Section B - Tues., 14, Dec., 1999, 12-2pm)

MARK CONVERSION CHART:

The chart below shows how the numerical grades in the course will be converted to letter grades.

A	93-100%
A-	90-92%
B+	87-89%
B	83-86%
B-	80-82%
C+	77-79%
C	73-76%
C	70-72%
D+	67-69%
D	60-66%
F	0-59%

EGR 210 - SOLID MECHANICS
PADNOS SCHOOL OF ENGINEERING
GRAND VALLEY STATE UNIVERSITY

COURSE OUTLINE
FALL SEMESTER 1998

OBJECTIVE:

There are three objectives for this course. First it is important that you master the content of this course as this is the foundation for engineering analysis as well as almost all of the mechanical engineering courses that follow. Second, it is important that you master the engineering approach to problem solving. Finally, you will be expected to develop critical thinking skills by applying concepts learned in class the mechanical systems.

INSTRUCTOR:

Dr. John Farris
Assistant Professor, School of Engineering
Office: Pad 146 OR Suite 618, Eberhard Center
Phone: 771-6755
email: jackh@gvsu.edu
www: http://claymore.engineer.gvsu.edu

CLASS TIMES:

M, W, 2-3pm, F, 2-4pm, PAD 168

OFFICE HOURS:

Monday, Wednesday, Friday 11-12
Thursday 2-3

TEXTS:

Mechanics of Materials, by J.M. Gere and S.P. Timoshenko, PWS Publishing
EGR 209/210 -Statics and Solid Mechanics Lecture Notes, by H. Jack

PREREQUISITES:

EGR 210 students they need to have taken a basic statics course

EXAMS:

There will be a final exam. All students will be expected to write tests at the scheduled time, make-up tests will be given only in the most extreme circumstances at the discretion of the instructor.

HOMEWORK:

You will not be able to learn this material if you do not do problems. To encourage you to do homework in a professional manner, random samples of the assignments will be collected and graded. This homework may be collected as soon as the next class after introduction, and when collected it is due immediately. All homework solutions should be logical, concise, clear, and readable.In general the following rules should be observed,

- Do all work on engineering computation paper, or on Mathcad.
- Multiple page solutions should be stapled and given page numbers.
- At the top of the page indicate your name, the date the work was done, and the course number.
- Each problem should begin with a brief problem statement (do not copy out the question).
- Free body diagrams will be required for most solutions, and should appear before the calculations.
- The problem solution should be concise, logical, clear, neat, and correct.
- The final answer should be clearly indicated with a box, or leader lines.
- Mathcad solutions should be done entirely within Mathcad (i.e., not with a calculator or scrap paper)

BEAM BUILDING PROJECT:

The objective of this project is to build a beam with the highest failure load to weight ratio using approved materials. A list of approved materials and geometry constraints will be provided. All beams will be tested and a report will be required. The report will detail how the student applied concepts learned in the class to the project.

GRADING:

The grade for this course will be determined as follows:

Exam	55%
Homework	30%
Project	15%

TENTATIVE SCHEDULE:

Dates	Lec.#	Topic
08/31	1	Course overview
	2	2D and 3D force review
	3	Equilibrium review
	4	Free body diagram review
09/09	5	Axial and shear stress
	6	Analysis of stress in rigid bodies
09/14	7	Oblique and generalized stress
	8	Strain and Failure
	9	Shear strain
	10	Moments Review

09/21	11	Torsion
	12	Centroids and parallel axis theorem review
	13	3D equilibrium review
	14	Loading and Factor if safety
09/28	15	Stress Failure
	16	Strain Failure
	17	Truss and frame review
	18	Internal forces in beams review
10/05	19	Moments of Inertia Review
	20	Pure Bending
	21	Transverse Loading
		Review
10/12	Review	
		Review
		Review
		Final Examination (2 hours)

MARK CONVERSION CHART:

The chart below shows how the numerical grades in the course will be converted to letter grades.

A	93-100%
A-	90-92%
B+	87-89%
B	83-86%
B-	80-82%
C+	77-79%
C	73-76%
C	70-72%
D+	67-69%
D	60-66%
F	0-59%

EGR 214 - ELECTRIC CIRCUITS I

4. INTRODUCTION

4.1 PURPOSE OF THE COURSE

Circuit analysis is important to all fileds of engineering. A clear trend has emerged in consumer products to merge both electronic and mechanical systems. Naturally, any engineer involved in the design of such products would need a knowledge of both the mechanical and electrical aspects of the design. This circuits course will cover the fundamentals involved in circuit analysis for both DC (Dirrect Current) and AC (Alternating Current). Towards the end of the course some useful devices (operational amplifiers) will be examined using the fundamentals in the first part of the course. There will be a number of laboratory experiments, and exposure to Computer Aided Circuit analysis tools.

4.2 RESOURCES

4.2.1 Problems to Try in the Textbook

The text will be XXXXXX

Try the following problems as the topics are covering in the lectures.

4.2.2 Internet

There are a wealth of internet sites for electronics. The following is a short list of useful sites to try.

4.2.3 References & Bibliography

A number of good circuits books have been written, and many are available in bookstores and the library.

XXXXXXX

4.3 EVALUATION

All work will be evaluated as follows,
i) A correct answer that is properly justified willo receive a mark of 100%.
ii) An answer that is correct but not clearly justified may receive fewer marks.
iii) Any question that does not have a ccorect answer will receive a mark between 0% and 50%.

This marking scheme should encourage you to do it right the first time, and to find ways to verify your solutions.

4.3.1 Laboratories

See the laboratory guide for details of specific labs.
i) Read the laboratory outline before entering the lab and do any required calculations beforehand.
ii) Show up propmtly at the beginning of the laboratory. Being late will only cost you.
iii) Take all required measurements and record them carefully.
iv) Always leave the lab in an equivalent or better state than you found it - failure to do so will result in penalties.
v) When not sure about a new instrument, ask.
vi) If you break something, bring it to the attention of the lab supervisor so that it may be fixed or replaced.
vii) Remember that a lab in not about marks, but about you getting to get hands on experience, and having time to explore physical phenomenon.
viii) Lab reports are to be neatly completed following normal report writing procatices.
ix) Try to work quickly at the start of the lab so you have time to explore the equipment at the end of the lab period.

4.3.2 Assignments

Will be assigned as required

4.3.3 Design Project

A project will given in the later part of the course to be done on the students own time. This project will then be judged against the work of other students to determine a ranking, and thus marks.

Grand Valley State University
School of Engineering
EGR 214
Technical Paper

OBJECTIVE

To write a professional quality technical paper.

PROCEDURE.

1. Select one of the first four laboratory reports (up to Wheatstone Bridges.)
2. Select an extension to the laboratory report. This will require that you spend additional laboratory time on your own. Possible extensions for each lab are outlined below.
   Lab 1: STANDARD ELECTRICAL LABORATORY INSTRUMENTATION
   - A possible expansion of this experiment is to investigate the temperature coefficient for carbon resistors and how a function for resistance versus temperature can be derived from empirical data.

   Lab 2: KIRCHHOFF'S CIRCUIT LAWS
   - Expand this lab by trying other circuit configurations of your choice (text book circuits are a good source) and repeat the analysis and measurement steps above. Note: the complexity of the circuit will effect your grade (i.e., trivial circuits will lower your grade.)

   Lab 3: TEE-PI EQUIVALENT CIRCUITS
   - Possible expansions for this lab are to study Tee and Pi circuits of problems from your textbook. Note: the complexity of the circuit will effect your grade (i.e., trivial circuits will lower your grade.)

   Lab 4: THE WHEATSTONE BRIDGE
   - Choose different values for R1 and R2;
   - Measure the current flow from point ‘a’ to ‘b’ instead of the voltage;
   - Solve the circuit (find all voltages and currents) for the unbalanced case and verify them by experiment.
3. Prepare a rough draft in Microsoft Word using the guidelines below.
   - The length of the report should be approximately 1,500 words (6 pages double spaced) not including illustrations or appendices.
   - Illustrations should be embedded in the text with figure or table numbers and titles. Full page illustrations should be put in an appendix.
   - Follow the guidelines for figures, equations, tables, etc. in the writing guide.
   - Use numbered sections including 0.0 Introduction, 1.0 Analysis, 2.0 Experiment (Verification), 3.0 Comparison and Discussion, 4.0 Conclusion, Appendices.
   - Refer to the attached example report.
   - This paper is for an educated reader, so the point of view should be selected carefully. Passive voice is the most common choice (i.e., avoid I, we, our, it, etc.)
4. Submit the rough draft report February 28th, 2000 and make an appointment for a review session with your laboratory instructor.
5. Attend the review session appointment. Your laboratory instructor will review your rough draft with you.
6. Make revisions to the rough draft and submit the final report within 1 week after your review meeting.

Grand Valley State University
School of Engineering

EGR 214 Experiment 1

STANDARD ELECTRICAL LABORATORY INSTRUMENTATION

OBJECTIVES

To investigate the digital multimeter and cadet trainers.

To investigate lumped carbon film resistors and their tolerance specifications.

To investigate voltage sources.

INTRODUCTION

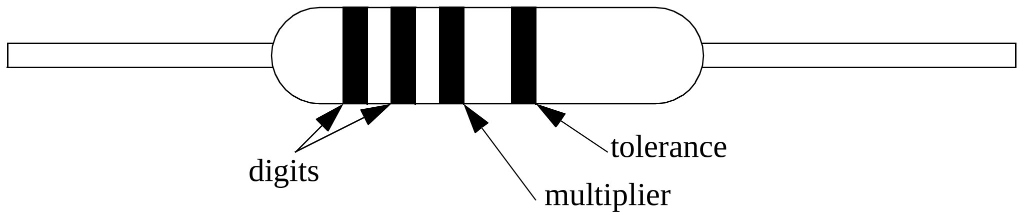
The multimeter is the most commonly used instrument for engineers, technicians and electricians making electrical measurements. Originally electrical work required multiple instruments for voltage, current and resistance. These instruments have been combined into a “multi”meter. Earlier multimeters used analog needles to indicate values, newer models use digital displays. These meters measure values such as:

voltage (voltmeter)
current (ammeter)
resistance (ohmmeter)

An inexpensive multimeter with limited capabilities can be purchased for $10. High precision multimeters with special features can cost over $1000. The precision of a multimeter is a function of the voltage ranges that can be measured (from nV to KV) and the number of digits on the read-out (typically 3 to 7).

Resistors are the simplest and most common circuit component. Resistors are mass produced and typically sell for under 1 cent. But, the production process is not precise, so the resistor values have tolerance values. Typical tolerance values are ±1% ($0.05), ±5% ($0.01), ±10% (<$0.01). The value indicated on the resistor is the nominal value, and the actual value will vary statistically about the nominal value. The tolerance band should contain approximately 3 standard deviations of the values.
Resistor values are indicated using colored bands read from one side to the other. To read the code start from the side that the color bands are closer to. Each color corresponds to a number, then a

multiplier, then a tolerance. There is often a gap between the tolerance band, and the other color bands. The color is shown in Figure 1.



Color	Digit	Magnitude
Black	0	1
Brown	1	10
Red	2	100
Orange	3	1,000
Yellow	4	10,000
Green	5	100,000
Blue	6	1,000,000
Violet	7	10,000,000
Grey	8	etc...
White	9	

Color	Tolerance
Gold	5%
Silver	10%
none	20%

If the bands read from the left were yellow, violet, red, gold the digits would be 47 multiplied by 100 to give 4700 ohms or 4.7Kohms with a tolerance of ±5%.

Figure 1 - Resistor Color Code

When first looking at resistor values the sequence does not seem rational. But, the sequence is devised so that any resistance value can be obtained by adding two or more resistors together. The spacing of the resistor values is determined by their tolerance (a larger tolerance gives a larger spacing between resistor values. A typical series of resistor values for a 5% tolerance is:

> 1.0, 1.1, 1.2, 1.3, 1.5, 1.6, 1.8, 2.0, 2.2, 2.4, 2.7, 3.0, 3.3, 3.6, 3.9, 4.3, 4.7, 5.1, 5.6, 6.2, 6.8, 7.5, 8.2, 9.1, 10.0, etc...

Batteries are typical voltage sources that use chemical reactions to create an electrical potential. They are also prone to variations in production and the limitation of the battery life. As a result new batteries will not produce identical voltages, and the voltage will decrease with use.

MATERIALS

1 - Digital Multimeter, Fluke Model 8050 (DMM)
1 - Circuit Prototyping System (CPS)
2 - 1.5V batteries
10 - resistors of two different values specified by instructor

ANALYSIS PROCEDURE

1. The spacing of resistors is a function of the nominal resistor values and the tolerances. The sequence is determines so that the positive tolerance value of a resistor will be equal to the negative tolerance value of the next resistor value in a the series. Develop a Mathcad document to calculate the resistor series for 5% and 10% tolerance resistors from 1ohm to 10Mohms.

$$R = R_{nom}\left[1 \pm \frac{TOL}{100}\right]$$

2. Set up a Mathcad calculation to allow the entry of individual resistor values and calculate the mean and standard deviation as required in verification step 4.

VERIFICATION PROCEDURE

1. Locate the Fluke 8050 Digital MultiMeter (DMM) and familiarize yourself with its operation by studying the operation manual attached. Setup the DMM for making DC voltage measurements.

2. Starting with the highest scale on the DMM, measure and record the voltage of a 1.5V battery as displayed on the DMM while the voltage ranges are selected in descending order. Observe and identify overload on the DMM and determine the scale that would give the most accurate reading. The term “record” refers to making log book entries (in Mathcad) of calculations and measured data.

3. Ask the instructor to provide two resistor values for you to measure. Obtain 10 identical resistors from the resistor cabinet, and verify these values using the color codes. These resistors will be plugged into the protoboards on the trainers. Connect two wires to either end of the resistors, and connect these to the multimeter. The basic layout of the protoboards is shown below.

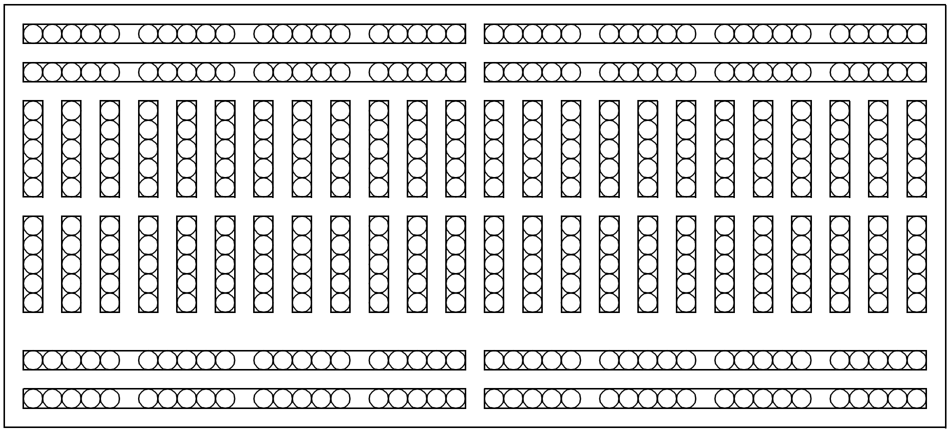


Figure 2 - Conductor Layout of the Protoboard

4. Set the DMM to measure resistance, and verify that the scale gives the highest accuracy for the resistors. Measure resistor values for both sets of resistors, and record these in Mathcad. Calculate the average and standard deviations for each of the resistor values.

$$\bar{R} = \frac{\sum_{i=1}^{n} R_i}{n} \qquad SD = \sqrt{\frac{\sum_{i=1}^{n} (R_i - \bar{R})}{n-1}}$$

COMPARISON PROCEDURE

1. Compare the resistor values in the parts cabinet to the resistor series calculated using tolerances.

2. Examine the resistor values to determine how many standard deviations are between the tolerance limits. Also determine the percentage deviation of the average resistor values from the nominal values. (Note: be careful to calculate the percentage from the nominal, not from the experimental.)

3. Compare the two battery voltage values.

4. Write a discussion and conclusion values for the results in general and discuss the value of the multimeter as an instrument. (Note: State facts and details, avoid vague and rambling statements.)

Grand Valley State University
School of Engineering
EGR 214 Experiment 2

KIRCHHOFF'S CIRCUIT LAWS

OBJECTIVES

To investigate Kirchhoff's Voltage Law (KVL).
To apply the voltage divider rule.
To investigate Kirchhoff's Current Law (KCL).
To apply the current divider rule.

INTRODUCTION

Kirchhoff's voltage and current laws are two statements that relate voltages and currents in an electric circuit. These two laws are all inclusive in that (1) they apply to *all* electrical circuits, and (2) they are the only laws needed, aside from the behavior of the electrical devices themselves and Ohm's law, to solve for all the voltages and currents in a circuit.

Kirchhoff's Voltage Law (KVL) states that

"*The algebraic sum of circuit element voltages around any closed path is zero.*"

Kirchhoff's Current Law (KCL) states that

"*The algebraic sum of all currents at a node is zero.*"

The phrase "algebraic sum" implies that there can be positive and negative quantities in forming the sum of voltages or currents. In other words, there is a dependency on an assumed direction to the currents and voltages. To establish the proper sign of a voltage or current, positive reference directions need to be established before a circuit analysis is started. In this course these positive reference directions are as follows:

1. Currents leaving a node are positive.
2. The voltage drop across a branch circuit element is positive at the tail of the arrow that represents the direction of current flow through the branch circuit element (see Fig. 1).

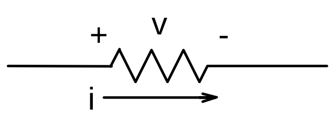


Figure 1. Sign conventions used for current flow through, and voltage drop across a circuit element.

Voltage Divider Rule

Kirchhoff's voltage law (KVL) will be demonstrated with the simple series circuit shown in Figure 2.

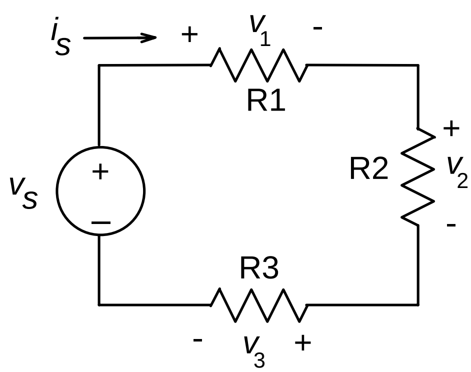


Figure 2. A simple series circuit.

Applying Kirchhoff's voltage law to the circuit in Fig. 2 yields:

$$v_1 + v_2 + v_3 - v_s = 0$$

Since the current is the same through each branch of the circuit and is equal to i_s (from KCL), applying Ohm’s law we have

$$v_1 = R_1 i_s \quad , \quad v_2 = R_2 i_s \quad , \quad v_3 = R_3 i_s \quad .$$

Therefore

$$v_s = R_1 i_s + R_2 i_s + R_3 i_s$$

and

$$v_s = i_s R_{eq}$$

where

$$R_{eq} = R_1 + R_2 + R_3 \qquad \text{and} \qquad i_s = \frac{v_s}{R_{eq}} \ .$$

In general, the voltage drop across any branch, *n*, can then be found from

$$v_n = R_n i_s = \frac{R_n v_s}{R_{eq}} \ .$$

This is the *voltage divider* rule. The voltage divider rule can be used to find v_2 in Figure 2 from

$$v_o = \frac{R_2}{R_1 + R_2 + R_3} v_s \ .$$

Current Divider Rule

The circuit "duals" of Kirchhoff's voltage law and the voltage divider rule are Kirchhoff's current law and the current divider rule. The voltage law was applied to resistances in series to determine the voltage divider rule. The current law will now be applied to resistances in parallel, as shown in Figure 3, to determine the current divider rule.

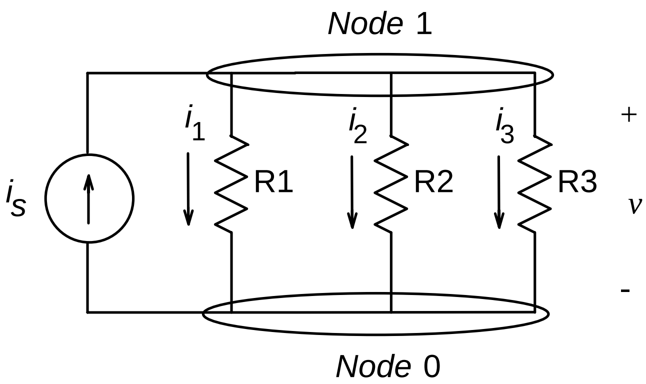


Figure 3 A simple parallel circuit.

Applying the current law to the circuit of Fig. 3, we have at *Node* 1,

$$i_1 + i_2 + i_3 - i_s = 0$$

and at *Node* 0,

$$-i_1 - i_2 - i_3 + i_s = 0 \ .$$

Using G_i as the conductance of the i^{th} branch, and since the voltage, v, is the same across each branch, the branch currents are

$$i_1 = vG_1 \ , \qquad i_2 = vG_2 \ , \qquad i_3 = vG_3 .$$

and therefore

$$vG_1 + vG_2 + vG_3 = i_s$$

thus

$$i_s = vG_{eq}$$

where

$$G_{eq} = G_1 + G_2 + G_3 \qquad \text{and} \qquad v = \frac{i_s}{G_{eq}} .$$

The current through any branch, n, can be found from

$$i_n = vG_n = \frac{G_n i_s}{G_{eq}} .$$

This is the *current divider* rule. The current divider rule can be used to find current i_2 in Figure 3 from

$$i_2 = \frac{G_2}{G_1 + G_2 + G_3} i_s = \frac{R_1 R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3} i_s$$

MATERIALS

1 - Circuit Prototyping System (CPS)
1 - Digital Multimeter Fluke Model 8050A or equivalent (DMM)
1 - 1.0 kΩ 1/4W resistor
1 - 2.0 kΩ 1/4W resistor
1 - 3.0 kΩ 1/4W resistor
Miscellaneous leads and connectors

ANALYSIS PROCEDURE

1. Using the circuit in Figure 2, and the resistor values R_1 = 1000, R_2 = 2000 and R_3 = 3000 nominal ohms find the voltage drop across each resistor if the source voltage is v_S=5V.
2. Determine the value of v_S in Figure 2 that will make i_s = 2.0 mA.
3. For the circuit shown in Figure 4, derive an equivalent resistance for the parallel combination of R2 and R3. Then combine that equivalent resistance with R1 so that there is only one equivalent resistor and one voltage supply. Use this to find the current i_1. Use the current and voltage dividers (as explained in the Introduction section) to find the current through (i.e., i_1, i_2 ,i_3) and voltage across (i.e., v_1, v_2 ,v_3) each resistor.

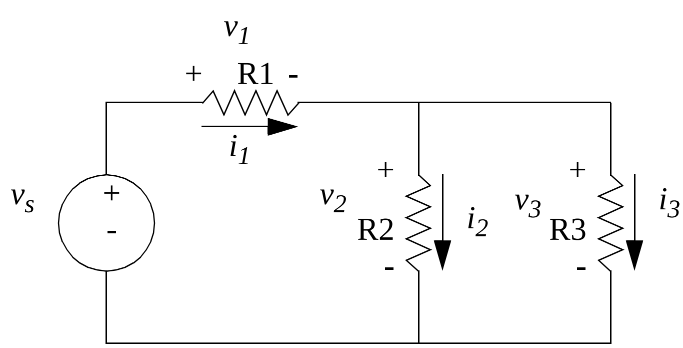


Figure 4. Simple combination series and parallel circuit.

VERIFICATION PROCEDURE (Build and Measure)

1. Obtain the resistors for this experiment and then measure and record their values as accurately as you can. Let R_1 = 1000, R_2 = 2000 and R_3 = 3000 nominal ohms, respectively. Refer to the DMM operation sheets, page 2-7. Note: when measuring resistance make sure that the resistor is not connected to the power supply. Never measure resistance when the resistor is energized.
2. Wire the circuit shown in Figure 2 onto the CDT. Use the +5V power supply on the CDT for the source.

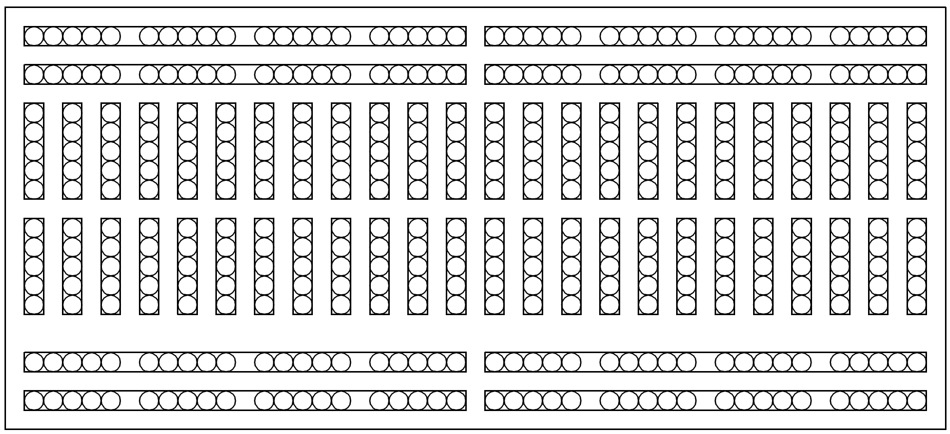


Figure 5. Conductor Layout of the Protoboard

3. For the circuit in Figure 2, verify KVL by measuring the voltage drop across each resistor and the actual source voltage and demonstrate that the algebraic sum of the voltages is zero (or close to zero.)
4. For the circuit in Figure 2, replace the 5V power supply with the adjustable positive voltage supply. Connect the DMM to measure the current in the loop and adjust the supply voltage, $v_{S,}$, until the current is i_s = 2.0 mA. Disconnect the DMM and measure the supply voltage. Note: see Figure 6 before measuring current with the DMM.)
5. Rewire the circuit on the CDT to be the circuit of Figure 4 using the previous resistors, R_1, R_2 and R_3. Measure the voltage drops across each resistor, and the currents through each resistor.

COMPARISON PROCEDURE

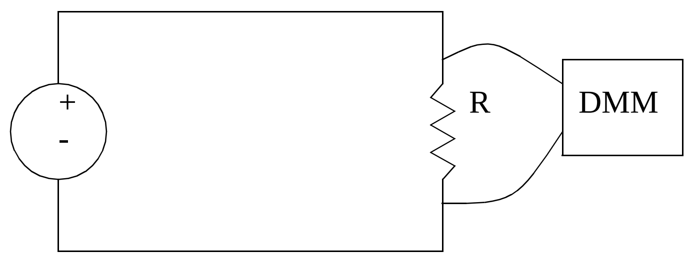
1. For the circuit in Figure 2, compare the calculated and measured values for voltage drops across each resistor with the supply voltage of 5V.
2. For the circuit in Figure 2, compare the calculated and actual supply voltage needed to get a current of i_S=2mA.

3. For the circuit in Figure 4, compare the calculated and measured voltages accross and currents through each resistor.

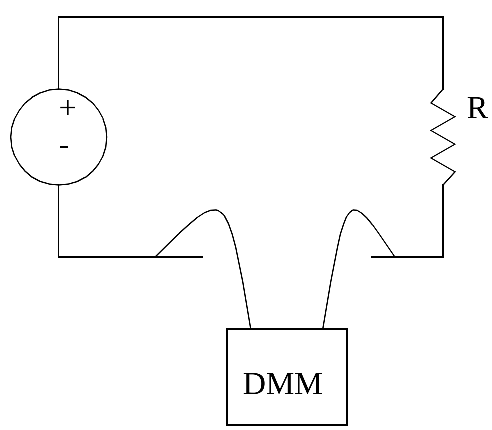
Note: When comparing the calculated and measured values use percentages relative to the calculated values.

$$\%\ \text{error} = \frac{\text{measured} - \text{calculated}}{\text{calculated}} 100\%$$

Note 2: When reading voltages, the multimeter probes are placed ACROSS the terminals (sides) of the resistor or voltage source. To measure voltages you do not need to break the circuit. See page 2-5 in the multimeter specifications.



Note 3: When reading currents, the multimeter probes are placed in the circuit so that current must flow THROUGH the meter. To measure current, you must break the circuit and insert the DMM so that the current flows through the meter. (this means you must disconnect something in the circuit, and connect the DMM between the disconnected ends, as shown below.) When the DMM is in the current measuring mode the meter has a very low resistance.Therefore if the DMM is placed across a circuit element in this mode it effectively "shorts out" the circuit element. Therefore, when the DMM is in the circuit measuring in ammeter mode, its placement in a circuit must be done with caution so that a power supply or other circuit element is not "shorted".



NOTE: It is good practice to leave the DMM set up for reading voltages. If the DMM is set up for reading current it is more likely to create a short circuit accidently.

Figure 6. DMM Connection for Voltage and Current Readings

Grand Valley State University
School of Engineering
EGR 214 Experiment 3
TEE–PI EQUIVALENT CIRCUITS

OBJECTIVES

To investigate how to make and use Tee-to-Pi and Pi-to-Tee equivalent circuits.

INTRODUCTION

Tee and Pi (or Y and Delta) networks occur often in electric and electronic circuits. Your ability to recognize these circuit structures and your ability to convert them from one form to the other are important skills for simplifying, understanding, and designing networks. A network often has to be simplified in order to understand its operation sufficiently well to be able modify its design. For two networks to be equivalent, their terminal characteristics must be the same. By terminal characteristics we mean the voltage-current relationship at each terminal pair. Refer to Figure 1.

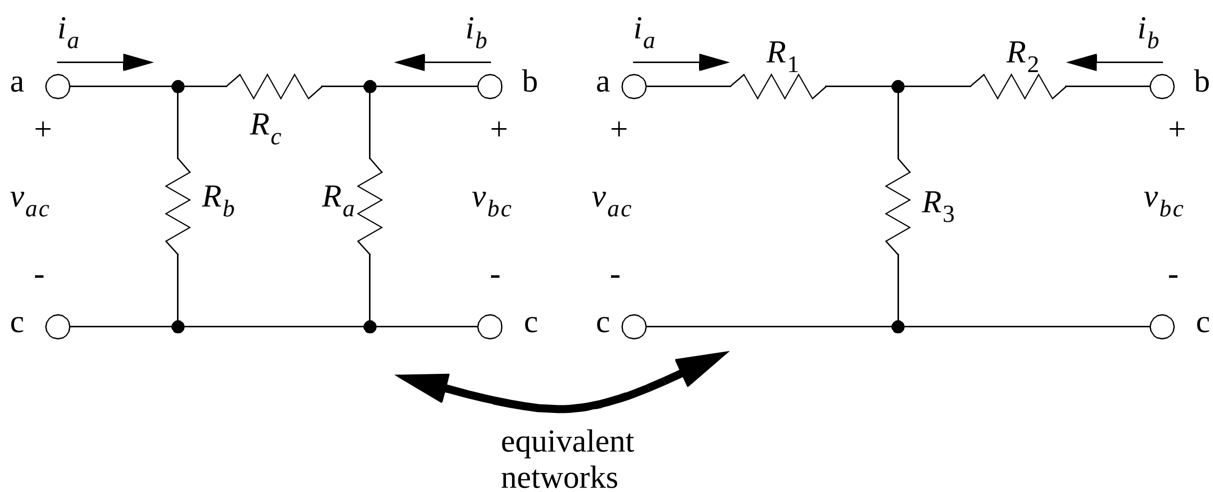


Figure 1. Equivalent Pi and Tee (or Delta and Y) networks.

For the circuits to be equivalent, we must have

$$R_{ac} = R_1 + R_3 = \frac{R_b(R_a + R_c)}{R_a + R_b + R_c}$$

$$R_{bc} = R_2 + R_3 = \frac{R_a(R_b + R_c)}{R_a + R_b + R_c}$$

$$R_{ab} = R_1 + R_2 = \frac{R_c(R_a + R_b)}{R_a + R_b + R_c}$$

We solve the above equation to obtain the Tee to Pi transformation equations:

$$R_a = \frac{R_1R_2 + R_2R_3 + R_1R_3}{R_1} \qquad\qquad R_1 = \frac{R_bR_c}{R_a + R_b + R_c}$$

$$R_b = \frac{R_1R_2 + R_2R_3 + R_1R_3}{R_2} \qquad \text{OR} \qquad R_2 = \frac{R_cR_a}{R_a + R_b + R_c}$$

$$R_c = \frac{R_1R_2 + R_2R_3 + R_1R_3}{R_3} \qquad\qquad R_3 = \frac{R_aR_b}{R_a + R_b + R_c}$$

MATERIALS

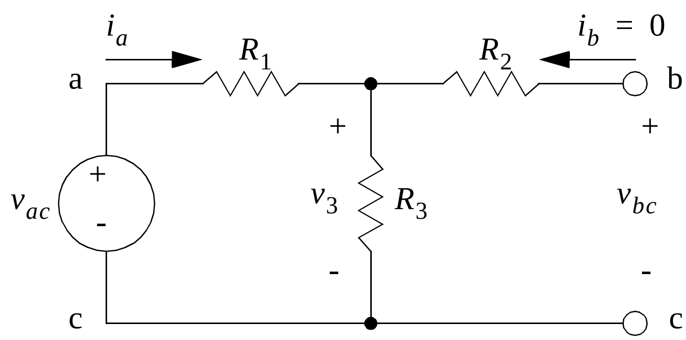
1 - Circuit Prototyping System (CPS)
1 - Digital Multimeter Fluke Model 8050A or equivalent (DMM)
3 - 1/4W resistors with values to be determined in lab
3 - 20 turn pots, 2Kohm
Miscellaneous leads and connectors
Tuning Sticks

DESIGN AND ANALYSIS PROCEDURE

1. Given a Tee network where R_1 = 1K, R_2 = 4.7K and R_3 = 2.2K, find the equivalent Pi network.

2. Engineers create designs to meet specifications. For example, telephone systems are often based on 600 Ω standards. What follows is a set of design requirements that need to be satisfied using a resistor network. Determine the values for each resistor in a Tee circuit (R_1, R_2, R_3) such that its terminal resistance R_{ac} is equal to 600 Ω, the output-to-input voltage ratio from left to right (that is v_{bc}/v_{ac}) equals 0.65 with

the terminal current $i_b = 0$, the terminal resistance R_{bc} is equal to 600 Ω, and the output-to-input voltage ratio from right to left (v_{ac}/v_{bc}) equal to 0.65 with the terminal current $i_a = 0$. Note that the network must be symmetrical because the terminal resistances are equal. Note: don't forget to write down the given information before starting to find resistor values.



Note: if the current i_b is zero, then the two resistors R_1 and R_3 will act as a voltage divider and v_3 will equal v_{bc}.

Figure 2. A Tee Network for i_b=0A.

3. Calculate the resistors R_a, R_b and R_c for a Pi network that is equivalent to the Tee you designed in step 2.

BUILD AND MEASURE PRODEDURE

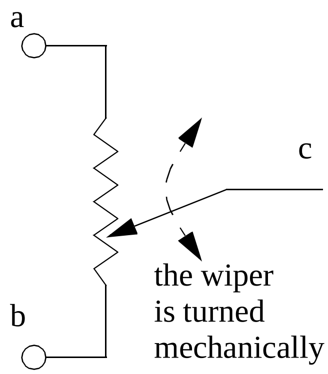
1. Set up a Tee network using the resistor values R_1 = 1K, R_2 = 4.7K and R_3 = 2.2K. Measure the resistances R_{ac}, R_{bc}, R_{ab}.

2. Set up a Pi network using the resistor values calculated in Analysis Procedure Step 1. Measure the resistances R_{ac}, R_{bc}, R_{ab}.

3. Select the resistors needed to implement the Tee circuit of the Analysis Procedure Step 2. (You may have to search through a batch of resistors to select values that are "right on".) Set up the Tee circuit and measure R_{ac}, R_{bc}, v_{bc}/v_{ac} and v_{ac}/v_{bc} for your Tee circuit. For example, to measure v_{bc}/v_{ac} select a voltage value for v_{ac} using the variable voltage supply on the CDT (a value between 5 to 10V is reasonable.) Measure both voltages using the DMM, and divide the values to find the ratio.

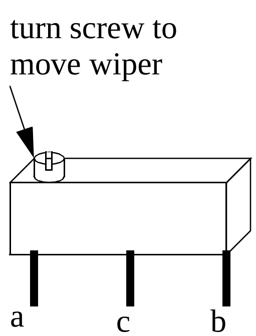
4. Select three "pots" (electrical jargon for potentiometers or variable resistors) to cover the resistance range needed for R_a, R_b, and R_c, respectively in Analysis Step 3. Adjust each pot to equal the resistance needed for R_a, R_b and R_c. Set up the Pi circuit with the pots and verify that it has the same parameter values as the Tee net-

work. (See figures 3 and 4 before building the circuit.)



Note: The potentiometer shown to the left has three terminals. Between terminals ‘a’ and ‘b’ there is a resistor. This can be a film, or a coil of high resistance wire. The center terminal ‘c’ is connected to a wiper that will slide along the resistor as a shaft is turned. When the wiper is closer to ‘a’, the resistance between ‘a’ and ‘c’ will be small, but the resistance between ‘c’ and ‘b’ will be near the maximum. If only two terminals are used, such as ‘a’ and ‘c’, this can be used as a variable resistor. Later you will connect ‘a’ and ‘b’ to a voltage supply and use ‘c’ as an adjustable voltage divider.

Figure 3. Potentiometers



Note: The potentiometers used in this laboratory will be in a small plastic package with three leads on the bottom, and a screw terminal on the top (or side.) Turn the screw on top with the tuning stick to adjust the resistance. The screw may be turned up to 20 revolutions, this makes the device more sensitive/accurate. When placing the pot into the protoboard the leads should all be inserted into the board, although only two will be connected for this experiment.

Figure 4. Potentiometer Packages

COMPARISON PROCEDURE

1. Compare the analysis and procedure values for the Pi and Tee circuits in Analysis Step 1 and Verification Steps 1 & 2 (i.e., calculate percent errors.)

2. Compare the results of Analysis Step 2 and Verification Step 3.

3. Compare the results of Analysis Step 3 and Verification Step 4.

Grand Valley State University
School of Engineering
EGR 214 Experiment 4

THE WHEATSTONE BRIDGE

OBJECTIVES

To verify the bridge balance equations by using the bridge to measure unknown resistor values.

INTRODUCTION

The Wheatstone bridge circuit (named after its inventor) is shown in Figure 1 below. The bridge is balanced, i.e. no current flow between points *a* and *b*, when the products of the

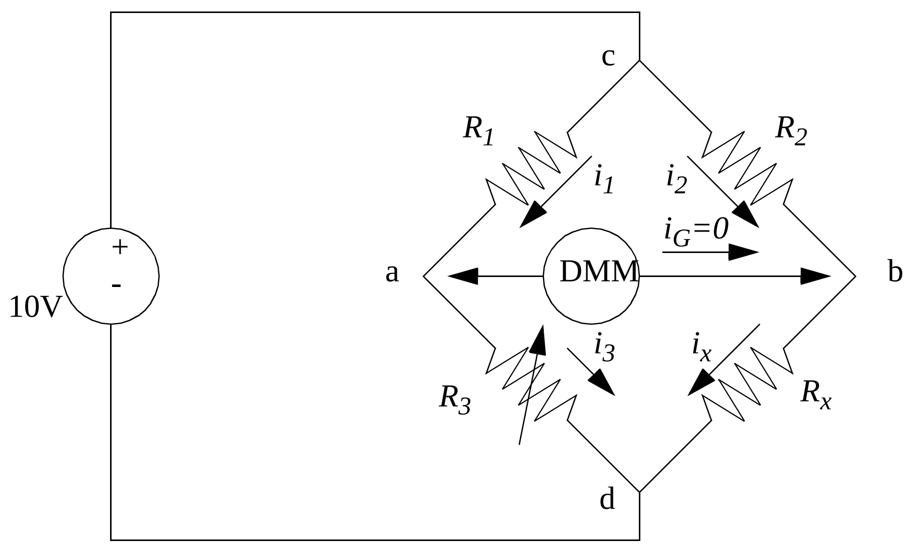


Figure 1. The Wheatstone bridge circuit.

cross-arm resistances are equal. That is, the bridge balance equation is

$$R_1 R_x = R_2 R_3 \qquad (1)$$

If R_1 is made equal to R_2, then when the bridge is balanced, $R_x = R_3$. This is a convenient way to make "in circuit" measurements unknown of impedances without having to disconnect components to connect the DMM. In this laboratory experiment only DC measurements will be made. However, these same techniques apply to measurements of complex AC impedance as well.

This bridge is common in most engineering disciplines. For example, it will be used in EGR 309 for strain gauge measurements.

MATERIALS

1 - Circuit Prototyping System (CPS)
1 - Digital Multimeter Fluke Model 8050 or equivalent (DMM)
2 - matched 1000Ω 1/4W resistors
1 - 1000Ω variable resistor (a potentiometer or "pot")
Several resistors of unknown value
Miscellaneous leads and connectors
Masking tape

DESIGN AND ANALYSIS PROCEDURE

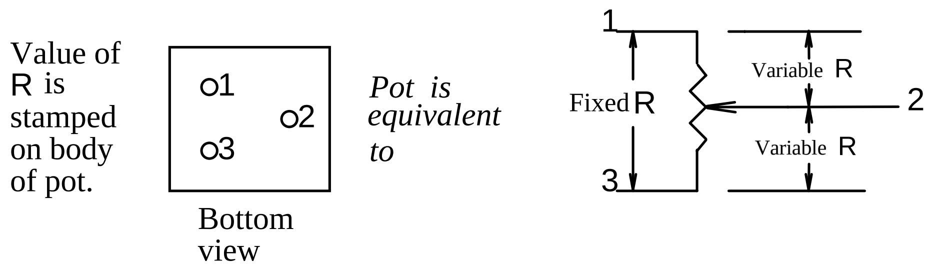
1. Examine the bridge in Figure 1. Develop an equation that will give the difference in voltage between points 'a' and 'b' as a function of the resistor values R_1, R_2, R_3 and R_x. Hint: use voltage dividers for the left branch to find v_a and a voltage divider for the right branch to find v_b. Note: this problem may also be solved using the current $i_g = 0$, KCL for nodes 'a' and 'b', and KVL for loops 'abc' and 'abd'.

2. Set the voltage between points 'a' and 'b' equal to zero and solve the equation to find the value of R_3 using R_1, R_2 and R_x.

BUILD AND MEASURE PROCEDURE

1. Obtain several 1000 Ω resistors and start measuring them with the DMM. Use masking tape on the resistor to identify the value of each resistor and record these values in your log book. After several resistor values have been recorded a pattern should emerge that should allow you to decide how close the values of your sample can be for the resistors to be considered "matched". You may be able to match them perfectly (within the measurement capability of the DMM), but don't spend too much time trying. Make a judgment and select a matched pair after a reasonable effort has been made to find the "perfect" match.

2. Set up the circuit of Figure 1. Use a resistor with a nominal value in the range 100 Ω to 1000 Ω as the unknown resistor R_x. Use a potentiometer for variable resistor R_3.



NOTE: The variable resistor, R_3, is formed from a potentiometer or "pot". A pot is a three terminal device as indicated in Figure 2. Terminals 1 and 3 are the ends of a *fixed* resistor with a value, *R*, stamped on the body of the pot. Terminal 2 is connected to the *wiper*, a movable contact that is in pressure contact with the distributed resistance of the pot. To make a variable resistance, the circuit must be connected to terminal 2 and either terminal 1 or 3 as shown in Figure 2. The value of variable resistance is the resistance contained between these two terminals.

Figure 2. Pinout diagram of a miniature, multiturn potentiometer.

3. Measure the resistance of R_x by adjusting the variable resistor R_3 until the bridge is balanced. Use the DMM to measure the voltage from point *a* to point *b* in the circuit and adjust R_3 for a zero reading on the DMM.

4. Once balance has been achieved, remove R_3 and measure its resistance with the DMM. Calculate the value of R_x using the bridge balance equation.

5. Repeat steps 3 and 4 for another "unknown" resistor.

COMPARISON PROCEDURE

1. Given the resistor values measured in Build step 1, and the resistor R_x selected in Build step 2, calculate the value of R_3. Compare this to the actual resistor value measures in Build step 3.

2. Repeat the previous step for Build step 5.

Grand Valley State University
School of Engineering
EGR 214 Experiment 5

THE NODE–VOLTAGE METHOD OF CIRCUIT ANALYSIS:
An Application of Kirchhoff's Current Law

OBJECTIVES

To use the node-voltage circuit analysis method to determine all the node voltages in a circuit with respect to a reference or "datum" node.

INTRODUCTION

The node-voltage method of circuit analysis consists of the following sequential steps:

1) All nodes of the circuit are identified and one node is selected as the "datum" or reference node.
2) All node voltages are defined with respect to the datum node.
3) All of the branch currents are expressed in terms of the node voltages using the positive reference direction: "the positive voltage drop across any branch is at the tail of the branch current arrow".
4) Kirchhoff's current law (KCL) is written at each node using the positive reference direction: "branch currents out of a node are positive".
5) The resulting set of node-voltage equations is then written in matrix form. The resulting matrix of coefficients is called the *admittance matrix* for the circuit.
6) The node voltages are found by solving the set of linear equations using mathematical techniques you have previously learned. By this lab period, you are expected to be familiar with the following techniques for solving simultaneous linear equations:
   - substitution and variable elimination by hand.
   - matrix methods using Mathcad or a calculator.
     - Cramer's rule using determinants.
     - the inverse matrix method.
     - Gauss-Jordan row reduction

The node-voltage method of circuit analysis will be verified in this lab by comparing calculated node-voltage values to measured values.

MATERIALS

1 - Circuit Prototyping System (CPS)
1 - Digital Multimeter Fluke Model 8050 or equivalent (DMM)
7 - 1/4 W resistors of various values
Miscellaneous leads and connectors

DESIGN AND ANALYSIS PROCEDURE

1. Analyze the circuit shown in Figure 1 using the symbolic resistor values and the node-voltage method. Create an *admittance* matrix for this circuit and then solve the resulting system of linear equations using Mathcad and your calculator.

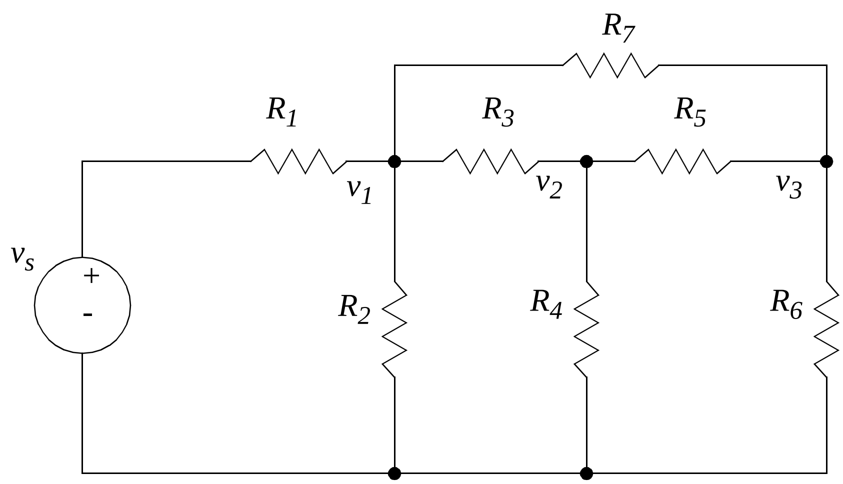


Figure 1. The circuit to be analyzed using the node-voltage method.

BUILD AND MEASURE PROCEDURE

1. You will study the circuit shown in Figure 1. Select the source voltage from the range of voltages available on the CDT and seven 1/4 W resistors of various values. Select resistor values so that for the source voltage selected, the power dissipation in each resistor does not exceed 1/4 W. A "worst case" design criteria is to limit the total power from the source to be less than 1/4 W. Therefore, if each of the seven resistors chosen has a value greater than $V^2/0.25$, then the power dissipated in each resistor will not exceed resistor's rating. For example, if 10 V is chosen for the supply voltage, then a *minimum* resistance of $100/.25 = 400\ \Omega$ for each of the resistors keeps the power dissipated in each resistor less than 1/4 W.

2. Measure the values of the resistors you have chosen as precisely as you can and record their values. Set or measure the power supply to the value you have chosen.

3. Set up the circuit of Figure 1 on the CDT using your measured resistors and experimentally analyze the circuit. (You must decide which currents and/or voltages to measure.) To measure the node voltages, first connect the black "common" lead of the DMM to the circuit datum node and leave it there. Then probe each node with the red lead to measure the node's voltage.

COMPARISON PROCEDURE

1. Compare your measured and calculated node voltage values and account for any discrepancies. If you have controlled the experiment, then this should result in direct data comparisons of 1% or less.

Grand Valley State University
School of Engineering
EGR 214 Experiment 6

THE MESH–CURRENT METHOD OF CIRCUIT ANALYSIS:
An Application of Kirchhoff's Voltage Law

OBJECTIVES

To use the mesh-current circuit analysis method to determine all the mesh currents in a circuit.

INTRODUCTION

The mesh-current method of circuit analysis requires the following sequential steps:

1. All meshes are identified by a mesh current. The mesh current direction is determined at the time the meshes are assigned. The choice of mesh current direction is arbitrary. A popular choice is to take the mesh current "out of" the "+" terminal of the voltage source. This usually results in a clockwise current direction that is used for all the remaining meshes of the circuit.
2. All the branch voltage drops are expressed in terms of the mesh currents using the positive reference direction: "the positive voltage drop across any branch is at the tail of the branch current arrow".
3. Kirchhoff's voltage law (KVL) is written around each mesh following the mesh current direction. The positive reference direction used to determine the algebraic sign of the branch voltage drops is the same as that in step 2.
4. The resulting set of mesh current equations is then written in matrix form. The resulting matrix of coefficients is called the *resistance matrix* for the circuit.
5. The mesh currents are found by solving the set of linear equations using mathematical techniques you have previously learned. By this lab period, you are expected to be familiar with the following techniques for solving simultaneous linear equations:
   - substitution and variable elimination by hand.
   - matrix methods using Mathcad or a calculator.
     - Cramer's rule using determinants.
     - the inverse matrix method.

The mesh-current method of circuit analysis will be verified in this lab by comparing calculated current values to measured values.

MATERIALS

1 - Circuit Prototyping System (CPS)
1 - Digital Multimeter Fluke Model 8050 or equivalent (DMM)
7 - 1/4 W resistors of various values
Miscellaneous leads and connectors

DESIGN AND ANALYSIS PROCEDURE

1. Analyze the circuit shown in Figure 1 using the symbolic resistor values and the mesh-current method. Create a *resistance* matrix for this circuit and then solve the resulting system of linear equations using Mathcad and your calculator.

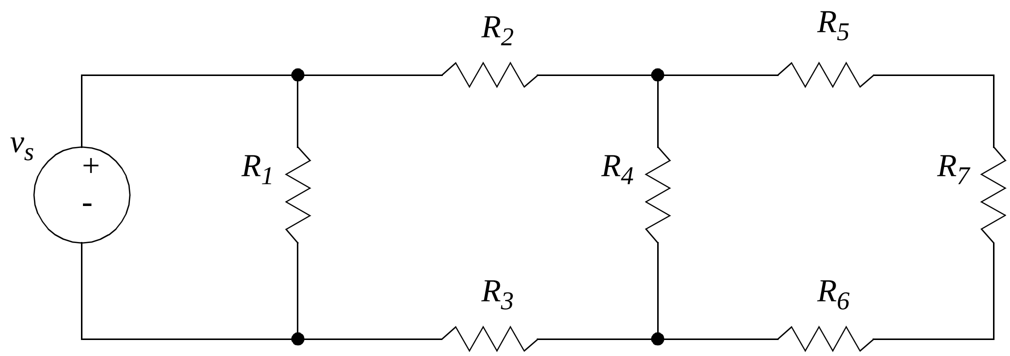


Figure 1. The circuit to be analyzed using the mesh-current method.

BUILD AND MEASURE PROCEDURE

1. You will study the circuit shown in Figure 1. Select the source voltage from the range of voltages available on the CDT and seven 1/4 W resistors of various values. Select resistor values so that for the source voltage selected, the power dissipation in each resistor does not exceed 1/4 W. A "worst case" design criteria is to limit the total power from the source to be less than 1/4 W. Therefore, if each of the seven resistors chosen has a value greater than $V^2/0.25$, then the power dissipated in each resistor will not exceed resistor's rating. For example, if 10 V is chosen for the supply voltage, then a *minimum* resistance of $100/.25 = 400\ \Omega$ for each of the resistors keeps the power dissipated in each resistor less than 1/4 W. (Note: the resistors you select should be much larger than the minimum.)
2. Measure the values of the resistors you have chosen as precisely as you can and record their values. Set or measure the power supply voltage to the value you have chosen.
3. Set up the circuit of Figure 1 on the CDT using your measured resistors and experimentally analyze the circuit. (You must decide which currents and/or voltages to measure.) Measure each mesh current by inserting an ammeter at an appropriate point in the mesh.

COMPARISON PROCEDURE

1. Compare your measured and calculated mesh current values and account for any discrepancies. If you have controlled the experiment, then the data should result in direct data comparisons of 1% or less.

Grand Valley State University
School of Engineering

EGR 214 Experiment 7

SUPERPOSITION

OBJECTIVE

To investigate the application of the superposition principle to the analysis of electric circuits.

INTRODUCTION

The superposition principle is a very important analysis tool that is applicable to all *linear* systems. In electric circuits superposition is usually applied in two ways:

1. **Scaling.** If the single independent source of an electrical network is multiplied by a constant, then each response of the network is multiplied by the same constant.
2. **Additive**. If two or more independent sources are used to excite an electrical network, then the response of the network can be found by adding the responses of that network to each independent source individually with every other source deactivated (turned off).

In this lab the additive superposition property will be investigated. Three independent voltage sources will be used in the circuit shown in Figure 1. The desired response for this circuit with all sources energized is node voltage v_2. The objective of this experiment is to analyze the circuit of Figure 1 using superposition and then to verify the principle by measurement.

The first step in the analysis is to solve for v_2 due to each source acting individually with the other sources deactivated. These voltages will be identified as

$\left. v_2 \right|_{v_1}$, $\left. v_2 \right|_{v_3}$ and $\left. v_2 \right|_{v_4}$.

To deactivate a voltage source, do the following:

1) set the voltage to zero, and
2) replace the voltage source with a short circuit.

Therefore, to find $\left. v_2 \right|_{v_1}$ ıis circuit, the leads connecting nodes 3 and 4 to their respective sources must be disconnected from the sources and reconnected to the circuit datum. This deactivates sources 3 and 4 and replaces them with a short so that the voltage at node 2 is due to source 1 alone. This procedure is then repeated for each of the other sources. The total response, by superposition, is the sum of the individual responses. That is,

$$v_2 = v_2\big|_{v_1} + v_2\big|_{v_3} + v_2\big|_{v_4}\ .$$

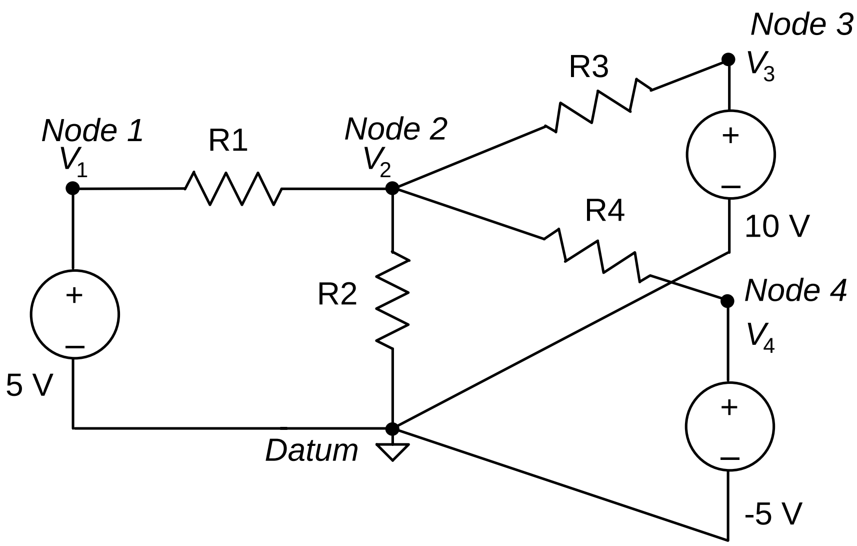


Figure 1. A circuit for illustrating superposition.

MATERIALS

1 - Circuit Prototyping System (CPS)
1 - Digital Multimeter Fluke Model 8050 or equivalent (DMM)
4 - 1/4 W resistors with values to be selected in lab.
Miscellaneous leads and connectors

DESIGN AND ANALSYS PROCEDURE

1. Calculate the voltage v_2 with only v_1 energized, namely $v_2\big|_{v_1}$ en repeat the calculation for v_3 and v_4, respectively. The calculated value for v_2, by superposition, is the sum of these voltages.

BUILD AND MEASURE PROCEDURE

1. Select 4 resistors using the power criteria established in previous labs for the highest voltage source used. Measure and record the actual value of each resistor.

2. Measure and record the voltage of the voltage source.

3. Set up the circuit in Figure 1 and measure v_2 with only v_1 energized. Compare this voltage with the value calculated in analysis step 1. Be sure that when $v_2\big|_{v_1}$ is measured that sources 3 and 4 are correctly deactivated (turned off). (Note: when removing a power supply, don't just put a wire across the terminals - you will blow a fuse.)

4. Repeat step 3 for $v_2\big|_{v_3}$ and $v_2\big|_{v_4}$.

5. Measure v_2 with all sources on.

COMPARISON PROCEDURE

1. Compare the measured and calculated values.

Grand Valley State University
School of Engineering

EGR 214 Experiment 8

THEVENIN'S THEOREM

OBJECTIVES

To investigate the theoretical and practical application of Thevenin's theorem to circuit analysis.

INTRODUCTION

Thevenin's theorem states that "Any linear network that contains branch circuit elements and sources (voltage, current, independent as well as controlled sources) can be reduced to an equivalent circuit that contains a single independent voltage source and series impedance." This equivalent circuit is called a "Thevenin's equivalent circuit". This is quite a remarkable theorem since it implies that no matter how complicated a circuit may be, it can always be reduced to an equivalent circuit consisting of a *single* independent voltage source and a *single* series impedance. Therefore, a complicated circuit can be thought of as a simple Thevenin equivalent circuit.
For this experiment the only circuit considered will be resistive with a single independent voltage source. For a circuit with "output" terminals designated *a* and *b*, the Thevenin equivalent will replace the circuit at these terminals as shown in Figure 1.

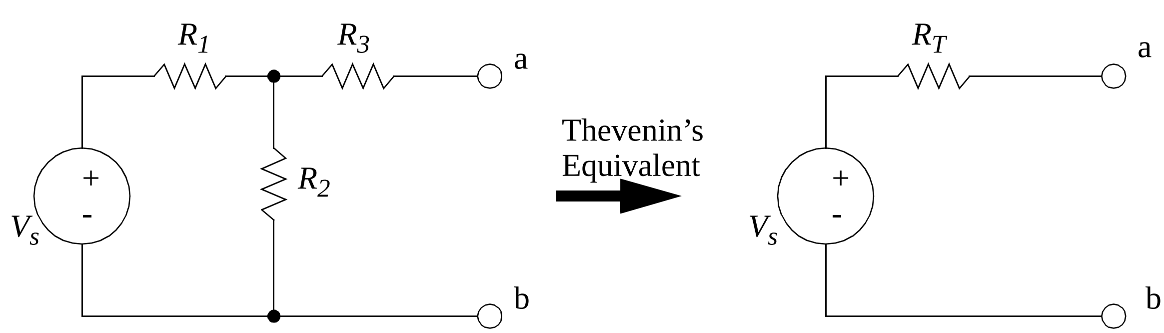


Figure 1. Example Thevenin's equivalent circuit.

In this lab we will determine the Thevenin equivalent circuit using both analytical and experimental methods. Analytically, the Thevenin's equivalent circuit can be found as follows:

1. Find the *open* circuit voltage at the terminals *a* and *b*.
2. Deactivate (that is, de-energize) all independent sources (but *not* the controlled sources) in the circuit. Independent voltage sources are replaced with shorts and independent current sources are replaced with opens to deactivate them.
3. With all independent sources deactivated, "look back" into terminals *a* and *b* and calcu-

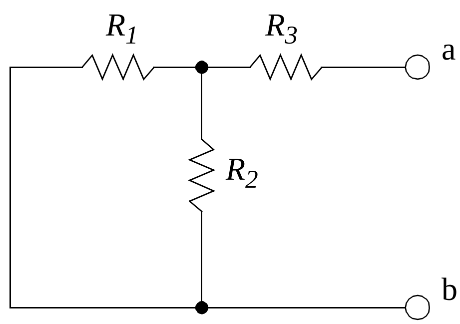
late the equivalent resistance, R_T.

4. The Thevenin's equivalent circuit is then an independent voltage source with a voltage equal to the open circuit voltage in series with the Thevenin's equivalent resistance.

We apply the above steps for the circuit shown in Figure 1. The open circuit voltage can be found by applying the voltage divider rule

$$V_{oc} = \frac{R_2}{R_1 + R_2} V_s$$

The Thevenin's equivalent impedance can be found by deactivating the source and looking back into terminals *a* and *b* as shown in Figure 2. The Thevenin's equivalent resistance can then be calculated by simply adding the resistance of R_3 to the resistance of the parallel combination R_1 and R_2.



$$R_T = R_3 + R_1 \parallel R_2$$

Figure 2. Finding the Thevenin's equivalent resistance by turning off independent sources.

Part of this experiment is to verify that the two parameter Thevenin's equivalent circuit is indeed equivalent to the original circuit. The test for equivalency is to determine if the *v-i* relationship matches at the *a* and *b* terminals. This can be accomplished by plotting the output voltage versus current as in Figure 3 for both circuits and comparing the two plots. Since the circuits are linear, the *v-i* curve for the *a* and *b* terminals will be a straight line with a negative slope because the terminal voltage must decrease as the load current increases. Therefore, only two points are required to define the line. For practical circuits, there are two obvious points to use. These points are (1) at no-load or open circuit where the source current is zero, and (2) at full load where the source current is the maximum the source can supply without burning up. Actually, any load resistance can be used so long as the load current does not exceed that which the circuit's power sources can supply. Circuit loads are just resistances that are put across the output terminals of a circuit in order to cause a current flow.

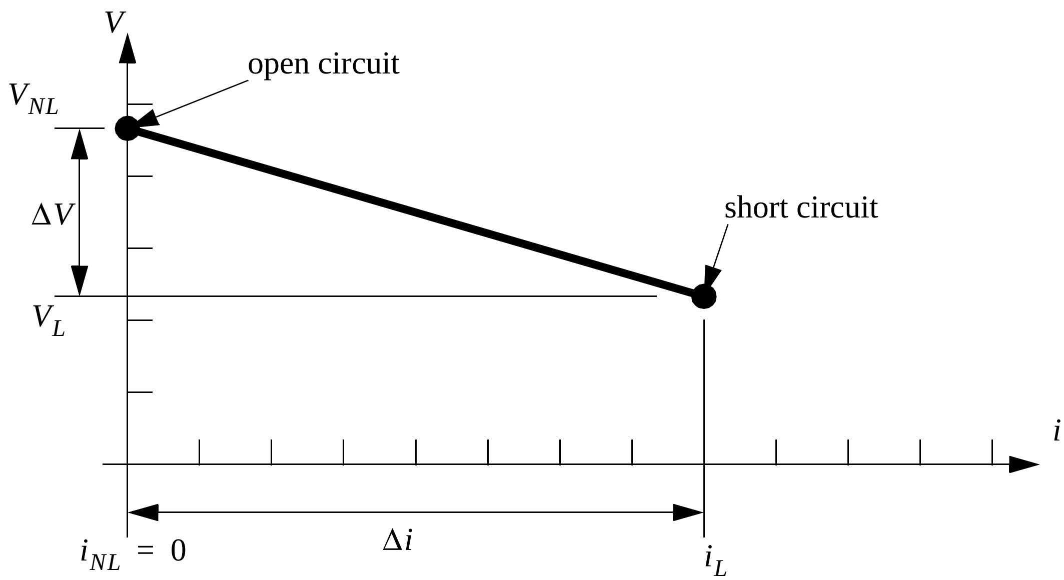


Figure 3. Output voltage droop as a function of load current.

Once a current has been established for the Thevenin equivalent circuit, there will be a voltage drop ΔV from the no-load value as shown in Figure 3. From Figure 3

$$V_{NL} = V\big|_{i=0} \qquad i_L = V_L / R_L \qquad V_L = V_{NL} - i_L R_T$$

Therefore

$$\frac{\Delta V}{\Delta i} = \frac{V_{NL} - V_L}{i_L - 0} = \frac{V_{NL} - V_L}{i_L}$$

or

$$R_T = \frac{\Delta V}{\Delta i}$$

This relationship for determining R_T can be applied to any circuit no matter what the circuit may consist of. In most instances the circuit may be a box with two terminals and no knowledge of the circuit inside the box. Thevenin's equivalent circuit for this box may be found by measuring V_{NL}, V_L and i_L and then calculating ΔV and Δi.

MATERIALS

1 - Circuit Prototyping System (CPS)
1 - Digital Multimeter Fluke Model 8050A or equivalent (DMM)
3 - 1/4W resistors with values to be selected in lab.

1 - Multiturn pot with value to be determined in lab.
Miscellaneous leads and connectors

DESIGN AND ANALSYS PROCEDURE

1. Design the circuit of Figure 1 by selecting values for R_1, R_2, R_3 and V. Remember to keep the worst case design criteria in mind, $R > 4V^2$. Measure the actual values of your resistors.

2. Calculate the theoretical values for V_{NL} and R_T for the circuit of Figure 1.

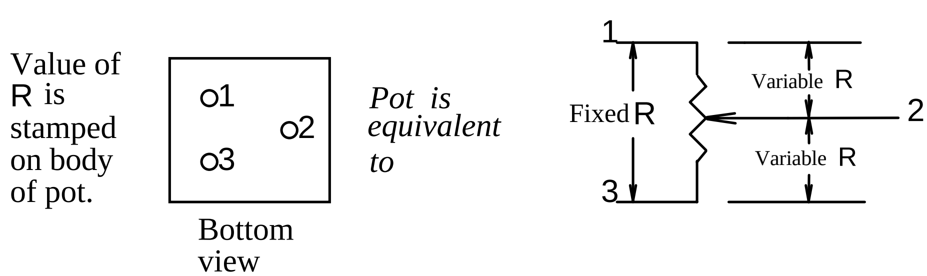
3. Determine a suitable resistive load R_L for your circuit. That means determine a value for R_L such that the current flow through R_L from terminal *a* to *b* causes the voltage from terminal *a* to *b* to drop to around 1/2 of the no-load value. Choose a resistor with the standard resistance value for your R_L.

BUILD AND MEASURE PROCEDURE

1. Set up the circuit of Figure 1 using the resistor values selected for R_1, R_2, R_3 in Design step 3. Set the value of V to the value you have selected.

2. Measure and record V_{NL}. Apply the load R_L you have selected to the terminals of your circuit and determine ΔV and Δi. Calculate the Thevenin's resistance $R_T = \Delta V/\Delta i$.

3. Replace the actual circuit used in steps 1 and 2 with the Thevenin equivalent circuit. Use a multiturn potentiometer or "pot" for R_T. Select a pot with a maximum resistance value that is greater than twice the desired R_T value. Set the pot's resistance to R_T using the DMM.



NOTE: A pot is a three terminal device as indicated in Figure 4. Terminals 1 and 3 are the ends of a *fixed* resistor with a value, *R*, stamped on the body of the pot. Terminal 2 is connected to the *wiper*, a movable contact that is in pressure contact with the distributed resistance of the pot. To make a variable resistance, the circuit must be connected to terminal 2 and either terminal 1 or 3 as shown in Figure 4. The value of variable resistance is the resistance contained between these two terminals.

Figure 4. Pinout diagram of a miniature, multiturn potentiometer.

4. Load the Thevenin equivalent circuit with the same load R_L used in step 2.

COMPARISON PROCEDURE

1. Compare the calculated theoretical and measured values of V_{NL} and R_T for your circuit for design steps 1 to 3 and build steps 1 and 2.

2. Repeat the last step for build step 3.

3. Compare the values of ΔV measured in build step 2 with values measured in build step 4.

Grand Valley State University
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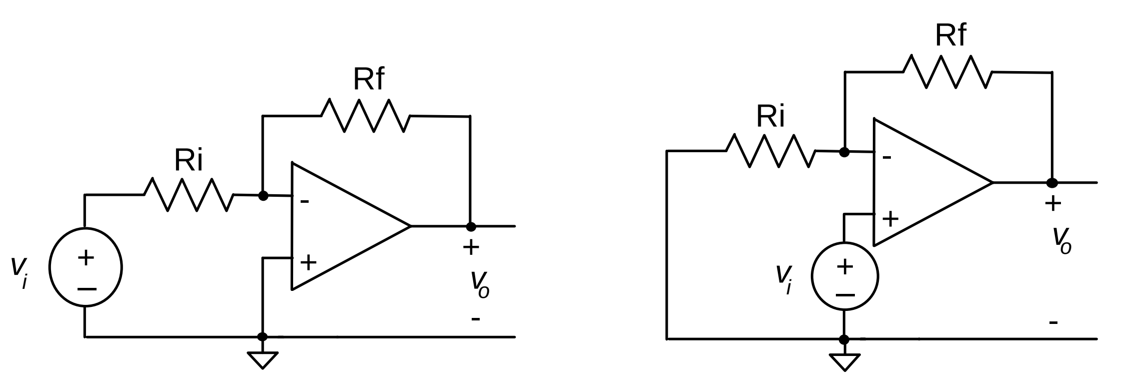
EGR 214 Experiment 9
INVERTING AND NON-INVERTING AMPLIFIERS
USING OP-AMPS

OBJECTIVE

To investigate the design of inverting and non-inverting operational amplifiers.

INTRODUCTION

An ideal operational amplifier (or *op-amp*) has infinite gain, infinite input impedance and zero output impedance. With the development of integrated circuit technology, current state-of-the-art op-amps very nearly approach this ideal. Oddly enough, as a *linear* circuit element the ideal op-amp is useless. In order to make a linear amplifier with an op-amp, the op-amp must be used with an external negative feedback circuit. Negative feedback is required to control the gain of the amplifier as well as its frequency response (bandwidth). In this lab, only gain and input impedance will be controlled by design. The inverting and non-inverting amplifier circuits are shown in Figure 1.



(a) Inverting operational amplifier

(b) Non-inverting operational amplifier

Figure 1. Basic operational amplifier circuits.

For the inverting amplifier, Figure 1*a*, the input to the op-amp constitutes a current summing point so that

$$-\frac{v_i}{R_i} - \frac{v_o}{R_f} = 0$$

Now the closed-loop gain of a circuit, A_v, is defined as the output voltage divided by the input voltage, that is

$$A_v = \frac{v_o}{v_i}$$

so that for the inverting amplifier, the closed-loop gain is

$$A_v = -\frac{R_f}{R_i}$$

upon combining the above equations.

For the non-inverting amplifier, Figure 1*b*, we have

$$v_o = v_i + R_f \frac{v_i}{R_i}$$

so that the closed loop voltage gain, A_v, is

$$A_v = \frac{v_o}{v_i} = 1 + \frac{R_f}{R_i}$$

MATERIALS

1 - Circuit Prototyping System (CPS)
1 - Digital Multimeter Fluke Model 8050 or equivalent (DMM)
1 - Oscilloscope Tektronix Model 2215 or equivalent (SCOPE)
1 - Function Generator Wavetek Model 191 or equivalent (FG)
1 - 741 op-amp IC
Various 1/4 W resistors for amplifier design
Miscellaneous lead and connectors

DESIGN AND ANALSYS PROCEDURE

1. Design an inverting amplifier circuit using the 741 op amp to have a closed-loop voltage gain, A_v, equal to –10. Measure and record the actual values of R_i and R_f.

2. Repeat step 1 for a gain of +10 with the non-inverting amplifier.

BUILD AND MEASURE PROCEDURE

1. Set up the 741 op-amp circuit you have designed on the CPS. Make sure the power is <u>*OFF*</u> as you build the circuit. Connect $+V_{CC}$ and $-V_{CC}$ to the +12 V and –12 V supplies, respectively, on the CPS. Sketch the circuit in your logbook. For your reference, the pin-outs of the 741 mini-DIP are shown in Figure 2.

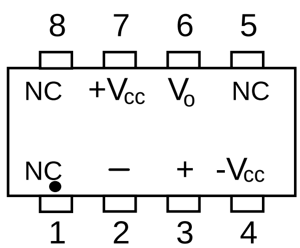


Figure 2. 741op-amp pinouts (looking down on the DIP package).

2. Turn the CPS on and with the input voltage to the amplifier set to zero ($v_i = 0$) check to see that the output voltage, v_o, is also zero. If it isn't, check to make sure your circuit is connected correctly.

3. Put a small, less than 1 V, positive DC voltage into the input, (i.e., $v_i < 1$ V). Measure and record the output voltage, v_o. Calculate the voltage gain, A_v, and compare this value to your design. Do the same with a voltage time function from the FG (sine, square or triangular wave form). Measure the output voltage, v_o, on the SCOPE.

4. Repeat steps 1 through 3 for the non-inverting amplifier.

COMPARISON PROCEDURE

1. Compare the experimental results for both amplifiers to the design objectives.

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EGR 214 Experiment 10

CAPACITANCE

OBJECTIVES

To investigate the voltage-current (*v*-*i*) relationship for circuit capacitance.

To investigate the operation of a physical device called a “capacitor”.

INTRODUCTION

A capacitor is a physical device for storing charge. Using a water analogy, a capacitor is like a bucket in which water is accumulated or stored. A capacitor accumulates or stores electrical charge.
A physical model of capacitor operation is that the amount of charge stored in the capacitor is proportional to the voltage across the capacitor. The proportionality constant between voltage and charge is the “capacitance” value of the capacitor. This relationship is stated as

$$q = Cv \quad (1)$$

where q is the charge in coulombs, v is the voltage in volts and C is the capacitance in farads. From the definition of current, $i = dq/dt$, the *v*-*i* relationship (that is, the branch element circuit model for a capacitor) can be found by taking the derivative of the above equation

$$i = \frac{dq}{dt} = \frac{d(Cv)}{dt} = C\frac{dv}{dt} + v\frac{dC}{dt}.$$

In this experiment, only capacitors with constant values will be used so that $dC/dt = 0$. Thus, the *v*-*i* characteristic to be verified in this experiment is

$$i = C\frac{dv}{dt}. \quad (2)$$

Currently, the most convenient instrument available to measure and display voltage time functions is the oscilloscope or “scope”. The scopes used in EGR 214 require a repetitive wave form to clearly display a voltage time function. Therefore, for this experiment it is desirable to make either the voltage, v, or the current, i, a periodic time function with period, T, and display the other variable on the scope for measurement.

Since a scope is designed to display voltage, current will be selected as the periodic parameter and the voltage across the capacitor will be displayed on the scope. Because of Eq (1), the voltage displayed is a measure of the charge on the capacitor at any instant of time.

The time function used for the current will be a square wave with zero average value. That is, the area under the curve above the horizontal axis is equal to the area under the curve below the axis. The current wave form is shown in Figure 1.

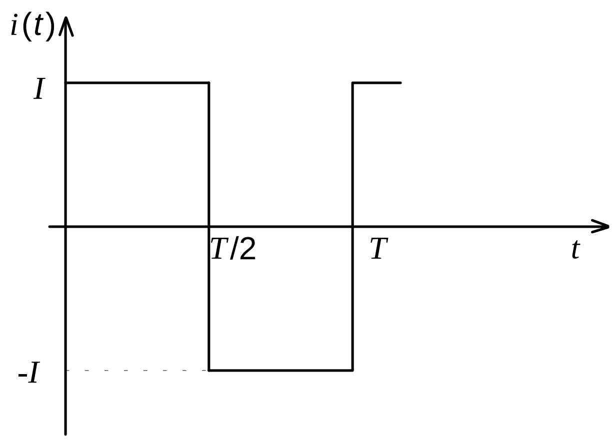

Figure 1. Current square wave used to drive the integrator circuit.

The voltage across a capacitor can then be found by integrating Eq (2) to get

$$v(t) = v(0) + \frac{1}{C}\int_0^t i(t)dt \quad , \quad 0 \le t \le T/2 \quad (3) \quad .$$

Since the current is constant during the time that charge is flowing into (+*i*) or out of (–*i*) the capacitor, the voltage across the capacitor has the time function shown in Figure 2

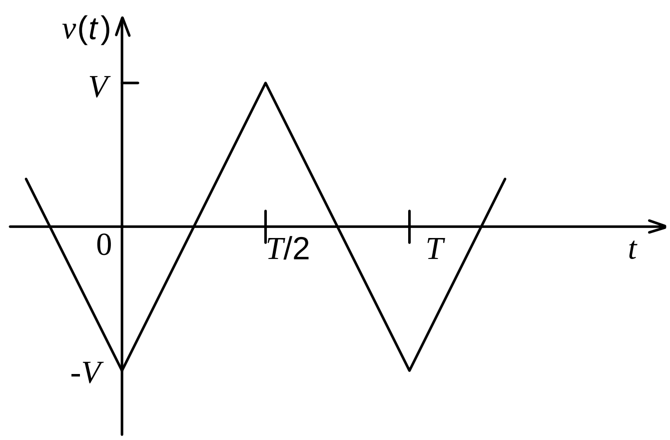

Figure 2. The time function of the voltage across the capacitor is a triangular wave when its current is a square wave.

and is described by the equations

$$v(t) = -V + \frac{It}{C} \quad \text{for} \quad 0 \le t \le T/2$$

and

$$v(t) = V - \frac{It}{C} \quad \text{for} \quad T/2 \le t \le T$$

Since the current square wave has zero average value, the voltage across the capacitor must also have zero average value. This implies that the voltage wave form's amplitude, *V*, is symmetrical about the time axis and

$$V = v(T/2) = -v(0).$$

We can solve for the amplitude from the fact that

$$v(T/2) = -v(T/2) + \frac{I(T/2)}{C} = -v(T/2) + \frac{IT}{2C}$$

for the periodic wave form. Thus

$$v(T/2) = \frac{IT}{4C} = \frac{I}{4Cf} \quad (4)$$

since the period, *T*, is the reciprocal of the frequency, *f*. From the above relationships, we also have

$$v(0) = -\frac{I}{4Cf}.$$

MATERIALS

1 - Circuit Prototyping System (CPS)
1 - Oscilloscope, Tektronix Model 2215A or equivalent (SCOPE)
1 - Function Generator, Wavetek Model 191A or equivalent (FG)
1 - LCR Meter, Leader Model 745G or equivalent (LCR Meter)
1 - 10 kΩ 1/4 W resistor
1 - 1 MΩ 1/4 W resistor
1 - Op amp, 741C
Capacitors with values to be determined during the experiment.
Miscellaneous leads, connectors and scope probes.

PROCEDURE

Note: This week you must divide the procedure steps into analysis, verification and comparison sections.

1. In the expression for the peak or maximum voltage (and peak charge) across the capacitor (Eq (4)), there are three parameters: *I*, *C*, and *f* which determine $v(T/2)$. In order for this experiment work, values for each of these parameters must be determined for permissible values of the peak voltage. If this were a pure analysis problem, then values for these parameters would have been specified in the problem or four independent equations would have been given so that we could solve for unique values for each of these parameters (a right answer type of problem). However, these parameters will not be specified for you in this experiment. Instead, you

will have to *design* this experiment. That is, you will have to choose suitable values for these parameters.

In a typical design problem there are more parameters and variables that have to be specified than there are equations to determine them. In our problem we have a single equation that relates the three parameters to the maximum voltage amplitude. The values for the three parameters and voltage must be determined. Once any three values are specified, the value of the fourth can be determined from the peak voltage equation (i.e., Eq (4)).

For this experiment, a reasonable value for I is 1.0 mA since we can only draw a small current from the FG (due to the FG's design). The FG is also limited to a peak or maximum output voltage of 10 V. A constant current from the FG can be obtained by using an op amp and placing the capacitor in the op amp's feedback circuit. The current charging the capacitor is then determined by the input resistance, R_i, to the op amp and R_S, the source resistance internal to the FG. The combined input and internal source resistance must be about 10 kΩ since 10V/.001A = 10,000 Ω. The voltage across the capacitor is limited to the supply voltage used to power the op amp. This means that $v(T/2) < 12$ V. Values have now been established for two of the four parameters. The next step is to choose values for either C or f and solve for the remaining parameter. Familiarize yourself with the types and values of the capacitors available in the lab and make a choice of C or choose a frequency greater than 500 Hz but less then 10 kHz and solve for C. See Appendix A for how to read coded capacitor values.

Using either approach, design the experiment by determining values for C and f. Select the capacitor and measure its actual value with the LCR Meter.

2. Setup the circuit shown in Figure 3, which is often referred to as an *integrator* circuit.

3. In the circuit of Figure 3, the voltage between the op amp inputs must always be approximately zero. That is, the voltage ε 0. For the circuit of Figure 3, with the "+" input connected to the datum, the "–" input is sometimes referred to as a "virtual ground". Therefore, the output voltage, v_o, is the voltage across the capacitor. The 1 MΩ resistor across the capacitor allows a little bit of current to bypass the capacitor in either direction to balance the positive and negative voltage swings so that the average value of the voltage output is zero.

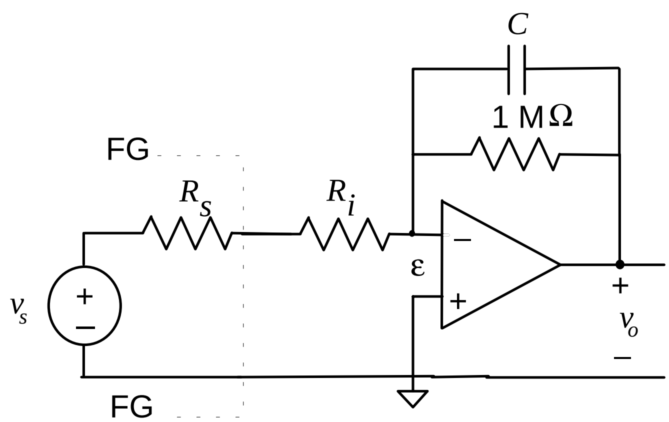

Figure 3. Op amp integrator circuit.

4. Analyze, measure and compare the voltage across the capacitor for the design values you have chosen.

Grand Valley State University
School of Engineering
EGR 214 Experiment 11
INDUCTANCE

OBJECTIVES

To investigate the *v-i* relationship for the branch circuit element, inductance.
To investigate the operation of a physical device called an *inductor.*

INTRODUCTION

Background Reading for Interest

Physically, an inductor is simply a coil of wire. Current flowing through a wire creates a magnetic field. The magnetic field created by a section of wire through which current is flowing interacts with adjacent sections of the same wire and induces voltages in those sections of the wire. The total voltage induced across the inductor, *v*, is proportional to the rate of change of magnetic flux, Φ, by Faraday's law

$$v = N\frac{d\Phi}{dt} \qquad (1)$$

where *N* is the number of turns for the coil of wire through which current is flowing. If *N* is assumed to be constant, then the voltage expression can be written as

$$v = \frac{d(N\Phi)}{dt}. \qquad (2)$$

The term *N*Φ is called the *flux linkage* and is related to the magnetic field that is made by current flowing through one turn linking with all other turns in the coil. The magnetic flux, Φ, is proportional to current or $\Phi \approx i$ which is Ampere's law. The proportionality constant is $N/\Re$ where *N* is the number of turns and $\Re$ is a term that is dependent on the physical properties of the coil and is called the *reluctance*. Therefore,

$$\Phi = \frac{N}{\Re} i. \qquad (3)$$

By combining Faraday's law with Ampere's law, the *v-i* relationship for an inductor can be derived as

$$v = \frac{N^2}{\Re}\frac{di}{dt}. \qquad (4)$$

The term $N^2/\Re$ is a constant that is called *inductance* and given the symbol *L*. Inductance has the unit *henry* named after the American physicist Joseph Henry. Therefore, the equivalent branch circuit *v-i* relationship for an inductance is

$$v = L\frac{di}{dt} \quad . \qquad (5)$$

Notice that from Faraday's law, Eq (2),

$$\frac{d(N\Phi)}{dt} = L\frac{di}{dt}$$

so that the flux linkage $N\Phi = Li$. This means that flux linkage in an inductor can be thought of as being analogous to charge in a capacitor by comparing

$$q = Cv$$

with

$$N\Phi = Li.$$

Capacitance and inductance are circuit element "duals" in that the roles of *v* and *i* are interchanged in their *v*-*i* relationships.

The Experiment

In order to verify the *v*-*i* relationship for the inductor, the same type of experiment used in Experiment 10 for the capacitor will be applied to the inductor. In verifying the capacitor's *v*-*i* relationship, a constant current square wave was used to drive the capacitor and the capacitor's voltage was displayed and measured. In this inductor experiment, a constant current will also be used to drive the inductor and the voltage across the inductor will also be displayed and measured. However, since the capacitor and inductor are duals of each other, if the current time function selected to drive the inductor is a triangular wave instead of a square wave, then the output will be a voltage square wave. This is just the opposite behavior of the capacitor.

There is, however, a significant difference between the physical operation of these devices. Charge is a material that can be stored like water so that in the capacitor experiment, the capacitor started with an initial state of zero charge and was then alternately charged and discharged periodically the same amount so that the charge always returned to zero at the end of the period. Flux linkage cannot be stored like charge since it is a derivative away, i.e. $i = dq/dt$, from charge. In order to "store" a state of flux linkage, a continuous (DC) current must flow through the inductor.

There will be another change from Experiment 10. In this experiment you will use peak-to-peak voltages rather than amplitude voltages to describe the voltage waveforms. This change will give you experience in dealing with a commonly used way to specify and make scope voltage readings.

MATERIALS

1 - Circuit Prototyping System (CPS)
1 - Oscilloscope Tektronix Model 2215A or equivalent (SCOPE)
1 - Wavetek Model 191A Function Generator or equivalent (FG)
1 - LCR Meter, Leader Model 745G or equivalent (LCR Meter)
2 - 1/4 W resistors (1@10kΩ and 1@50kΩ)
1 - 1 nF capacitor
1 - Op amp 741C
1 - 0.3 to 1.0 H Variable Inductor
Miscellaneous leads and connectors and scope probes

DESIGN AND ANALYSIS PROCEDURE

1. Analyze the circuit of Figure 1. Assume the inductor is ideal to start your analysis. That is, assume that the resistance of the inductor, R_L, is zero (i.e., the inductor is lossless).

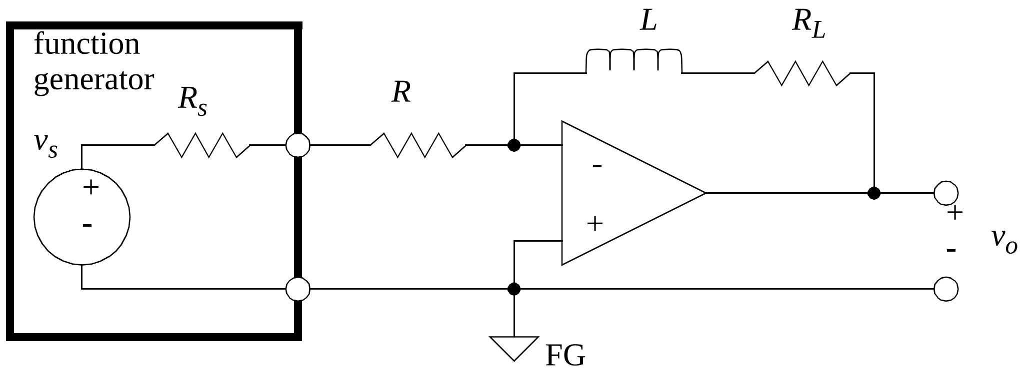

Figure 1. An op amp differentiator circuit.

Select v_S(t) to be a triangular wave with peak-to-peak voltage of, V, volts and a frequency, f, or period, $T = 1/f$, as shown in Figure 2. Thus, the source voltage is given by

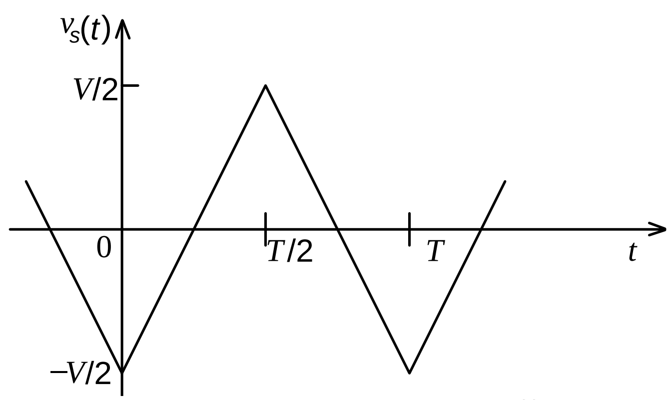

Figure 2. Voltage triangular wave used to drive the differentiator circuit.

$$v_S(t) = \frac{Vt}{T/2} - \frac{V}{2}, \qquad 0 \le t \le T/2 \tag{6}$$

and the current through the inductor is

$$i(t) = \frac{-2V_f}{R}t - \frac{V}{2R}, \qquad 0 \le t \le \frac{T}{2}. \tag{7}$$

Since the voltage function described is peak-to-peak, the current through the inductor is also a peak-to-peak value. Therefore, the output voltage induced across the inductor is also a peak-to-peak value and equal $V_o(t) = L\frac{d}{dt}i = -\frac{2VfL}{R}$ to.

For the positive slope of the triangular wave, the output voltage is a negative constant value and for the negative slope the output is a positive constant value. Therefore, the output voltage of the ideal inductor is a square wave with a peak-to-peak value of $4VfL/R$, as shown in Figure 3.

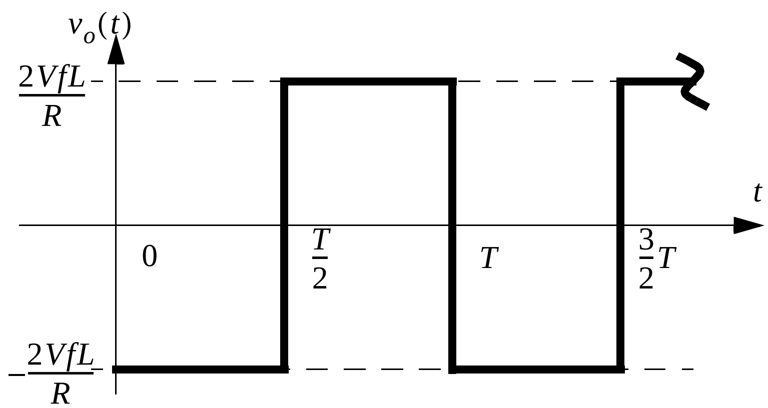

Figure 3. The time function of the differentiator's output voltage for an ideal inductor.

The actual output voltage, $v_0(t)$, is the voltage across the real inductor. From the model in Figure 1, the real inductor is made up of an inductance in series with a resistance, R_L. The inductor resistance, R_L, not only includes the DC resistance of the coil wire that makes the inductor, but also all the core losses on which the coil is wound. Therefore, R_L is always larger than the DC resistance measured with a DMM.

BUILD AND MEASURE PROCEDURE

1. Adjust the inductor for a value around 0.4 H and measure its exact value on the LCR meter. Make R = 10 kΩ, this will be much larger than the value of R_S, which is approximately 50 ohms.
2. Set up the circuit of Figure 1 and get it working. This will require the addition of a series connection of 50 kΩ and 1 nF in parallel with the inductor. This is a frequency compensation network whose purpose is to eliminate the high frequency sinusoidal wave form that rides on the square wave.
3. Set the FG for a frequency of 1 kHz and a triangular wave output with an amplitude of 20 V peak-to-peak.
4. Display the $v_o(t)$ on Channel 2 of the SCOPE and synchronize the output to the input voltage on Channel 1.
5. Measure the peak-to-peak output voltage with the SCOPE and compare it with the value calculated in step 1.

COMPARISON PROCEDURE

1. Compare the calculated and measured peak to peak voltages.
2. Discuss the shape of the waveforms.

APPENDIX A - PRACTICAL INDUCTOR ISSUES

The inductor's resistance, R_L, can be estimated from the inductor's quality factor (Q value). The Q value is a measure of the energy stored per cycle compared to the energy input per cycle. Later work in a more advanced course will show that

$$Q = \frac{2\pi f L}{R_L} \tag{8}$$

so that the inductor's resistance can be determined from

$$R_L = \frac{2\pi f L}{Q} \quad . \tag{9}$$

The inductor's Q value can be measured using an LCR meter available in the laboratory. The real output voltage, $v_o(t)$, is then the sum of two components, the voltage induced by the inductor, Ldi/dt and the voltage drop across R_L. Hence,

$$v_o(t) = -\left[\frac{2VfL}{R} + \frac{2VfR_L t}{R}\right] \quad , \quad 0 \le t \le \frac{T}{2} \quad . \tag{10}$$

The term contributed by the voltage drop across R_L will force the output voltage waveform to slope rather than be flat (See Figure 4 and compare with Figure 3.). The amount that the voltage will deviate from flatness over a half period is

$$v_o\left(\frac{T}{2}\right) = \frac{2VfL}{R} + \frac{2VfR_L T}{2R} \tag{11}$$

or

$$\Delta v_o\left(\frac{T}{2}\right) = \frac{VR_L}{R} \tag{12}$$

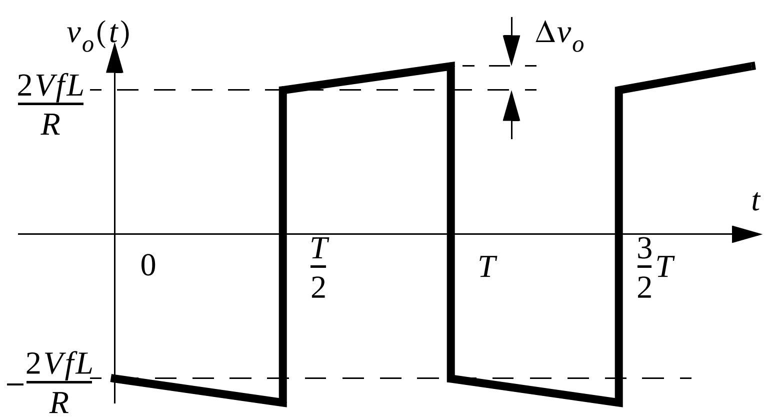

Figure 4. The time function of the differentiator's output voltage for a real inductor.

Therefore,

$$R_L = \frac{\Delta v_0 (T/2) R_S}{V} \quad . \tag{13}$$

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EGR 214 Experiment 12

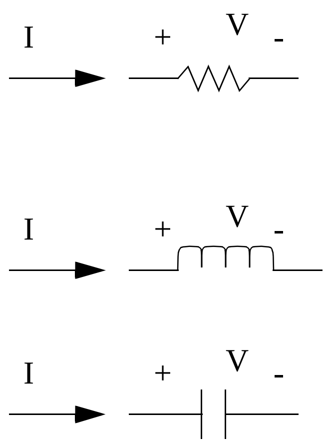
SINUSOIDAL STEADY-STATE ANALYSIS

OBJECTIVES

To relate sinusoidal input and output voltages using phasors.

INTRODUCTION

You have already learned many techniques to analyze DC circuits. These same techniques can be used to analyze AC circuits using phasors. A phasor represents a complex resistance that is called an impedance. Figure 1 shows the impedances for resistors, capacitors and inductors. For a resistor the impedance is real. Both the inductor, and capacitor, have complex impedances, indicating a phase shift.



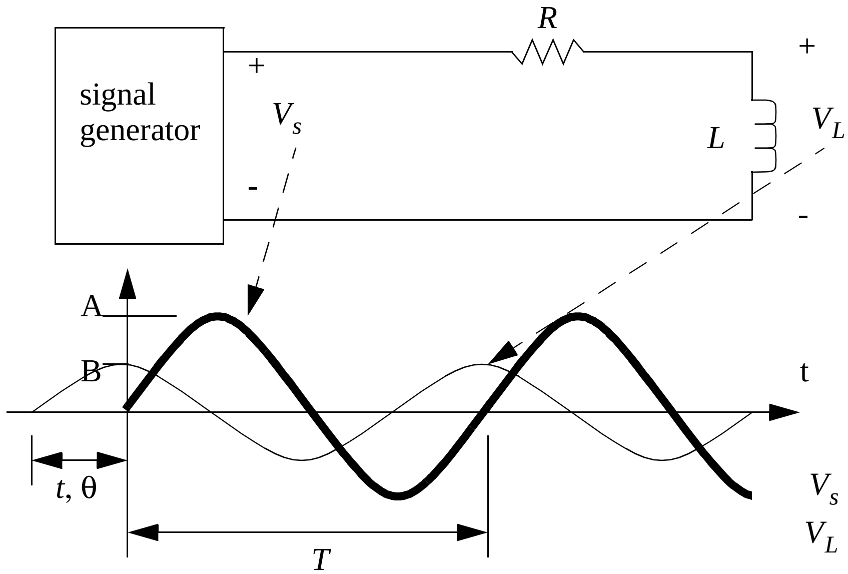
$$V = IX_R \qquad X_R = R$$

$$V = IX_L \qquad X_L = j\omega L$$

$$V = IX_C \qquad X_C = \frac{1}{j\omega C} = \frac{-j}{\omega C}$$

Figure 1 - Impedances for Passive Circuit Components

Consider the voltage divider in Figure 2. The output sine wave has a lower amplitude than the input, but it is also shifted (offset) in time. The offset between the waves is usually expressed as an angle, instead of time. Equations 1 and 2 represent the waves seen. The values for Vs are determined by the settings on the signal generator. We can calculate the values of B and θ using the voltage divider rule, and the phasor representation. In the figure the output leads, or is ahead of the input, by θ.



$$V_s = A\sin(\omega t + 0) \quad (1)$$

$$V_L = B\sin(\omega t + \theta) \quad (2)$$

$$\theta = \pm 2\pi\left(\frac{t}{T}\right) \quad (3)$$

Figure 2 - A Voltage Divider

As you learned in class, a phasor has a magnitude and angle. The magnitude is the value from the center line, to the peak voltage. The phase shift is the angular displacement from the reference wave. The voltages in Figure 1 can be rewritten using phasors as shown in equations 4 and 5.

$$V_s = A\angle 0 = (A) + j(0) \quad (4)$$

$$V_s = B\angle\theta = (B\cos\theta) + j(B\sin\theta) \quad (5)$$

Figure 2 - Phasor Representation of Voltages

Notice that the frequency ω is not included in equations 4 and 5. But, it does influence the impedance values in the example in Figure 3. These values can be used to calculate the output voltage based on the input voltage from the signal generator. The example substitutes the impedance values into the voltage divider equation, then assumed values are used to solve for the output, V_L. The resulting complex number can be converted to polar notation, to give the angle and phase shift for the output.

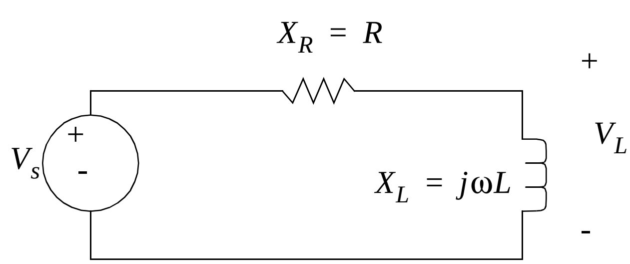


Figure 3 - Phasor Analysis of Circuit

Using the voltage divider law,

$$V_L = V_s\left(\frac{X_L}{X_R + X_L}\right) \tag{6}$$

consequently,

$$V_L = A\angle 0\left(\frac{j\omega L}{R + j\omega L}\right). \tag{7}$$

Assume $\omega = 100\frac{rad}{s}$, $R = 100ohm$, $A = 5V$ and $L = 0.4H$,

Substituting these values into equation 7 we get,

$$V_L = 5V\angle 0\left(\frac{j\left(100\frac{rad}{s}\right)(0.4H)}{(100ohm) + j\left(100\frac{rad}{s}\right)(0.4H)}\right)$$

$$\therefore V_L = (0.69 + 1.72j)V$$

$$\therefore V_L = \sqrt{0.69^2 + 1.72^2}V\angle \mathrm{atan}\left(\frac{1.72}{0.69}\right) = 1.88V\angle 1.19rad \tag{8}$$

MATERIALS

1 - Circuit Prototyping System (CPS)
1 - Oscilloscope, Tektronix Model 2215 or equivalent (SCOPE)
1 - Function Generator, Wavetek Model 191A or equivalent (FG)
1 - Digital Multimeter, Fluke Model 8050 or equivalent (DMM)
1 - LCR Meter, Leader Model 745 or equivalent (LCR Meter)
1 - 1000 Ω Resistor
1 - 0.1 uF Capacitor
Miscellaneous leads, connectors and SCOPE probes

DESIGN AND ANALYSIS PROCEDURE

1. Analyze the circuit shown in Figure 4 to find the relationship between a sinusoidal input, and the resulting output. Assume the component values are R=1000ohms, C=0.1uF. Assume the input voltage from the signal generator has a magnitude of 10V, at a frequency of 1000Hz. (Note: don’t forget to convert to radians/sec.)

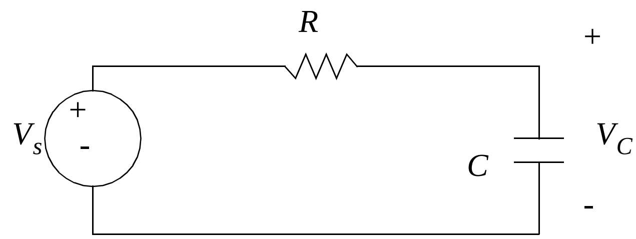


Figure 4 - Capacitance Voltage Divider Circuit

BUILD AND MEASURE PROCEDURE

1. Measure the capacitance and resistance of the selected components, and then use them to build the circuit shown in Figure 4.
2. Set up a sinusoidal input with a frequency about 1000Hz, and a magnitude of a few volts. Use this signal as the reference - channel A on the scope.
3. Measure the output voltage magnitude, and phase shift on the oscilloscope.

COMPARISON PROCEDURE

1. Compare the calculated and experimental values for output magnitude and phase shift.

Grand Valley State University
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EGR 214 Experiment 12

SINUSOIDAL STEADY-STATE ANALYSIS

OBJECTIVES

To apply AC phasor analysis techniques to LR and CR circuits.
To investigate making AC amplitude and phase measurements with an oscilloscope.

INTRODUCTION

In most electric circuit applications, the circuit has been connected to a sinusoidal voltage source for a relatively long time (for example, appliances plugged into the 60 Hz power distribution system). This implies that for any response in the circuit (voltage or current), the transient part of the total response has died away and only the steady-state part remains. If the forcing function is a sinusoidal voltage at frequency, *f*, every response in the circuit is also sinusoidal at frequency *f*. Analysis of an LCR circuit with a sinusoidal forcing function in the steady-state must be concerned with the time delay or phase as well as the amplitude of the response at every point in the circuit.
In this lab techniques for calculating and measuring the phase and amplitude of the sinusoidal steady-state response will be investigated. Since the frequency is the same throughout the circuit, the approach used is to disregard the function part (*i.e.*, the sinusoidal part) and to use complex reactive or phasor analysis to keep track of time delays and amplitudes throughout the circuit. The first circuit analyzed in this way will be the series LR circuit of Figure 1.

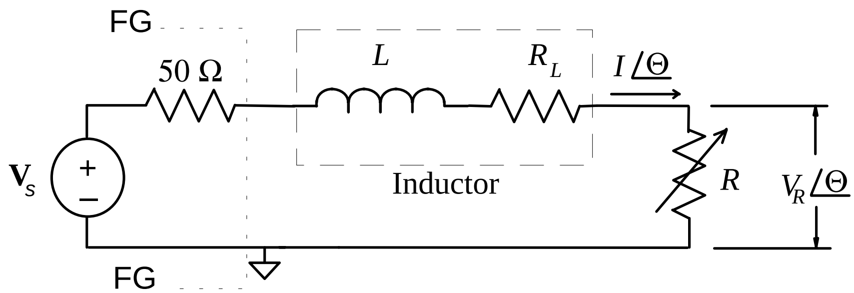

Figure 1. A series LR circuit.
In this circuit current through the inductor must lag behind the voltage across itby 90. Voltage and current are in phase through the resistor and the voltage drops across the resistor and inductor must add to equal the applied voltage. This means that the voltage drops across the inductor and resistor are 90° out of phase and the voltage drop across the resistor must lag behind the voltage drop across the inductor. These phase relationships are illustrated in Figure 2.

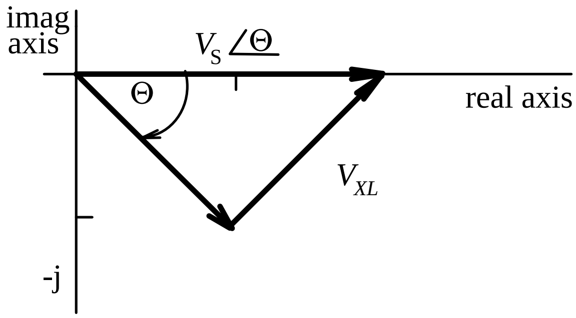

Figure 2. Resistor voltage lags the inductor voltage in a series LR circuit.
Let the current through the series LR circuit be **I**. If the input voltage source, $\mathbf{V}_S$, is taken as phase reference, then **I** is

$$\mathbf{I} = \frac{\mathbf{V}_S}{R_T + jX_L}$$

and its magnitude is

$$I = \frac{V_S}{\sqrt{R_T^2 + X_L^2}}$$ at a phase angle $\Theta = -\tan^{-1}(X_L/R_T)$

where $R_T = 50 + R_L + R$.
For $L = 0.4$H, $R_T = 2200\ \Omega$, $V_S = 10\ V_{P\text{-}P}$ and $f = 1000$ Hz, the inductor's reactance is $X_L = 2\pi(1000)(0.4) = 2513.3\ \Omega$, so that the magnitude and phase of the current are,

$$I = \frac{10}{\sqrt{2200^2 + 2513.3^2}} = 3.0\ \text{mA},$$

$$\Theta = -\tan^{-1}\left(\frac{2513.3}{2200}\right) = -44.8^\circ.$$

This means that the voltage across R is $V_R = R$ x (3.0 mA) and its phase is the same as that of I. Also, the voltage across the inductor is $V_L = (2513.3\ \Omega)$ x (3.0 mA) = 7.54 V and its phase is 90° greater than that of I.
If the inductor is replaced with a capacitor, the analysis is the same except that current through the capacitor now leads the voltage across it. This means that with the voltage source taken as reference ($\theta = 0$), the current will have a positive rather than negative phase angle.

$$\mathbf{I} = \frac{\mathbf{V}_S}{R_T - jX_C}$$

and

$$I = \frac{V_S}{\sqrt{R_T^2 + X_C^2}}$$ at phase angle $\Theta = -\tan^{-1}(X_C/R_T)$

MATERIALS

1 - Circuit Prototyping System (CPS)
1 - Oscilloscope, Tektronix Model 2215 or equivalent (SCOPE)
1 - Function Generator, Wavetek Model 191A or equivalent (FG)
1 - Digital Multimeter, Fluke Model 8050 or equivalent (DMM)
1 - LCR Meter, Leader Model 745 or equivalent (LCR Meter)
1 - Variable Inductor with L ≈ 0.4 H
1 - 5000 Ω Variable resistor (either single or multi-turn)
1 - 0.068 μF metallized polyester capacitor
Miscellaneous leads, connectors and SCOPE probes

PROCEDURE

1. Measure the series inductance on the LCR meter and adjust the inductor for a value of L = 0.4 H. Read the value of Q at f = 1 kHz and calculate R_L from the formula
$R_L = 2\pi fL/Q$
Measure and record the exact value of the capacitor.
2. Analyze the series circuit of Figure 1 and determine the value of R required to have its voltage lag behind the source voltage by 45^0 with a source voltage of 10 V_{P-P} at 1 kHz.
3. Set up the circuit of Figure 1 and drive it with a 10 V_{P-P} sine wave at 1 kHz. Display the FG output on Channel 1 of the SCOPE and trigger from Channel 1. Connect Channel 2 to the FG output and adjust both displays until the sine wave amplitude extends from top to bottom of the display. Make sure both channels are matched by inverting Channel 2 and displaying the difference of the two channels. If any signal remains, then readjust the amplitude and phase of the probe to one of the channels until they are matched.
4. Measure the phase of the output sine wave relative to the input sine wave. Put the scope in X-Y mode and observe a diagonal trace extending from the upper right corner to the lower left corner of the display. This represents a *Lissajous pattern* for two sine waves that have zero phase difference between them. Refer to Figure 3a. Two sine waves that have a 90° phase difference between them will produce a circular Lissajous pattern. For any other angle between 0° and 90°, the Lissajous pattern is an ellipse. The Lissajous pattern on the SCOPE is used to measure the phase difference between two sine waves.

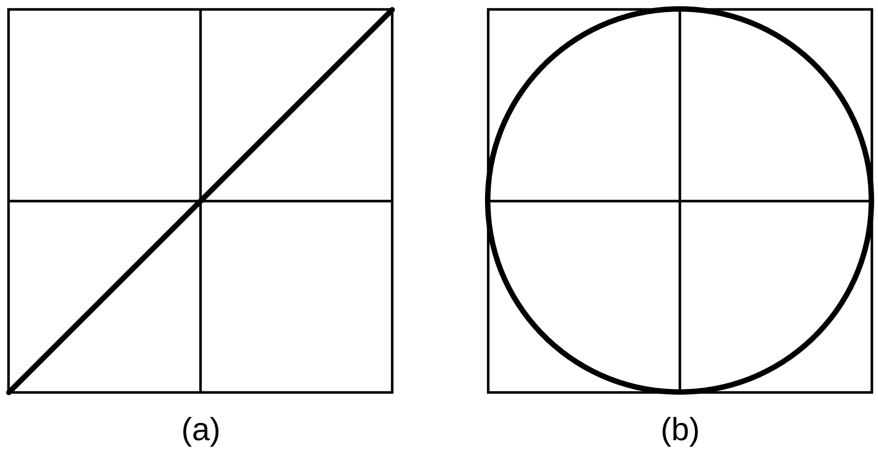

Figure 3. Lissajous pattern for two sine waves that have (a) 0° phase difference between them, and (b) a 90° phase difference.

From Figure 4 observe that if the signals to Channels 1 and 2 of the SCOPE are matched in amplitude, then the ratio of the vertical intercept of the elliptical Lissajous pattern to the vertical scale is the sine of the phase angle, sin(θ). Let the peak display be A and the vertical intercept be B. Then, $\sin(\theta) = B/A$.

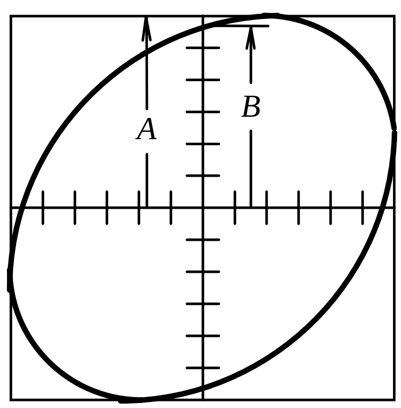

Figure 4. Phase determination from an elliptical Lissajous pattern.

Another technique for measuring phase that is good for small angles is to measure the amplitude difference between two equal amplitude sine waves. That is

$$B\sin(\omega t + \phi) = A\sin(\omega t) - A\sin(\omega t + \theta) \quad (1)$$

$$B\sin(\omega t)\cos(\phi) + B\cos(\omega t)\sin(\phi) = A\sin(\omega t) - A\sin(\omega t)\cos(\theta) - A\cos(\omega t)\sin(\theta) \quad (2)$$

$$B\sin(\omega t)\cos(\phi) + B\cos(\omega t)\sin(\phi) = A(1 - \cos(\theta))\sin(\omega t) - A\cos(\omega t)\sin(\theta) \quad (3)$$

So that, $B\cos(\phi) = A(1 - \cos(\theta))$ and $B\sin(\phi) = -A\sin(\theta)$

$$B^2 = A^2(1 - \cos(\theta))^2 + A^2\sin^2(\phi)$$

$$(B/A)^2 = 2(1 - \cos(\theta)) \text{ or } \cos(\theta) = 1 - (B/A)^2/2$$

However, cos(θ) can be expanded in a power series as: $\cos(\theta) = 1 - \theta^2/2 + \theta^4/24 -$ Therefore for θ small, $1 - \theta^2/2 \approx 1 - (B/A)^2/2$ or $\theta \approx (B/A)$ where B is the amplitude of the difference of two equal amplitude sine waves with amplitude, *A* and θ is in radians.

5. Connect the SCOPE so that the voltage from the source drives the x input while the voltage across the variable resistor drives the y input.
6. Adjust the variable resistor until the Lissajous pattern measurement of phase for the variable resistor measures 45°. As the variable resistance is changed, its voltage drop will also change. Keep adjusting the SCOPE's variable attenuator so that the x and y amplitudes remain equal. This is essential for correct angle measurements.
7. Remove the variable resistor from the circuit. Measure the resistance of the variable resistor and compare its value to the value calculated in step 2.
8. Replace the inductor with the 0.068 μF capacitor and repeat steps 2 through 7. Since R_L for a capacitor is zero, so there is no need to do step 1.
9. Pick other values of phase angle and/or values of resistance and repeat steps 1 through 7. Record your results in the log book.

Grand Valley State University
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EGR 214 Experiment 13

RMS VALUES AND EQUIVALENT HEATING

OBJECTIVES

To calculate the *rms* value of an arbitrary voltage time function.
To investigate the power contained in an arbitrary voltage time function.
To compare the power delivered by a time varying (AC) voltage source to the equivalent power delivered by a non-time varying (DC) source.

INTRODUCTION

The descriptor *rms* (short for *root-mean-square*) is a designation that is used to describe power in time varying electrical systems. It's a way of defining the amplitude of a time varying voltage or current so that the same power is delivered as an non-time varying voltage or current.
The *rms* amplitude can be found by determining the average power delivered to a 1 Ω resistor. We know that the average power delivered to the 1 Ω resister is

$$P_{avg} = \frac{1}{T}\int_{t_0}^{t_0+T} i^2(t)dt = (i_{rms})^2 .$$

This type of average is called a *root-mean-square* average or *rms* average.
For a sine wave, $i(t) = I_m \sin(\omega t)$, the average power delivered to the 1 Ω resistor is

$$P_{avg} = \frac{I_m^2}{2} ,$$

while for a DC signal, the average power delivered to the 1 Ω resistor is $(I_{dc})^2$. Equating the AC and DC average powers, we have

$$(I_{dc})^2 = (i_{rms})^2 = I_m^2/2.$$

Therefore, for a *sine* wave

$$i_{rms} = \frac{I_m}{\sqrt{2}} = 0.707 I_m .$$

The equivalent I_{dc} value is called the *rms* value of the sine wave, and we say that the *peak* to *rms* conversion factor is one over the square root of two or 0.707. This implies that if a time varying voltage with an amplitude of V_m is applied to a resistance, R, then the amount of power dissipated (converted to heat) in the resistance is $V_{rms}^2/R = V_m^2/2R$.
There is a unique conversion factor for every voltage or current waveform. An objective of this laboratory exercise is to calculate conversion factors for waveforms produced by most function generators.

MATERIALS

1 - Circuit Prototyping System (CPS)
1 - Digital Multimeter, Fluke Model 8050 or equivalent (DMM)
1 - Temperature Probe, Fluke Model 80T-150 or equivalent
1 - Oscilloscope, Tektronix Model 2215 or equivalent (SCOPE)
1 - Function Generator, Wavetek Model 191A or equivalent (FG)
1 - 100 Ω 1/4 W resistor
Miscellaneous leads, connectors and scope probes

DESIGN AND ANALYSIS PROCEDURE

1. Calculate the *peak* to *rms* conversion factor for a sine wave.

2. Calculate the *peak* and *rms* voltage amplitudes that a sine wave must have in order to dissipate 200 mW in a 100 Ω resistor. Also calculate the DC voltage that will dissipate 200 mW in the 100 Ω resistor. (You can select another power so long as it does not exceed 250 mW.)

BUILD AND MEASURE PROCEDURE

1. Use the SCOPE to set the *peak* voltage amplitudes for the the sine wave across the 100 Ω resistor and measure the temperature rise of the resistor. Also apply a DC voltage across the resistor and measure the temperature rise.

2. Measure the *rms* voltage with the DMM.

COMPARISON PROCEDURE

1. Compare the power level produced by the time-varying sine wave with that produced by the DC voltage. Are these power levels the same?

2. Compare the voltage measured with the DMM with your calculated value for the sine wave. Your DMM should give a "true" *rms* reading. Does it?

Grand Valley State University
School of Engineering

EGR 214 Experiment 14

USEFUL OP AMP CIRCUITS

OBJECTIVES

To design, build and test three useful op amp circuits: the voltage follower, analog summing amplifier and the difference amplifier.
To develop formal report writing skills.

PROCEDURE

1. Design and build a voltage follower using a 741. Use the SCOPE to display its response to a square wave with zero DC offset and ≈50% duty cycle. Measure both its input and output slew rates and compare them with the manufacturer's specified values given in the laboratory.
2. Design and build a difference amplifier whose output is $v_0 = 0.5(v_1 - v_2)$. Test it by applying the same square wave to both inputs. Accurately measure the output, which will not be zero. There should be a small square wave with monster spikes. Explain what you see. (Explain means to tell why, not what.)
3. Design and build an analog adder which will produce the output $v_0 = -2v_1 - 3v_2$. Use input and feedback resistors in the kilohm range. Predict and record the performance of your analog adder. Next, investigate what happens when the feedback and input resistors are made low (≈tens of ohms). Describe what you see when you apply a 40 mV sine wave. Now describe what happens as you gradually increase the amplitude of the sine wave. Explain.

DESIGN AND ANALSYS PROCEDURE

BUILD AND MEASURE PROCEDURE

COMPARISON PROCEDURE

EGR 345 - DYNAMIC SYSTEM MODELLING AND CONTROL

5. OVERVIEW

5.1 RESOURCES

5.1.1 Practice Problems

• The following chapters and problems are suggested, in addition to the laboratory materials and the course notes.

• The suggested problems are recommended to help you examine the basic properties of the problems. The required problems must be submitted. Doing only the required problems will leave you at a disadvantage. Historically, students who do not do these problems on a regular basis typically earn final marks that are TWO LETTER GRADES below their peers.

Read	Description	Suggested
cf 1.1-5	Introduction	none
cf 2.1-4	Translation	1,2,4,7,10,12,15,18,22,23,25,27
cf 3.1-3	State Variable Form	3,5,8,9,11,12,13,15,18,21,24,26
cf 4.1-4	Rotation	2,6,7,10,13,18,19,26,29
cf 5.1-7	Electrical systems	3,7,9,12,17,18,21,24,27,31
cf 6.1-6	1st and 2nd order sys.	1,2,5,8,12,16,20,25,27,28
cf 7.1-5	Laplace transforms	3,6a,6b,7,8,10,14,17,21,23,25,32,35
cf 8.1-7	Transfer functions	2,5,7,10,12,14,16,17,20,23,27,29,31,35,39
cf 13.1-5	Block diagrams	1,3,4,6,7,9,13,15,18,24,26,27,30,32,34,36
cf 14.1-5	Feedback and controls	2,5,9,14,17,19,23

5.2 DESIGN PROJECT

• Overview: This will involve a competitive design to see who can design a servo control system that can respond the fastest.

• Description:

1. The control system will be for a fire-fighting water cannon that has a rotating base. The

cannon will actually be a water hose, and the fire will be buckets with marked heights that must be filled. The cannon will start in a neutral position away from the buckets. Once activated the cannon will move to a bucket, fill the bucket, and then move to fill a second bucket. When done the cannon must rotate back to a neutral position.

2. The cannon assembly will be provided, as shown in the figure below. This assembly will include
3. The rules will include a

• Required:

1. A written report describing the design details.
2. A device.
3.

5.3 EGR 345 - LABORATORY EXPERIMENTS

• The laboratory work will help enforce the concepts presented in this and previous courses.

• Various labs will require pre- or post-lab work.

• General rules include:

- Unless specified, work is to be done individually.
- All written work is to be clear and accurate.

5.3.1 Lab 1 - Introduction to Resources and Tutorials

• These tutorials prepare you to use computer and other resources throughout the semester.

5.3.1.1 - Tutorial 1a - Creating Web Pages

• The general steps are:

1. Get a computer account on ‘claymore.engineer.gvsu.edu’ from Prof. Jack. This account will have a prototype web page that you can edit.
2. Go to a laboratory (EC 616), or home computer and run ‘Netscape Communicator’. Go to ‘claymore.engineer.gvsu.edu’ and look for your account under ‘students’. You should be able to find a page that starts with ‘YOUR_NAME_GOES_HERE’.
3. In Netscape (with your home page showing), select ‘edit’ from the tool bar, or under ‘file’ select ‘edit’ or ‘edit page’. You will be asked if you want to save the page.

Create a ‘temp’ directory on the computer. This directory will be used to temporarily hold your web page files. Make sure that the files will be saved in the ‘temp’ directory, and then ‘save’ the files. An editor will start on the screen.

5. The editor behaves much like Microsoft Word, with some subtle differences. At this point add your name, and change your email address to your river account. You can change your email address by clicking on the email link, and then clicking on the chain link near the top of the screen.
6. To upload the changes you have made to the website, select ‘publish’. You will need to indicate the file name as ‘index.html’, the destination as ‘ftp://claymore.engineer.gvsu.edu/home/YOUR_NAME/public_html’. You will also need to enter your user name and your password (DO NOT SAVE THE PASSWORD - SOMEBODY ELSE CAN GET ACCESS TO YOUR ACCOUNT). You should see a message that indicates files have been uploaded successfully.
7. Use Netscape, not the editor, to see if the changes have occurred. Your changes may not show up on the browser. This is because Netscape does not reload pages every time to look at them. Pages are often stored for up to 1 month on the PCs hard drive, and reused when you look at them. There are two ways to update the screen before this time limit - click on the reload button.
8. Next we will add links to your home page. First, run Mathcad, and create a simple file, and then save it in the same folder/directory you saved. Use a file name that is all lower case such as ‘test.mcd’ - any upper case letters cause problems in Windows 95.
9. Get your home page back in the Netscape editor. Someplace type the word ‘GVSU’. Use the mouse to select what you just typed, and then click on the link button. For the link name enter ‘http://www.gvsu.edu’, and apply the change. This will now be a link to the Grand Valley home page. For your Mathcad file type something like ‘Mathcad file’, highlight it, and add a link to ‘test.mcd’. This link will connect to your Mathcad file.
10. Publish the file, but first add the Mathcad file to the list of files at the bottom of the screen.
11. Test the page.

• Some tips are,

- Windows will not allow multiple applications to open the same file at the same time. If you seem to be having trouble opening a file, make sure it is not open in another application.
- As you add other files to your homepage, put them in the ‘temp’ directory. This will make all of the procedures simpler.
- Try to make your web pages small, and link them together. This will decrease download time and make browsers happier.
- Avoid using excessive images. Anything over 10K will make it very slow downloading over modem. Anything over 100K makes modem downloading painfully slow.
- When putting images on the web page use ‘jpg’ for photographic images, and ‘gif’ for line images. ‘jpg’ images can be compressed more than ‘gif’, but lines will become blurred.
- To link to other files or web pages there will be a ‘link’ command. If you want to add a

file that is in your ‘temp’ directory, just put the name of the file in the ‘URL’ field.
- Watch upper/lower case. This is a major cause of web page problems. It is best to keep to lower case for all file names.

5.3.1.2 - Tutorial 1b - Introduction to Mathcad, Working Model 2D and The Internet

• Objective:

Working Model 2D, Mathcad and the Internet will be used in this course. In some cases students have not been exposed to one or more of these software packages in the past. This session will be used as a refresher for those with little prior exposure, and as a tutorial for those with no experience.

• Theory:

Mathcad is a software package that allows us to do complex calculations both numerically and symbolically. To learn it initially will require a time investment. But, when doing calculations later, it will save a significant amount of time and reduce calculation errors.

Working Model 2D is a software package that allows us to set up systems of multiple rigid bodies. We can then apply forces, moments, etc. and then see how the system dynamics are effected. In comparison, Mathcad will allow longer, precise calculations, whereas Working Model allows faster results with reduced accuracy. Working Model also presents a visual simulation - this allows a more intuitive understanding of a dynamic system.

The Internet is a huge collection of computers providing information and connection on an unprecedented scale. It has become a standard business tool, and continues to evolve.

• Procedure

1. (If needed) Go over the Mathcad tutorial provided.
2. Use Mathcad to calculate the position of a ball that has been held then released just above the surface of the earth, and add the file to your home page.
3. (If needed) Go over the Working Model tutorial provided.
4. Repeat the problem solved in Mathcad with Working Model and add the file to your home page.
5. (If needed) Get a computer account set up, and create a home page.
6. Go to a search engine and find a website for a major business that is related to your co-op position and add a link to it on your home page. Explain how the business is related to your co-op position.

• Post-lab:

None

• Submit:

1. A Mathcad file linked to your home page.
2. A Working Model file linked to your home page.
3. An explanation and a link to a company on your home page.

5.3.1.3 - Presentation 1a - Introduction to Library Searches

• Objective:

To prepare students to use the libraries resources in typical research studies.

• Theory:

The essential purpose of engineering is to apply principles of the arts and sciences to solve real problems. Scientific principles tend to evolve over time, but the essential principles and written works are valid for a number of decades or centuries. As a result, books can be excellent resources for this knowledge. The applications that make use of the basic principles tend to be more revolutionary. As a result, printed books have a value for teaching the fundamentals, but the 'state of the art' must often be found in magazines, journals, etc. To put this in simpler terms, when we look for scientific resources, we will often use sources over a decade old. When using engineering resources, most will be less than five years old. Until recently, print has been the major means of exchanging information, and libraries have been the traditional repositories of printed materials. To deal with the extensive number of publications available in a library, we need to learn how to search for needed information, and what resources are available.

New technology has changed access to library materials. Libraries pool resources and share materials. Internet technology has also helped increase accessibility. In particular internet tools allow the entire library catalog to be examined without visiting the library. There are also a number of resources that can be searched and retrieved over the internet.

• Procedure

1. A presentation will be made by Mr. Lee Lebin, the University Library Director.
2. Use the library resources to identify an application of systems modeling.

• Post-lab:

1. Search for library resource.

• Submit:

1. A copy of the material referenced.

5.3.2 Lab 2 - Computer Based Data Collection

5.3.2.1 - Prelab 2a - Tutorial for LabVIEW Programming

Objective:

To learn the basic use of LabVIEW.

Theory:

To obtain the greatest computing power and flexibility we need to write computer programs. But, traditional programming languages are not well suited to designing user interfaces and dealing with data flows.

Most computer programs are written with lines of program and compiled to execute. LabVIEW allows you to “write” programs using graphical symbols. This graphical programming approach allows systems to be designed by connecting the symbols with "wires" (i.e., lines).

Equipment:

PC with LabVIEW software

Procedure:

1. Go through the LabVIEW QuickStart Guide provided in the laboratory. This will also be good review for those who have used LabVIEW in previous courses.
2. Write a Labview program that will count from 1 to 100, square the values, and print the results on a strip chart.

Marking:

1. The VI created should be posted to the web.

5.3.2.2 - Prelab 2b - Overview of Labview and the DAQ Cards

- To obtain the greatest computing power and flexibility we need to write computer programs. But, traditional programming languages are not well suited to designing user interfaces and dealing with data flows.

- LabVIEW allows you to “write” programs using graphical symbols. This graphical programming approach allows systems to be designed by connecting the symbols with "wires" (i.e., lines).

- The remainder of the labs will focus on using LabVIEW to write programs to allow a computer to interact with the environment outside the computer.

• The computers we will use all have DAQ (Data AcQuisition) boards - National Instruments PCI-1200 DAQ cards. These cards have capabilities that include:

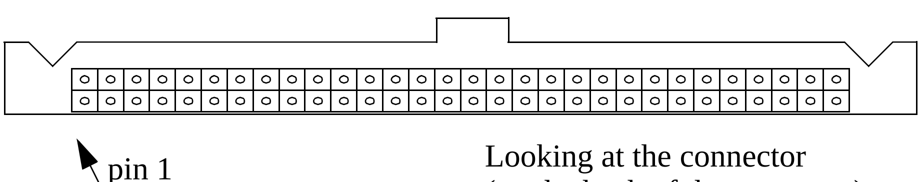
24 I/O bits - TTL 0,5VDC, 20mA max.
8 single ended or 4 double ended analog inputs - 12 bits
3 counters - 16 bits
2 analog outputs - 12 bits

• The connector for the card can be found on the back of the computer. It will have a connector with pinouts like the one shown below. A ribbon cable will be used to make electrical connection to the connector in the back of the computer.

2	ACH1	1	ACH0
4	ACH3	3	ACH2
6	ACH5	5	ACH4
8	ACH7	7	ACH6
10	DAC0OUT	9	AISENSE/AIGND
12	DAC1OUT	11	AGND
14	PA0	13	DGND
16	PA2	15	PA1
18	PA4	17	PA3
20	PA6	19	PA5
22	PB0	21	PA7
24	PB2	23	PB1
26	PB4	25	PB3
28	PB6	27	PB5
30	PC0	29	PB7
32	PC2	31	PC1
34	PC4	33	PC3
36	PC6	35	PC5
38	EXTTRIG	37	PC7
40	EXTCONV	39	EXTUPDATE
42	GATB0	41	OUTB1
44	GATB1	43	OUTB2
46	OUTB2	45	CLKB1
48	CLKB2	47	GATB2
50	DGND	49	+5V

LEGEND:

Analog inputs - ACHx
Analog input ground - AISENSE/AIGND
Analog outputs - DACxOUT
Analog output ground - AGND
Digital inputs and outputs - PAx, PBx, PCx
Digital input/output ground - DGND
Control handshaking - EXTTRIG, EXTUPDATE, EXTCONV
Counter inputs/outputs - OUTBx, GATBx, CLKBx



pin 1

Looking at the connector
(on the back of the computer)

NOTE: LABVIEW MANUALS ARE AVAILABLE ON-LINE, AND CAN BE FOUND ON THE COURSE HOME PAGE - LEAVE THEPAPER MANUALS IN THE LAB.

5.3.2.3 - Experiment 2 - Introduction to LabVIEW and the DAQ Cards

Objective:

Learn to use computers equipped for A/D and digital inputs.

Theory:

The computer reads data at discrete points in time (like a strobe light). We can read the data into the computer and then do calculations with it.

To read the data into a computer we write programs, and use "canned" software to help with the task. LabVIEW allows us to write programs for data collection, but instead of typing instructions we draw function blocks and connect them. How we connect them determines how the data (numbers) flow. The functions are things like data reads and calculations.

In this lab we will be using Labview to connect to a data acquisition (DAQ) board in the computer. This will allow us to collect data from the world outside the computer, and make changes to the world outside with outputs.

When interfacing to the card using a program such as Labview, there must be ways to address or request information for a specific input or output (recall memory addresses in EGR226). The first important piece of information is the board number. There can be multiple DAQ boards installed in the computer. In our case there is only one, and it is designated device ’1’. There are also many inputs and outputs available on the card. For analog outputs there are two channels so we need to specify which one when using the output with 0 or 1. For analog inputs there are 8 channels, and as before, we must specify which one we plan to read from using 0 to 7. For digital I/O there are a total of 24 pin distributed across 3 ports (1 byte each). Therefore when connecting inputs and output we must specify the port (PA=0, PB=1, PC=2) and the channel from 0 to 7. Note is that we can make the ports inputs or outputs, but not mixed - in other words we must pick whether a port will only be used for inputs or for outputs.

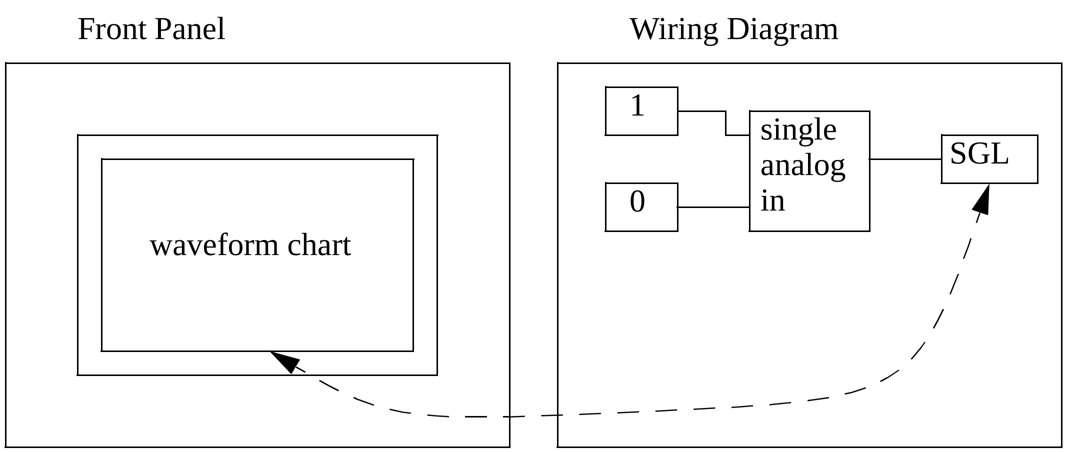
The voltage levels for the inputs and outputs are important, and you will need to be aware of these. For the digital outputs they will only ever be 0V or 5V. But the analog inputs and outputs will vary from -5V to 5V. This is build into the board. If we exceed these voltage limits by a few volts on the inputs, the boards have built in protection and should be undamaged. If we exceed the input voltages significantly, there is a potential to permanently damage the board.

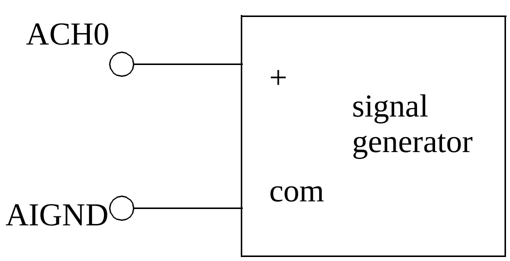
Equipment:

PC with LabVIEW software and PCI-1200 DAQ card
Interface cable
PLC trainer boards
Signal generator
Digital multimeter

Procedure:

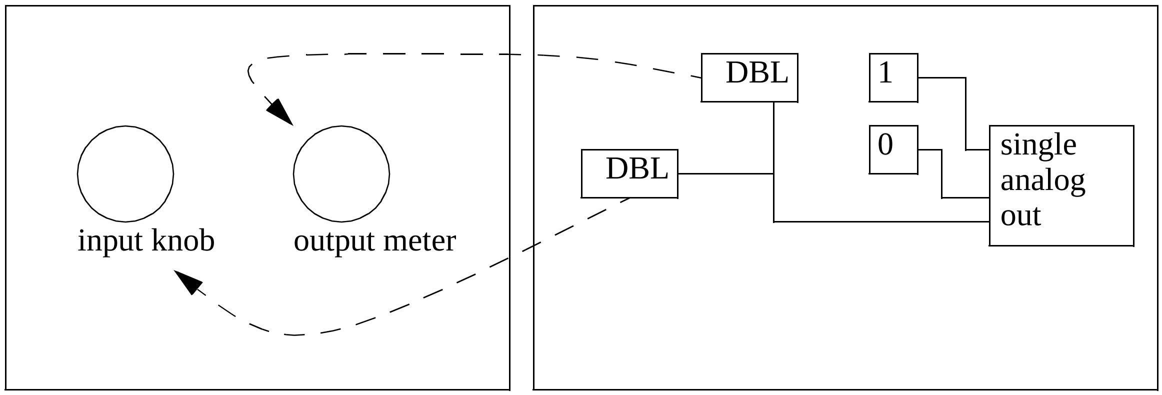
1. Go through the LabVIEW QuickStart Guide provided in the laboratory. This will also be good review for those who have used LabVIEW in previous courses.
2. Enter the LabVIEW program (layout) schematically shown below and connect a signal generator to the analog input (ACH0). (Note: there is a pin diagram for the connector in the Labview tutorial section.) Start the signal generator with a low frequency sinusoidal wave. Use the 'DAQ Configure' software to test the circuitry and verify that your hardware is operational. Then run your Labview program. Record the observations seen on the screen.

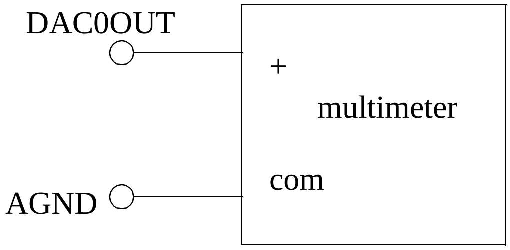




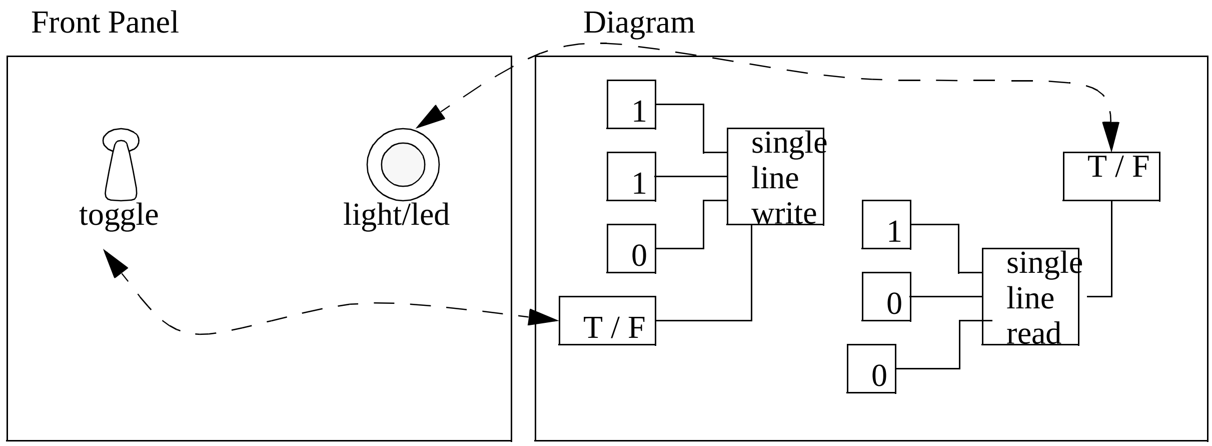
3. Connect the multimeter as shown below. Test the circuit using the 'DAQ Configure' utility. Enter the LabVIEW program schematically illustrated below and then run it. You should be able to control the output voltage from the screen using the mouse. Record your observations.

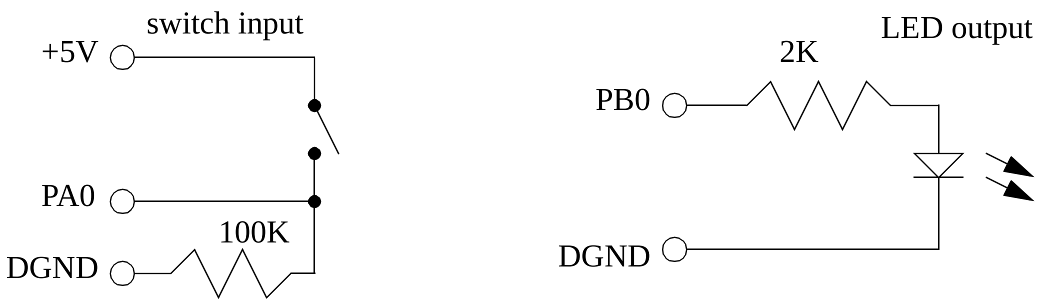
User Display Diagram





4. Connect the digital input and output circuits to the DAQ card and use the test panel to test the circuits. To do this, run the 'DAQ Configure' utility, double click on the 'PCI-1200', run the test panel window and ensure that the inputs and outputs are working correctly. Create the LabVIEW screen schematically illustrated below. This should allow you to scan an input switch and set an output light. When done, quit the program and run your LabVIEW program.





Marking:

1. A laboratory report should be written, including observations, and posted to the web.
2. The programs (VIs) that use the DAQ card should be posted to the web.

5.3.3 Lab 3 - Sensors and More Labview

5.3.3.1 - Prelab 3 - Sensors

Theory:

Sensors allow us to convert physical phenomenon to measurable signals, normally voltage or current. These tend to fall into one of two categories, discrete or continuous. Discrete sensors will only switch on or off. Examples of these include,

Inductive Proximity Sensors - use magnetic fields to detect presence of metals
Capacitive Proximity Sensors - use capacitance to detect most objects
Optical Proximity Sensors - use light to detect presence
Contact Switches - require physical contact

Continuous sensors output values over a range. Examples of these are,

Potentiometers - provide a resistance proportional to an angle or displacement
Ultrasonic range sensors - provides a voltage output proportional to distance
Strain Gauges - their resistance changes as they are stretched
Accelerometers - output a voltage proportional to acceleration
Thermocouples - output small voltages proportional to temperature

In both cases these sensors will have ranges of operation, maximum/minimum resolutions and sensitivities.

Prelab:

1. Prepare a Mathcad sheet to relate sensor outputs to the physical phenomenon they are measuring.

5.3.3.2 - Experiment 3 - Measurement of Sensor Properties

Objective:

To investigate popular industrial and laboratory sensors.

Procedure:

1. Sensors will be set up in the laboratory at multiple stations. You and your team should circulate to each station and collect results as needed. Instructions will be provided at each station to clarify the setup. The stations might include,
   - a mass on a spring will be made to oscillate. The mass will be observe by measuring position and acceleration.
   - a signal generator with an oscilloscope to read voltages phenomenon observe should include sampling rates and clipping.
2. Enter the data into Mathcad and develop a graph for each of the sensors relating input and output.

Submit:

1. A full laboratory report with graphs and mathematical functions for each sensor.

5.3.3.3 - Experiment 3b - Brushless Servo Motors and Controls

Objective:

To investigate industrial motors and controllers and develop a mathematical model.

Theory: The industrial motors and controllers to be used in this laboratory are manufactured by Allen-Bradley. The controllers are Ultra 100 drives, and the motors are Y-series brushless servo motors.

Prelab:

1. Visit the Allen Bradley web site (www.ab.com) and investigate the controllers and mototrs to be used in this laboratory: Ultra 100 drives and Y-1003-2H motors.

Procedure:

1. Follow the provided tutorial for Ultra 100 drives.
2.

Submit:

1. Graphs of response curves
2. A mathematical model of ______

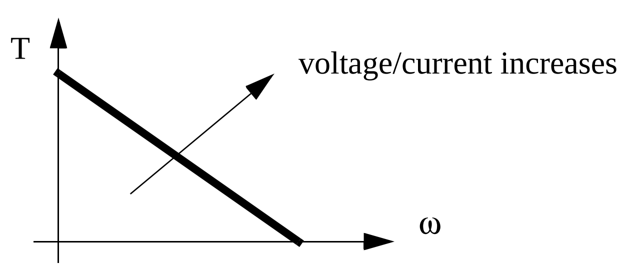
5.3.4 Lab 4 - Motors

• This set of labs will examine devices that have multiple phenomenon occurring.

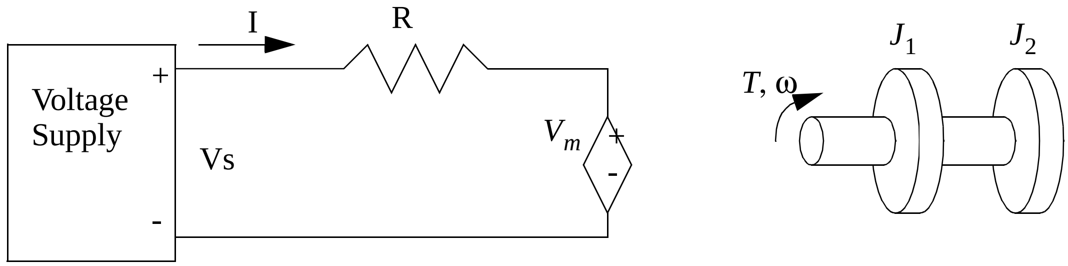
5.3.4.1 - Prelab 4a - Permanent Magnet DC Motors

• Theory:

DC motors will apply a torque between the rotor and stator that is related to the applied voltage or current. When a voltage is applied the torque will cause the rotor to accelerate. For any voltage and load on the motor there will tend to be a final angular velocity due to friction and drag in the motor. And, for a given voltage the ratio between steady state torque and speed will be a straight line.



The basic equivalent circuit model for the motor is shown below. We can develop equations for this model. This model must also include the rotational inertia of the rotor and any attached loads. On the left hand side is the resistance of the motor and the 'back emf' dependent voltage source. On the right hand side the inertia components are shown. The rotational inertia J1 is the motor rotor, and the second inertia is an attached disk.



Because a motor is basically wires in a magnetic field, the electron flow (current) in the wire will push against the magnetic field. And the torque (force) generated will be proportional to the current.

$$T = KI \qquad \therefore I = \frac{T}{K}$$

Next, consider the power in the motor,

$$P = V_m I = T\omega = KI\omega \qquad \therefore V_m = K\omega$$

Consider the dynamics of the rotating masses by summing moments.

$$\sum M = T = J\left(\frac{d}{dt}\right)\omega \qquad \therefore T = J\left(\frac{d}{dt}\right)\omega$$

The model can now be considered as a complete system.

The current-voltage relationship for the left hand side of the equation can be written and manipulated to relate voltage and angular velocity.

$$I = \frac{V_s - V_m}{R}$$

$$\therefore \frac{T}{K} = \frac{V_s - K\omega}{R}$$

$$\therefore \frac{J\left(\frac{d}{dt}\right)\omega}{K} = \frac{V_s - K\omega}{R}$$

$$\boxed{\therefore \left(\frac{d}{dt}\right)\omega + \omega\left(\frac{K^2}{JR}\right) = V_s\left(\frac{K}{JR}\right)}$$

Looking at this relationship we see a basic first order differential equation. We can measure motor properties using some basic measurements.

• Prelab:

1. Integrate the differential equation to find an explicit function of speed as a function of time.

2. Develop a Mathcad document that will accept values for time constant, supplied voltage and steady state speed and calculate the coefficients in the differential equation for the motor.
3. In the same Mathcad sheet add a calculation that will accept the motor resistance and calculate values for K and J.
4. Also add a calculation to use the unloaded motor torque the motor is stalled (omega = 0) to find the K value.
5. Get the data sheets for an LM675 from the web (www.national.com).

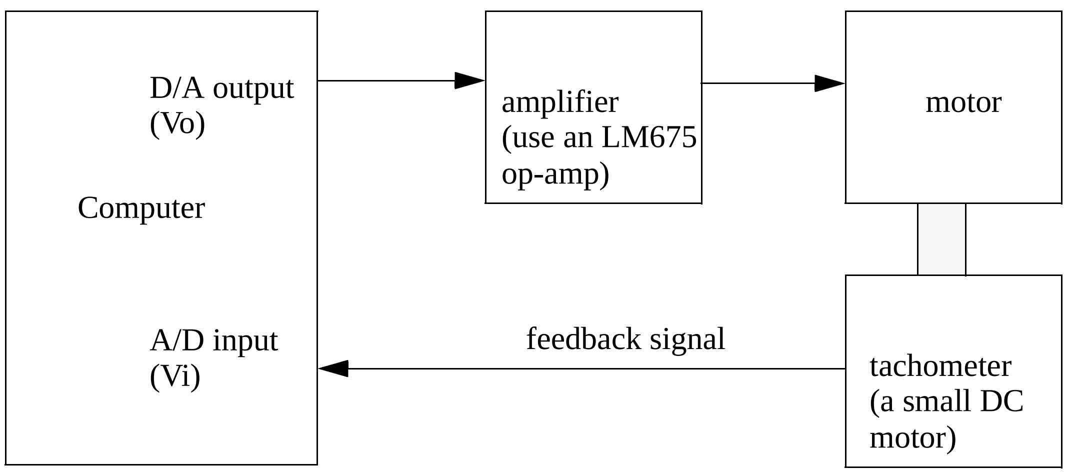
5.3.4.2 - Experiment 4a - Modeling of a DC Motor

• Objective:

To investigate a permanent magnet DC motor with the intention of determining a descriptive equation.

• Procedure

1. With the motor disconnected from all other parts of the circuit, measure the resistance across the motor terminals.
2. Connect the motor amplifier, motor and computer as shown in the figure below.



3. Write a Labview program that will output an analog output will be used to drive the motor amplifier. An analog input will be used to measure the motor speed from the tachometer.
4. Use a strobe light to find the relationship between the tachometer voltage and the angular speed.
5. Obtain velocity curves for the motor with different voltage step functions.
6. Use a fish scale and a lever arm to determine the torque when the motor is stalled with an input voltage.

• Post-lab:

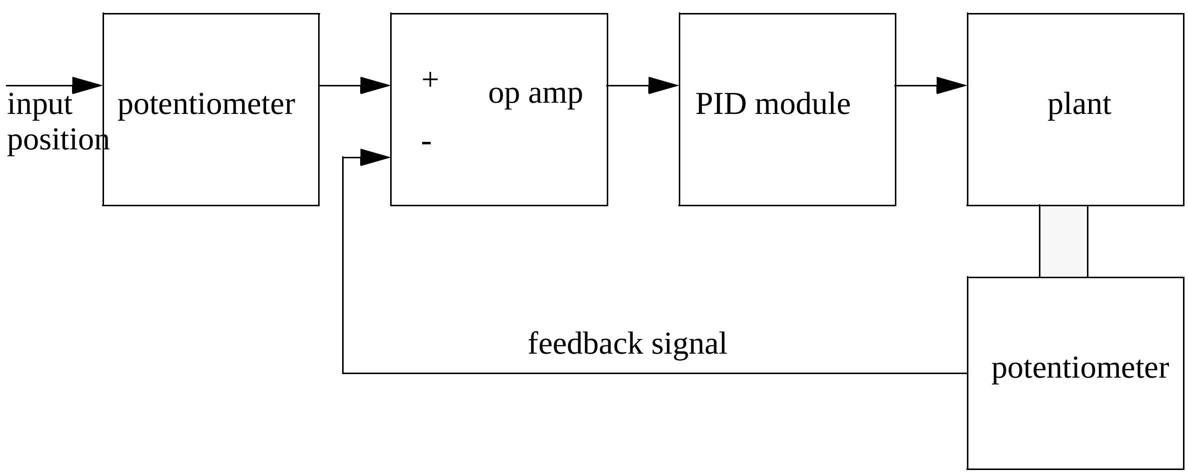
1. Determine the values of K for the motor. Determine the J for the rotor, and calculate J values for different load masses added.
2. Use the values of R, J and K to compare theoretical to the actual motor response curves found in procedure step #5.
3. Use the values of R, J and K to determine what the stalled torque should be in procedure step #6. Compare this to the actual.
4. Find the time constant of the unloaded motor.

• Submit:
 1. All work and results.

5.3.5 Lab 5 - Motor Control Systems

5.3.5.1 - Prelab 5a - DC Servo Motor PID Controller

• Theory:



Recall that by itself a motor is a first order system, but by adding a mass to it will become a second order system. A PID controller is well suited to controlling second order systems. But, tuning a PID controller is an art. The proportional gain sets to overall response. This should be tuned first so that the motor generally responds quickly, but doesn’t overshoot the goal. The derivative term should be set next so that the motor responds faster, and only overshoots the goal by an acceptable amount. Finally the integral portion is used to reduce the steady state error.

• Prelab:
 1. Try the PID controller example in Labview.
 2. Review the course notes on the PID controller.

3. Set up a Mathcad sheet to store/calculate rise time, settling time, overshoot, damping ratio, natural frequency.

5.3.5.2 - Experiment 5a - DC Servo Motor PID Controller

• Objective:
To investigate a simple motor controller.

• Procedure
1. Set up the feedback controller for PID control, and test for basic operation.
2. Vary the time constants and gain, and record the responses to an input step function. Calculate the important parameters, such as damping ratio and natural frequency.
3. Tune the controller for the best response (i.e. damping ratio = 1) using the technique described in the theory section.

• Post-lab:
1. Compare the final PID values with the simulated response for the system.

• Submit:
1. All work.

5.3.6 Lab 6 - Basic Control Systems

• DC motors are common system components to drive mechanical systems.

• Understanding how these motors behave is important.

5.3.6.1 - Prelab 6a - Servomotor Proportional Control Systems

• Theory:
DC servomotors typically have a first order (velocity) response as found in a previous lab.

$$\therefore \left(\frac{d}{dt}\right)\omega + \omega\left(\frac{K^2}{JR}\right) = V_s\left(\frac{K}{JR}\right)$$

We can develop a simple control technique for control of the velocity using the equation below. For this form of control, we need to specify a desired velocity (or position) by setting a value ’Vd’. The difference between the desired speed and actual speed is calculated (Vd-Vi). This will give a voltage difference between the two values.

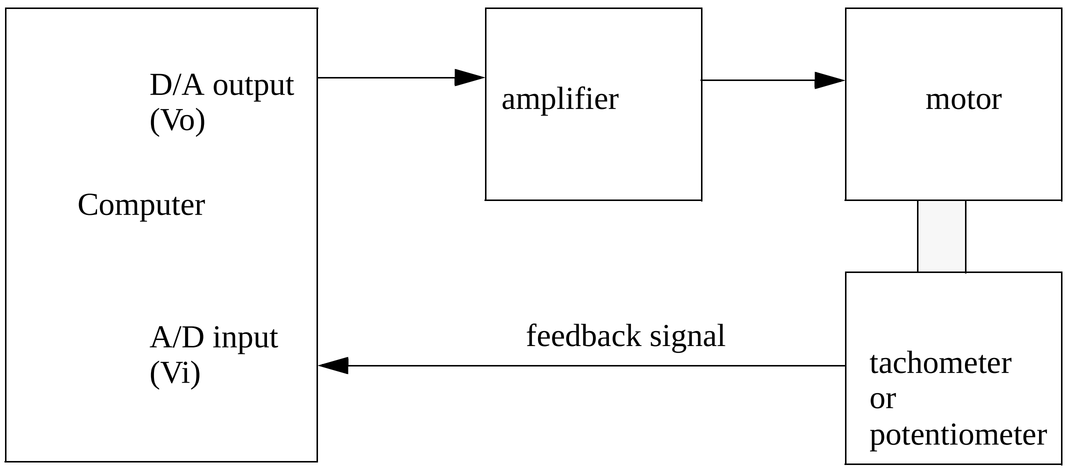
This difference is multiplied by a constant 'K'. The value of 'K' will determine how the system responds.

$$Vo = K(Vd - Vi)$$

where,

Vo = Voltage to motor amplifier to control speed
Vi = Voltage from tachometer to measure speed or position
Vd = Desired motor speed voltage (user input)
K = Controller gain

The basic controller is set up as shown in the figure below. We can use a Labview program to implement the basic control equation described above.



• Prelab:
1. Develop a Mathcad document that will model the velocity feedback controller given, motor parameters, desired velocity, an inertial load, and a gain constant. This is to be solved three different ways i) with Runge-Kutta integration, ii) integration of differential equations and iii) with laplace transforms.
2. Test the controller model using a step function.
3. Repeat steps 1 and 2 for a position controller system.

5.3.6.2 - Experiment 6a - Servomotor Proportional Control Systems

• Objective:
To investigate simple proportional servo motor control.

• Procedure
1. Set up the same system used for measuring the motor velocity in the previous lab. This

will be a velocity control system. Apply a step function input and record the response.

2. For several values of proportional gain ’K’, measure the response curves of the motor to a step function.
3. Replace the tachometer with a potentiometer, and repeat steps 1 and 2.

• Post-lab:
1. Compare the theoretical and actual response curves on the same graphs.
2. Find and compare the time constants for experimental and theoretical results.

• Submit:
1. All work and results.

5.3.7 Lab 7 - Basic System Components

5.3.7.1 - Prelab 7a - Mechanical Components

• Theory:

Recall that for a rigid body we can sum forces. If the body is static (not moving), these forces and moments are equal to zero. If there is motion/acceleration, we use d’Alembert’s equations for linear motion and rotation.

$$\sum F = Ma$$

$$\sum M = J\alpha$$

If we have a system that is comprised of a spring connected to a mass, it will oscillate. If the system also has a damper, it will tend to return to rest (static) as the damper dissipates energy. Recall that springs ideally follow Hooke’s law. We can find the value of the spring constant by stretching the spring and measuring the forces at different points or we can apply forces and measure the displacements.

$$F = K_s \Delta x$$

$$\Delta x = x - x_0$$

$$F = K_s(x - x_0)$$

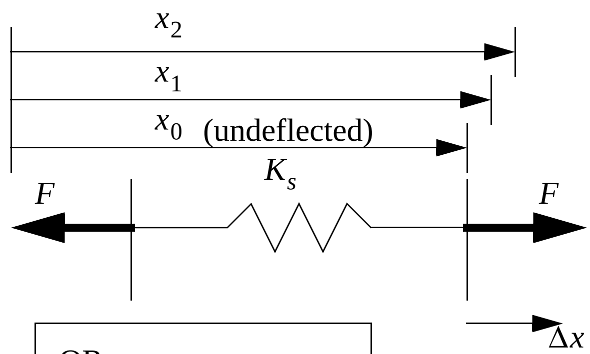
$$K_s = \frac{F_1}{x_1 - x_0} = \frac{F_2}{x_2 - x_0}$$

$$\frac{1}{K_s} = \frac{x_1 - x_0}{F_1} = \frac{x_2 - x_0}{F_2}$$

$$x_0 = x_1 - \frac{F_1}{K_s} = x_2 - \frac{F_2}{K_s}$$

$$\frac{1}{K_s}(F_2 - F_1) = x_2 - x_1$$

$$K_s = \frac{F_2 - F_1}{x_2 - x_1}$$



OR

$$F = K_s x$$

$$\Delta F = K_s \Delta x$$

$$K_s = \frac{\Delta F}{\Delta x}$$

$$K_s = \frac{F_2 - F_1}{x_2 - x_1}$$

In many cases we will get springs and devices that are preloaded. Both of the devices used in this lab have a preloaded spring. This means that when the spring has no force applied and appears to be undeflected, it is already under tension or compression, and we cannot use the unloaded length as the undeflected length. But, we can find the true undeflected length using the relationships from before.

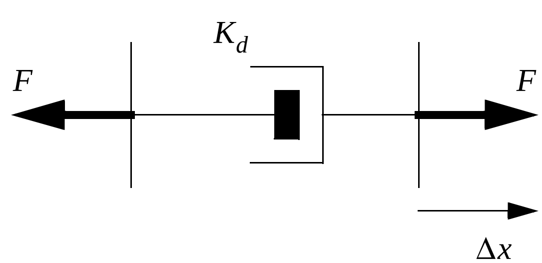
$$x_0 = x_1 - \frac{F_1}{K_s} = x_2 - \frac{F_2}{K_s}$$

Next, recall that the resistance force of a damper is proportional to velocity. Consider that when velocity is zero, the force is zero. As the speed increases, so does the force. We can measure this using the approximate derivatives as before.

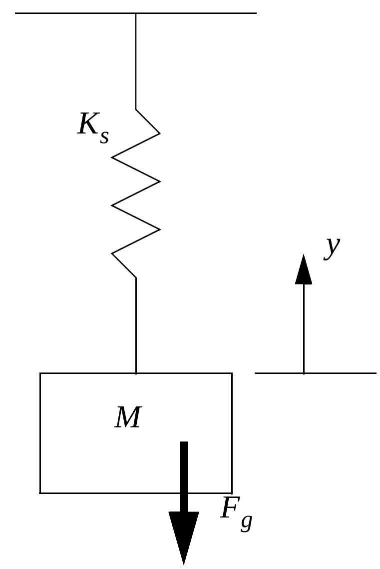
$$F = K_d \frac{d}{dt} x$$

$$F = K_d \left(\frac{x(t + \Delta T) - x(t)}{\Delta T} \right)$$

$$K_d = \frac{F \Delta T}{x(t + \Delta T) - x(t)}$$



Now, consider the basic mass-spring combinations. If the applied forces are static, the mass and spring will remain still, but if some unbalanced force is applied, they will oscillate.



$$+\uparrow \sum F_y = -F_s - F_g = M\left(\frac{d}{dt}\right)^2 y$$

$$-K_s y - Mg = M\left(\frac{d}{dt}\right)^2 y$$

$$M\left(\frac{d}{dt}\right)^2 y + K_s y = -Mg$$

$$y_h(t) = C_1 \cos\left(\sqrt{\frac{K_s}{M}}t + C_2\right)$$

$$y_p(t) = A$$

$$\left(\frac{d}{dt}\right) y_p(t) = 0$$

$$\left(\left(\frac{d}{dt}\right)^2 y\right) y_p(t) = 0$$

$$M(0) + K_s(A) = -Mg \qquad \therefore A = \frac{-Mg}{K_s}$$

$$y(t) = y_h(t) + y_p(t) = C_1 \cos\left(\sqrt{\frac{K_s}{M}}t + C_2\right) + \frac{-Mg}{K_s}$$

Assume we start the mass at rest at the equilibrium height.

$$y(0) = 0 = C_1 \cos\left(\sqrt{\frac{K_s}{M}}(0) + C_2\right) + \frac{-Mg}{K_s}$$

$$\therefore C_1 = \frac{Mg}{K_s \cos(C_2)}$$

$$y'(0) = 0 = C_1 \sqrt{\frac{K_s}{M}} \sin\left(\sqrt{\frac{K_s}{M}}(0) + C_2\right)$$

$$\therefore C_2 = 0$$

$$y(t) = \left(\frac{Mg}{K_s}\right) \cos\left(\sqrt{\frac{K_s}{M}}t\right) + \frac{-Mg}{K_s}$$

The natural frequency is found by completing one time period,

$$2\pi = \sqrt{\frac{K_s}{M}}T = \sqrt{\frac{K_s}{M}}\frac{1}{f}$$

$$\therefore f = \frac{1}{2\pi}\sqrt{\frac{K_s}{M}}$$

In the lab an ultrasonic sensor will be used to measure the distances to the components as they move. The sensor used is an Allen Bradley 873C Ultrasonic Proximity Sensor. It emits sound pulses at 200KHz and waits for the echo from an object that is 30 to 100cm from it. It outputs an analog voltage that is proportional to distance. This sensor requires a 18-30 VDC supply to operate. The positive supply voltage is connected to the Brown wire, and the common is connected to the blue wire. The analog voltage output (for distance) is the black wire. The black wire and common can be connected to a computer with a DAQ card to read and record voltages. The sound from the sensor travels outwards in an 8 degree cone. A solid target will give the best reflection.

- Prelab:
    1. Review the theory section.
    2. Extend the theory by finding the response for a mass-spring, mass-damper, and mass-spring-damper system (assume values).
    3. Set up a Mathcad sheet for the laboratory steps.

5.3.7.2 - Experiment 7a - Mechanical Components

• Objective:

This lab will explore a simple translational system consisting of a spring mass and damper using instrumentation and Labview.

• Procedure

1. Use two masses to find the spring constant or stiffness of the spring. Use a measurement with a third mass to verify. If the spring is pretensioned determined the 'undeformed length'.
2. Hang a mass from the spring and determine the frequency of oscillation. Determine if the release height changes the frequency. Hint: count the cycles over a period of time.
3. Connect the computer to the ultrasonic sensor (an Allen Bradley Bulletin 873C Ultrasonic Proximity Sensor, see www.ab.com), and calibrate the voltages to the position of the target (DO NOT FORGET TO DO THIS). Write a Labview program to read the voltage values and save them to a data file. In the program set a time step for the voltage readings, or measure the relationship between the reading number and actual time for later calculation.
4. Attach a mass to the damper only and use Labview to collect position as a function of time as the mass drops. This can be used to find the damping coefficient.
5. Place the spring inside the damper and secure the damper. This will now be used as a combined spring damper. In this arrangement the spring will be precompressed. Make sure you know how much the spring has been compressed when the damper is in neutral position.
6. Use the spring-damper cylinder with an attached mass and measure the position of the mass as a function of time.
7. Use Working Model 2D to model the spring, damper and spring-damper responses.

• Post-lab:

1. Determine if the frequency of oscillation measured matches theory.
2. Compare the Labview data to the theoretical data for steps 2, 4 and 6.
3. Compare the Labview data to the working model simulations.

• Submit:

1. All results and calculations posted to a web page as a laboratory report.

5.3.8 Lab 8 - Oscillating Systems

• Many systems undergo periodic motion. For example, the pendulum of a clock.

• To observe high frequency oscillations we need high speed data collection devices. The LabVIEW applications you have previously created are no longer adequate.

• To collect data faster we now will use an oscilloscope interfaced to LabVIEW.

5.3.8.1 - Prelab 8a - Oscillating Systems

• Theory:

Suppose a large symmetric rotating mass has a rotational inertia J, and a twisting rod has a torsional spring coefficient K. Recall the basic torsional relationships.

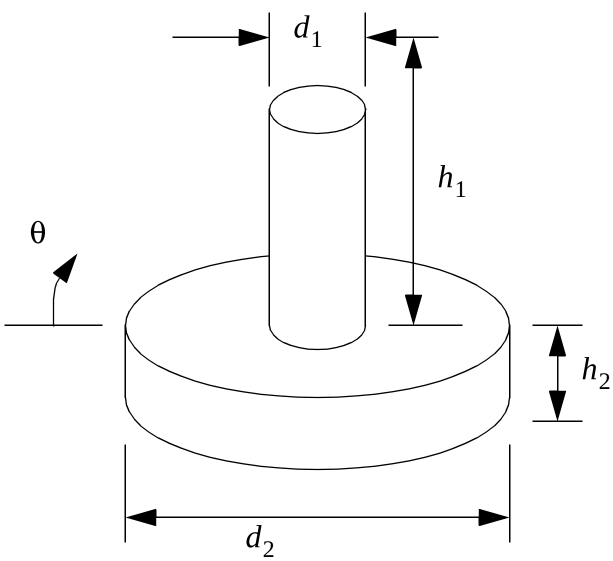
$$\sum T = -T = J\alpha = J\left(\frac{d}{dt}\right)^2\theta$$

$$T = K\Delta\theta = K(\theta - \theta_0)$$

We can calculate the torsional spring coefficient using the basic mechanics of materials

$$T = \frac{JG\theta}{L}$$

Finally, consider the rotating mass on the end of a torsional rod.



$$\sum T = -\left(\frac{J_1 G}{L}\right)\theta = J\left(\frac{d}{dt}\right)^2\theta$$

• Prelab:

1. Calculate the equation for the natural frequency for a rotating mass with a torsional spring.
2. Set up a Mathcad sheet that will
   - accept material properties and a diameter of a round shaft and determine the

spring coefficient.
- accept geometry for a rectangular mass and calculate the polar moment of inertia.
- use the spring coefficient and polar moment of inertia to estimate the natural frequency.
- use previous values to estimate the oscillations using Runge-Kutta.
- plot the function derived using the homogeneous and particular solutions.

5.3.8.2 - Experiment 8a - Oscillation of a Torsional Spring

• Objective:

To study torsional oscillation using Labview and computer data collection.

• Procedure

1. Calibrate the potentiometer so that the relationship between and output voltage and angle is known. Plot this on a graph and verify that it is linear before connecting it to the mass.
2. Set up the apparatus and connect the potentiometer to the mass. Apply a static torque and measure the deflected position.
3. Apply a torque to offset the mass, and release it so that it oscillates. Estimate the natural frequency by counting cycles over a long period of time.
4. Set up LabVIEW to measure the angular position of the large mass. The angular position of the mass will be measured with a potentiometer.

• Post-lab:

1. Compare the theoretical and experimental values.

• Submit:

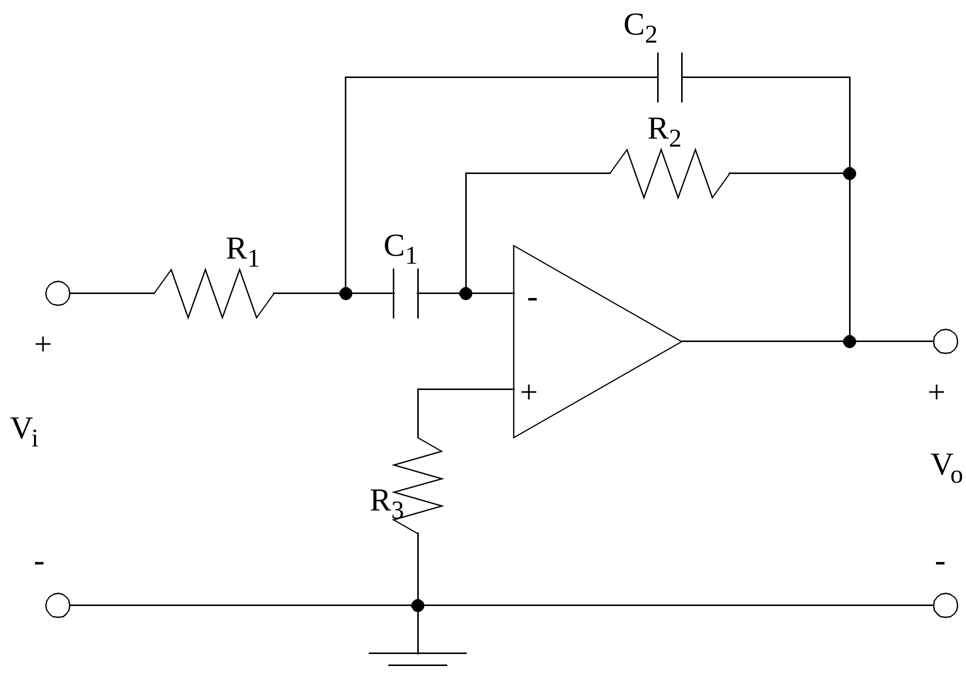
1. All work and observations.
2. Post the laboratory report to a web page.

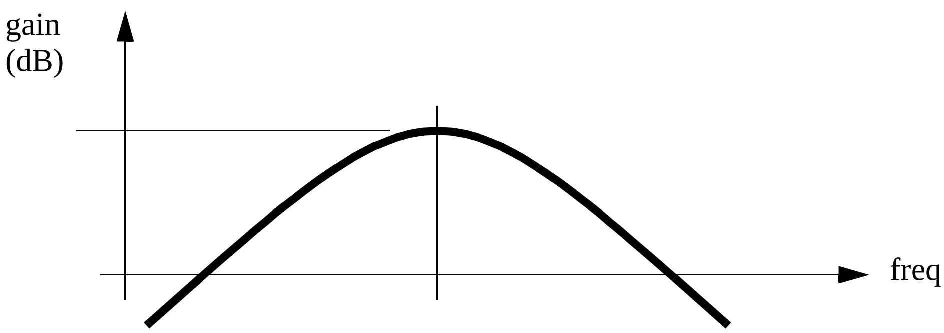
5.3.9 Lab 9 - Filters

5.3.9.1 - Prelab 9 - Filtering of Audio Signals

Theory:

We can build simple filters using op-amps, and off the shelf components such as resistors and capacitors. The figure below shows a band pass filter. This filter will pass frequencies near a central frequency determined by the resistor and capacitor values. By changing the values we can change the overall gain of the amplifier, or the tuned frequency.

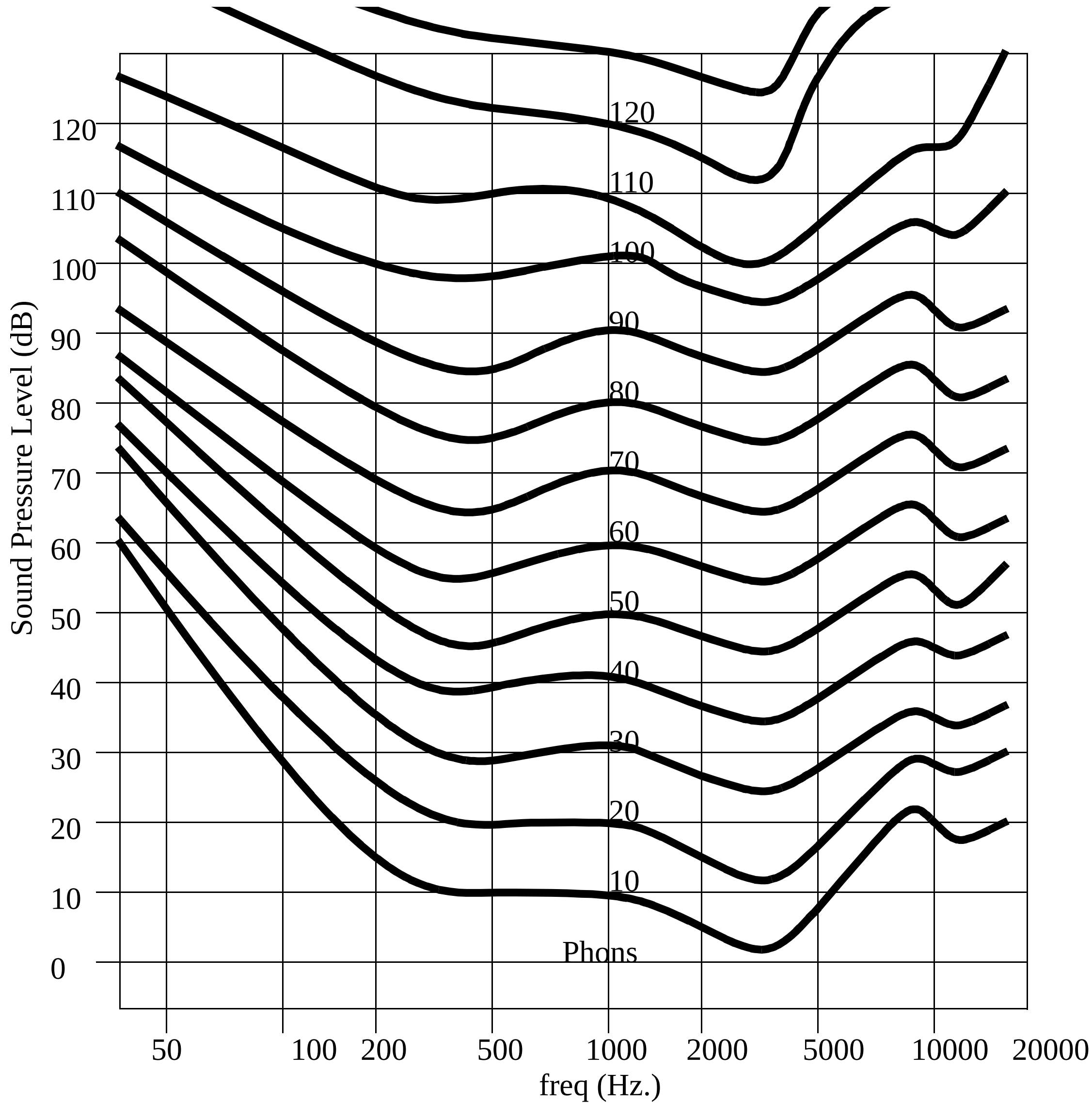




The equations for this filter can be derived with the node voltage method, and the final transfer function is shown below.

$$\frac{V_o}{V_i} = \left(-\frac{1}{R_1}\right)\left(\frac{sC_1R_1R_2}{1 + sC_2R_1 + sC_1R_1 + s^2C_1C_2R_1R_2}\right)$$

As dictated by the ear, audio signals have frequencies that are between 10Hz and 16KHz as illustrated in the graph below. This graph shows perceived sound level, with the units of 'phons'. For example, we can follow the 100 phons curve (this would be like a loud concert or very noisy factory requiring ear protection). At much lower and higher frequencies there would have to be more sound pressure for us to perceive the same loudness, or phon value. If the sound were at 50Hz and 113 dB it would sound as loud as 100dB sound at 1KHz.



You may appreciate that these curves are similar to transfer functions, but they are non-linear. For this lab it is important to know how the ear works because you will be using your ear as one of the experimental devices today.

Prelab:

1. Derive the transfer function given in the theory section.
2. Draw the Bode plot for the circuit given R1=R2=1000ohms and C1=C2=0.1uF. You are best advised to use Mathcad to do this.

5.3.9.2 - Experiment 9 - Filtering of Audio Signals

Objective:

To build and test a filter for an audio system.

Procedure:

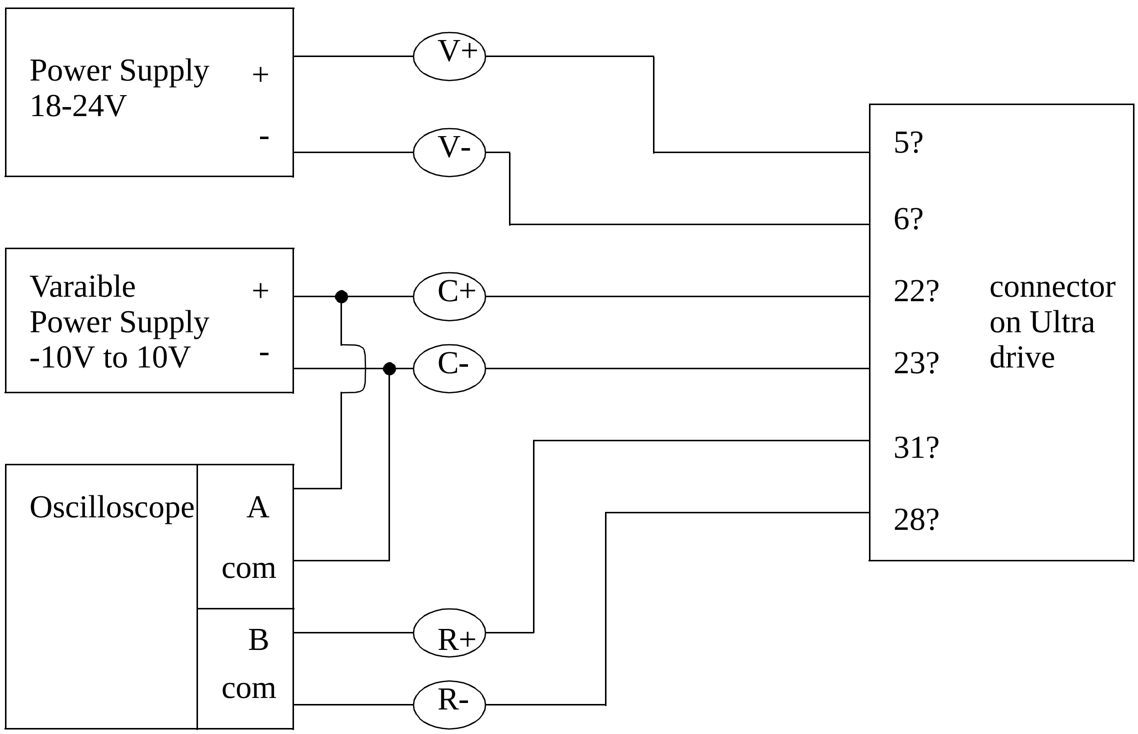
1. Set up the circuit shown in the theory section. Connect a small speaker to the output of the amplifier.
2. Apply a sinusoidal input from a variable frequency source. Use an oscilloscope to compare the amplitudes and the phase difference. Also record the relative volumes you notice.
3. Supply an audio signal, from a radio, CD player, etc. Record your observations about the sound.

Submit:

1. Bode plots for both theory and actual grain and phase angle.
2. A discussion of the sound levels you perceived.

5.4 TUTORIAL - ULTRA 100 MOTORS AND DRIVERS

1. Obtain the motor and controller sets. This should include a brushless servo motor (Y-1003-2H), an Ultra 100 Controller and miscellaneous cables. The cables are described below. located and verify they are connected as indicated in the sequence given below.
   a) the motor is connected to the controller with two cables, one for the power to drive the motor, and the other a feedback from the encoder. The encoder is used to measure the position and velocity of the motor. If not connected already, connect these to the motor controller.
   b) the controller should also have a serial cable for connecting to a PC serial port. Connect this to a PC.
   c) a custom made connector will be provided with some labelled wires. This will be used to connect to other devices for experimental purposes.
   d) a power cord to be connected to a normal 120Vac power source. DO NOT CONNECT THIS YET.
2. The custom made connector needs to be attached to devices to control and monitor the motor. The figure below shows a test configuration to be used for the tutorial. The letters in ovals correlate to the ends of the provided connectors. Do not turn on the devices yet.



3. Plug in the power cord for the Ultra 100 drive and look for a light on the front to indicate that it is working. WARNING: The motor might begin to turn at this point. Turn on the power supplies and the oscilloscope.
4. Run the 'Ultramaster' software on the PC. When prompted select 'drive 0'. At this point the software should find the drive and automatically load the controller parameters from the controller. when it is done a setup window will appear.
5. In the setup window ensure the following settings are made. When done close the setup window.
   Motor Type: Y-1003-2-H - this is needed so that the proper electrical and mechanical properties of the motor will be used in the control of the motor (including rotor inertia).
   Operation Mode Override: Analog Velocity Input - This will allow the voltage input (C+ and C-) to control motor velocity.
6. Select the 'Drive Configuration' window and make the following settings.
   Analog Output 1: Velocity - Motor Feedback - this will make the analog voltage output from the controller (R+ and R-) indicate the velocity of the motor, as measured by the encoder.
   Scale: 500 RPM/VOLT - this will set the output voltage so that every 500RPM will produce an increase of 1V.
7. Open the Oscilloscope on the computer screen and make the following settings. When done position the oscilloscope to the side of the window so that it can be seen later.
   Channel A: Velocity - command
   Channel B: Velocity - motor feedback
   Time Base: 50ms

8. Open the control panel and change the speed with the slider, or by typing it in. Observe the corresponding changes on the oscilloscope on the screen, and the actual oscilloscope.
9. Hold the motor shaft while it is turning slowly and notice the response on the oscilloscopes.
10. Open the tuning window and change the ’I’ value to 0. Change the motor speed again and notice the final error. It should be larger than in previous trials.
11. Leave the ’I’ value at ’0’ and change the ’P’ value to 50 and then change the speed again. This time the error should be larger, and the response to the change should be slower.
12. Try other motor parameters and see how the motor behaves. Note that very small or large values of the parameters may lead to controller faults - if this occurs set more reasonable ’P’ or ’I’ values and then reset the fault.
13. Set the parameters back to ’P’ = 200 and ’I’ = 66.
14. Stop the ’Control Panel’, this will allow the motor to be controlled by the external voltage supply. Change the voltage supply and notice how the motor responds.
15.

ADD: POSITION CONTROL, TORQUE CONTROL, CHANGING MOTION PROFILE

5.5 TUTORIAL - STEPPER MOTOR CONTROLLERS

Course Number:	EGR 345
Course Name:	Dynamic Systems Modeling and Control
Academic Unit:	Padnos School of Engineering
Semester:	Fall 2001
Class Times:	Lecture: 1-2pm - Mon, Wed, Fri in DEV136E Lab 1: 8-11am - Tue - Dr. Jack, KEB 205 Lab 2: 1-4pm - Tue - Dr. Blauch, KEB 205 Lab 3: 8-11am - Thurs - Dr. Blauch, KEB 205 Lab 4: 8-11am - Fri - Dr. Blauch, KEB 205
Description:	Mathematical modeling of mechanical, electrical, fluid, and thermal dynamic systems involving energy storage and transfer by lumped parameter linear elements. Topics include model building, Laplace transforms, transfer functions, system response and stability, Fourier methods, frequency response feedback control, control methods, and computer simulation. Emphasis on linear mechanical systems. Laboratory.
Prerequisites:	EGR 214, MTH 302, ENG 150
Corequisites:	EGR 314 - Dynamics
Instructor:	Dr. Hugh Jack, Office: 718 Eberhard Center Office hours: TBA Phone: 771-6755 Email: jackh@gvsu.edu Web: http://claymore.engineer.gvsu.edu
Textbook:	Jack, H. EGR345 Dynamic Systems Modeling and Control Course Notes, Grand Valley State University
Software:	Mathcad Working Model 2D Netscape Communicator FTP/Telnet Labview Excel C/C++ compiler
Goals:	The main objective of this course is to develop your knowledge and ability to mathematically model, simulate, and analyze dynamic systems. In the lab you will study the time and frequency response of dynamic systems and further develop your laboratory, data analysis, and report writing skills. During this course you will practice the application of differential equations to the

solution of practical engineering problems and then verify some of these solutions in the laboratory. The overall goal is to improve your engineering problem solving ability in the area of time-varying systems.

Another major objective is to improve your technical writing skills. To this end, this course has been designated a supplemental writing skills (SWS) course and significant time and effort will be spent on writing instruction and the creation of technical reports.

Instruction Methods: Lecture, discussion, laboratories, assignments and projects.

Prerequisite Topics:
1. Electric circuits
2. Statics
3. Trigonometry, algebra, matrices
4. Calculus, differential equations and Laplace transforms
5. Computer applications and programming in C
6. Physics

Topics:
1. Introduction and math review
2. Translation
3. Calculus and differential equations
4. Numerical methods
5. Rotation
6. Input-output equations
7. Circuits
8. Feedback controllers
9. Fourier and root-locus analysis
10. Converting between analog and digital
11. Sensors
12. Actuators

Grading:

Design project	10%
Labs and SWS writing skills	40%
Assignments	10%
Quizzes and final exam	40%

Note: A student must pass all components of the grading to receive a passing grade in the course.

Tests and assignments will be given at natural points during the term as new material is covered. Laboratory work will be assigned to reinforce lecture material and expose the student to practical aspects of systems modeling and control. Special attention will be paid to writing skills in the laboratories. A final examination will be given to conclude the work, and test the students global comprehension of the material. A design project will be done in class to emphasize lecture and lab topics. Details of this will be announced later.

SWS Required Statement:

This course is designated SWS (Supplemental Writing Skills). As a result you MUST have already taken and passed ENG150 with a grade of C or better, or have passed the advanced placement exam with a score of 3 or higher. If you have not already done this, please see the instructor.

The official university SWS statement is:

> " This course is designated SWS (Supplemental Writing Skills). Completion of English 150 with a grade of C or better (not C-) is the prerequisite. SWS credit will not be given to a student who completes the course before the prerequisite. SWS courses adhere to certain guidelines. Students turn in a total of at least 3,000 words or writing during the term. Part of that total may be essay exams, but a substantial amount of it is made up of finished essays or reports or research papers. The instructor works with the students on revising drafts of their papers, rather than simply grading the finished pieces of writing. At least four hours of class time are devoted to writing instruction. At least one third of the final grade in the course is based on the writing assignments."

SWS Practical Implementation:

The main source of writing grades are the laboratories and they are worth 40% of the final grade. You may look at all of this grade as writing. If the level of writing is not acceptable it will be returned for rewriting and it will be awarded partial marks. It is expected that the level of writing improve based upon feedback given for previous laboratory reports. A lab that would have received a grade of 'A' at the beginning of the term may very well receive an 'F' at the end of the term. It is expected that a typical lab will include 500-1000 words, and there will be approximately 10 labs in the course. Writing instruction will be given in the labs at appropriate times and this will total four hours.

Grading Scale:

A	100 - 90
A-	89-80
B+	79-77
B	76-73
B-	72-70
C+	69-67
C	66-63
C-	62-60
D+	59-57
D	56-55

6. OLD 345 STUFF

6.1 ASSIGNMENTS

6.1.1 Homework

• Assignments will be given at points throughout the term to reinforce challenging concepts.

6.1.2 Supplemental Writing Skills Requirement

• The official university SWS statement is:

> " This course is designated SWS (Supplemental Writing Skills). Completion of English 150 with a grade of C or better (not C-) is the prerequisite. SWS credit will not be given to a student who completes the course before the prerequisite. SWS courses adhere to certain guidelines. Students turn in a total of at least 3,000 words or writing during the term. Part of that total may be essay exams, but a substantial amount of it is made up of finished essays or reports or research papers. The instructor works with the students on revising drafts of their papers, rather than simply grading the finished pieces of writing. At least four hours of class time are devoted to writing instruction. At least one third of the final grade in the course is based on the writing assignments."

• These requirements will be fulfilled through the laboratory reports for the semester. It will be expected that the level of performance in the laboratory continually improve based upon feedback from the instructor.

• PLEASE NOTE THERE IS A WRITING GUIDE THAT FOLLOWS THE LABORATORY DESCRIPTIONS.

6.2 OLD LAB STUFF

6.2.1 Lab 3 - Writing Lab Reports

• The purpose of this laboratory is to prepare you for the skill needed for the remaining laboratory reports this semester.

6.2.1.1 - Prelab 3a - Writing Skills

Objective: To give students a perspective on the purposes of writing.

• Theory:

Before starting to write you need to make some clear decisions. These include,

- Who are you writing for? Who is your audience?
- What does the reader want to know?
- What is the objective for the written work?

After answering these basic questions you can plan the layout for the paper.

- What are the general divisions for the topics?
- Is there a conventional forum for the topics?
- What is a logical flow for the work?
- What can you tell the reader that they need to know?
- What is a reasonable depth or level for the writing?

At this point personal styles will drive writing techniques. For technical work it's best to follow this general sequence:

1. Determine major questions that need to be researched (lay out what you know in point form)
2. Do research as required (add point form notes and add references for things that aren't obvious, or may be useful to others interested in the area. It is very helpful to add equations and figures at this point.
3. Review, rearrange, and edit the point form notes. Check to see that they match your writing objectives.
4. Group and divide the notes into sections. Check to see if the sections flow.
5. Go through and convert the point form to sentences, etc.
6. Proof read and fix obvious problems.
7. Give to somebody else to proofread. It is best to use a technical reader.
8. Proof read again, and then format.
9. Skim to check that the general appearance is good.

• Procedure:

1. Read the writing section later in the notes

6.2.1.2 - Prelab 3a - Acceleration Due To Gravity

• Objective:

To estimate the acceleration due to gravity.

• Theory:

We know from basic physics that acceleration is the second derivative of position. If we are dropping a small object near the surface of the earch gravity is nearly constant. If gravity is giving us a constant acceleration we can integrate this twice to get the following function for height.

Assume constant acceleration due to gravity

$$a = \left(\frac{d}{dt}\right)^2 y = g$$

Integrate once to get velocity, and add in the initial velocity

$$v = \int (a)dt = \int g dt = gt + v_0$$

Integrate again to get position, and add in the initial position

$$y = \int (v)dt = \int (gt + v_0)dt = \frac{gt^2}{2} + v_0 t + y_0$$

• Procedure:

1. Prepare a Mathcad worksheet to calculate acceleration given the time and distance an object has dropped.
2. In the same Mathcad worksheet, prepare a mean and standard deviation calculation for 5 data points.

6.2.1.3 - Experiment 3a - Writing Tutorial

• Objective:

To review methods for writing laboratory reports.

• Procedure:

1. The lab will begin with a discussion of writing skills and writing techniques.
2. Obtain a set of masses, stop watches and year sticks.
3. Drop the masses from different heights and measure the time it takes to reach the floor. Repeat each measurement 4 times and do this for 5 different release heights.
4. The laboratory instructor will then guide you through the steps of preparing the laboratory report for the experiment you have just done.

• Post-lab:

None.

• Submit:

1. The prelab work.

2. The report prepared.

6.2.2 Lab 4 - Introduction To Systems Modeling Concepts

6.2.2.1 - Prelab 4a - Introduction to Mechanical System Modeling

• Theory:

Recall Newton's second law and the definitions for acceleration,

$$F = Ma \qquad\qquad a = \left(\frac{d}{dt}\right)^2 y$$

Recall the basic definition of a derivative,

$$\frac{d}{dt}f(t) = \lim_{\Delta T \to 0}\left[\frac{f(t+\Delta T) - f(t)}{\Delta T}\right]$$

Therefore the second derivative is,

$$\left(\frac{d}{dt}\right)^2 f(t) = \lim_{\Delta T \to 0}\left[\frac{\frac{d}{dt}f(t+\Delta T) - \frac{d}{dt}f(t)}{\Delta T}\right]$$

$$\left(\frac{d}{dt}\right)^2 f(t) = \lim_{\Delta T \to 0}\left[\frac{\left(\frac{f(t+2\Delta T) - f(t+\Delta T)}{\Delta T}\right) - \left(\frac{f(t+\Delta T) - f(t)}{\Delta T}\right)}{\Delta T}\right]$$

$$\left(\frac{d}{dt}\right)^2 f(t) = \lim_{\Delta T \to 0}\left[\frac{f(t+2\Delta T) - 2f(t+\Delta T) + f(t)}{(\Delta T)^2}\right]$$

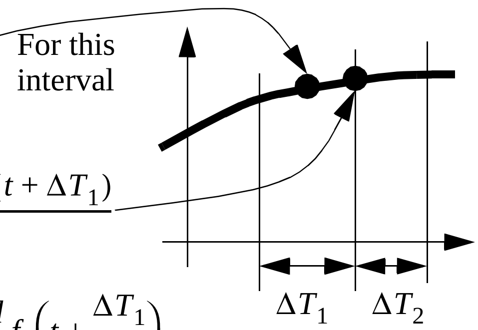
In other words, if we read values at times fairly closely spaced we can approximate the derivatives with combinations of values of a function spaced in time.

$$\boxed{\frac{d}{dt}f(t) \approx \frac{f(t+\Delta T) - f(t)}{\Delta T} \qquad \left(\frac{d}{dt}\right)^2 f(t) \approx \frac{f(t+2\Delta T) - 2f(t+\Delta T) + f(t)}{(\Delta T)^2}}$$

Now consider the case when the first and second time steps are not the same. The approximation becomes rougher. Note: the notation changes here because we are now dealing with time steps of finite, but small, size.

$$\frac{d}{dt}f_1\left(t + \frac{\Delta T_1}{2}\right) \approx \frac{f(t + \Delta T_1) - f(t)}{\Delta T_1}$$

$$\frac{d}{dt}f_2\left(t + \Delta T_1 + \frac{\Delta T_2}{2}\right) \approx \frac{f(t + \Delta T_1 + \Delta T_2) - f(t + \Delta T_1)}{\Delta T_2}$$

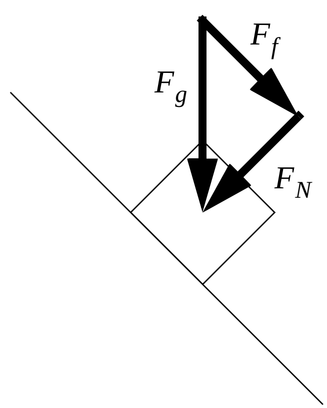


$$\left(\frac{d}{dt}\right)^2 f_{12}(t + \Delta T_1) \approx \frac{\frac{d}{dt}f_2\left(t + \Delta T_1 + \frac{\Delta T_2}{2}\right) - \frac{d}{dt}f_1\left(t + \frac{\Delta T_1}{2}\right)}{\left(t + \Delta T_1 + \frac{\Delta T_2}{2}\right) - \left(t + \frac{\Delta T_1}{2}\right)}$$

$$\boxed{\left(\frac{d}{dt}\right)^2 f_{12}(t + \Delta T_1) \approx \frac{\left(\frac{f(t + \Delta T_1 + \Delta T_2) - f(t + \Delta T_1)}{\Delta T_2}\right) - \left(\frac{f(t + \Delta T_1) - f(t)}{\Delta T_1}\right)}{\frac{\Delta T_1 + \Delta T_2}{2}}}$$

Note: The time periods should be relatively small to get more accurate estimates. If the time steps are not equal we must use higher order approximations of the integrals.

Finally, consider the relationship among the gravitational, frictional and normal forces for a block sliding on a surface.



• Prelab:

1. Review the theory section.
2. Set up a Working Model 2D example for the acceleration of a block sliding on a surface.
3. Set up a Mathcad document that uses both of the methods for determining acceleration using equal sized time steps, and unequal time steps. Note: To do iterative calculations in Mathcad you can put the equations in a matrix, or write a script.

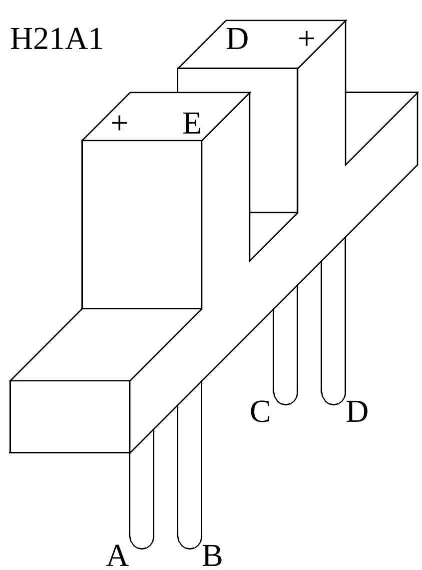
6.2.2.2 - Experiment 4a - Introduction to Mechanical System Modeling

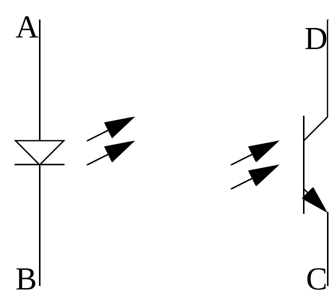
• Objective:

To determine acceleration using simple measurements.

• Procedure: (groups of 4 should rotate between steps 1 and 2)

1. Set up a dry slope and slide a mass down it. A strobe light will be used to generate equal time divisions. Assign one person to release the mass, and three people to mark positions as the mass slides (on the first, second and third strobes). Measure the positions at each strobe and record. Use the Mathcad document to calculate acceleration.
2. Set up a dry slope and slide a mass down it. There will be three position sensors placed at equal distances (see figures below). The position sensors will be connected to a computer running LabVIEW. Release the mass and measure the times at which is passes the three points on the slope. Use the Mathcad document to calculate acceleration.





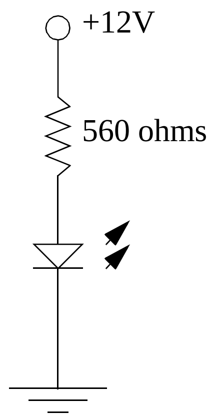


Photo emitter

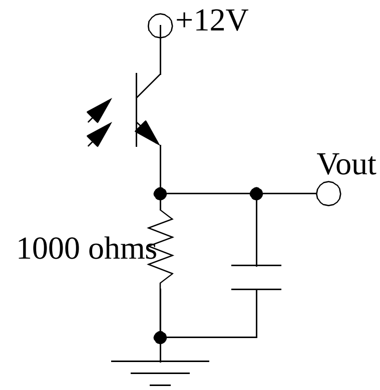


Photo Detector

• Post-lab:

1. Use Mathcad to estimate the coefficient of kinetic friction between the block and inclined surface for both tests.
2. Verify the calculations by running a simple experiment in Working Model 2D.

• Submit:

1. All Mathcad and Working Model 2D files by posting to web pages
2. A final statement about the overall experiment and the results.

6.2.3 Tutorial 6a - Data Collection with an Oscilloscope and LabVIEW

• Objectives:

1. To collect a single sweep of Tektronix 2230 oscilloscope data.
2. To plot single sweep data on the HC100 digital plotter.
3. To control a Tektronix PS5010 programmable power supply.
4. To control GPIB instruments with LabVIEW.

• Theory:

We need to observe how system behavior changes over time. To do this we can take successive readings and then plot them as a function of time. If we look at the screen of an oscilloscope, the horizontal axis represents time and the vertical axis voltage. One significant problem with any time based sampling device is when to start recording. We use certain settings to trigger the beginning of the beam scan. Each type of signal will require a different type of trigger, and so oscilloscopes have multiple settings to make them adaptable.

We will connect the lab oscilloscope to the computer with an interface card and cable. The interface between the computer and oscilloscope is called GPIB (General Purpose

Instrument Bus) and is also known as IEEE-488. It is a networking scheme that will allow more than one device to be connected to the computer by using chains of cables. To interface to GPIB devices, we need a special interface card in the computer and interface software. We will use LabVIEW to communicate with the oscilloscope.

In general, an oscilloscope can sample voltages at rates from 0Hz up to about 1GHz. A typical inexpensive oscilloscope will sample data up to 10MHz. The DAQ card in the computer have the potential to sample up to 100KHz.

Materials/Equipment:

Tektronix 2230 Oscilloscope
Tektronix PS5010 Power Supply
Scope probes
Tektronix HC100 Plotter
Red and Black Banana Jack Plugs (with alligator clips)
PC with GPIB Interface and LabVIEW

Procedure:

1. Before turning on the power to the oscilloscope, you must give it an address as a GPIB device. The address is a number XX set with dip switches. These are found on the side of the oscilloscope and switches 1, 6 and 8 should be set to "1". All others should be set to "0".
2. The oscilloscope is a very flexible device that can be reconfigured for various measurements. To set various parameters, we use the switches on the front panel, near the display. Set the switches on the front to match the descriptions below:
   POSITION CURS-SELECT WAVEFORM (in) -
   1K-4K (in) - this sets the speed of the data collection
   ROLL SCAN (out) - keep the display steady
   PRETRIG-POST TRIG (out) -
   SAVE-CONTINUE (out) - scan repeatedly
   STORE-NON STORE (out) - don’t store the screen
   SLOPE (out) - deselects the input slope as a trigger
   A&B INT (CH 1) - selects channel 1 to trigger channel A
   A SOURCE (INT) - uses an internal clock for the sweep time
   A EXT COUPLING (DC) - sets the input signal as DC
   HORIZONTAL MODE (A) - sets channel A for the sweep axis
   VERTICAL MODE (CH1) - uses the magnitude of channel 1 for height
   X-Y (out) - do a normal time sweep
   BW LIMIT (out) -
   A AND B SEC/DIV (1 ms) - sets the scan divisions on the scope
3. Now set up the power supply and connect it to the oscilloscope so that it will supply a signal. To do this, you need to connect the probe to the oscilloscope (CH1) and then to the positive and common terminals of the power supply.
4. You can now set up a signal to be measured. Turn on the power supply and then program it for 10V on the POS, and 0V on NEG supplies. The OUTPUT should be OFF. Finally, lock the program by pressing LOCK. You may now set up the scan

trigger on the oscilloscope. Start the scope scanning continuously in the A TRIGGER mode by pressing P-P AUTO (on). Next you need to ’zero’ CH1. To do this, set the input to GND and use CH1 POSITION to center the trace. Once centered, change the input from GND to DC. The trace on the screen should now reflect the actual input. Set the scale to 2 VOLTS/DIV.

5. Scope is in analog mode.
6. Put scope in store mode by pressing the STORE button.
7. Move cursor and observe values.
8. Connect scope to plotter with GPIB cable and plot waveform.
9. Turn off scope, disconnect from plotter, connect to computer. Set the address dip switches on side so that only switch 1 is set to "1", all others set to "0". Turn on the scope.
10. Run LabVIEW and load GPIB vi. This is found under XXXXXXX. Verify GPIB setting, scope should be device 1.
11. Load the LabVIEW vi for the scope "XXXXXXXXX.
12. Capture a scan of data into LabVIEW.

KINEMATICS AND DYNAMICS

7. OVERVIEW

7.1 PHILOSOPHY

• The best way to learn kinematics and dynamics analysis is by solving problems.

• A project will be used to enforce the design aspects of the course.

7.2 RESOURCES

7.2.1 The Web

The Web site ‘http://claymore.engineer.gvsu.edu’ should be used as an active reference for all students. Up to date information will be stored here, and can be printed. At the beginning of the term each student will be given an account on this machine, and will have a basic web page set up. During the term all work that is done will be added to these web pages. You are welcome to add additional information in this form. Note: assignments will be submitted by adding them to the web pages.

7.2.2 Software

Working Model - A very powerful software package for modeling the dynamics of mechanical systems. This will allow simulation of mechanical systems quickly and easily. It can import dxf files from autocad for geometry, and export numbers to other packages, such as excel. A tutorial guide will be provided, and students are welcome to purchase a student edition. There is also a free (but limited) demo version available that will basically allow practice and viewing of other working model files.

MathCAD - This package will do symbolic and numerical analysis of mathematics. This package will also produce graphs. Each student is expected to be familiar with all aspects of this package. Manuals are available.

AutoCAD - A primary tool for generation of drawings and geometry. This will be used to produce drawings (note - use dxf formats working model applications and gif for web applications).

Netscape Communicator - this package will allow web browsing, and it also has a built in editor so that you may update files for home pages. This can be obtained on-line at no cost.

Excel - This or another spreadsheet may be used to produce better plots than what has been obtained in working model. It is also possible to do some calculations with it.

FTP/Telnet - FTP will allow you to download and upload files to the web server. When updating web pages you must download the 'html' file, edit it locally, then upload it to the remote machine. This utility should be available on all networked PCs.

7.2.3 References/Bibliography

Chironis, N.P., Sclater, N., Mechanisms and Mechanical Devices Sourcebook, 2nd Edition, McGraw-Hill, 1996

Erdman, A.G. and Sandor, G.N., Mechanism Design Analysis and Synthesis, Vol. 1, 3rd Edition, Prentice Hall, 1997.

Jones, F.D., Ingenious Mechanisms for designers and inventors, Industrial Press Inc., Volumes 1-4, 1930.

Shigley, J.E., Uicker, J.J., Theory of Machines and Mechanisms, 2nd Edition, McGraw-Hill, 1995.

7.3 ASSIGNMENTS

• The assignments are to be done individually from beginning to end. My experience shows that study groups are of great help, and will help a student get by many small problems quickly. But students who never do any problems individually (i.e., assignments) always do poorly when they must solve problems themselves on exams.

• Stassen's Ten Commandments for Assigned Calculations

The following format requirements must be met before an assignment will be accepted or given credit.

1. The problem must be clearly identified at the top left of the page. The name of the author must be placed at the upper right-hand corner of the front page.

2. All calculations must be shown and a clear “heading” must be given with each step of the calculations.
3. All units must be attended to properly in balanced equations. Answers without units are not valid, except 0, variables, or unitless values such as ratios.
4. Where applicable, references must be given for all uncommon relationships or empirical values obtained from textbooks.
5. Clear diagrams must be provided where necessary.
6. Do not use unnecessary terms like “I” or verbose terms such as “to find”, etc. It is expected that proper and concise statements are made where needed.
7. At the conclusion of each problem the final result must be clearly summarized and indicated.
8. Where necessary a conclusion should be drawn or a final comment made. Sometimes a recommendation is necessary and should be included in the report.
9. Reports must be written on one side of letter size paper. Only in the case of graphic solutions can “odd” paper sizes be used, but these must be folded to size. Computer based work should print nicely on letter size paper.
10. Calculations should progress in a logical and sequential manner to the final result.

7.4 PROJECT

- The project will be discussed in class, but basically a complex mechanism of some sort will be designed and constructed on a competitive basis. Students are encouraged to present the results of their work at the student research day in April. Potential topics include,
    - a large catapult, or equivalent device, that is capable of projecting a payload of at lead 10 pounds a distance greater than 100 feet. This device should be easy to move, and can be recharged without special power sources. This is a team project.
    - write programs in Java to do various elements of kinematic design. This would be an individual project(s).
    - an autoloader for a keytag rounder
    - other project ideas will be entertained

7.4.1 Previous Project Topics

Disc Brake Redesign - Beard, J. - A novel disc brake will be designed using a linkage to actuate the callipers. The design will be simulated, and a model will be built to test the concept.

Catapult - Cummings, J., Freeman, T. and Ramsdell, S. - A catapult or equivalent mechanism will be designed for general use in the department. The design will be portable and capable of launching a 10 pound projectile up to 100 feet. A design will be selected, simulated, built and tested.

Java Applets - Jamison, D. - Applets will be written in Java to help some aspect of kinematics. This will include learning Java, selecting a program objective, writing code, and debugging.

Light Vehicle Loader - Jezewski, C. -To load a snow mobile or waterski onto a pickup truck a mechanism will be designed that can be operated by hand. This mechanism should be light-weight, but allow easy operation. The definition of requirements, design. simulation, construction and testing will be done.

Auto Pitcher - Maxim, J. - The machine will lob balls straight up from a base so that a child may practice batting skills. The balls will be thrown to variable heights to accommodate different batter sizes. The machine will be designed, analyzed, simulated, built and tested.

Stamped Parts Sorting - Mead, M. - To sort good and bad parts that have just been stamped, a mechanism will be designed for ejecting bad parts.

Java Applets - Stehouwer, C. - Applets will be written in Java to help some aspect of kinematics. This will include learning Java, selecting a program objective, writing code, and debugging.

Prosthetic Knee - Wiersma, J. - The motion of a knee is complex, but can be approximately modeled with a mechanism. A mechanism will be designed, simulated, constructed and tested. Final data values will be compared to physiological data.

7.4.2 Winter 1999 Project Topics

Project Name:
Designer:
Summary:
Deliverables:

7.5 PROBLEMS/READING

7.5.1 Erdman and Sandor

• The following section, and problems are suggested in the text,

Chapter 1 - Introduction to Kinematics and Mechanisms
Read Sections: 1-9
CDRom: Look at the sample problems for the chapter.

Suggested Problems: 2, 4, 11, 19, 25, 36, 52
Required Problems: 16(MC), 27(MC), 61(MC), 16(WM)

Chapter 2 - Design and Computer Aids
Read Sections: 1-6
CDRom: N/A
Suggested Problems: N/A
Required Problems: N/A

Chapter 3 - Displacement and Velocity
Read Sections: 1-11 (only skim 2), appendix
CDRom: Look at the sample problems for the chapter.
Suggested Problems: 1, 3, 6, 9(use complex method), 12, 23c), 36b), 63b), 71(wm)
Required Problems: 8(MC), 24c)(MC), 24c)(WM), 52c)(MC)

Chapter 8 - Mechanisms Synthesis
Read Sections: 1-3, 13-15
CDRom: Look at the sample problems for the chapter.
Suggested Problems: 10, 17, 20b)
Required Problems: 21 b)(MC), 21(WM)

Chapter 4 - Acceleration
Read Sections: 1-5
CDRom: Look at the sample problems for the chapter.
Suggested Problems: 5, 9, 37, 58
Required Problems: 13(MC), 13(WM), 42(MC)

Chapter 5 - Mechanism Dynamics
Read Sections: 1-7 (only skim sections 2-5)
CDRom: Look at the sample problems for the chapter.
Suggested Problems: 1, 19, 23
Required Problems: 8 e)f)(MC), 8 e)f)(WM)

Chapter 6 - Cams
Read Sections: 1-6, 8-10
CDRom: Look at the sample problems for the chapter.
Suggested Problems: 1, 7, 37
Required Problems: 35 (Develop the geometry for the cam in Mathcad. Export the geometry to Autocad via a text file. Export the geometry in DXF format to Working Model and simulate the motion.)

Chapter 7 - Gears
Read Sections: 1-9
CDRom: Look at the sample problems for the chapter.
Suggested Problems: 1, 2, 3, 16
Required Problems: 6 (Design matching gears. Create the geometry in Autocad. Export this geometry to Working Model and simulate their operation.)

7.6 PROFESSIONAL PRESENTATIONS

• Presentations will be a maximum length of 5 minutes, and will be followed by questions. Topics can be based on suggested problems, or on selected topics.
  - One source of topics might be, the Mechanisms and Mechanical Devices Sourcebook - pgs: 13, 36, 73, 81, 108, 116, 212, 260, 267, 272, 280, 284, 366, 416.
  - presentations should use overheads or be web based.
  - presentations should be made as if you are presenting to your peers on a design teams. The presentations don't need to be elaborate, but they should be enlightening.

Course Number:	EGR 352 - Section A
Course Name:	Kinematics and Dynamics of Machinery
Academic Unit:	Padnos School of Engineering
Semester:	Winter 1999
Class Times:	2:40-3:55pm - Mon, Wed, Fri in 611EC
Description:	The kinematics of machines are analyzed explicitly and approximately using computer based mathematical techniques. Topics covered include planar mechanisms, positions, velocities, accelerations, spatial mechanisms, cams, gears, planar dynamics and spatial dynamics.
Prerequisites:	EGR 312, MTH 302
Instructor:	Dr. John Farris office: EC 618 office hours: 4-5pm - Mon, Wed, Fri phone: (616) 336-7267 email: farrisj@gvsu.edu web: http://claymore.engineer.gvsu.edu
Textbook:	Erdman, A.G., Sandor, G.N., Mechanism Design; Analysis and Synthesis, Vol. 1, 3rd Edition, Prentice Hall, 1997. Jack, H. EGR 352 Course Notes, GVSU.
Computer Access:	The student is expected to be able to use the following software packages. Working Model, version 4 MathCAD version 7 AutoCAD version 14 Netscape Communicator FTP/Telnet Excel Suitable hardware and software are available in EC 616.
Objectives:	a) To give students a clear understanding of the inner nature of mechanisms and machinery. b) To stimulate students innovation and creativity in designing mechanisms and mechanical systems. c) To make use of modern computer based design tools
Instruction Methods:	Lectures, projects and discussions.

Tentative Schedule:

Date	Topic #	Book	Topic
01/11	1	Chapter 1	Course introduction, design and definitions
	2		Basic mechanism types and diagrams
	3		Grashofs equation and degrees of freedom
1/18	4	Chapter 2	Design and mechanisms
	5	Chapter 3	Review of applicable mathematics
	6		Position notations and equations
1/25	7		Position analysis of mechanisms
	8		Mechanism Paths
	9		Introduction to velocity
2/1	10		Instantaneous centers
	11	Chapter 8	Design of mechanisms
	12		Mechanisms synthesis
2/8	13		Two and three position design
			MID TERM EXAM
02/15	14	Chapter 4	Introduction to acceleration
	15		Calculation of accelerations
	16	Chapter 5	Statics of mechanisms
2/22	17		Planar dynamics
	18		Dynamics of mechanisms
	19	Chapter 6	Cam types and applications
3/1	20		Motion profiles
	21		Cam design
			MID TERM EXAM
03/15	22	Chapter 7	Gears
	23		Involute tooth profile
	24		Design of spur gears
3/22	25		Helical gears
	26		Bevel gears
	27		Worm gears
3/29	28		Planetary gears
	29	Supplement	Matrix based analysis of spatial mechanisms
4/5	30		Inverse kinematics
	31		Jacobian matrix
	32	Supplement	Kinematics and dynamics of internal combustion engines
04/12			Project Work
04/26			Presentations

Grading:

Tests	30%
Assignments	15%
Professional Participation	10%
Final Project	20%
Final Exam	25%

Tests and assignments will be given at natural points during the term as new material is covered. Students will be expected to participate on a professional level during the course, and so individual work will be assigned at times, with expectation that it will be presented to the students/peers during lecture times. A final project, involving construction, will be assigned and tested later in the term. Marks will be some combination of performance and report. A final examination will be given to conclude the work, and test the students global comprehension of the material.

EGR 367 - MANUFACTURING PROCESSES

8. OVERVIEW

8.1 GENERAL INFORMATION

8.1.1 Author

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8.1.2 Acknowledgements

There are a number of faculty who have contributed to this course in the past. And, in particular, there are three faculty members who have made particular contributions of note.

Professor Roger Lewis of Ryerson Polytechnic University developed a set of course notes that are essentially the basis of these notes. His efforts were not trivial and should not be overlooked.

Professor Norm Ferguson of Ryerson Polytechnic University developed a handbook called “Metrology; The science of precise measurement”. This was also of invaluable assistance when assembling these notes.

Professor Shirley Fleischmann has worked on developing the GVSU flavor of this course and has prepared a number of labs and learning experiences.

8.2 READING

8.2.1 Required Reading In Shea

8.2.2 Supplemental Reading In Todd et.al.

• The following sections must be used for reading in addition to the course notes.

- Introduction to Manufacturing Processes
    - pg. xiii
- Cutting Processes
    - Turning
        - pg. 153 - Turning/Facing
        - pg. 101 - Parting/Grooving
        - pg. 91 - Lathe Boring
        - pg. 159 - Vertical Boring
        - pg. 149 - Thread Cutting
        - pg. 41 - Die Threading
    - Cutting Methods and Economics
        - course notes
    - Drilling
        - pg. 43 - Drilling
        - pg. 109 - Reaming
        - pg. 71 - Horizontal Boring
        - pg. 79 - Jig Boring
        - pg. 105 - Precision Boring
        - pg. 143 - Tapping
    - Milling
        - pg. 49 - End Milling
        - pg. 7 - Arbor Milling
        - pg. 120 - Routing
        - pg. 59 - Gear Hobbing
        - pg. 61 - Gear Milling
        - pg. 151 - Thread Milling
    - Sawing
        - pg. 14 - Band Saws
        - pg. 28 - Circular Saws
        - pg. 118 - Reciprocating Saws
    - Grinding
        - pg. 137 - Surface Grinding
        - pg. 35 - Cylindrical Grinding
        - pg. 73 - Internal Grinding
        - pg. 21 - Centerless Grinding
    - Broaching, Filing (optional)
        - pg. 12 - Filing
        - pg. 116 - Reciprocating Filing
        - pg. 16 - Broaching
        - pg. 65 - Honing
    - Miscellaneous Processes (optional
        - pg. 124 - Shaping/Planing

pg. 175 - Wire EDM
pg. 173 - EDM Grinding
pg. 198 - Electrochemical Machining
Composites
pg. 228 - Filament Winding
Rapid Prototyping
course notes only
Abrasives
pg. 2 - Abrasive Jet Machining
pg. 122 - SandBlasting
Quality Control, Metrology and the Environment
course notes only

8.2.3 Supplemental Reading In Kalpakjian

• In the text read the following sections, and answer at least the following problems. It is advised that you also ‘skim’ the other problems to identify weak spots in your knowledge.

Big Picture - Chapter 0 (pg. 1) - General Introduction
Cutting and Machine Tool - Chapters 20, 21, 22, 23, 24
Casting - Chapters 10, 11, 12
Plastics, Composites and Rapid Prototyping - Chapters 7, 18
Powdered Metallurgy - Chapter 17
Forging, Forming and Rolling of Sheet Metals - Chapters 13, 16
Joining - Chapters 27, 28, 29, 30
Forming of Bulk Metals - Chapters 14, 15
Finishing - Chapters 31, 32, 33, 34
Abrasive, Jet, Chemical, Arc and Beam Cutting - Chapter 25, 26
Competitive Manufacturing - Chapter 38, 39, 40
Quality Control, Metrology and the Environment - Chapters 35, 36, 31, 37
Properties of Metals - Chapters 1, 2, 3, 4, 5, 6

8.3 RESOURCES

• The following are resources that you may use to further investigate processes.

8.3.1 Videos

• The following videos can be checked out from the engineering store room - many of these will be shown in class,

- Turning and lathe basics
- Milling and machining center basics
- CNC training - Pro-light mill
- Vertical mill / lathe safety / operations
- Engineering Administrative Aspects of MIL-STD-105D (3 tapes)
- A Future in Metal Casting
- Injection Molding Machine
- Electrical Discharge Machining
- Basics of Grinding
- Sheet Metal Stamping Dies and Processes
- Sheet Metal Shearing and Bending
- Plastics Basics Tapes 1: The Injection Molding Machine
- Plastics Basics Tapes 2: The Injection Molding Process
- Plastics Basics Tapes 3: Injection Molds
- Injection Molding Machine (a promotional video)
- Cutting Tool Materials
- Cutting Tool Geometries
- Fundamental Manufacturing Processes: Casting
- Fundamental Manufacturing Processes: Blow Molding
- Fundamental Manufacturing Processes: Heat Treating
- Composites in Manufacturing
- Fundamental Manufacturing Processes: Thermal and Abrasive Waterjet cutting
- Fundamental Manufacturing Processes: Workholding
- etc...

8.3.2 Bibliography

Armarego, Brown, Machining of Metals, Prentice Hall

ASME, Handbook of Industrial Metrology, Prentice Hall

Boothroyd, G., Fundamentals of Metal Machining, McGraw-Hill

Busch, E., Fundamentals of Dimensional Metrology, Delmar/Nelson

Charbonneau, Webster, Industrial Quality Control, Prentice Hall

Etall, D., Manufacturing Processes and Materials for Engineers, Prentice Hall

Groover, M.P., Fundamentals of Modern Manufacturing; Material, Processes and Systems, Prentice Hall, 1996.

Guldner, F.J., Statistical Quality Assurance, Delmar/Nelson

Juran, Gryna, Quality Planning and Analysis (2nd edition), Wiley & Sons

Kalpakjian, S., Manufacturing Engineering and Technology, 3rd Edition., 1995.

Krar, O., St. Amand, Technology of Machine Tools (3rd Edition), McGraw-Hill

ShotBolt, G., Metrology for Engineers, Cassell & Company

Todd, Manufacturing Processes Reference Book, Industrial Press, 1994.

8.4 PROJECTS

8.4.1 Fabrication Project

• A major project will be conducted as part of this class to ensure that all students obtain some hands-on experience. This project can be done individually, or as a component of a group project. Projects must use a variety of manufacturing techniques. Each project will involve a number of steps,

1. submit a short written proposal that outlines the basic design, expected operations, and required equipment/operations. (last week of September/January)
2. approval/changes based upon professor comments. (first week of October/February)
3. detailed drawings and process plans done and submitted. (second week of October/February).
4. gathering of materials, and doing work. NOTE: a log must be kept on a regular basis.
5. progress meeting near the midpoint (after Halloween/March Break).
6. completion of work (second last week of term).
7. submission of a written report (on-line) summarizing daily logs, details, drawings, process plans, logs, etc.
8. oral presentation of final results (in scheduled exam time).

• Typical projects might include,
- a cannon made of brass that can fire small projectile using a spring.
- a small press (team project).
- a complex part made using the CNC milling machine or lathe.
- the frame for a CNC drill press
- sheet metal
- etc.

• Some materials for the project,
- 1” brass rod is available for use in the shop

- other scrap materials are also available
- you can purchase specialty metals at a number of local companies
- Riders Hobbies on 28th St. sells small items suited for finishing

• An example of a process plan sheet is shown below. As state below, these must be completed with drawings BEFORE work begins.

OPERATION SHEET

Part No.	*CLP023456-4-92-023*	Material	*steel 1040*
Part Name	*Widget*		
Orig.	*H.Jack*	Changes	
Checked	*I. M. Boss*	Approved	*D. O. Little*

No.	Operation	Machine	Setup	Time (hrs.)
0010	*Saw off and slug 1.75 dia. hole*	*Dept 12. Saw 3*		*.3*
0015	*R'Turn 6.00 dia. stock to 5.210/5.190* *R'Bore 1.75 dia to 2.00* *F'Bore 2.00 to 2.005/2.015*	*G.E. Turn Lathe*	*Hold in counter centrifugal Chuck*	*1.2*
0025	*Deburr all edges*			*5 mins.*

8.4.2 Previous Projects

L. Brown - Meat Tenderizing Hammer - A hammer will be designed for pounding meat to tenderize it. The construction will be all metal, with a knurled handle, and a ridged face.
A. Edler - Firearm Magazine Retainer Clip - A small clip will be remanufactured for a cartridge magazine for a rifle. This will involve turning and milling operations.
B. Fett - Mold For Blow Molding Machine - A design and construction of a mold for a miniature Coke bottle with a GVSU logo on the side. The geometry will be designed in Ideas and converted to G-codes using CAMworks. This will be cut on an NC mill off site.
J. Klein - Black Powder Cannon - A black powder cannon will be designed and built. It will also have a base capable of absorbing the recoil.
B. Kuieck & B. Momber - Press, Bender and Break - A press frame will be completed and attachments will be designed and built for pressing, bending tubes and shearing metal.
A. McMullan - Canon - A small cannon will be constructed with the intention of eventually retrofitting it with controls in a later class.
L. Mercer - A Small Tap Wrench - A Small tap wrench will be designed and built to accommodate smaller taps.
L. Muckey - Propeller Fairwater - A fairwater will be designed for the solar boat. It will allow the

afterwash of the propeller to reconverge smoothly. Appropriate mounting threads and features will also be included.

E. Palmbos - Adjustable Tap Wrench - An adjustable tap wrench will be designed and built that uses two halves to hold the tap.

M. Sherd - Lamp - A lamp will be made of brass and wood.

C. Smith - Lug Wrench - A Lug wrench will be designed and built for standard automotive nuts.

J. Thelen - Bicycle Part Replacement - A part that allows repositioning of a bicycle seat will be reverse engineered and built.

8.5 LABORATORIES

8.5.1 LAB - TECHNOLOGY AND MANUFACTURING

8.5.1.1 - LAB - Introduction to Metrology and Design of Experiments

Objective: To explore basic measuring instruments and conduct a simple design of experiments analysis.

Pre-Lab:

1. Read section later in the noted on design of experiments.

Materials:

- micrometer
- calipers
- specimen sets
- surface plate
- height gage
- gage blocks
- dial indicator

Group Size:

- groups of 3

Procedure:

1. A brief presentation on the use of micrometers, calipers and dial indicators will be made at the beginning of the lab.
2. Measure the specified dimension on the parts using the micrometer and calipers. Put both dimensions side by side in a table.

3. Mount a dial indicator and measure the same specimens in step 2, put these values in the table also.
4. A brief presentation on design of experiments will be made.
5. An experiment will be conducted that evaluates the measurement abilities of micrometers. The two variables in question are the variation between two users and the use of the clutch/no clutch. Set up the appropriate chart that varies these two parameters and determines the effect and correlation.
6. A specimen set will be supplied. An SPC analysis of these specimens needs to be done.

Submit: (in standard lab format)

1. The table of values measured by micrometer, calipers and height gages with a description of differences.
2. The design of experiments data, calculations and conclusions.
3. The SPC analysis.

8.5.1.2 - DEMO - Process Planning and Machining Demo

Purpose:

a) To observe a series of Machine Tool operations, in the manufacture of the component shown.
b) To introduce the students to the concept of process planning.

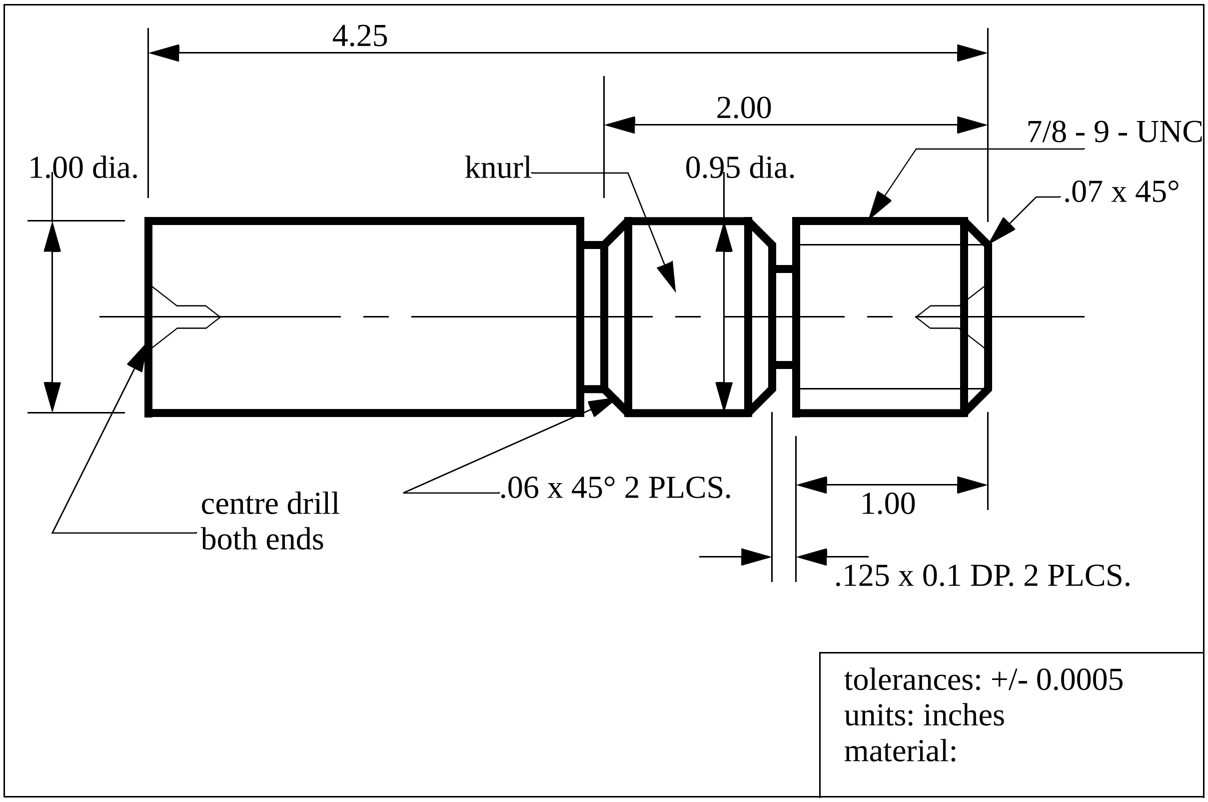
Pre-Lab:

1. Read over the drawing, and the process plan before the laboratory.

Materials:

Lathe and tools for knurling, facing, center drilling, parting (1/8”), UNC threading, turning, 45° form
1” bar stock, brass
Cutoff saw
Micrometer

Component Drawing:



Procedure:

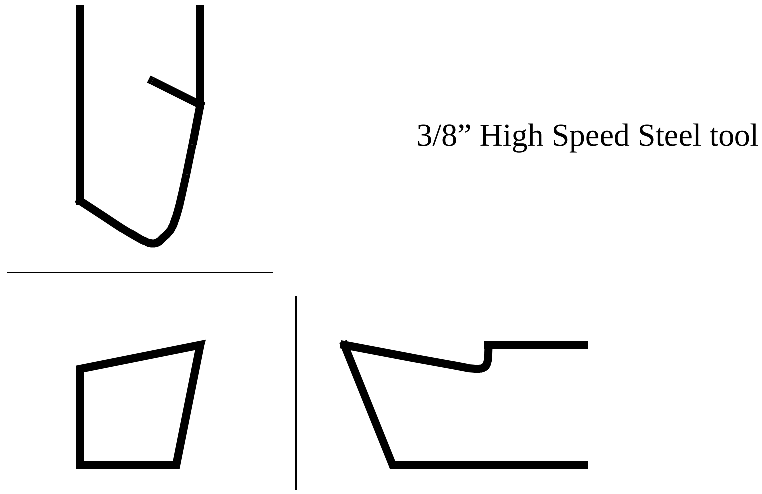
1. Discuss safety in the shops with Mr. Bob Bero.
2. The will make the part above, or something similar.
3. Tour the remainder of the shops.

CAUTIONS:

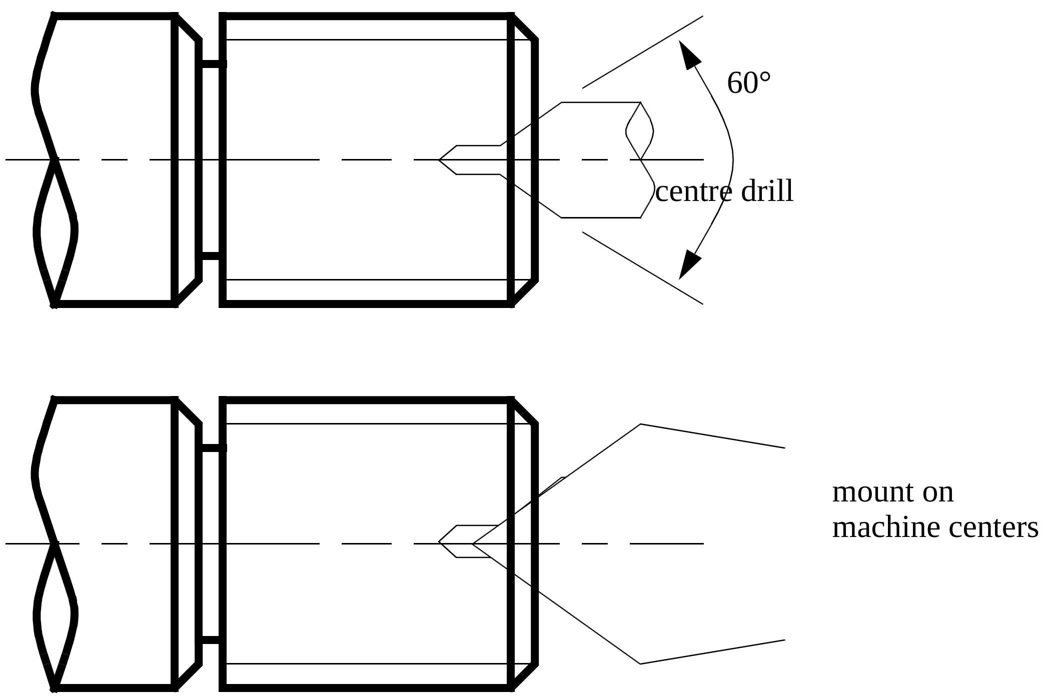
1. Power will be on in the machine shop.
2. For your safety, refrain from touching any machine buttons or levers.
3. Do not handle swarf (metal chips) from the cutting processes, they are hot, and sharp and WILL cause at least some harm.

Cutting Tool:

A variety of cutting tools are available in a quick change fixture, but a typical lathe toolbit is shown below.



Centre Drill & Machine Centre:



Surface Cutting Speed:

$$CS = \frac{\pi D(RPM)}{12}$$

CS = 100 fpm for optimum cutting conditions with mild steel work, and high speed steel tools (200 fpm for brass?)

Process Planning Sheet:

OP #	Description	Department
05	cut off bar stock 1” dia. 4 3/8” long.	cut off saws
10	deburr with a file	bench
15	hold in a 3 jaw chuck face and centre drill both ends	lathes
20	turn two diameters hold between centers	lathes
25	Under cut grooves using a 0.125” parting tool	lathes
30	chamfer 2 @ 0.06” & front @ 0.07”	lathes
35	cut thread 7/8 - 9 - UNC	lathes
40	Knurl 0.95” dia.	lathes
45	Inspect part to drawing	inspection

Submit:
Nothing

8.5.1.3 - LAB - Paradigm of Technology (tentative)

Objective: To form an opinion on technological change

Pre-Lab:

1. Read the article “XXXX, XXXX and Assault Rifles” by XXXXXXXXX.

2. Write a point form summary of the article.

Materials:

Paradigm Video Tape
VCR/TV
Student provided objects

Procedure:

1. Discuss the article.
2. In groups of about four, select a simple object that has been introduced in the last century. Next, consider the social impact the object has had, including value, life-style and economic changes.
3. View the video tape and take notes about the basic points of the philosophy, evidence that it is realistic.
4. Discuss the video.
5. Discuss the statement - “When somebody says ‘they should have thought of that’ they are talking about the stewards of technology.” Next, identify the stewards of technology.

Submit:

Nothing

8.5.2 LAB - HEAT TREATING OF STEELS AND THE JOMINY TEST

Objective:

To quantify the effects of heating and cooling on the properties of steel.

Pre-Lab:

1. Go to the engineering library and get the ASTM standard ‘A 255 - 85’
2. Read the ASTM A255-85 standard.
3. Review materials on heat treating and steel microstructures from EGR250.

Theory:

Iron is a useful material, but it tends to lack hardness, as a result we can turn it into steel. Steel is made by adding elements such as carbon, silicon, molybdenum, chromium, etc. to iron. These materials do not mix in a homogeneous form and they form quite complex structures. To complicate matter the heating and cooling of the metals causes the alloying elements to form different structures in the iron. Most of these structures tend to have phases that are primarily one type of material, such as ferrous carbide, which has a higher melting temperature. When a single material forms in a region is tends to form a single grain of metal, under the microscope we can look for these regions.

When heated past 1700degF for a few hours, the steel is still solid, but the microstructure normalizes into Austenite, and the alloying elements tend to distribute themselves evenly. After this the structure will take different forms, depending mainly upon how quickly it is cooled. At low cooling rates the iron, carbon and other elements tend to separate out at different rates. As a result a slow cooling rate (such as air cooling) will lead to pearlite. This material has ridges of ferrite and cementite tightly combined to form a pattern like gray mother of pearl under the microscope. Sometimes a pattern will emerge that looks like a fingerprint. A slower cooling rate will result in pearlite with larger features. The slowest cooling rates (especially annealing) tend to lead to large grains of ferrite. Under a microscope ferrite looks shiny and white. A faster cooling rate will lead to a tighter looking combination of elements called Martensite. This looks like a very tight random pattern of light and dark under the microscope. If we can manage to cool the material fast enough to avoid to avoid the formation of other forms we will also have some retained Austenite. This tends to form as sharp spears shaped grains. There are other structures that occur, but they are rarely seen or require electron microscopes, such as Bainite.

The microstructure of a metal can be determined by polishing the surface to make it flat, and then using an etchant to make the surface more visible. A microscope is then used to observe the structure. Careful observation can determine the structure of the metal. We can also use Isothermal transformation graphs (found in materials handbooks) to theoretically estimate what microstructures are present in a material.

The hardness of a material can be measured using a hard stylus that is pushed into the surface of the work. Hardness is a function of how deep the stylus penetrates the surface (We will use the Rockwell C scale).

8.5.2.1 - Part A - End Quenching For the Jominy Hardness

Materials:

- heating oven with thermometer
- 1” 1045 steel bar stock
- 1” 4140 steel bar stock
- quenching apparatus and water source
- tongs
- surface grinder
- stain/marker
- Rockwell C hardness tester
- ruler/scale
- scribe
- specimen stand at hardness tester
- safety glasses

Procedure:

1. Mr. Bero will heat the bar of steel in a high temperature oven until it is at austenite tem-

perature (this will be approximately 1700°F and take approximately 3 hours).
2. The quenching apparatus will be set up and the water flow adjusted to a specified rate, the temperature will be checked.
3. When all is prepared, the part will be removed from the oven, then placed in the quenching apparatus. Note the end that was quenched.
4. After cooled sufficiently (the following laboratory period), grind more than 0.015” off opposite sides of the bar to make flats for harness testing. Take care not to overheat the metal, as this might change the material properties. Use safety precautions.
5. Stain one side of the bar - this will help locate test points later. On the stained surface, mark off points every 1/16” using the scribe for the first inch from the quenched end, after that mark off points every 1/8” inch.
6. Check the setup of the hardness testing machine.
7. Take hardness test readings in the Rockwell C scale along the flat face of the bar near the scribed points, and record values. It is necessary to support the specimen with a stand when it hangs over the side of the specimen table. Be careful to wait at least 15 seconds when taking readings, even if the readings look done before this time, they are not.
8. Polish and etch the entire flats ground on the opposite side of the bars using the techniques in part b of this lab. Examine the microstructure from the quenched end of the bars.

Submit:

1. Graph the results of the hardness tests.
2. Provide additional details required in sections 8.1.1, 8.1.2 of ASTM A255.
3. Discuss the correlation of hardenability to theory.
4. Discuss the microstructure of the bars.

8.5.2.2 - Part B - Microstructure

Materials:

4 buttons of 1045 steel, marked #1 to #4
4 buttons of 4140 steel, marked #5 to #8
heating oven
tongs
quench bath
cooling tray
water sanding station
diamond polisher and extender fluids
microscope
nitric acid
glass eye dropper
safety glasses
sink and running water

Procedure:

1. Before the lab, buttons #1,2,3,5,6,7 will be preheated to Austenite/annealing temperatures.
2. During the laboratory the buttons will be removed. Air cool buttons #1 and #5. Water quench buttons #2 and #6. Buttons #3 and #7 are left in the oven for an extended period of time for annealing.
3. Once cool, the buttons will be taken to the specimen room where they will be polished on the water sanders. Start with the courser paper, and work to the finer paper. This requires some attention to technique. The process may take a few minutes on each belt. Try not to move in straight lines, a figure eight pattern work well. move to a finer grit of sandpaper until done.
4. When the surfaces are relatively polished, do a finishing pass on the diamond grit polisher. Start with the diamond wheel. Use a drop of extender on the wheel, and move the sample about. This may take more than a minute. When done proceed to the Alumina wheel, and follow a similar procedure.
5. When the surface has a mirror like finish, put a drop of nitric acid on it (USE SAFETY PROCEDURES). The surface should darken, and then you may wash the acid off in the sink.
6. Using a specimen microscope, examine, and draw the microstructures of the materials. Also note the microstructures that are visible. If you find a good example of Pearlite, inform the others in the laboratory.
7. Develop a chart that categorizes the different steels, treatments, and their properties.

Submit:

1. Discuss the microstructures seen in the microscope, and identify phases.
2. Locate appropriate Isothermal Transformation Diagrams for the steels used in the lab and use these to estimate the microstructure.
3. Discuss the relationship between the micrographs and the expected values - refer to the phase diagrams.

8.5.3 LAB - CUTTING

8.5.3.1 - Cutting Forces

Objective: To investigate the relationship of the cutting variables to cutting forces

Theory:

Pre-Lab:

1. Review Merchants force circle.
2. Review the surface roughness measurement section of notes.

Materials:

Lathe
Tool force dynamometer, centerline mount, and gages
Tachometer
Single cutting edge tool
Thin walled aluminum tube mounted in chuck (secured for cantilevered cut)
Profilometer
Safety glasses
Micrometer

Procedure:

1. Ensure that the lathe is set for orthogonal cutting, and that all instruments are functioning. Test the cutting forces by pushing the tool. Test the tachometer by turning on the lathe and synchronizing. Ensure that the cutting tool edge is perpendicular to the rotation of the work.
2. Measure the Inner and outer diameters of the tube.
3. Put on Safety Glasses. Turn on the lathe and Take a cut at the first speed and feed. Use the tachometer to verify speed, and use the strain gages to measure the cutting forces. Remove the chip, and measure the thickness, and observe the surface conditions. Mark it for later reference.
4. Taking the same measurements, make several cuts at different cutting speeds and then at different feed rates.

RESULTS - CUTTING FORCES

Material: Aluminum /alloy - Dia. = inches

Depth of cut = inches

Mean diameter = inches

Tool: Material: High Speed Steel

Rake Angle α = degrees

Feed Rate = 0.005 inches/rev

For variable velocity

RPM Settings	RPM Measured	Velocity (ft/min.)	F_c (lbs.)	F_t (lbs.)

For variable feed

RPM setting: Set = 140 RPM, actual = , velocity = ft/min.

Feed (in./rev.)	F_c (lbs.)	F_t (lbs.)

Submit:

1. Estimate the cutting forces, and horsepower required for each cut based on the data.
2. Calculate HPu and correction factors ‘c’ for the different cutting conditions. Compare these to those found in the notes.
3. For variable feed, plot graphs for Fc/feed and Ft/feed on the same graph.
4. For variable speed, plot graphs for F_c/V and F_t/V on the same graph.

8.5.3.2 - Surface Texture

Objective: To investigate the relationship of the cutting variables and surface roughness

Pre-Lab:

Review the textbook and section later in the notes on surface roughness measurements.

Materials:

Mill with fly cutter mounter
flat brass stock
flat steel stock
Profilometer
Safety glasses

Procedure:

1. Test the calibration of the profilometer against a standard.
2. Mount the brass in the mill.
3. Make cuts at different speeds, feeds and depths using the methods of DOE. Measure the surface roughness parallel and perpendicular to the cutter path.
4. Replace the brass with steel. Take 2 cuts using parameters from step 3. Compare the surface roughness values.
5. Replace the tool with a new tool having a rounder cutting radius. Take 2 cuts using parameters from step 4. Compare the surface roughness values.
6. Repeat step 5 with brass.

Submit:

1. The DOE for speeds feeds and tool nose radius.
2. A numerical comparison of the surface roughness when cutting brass/steel and large/small cutter radius.

8.5.4 LAB - PLASTICS

All students are expected to do the Injection Molding lab, and the Vacuum Forming lab. But there will be a choice between the Thermoset Casting, and Composites labs.

8.5.4.1 - Injection Molding

Objective: To be exposed to the basic process and parameters of injection molding using a bench-top machine.

Pre-Lab:

None

Theory:

Typical injection molding machines will take solid thermoplastic materials in pellet form. The pellets are sometimes dried in ovens first, as plastic is hygroscopic, and will absorb water when left to sit for any time. The plastic pellets are poured into a hopper, and into a chamber. This chamber uses a combination of heating and shearing to make a high pressure homogenous molten mixture. The shearing and pressurizing is done using an auger like screw. When the plastic is injected, it is pushed into the mold in one shot. The mold is typically cooled with water channels, and the plastic quickly fills the mold and solidifies. If too much plastic has been injected it will tend to squeeze out of the mold and leave 'flash' that looks like thin fins. If the plastic hardens too quickly in the mold you will be able to se flow marks on the surface of the part. If too little pressure was used, the mold will not be filled, and the result will be a 'short-shot' part.

The benchtop model we will use in the lab does not use a screw for the plastic, but instead the plastic is heated in a chamber, and a plunger pushes the plastic into the mold. This means that the plastic may not have been completely melted by the heating alone. The plunger is also advanced using supplied air pressure, if the air pressure is lower than normal, there might not be enough shot pressure and a short-shot could result.

Materials:

Benchtop injection molding machine with proper electrical and air supply hook-ups
Tensile test specimen die
High density polyethylene beads
Stopwatch
Marker
Tensile Tester
1" Micrometer

Procedure:

1. Turn on both heaters to the suggested settings and allow to warm up (approx. 1 hour) to 475°F for the barrel, and 500°F for the nozzle.
2. Load the raw plastic into the hopper of the machine.
3. Cycle the machine for about 10 seconds to ensure proper operation. Repeat this until

you are getting good parts.

4. Make three specimens at different cycle times, 2 10 and 30 seconds. Mark all specimens for later reference. If the cycle time on the machines is set to a large value, a stop-watch can be used, and the cycles stopped manually at the desired times.
5. Now, using a cycle time of 10 seconds, and make two new parts, this time varying the barrel temperature above and below the suggested temperature by ±25°F.
6. Set the barrel chamber temperature back to 475°F, and this time vary the nozzle temperature for two separate parts by ±25°F.
7. Set the nozzle temperature to 500°F, and make two final shots, varying the air supply pressure down from the maximum by 20psi, then another 20psi.
8. Make and record observations for all of the parts.
9. Measure the dimensions of the thinnest section, and then test the strength of the specimens in the tensile tester.

Submit:

1. A table of values of molding conditions and the expected outcomes.
2. Discussion of the results based on the properties of the plastic used.
3. A reason for the resulting material strengths.

8.5.4.2 - Vacuum Forming

Objective: To explore the process of vacuum forming, and determine the relationship between process parameters.

Pre-Lab:

None

Theory:

If we heat a sheet of thermo plastic material enough it will become pliable. Overheating will melt the sheet. Our objective when vacuum forming is to heat the sheet so that it becomes pliable. While the sheet is still hot, we position it over a mold, and then pull it down onto the mold. We then pump the air out from beneath the sheet to create a vacuum. This vacuum will create a pressure of 0 to 15psi on the plastic. If done quickly enough, the plastic will move down to take the shape of the mold before it hardens. The temperature required to heat the plastic depends upon the type of material. When forming the sheet the original sheet is deformed and typically thinner.

Materials:

12 sheets of polyethylene cut into 12” squares
small scraps of each material for temperature testing
vacuum forming equipment
heating oven

vernier micrometer
vernier calipers
knife or scissors
thermometer
stopwatch
steel scale

Procedure:

1. Position the thermocouple in the oven so that it is far away from the heating elements, but close to where the plastic will be. Preheat the oven to just below a suitable temperature for polyethylene (275°F). The correct temperature for each material can be estimated by using the test scraps of material (they should start to sag just below the suitable temperature).
2. Insert a specimen of polyethylene into the frame and secure - align the 1” grid to marks on the frame so that the following grids can also be aligned. Roll the tray into the oven, heat for 20 seconds or until the material starts to sag, measure and record this time. Measure the temperature of the thermocouple as the sample is being pulled from the oven. Quickly slide the specimen out to the vacuum former, and start the cycle. When the cycle is done, remove the specimen.
3. Set up and conduct a DOE that examines the effects of oven temperature and hold time in the oven.
4. When done Cut down the same center line of each specimen and measure the thickness at critical points (the nose) and the radius in a given tight corner.

Submit:

1. The DOE and conclusions.

8.5.4.3 - Blow Molding

Objective: To explore the process of blow molding, and the effects of process parameters.

Pre-Lab:
None

Theory:
None

Materials:
blow molding machine
raw plastic
micrometer
knife or scissors
stopwatch

Procedure:

1. Set up and run a simple part.
2. Set up and conduct a DOE that examines the effects of temperature and advance time.
3. When done Cut down the same center line of each specimen and measure the thickness in the top middle and bottom ball.

Submit:

1. The DOE and conclusions.

8.5.4.4 - Thermoset Casting (tentative)

Objective: To investigate resin casting, and the effects of heat on setting.

Pre-Lab:

None

Theory:

This lab will use the ‘Alumalite’ two part polymer system. The two parts are measured out in equal volumes and mixed together. Once mixed these parts form long polymer chains. By themselves this would leave a rubbery solid. Crosslinking also occurs which makes these materials stiff. During this process at least some heat is released as bonds are broken and made. In the presence of heat this reaction will occur faster, and polymerization will be more complete. when fully cured the Alumalite will have a beige, or creamy appearance. When not fully cured the result will be a semi-transparent brown, that may still be sticky. This material will tend to gel within a minute, and be solid within two, so speed is required as soon as the two components have been mixed.

Materials:

Alumalite part A and B
Graduated cylinders
Disposable mixing cups
Disposable stirring rods
Plastic gloves
Safety goggles
Apron
Mask if prolonged usage
Rubber mold with thermocouples
Silicone, or other release agent
Heating gun/oven
Stopwatch

Procedure:

1. Place the mold in a freezer to chill it for an hour before use.
2. Estimate the volume of the mold, using a previous part.
3. put on apron, safety goggles, and gloves. If the ventilation is poor, or the work prolonged, use a breathing mask.
4. Taking care to use the proper cylinder for the proper Alumalite component, measure out two equal volumes or parts A and B to each cylinder. The volume should be just over half the required total.
5. Make sure that all mixing, and measuring facilities are ready.
6. Remove the mold from the freezer. Clean the mold, and spray with release agent.
7. Hook up and verify the operation of the thermocouples.
8. Pour the two components into the mixing cup, and mix thoroughly - a brownish mixture will appear in a few second.
9. Pour this into the mold, and start the stopwatch, and start measuring temperature. Use an air jet to keep the surface of the part cooler.
10. At regular intervals (10 seconds) measure temperature, and touch the surface lightly to see if it has solidified. Record the time when the surface becomes ‘solid but tacky’ as the gel time. Record the time when the surface becomes hard as the set time.
10. When satisfied that the process is complete, remove the part and make observations.
11. Repeat the process, but this time at normal room temperature.
12. Repeat the process again, but this time use a an oven to preheat the mold, and a heat gun/oven to speed the process.

Submit:

1. Draw graphs of the heats of the three tests, and draw on lines for gel time, and set time.
2. Draw conclusions about the results of the experiments.

8.5.4.5 - Composites

Objective: This laboratory will expose the student to fibre-resin composite materials. This will include a basic demonstration of construction techniques, and testing of completed parts to estimate material strengths.

Pre-Lab:

None

Theory:

Composite materials provide high strength and stiffness with low weight pieces. In many cases the strength and stiffness to density ratio is about 5 times that of steel and aluminum. In addition these materials are easier to work into complex shapes than the metal equivalents. These advantages are mainly due to the macroscopic combination of high strength fibres, and a low strength binder (resin). Typical materials used for fibres are glass, carbon, and aramid (kevlar). The strength of the composite can be closely approximated by finding the fractional cross sectional area the materials (resin/fibres), and their respective material properties. A weighted sum is done to find the aggregate properties.

Composite parts are made using molds. The fibre cloth is cut to shape while paying attention to the direction of the fibres, for strength. After the fibre has been cut to shape, for the number of layers required, the mold is coated with a parting agent, such as silicone. The resin is mixed just before the layup begins because the resin has a pot life of a few minutes before it hardens. A roller is used to apply a thing layer of resin over the entire surface. The first layer of fibre is applied to the surface, and the roller is used to apply another layer of resin on top. Fibre and resin are alternately applied until the entire part is built up. When this is complete, the part is left to harden (30 minutes to 12 hours). At this time the part should separate cleanly from the mold. The edges are trimmed and the part is complete. Before the part is cured the composite will be weaker. Heat may be used to speed the curing process.

The construction method described above is called wet layup, and is commonly used in small batch composite construction. This method generally produces the poorest composite material properties of all methods. This is due to the manual application of the resin. A ratio of approximately 65% fibre to resin is required throughout the part for optimal strength, but this is difficult to obtain when manual application is used. Secondly, a number of voids (air bubbles) are present in the material. Below 0.5% voids in the material the strength is largely unaffected, but above this the strength drops of 7% for each 1% of voids up to 4% voids in the matrix. Another point of interest is that most composites undergo an elongation of approximately 1 to 5% before they rupture without any plastic deformation.

Composite Material	Tensile Strength (MPa)**
unidirectional carbon	1550
unidirectional glass	965
unidirectional kevlar49	1378
undirected glass mat	???

** Note: These figures are for 65% fibre/resin ratio, and must be corrected for lower ratios in the specimens provided - assume 40%.

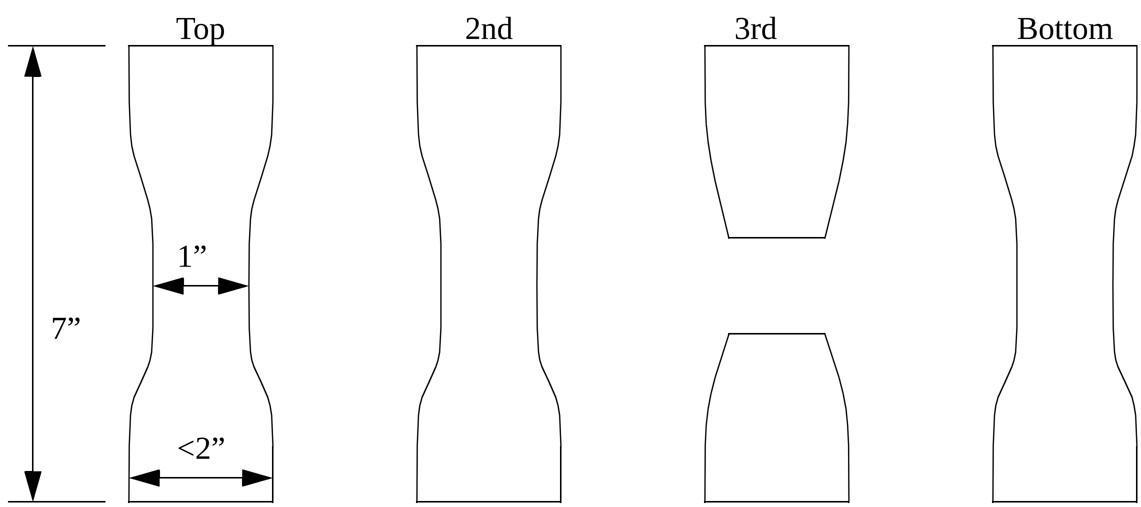
Materials:

- Fiber Glass kit (glass mat, resin and hardener)
- Scissors
- Gloves
- Apron
- Safety goggles
- Mask
- Wax paper (or similar)
- Cardboard
- Pins
- Disposable mixing container
- Disposable mixing stick

Disposable brush
Tensile tester
Micrometer
Microscope
Heating Oven
Paper and Pen

Procedure:

1. On a piece of paper, trace out a tensile test specimen. Cut out this shape as a template.
2. Put on the rubber gloves, apron, and goggles.
3. Use the template and scissors to cut out 10 test specimen layers from the bidirectional glass weave mat. Try to trim these so that they are all the same size.
4. Cut the template so that the entire end, and about 1” of shaft remains. Cut out 16 copies of this template.



5. Now, lay out the larger samples in piles of 1, 2, 3 and 4. With each pile put four of the end pieces. These four pile will be the four tensile test specimens made.
6. Next draw the shape of the test specimens on the cardboard and lay out the wax paper on top. Put the first layers of the samples on top and pin at the ends.
7. Mix about 1 cup of the resin and hardener in the mixing cup. Stir quickly until thoroughly mixed.
8. Dip the brush in the resin, and coat the four specimens. Try to wet the mat, but don’t soak it.
9. Add the next layer of glass mat, and brush on more resin. Continue until all layers are done.
10. Allow the parts to stiffen, and then place in an over to speed curing.
11. Measure the dimensions of the thinnest cross sections of the specimens.
12. Look at the specimens under a microscope and draw what you see. Take special care to look for fibers and air bubbles.
13. Use the tensile tester to find the stiffness, and the ultimate tensile strength.

Submit:

1. Strength of materials calculations regarding the estimated strength of the composites.

8.5.5 LAB - CASTING

Objective: To observe the basic elements of the casting process

Time & Location: Tues., Mar., 2, 2:00p.m., Caulder Arts Building, Allendale

Pre-Lab:

1. Review the casting material in the course notes and the text.

Materials:

1. Styrofoam patterns
2. Mold packing sand - silica or zircon
3. Gates for the patterns
4. Buckets for patterns and sand
5. Bronze ingots
6. Melting furnace, cupola, winch, drop pit, etc.
7. Band saw
8. Specimen polishing equipment and microscope
9. Micrometer and vernier calipers
10. Foam working tools - hot melt glue gun, foam cutters, knives, etc.

Procedure:

1. Prepare the styrofoam patterns by doing and trimming, gluing, etc. You will be given a few basic designs at the start of the laboratory. These designs will include
   - a series of balls to determine metal flow
   - a thin wall part to determine warping, etc. (measure wall flatness)
   - a rectangular piece to be measured for dimensional changes and surface warping (measure the overall dimensions)
   - two balls to be examined for microstructure.
2. Glue the patterns to a gate/runner system, also made of styrofoam. The best results will be to have a top mounted runner. Make sketches of every pattern and the gate placement.
3. Heat the bronze in the furnace to at least 1200°F.
4. Measure the dimensions of the parts before placing them in the sand. Partly fill a container with the sand to support the foam core. Make sketches of the part placement in the sand relative to other parts.
5. Orient the top of the runner so that the pattern is resting on the sand bed. and continue to add sand carefully. Care should be taken not to break the foam core when adding sand. A gentle vibration, or tamping will help to settle the sand throughout the filling operation. When done, continue to bump, or vibrate the sand until it is settled.
6. Check to see that the buckets are all ready for a pour. Ensure that the pourer, and all oth-

ers involved are wearing safety glasses, aprons, and appropriate footwear. Make sure that adequate ventilation systems are on - the evaporated foam will smell.

7. Winch the cupola, now full of molten bronze up, and move it to the pour pit so that it is ready to pour.
8. When casting you must pour the metal once, quickly and steadily. DO NOT HESITATE - Any hesitation will ruin the part. Pour until the pool of molten metal can be seen at the top of the runner.
9. Let the mold stand for a few minutes to solidify, and then remove the part from the sand Parts may be quenched to speed cooling, but remember to let one of the balls air cool. The sand can be removed by hitting the part carefully with a hammer.
10. Cut one of the large body parts open with a saw, and look for voids and inclusions.
11. Polish and etch one of the internal faces of the balls (one quenched and the other air cooled). Examine the microstructure of the metal near the side, and the center of the mass.
12. Make observations comparing before and after dimensions, as well as other details.

Submit:

1. A general discussion of dimension changes before and after casting.
2. A list of design features, and how well they were cast using charts and other exhibits.
3. A discussion of the microstructure.

8.5.6 LAB - DESIGN FOR DISASSEMBLY (DFD)

Objective: To examine a product to determine how well it is suited to disassembly for recycling.

Pre-Lab:

1. Read the handout “Environmental Aspects of Design”.
2. Read the textbook section on “Design for Assembly, Disassembly and Service”.
3. Review the theory section below.

Theory:

The very nature of any product is that is made of groups of dissimilar materials that have been shaped and connected in a strong manner to serve some function. It is this very connection of dissimilar materials that make the individual materials harder to reclaim at the end of a products life. To complicate matters the consumer often selects a product based on cost of manufacturing, not the total life cycle cost. As a result, most engineering design tools focus on making assembly more efficient using techniques such as Design For Assembly (DFA). Some basic axioms of DFA include,

- For Parts
    1. Eliminate/minimize tangling between parts in feeders.
    2. Use symmetry to reduce the orientation time during handling

3. If symmetry is not possible, use obvious features to speed orientation

• For Products
4. Reduce the number of parts when possible
5. Build the part in layers from the top on the bottom, using gravity to locate parts
6. Have the already assembled product stable on the work surface
7. Have the work lie in a horizontal plane
8. Use chamfers and fillets to ease mating of parts.
9. Use snap-fits, and other quick fasteners, avoid screws, glue, etc.

Inadvertently, many of the DFA methods also make disassembly easier. For example, axioms 4, 5, 6, 7 will make parts easier to disassemble. Step 9 can also make these easier to disassemble if the right type of connectors are used. Steps 1, 2, 3, 8 can have an ergonomic effect on the worker doing the disassembly work. By themselves these axioms focus on the assembly, but ignore the sorting of the part materials. So, we can add a few simple axioms to speed recycling.
1. Avoid trapped fluids that will leak
2. Mark all non-ferrous materials for easy sorting
3. Make all pieces of single materials
4. Make reusable parts in easily disconnected modules
5. Make all assembly connectors easy to disconnect

Like most design methods, these points are used to guide design, and not control it. Frequently the rules must be put aside because of technical limitations, customer expectations, etc. When possible we need to review designs to estimate where these changes can occur with no serious impact on the products performance, and where they are desirable for environmental and economic gains.

Materials:
Consumer product(s) - (Winter 1997 it was a dish washer)
Basic hand tools
Scrap bins

Procedure:
1. Discuss the basic principles of disassembly and manufacturing.
2. Examine the machine for general issues before disassembly, such as disconnects, and emptying water.
3. Disassembly the machine one component at a time. As each component, or group of components, is removed address each of the following points,
- could the part/assembly be resold as a replacement part?
- is the material obvious?
- how much effort was required to separate the part - eg. tools or access?
- how easy was to part to handle?
- is the part ready for recycling, or do other operations need to be done?
- does the part need to be discarded?

4. Sort the parts by material, and prepare to take to Padnos Scrap Yard.
5. Estimate the fractions of recovered materials by type, and unrecoverable materials.
6. In small groups discuss design changes that would ease recycling.

Submit:

1. 5 different large design changes (with drawings) that would make the product easier to disassemble.
2. Suggest 5 small design changes that would make the parts easier to recycle.
3. Estimate the loss or profit in recycling the dishwasher. Assume your hourly rate is $15/hr.

8.5.7 LAB - WELDING, SOLDERING AND GLUEING

Objective: To join various materials and test joint strength.

Pre-Lab:

1. Review the appropriate material in the course notes and the text.

Theory:

There are three main methods for joining materials i) a filler that solidifies and bonds unmelted bases, ii) a filler and base material are melted and join together, iii) base materials are heated and melt and then solidify together.

Materials:

Arc Welder and rods
Acetylene gas welder and rods
Propane torch and solder
1/4” iron plates
Cyanoacrylate glue
5 minute epoxy
Popsicle sticks
Tensile tester

Procedure:

1. Join the metal and wood samples using the available techniques.
2. Pull the specimens in the tensile tester and observe the failure types and strengths.

Submit:

1. A general discussion of bonding strength.
2. Comparison of bond strength to material strength

8.5.8 LAB - SHEET METAL SHEARING AND DRAWING

Objective: To observe the forces required to deform and shear sheet metal.

Pre-Lab:

1. Review the appropriate material in the course notes and the text.

Materials:

1. Hydraulic press
2. Sheet metal shear
3. 1/16” sheet metal, aluminum and steel
4. Permanent ink marker
5. Steel scales
6. Computer with DAQ card and labview program
7. Sheet metal break

Procedure:

1. Set up the press and select a variety of sheet metal thicknesses. Draw a 1/2” square grid on the sheet metal. Measure the thickness of the sheet.
2. Use the press to draw the metal. Note the maximum force, and the area under the force/displacement curve as the deformation energy. Look at the now deformed squares on the piece and estimate the strain in each square, along the cross section of the part.
3. Shear various piece in the shear, and record the forces. Note, you will probably need to measure the angle of the blade to the work and the thickness of the sheet.
4. Examine the edges of the sheared pieces with a magnifying glass or microscope. Identify where the material sheared. Compare the shear forces to theory.
5. Use the sheet metal break to bend pieces of sheet metal. When bending carefully record the angle bend to, and then the angle the piece springs back to. Measure the bend radius and sheet thickness, then compare the results to theory.

Submit:

1. A full lab report including all data, observations, calculations, and final results.

Course Number: EGR 367
Course Name: Manufacturing Processes

Academic Unit: Padnos School of Engineering

Semester: Fall 1999

Class Times: 10-11 am - Mon, Wed, Fri

Lab Times: Sec. 1, Wed., 2-5pm

Description: The objective for this course is to expose the student to as many aspects of manufacturing as possible in the time available. This will include properties of materials as well as the processes that convert these materials into specific products. Particular attention will be given to machining processes first so that the student may have a perspective for understanding. This will then be followed with examination of other manufacturing areas.
Throughout the course frequent assignments and/or quizzes will be used for each section of material. In addition each student will be expected to participate in laboratory experiments, plant tours, a minor research project, and a large final project.

Prerequisites: EGR 250 or equivalent

Instructor: Dr. Hugh Jack

office:	EC 716
office hours:	11-12am - Mon, Wed, Fri
phone:	(616) 771-6755
email:	jackh@gvsu.edu
web:	http://claymore.engineer.gvsu.edu

Textbooks: Todd, Manufacturing Processes Reference Book, Industrial Press, 1994
Jack, H. EGR 367 Course Notes, Grand Valley State University

Software: MathCAD
Netscape Communicator
FTP/Telnet

Objective: When done the student should be able to select manufacturing processes and parameters. Students should also be able to build simple parts.

Instruction Methods: Lectures, labs, projects and discussions.

Tentative Schedule:

Lectures	Topic
1	General Introduction
2-10	Cutting Theory and Machine Tools
11	Metal Properties and Heat Treating Review
12-14	Casting Metals
15-18	Molding Plastics
19	Powdered Metal
20-24	Sheet Metal
25-28	Welding, Torch Cutting, Forming
29-30	Painting, Finishing
31-32	Electrical, Chemical Machining
33-34	Composites
35	Rapid Prototyping
36-37	Abrasives
38-39	Quality and Measurement
40	Environmental Issues
	FINAL PRESENTATION - 4-6pm wednesday

Experiments: A variety of laboratory experiments will be conducted throughout the term. The intent of these labs is to introduce you to the concept of each manufacturing process and to provide you with a hands-on experience in which you measure process variables and make technical inferences about them. Each laboratory will be written up in standard laboratory format including; purpose, apparatus, theory/prelab, procedure/results, discussion, conclusions. This format will be described further by the instructor. Every report must be clear, concise, justified and accurate. Several experiments will require the use of DOE for planning and analysis, as detailed in the laboratory guide. These experiments include,

1. Metrology and DOE
2. Design for Disassembly (DFD)
3. Heat Treating and Hardness Testing
4. Submit proposals for machining project, and start work
5. Cutting forces and surface roughness
6. Lost foam casting
7. Thermoset plastic casting, composite construction, and injection/vacuum molding

Plant Tours: During the term we will visit a number of factories. During these visits we will see a number of manufacturing processes and techniques. To help recall details at a later date, each student will a resource sheet outlining interesting details, and drawing useful conclusions. The memos are not to exceed one page in length, and are to be clear and concise.

1. Scrap Processing Facility
2. Heat Treating

3. Casting
4. machining/lasers, etc
5. Stamping/forming
6. Sheet metal/welding
7. plastic molding/extrusion

Grading:

Assignments	15%
Experiments	25%
Final project	30%
Quizzes	25%
Plant Tours (mandatory)	5%

Tests and assignments will be given at natural points during the term as new material is covered.

Final Project: Each student is expected to produce some thing using at least 10 different and distinct turning or milling operations. The things may be done individually or by groups to be assembled into something more complex. This project involves use of the machines shop, and must have demonstrable results to pass the course. Some examples of possible projects are,

miniature cannon (1 person)
small vice (1 person)
small press (small team)
robot frame (large team)

Grading Scale:

A	100 - 90
A-	89-80
B+	79-77
B	76-73
B-	72-70
C+	69-67
C	66-63
C-	62-60
D+	59-58
D	57-55

Course Number: EGR 520
Course Name: Manufacturing Processes

Academic Unit: Padnos School of Engineering

Semester: Winter 2000

Class Times: 5:30-8:45 pm - Mon

Description: The objective for this course is to expose the student to as many aspects of manufacturing as possible in the time available. This will include properties of materials as well as the processes that convert these materials into specific products. Particular attention will be given to machining processes first so that the student may have a perspective for understanding. This will then be followed with examination of other manufacturing areas.
Throughout the course frequent assignments and/or quizzes will be used for each section of material.

Instructor: Dr. Hugh Jack

office:	EC 716
office hours:	4-5pm - Mon, Tues
phone:	(616) 771-6755
email:	jackh@gvsu.edu
web:	http://claymore.engineer.gvsu.edu

Textbooks: Schey, Manufacturing processes

Jack, H. EGR 367 Course Notes, Grand Valley State University

Software: MathCAD
Netscape Communicator
FTP/Telnet

Objective: The student should have some knowledge of the major manufacturing processes is use today.

Instruction Methods: Lectures, demonstrations and discussions.

Tentative Schedule:

Date	Topic
03/15	General Introduction

	Quality and Measurement
03/22	Material Properties
03/29	Cutting Theory
	Cutting Tools
	Cutting Tools
04/05	Metal Properties
	Casting
	Plastics
04/12	Composites
	Forming
	Powdered Metallurgy
04/19	Joining
	Sheet Metal
04/28	FINAL EXAMINATION

Grading:

Quizzes	60%
Assignments	40%

Tests and assignments will be given at natural points during the term as new material is covered.

Grading Scale:

A	100 - 90
A-	89-80
B+	79-77
B	76-73
B-	72-70
C+	69-67
C	66-63
C-	62-60
D+	59-57
D	56-53
D-	52-50

Reading List

Kalpakjian

Class 01 - Introduction
Class 02 - Metrollogy - chapters 0, 35, 36
Class 03 - Quality Control - chapter 31, 37
Class 04 - Basic Cutting - chapter 20, 21
Class 05 - Turning, Milling, Drilling - chapter 22, 23, 24
Class 06 - Materials - chapter 1, 2, 3
Class 07 - Materials - chapter 4, 5, 6
Class 08 - Casting - chapter 10, 11, 12
Class 09 - Sheet Metal - chapter 13, 14, 15
Class 10 - Plastics - chapter 16, 17, 18
Class 11 - Welding - chapter 27, 28, 29
Class 12 - Project Presentation

EGR 520

Manufacturing Processes and Materials

Course Coordinator: Hugh Jack

8.6 TOURS (TENTATIVE)

- When on plant tours, students will be required to observe and record significant items on the sheets given below.

EGR 367 Manufacturing Processes
Plant Tour Resource Statement
Seymour and Esther Padnos School of Engineering
Grand Valley State University

Company / Division / Site		
Address		Web Site
Contact Person		Company Phone
Phone	Fax	email

Nature of Company / Customers
Main Processes / Materials Used
Strengths / Challenges
Other Comments

Prepared By: ______________________ Date: ______________________

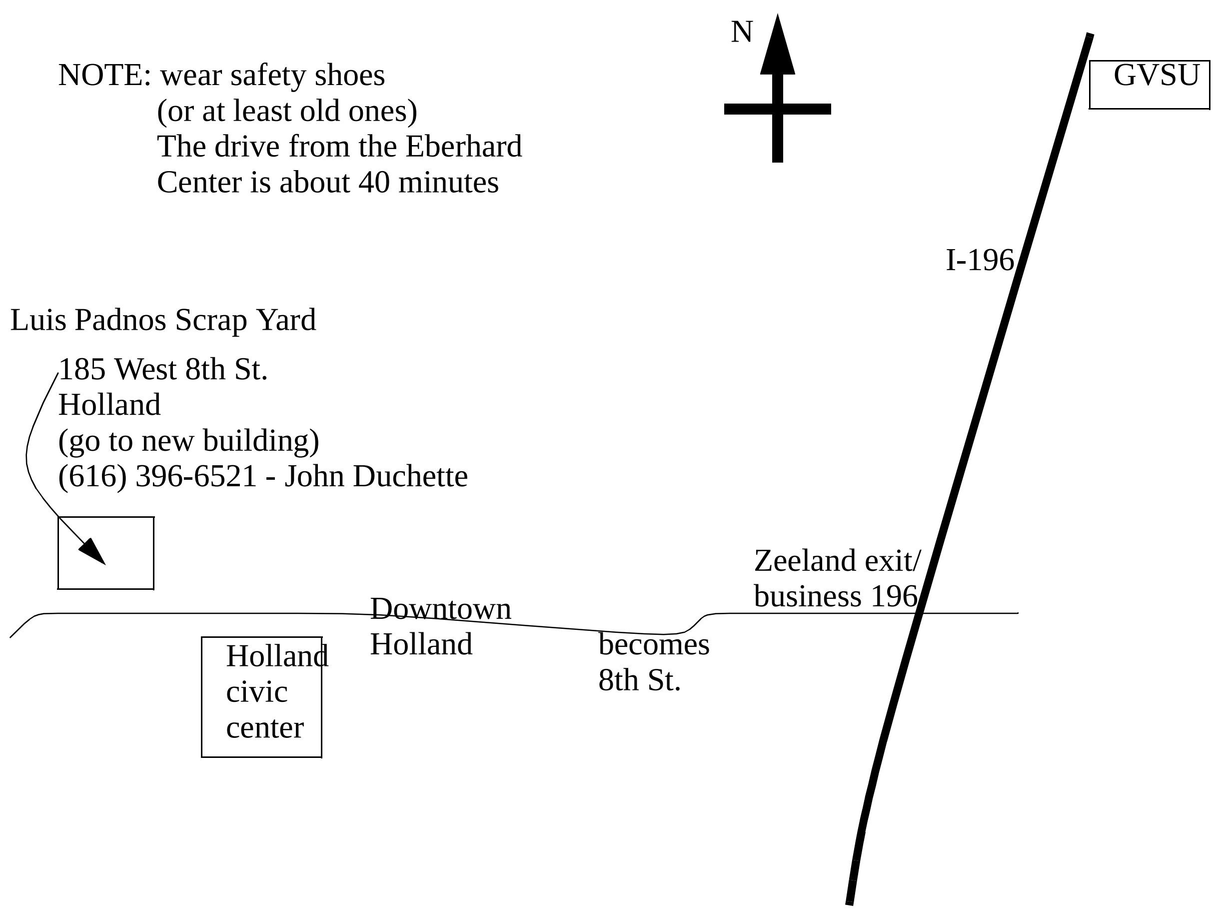
8.6.1 TOUR - PADNOS SCRAPYARD

Date and Time: Wed., Sept., 10, 2:45-4:15 p.m.

Pre-Tour: Read the Padnos Scrap Yard Case Study again.

Highlights: A large facility for reclaiming metals that has received the Ford Q-1 award for the quality of their shredder scrap. On-site the facilities include a briqueting operation for fine turnings, car shredding, sizing operations for various large scrap, aluminum melting, pressing operations for high grade scraps and an extensive machine shop for fabricating much of their own equipment. Environmental concerns are addressed at all points in the facility.

Map:



Some Items to Look For (only a start):

1. What is Q-1 and what does it mean?

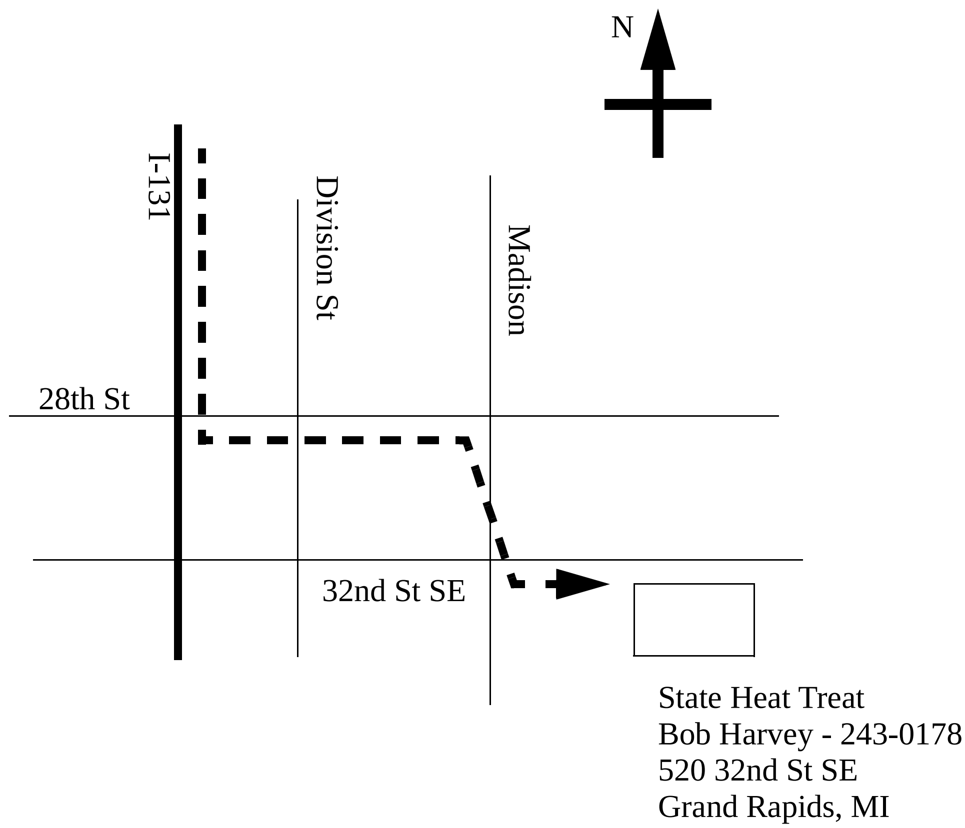
2. Metal types.
3. What are the sources of the metal?
4. How does the scrap arrive?
5. Quality control.
6. Landfill materials
7. The shredding process and the output.
8. Preprocessing of automobiles.
9. Input materials that cause problems.
10. Separation operations (manual/automatic).
11. Contaminants such as oil.
12. CFCs.
13. Bailing.
14. Equipment designed in-house

8.6.2 TOUR - STATE HEAT TREATING

Date and Time: Wed., Sept., 2, 2:45-4:15 p.m.

Highlights: Industrial scale heat treating of processes. This includes atmoshphere ovens, indiction hardening, aluminum, etc.

Map:



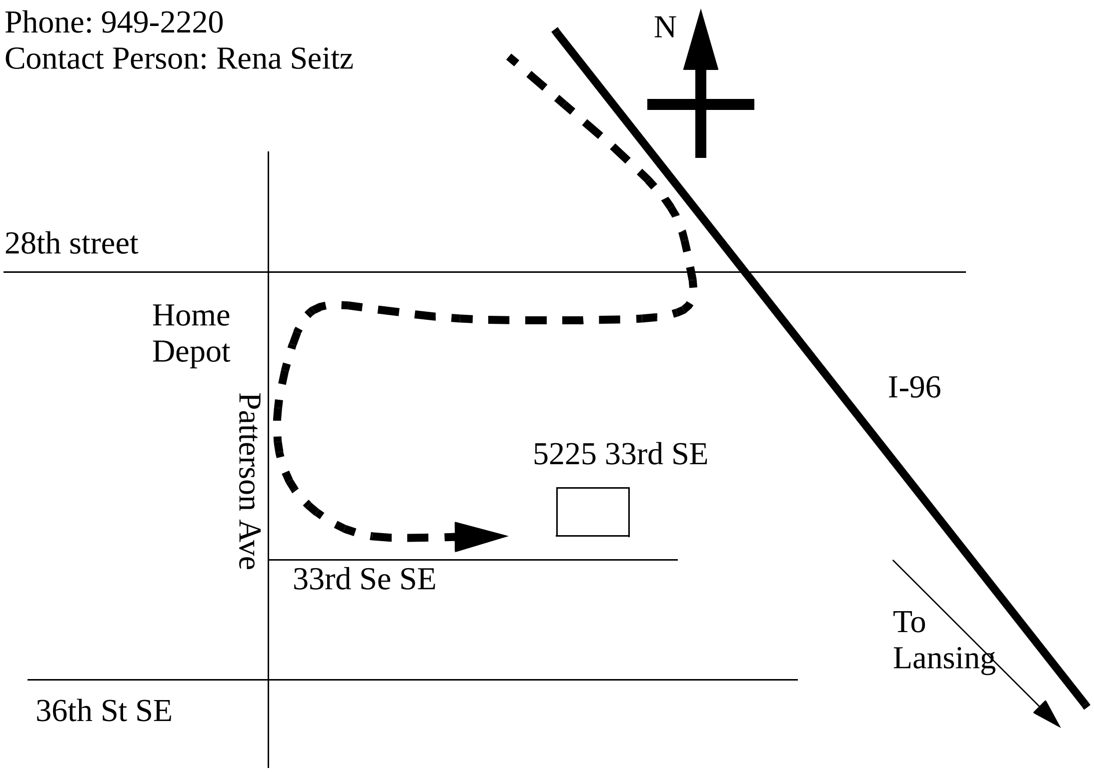
8.6.3 TOUR - PARAGON DIE & ENGINEERING

Date and Time: Wed., Sept., 2, 2:45-4:15 p.m.

Highlights: They manufacture plastic molds for large parts. Most of the molds are for injection molds, and are up to the size of full dashboards. They have a number of large CNC machines, a 3000 ton injection molding press for testing, an EDM machine, a large CMM, and numerous large machine tools. The company owner is Fred. M. Keller, the Keller Engineering Lab Building has been named after him.

Map:

Phone: 949-2220
Contact Person: Rena Seitz

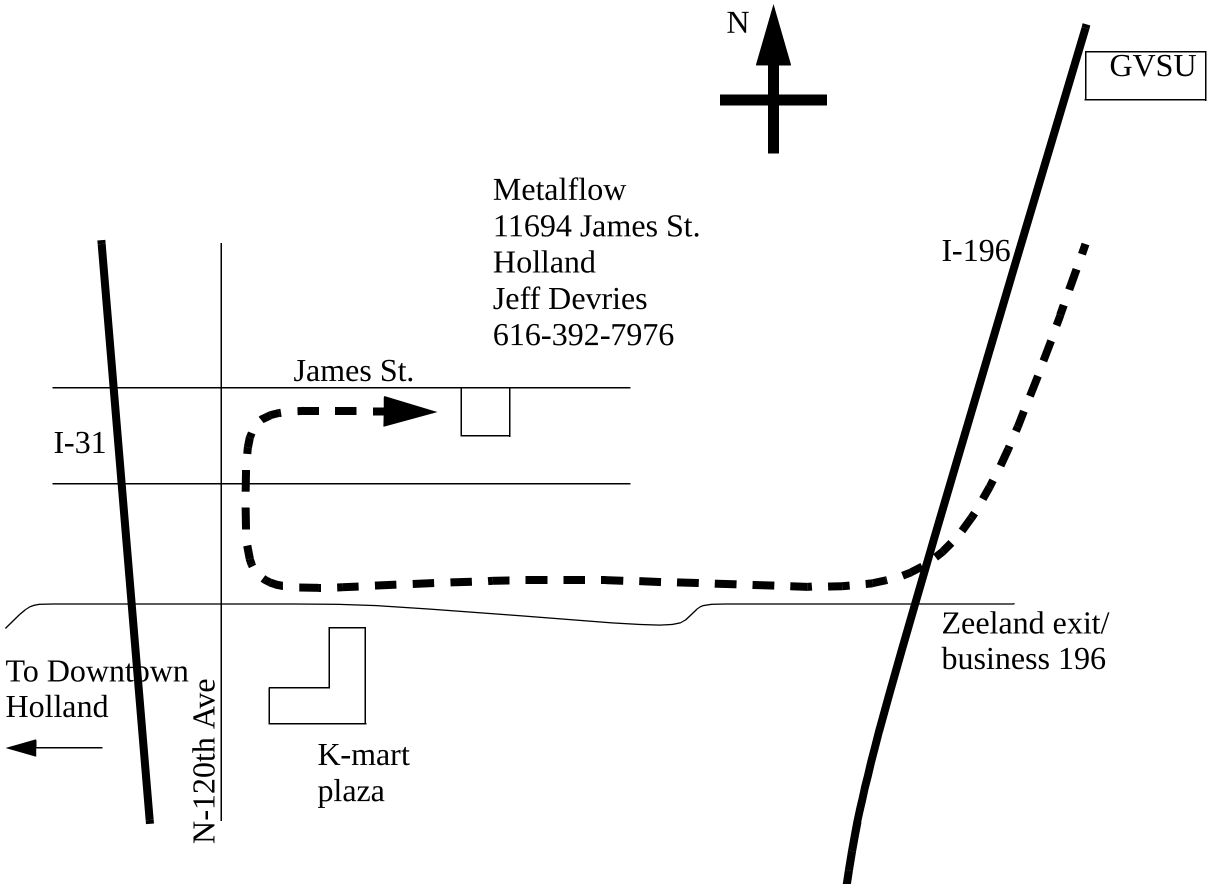


8.6.4 TOUR - METALFLOW

Date and Time: Wed., Sept., 2, 2:45-4:15 p.m.

Highlights: Deep drawing processes for autoparts suppliers and others. A wide variety of deep drawing machines, including automation. Use of CAD systems and NC machines to make dies.

Map:

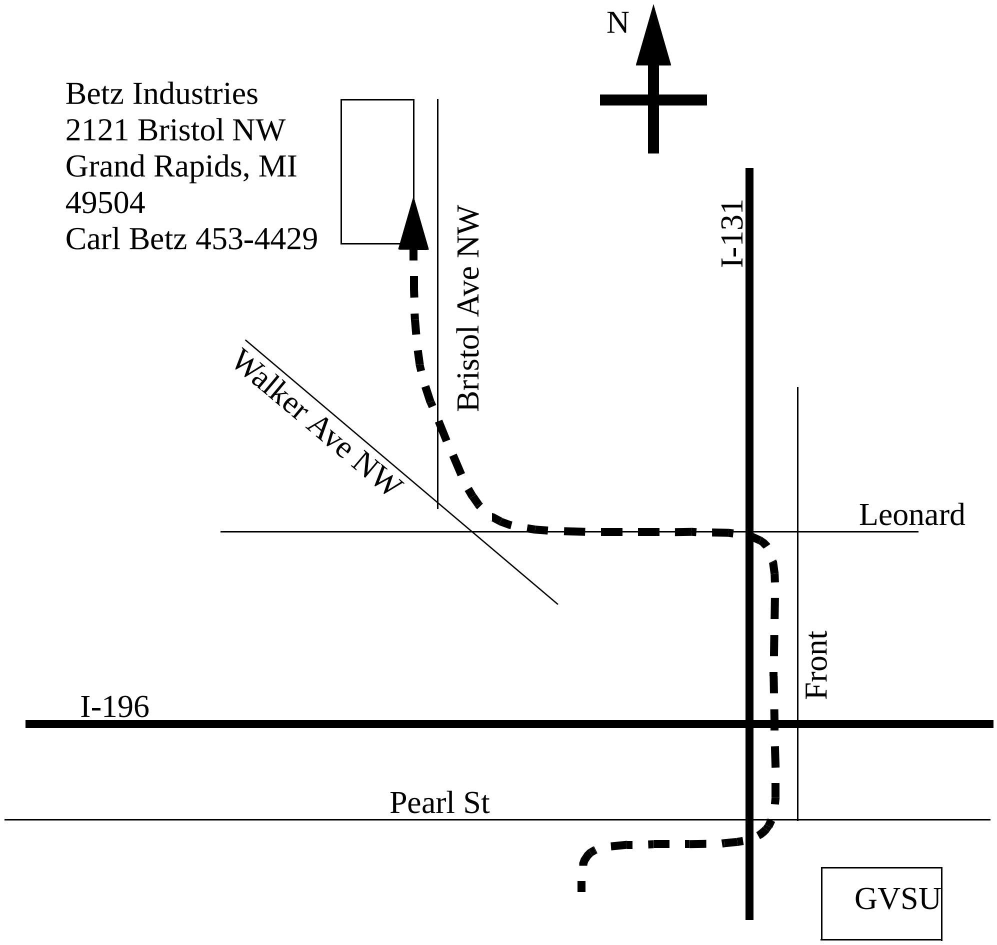


8.6.5 TOUR - BETZ INDUSTRIES

Date and Time: Wed., Nov., 2, 6-8:30a.m. (yes, early morning)

Highlights: An iron casting facility that does large castings, up to 50 tons. Many of the castings are done with lost foam, although traditional sand casting is also done. They have an extensive pattern making facility for the foam patterns that include many solid modelers and CNC machines. They do casting in the morning, because melting is done at night for utility costs.

Map:

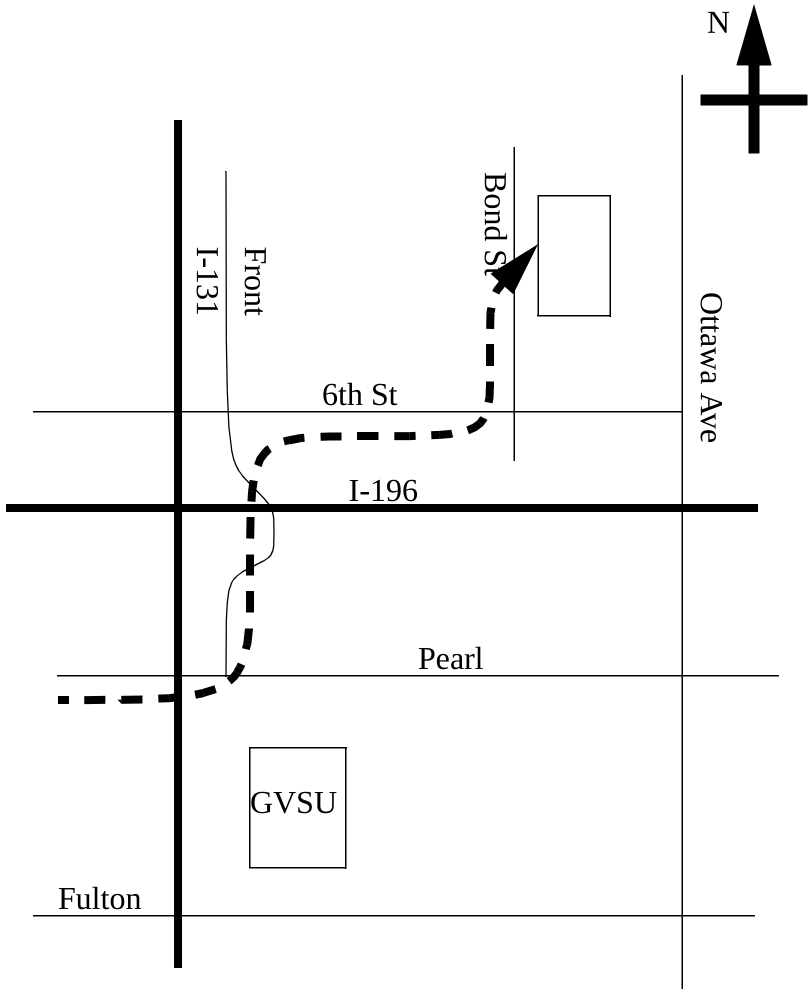


8.6.6 TOUR - GRAND RAPIDS SPRING AND STAMP

Date and Time: Wed., Sept., 2, 2:45-4:15 p.m.

Highlights: Many stamping and forming processes.

Map:



GRSS
Matt Mead
706 Bond Ave
Grand Rapids, MI
453-4491

8.6.7 OTHER TOURS (tentative)

• Other Tours are yet to be determined, but may include,

Drawform - sheet drawing, 500 Fairview, Zeeland, 49464 (616)772-1910
Shape - Rollforming - Dave Riemersma 616-846-8700
Blackmer Pump - Casting and machining - Doug Stolz, 1809 Century SW, Grand Rapids, 49509, 241-1611
Brill Cast - Die Casting - Ron Holland
Delphi - machining - Ed Dienno
Cascade Engineering - plastics - engineering
Nicholas Plastics - extrusion, compression molding - Mike Andres, 11700 48th Ave, 892-4100

8.7 TOURS

- When on plant tours, students will be required to observe and record significant items on the sheets given below.

EGR 367 Manufacturing Processes
Plant Tour Resource Statement
Seymour and Esther Padnos School of Engineering
Grand Valley State University

Company / Division / Site		
Address		Web Site
Contact Person		Company Phone
Phone	Fax	email

Nature of Company / Customers
Main Processes / Materials Used
Strengths / Challenges
Other Comments

Prepared By: ______________________ Date: ______________________

8.7.1 TOUR - PADNOS SCRAPYARD (tentative)

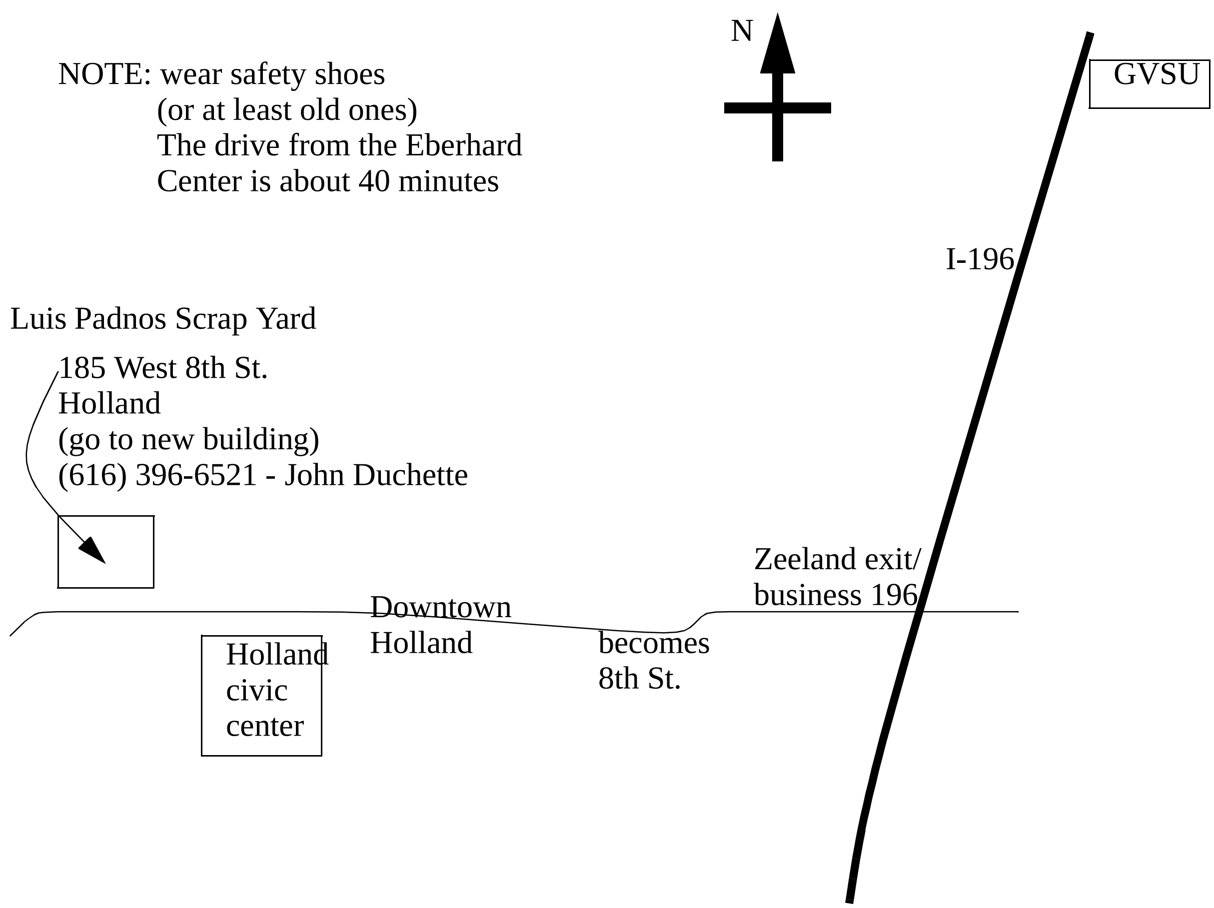
Date and Time: Tues., Feb., 2, 2:45-4:15 p.m.

Pre-Tour: Read the Padnos Scrap Yard Case Study again.

Highlights: A large facility for reclaiming metals that has received the Ford Q-1 award for the quality of their shredder scrap. On-site the facilities include a briqueting operation for fine turnings, car shredding, sizing operations for various large scrap, aluminum melting, pressing operations for high grade scraps and an extensive machine shop for fabricating much of their own equipment. Environmental concerns are addressed at all points in the facility.

Map:

NOTE: wear safety shoes
(or at least old ones)
The drive from the Eberhard
Center is about 40 minutes



Some Items to Look For (only a start):

1. What is Q-1 and what does it mean?
2. Metal types.

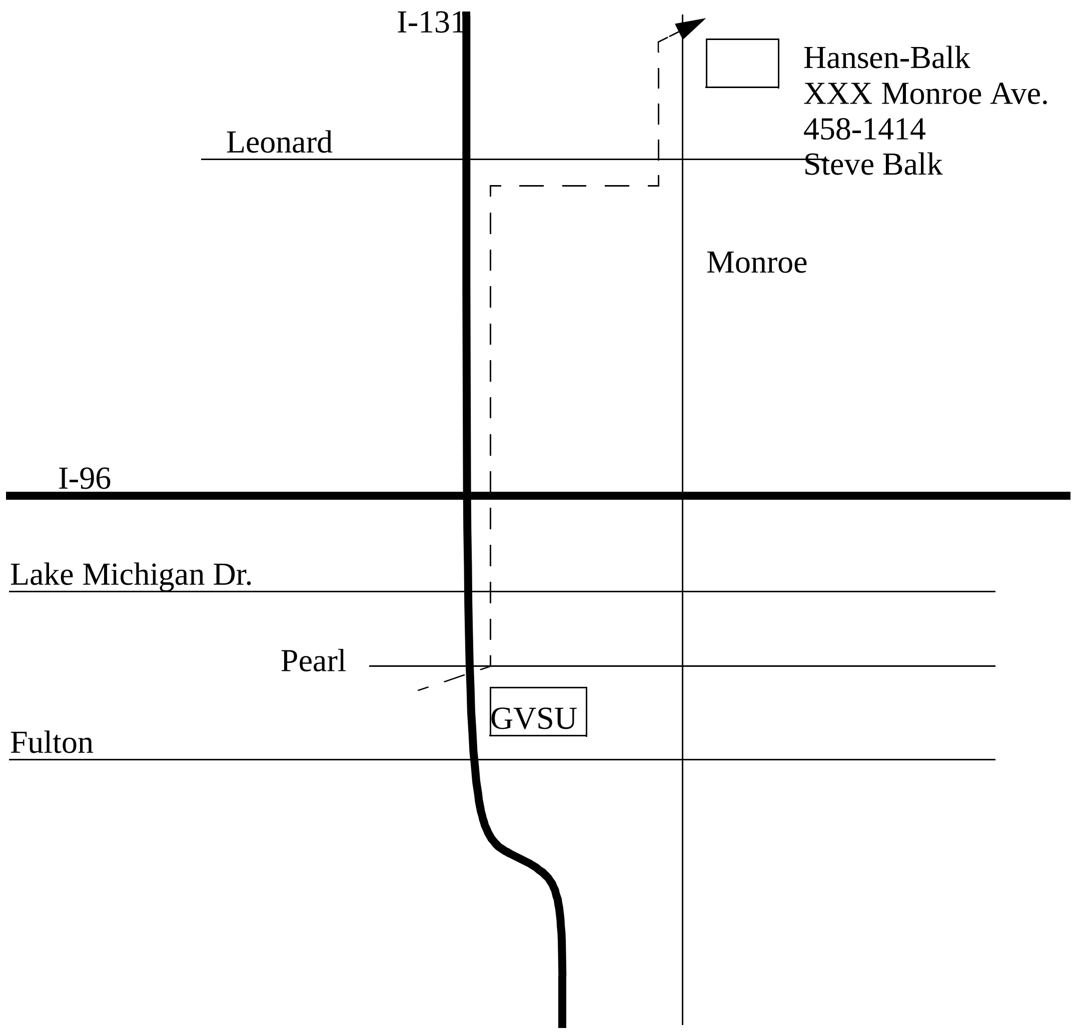
3. What are the sources of the metal?
4. How does the scrap arrive?
5. Quality control.
6. Landfill materials
7. The shredding process and the output.
8. Preprocessing of automobiles.
9. Input materials that cause problems.
10. Separation operations (manual/automatic).
11. Contaminants such as oil.
12. CFCs.
13. Bailing.
14. Equipment designed in-house

8.7.2 TOUR - HANSEN-BALK (tentative)

Date and Time: Tues., Feb., 9, 2:30-3:30pm

Highlights: Heat treating processes including annealing, tempering/quenching (oil, water and salt), case hardening and shot blasting.

Map:

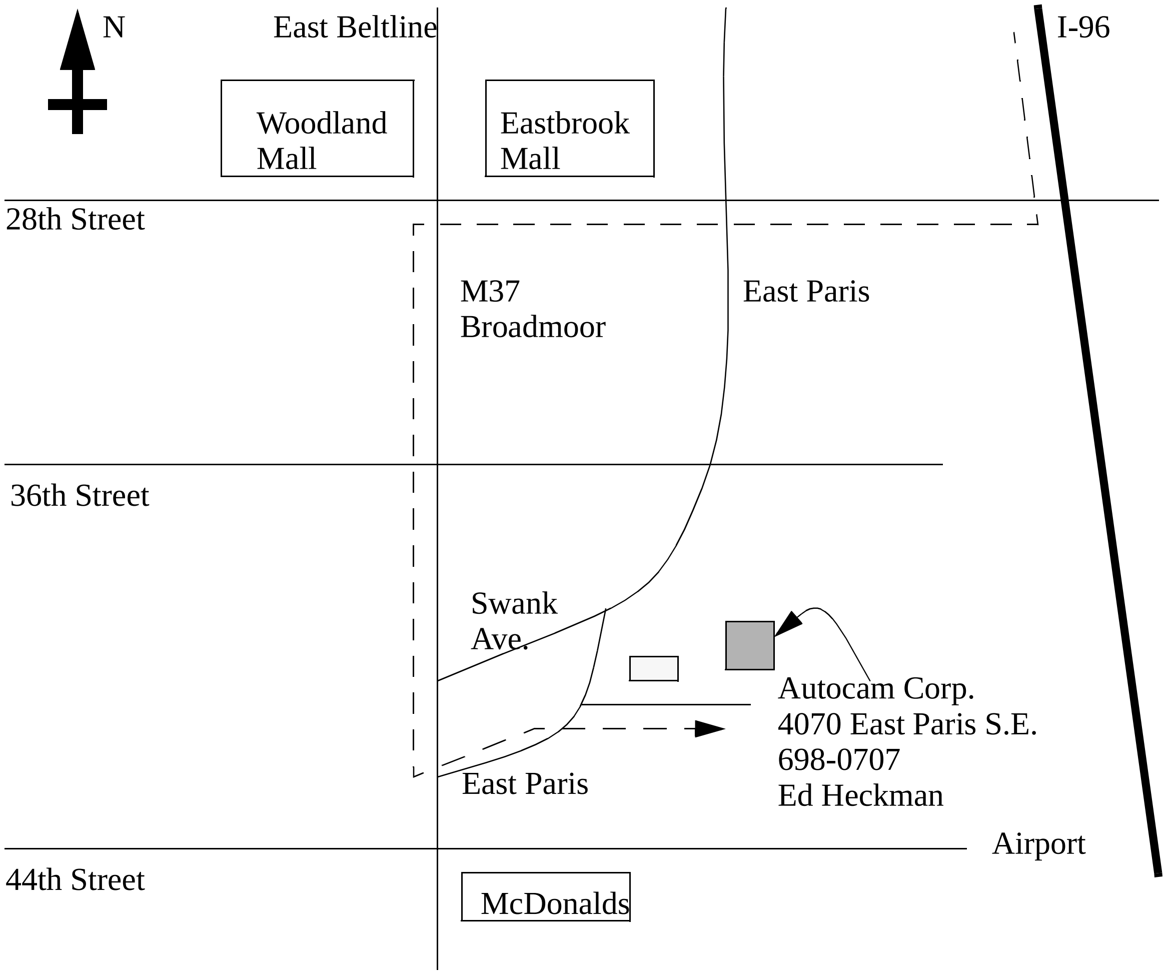


8.7.3 TOUR - AUTOCAM (tentative)

Date and Time: Tues., Feb., 23, 2:30pm

Highlights: Precision machining processes including grinding and turning for the autoparts and computer industries.

Map:



8.7.4 TOUR - ENGINEERING DESIGN SHOW IN CHICAGO

Date and Time: Tues., Mar., 16, bus leaves at 8am

Highlights: Thousands of exhibitors showing automation, robotics, CAD, processes, ...

Submit: 5 pieces of literature from different vendors that apply to something you did in your coop. Write a brief paragraph for the significance of each.

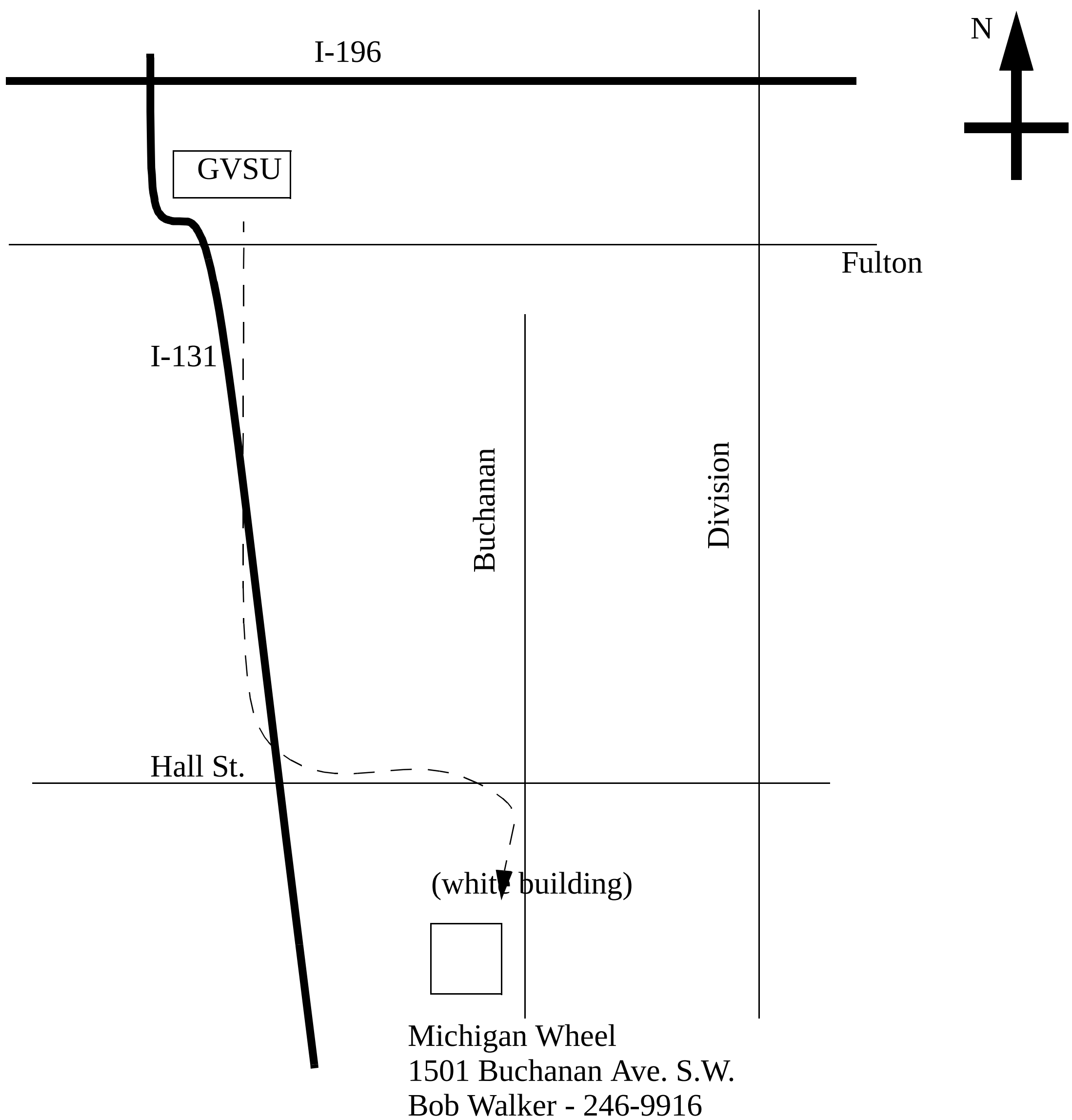
8.7.5 TOUR - MICHIGAN WHEEL (tentative)

Date and Time: Tues., Mar., 2, 1 p.m. -- NOTE EARLY TIME

Highlights: A Variety of Casting Processes

Map:

NOTE: Parking is limited, please share rides.

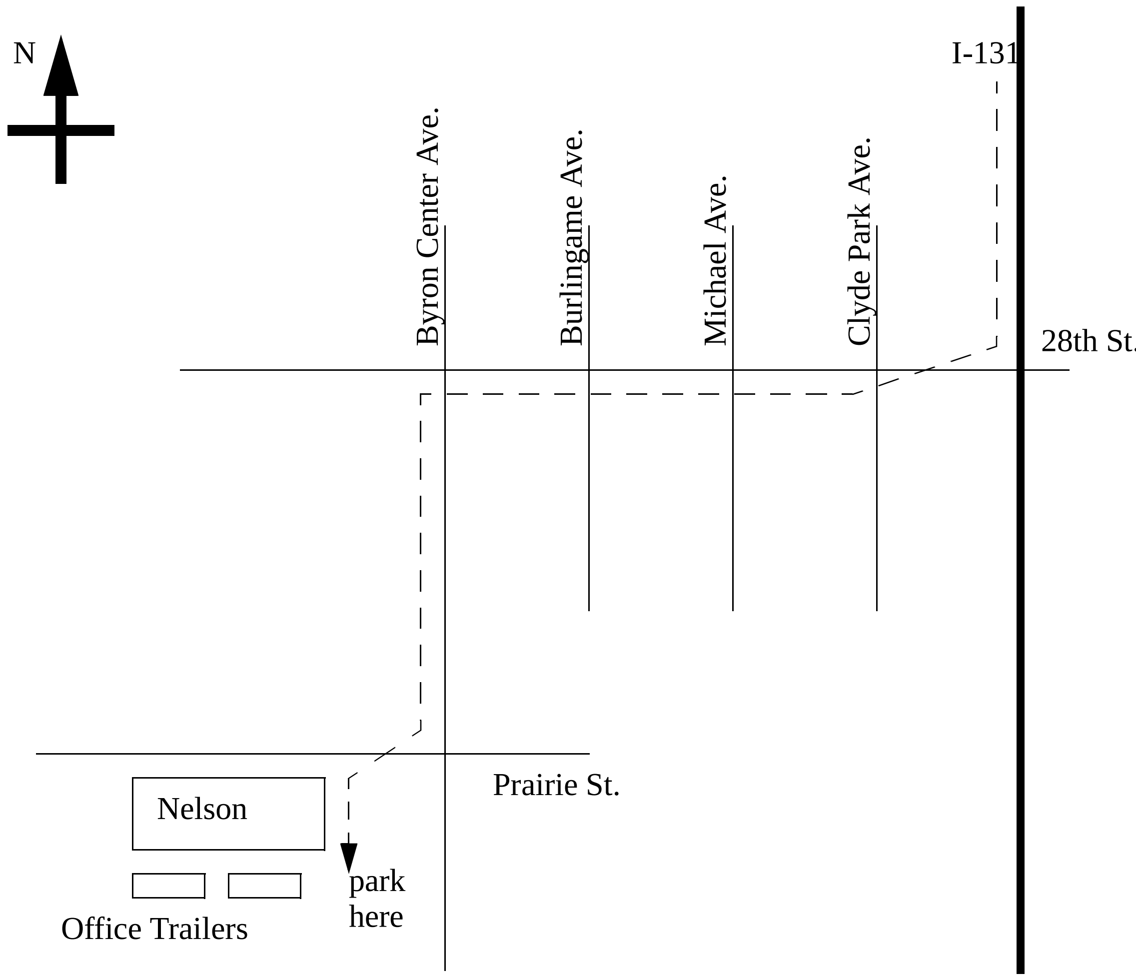


8.7.6 TOUR - NELSON METAL PRODUCTS (tentative)

Date and Time: Tues., Feb., 18, 3pm

Highlights:

Map:

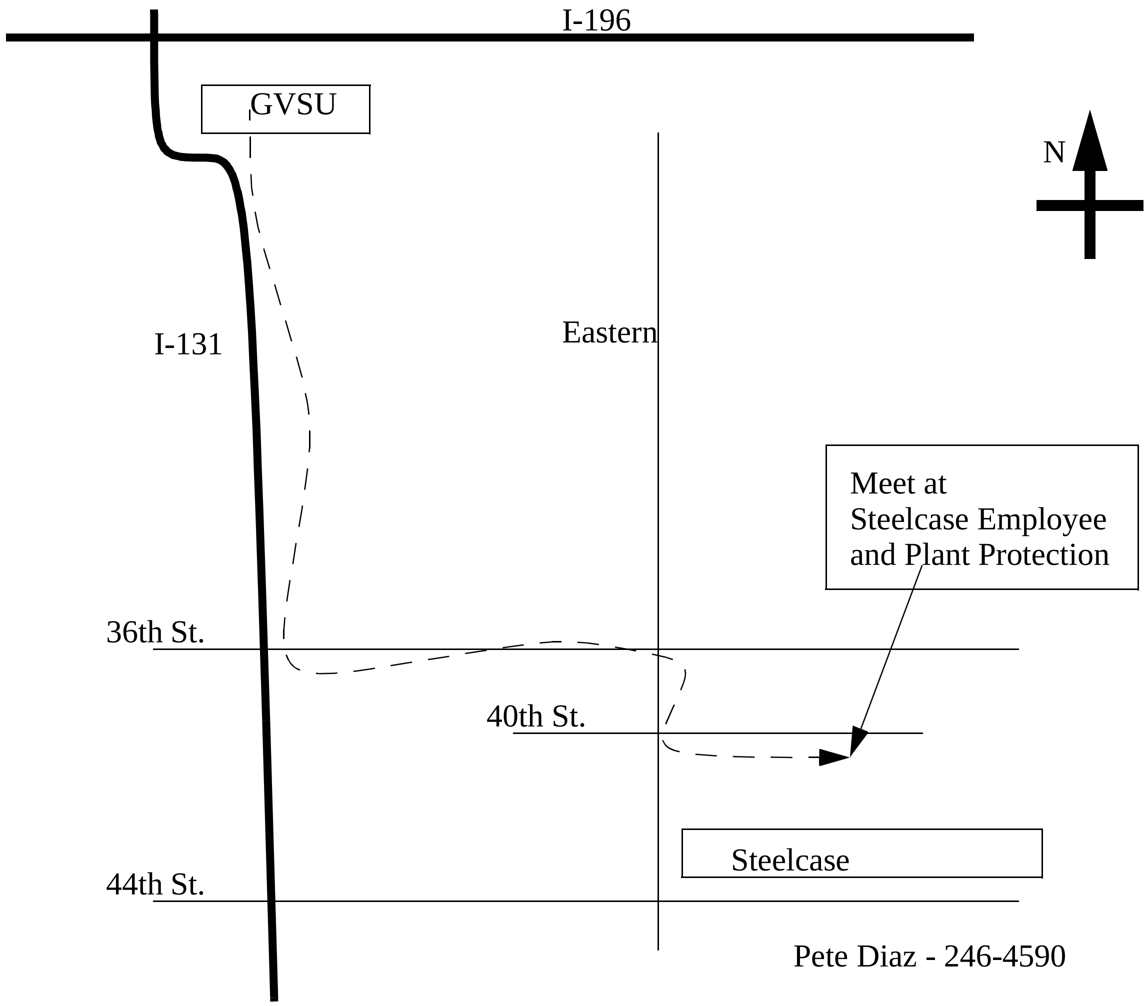


8.7.7 TOUR - STEELCASE (tentative)

Date and Time: Tues., Apr., 1, 2:30 p.m.

Highlights: A world leader in office furniture manufacturing with a wide range of sheet metal and finishing processes. Many sheet metal processes, painting, assembly, packaging, etc.

Map:

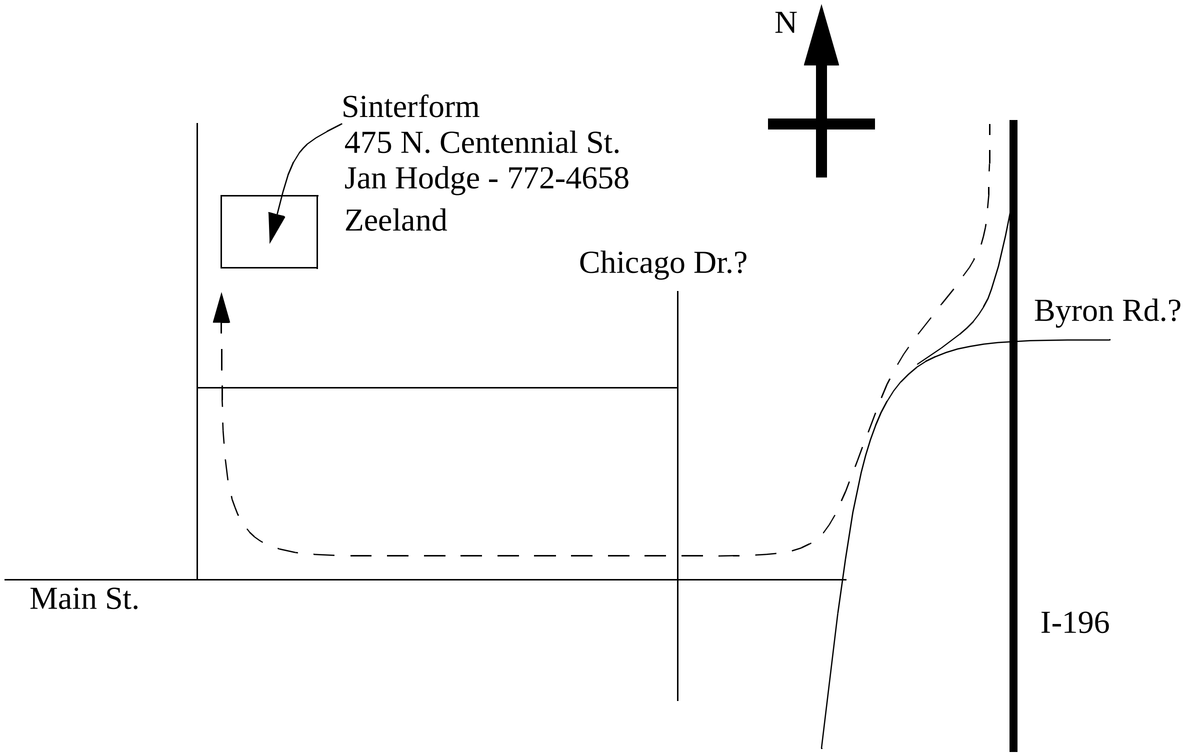


8.7.8 TOUR - SINTERFORM (tentative)

Date and Time: Tues., Apr., 8, 3pm

Highlights: A manufacturer of powder metallurgy parts.

Map:

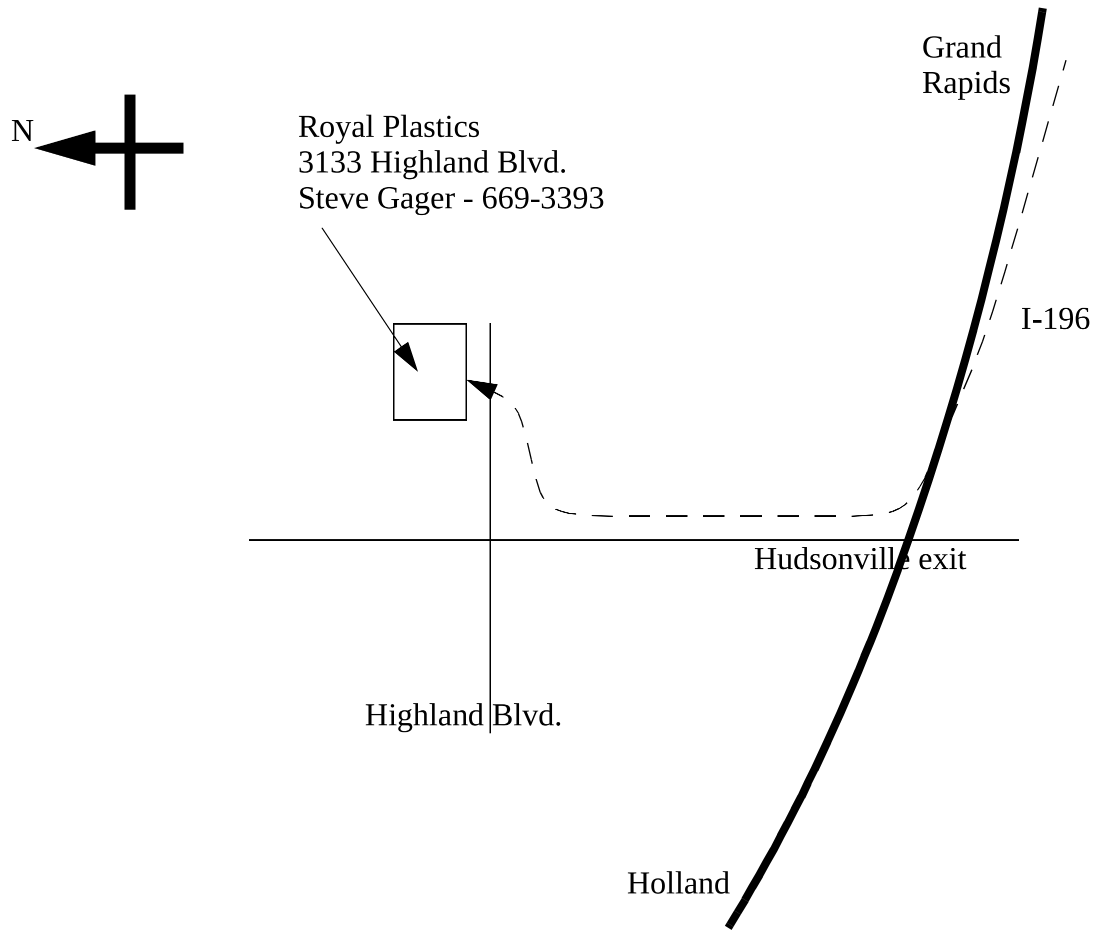


8.7.9 TOUR - ROYAL PLASTICS (tentative)

Date and Time: Tues., Apr., 15, 3 p.m.

Highlights: An industrial scale injection molder. They have numerous machines organized in bays. These allow flexibilty and makes it a very open environment. Other processes include embossing and ultrasonic welding.

Map:



8.7.10 OTHER TOURS (tentative)

• Other Tours are yet to be determined, but may include,
Drawform - sheet drawing
Shape - Rollforming - Dave Riemersma
Blackmer Pump - Casting and machining - Doug Stolz
Brill Cast - Die Casting - Ron Holland
Delphi - machining - Ed Dienno
Cascade Engineering - plastics - engineering
Nicholas Plastics - extrusion, compression molding - Mike Andres

EGR 450 MANUFACTURING CONTROLS

9. INTRODUCTION

9.1 OVERVIEW

• This course addresses a need for a comprehensive examination of modern control techniques found in manufacturing environments. The course will begin with evaluation of PLC's for discrete logic control. The course will then examine PLC usage for more complex control tasks. By the time the course is complete, students will comprehend how these work, and how they can be applied.

9.1.1 Resources

• A large collection of manuals for ALL of the equipment will be stored either in the lab room, KEB 209, or can be found at "www.ab.com". This will include manuals for,
  Micrologix
  PLC/5 processors, I/O card, etc (bulletin 1771)
  RSLogix software

9.2 READING/PROBLEMS

• Will be assigned in class.

9.2.1 Assignments

• Assignments will be given at appropriate times during the term.

9.3 PROJECT

Objective: Students will learn how to synthesize a control system by selecting and building a complete control system from beginning to end.

Method: The basic steps are outlined below,

1. Course begins.
2. Students (individuals or groups) will submit a proposal for a project within the first three weeks.
3. The instructor will review the proposal, and suggest changes as necessary.
4. During the term students will design, build and test their proposed projects.
5. In the last week of classes the final project will be demonstrated and formally presented. Reports are to be posted to the students web page before this presentation.

Notes:

- previous project reports can be seen via the course web pages.
- projects will involve construction and testing, except in unusual cases.
- NOTE: projects must work to receive a passing grade.

9.3.1 Previous Topics

• Brief descriptions of student projects follow.

• Previous topics for this or similar courses were,

Afrik, T., Hedman, M., Howe, M., Jousma, T., Muckey, L., Postema, J., Thelen, J. - ASME Student Design Competition - An entry for the competition will be conceived, designs and built with the intention of entering (and winning) the 2000 ASME Student Design competition.

Agnello - Customer Counter - A counter will be designed to detect the number of visitors to an archery range. This will be done with sensors arranged to count visitors. A system will be used to count visitors during variable periods. A PLC has been proposed, but other options are worth considering.

Andrevska - Fuzzy Logic Controller - A fuzzy logic controller will be designed and implemented using a Basic Stamp II chip. The controller will position a DC motor.

Baksik & Vinch - SoftLogix For Control of Material Handling Via Devicenet - A Devicenet based control system for a material handling system will be designed, purchased and built. The main system will be based around an AB SoftLogix controller.

Beard - Car Alarm - A car alarm will be designed and constructed using basic logic ICs and other circuitry to drive the actuators and sensors.

Bennett, Dunklin, Workman & Williams - Gumball Machine - A gumball will drop into a merry go round, go up an elevator, roll down a spiral track, be lifted in a bucket, bounce off a trampoline, and bounce out to be delivered.

Bernreuter - Water Heater Test System - A control system will be designed for testing water heaters. The focus of this project will be to use the alternate programming methods in the IEC-61131-3 PLC programming standard.

Beute - An Automated Drill - a fully automated drill press will be designed and constructed. Air cylinders and contact switches will be used.

Bouwhuis - Industrial PLC Training Materials - A PLC trainer board will be developed and built. Training materials will also be developed. These will be used by a local manufacturer to train hourly employees in the use and debugging of PLCs.

Brinkman - Audio Amp Cooler - A temperature sensor will be used to detect the temperature of a car audio amplifier. Circuitry will be designed and constructed to drive a cooling fan.

Brinks - Automatic Back Gage Setting - This project will involve the evaluation of a back gage system that exists on a shearing machine. An automatic control system will be selected and implemented to allow users to control the depth setting with a keypad entry.

Brogdan - Automated House - An X-10 modem with modular units will be used to allow a central PC to control devices in a house. A user interface will be designed, along with interface software to control the devices.

Bronkema - Automated House - A unit will be designed and built to allow control of an automated house using an embedded controller. This will monitor external lights, control lights, and allow house status reporting.

Brown, Miersen, Timmer - Basketball Arcade Game - An arcade version of a basketball game will be designed to store balls, and release them for a limited game time. Within the allowed time the user will have to make as many baskets as possible, and the count will be displayed with a status light.

Bultman - Automated Spot Light - A controller for a remote spotlight will be designed and constructed to allow adjustment via remote control, or adjustment via remote control. (Note: as proposed this project is too simple)

Buter - Defect Detection System - A system will be devised to detect a non-critical screw on an automotive floor console. If a missing screw is detected, an operator console will warn an operator to take corrective actions.

Burgess, S., DeBoer, M. - PLC Control of a Welding Station - A PLC will be integrated and programmed to control all aspects of a welding station. Issues to be considered include cycle times, safety, and manual/automatic modes.

Campeau - Hanging Tab Machine - A PLC with appropriate sensors and actuators will be used to add hanging tags to medical pouches. A machine for adding the pouches had been purchased and will be used to add the tags.

Chan, Sedine - Automated Bartender - A PLC will be used to prepare mixed drinks. The user will be able to select the proportions or drink type and the final product will be delivered.

Conner - Controls for a Stretching and Stapling Machine - The controls for a material stretching and stapling machine will be designed and implemented using a Micrologix 1500 and RS-Logix software.

Cowan - PLC Retrofit of Taping Machine - A PLC will be selected to replace an existing controller on a machine that creates a tape of screws. This will also require some redesign of the machine.

Cummings - Automatic Fishing Pole - An ice fishing pole will be fitted with control system that will watch to see when a fish has hit. When the fish has been detected the line will be slowly reeled in.

Curtis - Expansion Unit for Automatic Sprinkler Controller - A system will be designed that will ‘piggy back’ onto an existing sprinkler system. This will use the last set state to then switch on a supplemental state for the additional zones.

Davis - Screw Machine Control - A set of limit gages will be designed for a screw machine. The gages will test completed parts, and allow out of tolerance parts to be diverted. Visual basic and a PLC will be used for control.

Dejong & McKervey - A Really Fancy Pencil Dispenser - A pencil dispenser with a few Rube Goldberg twists.

DeVos, R., Karlesky, M., Kuieck, B. - A Ground Breaking Robot - A hydraulically controlled robot will be designed and built for the ground breaking for the Keller Engineering Building. The robot will be controlled by a VR glove to allow a dignitary to guide the robot to break ground.

DeVries - Train Set Controller - An automatic train set controller will be designed so that a train set will run automatically, including switch track, lights, etc.

Dodge, Eddy, Oostdyk, Spikes - Art for New Building - This project will use equipment that is already owned by the school to develop an artistic display for the Keller Engineering building.

Dood, Fleischman, Sanford, Kozikoski - “Sip-and-Puff” Fishing System - An entry will be designed and built for the 2001 ASME design competition.

Duncan, Nicola, Vergas, “PLC Control of an AGV”, The chassis of an Automated Guided Vehicle has been constructed in the past. It has since been superseded by another vehicle. But, with the addition of some mechanical and electrical components, this AGV was restored to working order.

Emery - Stereo Amplifier Overheat Control - A basic controller will be used to monitor the temperature of a car audio amplifier. When the amplifier temperature rises too much the amplifier will be shut off, or the power output decreased. A PLC may be too expensive for this application.

Endres - FMEA for Chlorine Scrubber Control - A control system was previously constructed that will scrub chlorine gas in the event of a leak. There are numerous sensors and actuators to be considered.

Evans, W., VanEss, J. - Material Handling System Project - Various components for a mini manufacturing system will be designed and constructed. These functions will probably include a wood metering and cutting station, and a marble feeding station. This will complement the activities of the students in EGR 474.

Farley, T., Groeneweg, L. - Slot Car Lap Counter - A lap counter/timer will be constructed for a 1/64th scale car race track. The counter will use optical sensors to determine lap times and counter, and the results will be displayed on large LED displays.

Feenstra - Electric/Pneumatic Fire Cycle -

Fett - Shifter Test Apparatus - A Labview controlled test machine will be developed that will cycle an automotive shifter. Labview will be used to make some adaptations to the test strategy and analyze the results. Final data values will be output to database files.

Frei, Meneses - Injector Control System - The system will inflate an artificial lung through a process that involves partial inflation, with pauses. A variable posisiton valve will be used to change the flowrate as the lung fills. The system will be PLC based. More details are required soon.

Gehrke - Paint Line Model - A small model of a dip paint line with an overhead conveyor. There will be three stops on the line.

Glass & Werdon - Corner Cutter - A device will be designed that automatically rounds the corners on lexan keytags.

Goosen, Hills - Carnival Game Controller - A system will be devised to watch targets that have been set up. When balls are thrown the targets will be knocked down. A score display will be used, and a winner siren will be enabled. A PLC may be too expensive an option for this project.

Hansen - Servo Driven Bumper Cutoff - An existing system uses hydraulics to cut automobile bumpers. This system will be retrofit with a servo drive cutter so that the cutting blade stroke can be adjusted as the cutting blade wears. The operator will be able to control the blade stroke using an HMI.

Hart, J., Kern, E., Maas, C. - Automatic Hose Cutter - A machine will be design and built to allow hoses to be fed variable lengths and cut automatically. A keypad will be used to set the length, and a blade will be used to cut the hose.

Hitchcock - A Table Height Cycling Test Stand - A control system will be developed and built that can cycle table height adjusters for a fixed number of cycles. The system may drive either pneumatic cylinders or motors to drive the tables. A proximity sensor will be used to mark the end of the travel. Adjustments will be included to allow the height settings to be changed without reprogramming the PLC.

Hornacek & Tietz - RC Car Controlled by 68HC11 and Sensors

Hubbard - Fermentation Control System - A control system will be devised that will observe the density in a primary fermenter using a hydrometer. When the density drops below a set point the secondary fermentation vessel will be cleansed with a bleach solution, rinsed, and then the wort in the primary will be pumped across. Floats will be used for fluid levels. A micro PLC will be used for control.

Hultman - Drag Racing Timer System - A drag racing timer system will be designed with the ‘christmas tree’ and a digital display to indicate time and speed. The system will involve the design an construction of required circuitry and software development. The system will be based on a 68HC11 microcontroller.

Ivanov - PLC Demonstration Unit - A SLC-500 demonstration board will be designed and constructed. The board will include analog inputs, and motor.

Jamison - Animatronics - Anthropomorphic robotics will be designed and built. Through control they will exhibit lifelike features. This project may be too ambitious.

Johnson - PLC control of weld data quality - A system will be designed to watch signals coming from a welding station. These signals will indicate when a weld is good or bad. The PLC will use experimental parameters to determine the weld quality. An external display will be used to display information about weld quality.

Johnson - Satellite Dish Positioning System - A model of a satellite dish will be constructed. A motor will be controlled to reposition the dish via a user interface.

Kaye - Drag Racing Christmas Tree - A simulator unit for drag racing start lights will be constructed to allow drivers to improve reaction start of a run. A mini PLC will serve as the heart of this system, and will vary the light times in accordance with the national regulations.

Klein, J. - Temperature Control Unit - A unit will be designed an built to monitor temperature and switch a fan on/off when upper/lower temperature limits are reached.

The unit will be based on basic discrete electronics.

Klynstra - Crash Test Calibration and Control - A hydraulically driven crash test unit will use a Labtech program to calibrate and control the unit to ensure a precise impact velocity.

Knibbe, R. - Home Timing Unit - A clock module will be purchased and used as the core of system that will turn on room lights, fan, etc. External circuitry will be designed and built to allow the user to turn on the light independant of the clock.

Koperski, C., Powell, M., Schutter, N. - Skee Ball Machine - A machine will be designed for Skee Ball. When balls are rolled they will fall into one of four holes. While the game is active balls will be returned. Points will be totaled and displayed with an LED display. A light and siren will be turned on for a winning score.

Kunzi, B., Thomas, J. - Parts feeder for the EGR474 material handling system.

Lamfers, A. - A PLC Based Home Security System - An Allen Bradley SLC-1504 will be used for a home security system. This will include sensors on various doors and windows, and a light and alarm that will be triggered when there is an intrusion. The alarm will have arm/disarm functions and zone control.

Langendoen, Vermaire - Golf Game - A golf game will be designed that will allow balls to hit into cups. Scores will be tabulated and output on an LED display. A switch setting will allow the user to select various game option.

Langston, S. - Programming Package for Ladder Logic Simulation - A package will be written in C to simulate ladder logic. The program could be entered in a number of forms, and it will allow the user to change inputs and observe cthe results.

Lewis, Miller - Baseball Scoring System - A system will be designed and built that will automatically detect balls and strikes. The system will score the game and display the results on a display.

Likic - Automated Model Home - A model home will be built and controlled with a PLC. One major feature will be a security system that uses various sensors.

Ljubic, Ngui, “Control of a Rhino Robot with an Allen-Bradley PLC-5”, A rhino robot was in working condition, but lacked controls. Control via a PLC and a new keypad was added to allow direct control, and program execution of movements.

Lubbers, J., Scholten, J. - Container Changer for Production Equipment - An automated tote changer will be added to a production machine (makes elbows?). This will use pneumatics to drive a new mechanism to load and unload totes from the machine.

Magee, M. - Constant Volume Reheat System - A small model with 3 rooms will be controlled for temperature, pressure and humidity. The system will use heating elements, and various control elements to adapt system behaviour to compensate for different room settings and seasonal variations.

McInally, Wood - Automatic Camera Platform - A camera positioning system will be designed and built. This system will use a Basic Stamp chip to interface to a PC computer through a serial port.

McMullan, A., Mose, D. - Sprinter Timer - A timing system will be designed and built. The basic function will be to be tripped at the start line for a sprint, and stopped at the end of the distance. The elapsed time will be displayed on an LED readout.

Mead - Use of PLC to Control Indexing Table - An existing indexing table uses hard wired controls. A PLC will be used to control the table, and allow the user to program parameters.

Miller - Starship - An actuated model of the starship Voyager.

Moelker, N. - Travelling Sprinkler Stop -A system will be designed, built and installed to monitor a moving sprinkler. When it passes a certain distance a sensor will detect this limit and close a valve on the water main. This system should include appropriate start/stop/reset buttons, along with an optical sensor to determine when the sprinkler has reached the end of travel.

Mollema & Welch - Voice Controlled Robot - A microcontroller with a voice recognition IC will be used to control a mobile robot.

Moore - Electric Wheelchair - An existing wheelchair will be refurbished and tested. Additional work will be done to add a pressure switch to ensure a rider is in the chair, and a battery low indicator.

Morgan, Uken - Drag Tank Retrofit - A drag controller will be designed and built for the drag tank in EC713. This unit will allow a target speed to be specified, and also read the actual drag speed.

Morrell - Vision Directed Control of a Robot - A DVT vision system will be configured and setup to control a Fanuc RJ-2 robot. The vision system will compare scenes to determine part offset. Offset and orientation vectors will be sent to the robot via an RS-232. The robot will then adapt to the location and orientation of the part. This will be a prototype system, so statistical tests of performance will be done.

Munster - Vision Control System - A proof of concept system will be developed around a vision system. The vision system will locate an object in a field of view. The location will be sent over a serial cable to direct an x-y positioning axis. An HMI will be added to allow limited user interaction, and simple reporting.

Muthucumarasamy, Porter, “PLC Programming for a Material Handling System”, A system was donated to Ryerson. The system was previously assembled, and basic programing of the PLC was done. This project completed the programming.

Nahin - Design and Construction of NC - This multi part project will begin with the design of mechanical and control system for a small NC lathe. In future course projects this will be outfitted with a control computer.

Nink & Seco - An External Keypad Based Car Door Lock - A Car door locking/unlocking system will be designed and built around an Altera based controller. This system will have a keypad mounted outside the car with a keycode to lock and unlock the driver door. When an incorrect code is entered a horn and lights will be activated.

Olthof - Train Set Controller - An automated train set controller will be designed and built. This will allow switching of tracks, coordination of lights, power switching to tracks, etc. The type of controller must be determined.

Palmbos, E. - Retrofit of House Electrical Control System - The current house uses 24Vdc to drive relays at the lights to switch 115Vac. The relays are starting to fail, and a redesign is needed. Replacement relays will be found and a rectified voltage will be used to control them.

Peterson - Bedroom Security System - An alarm system for a single room will be developed to monitor motion. Knocks will be required before entry is permitted. The system will be controlled with a Mitsubishi PLC.

Phoa, “A PLC controlled Box Orientation Device”, The existing system was put in working order, and the PLC was programmed to ensure complete functionality of the device.

Remelts - Automatic Guitar Tuner

Rollenhagen - Home Security System - A home security system based on the Basic Stamp chip will monitor various inputs. In the event of an alarm, it will turn on a siren for a set time and then reset.

Rutgers - Automatic Guitar Tuner

Schmitt - Remote Control of Car With PC

Schulz - Design of a PWM Motor Controller - A high current pulse width modulated (PWM) motor controller will be designed, built and tested. This will be used in the future by the electric race team.

Scott - Hatchback Unlatch Mechanism - A hatchback controller for a small car will be designed so that it will latch/unlatch automatically. A remote control will also be considered.

Seaver - Thermoforming Process Controller - An existing thermoforming machine will be retrofit with a system to load and unload a blank from the oven with variable cycle times.

Serebryakov - Speaker Directivity Index Measurement - A turntable arrangement will be developed to support hardware and software for measuring speaker loudness at various angles. This apparatus will use a PLC to position the table as requested.

Sham, Sutander, “PLC Control of an Automated House”, A house was developed with a number of automated systems. These allowed windows, doors etc to be opened/ closed to meet changing environmental conditions. The system will also include other useful features such as a burglar alarm.

Sietsema - Car Alarm - A car alarm will be designed and constructed.

Silcox - Cat Feeder - An automate cat feeder will dispense food at regular intervals as controlled by an electromechanical timer. A sensor will stop the feeding cycle if food remains in the dish. Another sensors will be used to indicate when the food hopper is empty.

Singhal, M. - Computer Controlled Model Railroad- A three part system will be design and implemented. There will be a Visual Basic program at the front end that will allow the user to specify actions and monitor status. An RS232 connection to a Basic Stamp chip will communicate commands, and the Basic stamp chip will control the train set. Functions will include train speed, switch tracks, etc.

Smith, Tang, “Traffic Light Control for Optimal Flow”, Multiple sets of traffic lights were constructed, and controlled via a PLC. The Control programs in the PLC were such that the traffic lights adapt to nonuniform traffic flow.

Springer, T. - Table Lifting Machine - Controls for a machine will be designed and implemented to clamp and raise a work surface. There will actually be two independant work surfaces.

Turner - PLC Control of Waterjet Machine - A waterjet machine controlled by PLC will be reprogrammed. The goal will be to allow cutting of one or more parts in foam.

Tuttle - PLC - A 6811 will be used to implement a simple PLC

Ulbikas, Chetcuti, “Upgrade of PLC controlled robot”, An existing robot that is connected to a PLC was put back in working order, and a keypad was added for direct, and programmed control of the robot.

Vanderkolk - LabVIEW Interface To Dynamometer - LabVIEW will be interfaced to a cutting force dynamometer. The cutting forces will be displayed for easy reading, and graphs of values may be written to files.

Wan, Lim, “Automated Car Wash”, A carwash model was built, and outfitted with sensors and actuators. A PLC was used to control various function such as a security keypad, driers, belt, wax, etc.

Wiersma, Stehouwer - Keytag Corner Rounder - Retrofitting for a keytag rounder will be completed so that it is fully automated. This will include a chute for incoming parts, an automate clamping mechanism, etc.

Wong, Kan, “Design and Control of a Conveyor Offloading Robot”, A robot was designed, built and controlled by a PLC for sweeping objects off a conveyor belt.

Woodard - Flooding Alarm - An alarm will be developed to detect flooding in a house in the event of power failure. This device will need to detect when the house power is off, and when water is present.

9.3.2 Possible Topics

• Some projects I want done are (in priority),

1. a device for the ASME student design competition (juniors only)
2. complete the retrofit of the drag tank in EC713 with Labview
3. build devices for the GVSU workcell or automation labs
4. develop a fuzzy logic controller with the 68HC11
4. write software for petri net based programming
4. write software for programming a PLC

• Other topic sources include (in priority),

1. do a project for a local company or somebody in GVSU
2. select a project based on personal interest

9.3.3 Final Project Requirements

• The final requirements for the projects are list below. Unless you have been specifically and deliberately told to otherwise, use these as requirements.

1. A demonstration of your working project.
   - This will be on the same day as the senior project presentations.
   - Some students may use videos of their projects by prior arrangements with the instructor.
   - The projects are to be set up in EC 713. Other spaces are available on request.
   - Those requiring air supplies, or 220Vac will be in EC713 only. If you have these need, speak to Bob beforehand to make sure you will have them.
   - Have the demonstrations set up BEFORE 11am. They can be taken down after the Ring ceremony.
   - Have the demonstrations taken down, and all parts returned by Monday.

You are expected to be at your display between 2pm and 3:30pm.

2. You will need to present a poster for your project.
   - This will be similar to the poster for your senior project. See an example in the EC718 conference room if necessary. These should be neatly done. I suggest that you use “foam core” board that will support itself.
   - Use a table available in one of the class rooms.
3. A report that is posted to the web.
   - For teams, the report can be posted to one homepage, and links added by other students on the team.
   - A project without a report will not be accepted.
   - The report should be posted before the demonstration.
   - The report should contain technical details. Keep in mind that when you are gone another student may want to use your report. The more questions they need to ask, the lower your grade.
   - Add digital photographs, schematics, etc. to illustrate what you have done.
   - Examples of previous reports can be found at,
     - http://claymore.engineer.gvsu.edu/~vincha/index.html/page2.html
     - http://claymore.engineer.gvsu.edu/~morrells/egr450.html
     - http://claymore.engineer.gvsu.edu/~kerne/450/EGR450Web.html
     - http://claymore.engineer.gvsu.edu/~devosr/450project

9.3.4 Proposed Topics Summer 2001

Name(s): T. Adams
Title: Wheelchair Pressure Measurement
Description: A system will be designed and built to measure the pressure on a wheelchair seat pad over time, and log these values to a file. The data will be used to design a system that will apply and release pressure.
Deliverable(s): A working system, a web based report on the system, an engineering report that describes the device and draws conclussions from the data for the company.

Name(s): B. Bialk
Title: Control of Conveyor
Description: A conveyor system that was designed and build for EGR 409/367 will have controls added so that it may be controlled from a PLC. This will include the use of a diverter that may be used to sort packages based on size.
Deliverable(s): A working system, and a web based report.

Name(s): R. Clark, S. Dohm, A. Dyer, S. Steinke, R. Valenzuela
Title: ASME Design Competition
Description: An entry will be developed for the ASME 2002 Student Design Competition. This will be developed within the given rules, and be working at the completion of the course
Deliverable(s): A working project entry and a web based report.

Name(s): T. DeJonge
Title: Control of a Heat Stake Machine
Description: Controls for a heat stake machine will be designed and built for a local company. This will involve the design of all electrical components, working with trades to get electrical and mechanical ork done, and final programming of the machine.
Deliverable(s): A working machine, a web based report, and engineering documentation and a user manual for the company.

Name(s): M. Eissa
Title: PLC Control of Assembly Fixture
Description: An assembly fixture that will be used by a local company to assemble machine that will uses a number of slides, pins and other actuators to assemble a panel. This project will involve the design and construction/implementation of all wiring and programming.
Deliverable(s): A working fixture, engineering and maintenance documentation and a web based report.

Name(s): R. Gallatin, M. Jousma, B. Karabelski
Title: A Small Work Cell
Description: Equipment that was originally developed in EGR 409/367 will be refit and used to construct a small workcell. The task of the cell will be to handle cans and drill holes in them.
Deliverable(s): A working cell and a web based report.

Name(s): J. Grimshaw, P. Hupcik

Title: Upgrade of The Keytag Maker
Description: The keytag maker will be updated including refitting it with new sensors to detect the holes in the plastic strip, replacing the current servo control system with an Ultra 100 unit. The project will also consider the feasibility of changes to the keytag rounder.
Deliverable(s): An updated keytag maker and a web based report.

Name(s): M. Gutierez, C. Williams
Title: Redesign and Control of Sketching Device
Description: An existing device for doing simple sketches will be redesigned mechanically and electrically so that it may be controlled with a PLC. The final unit will use optical sensors so that it may be operated behind a window.
Deliverable(s): A working unit and a web based report.

Name(s): T. Mathews
Title: Retrofit of a Dumpster Testing Station
Description: An existing system is used by a local manufacturers to test dumpsters by filling them with a load, and then dumping the contents out repeatedly. The machine needs to be updated to meet new test standards. This will involve redesign of some of the mechanical and electrical systems. The program in the PLC will be updated to reflect the changes to the system.
Deliverable(s): A working machine, a web based report, engineering documentation and a users manual.

Name(s): M. Maschewske
Title: Extrussion Monitoring Station
Description: A system will be designed and build for a company to monitor an extrusion station. This will monitor process variables (how?) and then display messages on a scrolling LED screen. The project will involve the design, partial wiring and programming of the system.
Deliverable(s): A working system, a web based report, engineering docuentation and a users manual.

Name(s): J. McJones
Title: Control of Automatic Tool Changer
Description: A CNC machine tool has been fitted with an open architecture controller. This controller does not control the automatic tool changer. To get this functionality a PLC will be added to the system to control the tool changer. This will involve control of the magazine, and loading arm. The PLC will communicate with the CNC controller (via RS232?) to determine when a tool is to be changed.
Deliverable(s): A working tool changer, a web based report, a maintenance document and an engineering design report.

Name(s): D. Vidinlic
Title: Upgrade of Assembly Station
Description: An assembly station will be upgraded for a local company to include two new sensors, a manual switch and an updated program to ????.
Deliverable(s): A working syste, a web based report, engineering documentation and users manuals.

9.4 AVAILABLE EQUIPMENT

• The following are cards for the Allen Bradley PLC racks

1	1747-L30A A SLC500
3	1747-L40A B SLC500
	1771 External Power Supply
1	1771-AA 4 Slot I/O Chasis
6	1771-A2B 8 Slot I/O Chassis
8	1771-IB (12-24V) DC Input Module
4	1771-IBD (10-30V)DC Input Module
	1771-IBN (10-30V)DC High True Input Module
2	1771-IFE Analog Input Module (12 bit)
1	1771-IG TTL Input Module (+5V)
2	1771-IJC Encoder/Counter Module 5V I/O
1	1771-IKC Encoder/Counter Module 12-24V I/O
1	1771-IT (12-24V) Fast Response DC Input Module
8	1771-IV (12-24V)DC Driver Logic Input Module
1	1771-IXE Thermocouple/millivolt input module
	1771-KA2 Communication Adapter Module
	1771-KA3 DH+ PLC-2 Interface
	1771-KF Data Highway/RS-232C Interface Module
3	1771-M1 Stepper Motor Controller Module
	1771-OA (120V)AC Output Module Series B
15	1771-OB (12-24V) DC Output module - Series B
	1771-OBD (10-60V)DC Output Module
	1771-OBN (10-30V)DC High True Output Module
1	1771-OFC Analog Output (12 bit) Series B
	1771-OFE1 Analog Output Module (12 bit voltage)
2	1771-OFE2B Analog Output Module
2	1771-OGC TTL Output Module (+5V)
2	1771-OGD TTL Output Module
3	1771-OJ Pulse Output Expander Module
2	1771-OW Selectable Contact Output Module
34	1771-WA Small Screw Terminal
1	1771-WD Medium Screw Terminal
22	1771-WH Large Screw Terminal
	1784-KTK1 Peer Communication Link Interface Module

1784-KTP Processor Communication Interface
1785-KA Communication Adapter Module
1 1785-L11B/C PLC5/11 processor
4 1785-L11B/E PLC5/11 processor ver. E01
4 1785-LTB PLC5/15 processor ver. B

9.5 LABORATORY EXPERIMENT GUIDELINES

General Objective of Laboratories:

The laboratory experiments will allow the student to apply the theoretical techniques learned during this and previous controls courses. While implementing the theoretical controls techniques, the students will also learn the practical aspects of modern controls technologies. The first labs will introduce the student to Programmable Logic Controllers. The final labs will focus on advanced applications and control of a small scale industrial process.

• Notes:
1. Prelabs are essential, and must be done before every lab session when required.
2. Prelabs require that some assumptions be made.
3. The lab period should be used for debugging prelab work.
4. Labs are to be handed in before leaving.
5. Prelabs for individual labs are to be done individually. Prelabs for group labs are to be done in groups.

• The projects sheets that are in the lab notes are to be filled out as follows,

PLC Project sheet - identifies the project, packet contents and contact person.

Project Notes:

System Description - a succinct paragraph stating how the system will behave

I/O Notes - description of all inputs and oututs.

Design Notes - A detailed description f the control system. This description must be in the form of a state diagram, flow cart, sequential function chart, Boolean equations or ruth table.

Application Notes - For our use this page will usually contain a test plan. A test plan lists the test cases needed to verify correct operation of the system. Each test case consists of a set of inputs and the corresponding outputs. A complete test plan ensures proper operation of the system in all states.

Input/Output Card - Detailed plan for attaching the inputs and outputs to the PLC.

Program Listing - A list of ladder logic to implement the system.

• NOTE: IN ORDER TO COMPLETE LABS IN THE TIME ALLOTED THE PRELAB WORK MUST BE COMPLETED BEFORE ATTEMPTING THE LAB EXERCISE

Course Number:	EGR 450
Course Name:	Manufacturing Control Systems
Academic Unit:	Padnos School of Engineering
Semester:	Summer 2001

Class Times:	12-2 pm - Mon, Wed, Thurs, first half of semester
Lab Times:	Sec. 1, Fri., 12-3pm (Prof. Blauch) Sec. 2, Fri., 8-11am (Prof. Blauch) Sec. 3, Wed., 3-6pm (Prof. Jack)

Instructor:

Dr. Hugh Jack

office:	EC 716
office hours:	2-3pm - Mon, Thurs
phone:	(616) 771-6755
fax:	(616) 771-6642
email:	jackh@gvsu.edu
web:	http://claymore.engineer.gvsu.edu

Description:	An introduction to the control of machines and processes widely used in manufacturing. Topics include programmable logic controllers, actuators and sensor for discrete and continuous systems, structured design techniques, memory structures, data handling functions, A/D and D/A converters, data communications, and hierarchical control. The technical issues involved in implementing control schemes are presented. (3-0-3). Four credits. Offered spring-summer semester.
Prerequisites:	EGR 214
Textbooks:	Jack, H. Automated Manufacturing Systems; PLCs, 2001.
Software:	Netscape Communicator PLC programming software FTP/Telnet
Objective:	When done the student should be able to design and implement control systems for typical industrial problems.

Instruction Methods: Lectures, labs, projects and discussions.

Tentative Schedule:

Week	Topic
1	PLC Introduction PLC Logic and Connection Sensors and Actuators
2	Combinatorial Logic
3	Sequential Logic
4	Advanced Data Functions
5	Analog I/O and controls
6	Data Communications Design Issues

Tentative Laboratory Projects:

1. Introduction to micro PLCs

2. Basic ladder logic design and PLC interfacing - combinatorial press control
3. Intermediate ladder logic design and PLC interfacing - encoder controlled motor
4. Advanced ladder logic design and PLC interfacing - sequential traffic lights
5. Introduction to PLC-5s
6. Analog I/O and PID Control
7. PLC Networking and Serial Communications - with DH+ and RS-232C
8. Control of a multistation keytag maker
9. Control of a multistation keytag maker (cont'd)
10. Introduction to embedded controllers
11. Programming embedded controllers

Grading:

Laboratories	25%
Project	40%
Tests and Assignments	35%

Tests will be given at natural points during the term as new material is covered. A major final project, involving design, construction and testing, will be proposed early in the term, and be completed later in the term. Marks will be some combination of performance and report. A final examination will be given to conclude the work and test the students global comprehension of the material.

Grading Scale:

A	100 - 90
A-	89-80
B+	79-77
B	76-73
B-	72-70
C+	69-67
C	66-63
C-	62-60
D+	59-57
D	56-50

9.6 FUNDAMENTAL PLC LABORATORIES

• The fundamental laboratories are designed to cover basic understanding of the technology aspects, and some basic theory of practical control systems. Some of the laboratories will be conducted before the material has been covered in class. When this is the case, all efforts will be made to ensure that the level of knowledge is sufficient.

9.6.1 Lab 1 - Introduction to Micrologix Controllers

Objective:
To learn the basic operation of low costAllen-Bradley programmable logic controllers.

Pre-Lab: None.

Resources: Micrologix 1000 Hardware and RSLogix 500 Software manuals (www.ab.com)

Equipment:
Micrologix in travel cases
RSLogix 500 software
PC computer with windows/dos

Procedure:
1. Follow the Micrologix tutorial later in the notes.

Marking:
1. A pass grade will be assigned to students that complete the tutorial and print out the final program in the tutorial.

9.6.2 Lab 2 - Introduction to Programmable Logic Controllers

Objective: To first make all required electrical connections, then program an Allen Bradley Micrologix PLC, and design ladder logic programs.

Pre-Lab: (NOTE: These, and all other Pre-labs will be checked before every lab. A mark of zero will be assigned when prelab materials have not been completed before the start of the laboratory)
1. Review the tutorial for the micrologix controller done the previous week. The manuals and PLCs will be left in a convenient location.
2. Develop a simple flowchart for the process description below.
3. Develop ladder logic for the process below, and develop a set of test inputs to verify the

operation. The ladder logic can be developed before the laboratory and brought in on disk. All ladder logic must be commented.

4. Select a process and develop a description of an interesting control function (use boolean equations, flowcharts, or some other structured design technique). After this you may write your own individual ladder logic program for the PLC. The most creative programs will receive top marks. Develop a table of test values to verify operation.

Process Description:

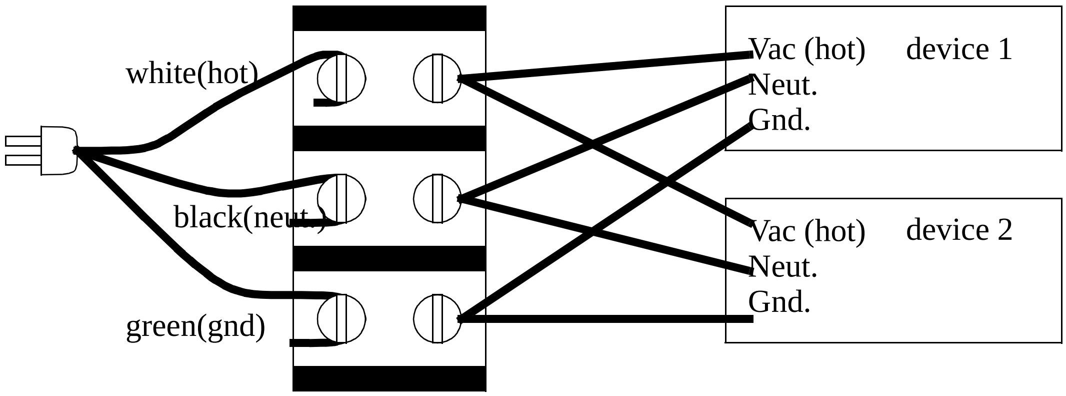
There are four sensors on a large stamping press. One of the sensors (I/2) is on when a blank is present and ready for stamping. A second sensor is off when there are hands inside the press (I/3). A third sensor (I/4) is a start push-button. It is on momentarily when the press is to go into an active state (O/1). The fourth push-button (I/5) is a stop button, and all should stop when it is pushed.

There are also two outputs available. One output (a status light) is the press-on (O/0). It is active after the start button is pushed, this can be shut off if the stop button is pushed. The press will begin stamping cycles if the press-on output (O/1) is active. This will occur when the press-on output is active, and a part is present, and there are not hands inside.

Electrical Description:

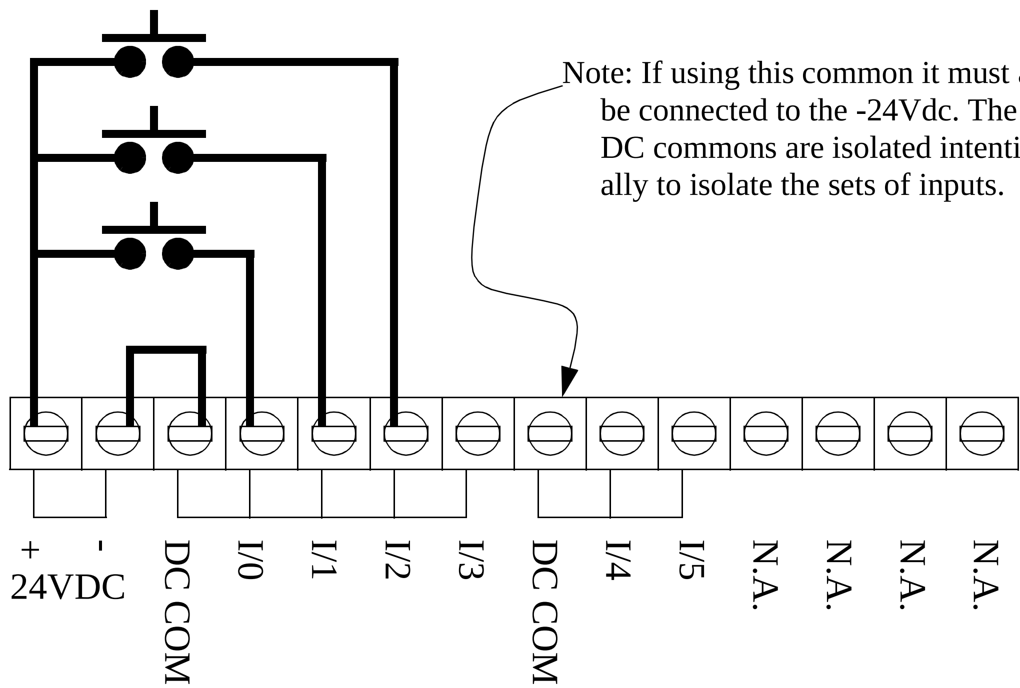
This lab will involve wiring 115Vac from the wall supply. When doing this we will use loose electrical cords and connect them to the PLCs. Some special items must be noted.

1. DO NOT PLUG IN THE SYSTEM UNTIL all wires have been connected and checked.
2. Make sure the ground is connected to all devices.These are typically color coded as green, or have a ground symbol. Note: power should not flow through the ground, it is only for emergencies to draw current out of the cases of electrical equipment, and into the ground beneath the building.
3. Normally the AC has 2 wires (for a single phase). For consumer applications we need to make sure the polarity is correct, so that the ‘hot’ wire is switched off, making electrical shocks less likely. Note: in reality, even if these wires are backwards the power will still be delivered.
4. After connecting the power to the devices, it is a good idea to plug them in and check operation before proceeding to connecting other devices.
5. Try not to daisychain power connections (like a string of christmas lights), but connect the power cord to a terminal strip, and then connect to each device to the terminal strip. (see the figure)
6. Do not leave loose, or exposed wires. These will only lead to short circuits, electric shocks, or other problems. Tighten the wires. If doing this for permanent jobs, the wire should also wrap around the screw.



Inputs and outputs also require a few notes:

1. A PLC never has an internal power supply for inputs or outputs. You must always connect an external power supply for inputs or outputs. Note that the Micrologix does have a small 24Vdc power supply, but it is not connected to any of the inputs or outputs, and it will not drive a large load.
2. The ground and common are terms that are badly confused. A true ground is an electrical connection to the ground beneath a building that will draw away current if there is an electrical fault. A common is a reference voltage for all parts of a circuit, typically 0V. When connecting devices such as sensors and actuators we want to connect them to a common. This problem is normally overlooked, but when we have systems with mixed power sources (eg. 115Vac, low voltage DC) we must separate these. DO NOT CONNECT the common to the ground. BE WARNED, many low voltage devices (such as power supplies, sensors, etc.) show the common as a ground.
3. Remember for relay outputs there is no common, the output is just a switch.



Equipment:

PC with micrologix programming software
PLC trainer boards
Wires, wire cutters and wire strippers
Screwdrivers

Procedure:

1. Make all necessary connections, and start the software and PLC.
2. As a group, enter and test a ladder logic program as developed in step 3. of the pre-lab. The program will be checked by monitoring on-line, and by completing the test table. The professor must check that the program is operational and assign a grade.
3. Individually enter and test your original ladder logic program from step 4. The test table must be completed to verify the operation. The instructor will check the results and assign a grade.

Marking:

50% Pre-lab (individual).
20% Procedure step 2 results (group).
30% Procedure step 3 results (individual).

9.6.3 Lab 3 - Simple Motor Control

Objective:

The PLC will be used to control a DC motor, and a simple encoder will be used to detect position.

Equipment:

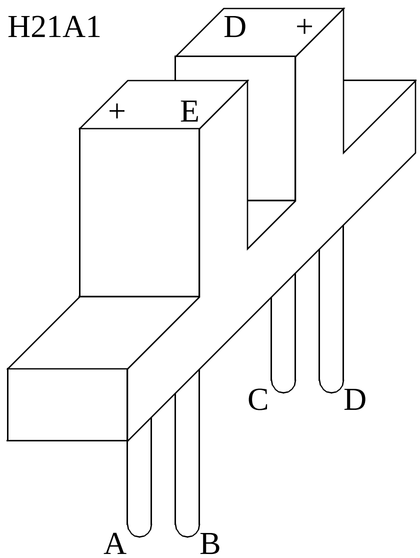
PC with micrologix programming software
PLC trainer boards
Wires
LEDS
Motors with gear head
Encoder disk
560 ohm resistor
1K resistor
1 uF capacitor
photo emitter/detector pair (H21A1)

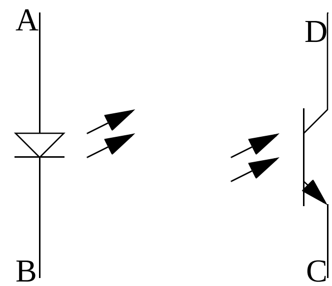
Pre-Lab:

1. Develop a state diagram for a program to turn the motor shaft 3 times if button A is pushed, or 6 times if button B is pushed.
2. Develop ladder logic for the motor controller.

System Description:

The motor will be driven with 12V, switched by an output relay in the PLC. This will cause rotation at approximately 100rpm. A simple encoder will be made by using a clear disk with blacked-out areas. The disk will rotate with the shaft of the motor. An optical sensor will be used to detect the blacked-out areas. The result will be input pulses that go into the PLC. By counting the pulses we can tell how many times the shaft has rotated. The figure below shows the photodetector circuit.





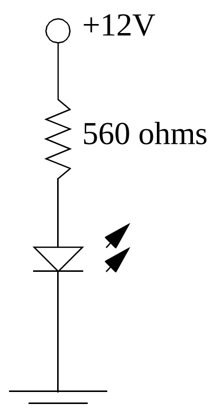


Photo emitter

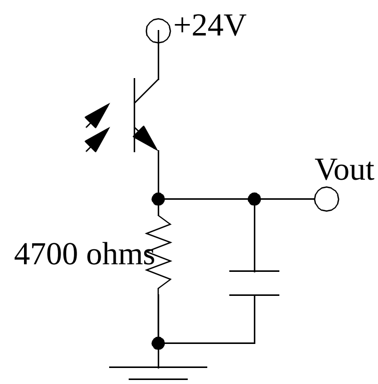
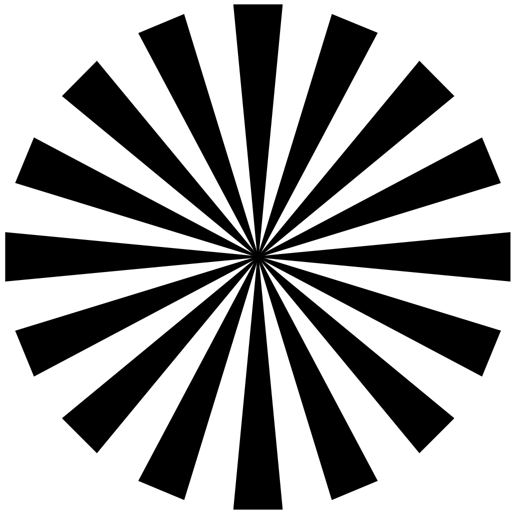


Photo Detector

The light beam will be broken with encoders that have the general pattern given below.



Procedure:

1. Connect the motor, PLC, and any required wiring.
2. Load and test the program for correctness.

Marking:

50% Prelab
50% Results in lab

9.6.4 Lab 4 - Sensors, Actuators and Wiring

Objective: To gain experience wiring inputs and outputs to a PLC with common actuators

Pre-Lab:

1. Examine the hardware description below and complete the hardware design. This should be done in Autocad, or in a PC sketching program. It may help to look through the implementation chapter near the end of the textbook.
2. Develop ladder logic that will use the hardware. Each student should develop their own individual design. The level of complexity should be beyond that used in the motor control lab (lab 3).

Process Description:

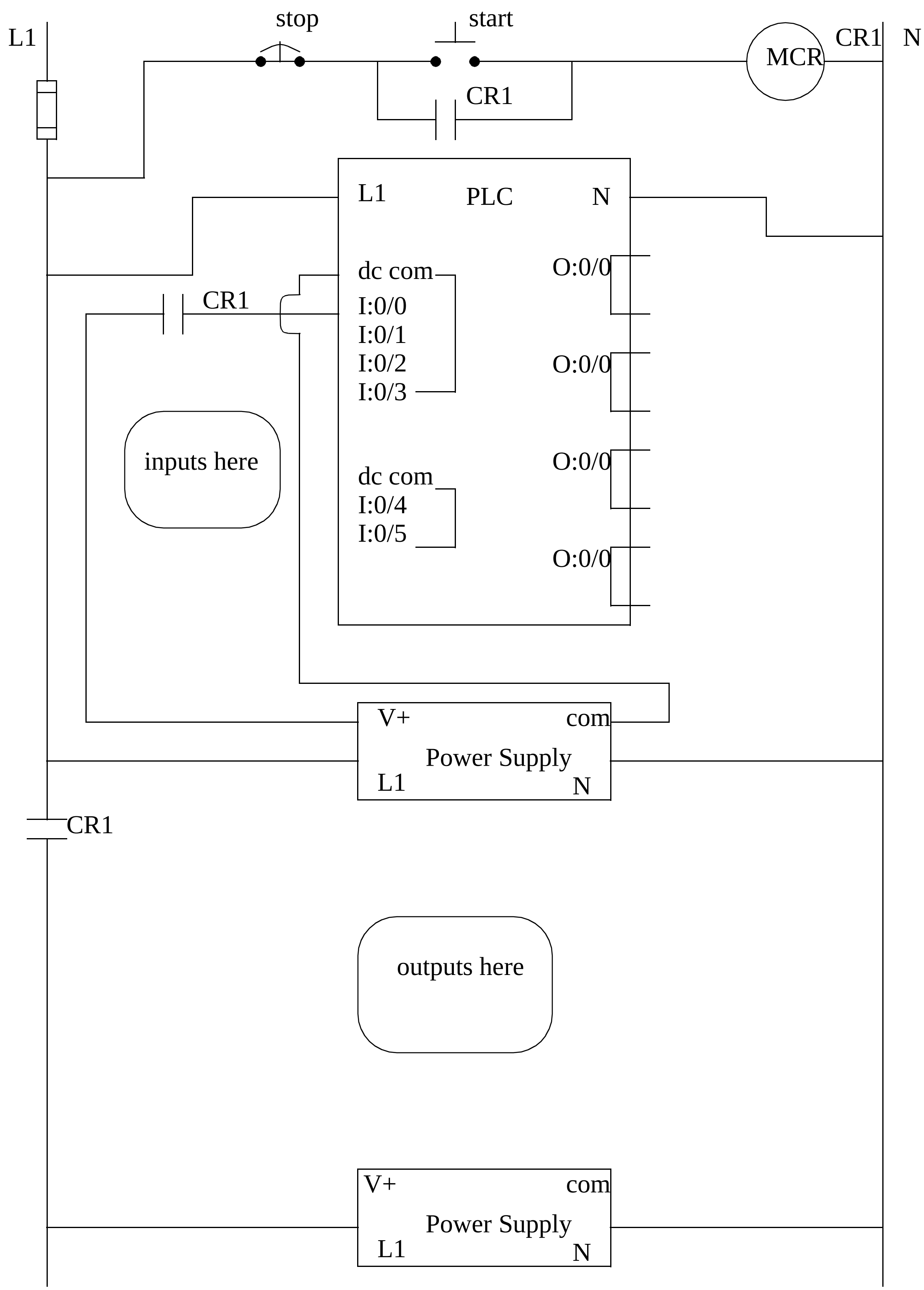
The laboratory focus will be on building the system shown in the wiring diagram below. In the diagram the AC power is connected across the ‘L1’ and ‘N’ rails (vertical lines). The connections to the devices are indicated as shown on the devices. The inputs and outputs to be connected to the system include:

- The inputs to the PLC will be

inductive proximity sensor 'A'
photo proximity sensor 'B'
NO start button
contact switch

• The outputs are-

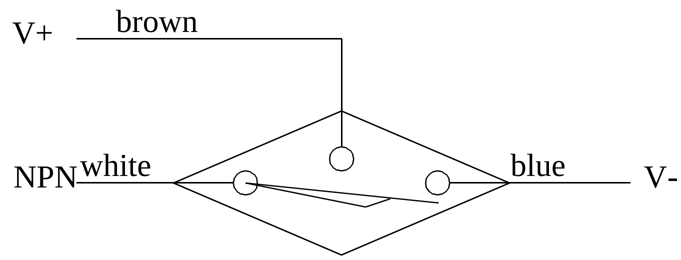
1 relay output to switch a 120Vac light 'L' (or an equivalent load)
1 pneumatic solenoid valve 'V'
1 regular solenoid
12Vdc motor (small) 'M'



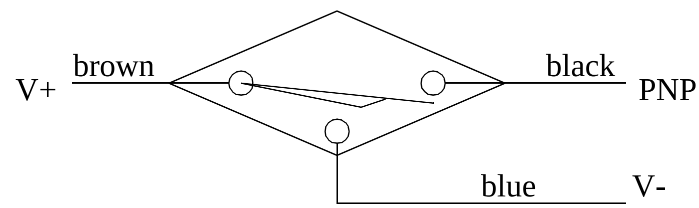
The system is wired to include an estop that will cut the power to the outputs, but allow the plc and inputs to continue working.

The sourcing and sinking sensors to be used for the lab are shown with their conventional systems, as shown below.

NPN (sinking)



PNP (sourcing)



Procedure:

1. Build the system as shown, including the fuse and E-Stop. During the laboratory this might be modified to include an MCR to control the power.
2. Individually enter and test your ladder logic.

9.6.5 Lab 5 - Introduction to PLC-5 Controllers

Objective:

To learn the basic and intermediate functions of the Allen Bradley PLC-5 Controllers.

Pre-Lab: (due at the start of lab period)

None.

Equipment:

PLC-5 processors, cards, racks and cables
RSLogix and RSLinx software and computers
Power supplies
Wire and screwdrivers
Voltmeters

Procedure:

1. Follow the PLC-5 tutorial later in the notes.

Marking:

All/Nothing based on completion of the tutorial.

9.6.6 Lab 6- Sequential Logic Control

Objective:

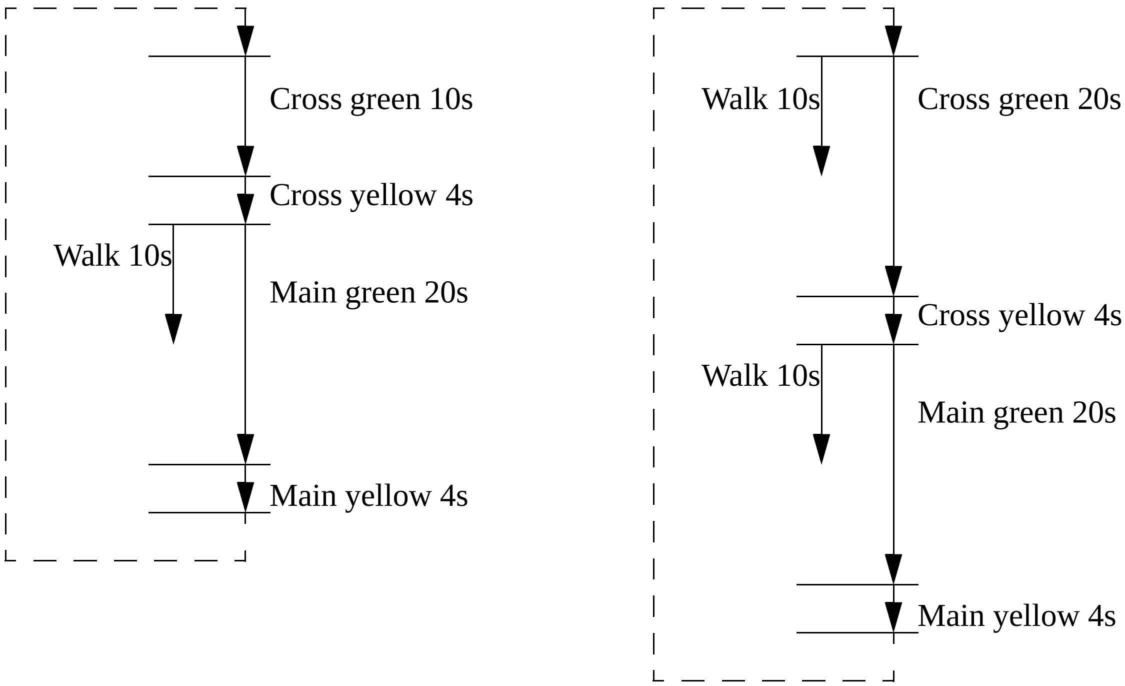
Develop a PLC program that will control a miniature set of traffic lights. These lights will go through a normal sequence, but will have pedestrian cross walk buttons that will activate a cross walk signal when pressed. When done the student should understand the design and implementation of time dependent control circuits.

Pre-Lab: (due at the start of lab period)

1. Draw a state transition diagram for the traffic lights given the process description below.
2. Write the ladder logic model for the state transition diagrams.
3. Develop an exhaustive test table that will test all of the possible transition states for the traffic lights.
4. Develop a creative description of a process for the PLC that is time dependent. Create the state transition/petri net/etc model for the problem. Then create the ladder logic to support the design. Note: the boards for these labs also contain relays, switches, buzzers, lights, a motor, optical sensors, etc. A test method must be developed for the results.

Process Description:

We want to develop a controller for a set of traffic lights that is at the cross of Main St. and a less used Cross Rd. The lights under two possible sequences as shown below. In the normal sequence the green for cross is shorter with no cross walk light. If a cross walk button is pushed while the Main light is green or yellow the Cross green light will be on longer with a walk sign.



No Cross walk button   Cross walk button pushed

Equipment:

PC with PLC programming software
PLC-5 processors, cards, racks and cables
4 red LEDs
2 yellow LEDs
4 green LEDs
10@ 1K resistors
Wires

Procedure:

1. The instructor will describe how to connect the PLC, power supply, buttons, etc at the beginning of the laboratory period. As a group you will connect the circuits. Components used will include push buttons and red/yellow/green LEDs for lights.
2. As a group, enter and test the ladder logic for pre-lab 2 and conduct tests in pre-lab 3. The instructor must check the performance.
3. Individually wire, enter and test the pre-lab step 4. The results must be demonstrated to the professor. Marks will be deducted for excessive debugging time. (1% per minute past 30 minutes up to 100%)

Marking:

50% Pre-lab (individual).
30% Procedure step 1 (group).
20% Procedure step 2 (individual).

9.6.7 Lab 7a - Analog Input/Output

Objective:

To explore analog inputs and outputs on PLCs and mathematical calculations.

Pre-Lab: (due at the start of lab period)

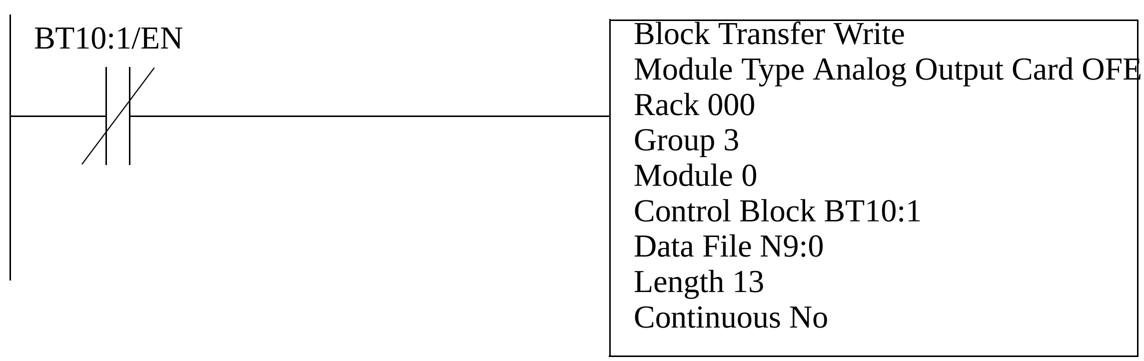
1. Write simple programs to read and output analog voltages from the PLC.
2. Develop the ladder logic to read an analog voltage, perform a calculation, and output the result as an analog voltage. The equation is,

$$Vout = \sqrt{Vin^2 + 1} - 1$$

Process Description:

Analog inputs and outputs are done with multipurpose cards in the PLC rack. To control these cards there is some overhead required to set voltage ranges, scales, values, etc. We do this by putting values in the PLCs integer memory, and then the contents are moved to the analog I/O card where values are read or set.

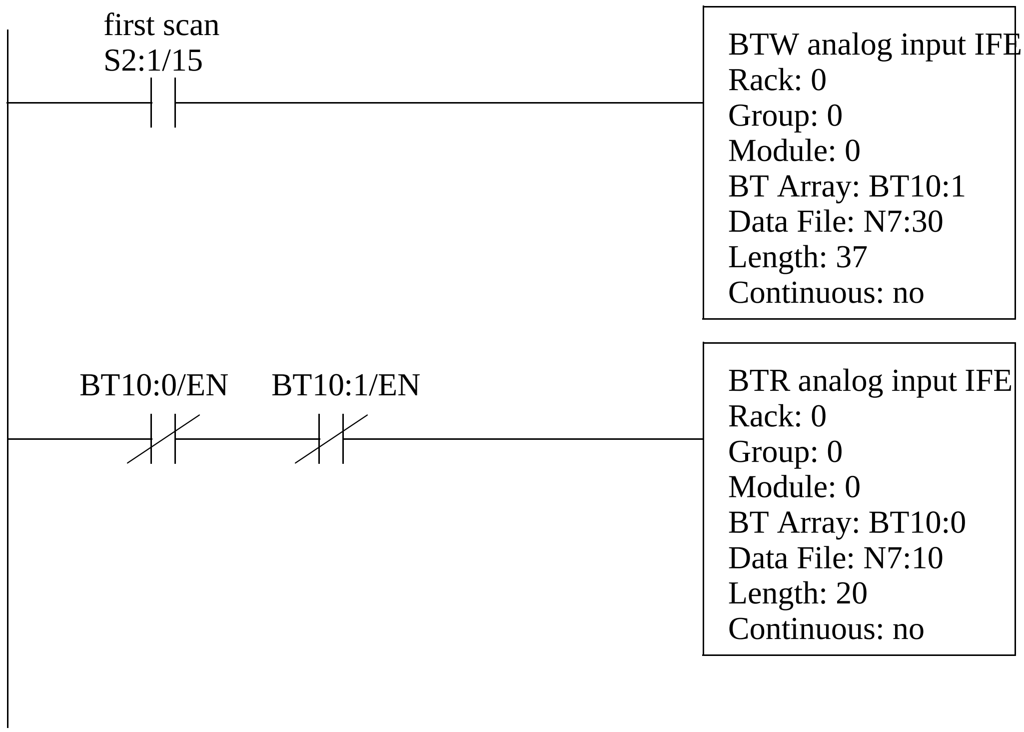
To write voltages to the PLC we set up a block of memory, the function shows this starting at N9:0, and it is 13 words long. The contents are described in the analog card manual. The block transfer function also needs a control block of memory, this is BT10:1



Note: You will need to fill in the appropriate analog value to write to the output by putting BCD values in the memory (in the example above the memory block N9). The values 2800 in location N9:0 should cause an output voltage of approx. 2V, an value of 0 should result in an output of -10V, and a value of 2047 should give an output of 0V. The scaling values for channel 1 should be set from 0 (in N9:5) to 4095 (in N9:6).

Note: If the advance contact is on constantly the card will not output a voltage.

To read voltages we use a similar method. In the example below the input value will be read when the analog input is on. When done the result will be stored in N7:10+4 = N7:14. The value will range from -4095 for -10V to 4095 for 10V.



N7:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	Note: in binary
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
32	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	
.....	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	= 0
	0	1	0	0	0	0	0	0	1	0	0	1	0	1	0	1	= 4095h
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

The basic operation is that the BTW will send the control block to the input card. As shown this will only be for channel 1, with a range of -10V to 10V.

Note: ‘scan’ should only be on briefly. If it is on constantly the card will not read voltages.

Equipment:

PLC-5 processors with analog input/output cards

Computers with RS-Logix programming software
Voltmeters
Power Supplies

Procedure:

1. Test the simple programs to input and output voltages from the PLC. (Note: The block transfer devices should be closest to the CPU AND use the PLC is single slot addressing mode.)
2. Implement prelab step #2 and test with a multimeter and voltage supply. Use a number of values to confirm.

Marking:

40% prelab
60% working programs in the lab

9.6.8 Lab 7b - PID Control

Objective:

To explore PID control.

Pre-Lab: (due at the start of lab period)

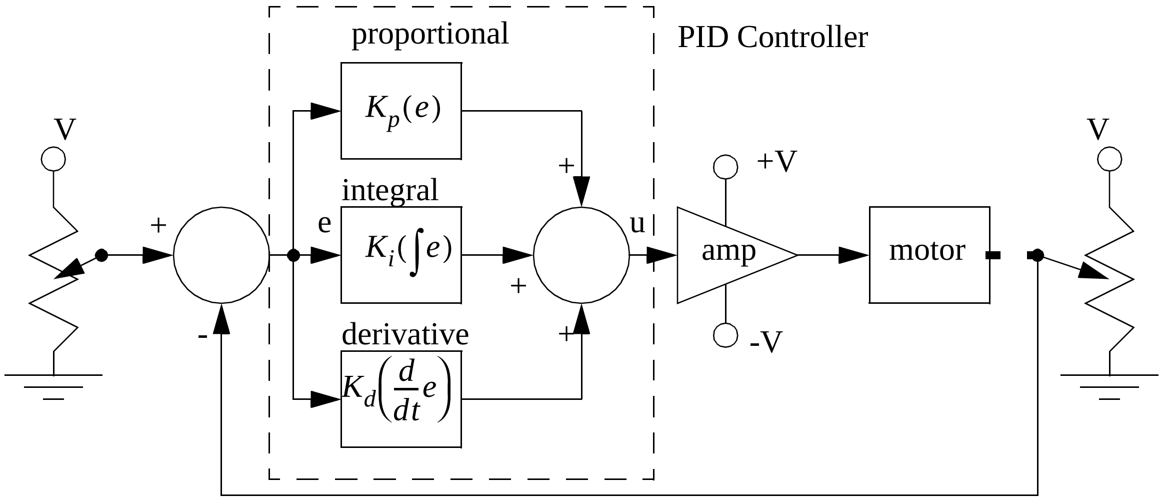
1. Write simple programs to read and output analog voltages from the PLC and perform PID control of a motor speed.

Process Description:

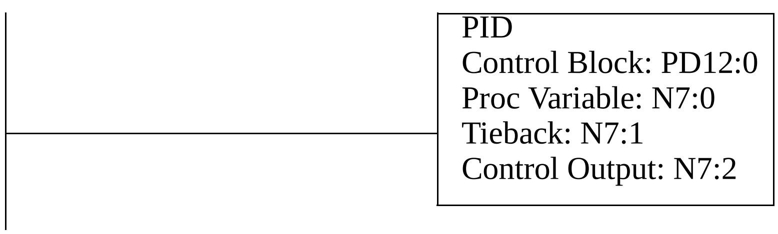
The basic equation for a PID controller is shown below. This function will try to compensate for error in a controlled system (the difference between desired and actual output values).

$$u = K_c e + K_i \int e dt + K_d \left(\frac{de}{dt} \right)$$

The figure below shows a basic PID controller in block diagram form.



The PID calculation is effectively a calculation in the PLC. One basic method of PID control is i) read voltage, ii) do PID calculation, iii) set output voltage. (Note: it is also common to get a self contained PID card for the PLC that deals with all inputs and outputs). The ladder logic below shows a PID control function.



This calculation uses the feedback variable stored in ‘Proc Location’ (as read from the analog input). The result is stored in N7:2 (to be an analog output). The control block needs to be created and values put in to configure the PID instruction

Equipment:

PLC-5 processors with analog input/output cards
Computers with RS-Logix programming software
Voltmeters
Power Supplies
Motor/Amplifier pairs

Procedure:

1. Test the PID control program.

Marking:

40% prelab
60% working programs in the lab

9.6.9 Lab 8 - Communications

Objective:

To explore the connection of a PLC to other PLCs using the data highway network, and to communicate with computers using RS-232 serial communications.

Pre-Lab: (due at the start of lab period)

1. Write two programs to run on separate PLCs. When a button is pushed on one PLC (node #1), it should send data to another PLC to turn on an output. The message should be passed using the DH+ network. Write a second program that uses DH+ to run on a PLC so that when a button is pushed it requests data to set an output.
2. Write a program to send a message out the RS-232 port on the PLC (to a connected PC running a terminal program) when an input is active.

Process Description:

As with the previous use of analog input and output cards, we need to set up blocks of memory that contain communication information. These blocks indicate what is to be sent and where.

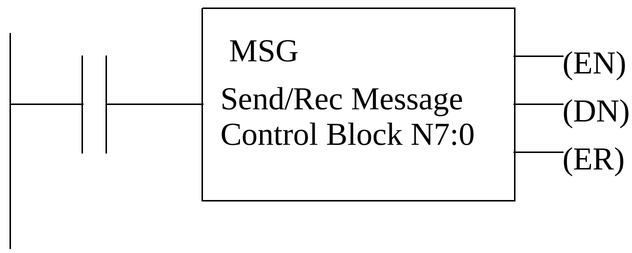
The Data Highway Plus, DH+, network uses a single path to connect numerous devices. To use this the block of memory below must be used to set up the information to be sent or received.

Read/Write	Read
Data Table	N7:23
Size	20
Local/Remote	Local
Remote Station	N/A
Link ID	N/A
Remote Link type	N/A
Local Node Addr.	10
Processor Type	PLC-5
Dest. Addr.	N7:23

Block of data stored in memory N7:0

Note: when entering the message (MSG) command into the PLC-5, a pop-up menu will appear and ask for the data items shown here.

When PLCs communicate, one PLC must write contents of its memory to a second, or one PLC must request contents of memory from a second. The program below shows the basic steps involved in communication.


MSG
Send/Rec Message
Control Block N7:0
(EN)
(DN)
(ER)

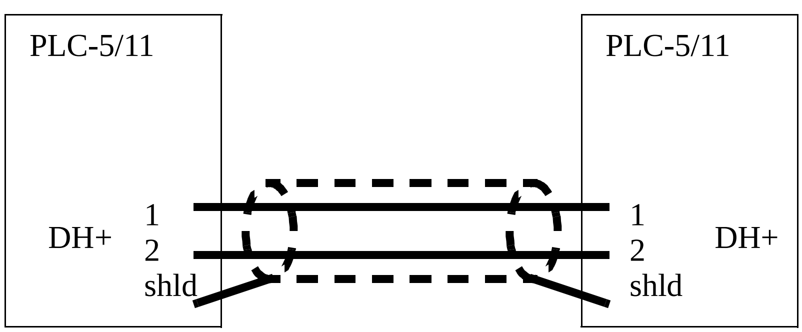
	Sending PLC	Receiving PLC
Read/Write	Write	Read
Data Table	N7:23	N7:23
Size	20	20
Local/Remote	Local	Local
Remote Station	N/A	N/A
Link ID	N/A	N/A
Remote Link type	N/A	N/A
Local Node Addr.	2	1
Processor Type	PLC-5	PLC-5
Dest. Addr.	N7:23	N7:23

Note: the PLCs both need a different DH+ node address, this is set using the jumpers on the back of the PLC-5 cpu card.

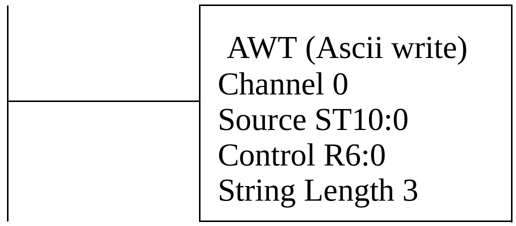
Switches 1-3 represent the least significant digit and switches 4 through 7 represent the most significant digit. The settings for node 3 would be

1 2 3 4 5 6
UUDDDD

To connect the devices a three conductor wire is needed. The connection is shown below and the wires are connected to the same terminals on the other PLC(s). The shield terminal should be connected to the metal sheath in the wire.



Serial communications can be done using an RS-232 interface. This is the most common interface available (most personal computers have 2). On the PLC-5 CPU there is one RS-232 interface that we have been using for programming, we can also use this for normal communication. (Note: it is very common to purchase a separate card that provides a serial port. This keeps the port on the CPU available for programming.)



This command will write a string to the serial port on the front of the CPU. The string to be written to the port will have to be stored in memory. In this case ASCII string memory (ST10) can be created to hold it. At this location in memory, we need to manually enter the string.

Data Stored in memory	ST10:0	“ABC”

--- This will result in ABC being printed on the terminal

Equipment:

PLC-5s
RS-232 Communication cables
Data Highway cables
Screw drivers
2 Computers

Procedure:

1. Join your team with another team to test the DH+ program. Wire the PLC DH+ on each CPU together. Pick one as node 1 and the other as node 2 and set the switches on the back of the CPU cards. Test the prelab programs.
2. (single teams) Have two computers available. One will be used for programming the PLC, and the other will be used as an ASCII terminal. Enter and download the program to the PLC as normal. Disconnect the serial cable, and connect it to the other PC. Run ‘hyperterm’ and test the program.

Marking:

50% prelab (individual)
50% working programs (group)

9.6.10 Lab 9 - DVT Vision Systems

Objective: To use a vision system as a PLC sensor

Pre-Lab:

1. Examine the DVT training CD. In particular review ......
2. Follow the DVT tutorial that follows with the CD to prepare yourself to use the units in the lab.
3. Develop a ladder logic program using an SFC to perform the task described below.
4. Develop a wiring diagram (as in lab 5) for the system. This should be done on a computer.

Process Description:

A process will be designed to.....

Procedure:

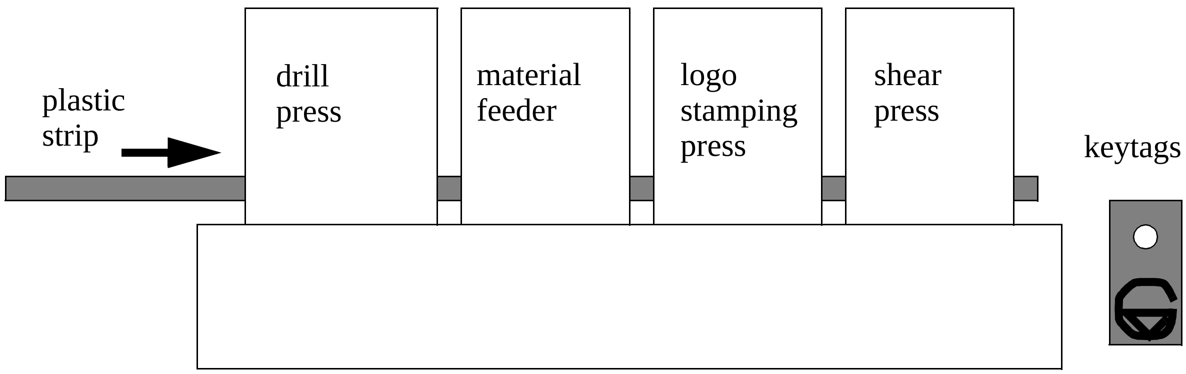
1. Set up the DVT camera using the DVT software to perform the required inspection.
2. Connect the camera to the PLC so that it may detect pass and fail conditions.
3. Enter and test the ladder logic in the PLC.

9.7 ADVANCED PLC LABORATORIES

• Labs 10a, 10b, 10a, 10b - These four labs are complimentary, and each week there will be four groups that will rotate through all four labs.

• Group Size: 3 students, 4 rotating stations

• These laboratories will be used to pull together 4 individual control systems into a complete manufacturing control system. Although each group will solve a different control problem, each laboratory will end with all stations in a fully functioning control system.



• These four labs will all use an Allen-Bradley PLC-5 to control the stations.

• The descriptions below will be used to develop a design and ladder logic before arriving at the laboratory. All laboratories are to be done on design sheets like those found in the course notes, or equivalent.

• The basic schedule for the first lab is shown below for the first and second weeks.

WEEK 1

Lab Day	Lab 10a	Lab 10b	Lab 11a	Lab 11b
Monday	group 1	group 2	group 3	group 4
Tuesday am	group 1	group 2	group 3	group 4
Tuesday pm	group 1	group 2	group 3	group 4
Wednesday	group 1	group 2	group 3	group 4

WEEK 2

Lab Day	Lab 10a	Lab 10b	Lab 11a	Lab 11b
Monday	group 4	group 3	group 1	group 2
Tuesday am	group 3	group 4	group 2	group 1
Tuesday pm	group 4	group 3	group 1	group 2
Wednesday	group 3	group 4	group 2	group 1

• NOTE: In this lab three of the stations use the hole detect to start an operation. Even when the operation is done the hole in the keytag will remain. You must write your program so that after the press has retracted the process will not start immediately. Only after the hole is gone will the program start looking for a new hole. You might want to add another state that waits until the hole is gone.

9.7.1 Lab 10a - Shear Press

Objective:

A PLC will be used for control of a hydraulic cylinder that will shear off keytags.

Pre-Lab:

1. Examine the other components in the lab and determine what is required for proper operation of the shear.
2. Design the controls for the press.
3. Develop the ladder logic required for operation

Process Description:

The shear press will detect when the material is in place for shearing when a hole is detected by an optical sensor mounted. When sensed it will set a bit true in memory (B3:0/0) that will cause the material feeder to stop. A pneumatic cylinder will be actuated to clamp the strip. At this point shearing will begin by advancing the hydraulic cylinder until a hydraulic cylinder advanced limit switch is actuated. At this point the advance solenoid will be turned off, and the return cylinder solenoid will be actuated. This will continue until the retracted limit switch is actuated. At this point both the hydraulic solenoids are turned off. Finally the pneumatic solenoid is released, and the material feeder is allowed to continue.

PLC Outputs:

A DC Output card will be placed in slot 1 to output 12Vdc.
O:001/00 shear retract solenoid
O:001/01 shear advance solenoid
O:001/02 pneumatic solenoid to clamp material

PLC Inputs:
A DC Input card will be placed in slot 0 to accept 12Vdc.
I:000/00 hydraulic cylinder retracted limit switch
I:000/01 hydraulic cylinder advanced limit switch
I:000/02 hole detected sensor
I:000/03 control power on (master power for the station)
I:000/04 auto mode selected (must be on for plc operation)
I:000/05 hydraulic power on

Procedure:
1. Make the electrical connections between the PLC and the shear station.
2. Enter the Ladder logic, and test the module by itself.
3. Integrate the components with the other parts of the system and produce parts.

9.7.2 Lab 10b - Feeder Positioning

Objective: a PLC will be used to position a material transport system driven by a stepper motor.

Pre-Lab:
1. Examine the other components in the labs and determine what is required for proper operation of the feeder.
2. Design the controls for the material feeder.
2. Develop the ladder logic required for operation

Process Description:
The feeder uses a stepper motor to advance the material strip. The feeder will continue to advance the material until one of the other machines orders the feeding to stop by setting flags true in memory locations (B3:0/00, B3:0/01, B3:0/02). The stepper motor is driven by specifying direction (we will always go forwards), and each time an output is pulsed it will step forward one pulse. It will take a large number of pulses to move the material one inch. Immediate outputs may make it possible to generate pulses faster that the ladder logic scan rate.

PLC Outputs:
A TTL (transistor) Output card will be placed in slot 2 to output 5Vdc.
O:002/00 each pulse moves the stepper motor one pulse
O:002/01 forward/reverse direction selector

PLC Inputs:

A DC Input card will be placed in slot 0 to accept 12Vdc.

I:000/06 control power on (master power for the station)
I:000/07 automatic mode on (must be on for PLC control)

Procedure:

1. Make the electrical connections between the PLC and the feeder station.
2. Enter the Ladder logic, and test the module by itself.
3. Integrate the components with the other parts of the system and produce parts.

9.7.3 Lab 11a - Stamping Press Control

Objective: a PLC will be used to control an stamping press.

Pre-Lab:

1. Examine the other components in the lab and determine what is required for proper operation of the press.
2. Design the controls for the press.
2. Develop the ladder logic required for operation

Process Description:

The stamping press will detect when the material is in place for stamping (embossing) when a hole is detected by an optical sensor mounted. When sensed it will set a bit true in memory (B3:0/01) that will cause the material feeder to stop. A pneumatic cylinder will be actuated to clamp the strip. At this point stamping will begin by advancing the hydraulic cylinder until a hydraulic cylinder advanced limit switch is actuated. At this point the advance solenoid will be turned off, a two (or more) delay (0.5s) is required to allow the embossing to occur. After this the return cylinder solenoid will be actuated. This will continue until the retracted limit switch is actuated. At this point both the hydraulic solenoids are turned off. The pneumatic solenoid is released, and the material feeder is allowed to continue.

PLC Inputs:

A DC Input card will be placed in slot 0 to accept 12Vdc.

I:000/10 hydraulic cylinder retracted limit switch
I:000/11 hydraulic cylinder advanced limit switch
I:000/12 hole detected sensor
I:000/13 control power on (master power for the station)
I:000/14 auto mode selected (must be on for plc operation)
I:000/15 hydraulic power on

PLC Outputs:

A DC Output card will be placed in slot 1 to output 12Vdc.

O:001/04 press retract solenoid
O:001/05 press advance solenoid
O:001/06 pneumatic solenoid to clamp material

Procedure:
1. Make the electrical connections between the PLC and the press station.
2. Enter the Ladder logic, and test the module by itself.
3. Integrate the components with the other parts of the system and produce parts.

9.7.4 Lab 11b - Variable Feed Drill

Objective: a PLC will be used to control a variable feed drill

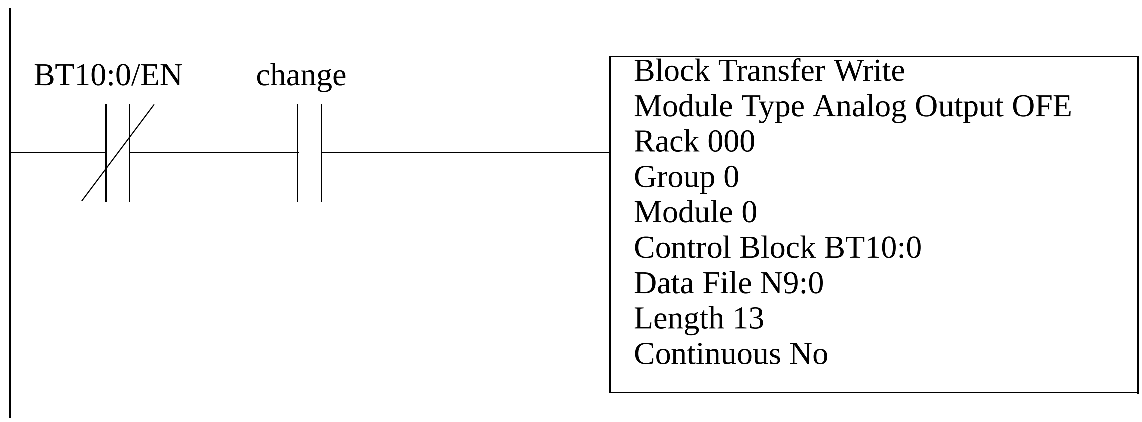
Pre-Lab:
1. Examine the other components in the lab and determine what is required for proper operation of the drill.
2. Design the controls for the drill.
3. Develop the ladder logic required for operation

Process Description:

The drill press will detect when the material is in place for drilling when a hole is detected by an optical sensor mounted. When sensed it will set a bit true in memory (B3:0/02) that will cause the material feeder to stop. A pneumatic cylinder will be actuated to clamp the strip. At this point drilling will begin. There are three modes for controlling the drill described below (We will use mode ii). When the drill is done the pneumatic solenoid is released and the material feeder allowed to continue.

i) Fully Automatic - the drill action will be actuated by first advancing the drill down until it hits an advance limit switch. At this point the drill will be moved up, until the retracted limit switch is set. The controller uses a PID loop, and will slow when it approaches the material.

ii) Velocity Control - the drill may also be controlled using analog output card for feed velocity, and using digital inputs to measure position. The limit switches are used as in mode i). For drilling the analog output card should produce a voltage about +2V, -10V is used for retracting, and 0V for no motion. The ladder logic below will make the analog output card drive the drill to advance when a bit is set, and retract when a second bit is set, otherwise the drill will be idle.



Note: You will need to fill in the appropriate analog value to write to the output by putting BCD values in the memory N9:0. The values in location N9:0 should cause an advance (i.e. 2800), a retraction (i.e. 0) and idle (i.e. 2047).

Note: Do not keep the change bit engaged, because the analog output card will not update the output.

iii) Position Control - the drill may also be controlled by specifying a target position. The limit switches used in i) should be used to check for errors.

PLC Inputs:

A DC Input card will be placed in slots 0 and 4 to accept 12Vdc.

I:000/16 drill retracted limit switch
I:000/17 drill advanced limit switch
I:004/00 hole detected sensor
I:004/01 control power on (master power for the station)
I:004/02 auto mode selected (must be on for plc operation)

(optional) A TTL (transistor) Input card will be placed in slot 5 to accept 5Vdc. These inputs are used to calculate actual drill position.

I:005/00 actual drill position bit 0 (1/128”)
I:005/01 actual drill position bit 1 (1/64”)
I:005/02 actual drill position bit 2 (1/32”)
I:005/03 actual drill position bit 3 (1/16”)
I:005/04 actual drill position bit 4 (1/8”)
I:005/05 actual drill position bit 5 (1/4”)
I:005/06 actual drill position bit 6 (1/2”)
I:005/07 actual drill position bit 7 (1”)

PLC Outputs:

A DC Output card will be placed in slot 1 to output 12Vdc.

O:001/07 drill retract with PID controller (optional)
O:001/08drill advance with PID controller (optional)
O:001/09 pneumatic solenoid to clamp material
O:001/10 drill motor start relay

An Analog Output card will be placed in slot 3 to output -10 to +10Vdc and control drill velocity.

O:003/00 drill velocity voltage

(optional) A TTL (transistor) Output card will be placed in slot 6 to output 5Vdc.

O:006/00 desired drill position bit 0 (1/128”)
O:006/01 desired drill position bit 1 (1/64”)
O:006/02 desired drill position bit 2 (1/32”)
O:006/03 desired drill position bit 3 (1/16”)
O:006/04 desired drill position bit 4 (1/8”)
O:006/05 desired drill position bit 5 (1/4”)
O:006/06 desired drill position bit 6 (1/2”)
O:006/07 desired drill position bit 7 (1”)

Procedure:

1. Make the electrical connections between the PLC and the drill station.
2. Set up the I/O modules. You will need to make sure the analog output card is also set up. When setting it up use the ‘autoset’ values option. This will pick memory locations for the card to use - take note of these. (You will need to do this again when all of the programs are combined.) The use the ‘insert ladder rungs’ program to put the functions you need in the ladder diagram.
3. Enter the rest of the ladder logic, and test the module by itself.
3. Integrate the components with the other parts of the system and produce parts.

9.8 TUTORIALS

9.8.1 A-B Micrologix with RSLogix Software

9.8.1.1 - Installing the Software

• Goal: To learn how to install the software

• Note: These instructions should lead you point by point, but pay attention to the details on the computer screen.

• Instructions:
1. Turn on the computer, it will start to boot up.
2. Examine the contents of the software box. There should be manuals for the software and the PLC. There should also be a CDROM and a floppy disk. You will also find quick reference cards, training information, etc.
3. Put the CDROM in the computer. A screen should automatically appear asking you to install the software. Click on the install button and the installation should begin.
4. When prompted .....
5. After this install RS-Linx. This program will be handle communication between the ladder logic program and the PLC.

9.8.1.2 - Connecting The Hardware

• Goal: To learn how to connect the PLC to the computer.

• Instructions:
1. Open the PLC box and remove the documentation and PLC. Examine both. Flip up the terminal strip covers and look at the labels.
2. Connect the provided power cord. Plug the PLC in, turn it on and look to see if the power light turns on. Turn off the PLC before the next step. NOTE: the power is wired directly to the PLC L1, L2/N and ground terminals on the front of the PLC.
3. The communication cable has two connectors. The round connector plugs into the front of the PLC - there is a small door on the left hand side. The other end of the cable should plug into the back of the computer. This will either be in ‘COM1’ or ‘COM2’. Chances are if there is a serial mouse attached to the computer, it will be ‘COM2’. If you are not sure, you can try both later.
4. Turn on the power. You should see the ‘power’ light go on. Other lights may also be on.

9.8.1.3 - Running the Software

• Goal: To run the software and communicate with the PLC.

• Note: You should only need to do this the first time the software is set up.

• Instructions:

1. Move the mouse to the bottom left corner of the screen to where the “Start” button is located and click once. Next, click on “Programs” then “Rockwell Software”, then “RSLogix 500 English”, and finally “RSLogix 500 English”.
2. This should start the RSLogix ladder logic programming software. A blank window should come up. It will be necessary to open a project before beginning to program.

3. Select ‘File’-’New’ and then select theprocessor ‘Micrologix 1000’. Next, change the driver to ‘AB_DF1-1’. This may cause the software to start the RS-Linx program - if it does go to step 9, if not go to step 10.

4. (If RS-Linx has started and is on the screen) Go to ‘Communications’-’Configure Drivers...’-’RS-232 DF1 Devices’-’Add New’. Pick the appropriate COM port and set the device to ‘SLC-CH0’. Then select ‘Autoconfigure’. It should find the PLC and set the port appropriately. Click ‘OK’ and get the RSLogix software back.

5. Click ‘OK’ on the new file creation screen. The program will put up a project window. This will include a scrolling menu on the left that allows access to many functions of the PLC. The ladder logic will appear on the right hand side. At this point you are ready to enter some ladder logic.

9.8.1.4 - Setting up a new Project and Program

• Goal: To set up a new project file and a simple program.

• Note: A separate project file is needed for each controller. If a controller has multiple programs, each one should have a project file.

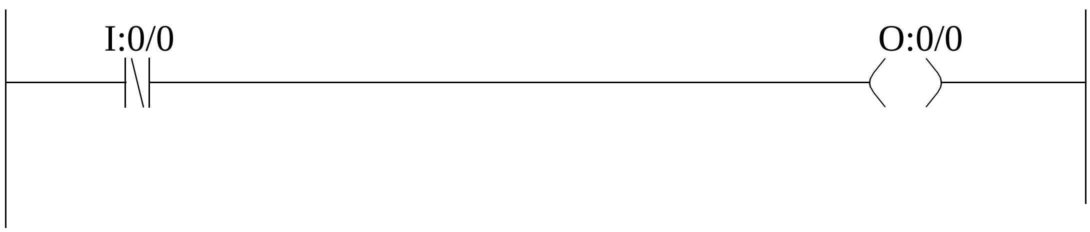
• Instructions:

1. A window will appear on the screen. On the right hand side is where ladder logic is entered and displayed. On the left are system settings. On the top are the controls used for programming and other functions.
2. Look carefully at the bar at the top of the screen. At the right hand side there are small symbols. Point to the left most symbol and hold down the left mouse button (keep it pushed for now). Drag the mouse down to the ladder logic window. A green box will appear, drag the mouse pointer to it and let the mouse button go. This should

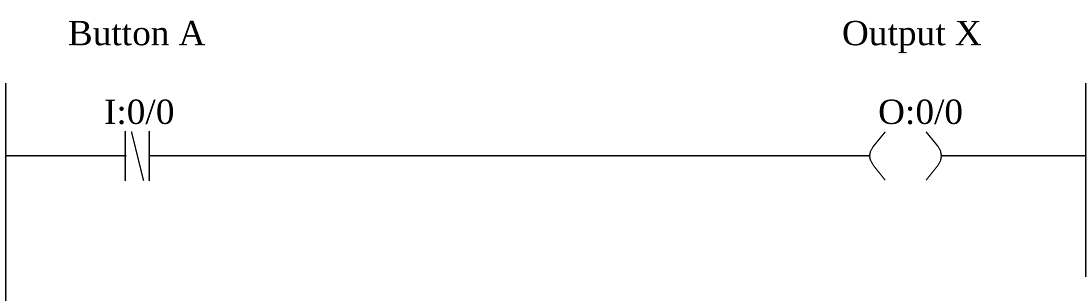
add an empty rung to the program.

3. Use the same method with the mouse to drag down a set of input contacts to the empty ladder rung.
4. Now drag down an output coil to the ladder logic run so that it looks like the one below.

5. Now the names of the inputs and outputs will be added. For the input contact, double click with the left mouse button on the “?” above the input contact. Type in the value shown below and press return. Do the same for the output coil. Note: what is displayed will appear different from what was entered.



6. Right click on the input contacts and select “Edit Description - I:0/0”. Enter the description for the contact “Button A”. Do the same for the output coil so that it looks like the figure below.



‘A<ENTER>’, press <ESC> when done.

9.8.1.5 - Downloading and Entering a Program

• Goal: To transfer a program to the PLC and run it.

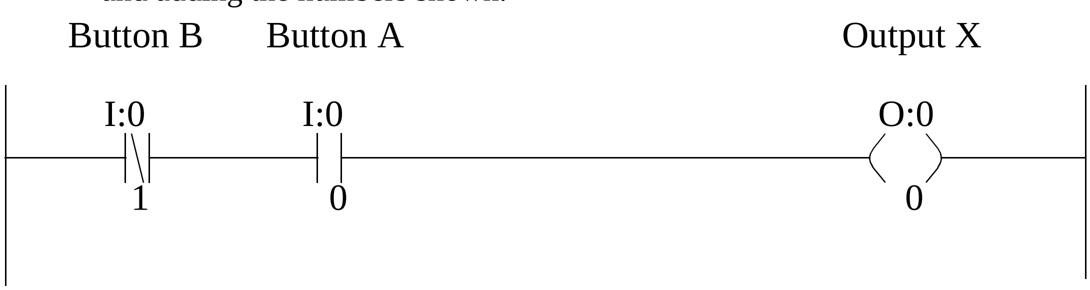
• Instructions:
1. At the top of the window select “Comms” then “Download”. You will be asked for a filename, enter ‘seminar’ for now. Later on you should give this a name related to the project.
2. You will be asked if you are sure you want to download, select “yes”. You may get a message that the SLC is in “RUN MODE”. If you select “Yes” the program in the PLC will stop running so that the new program can be downloaded. After the program is downloaded you will be asked if you want to switch back to “RUN” mode, select “Yes”.
3. When asked “Do you want to go Online?” select “Yes”. The screen will now show the actual state of PLC inputs and outputs. Turn on Input 0 to the PLC, and notice that the rung on the screen changes. It is also worth noticing that there is a slight delay between pushing the switch, and the change on the screen.

NOTE: After this point, keystrokes and menu choices will not be fully described.

9.8.1.6 - Complex Ladder Diagrams

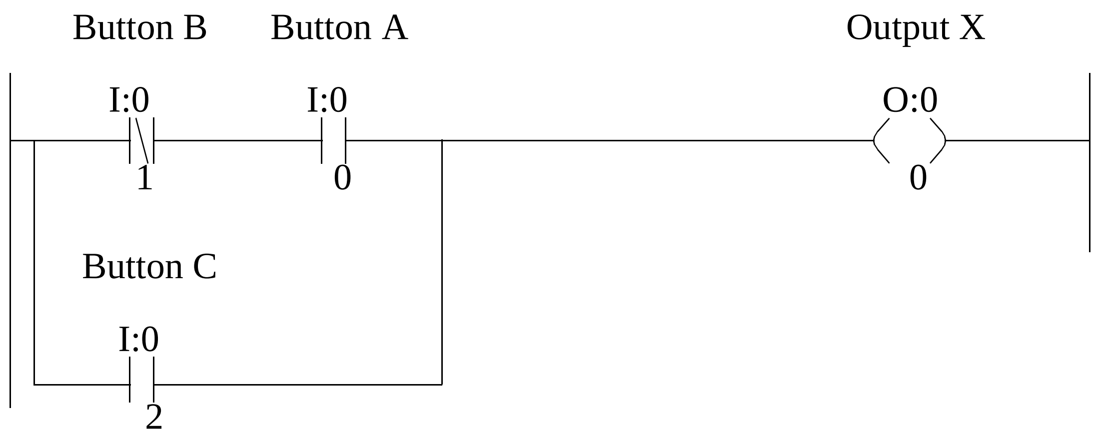
• Goal: Enter and edit ladder logic with branches and add comments.

• Instructions:
1. Start by disconnecting from the PLC by selecting “Comms”, then “Go Offline”. Edit the program to look like the progam below by dragging down a normally open contact, and adding the numbers shown.



2. Download the program to the PLC and run it. Push buttons and see how it behaves.
3. Go offline and add in the branch in the figure below. To do this drag down a branch icon from the bar above to a green box before the two input contacts. Then use the mouse to drag the other side of the branch (shown as a red box) to the other side of

the input contacts.



9.8.1.7 - Latches

• Goal: To learn how latches work

• Instructions:

1. Go offline and enter the following ladder logic.

2. Download the ladder logic and observe how the switches change the operation of the latches. Notice that the second last line of ladder logic has no effect - this is because the output ‘O:0/2’ was used twice, and only the last use counts.
3. After a latch is set (O:0/1) turn off the PLC, and turn it back on. Do the latched outputs

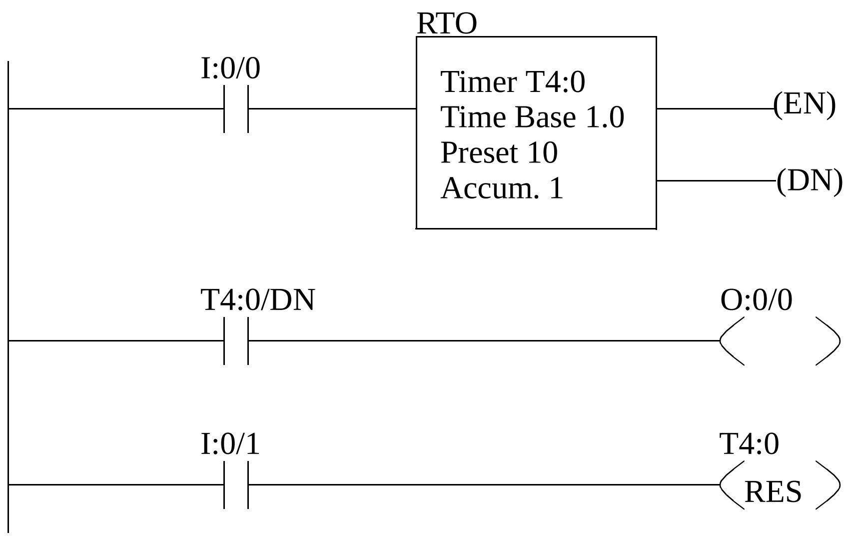
stay latched? The programming software will give an error message “Communications loss to processor“, just click “retry” to reconnect to the PLC.

9.8.1.8 - Timers

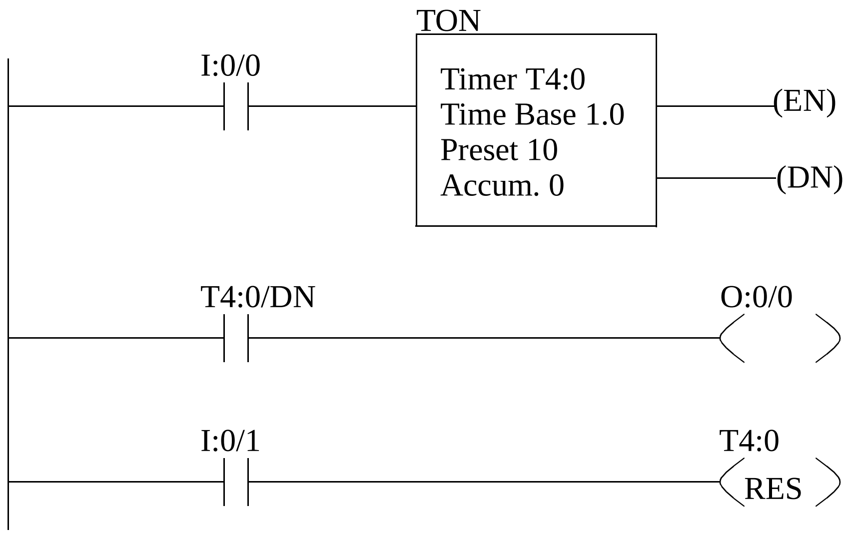
• Goal: To learn how timers work

• Instructions:

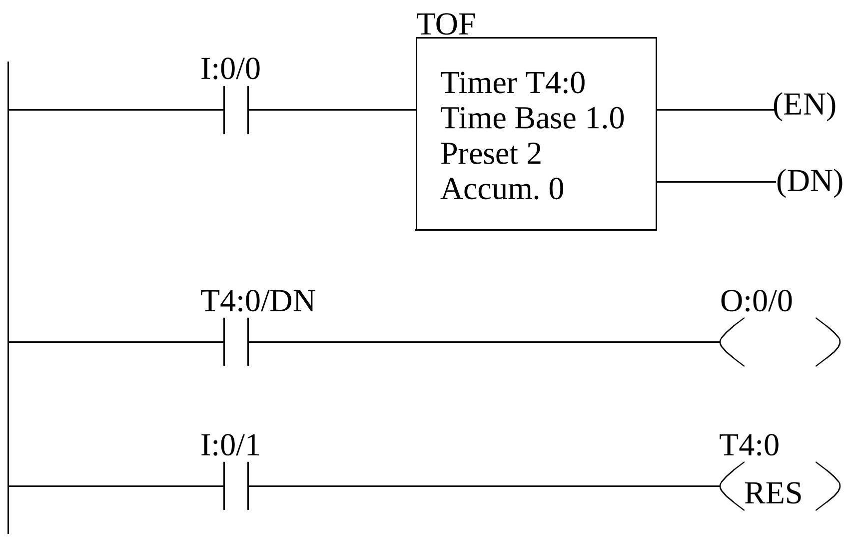
1. Go offline and enter the following ladder logic. The Timer function can be found by clicking on the “timer/counter” tab. You can return to the normal functions by clicking on the “user” tab.



2. Run the ladder logic and observe how the switches change the operation of the timers. Try running the timer by switching the input on and off a few times while it is counting.
3. After running the timer turn the PLC off and on, does the output stay on?
4. Change the counter so that it takes 2 seconds to run by clicking on the “preset” on the timer and then entering “2”.
5. Change the time base to 0.01 - you will need to go offline and download the program again. How does this change the operation of the timer?
6. Edit the ladder diagram to use a “TON” timer, as shown below. You will have to go offline to do this. SHORTCUT: Click on the “RTO” on the top of the timer, and then type in “TON” instead.



7. Run the ladder logic. This time the input must stay on for a full 10 seconds before the output will turn on. How is this different from the “RTO”?
8. Edit the ladder diagram so that it looks like the diagram below.

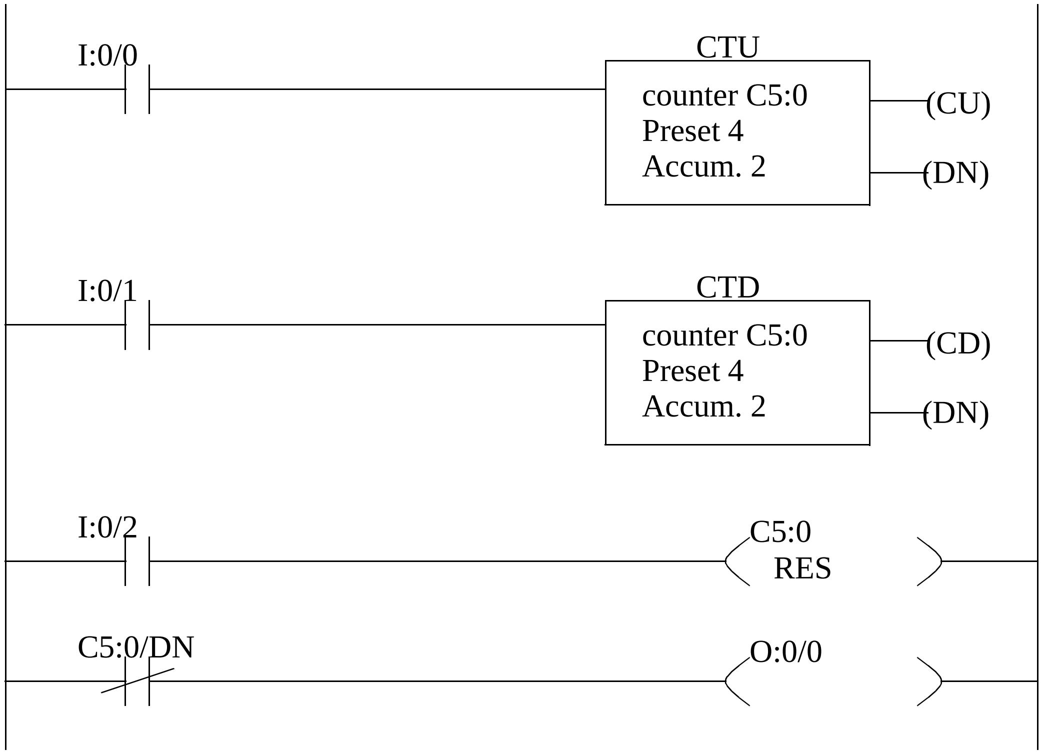


9. Run the ladder logic. This timer uses the switch turning off to start counting. Try pushing the switch a few times quickly then slowly.

9.8.1.9 - Counters

• Goal: To learn how timers work

• Instructions:
1. Enter to following ladder logic and observe how the switches change the operation of the counters. Does it match what was discussed earlier?

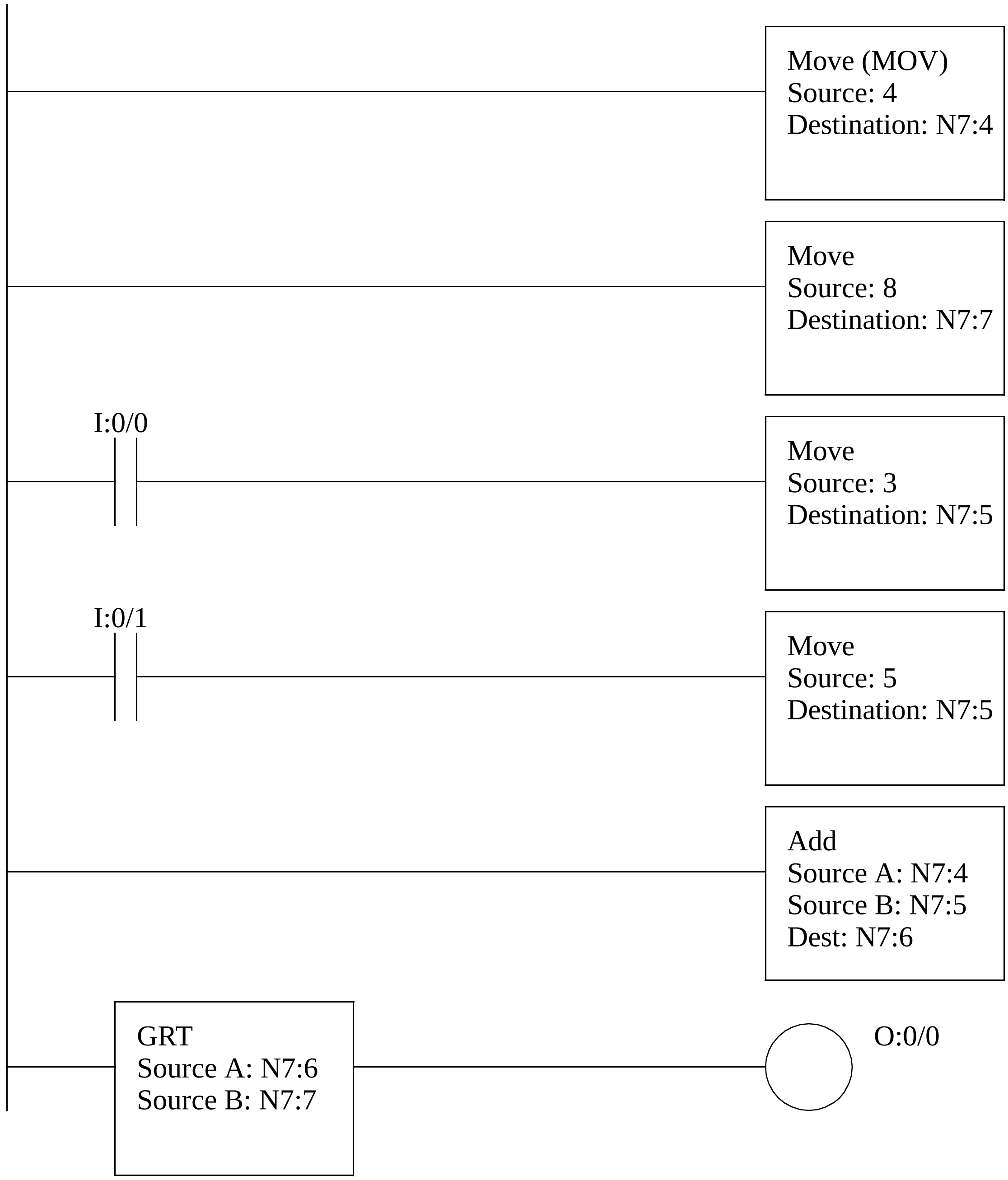


2. Modify the counter to count from 0 to 10.

9.8.1.10 - Basic Math Functions

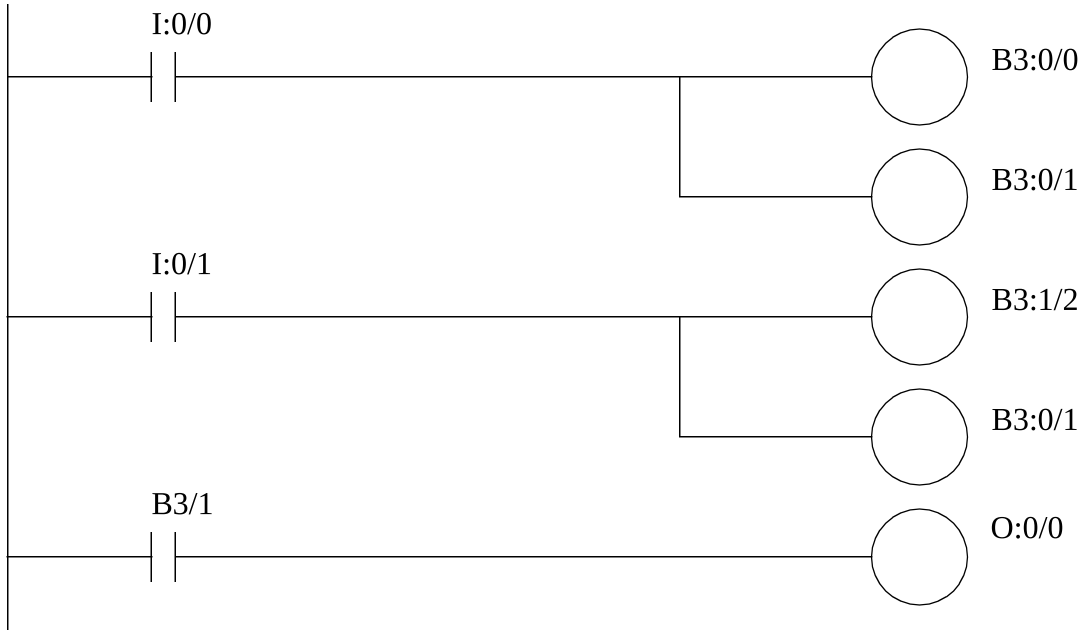
• Goal: To see basic mathematical calculations

• Instructions:
1. Now we will write a program that adds two numbers. If the sum is greater than 8 then an output will turn on. Enter the ladder logic and run the program. Watch the values displayed, and notice how inputs I:0/0 and I:0/1 change the values.



9.8.1.11 - PRACTICAL - BIT MEMORY

1. Run the software and start the off line programming module. Clear all of the memory and enter the following program.



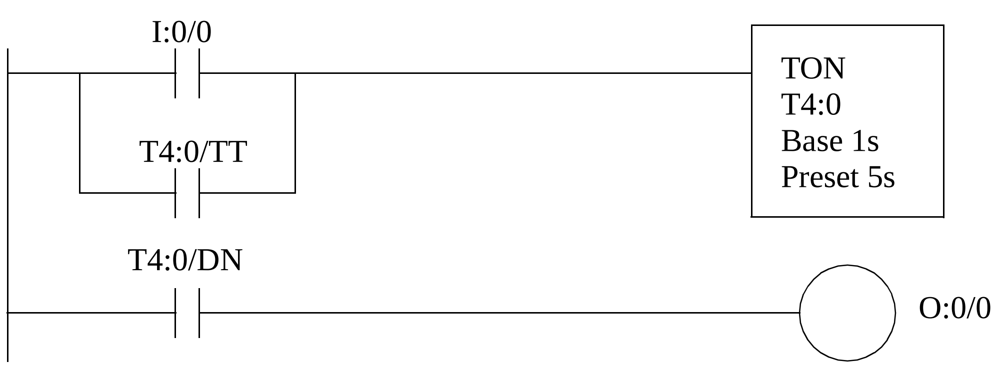
Note how the bit addresses changes. In particular B3:1/2 changed from the word format to the bit count format B3/18. The calculation is 1*16 + 2 = 18.

2. Download and run the program. In on-line programming mode, test the program to see how it behaves.

3. Next, look at the values in the memory of the PLC. First look at the left-hand side of the screen. One of the sections is labeled “Data Files”, under this there is “B3 - Binary”. Double click on this one to bring up a display window.

9.8.1.12 - PRACTICAL - TIMER AND COUNTER BITS

1. Run the ladder logic program and enter the following ladder logic. Run the program and see what happens.

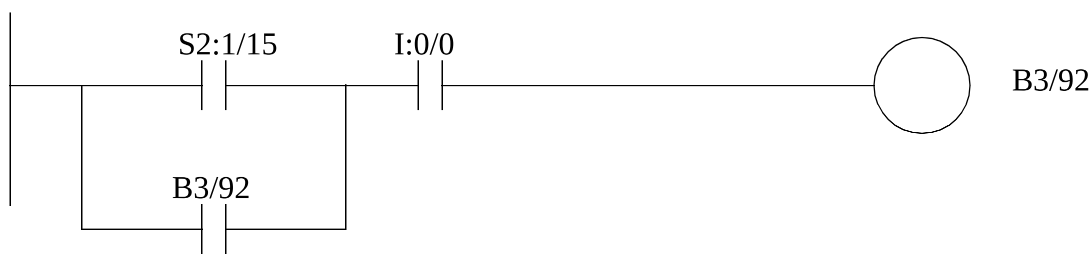


2.. Select the data file memory under “Data Files” as “T4:0”. Now press the input buttons and watch the values for T4:0 change.

9.8.1.13 - PRACTICAL - STATUS BITS AND OTHER MEMORY

1. Under “Data Files” select “S2 - Status” to display the status memory of the PLC. Look through and notice many of the values that are available. The values that are gray can only be written to, while the others can be set by on the screen or by a ladder logic program. Also notice that memory addresses are also provided.

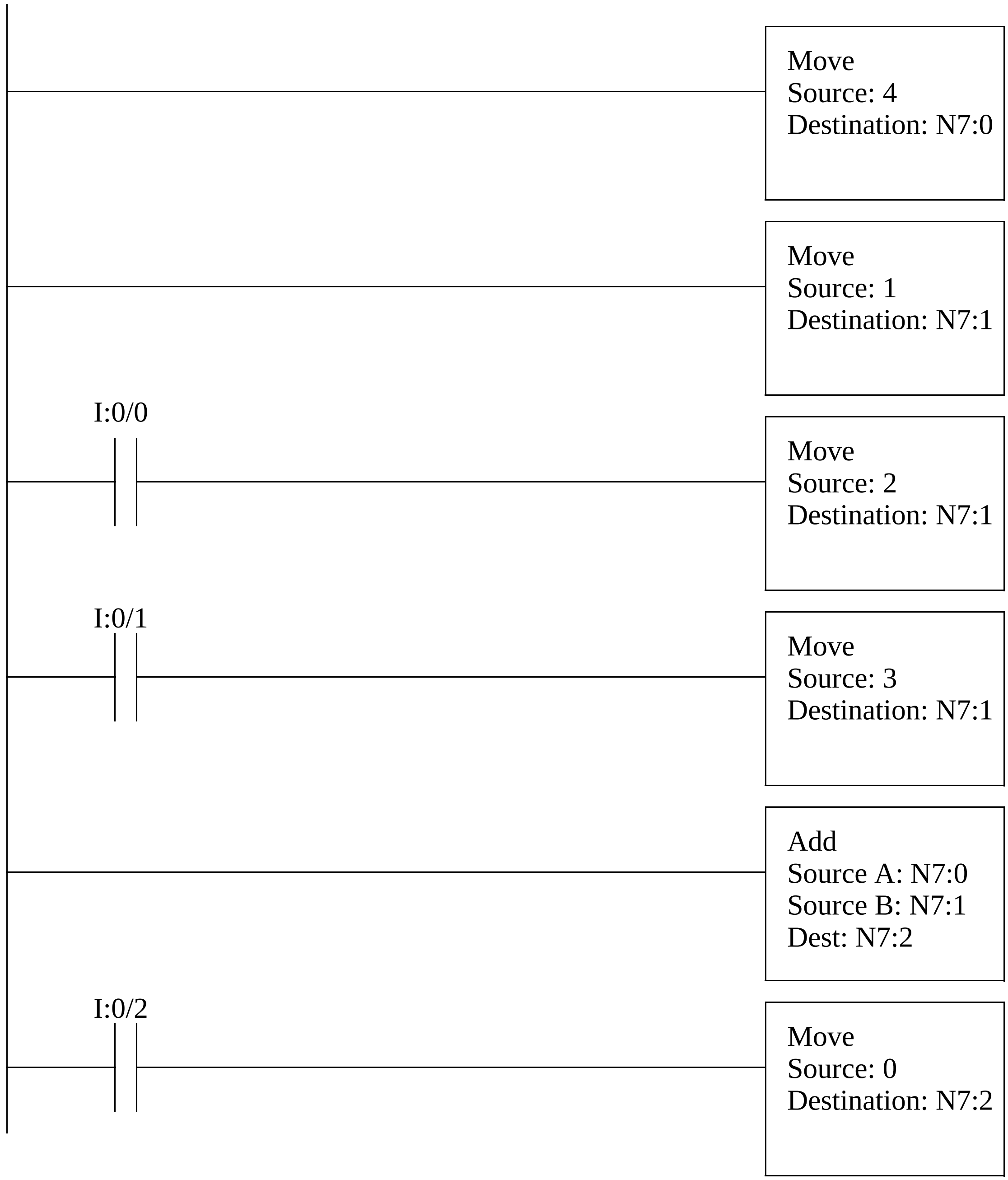
2. Enter the following ladder logic. Notice that the first scan value ‘S2:1/15” has been recognized as the first pass value. Download and run the program. Turn off the PLC and repeat. Notice how the bit is only set when the PLC is turned on.

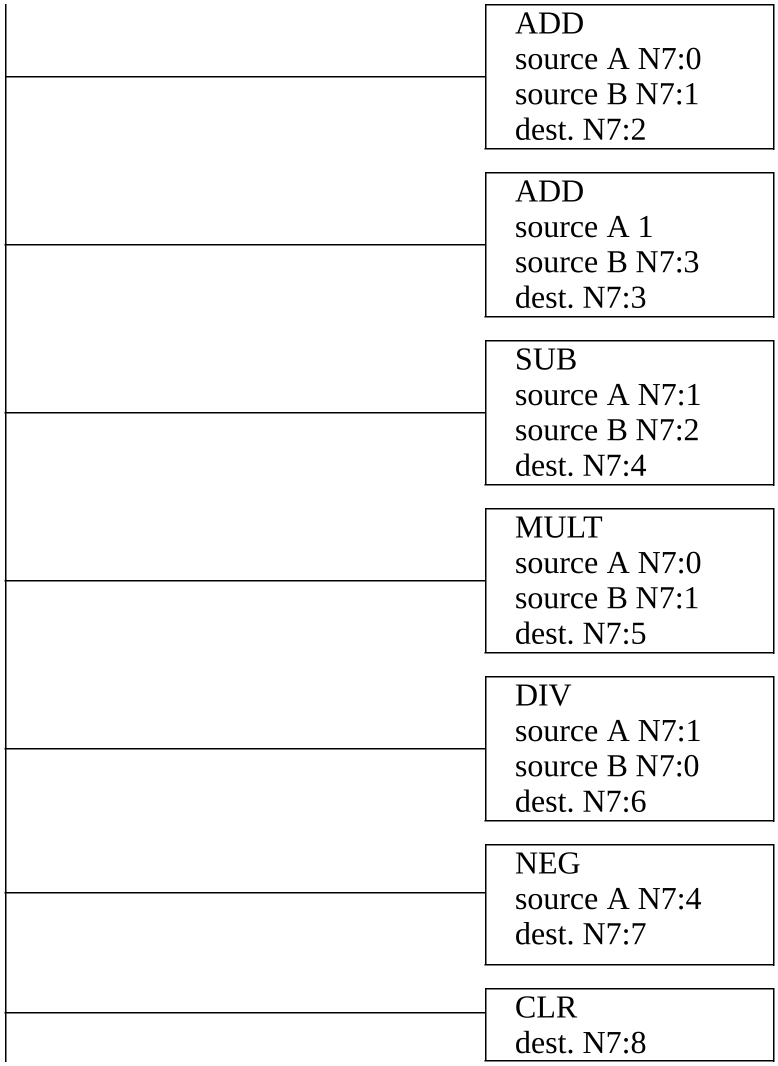


3. Go to “Database” then “Address/Symbol” and double click. This will bring up a list of labels for all of the IO points in the system, including those defined by the user, and predefined values such as status bits.

9.8.1.14 - PRACTICAL - INTEGER MATH

1. Enter the program below, and run it. Try pushing input buttons in different combinations and see what happens.


Move
Source: 4
Destination: N7:0
Move
Source: 1
Destination: N7:1
I:0/0
Move
Source: 2
Destination: N7:1
I:0/1
Move
Source: 3
Destination: N7:1
Add
Source A: N7:0
Source B: N7:1
Dest: N7:2
I:0/2
Move
Source: 0
Destination: N7:2

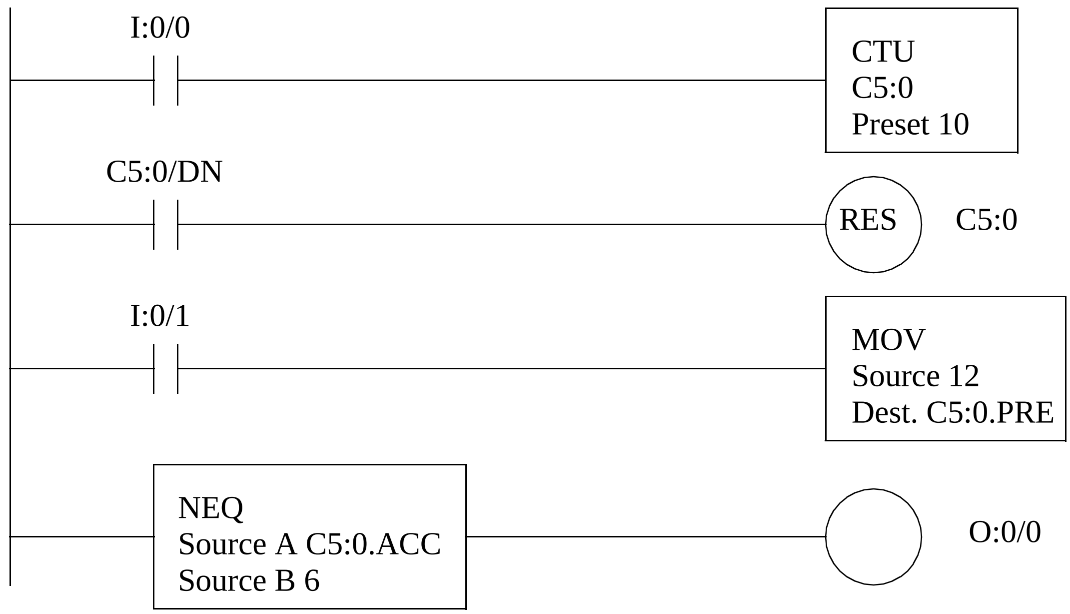


addr.	before	after
N7:0	10	10
N7:1	25	25
N7:2	0	35
N7:3	0	1
N7:4	0	-10
N7:5	0	250
N7:6	0	2
N7:7	0	10
N7:8	100	0

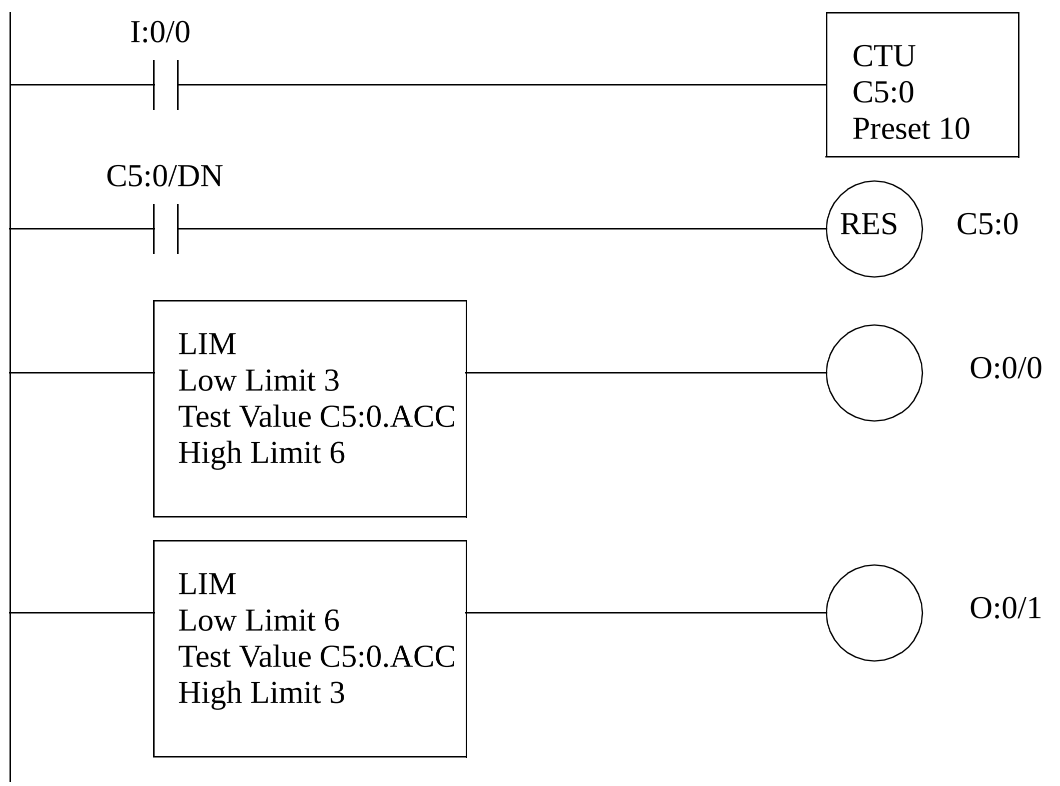
Note: integer values are limited to ranges between -32768 and 32767, and there are no fractions.

9.8.1.15 - PRACTICAL - COMPARISON FUNCTIONS

1. Enter and run the following ladder logic.



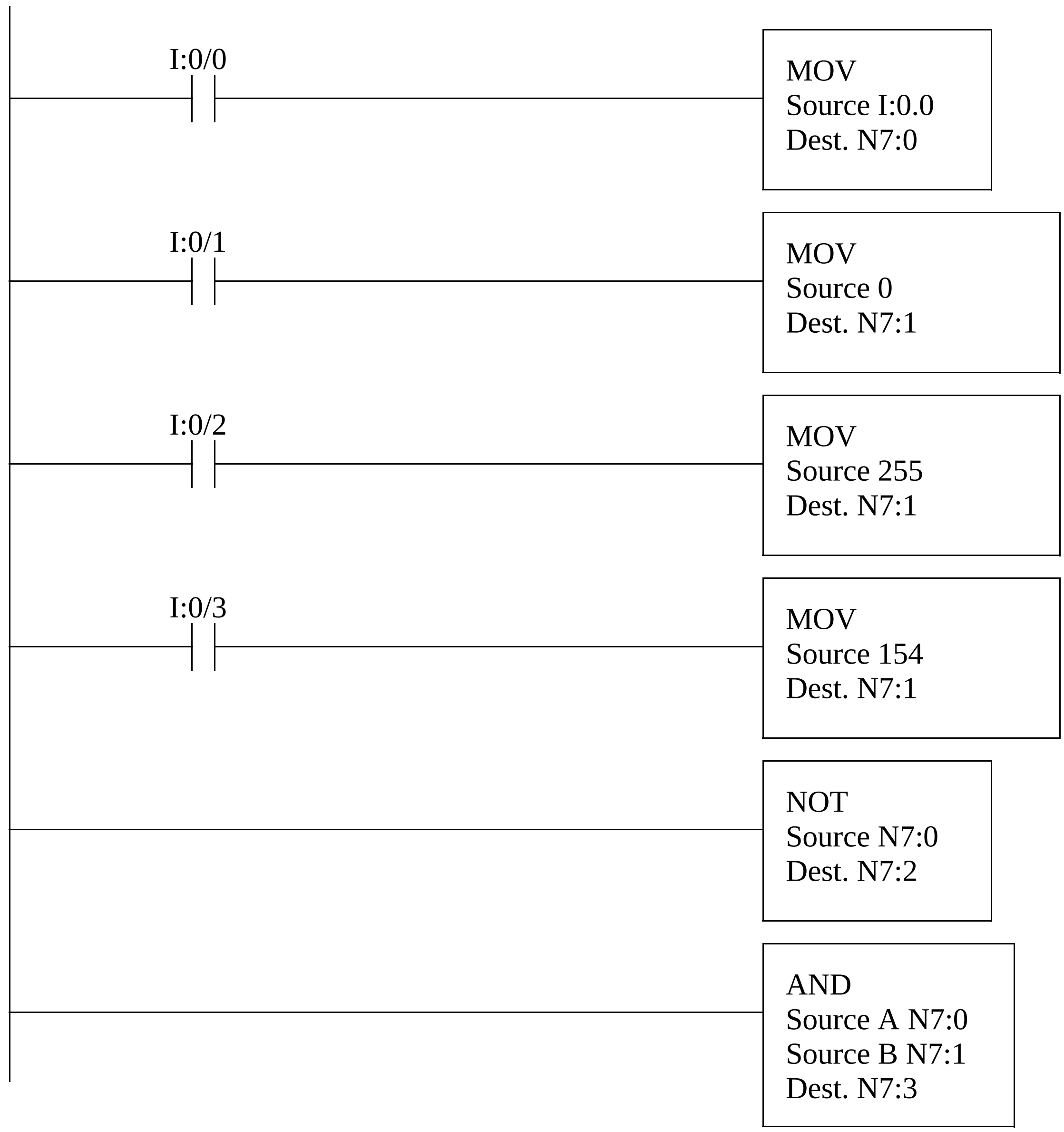
2. Modify the last ladder logic program to match the one below. Run the program.



3. Write a program that uses the other types of comparison functions.

9.8.1.16 - PRACTICAL - BOOLEAN FUNCTIONS

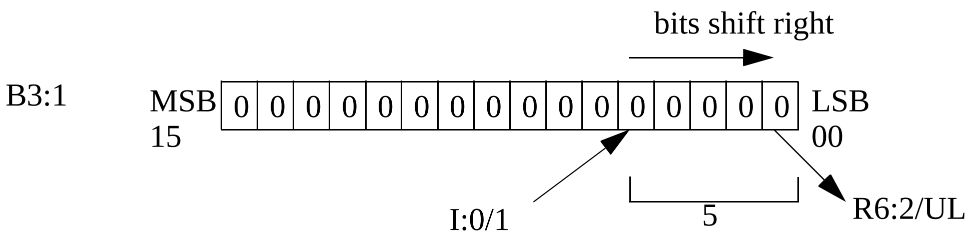
1. Enter and run the following program.

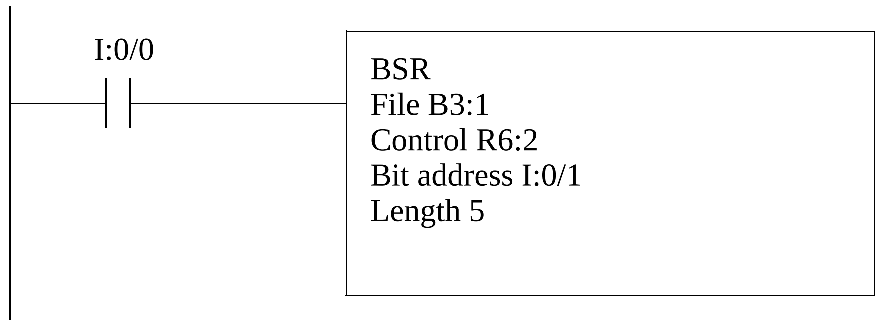


2. Try other Bolean logic functions in the previous program. Try changing the numbers written into N7:1.

9.8.1.17 - PRACTICAL - SHIFT REGISTERS

1. Enter and run the following ladder logic.

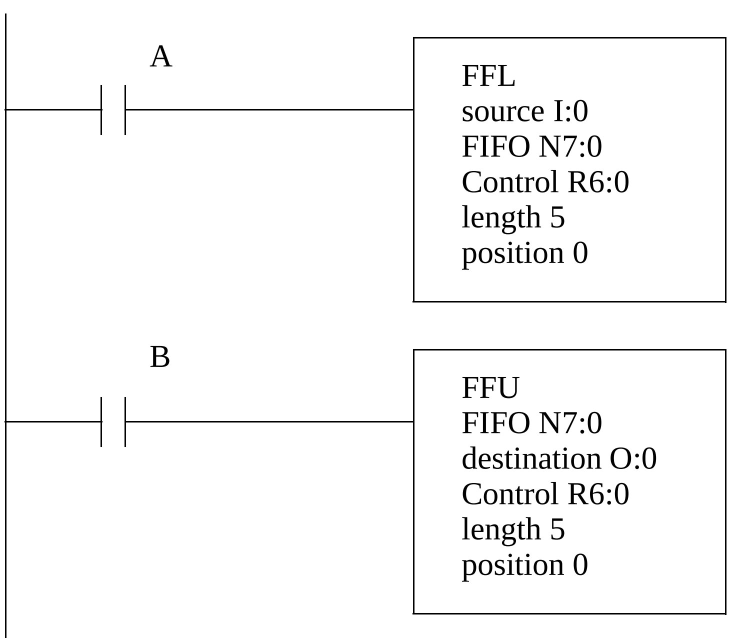




2. Modify the previous program to make lights flash across the outputs (like christmas tree lights).

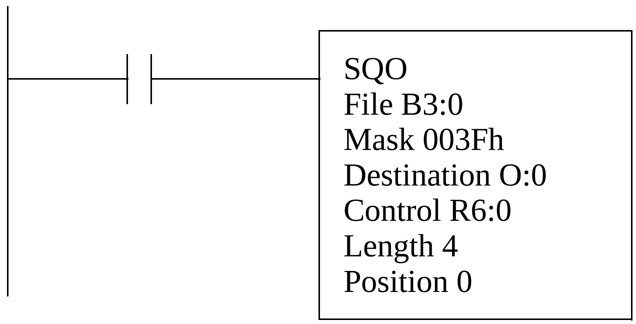
<u>9.8.1.18 - PRACTICAL - STACKS</u>

1. Enter and run the program below.



9.8.1.19 - PRACTICAL - SEQUENCERS

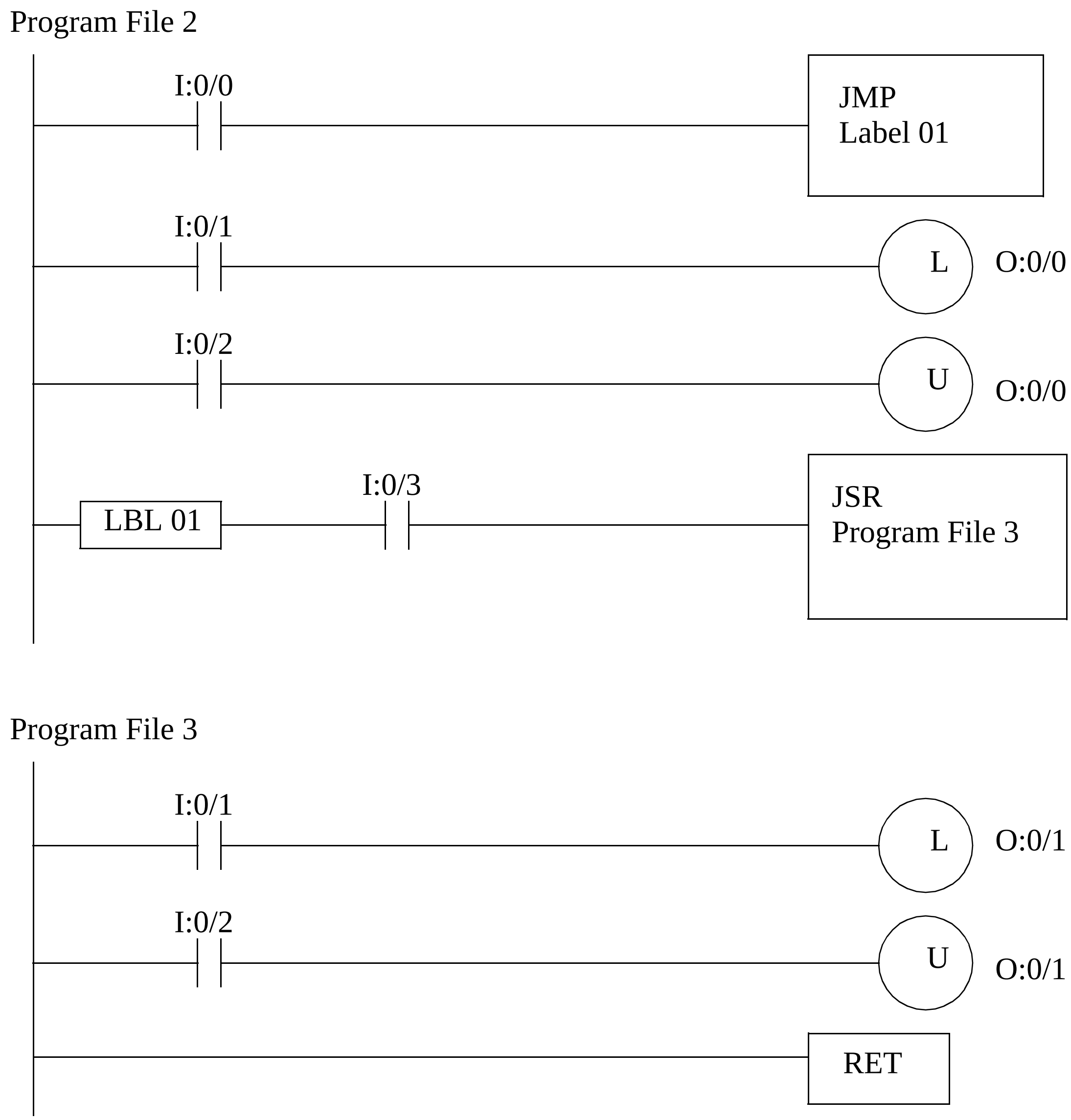
1. Enter and run the program below.



B3:0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
B3:4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
											EW - green	EW - yellow	EW - red	NS - green	NS - yellow	NS - red

9.8.1.20 - PRACTICAL - JUMPING AND SUBROUTINES

1. Enter and run the programs below.



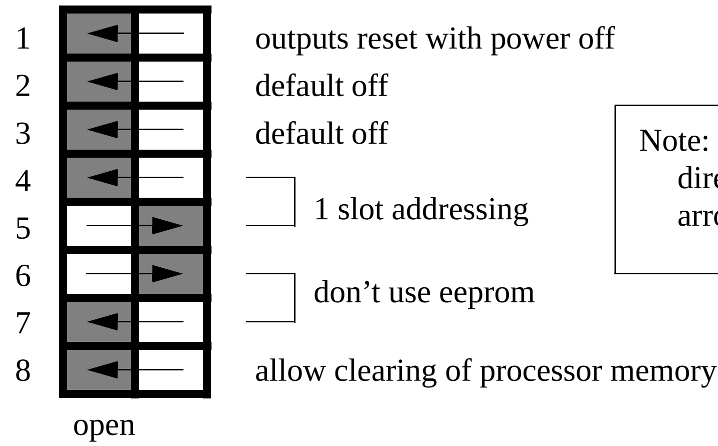
9.8.2 A-B PLC/5 CPUs with RSLogix and RSLinx Programming Software

9.8.2.1 - Basic Tutorial

1. Examine the PLC rack. Flip up the covers at the top of the cards. Flip down the terminal strips on the front of the cards. The cards can now be removed - this will require a bit of force, but the levers at the tops of the cards will help. Write down the card numbers, and the rack number they will look something like ‘1771-OB1’)

2. Look at the backplane of the PLC chassis. There are various connectors and switches. At this time we want to set the switches on the backplane as shown below. These can also bee seen in the “Quick Start Guide”

A. DIP switches

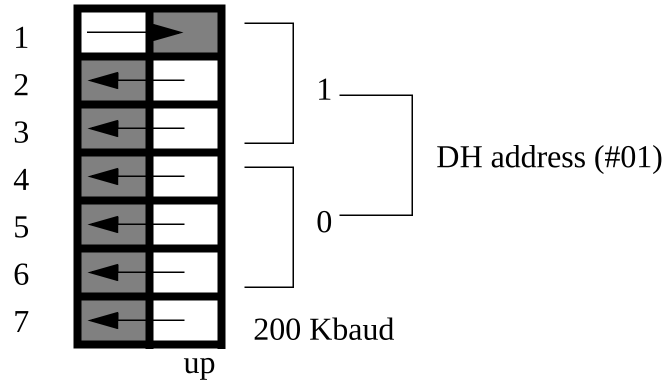


Note: push the switches in the direction indicated by the arrow.

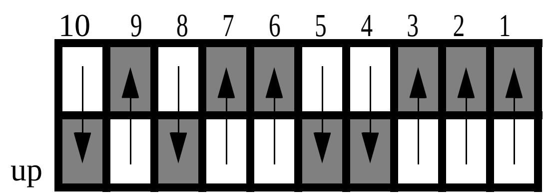
B. Set the ‘power supply in rack’ jumper. If the power supply is a separate stand alone unit select ‘N’. If the power supply is a card plugged into the rack select ‘Y’.

3. Look at the CPU card (PLC-5/11). Inside there are DIP switches that need to be set for communication parameters. (Look at the back of the CPU card and you will also find a legend for these switches.

BACK (S1) - Note: this sets the address of the processor for the data highway network.
(NOTE: we won't use this this week, but set it anyway. It will be used for the communication lab later)



BOTTOM (S2) - Note: this sets the 'CH0' connector on the front for RS-232C so that we may connect it to the PC serial port.
NOTE: When looking at the label on the PLC use the numbers because the label is not oriented the same as the switches.



4. Put the CPU card (only) back in the first slot in the rack. Turn the key to 'rem' for remote operation mode. Apply power and watch the status lights on the CPU. The 'proc' light should go on and stay a steady red, all other lights should be off. Have a look through the PLC5 quick start manual, pay extra attention to chapter 4.

5. Turn off the power and add a DC input card and DC output card to slots 0 and 1 (the order is not important, but write this down). Since we are using the 2 slot addressing mode these two slots will act like one, we refer to this as group 0. In total there are 8 slots, but in two slot addressing there are 4 groups. Each group has to have one input and one output card. This method allows us to have longer racks than normal. Apply power to the PLC and watch to see if the active light goes on (on the input card).

6. Turn off the PLC and plug the (null modem) RS-232 serial cable into the computer and the PLC 'CH0'. Turn on the computer and PLC, and wait until Windows has finished loading.

7. Run the programming software 'RSLogix 5 English'. A blank window should come up. It will be necessary to open a project before beginning to program. Another program, called RS-Linx', will also be used to communicate with the PLC.

8. Select 'File'-'New' and add a processor 'PLC-5/11', give the series/revision 'E', and give the

‘Processor Name’ a unique identifier. Next, change the driver to ‘AB_DF1-1’. This may cause the software to start the RS-Linx program - if it does go to step 9, if not go to step 10.

9. (If RS-Linx has started and is on the screen) Go to ‘Communications’-’Configure Drivers...’-’RS-232 DF1 Devices’-’Add New’. Pick the appropriate COM port and set the device to ‘SLC-CH0’. Then select ‘Autoconfigure’. It should find the PLC and set the port appropriately. Click ‘OK’ and get the RSLogix software back.

10. Click ‘OK’ on the new file creation screen. The program will put up a project window. This will include a scrolling menu on the left that allows access to many functions of the PLC. The ladder logic will appear on the right hand side. Next, we want to set up the PLC configuration. Select ‘IO Configuration’ and change the ‘chassis type’ to the type you wrote down earlier. Change the ‘Rack addressing’ to ‘2 slot’. Finally, change the cards in the rack to match the cards you added (click on the leftmost ‘chassis’ item). At this point the PLC layout should be complete.

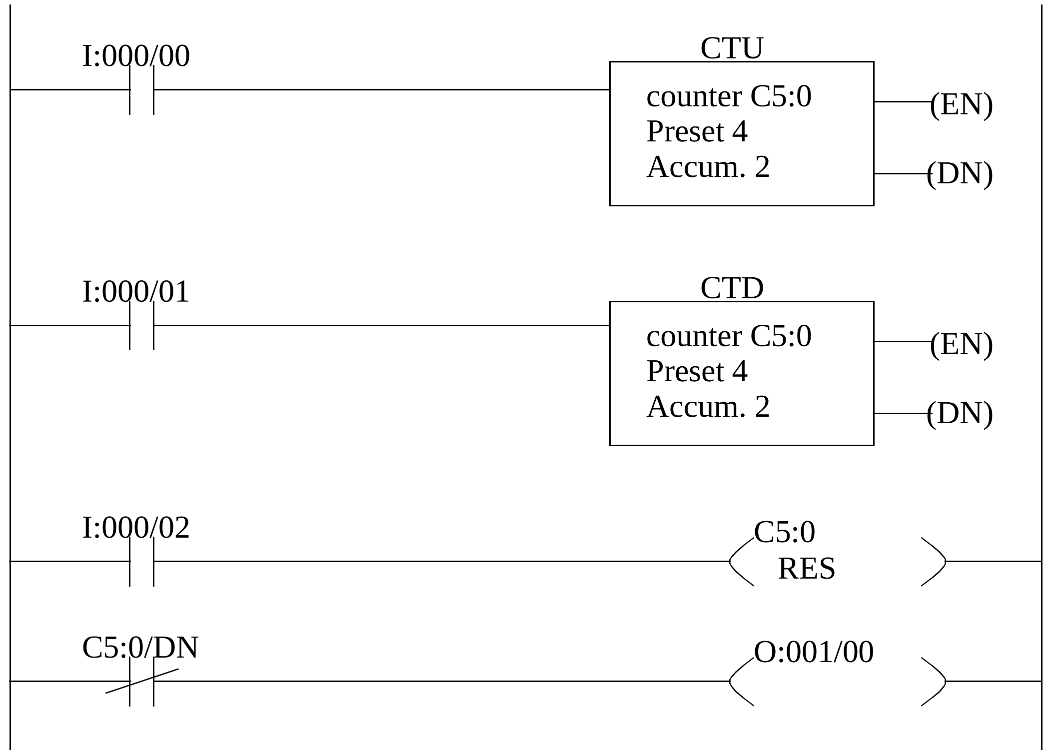
11. Now we can begin to enter ladder logic. To do this click on the line number box that says ‘0000’ and hit return - a new blank line of ladder logic should have been created. Move up to the icon bar that contains ladder logic symbols and select a normally open input contact - it should appear on the blank line. Enter the address ‘I:000/00’ to indicate the input card ‘I:’ on rack ‘0’ and group ‘0’ and input bit ‘/00’. Click on an output symbol and this should add an output to the ladder line. Enter the address ‘O:001/00’ to indicate the output card ‘O:’ for rack ‘0’ and group ‘0’ and output bit ‘/00’. (Note: because we are using two slot addressing the input and output cards are in two separate slots, but share the same group)

12. We are now ready to download and test the program. Go to the ‘Comms’-’Download’ option. Answer the questions as required, and the program should start to download. You may be asked if you want to go on-line, answer yes. If the PLC is running you will see the ‘proc’ light turn green.

13. Connect a 12V DC power supply to the common and input ‘00’ on the DC input card. You should see the input light go on. The ladder logic program should make the output ‘00’ on the output card also go on.

14. Use the ‘help’ button to search for a topic of interest.

15. Enter the ladder logic below, and test it using the 12V DC power supply.

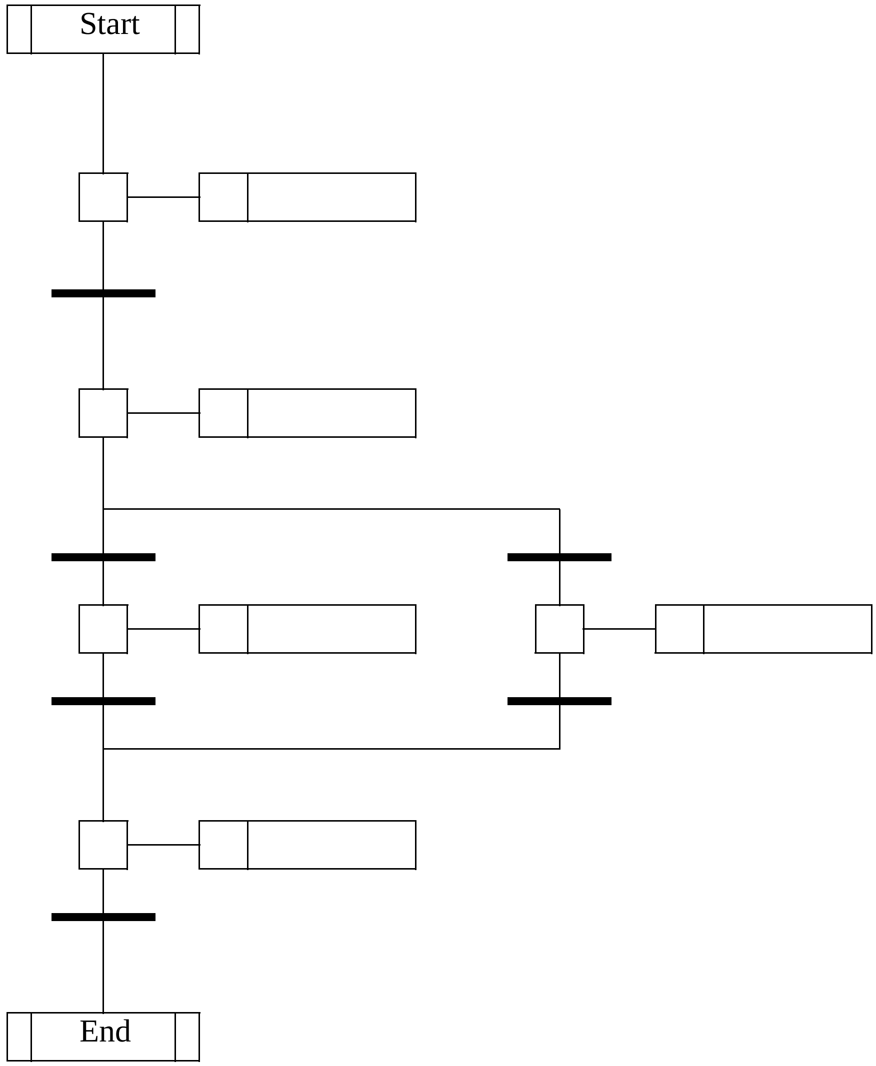


16. Try entering ladder logic from a previous tutorial or lab that uses a timer. (Note: You will need to adapt it to the new addresses on the PLC.)

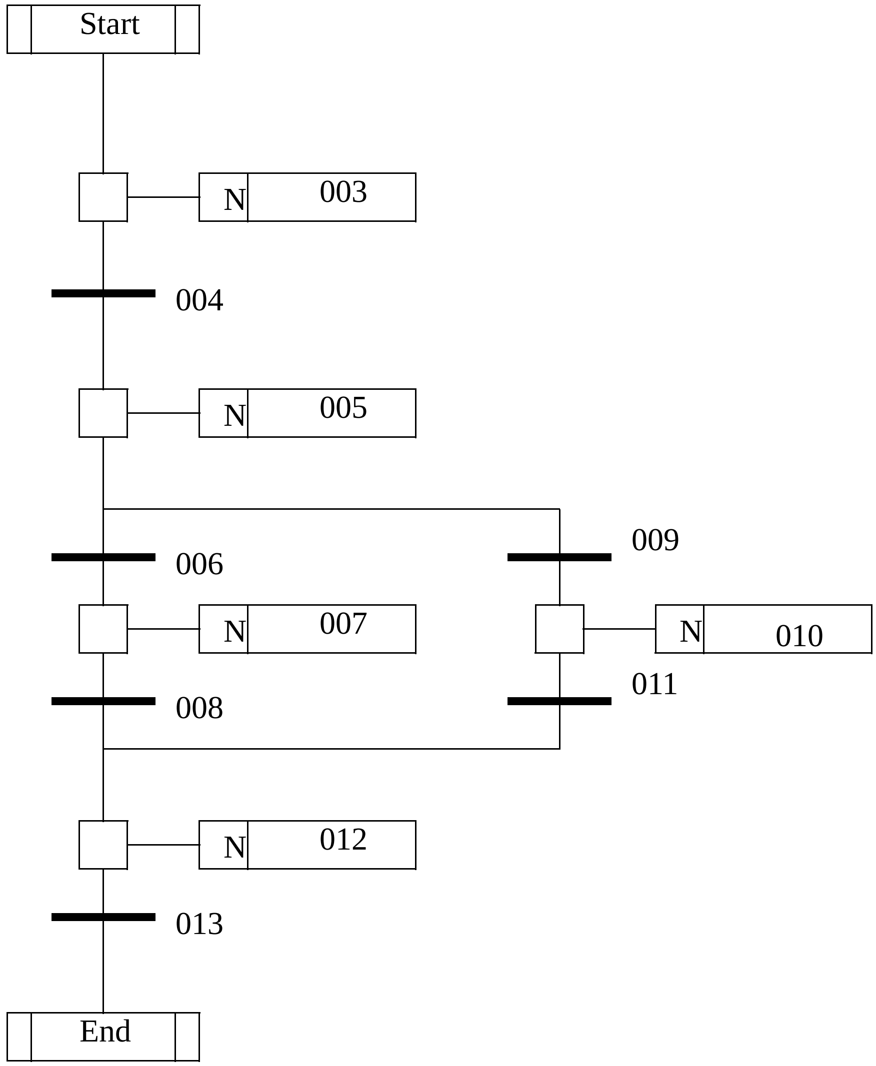
17. Flip through the "Getting Results with RSLogix5" book, and notice the general topics mentioned. Use the help screens to look up more information on various topics. Look for SFCs.

18. Now we will create an SFC. First, we need to close the current file and start a new one. Now, highlight the "Program Files" item on the main program screen. Click the right mouse button and select "SFC". Enter program "1" (not 3), select "SFC File", and name the file something unique. If you click "OK" then the program will be created and added to the project tree.

19. Open up the SFC edit window by double clicking on the "SFC" program file. The SFC edit window appears to the right and can be modified. Edit the program to look like the one below - don't worry about the contents just yet, but the form of the diagram must be the same.



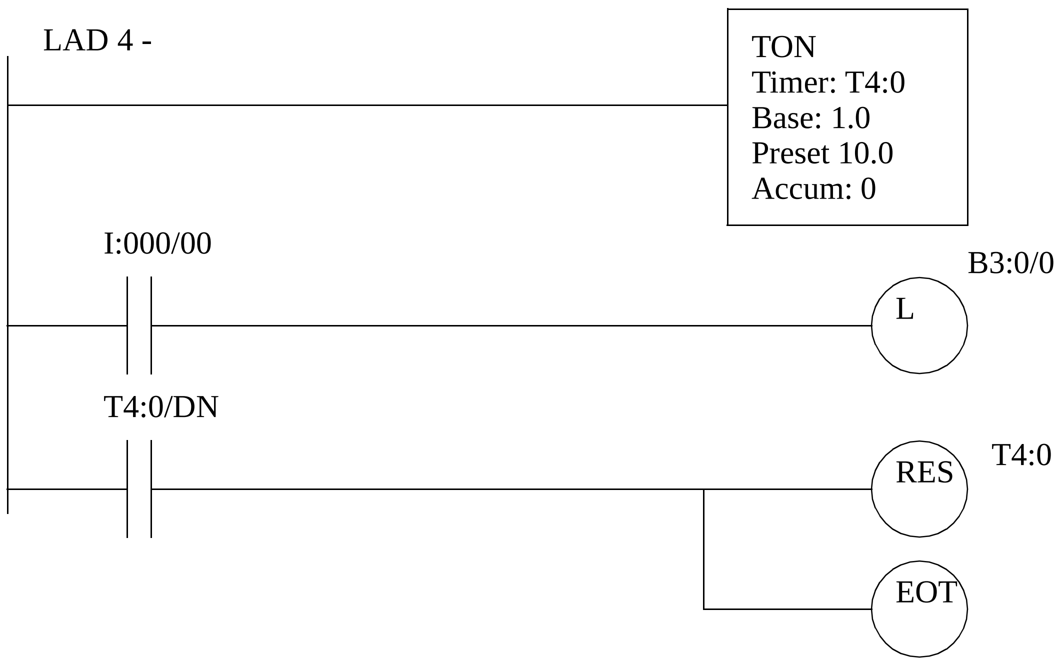
20. When done entering the diagram use “Edit” - “Verify SFC Chart”. The SFC diagram will now be replaced with something like the one below. Notice that ladder logic programs have been created. The numbers on the SFC diagram are related to the new ladder logic numbers. We will modify the ladder logic for each step and transition next.



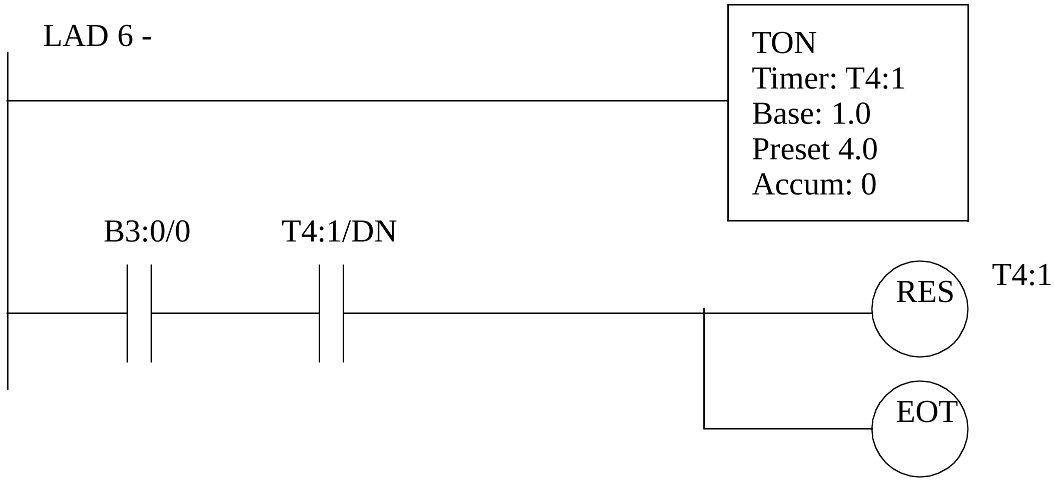
21. Double click on “Program Files” - “LAD 3-” and the SFC diagram will disappear and a ladder diagram will appear. This ladder corresponds to the first step in the SFC. So, here we want to do the actions required using ladder diagrams. Enter the ladder logic below for the program files.

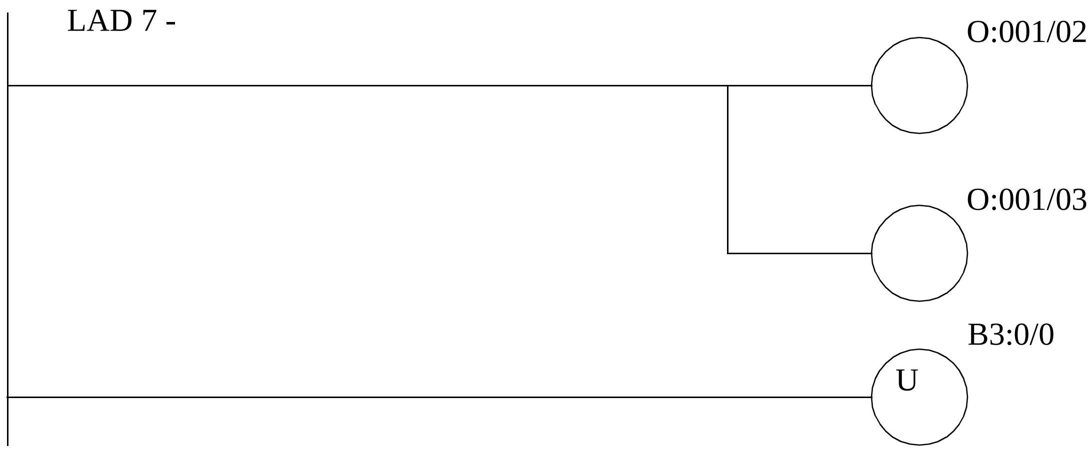
LAD 3 -

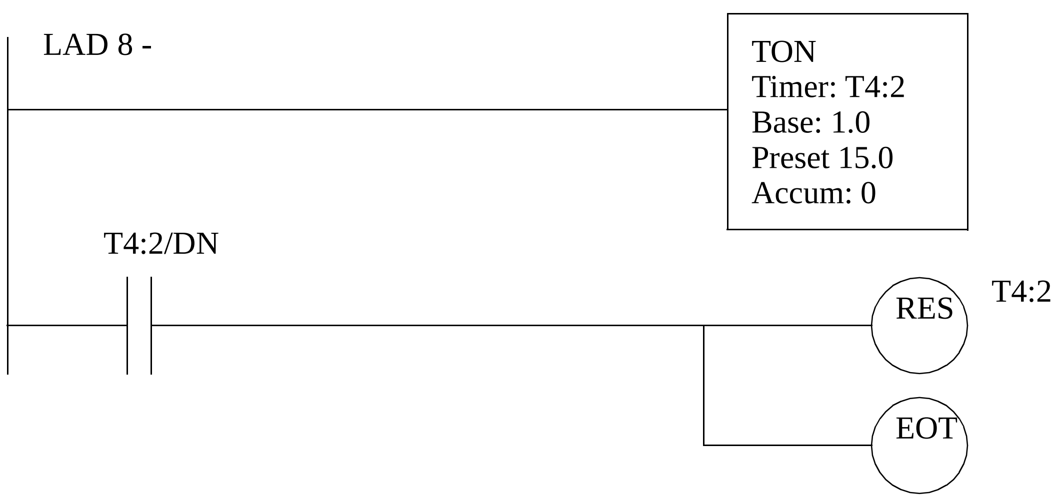
LAD 4 -



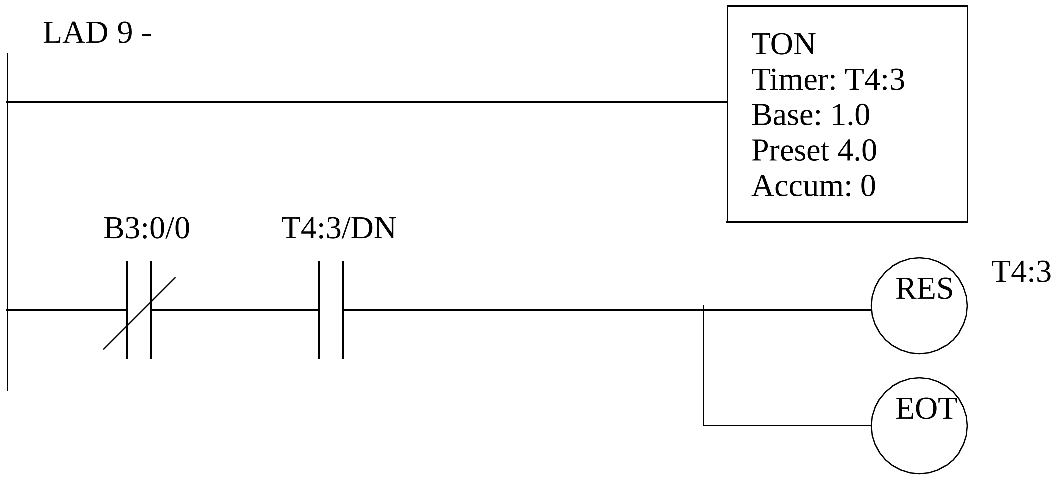
LAD 5 -


LAD 6 -
TON
Timer: T4:1
Base: 1.0
Preset 4.0
Accum: 0
B3:0/0
T4:1/DN
RES
T4:1
EOT


LAD 7 -
O:001/02
O:001/03
B3:0/0
U

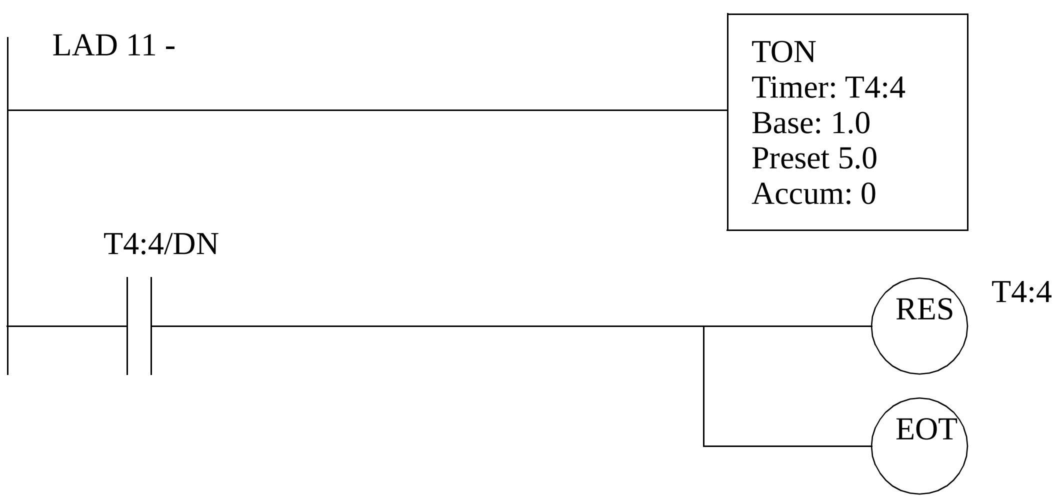

LAD 8 -
TON
Timer: T4:2
Base: 1.0
Preset 15.0
Accum: 0
T4:2/DN
RES
T4:2
EOT

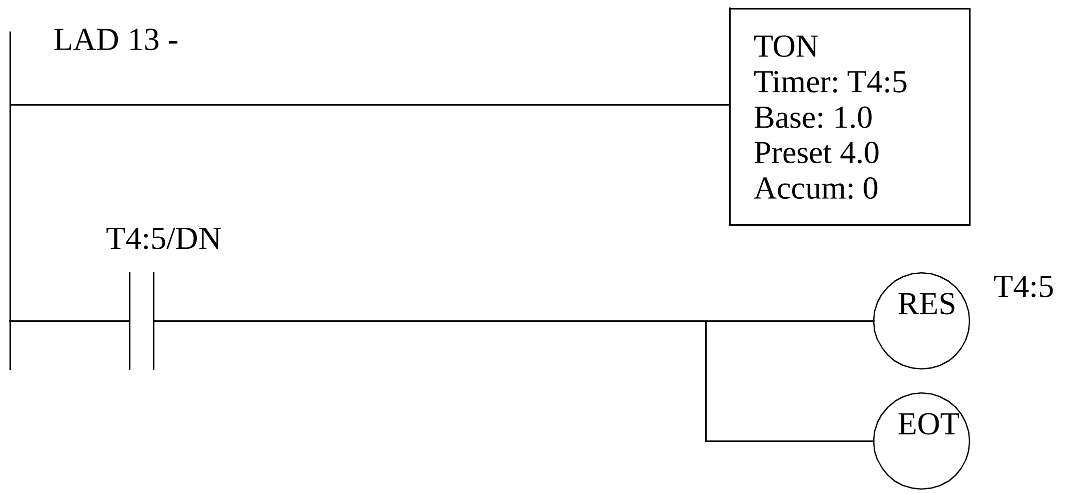
LAD 9 -



LAD 10 -

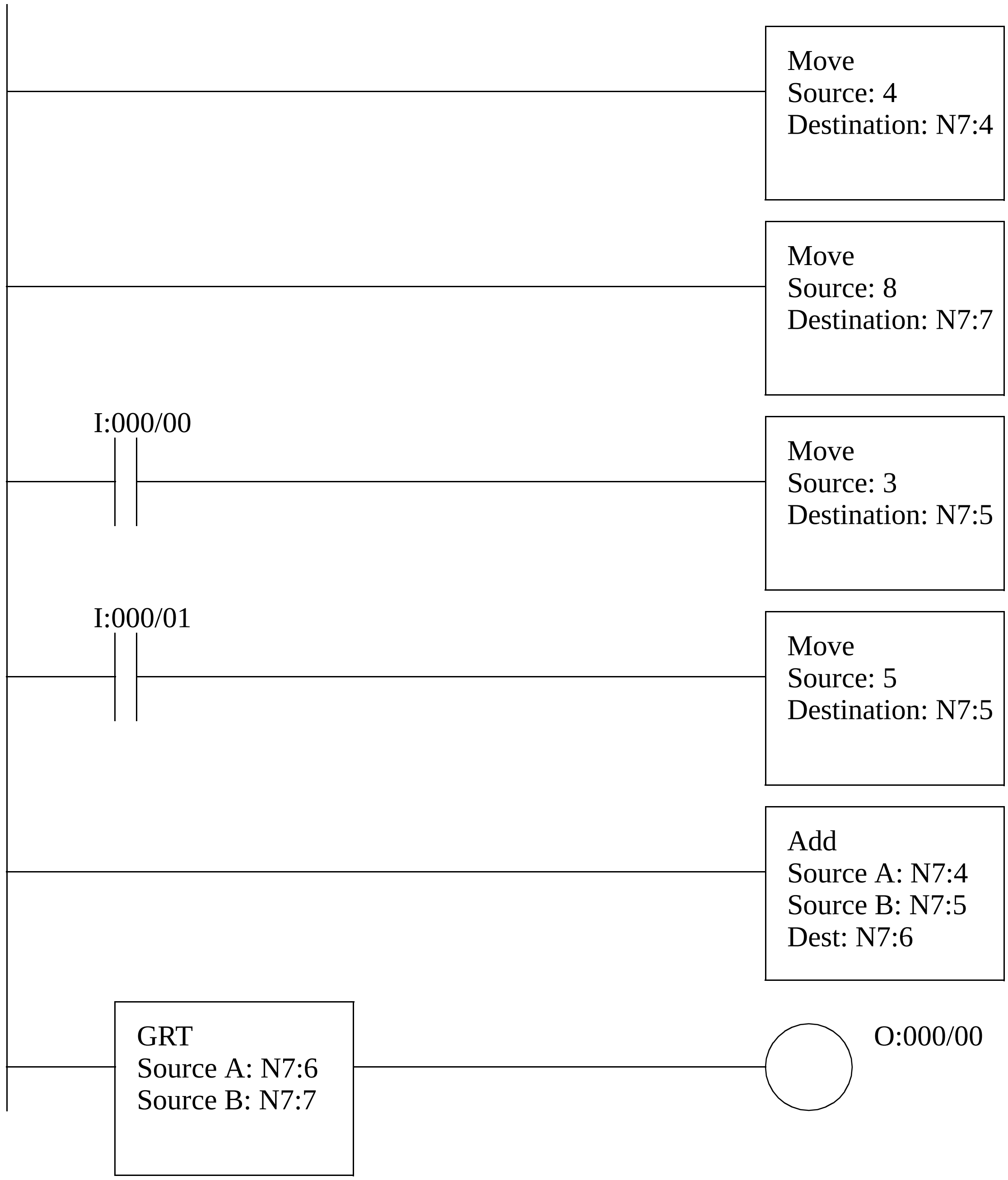
LAD 11 -



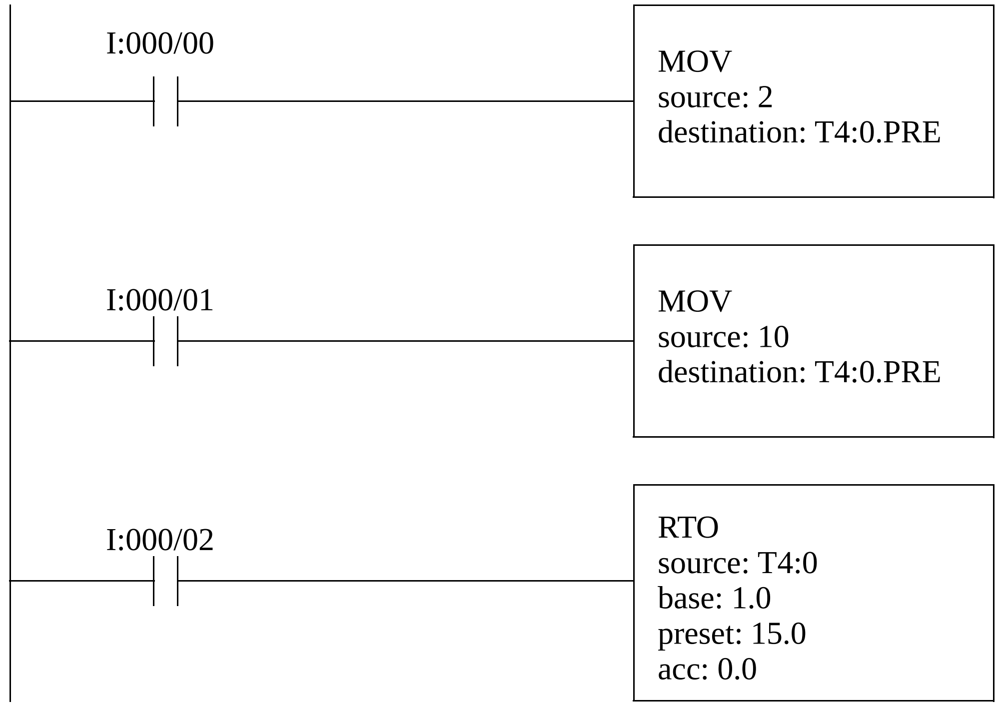


22. Run the program - You should see a traffic light configuration. With input ‘00’ changing the length of the green light.

23. Finally we will write a program that adds two numbers. If the sum is greater than 8 then an output will turn on. Enter the ladder logic and run the program. Watch the values displayed, and notice how applied voltages to inputs ‘00’ and ‘01’ change the values.

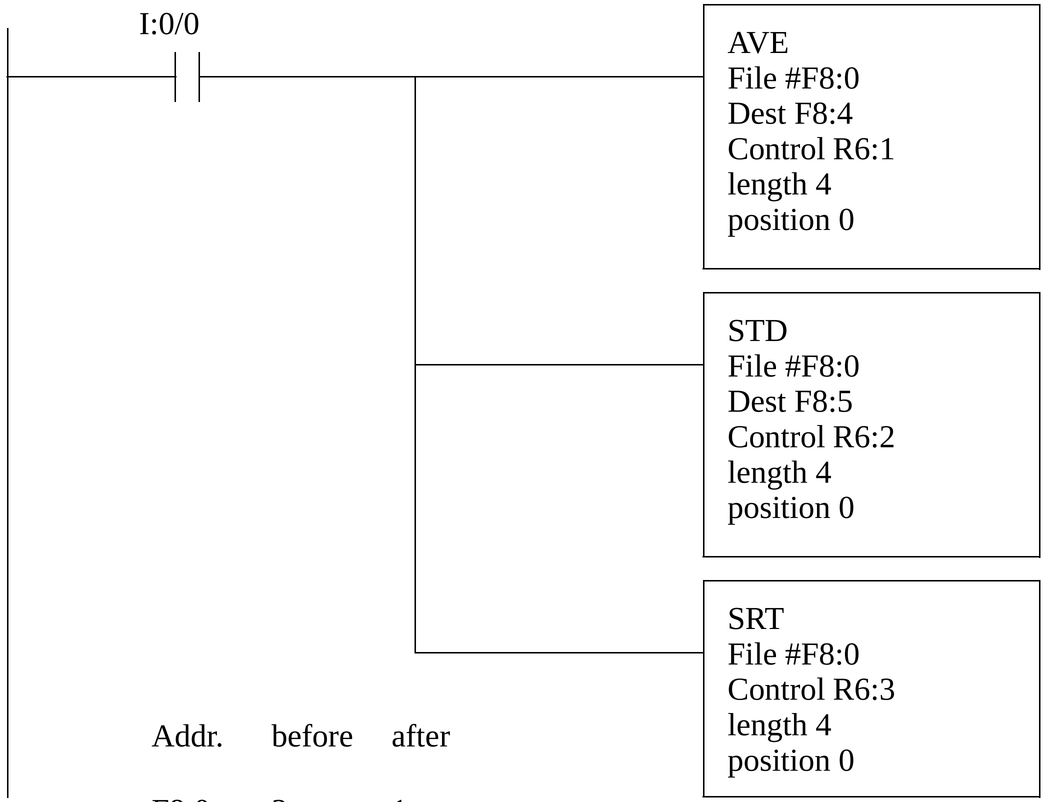


24. Enter and try the following program, it will directly influence timer preset values in memory. Try testing the basic operation. Then, set the preset to 2 seconds. Then cause the timer to pass the 2 second preset, note the result, but don't reset the timer. Set the preset to 10 seconds, and continue the timer increment.



9.8.2.2 - PRACTICAL - EVEN MORE MATH

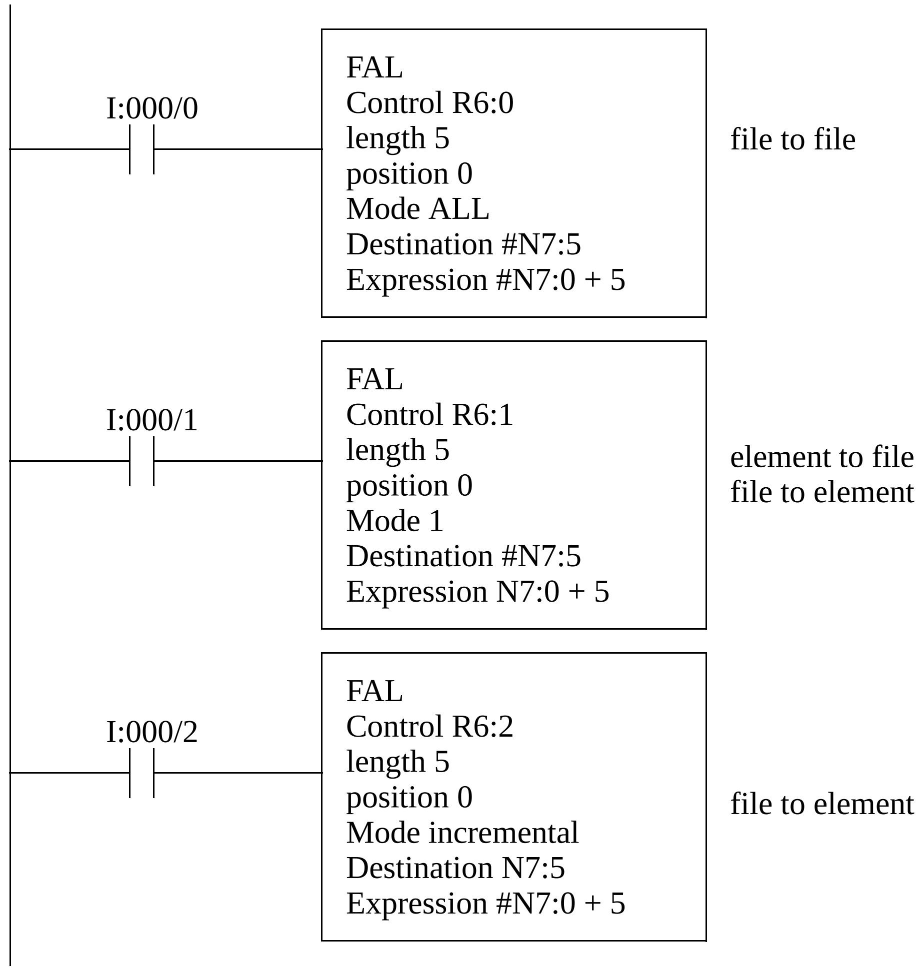
1. Enter and run the program below.



Addr.	before	after
F8:0	3	1
F8:1	1	2
F8:2	2	3
F8:3	4	4
F8:4	0	2.5
F8:5	0	1.29

9.8.2.3 - PRACTICAL - FILE ALGEBRA

1. Enter and run the following ladder logic.



9.8.2.4 - PRACTICAL - INDIVIDUAL EXERCISE

1. Write your own program to average the time time that an input is held on. Use a timer to find the time the button is held. Add comments to the rungs and symbols to the inputs and outputs.

10. DVT CAMERA TUTORIAL

NOTE: The camera is not required for this tutorial.

1. If the ‘Framework’ software is not installed, install it from the CD.
2. A window will appear called ‘PC Communications’. Select ‘Emulator’ then ‘Model 630’. Two windows should now be on the screen. The window called ‘DVT FRAMEWORK’ is the main programming software. The window titled ‘DVT SmartImage Sensor Emulator’ takes the place of an actual camera for tutorials like this one.
3. First we need to load images into the emulator window. To do this select ‘Configure’, then ‘Image Sequence...’. An ‘Image Sequence Configuration’ window will appear. Use ‘Browse for images’ and select the first image as ‘Image001.bmp’ and the last image as ‘Image008.bmp’. Then select ‘OK’ to load the images.
4. In the Framework window select the ‘Products’ then ‘Products Management’. Select ‘New’ and enter ‘tutorial’ as the product name. This will be used to store one or more tests for a particular product. Note: if the camera is to be used to test multiple types of products, the names of other products will also be entered here. Select ‘OK’ to dismiss the window.
5. We can now start the camera running. In the top toolbar there is a black triangle that points to the right (near a red circle). Click this to run the camera emulator.
6. Select a sensor for the product on the left side with ‘EdgeCount’. On the palete that appears select a line draw it so that it covers the circle. Select ‘OK’ and the tests should begin. The test status line will show the number of edges detected in the image.

EGR 474 - INTEGRATED MANUFACTURING SYSTEMS

11. LABS

12. TUTORIALS

• The following tutorials can be used to explore various technologies that support integrated manufacturing.

• Some tutorials depend upon other support materials that you will have access to throughout the semester. Many of these are manuals that have come with the software/hardware.

Course Number: EGR 474
Course Name: Integrated Manufacturing Systems

Academic Unit: Padnos School of Engineering

Semester: Summer 2001

Class/Lab Times: 3-6pm - Mon, Thurs in EC612

Description: An introduction to the integration of machines and processes into manufacturing systems. Topics include methods for interconnecting and networking devices, organizing functional groupings such as cells, production lines, material flow, collecting and organizing production data. The technical issues involved in implementing various control schemes will be presented. Laboratory.

Prerequisites: EGR 450

Instructor: Dr. Hugh Jack,
office: 718 Eberhard Center
office hours: 10-11am Mon, Wed, Thurs
phone: 771-6755
email: jackh@gvsu.edu
web: http://claymore.engineer.gvsu.edu

Textbook: Jack, H. EGR474 Integrated Manufacturing Systems Course Notes, Grand Valley State University

Software: AutoCAD, Netscape Communicator, FTP/Telnet
RSLogix Programming Software, Labview, C/C++ programming software, Linux, Windows NT, Postgres SQL, etc.

Goals: When done the student should be able to design, and implement an integrated manufacturing system. This will be done by classroom and laboratory exploration of flexible automation devices. In the laboratory work there will be a constant effort to integrate sub-systems into a larger framework. The course will conclude with a major project.

Instruction Methods: Lecture, discussion, laboratories, assignments and projects.

Prerequisites by Topic:

1. C, C++ and/or Java programming
2. Manufacturing control systems (or electrical)
3. Manufacturing processes
4. Production scheduling and control
5. Computer applications and programming
6. Linear algebra, trig., calculus, differential equations, etc.

Topics: (Topics 12-13 will be covered if time permits)

1. Multitasking, multiuser operating systems
2. Review of C and C++ programming
3. Databases
4. Communications and Networking
5. Interfacing to serial devices (with RS-232)
6. Robot programming and interfacing
7. CNC Equipment programming and interfacing
8. Material Handling Systems programming and interfacing
9. Interprocess and intercomputer communication (with TCP/IP)
10. Integration Issues
11. Flexible Manufacturing Systems
12. Vision Systems
13. CAD/CAM/CIM Overview

Grading:

Tests/Assignments	20%
Labs	30%
Final Project	30%
Final Exam	20%

Tests and assignments will be given at natural points during the term as new material is covered. Laboratory work will be assigned to reinforce lecture material and expose the student to practical aspects of automated manufacturing. A final project, involving construction, will be assigned and demonstrated later in the term. Marks will be assigned based on a combination of performance and report. A final examination will be given to conclude the work, and test the students global comprehension of the material. A final presentation and report is required.

Grading Scale:	A	100 - 90
	A-	89-80
	B+	79-77
	B	76-73
	B-	72-70
	C+	69-67
	C	66-63
	C-	62-60
	D+	59-57
	D	56-53
	D-	52-50

1. OLD OVERVIEW

1.1 RESOURCES

• We will make extensive use of texts that should have purchased or own already,

Bollinger, J.G. and Duffie, N.A., Computer Control of Machines and Processes, Addison-Wesley, 1989.

Chang, T.-C., Wysk, R.A. and Wang, H.-P., “Computer-Aided Manufacturing second edition”, Prentice Hall, 1991.

Kalpakjian, S., Manufacturing Engineering and Technology, Addison-Wesley (3rd. ed.), 1995.

1.2 PROJECTS

Objective: Students will learn how to synthesize a control system by selecting and building a complete integrated system from beginning to end.

Method: The basic steps are outlined below,

1. Course begins
2. Students (individuals or groups) will submit a proposal for a project within the first three weeks.
3. The instructor will review the proposal, and suggest changes as necessary.
4. During the term students will design, build and test their proposed projects.
5. In the last week of classes the final project will be demonstrated and formally presented.

1.2.1 Topics

• The following topics are some possible topics, in priority,

1. Projects for the workcell
    a) Develop a computer program for scheduling.
    b) Design and build a material handling station for the lab.
    c) Develop a product information database
    d) Develop a quality monitoring systems
    e) Write a workcell control program (either C or Java)
2. Select a problem from a local company
3. Select a project based on your interests
    a) Build a CMM that uses an arm with measured joint angles.

b) Design and build a robot.
c) Develop an idea of your own.
d) Design and build an NC machine.

1.2.2 Project Descriptions

Name:
Title:
Description:
Deliverables:

1.2.3 Previous Project Topics

"GVSU Workcell" (Jenny Agnello, Tom Johnson, Colin Moore, Lisa Nahin, Jeremy Scott) The material handling system at GVSU was designed to produce puzzles. The heart of the system was an Allen Bradley SoftPLC and Devicenet. It controlled a material handling system supplid by Worksmart Systems. The system included a robot for loading/unloading the mill. A CNC mill for cutting the parts. A vision system for inspecting the final parts. Various feeder and fixtures were designed and build by students in EGR450.

"Hole in Sphere Project" (Alex Wong, Robert Krygier, Andre Cargnelli, Ahmed Nensey) A mechanism will be designed and built for orienting spherical balls with small through holes. This will be done with a mechanism that uses three rollers for orientation, and an optical pair to detect the hole. An electromechanical control system will be used.

"Automated Robot Arm" (Lev Mordichaev, Karl Fung, Dennis Ngo, Nikko Chan, Edwin Wen, Elaine Rodrigues) A robot arm will be designed and built that can move up/down, left/right, and has a gripper that will open/close. The robot will be controlled via a computer program, and electrical connections to the robot.

"A Manually Controlled Robot" (Keith Lou, Sue Lee, Richard Dankworth, Phat N. Huynh, Howie Lam, Tarius Makmur) To build a manually controlled robot to perform a certain task using a joystick for control. This small scale robot will be capable of picking up an object, and positioning it in another location. And, for proof of concept, a set of fixtures, jigs or feeders will be constructed for a simple robotic task. Note: This project has too many people for construction of a robot only.

"A Box Sorting System" (Joey Aprile, Don Christie, Gabe Fusco, Mike Poczo) A conveyor based system will be designed and built for sorting boxes by a switched conveyor path. This will include construction of the conveyor, sensors, actuators, and control system.

"Automated Drink Dispenser" (Keith German, Dave Van Den Beld, Jeff Kempson, Brent

Rubeli, Michael Staples) Glasses on a conveyor belt will be transported to/from a dispensing station where they will be filled by an automated mechanism. The system will be designed and built, possibly using a PLC, or a PC for control.

"Self Leveling Platform" (Gerard Biasutto, Mario Borsella, Dino Farronato, Marco Gaetano, John Yuem) An actuated system will be designed and built to level a platform under tilting conditions. This will involve actuators positioned at four corners. A control system will be constructed to drive the actuating cylinders.

"Raytracing and Animation" (Greg Squires, Ed Hoskins, Marie Malyj, Allan Zander, Tara Hillebrandt) POVray was used to animate a sequence of images to illustrate a pipe layout

"NC Machining with SmartCAM" (Neil Babcock) A fishing reel was designed. The reel was cut on an NC machine using Smartcam software for programming.

"A graphical computer program for flow analysis on PC's" (James Barr) A computer program was written to do an analysis of a sphere moving through a fluid.

"Manufacturing Database" (K. Beute, M. Mead) A manufacturing database will be developed that allows operators to call up machine configurations based on part numbers. This system uses an HMI to allow easy operator access.

"Construction and control of Stiquito Robot" (T. Cowan and J. Cummings) A kit for a stiquito robot will be purchased and assembled. The appropriate interface electronics and software will be written to control the robot.

"Virtual Reality Modeling" (N. Dunklin) VRML will be explored and used to implement a 3D model of a complex part. This will allow a user to explore the 3D world using a simple internet browser.

"Automatic Generation of CNC Programs" (K. Gehrke) A computer program will be written in C/C++ to automatically generate computer programs in C or C++ to cut initials in keytags.

"Java Programming" (N. Kaye) The Java language will be learned, and a program will be written to cover some aspect of integration or automation.

"Computer Based Analysis of Battery Discharge Data" (R. Sietsema) A computer application will be developed using Excel, and a scripting language, to allow a user to do an analysis of battery discharge data.

"Force Feedback Joystick" (R. Serebryakov) A force feedback joystick will be designed and built. It will be interfaced to a PC and controlled with Labview.

"Design and Construction of Robot" (S. Williams) A robot will be designed and built. The robot will be interfaced to a computer for control.

1.2.4 Homework Problems

- The following chapters and problems are suggested, in addition to the laboratory materials and the course notes

- The suggested problems Chang and Wysk are recommended to help you examine the basic properties of the problems. the required problems assigned during the semester must be submitted. Doing only the required problems will leave you at a disadvantage.

Read	Description	Suggested	Required
cww7.1-5,7A,7B	PLCs	1,2,3,7,10,11,12	
cww8.1-3	Networks	1,2,3,5,6,8,10,11,12,13	
cww11.1-10	Robotics	1-4,8-13	
cww11.11	Vision		
cww9.1-9.4	NC machine tools	1-8,10,12,13,16,17,19	
cww10.1-10.6	NC programming	1-4,6-8	
cww3.1-3.?	CAD systems	3-9,13,15-18	
cww3.?-3.9	Splines		
cww6.1-6.5	Automation	1	
cww1.1-1.5	CAD/CAM/CIM	4-5,7-12	
cww15.4-15.7	Integration	5-6	
cww15.1-15.3	FMS systems	1-4	
cww6.6-6.7	Material Handling	4-7	
cww6.8	Automation economics	8	
cww11.8	Robot economics		
cww8.1-8.3	Networking	1,3,5-6,10,12,13	
TBA	Databases		
cww16.1-16.6	Planning and simulation	1-6,9	

1.2.4.1 - Solutions - Chapter 1

1.4

1.5

1.7

1.8

1.9

1.10

1.11

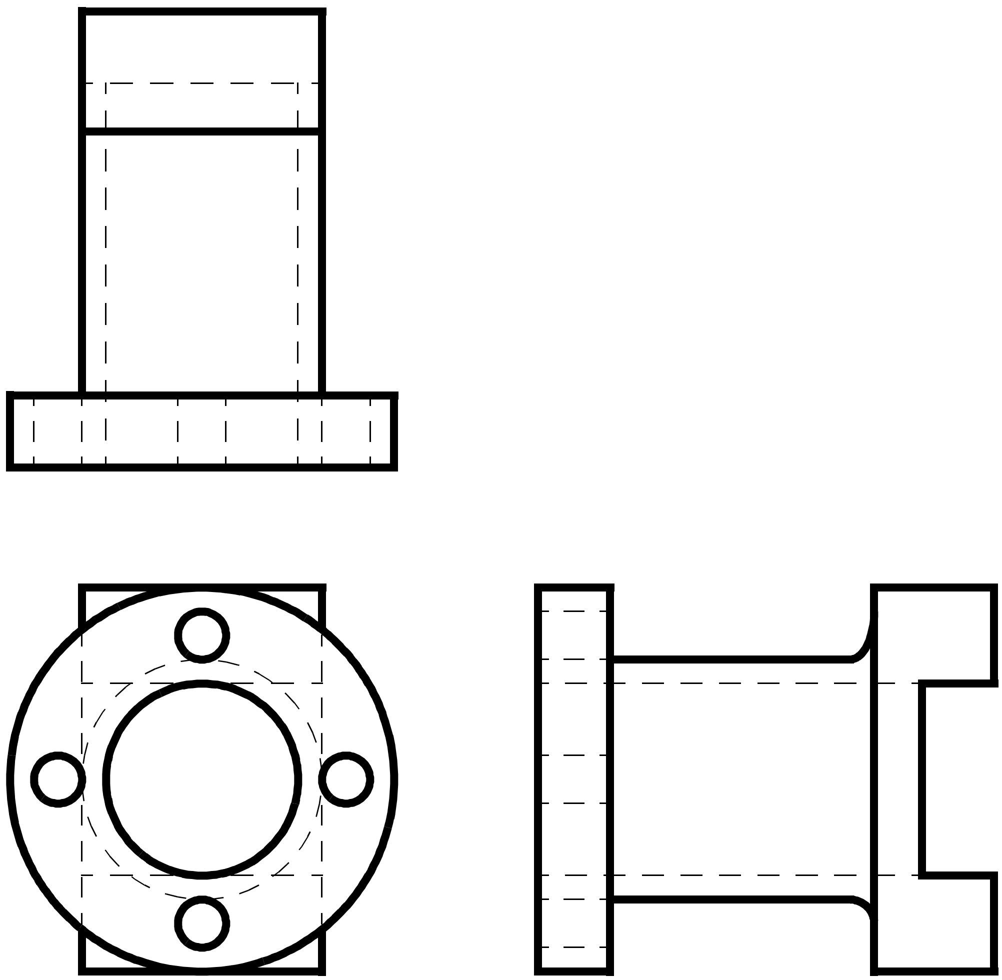
1.12

1.2.4.2 - Solutions - Chapter 2

1.2.4.3 - Solutions - Chapter 3 - CAD and Splines

3.3 There are three significant levels of solid models. The lowest level is the 2D line based model. To represent any real part with this we need two or three views. Mathematically is can be difficult or impossible to relate the lines in the different views. A 3D line based model is a bit better, the lines are all related, but determining where the inside/outside lies can be a problem. 3D solid models are the highest level and are useful because we can exactly determine what parts of space the geometry occupies. The mathematical exactness of the model makes it well suited to supporting other tasks after geometrical design such as finite element analysis, and automatic generation of NC programs.

3.4



Note: the figure in the text is incorrect
Note: not to scale and dimensions not given

3.5 Using the definitions of the book the major divisions include Mechanical, Architectural, Electrical/Electronic and Map Making. This list is not complete and can be expanded to include manufacturing (such as CNC milling), process (pipe layouts, etc.), textiles (clothing design and pattern making), etc.

3.6 CAD systems can be of benefit for engineering design when the geometry is to be reused. Examples of reuse include CNC program generation, FEA analysis, paper drawings, shipping drawing to customers, drawings imported into other designs, drawing will be revised. New CAD systems not mentioned in the book also allow designs to be treated like a sketchpad. Think of Pro/E that allows a design to change radically by altering one dimension on the screen. When users become proficient, CAD systems will make them more efficient. After a CAD systems has been in use for some time new designs can be done by modifying old CAD files.

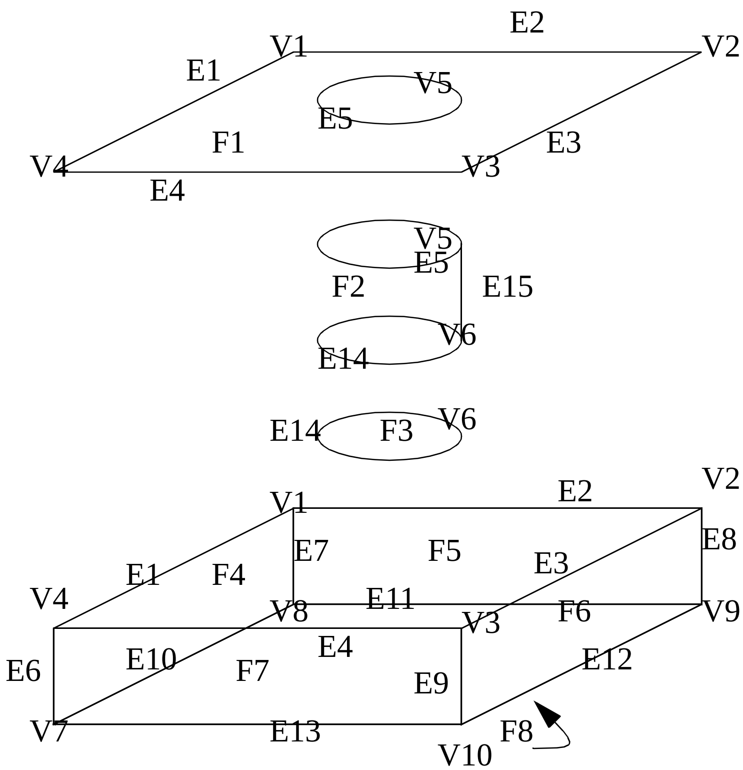
3.7 The major difference between a wire frame and solid model is the mathematical representation. The wire frame model only indicates where edge of the model lay in space. This leads to ambiguity, not knowing where the inside of the part lies. Another major problem is that the wire frame models do not allow curved surfaces to be drawn easily. (This can be with done approximately with difficulty using cross section drawings) Solid models contain a closed mathematical surface model, including all geometrical features.

3.8 Solid models contain part models with splined surfaces. These can be used directly to generate NC path programs. Surface modelers are also available, but uncommon these days.

3.9 We can used Euler's equation, there are no holes in the part faces so the Euler-Poincare equation is not necessary. Counting the geometrical entities shows that F = 4, E = 6, V = 4. Applying the formula shows that F - E + V = 2. Because this equals 2 the solid model is valid.

3.13 See answers for 3.3 and 3.7

3.15



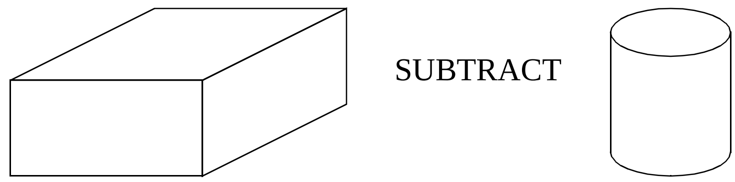
SHELL

S1=F1,F2,F3,F4,F5,F6,F7,F8

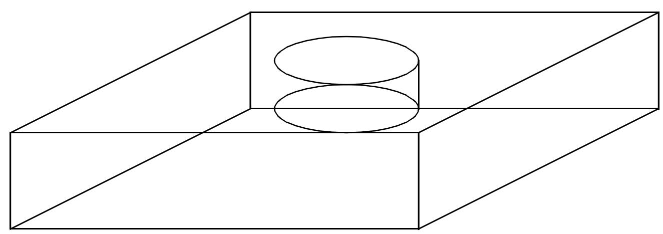
FACES	LOOPS	EDGES	VERTICES
F1=L1,L9	L1=E1,E2,E3,E4	E1=V1,V4	V1
F2=L2	L2=E5,E14	E2=V1,V2	V2
F3=L3	L3=E14	E3=V2,V3	V3
F4=L4	L4=E1,E6,E10,E7	E4=V3,V4	V4
F5=L5	L5=E2,E7,E11,E8	E5=E5,E5	V5
F6=L6	L6=E3,E8,E12,E9	E6=V4,V7	V6
F7=L7	L7=E6,E4,E9,E13	E7=V1,V8	V7
F8=L8	L8=E13,E12,E11,E10	E8=V2,V9	V8
	L9=E5,E15,E14,E15	E9=V3,V10	V9
		E10=V7,V8	V10
		E11=V8,V9	
		E12=V9,V10	
		E13=V7,V10	
		E14=V6,V6	
		E15=V5,V6	

3.16 This is a complex solidA simple count shows V = 10, E = 15, F = 8, L = 9, S = 1, G = 1. A simple calculation shows V-E+F-(L-F)-2(S-G)=0 . This equals 0, therefore the solid is valid.

3.17



3.18 For the pros/cons see earlier solutions. The wire frame is shown below.



1.2.4.4 - Solutions - Chapter 4

1.2.4.5 - Solutions - Chapter 5

1.2.4.6 - Solutions - Chapter 6

6.1 The production volume determines the tradeoff between these solutions. Hard automation works quickly, but retooling is expensive and time consuming. If the cost and downtime can be amortized over a larger number of unit cost drops very low. For smaller volumes and mixed product types the flexible automation can be a better choice.

6.4 Each geneva mechanism can be used to provide a single rate of operation. To get multiple rates we would need multiple mechanisms.

6.5

6.6

6.7

6.8

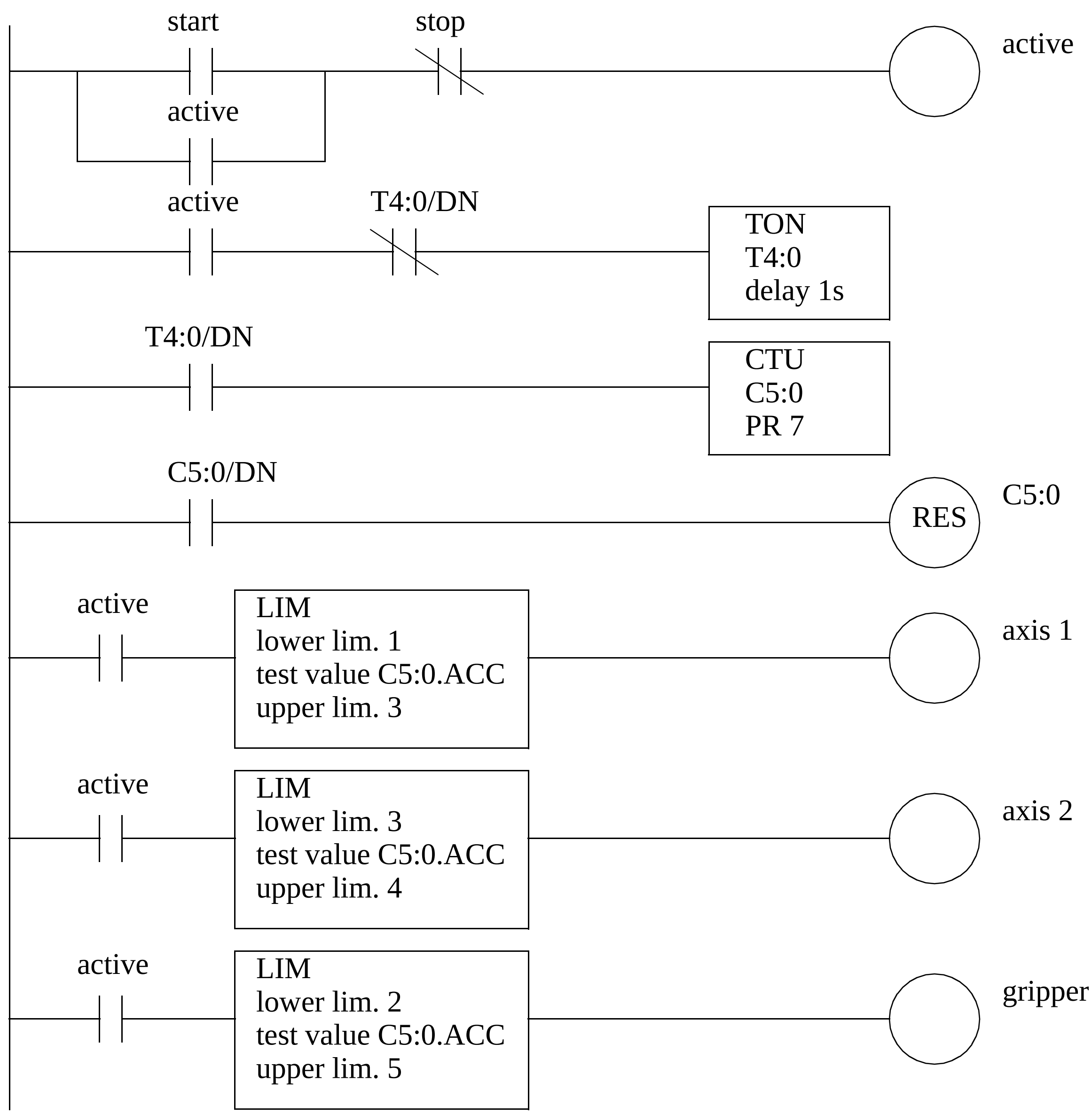
1.2.4.7 - Solutions - Chapter 7 - PLCs

7.1 Scan time can be critical to applications that have fast changing inputs or outputs. If the scan time is too long then a fast input may be missed. And, slow scans may prevent the system from responding fast enough for outputs.

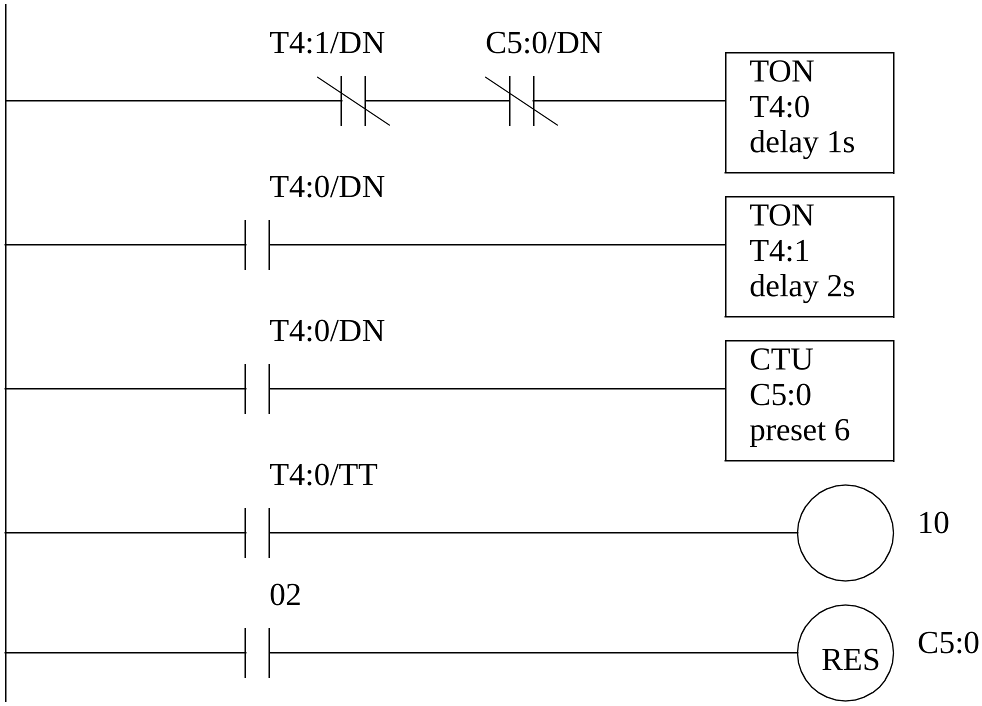
7.2 The advantages of a PLC over a relay panel is for larger applications, they are more reliable, less expensive, easier to program/change/debug, smaller, etc.

7.3 The advantages of a PLC over a microcomputer is that the PLC is more compact and rugged, the PLC costs less, PLCs can be repaired and replaced faster, PLCs have features designed for the factory floor, etc.

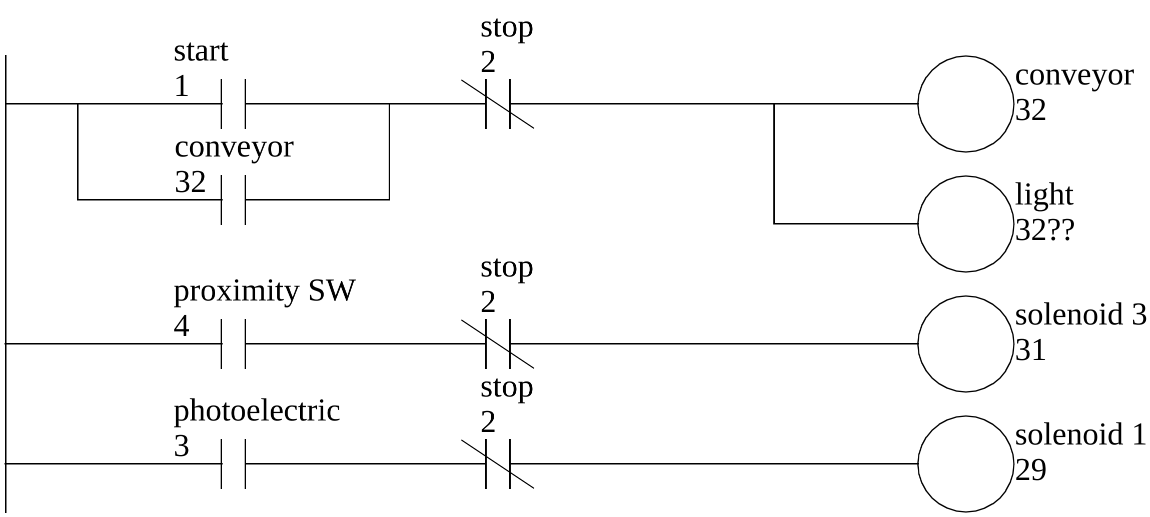
7.7 I will assume that there is a one second delay for each step.


start
stop
active
active
active
T4:0/DN
TON
T4:0
delay 1s
T4:0/DN
CTU
C5:0
PR 7
C5:0/DN
RES
C5:0
active
LIM
lower lim. 1
test value C5:0.ACC
upper lim. 3
axis 1
active
LIM
lower lim. 3
test value C5:0.ACC
upper lim. 4
axis 2
active
LIM
lower lim. 2
test value C5:0.ACC
upper lim. 5
gripper

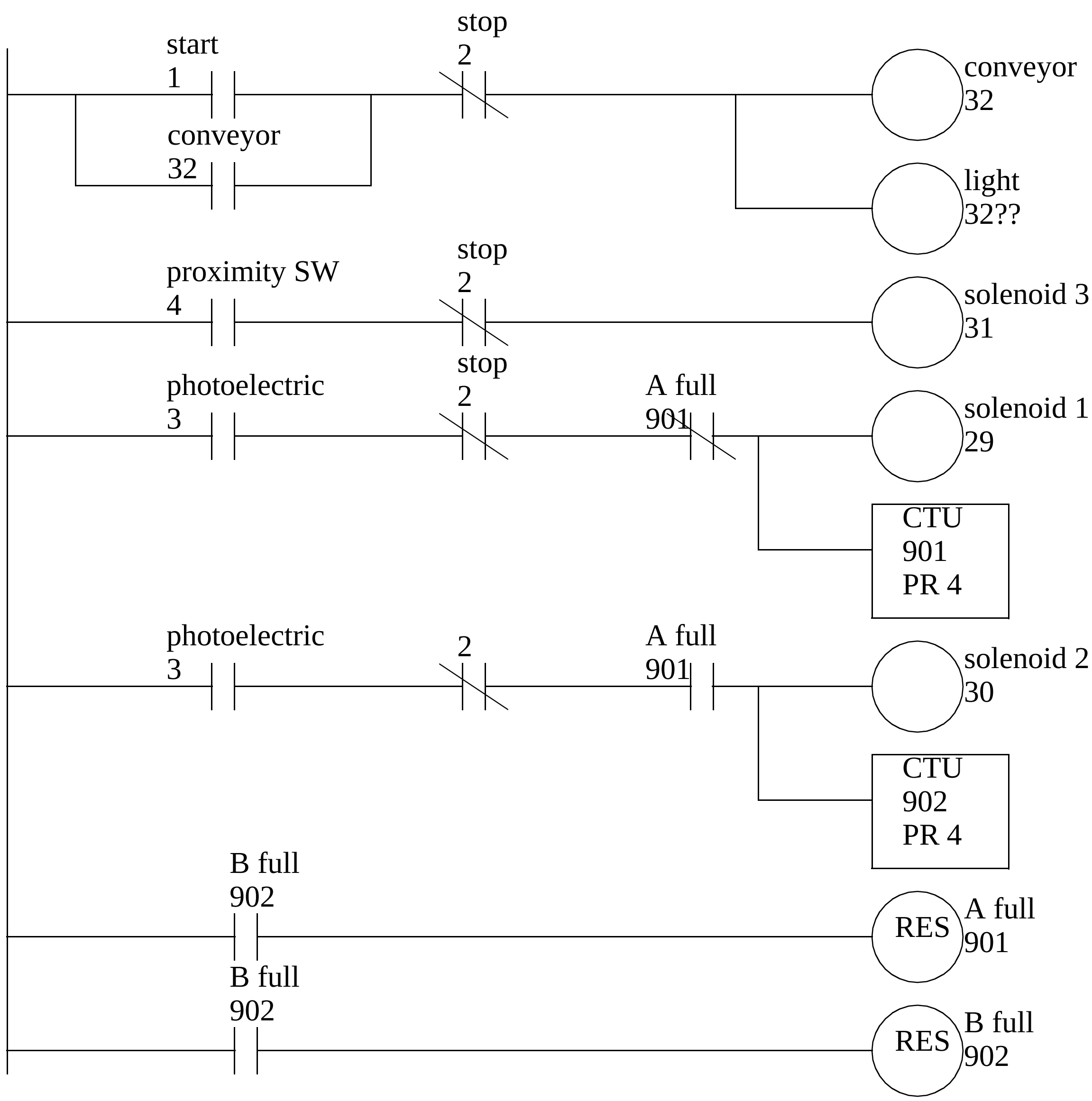
7.10


T4:1/DN
C5:0/DN
TON
T4:0
delay 1s
T4:0/DN
TON
T4:1
delay 2s
T4:0/DN
CTU
C5:0
preset 6
T4:0/TT
10
02
RES
C5:0

7.11


start
1
stop
2
conveyor
32
conveyor
32
light
32??
proximity SW
4
stop
2
solenoid 3
31
photoelectric
3
stop
2
solenoid 1
29

7.12



1.2.4.8 - Solutions - Chapter 8 - Networks

8.1 (decimal) 77, 65, 67, 48, 49, 78, 69, 32, 49, 32, 79, 70, 70

8.2 The following are shown as full ASCII serial data including start and stop states. The bytes are separated by ... to help reading.

'ON' using 1 start, 8 data, even parity, 2 stop = ...1001001111011..1001001110111...

'OFF' using 1 start, 7 data, odd parity, 2 stop = ...101001111111..101000110011...101000110011...

'idle' using 1 start, 8 data, space parity, 2 stop =

...1001101001011..1001100100011..1001101100011..1001100101011...

8.3 total bits = 8000 * (1start+7data+1parity+2stop) =88000 bits, min time = total bits/baud = 88000 bits / 300 (bits/sec) = 293.3 sec, time = (100% + 10%) min time = 322.7 sec

8.5 These problems will commonly occur when the sending and receiving computers do not have the same settings. The settings that can be baud rate and data bits. By changing baud rate and data bits the machines can be made to work correctly.

8.6 The pro-light mill is built around a normal PC, so it has an RS-232 port, but this is not being used for the CNC machine. The EMCO lathe has an RS-485 port that is connected to a dedicated RS-485 card in a computer. Programs are passed to the lathe using a DNC network.

8.8 A LAN, such as ethernet, can be compared to simple serial/parallel communication as below,
- networks connect all machines with minimal wiring
- networks allow high speed communication
- serial/parallel communication costs less
- networks allow longer distances
- serial/parallel communications do not need a server

8.10 base band - a network data transmission method that uses a voltage or current switched on/off to indicate bits.

broadband - a network data transmission schemes that uses multiple carrier frequencies to simultaneously transmit multiple data streams over a single wire.

medium-access control - this covers a variety of methods for controlling which network client can talk. If the clients all share a common wire this requires some effort to decide when to listen and when to be quiet.

packet - This is a collection of bits that is transmitted. In simple schemes a packet will hold a single byte. In more complex methods, the packet will consist of hundreds or thousands of bits that can transmit hundreds of bytes.

8.11 CSMA/CD - When multiple clients share a common data wire. When a client sends a message it will also listen to make sure that what was sent is what it hears back. If they don’t match there is a conflict with another client. When this happens they stop for a random time and then start again. When the network is being used lightly this is efficient, but as the network traffic become heavy the conflicts tend to interrupt transmissions more often, and then network slows down quickly.

8.12 The ISO/OSI model for networking layers allows networking software to be split into logical levels. It can be applied when specifying network standards, formats, protocols, and software. It is especially useful when comparing or interfacing different network standards.

8.13 A bridge will simply pass similar data packets between different subnets of the same types of LANs. A gateway will pass packets between dissimilar network types.

1.2.4.9 - Solutions - Chapter 9 - CNC Machines

9.1Major components of a CNC system are listed below,
frame - this is a large rigid mechanical frame that reduces flexing during cutting.
ways - these guide the motion of the carriage and tool in a straight line.
spindle - rotates the tool
tool changer/turret - this is on most machines and allows multiple tools to be quick changed
axis drives - these are typically motors and ball screws that move the work or cutting tool
control system - this moves the axes of the in coordination so that they follow the user program
user terminal - a place where programs can be run, tools changed, etc.
enclosure - an enclosure protects users
cooling/cutting fluid - a system for cooling the work and removing chips

9.2 Point-to-point motion is used for cutting longer straight lines. Contouring motions allow non-straight paths that are often used for complex rounded surfaces.

9.3 The program below allows circular interpolation of a surface.

```
void cut_circular(
        double c_x, double c_y, /* center of circle */
        double radius, /* radius of circle */
        int tol_type, /* tolerance type (don't see any difference in the book */
        double tol_max, /*tolerance of interpolation */
        double cs) /* cutting speed */
{
        double dx, dy, ddx, ddy; /* trajectory differentials */
        double x, y; /* tool coordinates */
        double phi, dphi_dt; /* current angle and differential */
        double delay; /* delay */
        double tol_phi; /* tolerance angle */
        int i; /* indexing variable */

        phi = 0.0; x = c_x + R; y = c_y; /* set the initial position */
        dphi_dt = cs / radius; /* find the cutting speed */
        tol_phi = acos( (R - tol_max) / R ); /* find the angle needed for the tolerance */
        delay = tol_phi / dphi_dt; /* find the time for the tolerance */
        for(phi = 0; phi <= 2*3.141; phi = phi + tol_phi){
        dx = -(y - c_y) * dphi_dt; dy = (x - c_x) * dphi_dt; /* first derivatives */
        ddx = - dy * dphi_dt ; ddy = dx * dphi_dt; /* second derivatives */
        x = x + dx + ddx/2.0; y = dy + ddy/2.0; /* update positions */
        update(x, dx, ddx, y, dy, ddy); /* call the motor control routines */
        sleep( delay); /* this function needs to delay for the given number of seconds */
        }

        return;
}
```

9.4 CNC machines can be controlled by a number of power sources. The typical sources are electric motors. Servo motors allow fast positioning with high torques. Stepper motors are used for smaller machines. They allow accurate positioning without feedback, but they are quite weak. Hydraulics and pneumatics are also used, but they are not well suited to positioning, so they are typically used for opening/closing doors, tool holders, etc.

9.5 The incremental coordinates are (19,0,-19), (-38,17,20), (13,-11,-5). This assumes we are starting at the first point.

9.6 The absolute coordinates would be (10,4,9), (29,4,-10), (-9,21,10), (4,10,5).

9.7 Accuracy indicates the precision with which we can specify a location of the tool. Repeatability is a measure of the random variation of the tool about that point.

9.8

$$CS = 8\frac{in}{min} = 0.133\frac{in}{s} \qquad BLU = 0.001\frac{in}{pulse} \qquad f = 10000Hz \qquad R = 10bits$$

$$V = \begin{bmatrix} 4 \\ 5 \end{bmatrix} - \begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 4 \\ 5 \end{bmatrix} \qquad |V| = 6.403in \qquad t = \frac{|V|}{CS} = 48.1s$$

$$P_{rate} = \frac{V}{BLU} = \begin{bmatrix} 4000 \\ 5000 \end{bmatrix} pulses \qquad R = \frac{P}{t} = \begin{bmatrix} 83.160 \\ 103.950 \end{bmatrix} \frac{pulses}{s}$$

$$P_{divide} = \frac{R}{f} = \begin{bmatrix} 120 \\ 96 \end{bmatrix} pulses$$

9.10

Given

$$BLU = 0.0001\frac{in}{pulse} \qquad CS_{max} = 100\frac{ft}{min} = 20\frac{in}{s}$$

Assume a lead screw pitch of 10 (arbitrary decision)

$$pitch = 10\frac{teeth}{in}$$

$$\frac{1}{BLU} = encoder(pitch)\left(1\frac{rev}{tooth}\right)$$

$$\frac{1}{0.0001}\frac{pulses}{in} = encoder\left(10\frac{teeth}{in}\right)\left(1\frac{rev}{tooth}\right)$$

$$encoder = 1000\frac{pulses}{rev}$$

$$f = \frac{CS_{max}}{BLU} = 200000Hz$$

9.12 An open loop CNC system does not use feedback. If the system uses stepper motors then this is typical. If the sytem uses servo motors, then an encoder is needed to measure the position, thus closing the loop (a closed loop feedback system).

9.13

9.16

$$resolution = \left(200\frac{pulse}{rev}\right)\left(10\frac{teeth}{in}\right)\left(1\frac{rev}{tooth}\right) = 2000\frac{pulses}{in}$$

$$BLU = \frac{1}{resolution} = 0.0005\frac{in}{pulse}$$

9.17

$$CS = 18\frac{in}{min} \qquad BLU = 0.001\frac{in}{pulse}$$

$$V = \begin{bmatrix} 3 \\ 4 \end{bmatrix} - \begin{bmatrix} 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 2 \\ 3 \end{bmatrix} \qquad |V| = 3.606in \qquad t = \frac{|V|}{CS} = 0.200min = 12s$$

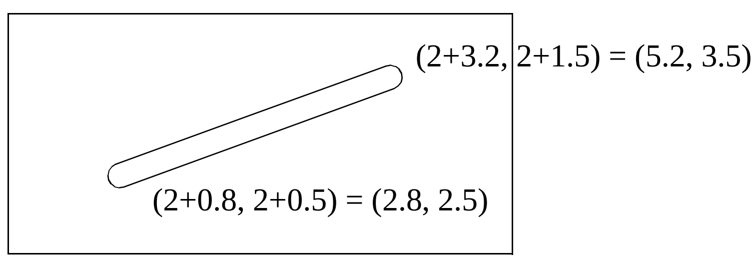
$$P = \frac{V}{BLU} = \begin{bmatrix} 2000 \\ 3000 \end{bmatrix} pulses \qquad R = \frac{P}{t} = \begin{bmatrix} 167 \\ 250 \end{bmatrix}$$

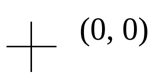
$$R_{max} = \frac{CS}{BLU} = 18000\frac{pulses}{min} = 300\frac{pulses}{s}$$

9.19 Sources of error in NC machining include: tool/machine/work/fixture deflection, tool wear, circular interpolation, backlash and friction in the machine, etc.

1.2.4.10 - Solutions - Chapter 10 - CNC Programming

10.1






```
N0010 G70 G90 M03
N0020 G00 X2.8 Y2.5 Z0.1
N0030 G01 Z-0.1
N0040 G01 X5.2 Y3.5
N0050 G01 Z0.1
N0060 G00 X0 Y0
N0070 M02
```

10.2

$$A = (40 - 10, 0) = (30, 0)$$

$$B = A + (0, 11.98 + 10) = (30, 21.98)$$

$$C = B + (10, 0) + 10(-\cos 60, \sin 60) = (35, 30.64)$$

$$O = (40 + 114.28 - 30, 10 + 26) = (124.28, 36)$$

$$D = O + \frac{40}{30}(-15, 25.98) = (104.28, 70.64)$$

$$E = (40 + 114.28 - 30, 10 + 26 + 30 + 10) = (124.28, 76)$$

$$F = (40 + 114.28 + 10, 10 + 26) = (164.28, 36)$$

$$G = (40 + 114.28 + 10, 10) = (164.28, 10)$$

$$H = (40 + 114.28, 0) = (154.28, 0)$$

```
N0010 G71 G90 M03
N0020 G00 X30
N0030 G01 X154.28
N0040 G03 Y10 I154.28 J10
N0050 G01 Y36
N0060 G03 X104.28 I124.28 J36
N0070 G01 X35 Y21.98
N0080 G03 Y21.98 I40 J21.98
N0090 G01 X30 Y0
N0100 G00 X0
N0110 M02
```

10.3

10.4

10.6

```
P0 = POINT/-1, -1, 0
P1 = POINT/1, 1, 0
P2 = POINT/1, 6, 0
P3 = POINT/6, 6, 0
P4 = POINT/10, 3, 0
P5 = POINT/10, 1, 0
P6 = POINT/5.5, 1, 0
L1 = LINE/P1, P2
L2 = LINE/P2, P3
L3 = LINE/P3, P4
L4 = LINE/P4, P5
L5 = LINE/P5, P1
C1 = CIRCLE/CENTER, P6, RADIUS, 2
PL1 = PLANE/P1, P2, P3
D = 1
CUTTER/D
FEDRAT/8
SPINDL/764
FROM/ P0
GO/TO, L1, TO, L5, ON, PL1
GOLFT/L1, PAST, L2
GORGT/L2, PAST, L3
GORGT/L3, PAST, L4
GORGT/L4, PAST, L5
GORGT/L5, PAST, C1
GORGT/C1, TO, L5
GORGT/L5, PAST, L1
GO/TO, P0
FINI
```

10.7

10.8

1.2.4.11 - Solutions - Chapter 11 - Robotics

11.1 a) cartesian = PPP, b) cylindrical = RPP, c) spherical = RRR, d) articulated = RRR, e) SCARA = RRP

11.2 The three first dof in a robot primarily provide positioning. The last three degrees of freedom provide orientation. This sound quite definite, but in truth these interact, and changes in the last three will often change position slightly, and changing position often changes orientation.

11.3 To find the inverse kinematics, we should first find the forward kinematics. By inspection we can find the inverse kinematics.

Forward kinematics

$$X = a\cos\alpha$$
$$Y = a\sin\alpha$$
$$Z = c$$

Forward kinematics

$$a = \sqrt{X^2 + Y^2}$$
$$\alpha = \operatorname{atan}(X, Y)$$
$$c = Z$$

11.4 Here we will assume that the origin of the robot is at the center of the shoulder. Again the inverse kinematics will be found by inspection.

Forward kinematics

$$X = a\cos\beta\cos\alpha$$
$$Y = a\cos\beta\sin\alpha$$
$$Z = a\sin\beta$$

Forward kinematics

$$a = \sqrt{X^2 + Y^2 + Z^2}$$
$$\alpha = \operatorname{atan}(X, Y)$$
$$\beta = \operatorname{atan}\left(\sqrt{X^2 + Y^2}, Z\right)$$

11.8

a) Palletizing of 3 lb boxes - I would recommend a servo motor based system with point to point positioning (the book defines point to point in a more restrictred manner). I would look for a cartesian robot with built in palletizing functions.

b) Spray painting in flammable environment - The robot should provide continuous path functions. For a drive system I would suggest either a servo motor system with sealed motors (to prevent sparking). Another alternative (not common) would be to use pneumatic actuators. Programming should also provide the ability to follow continuous smooth paths.

11.9 A compliant robot will help implementing this application, but a significant problem will be the necessity to mate the square shoulders of the pegs and holes. This would require that the peg be brought in at an angle and then stood up. This motion is difficult for a robot, even a compliant one. It is recommended that the pegs and holes be chamfered to allow self location.

11.10 Consider the task. The pallet sets out a 2 dimensional array, for this we need 2 dof. The orientation of the boxes on the conveyor and the pallet are rotated by 90deg., thus requiring 1 dof. If we assume the task is all performed on a single plane we can use a minimum of 3 dof total.

11.11 An accumulator will store hydraulic power (like a capacitor) when the fluid flow is low, and then deliver it when required. A hydraulic robot will not use power continuously, and the accumulator allows power in the robot to be more continuous, and make the robot more efficient.

11.12 As a task I select a record/CD changing arm in a juke box. For this task the arm must move to a linear rack position, pick a disc from the rack, lift it out rotate it and place it on a turntable. A cylindrical robot can perform the task easily. The height can go to the rack position, the radial distance can move in then out to pick the disk, and the rotation can be used to turn from the rack to the turntable. The tooling could be in a few forms. A set of curved fingers could hold the edges of the disc, with care not to touch the face. The disc could also be picked up with a suction cup. This would only cause trouble when it is closely packed with other discs in the rack.

11.13 In terms of economic cost a juke box will probably cost $1-5K, and is mass produced. The cost of the robot would be $20-50K. This is clearly not justifiable.

Note: The last example is not suited for an economic analysis for production. Consider a robot that is to replace a worker. The work station requires workers for two 8 hour shifts, five days a week for 48 weeks of the year at $8.50/hr +$4/hr benefits. The replacement robot will cost $50,000 and $20,000 is required for the tooling. Yearly maintenance is expected to be $15,000, and the salvage value will be $20,000 after 2 years. The company uses a yearly interest rate of 8% (compounded annually) and requires a ROI of 2 years. (Note: I will neglect tax savings)

First, find the present value for the workers. (assume labor costs will equal inflation)

$$C_{worker} = (8.50 + 4.00)(16)(5)(48) = 48000$$

$$PV_{worker} = C_{worker}\left(1 + \frac{1.08}{1.08}\right) = 96000$$

Next, find the present value for the robot. (assume all costs are fixed by contract)

$$PV_{robot} = (50000 + 20000) + 15000\left(1 + \frac{1}{1.08}\right) - 20000\left(\frac{1}{1.08}\right)$$

$$PV_{robot} = 80370.37$$

Finally, to compare the robot and the workers, we can see that for a 2 year ROI the robot is less expensive.

1.2.4.12 - Solutions - Chapter 12

1.2.4.13 - Solutions - Chapter 13

1.2.4.14 - Solutions - Chapter14

1.2.4.15 - Solutions - Chapter 15

15.1

15.2

15.3

15.4

15. 5

15.6

1.2.4.16 - Solutions - Chapter 16

2. OLD TUTORIALS

3. PRO/ENGINEER

Introduction:

If you have done drafting by hand, or used simple CAD programs such as Autocad you are used to a different approach to technical drawing. In drafting based programs you picture the part in your mind, and then draw lines and arcs for two, three or more views that represent the edges of the part. For example to draw a cube you draw three squares (front, top, right side views) using four lines for each square. The line dimensions must be correct, and then dimensions can be added after. When you are done the only major use is to print/plot the drawings.

With solid modeling based systems you start by entering the geometry of the object. For example a cube is a cube, not a set of lines. The solid modeler stores this geometry internally as a mathematical model of the surface and volume of the part. After entering the geometry it can be used for various tacks such as creating 3 view drafted drawings, creating NC codes so that it may be machines, doing finite element analysis. Most CAD packages now offer some level of solid modeling, including Autocad.

Pro/Engineer has its own method for entering the geometry that tends to focus on cross section profiles. You draw a profile of the part and then extrude or rotate it. This approach is well suited to parts that will be manufactured. The creation of the profile is the most like traditional drafting. For example to create a cube, you would first draw a square, and then extrude it into a cube. If the same square was rotated it would produce a cylinder. After the base part has been created, it can be added to or features can be cut out. The geometry of the part is not fixed, and it can be changed and manipulated at any time.

Note: When using the solid modeler be prepared to use 3D coordinate systems to define and manipulate parts.

1. Use the book “Pro/Engineer Tutorial and Multimedia CD” by Toogood and Zecher. Insert the CD and follow through a few until you feel comfortable. Then work through the book up to and including lesson 8.

2. Create a geometry for a die cavity (a simple box shaped cavity is sufficient). Use the Pro/E machining module to convert this to CL values. Look at the text file that was produced. This file is not yet ready for an NC mill. It requires post processing, which we will do later.

IND 807 - GEOMETRICAL MODELLING FOR DESIGN

DM:4. INTRODUCTION

Previous courses have dealt with aspects of Computer Aided Manufacturing, Manufacturing Processes, Computer Aided Design. This course will look at advanced CAD Systems, the geometrical models inside, and the implications to other areas of manufacturing.

DM:4.1 RESOURCES

DM:4.1.1 Software

The ideas software package will be used to perform the basic laboratories. (Version 6 will be used by the entire class). Ideas version7 is available, but it cannot be run effectively by the entire class, so Ideas version 6 will be the standard. Other software programs are provided on floppy disk. These are only intended for short term use, and are shareware. What this means is that if you plan to use them in the future, you are encouraged to send a small fee to the developer. (This model of software development and distribution should be encouraged) In addition, other software, will be made available for projects, and one of the assignments.

DM:4.1.2 Computer Resources

As usual the internet is a valuable source of information and software. You are encouraged to search the net for other software packages.

In addition, email will be the preferred method of communication. In general this will require less time, and get faster responses. email addresses, and computer accounts will be discussed in the first class.

DM:4.2 LABORATORIES

DM:4.2.1 Basic Solid Modelling With Ideas

Objective: To provide an introduction to solids modelling with Ideas, and the Silicon Graphics workstations.

Background Material: The ideas student guide should be read, and relevant exercises done, up to the end of chapter 3. Please do not skip sections.

Evaluation: You are required to produce a solid model of a coffee cup (including handle). After the cup is modelled, a printout of the wireframe, and shaded cup is required. Your cup will have proportions determined by your student number. A simple cup will get not full marks, so be creative.

3rd digit of student #	cup height	cup width
0	3in	3in
1	4in	3in
2	5in	3in
3	6in	4in
4	3in	4in
5	4in	4in
6	5in	5in
7	6in	5in
8	3in	5in
9	4in	6in

DM:4.2.2 More Solids Modelling With Ideas

Objective: To produce a more complex design incorporating assemblies, swept geometries, features, and splined surfaces.

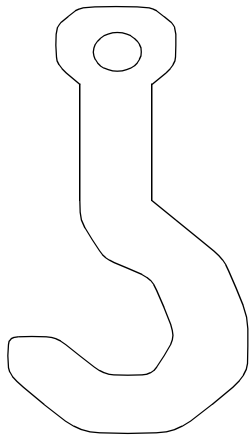
Background Material: Ideas Student Guide, up to the end of Chapter 7.

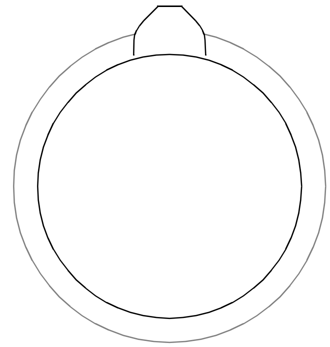
Evaluation:

1. A gear is to be modelled. This gear should have a tooth profile similar to that shown below. The number of teeth is listed in the table below. (Hint: profiles for teeth, copy for reproduction).

2. A hook is to be designed, having the inner and outer radii listed in the table below. This hook should have some laminate sections (at least 3), and rivets to hold it together. Three drawings are to be made with the hook at half size, and at double the size. (Hint: Using features may help)

3. Choose a design of your own. Your object should have at least 3 parts (at least 1 skin group). This design should display the major areas of Ideas covered up to the end of section 7. You will receive marks for creativity.





4th digit of stud #	# teeth	hook inner	hook outer
0	10	3in	4in
1	12	3in	5in
2	14	3in	6in
3	16	4in	5in
4	18	4in	6in
5	17	4in	7in
6	15	5in	6in
7	13	5in	7in
8	11	5in	8in
9	9	6in	7in

DM:4.2.3 Solid Modelling for a complete design

Objective: To create an assembly model of a product, which may then be examined for kinematic interference, and then design drafted.

Background Material: To the end of Chapter 10 in the Ideas student manual.

Evaluation: Each student is expected to design a piston assembly (one crude example is given below). The major piston dimensions vary from student to student based on your student number, and any dimensions not given can be approximated. The student will produce a report which has a title page, a VERY SHORT introduction/outline. The report should include shaded images for sales and marketing, drafted drawings for production, a drawing showing that the kinematic linkage of the piston does not cause collision. As usual marks will be assigned for creative, and correct work.

PISTON DIMENSIONS BY STUDENT NUMBER DIGITS

5th digit	piston radius	second digit	crank length

0	3cm	0	10cm
1	4cm	1	11cm
2	5cm	2	12cm
3	6cm	3	13cm
4	3cm	4	14cm
5	4cm	5	15cm
6	5cm	6	16cm
7	6cm	7	17cm
8	7cm	8	18cm
9	8cm	9	19cm

DM:4.2.4 Simple Finite Element Analysis

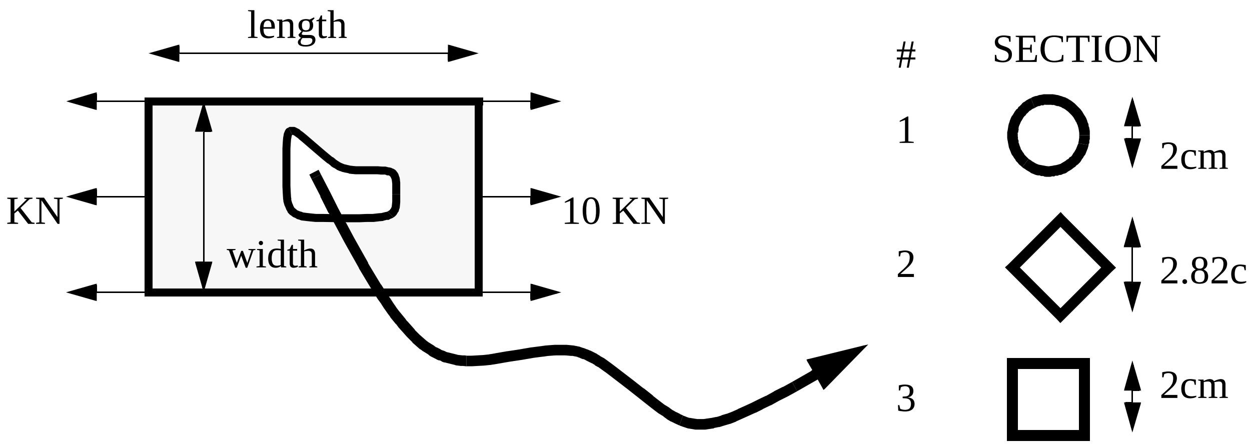
Objective: To try to do Finite Elements the Easy Way.

Background Material: To the end of Chapter 13 in the Ideas Student guide.

Evaluation: Create meshes for the sections described below, then solve for the given load cases. The section shape is determined by your student number, as are the load cases. You are expected to submit plots of the basic geometry, a deflected geometry, and stress contours. You are also expected to submit a conclusion describing the result of the analysis. You should also select a material which will give this section a factor of safety of approximately 2. You should position the section in the centre of the plate. (NOTE: FEM meshing in Ideas does not always work as expected, so be prepared).

PLATE DIMENSIONS BY STUDENT NUMBER DIGITS

6th digit	width	length	Hole Section #
0	5cm	4cm	1
1	5cm	4cm	2
2	5cm	5cm	3
3	6cm	5cm	1
4	6cm	6cm	2
5	6cm	6cm	3
6	7cm	7cm	1
7	7cm	7cm	2
8	7cm	8cm	3
9	8cm	8cm	1



DM:4.2.5 Better FEM

Objective: To try some more advanced FEM techniques, and lay the groundwork for advanced analysis.

Background Material: Up to the end of Chapter 16 in the Ideas Student Guide (NOTE: IF YOU ARE PLANNING TO USE FEM FOR YOUR YOUR FINAL PROJECT, YOU SHOULD WORK TO THE END OF CHAPTER 18 NOW)

Evaluation: Each student will select their own geometry to analyze. (Be careful, if it is too complicated you will have many problems). The loading conditions are also to be selected by the student. Perform the analysis, and produce enough documentation to support any conclusions you may be able to draw about the results of the test. Write a half page report which outlines briefly what you found. You will be evaluated by comparison of your report to those of other students.

DM:4.2.6 Advanced Analysis Techniques

Objective: To use either advanced FEM techniques, or to try a dynamic analysis of a product.

Background Material:
a) (Advanced FEM) Chapters 17 & 18 from the Ideas Student Guide
b) (Dynamics) Chapters 19 & 20 from the Ideas Student Guide

Evaluation (DO ONLY A OR B):

a) (Advanced FEM) The student will select a novel beam cross section of their own choosing. A complete analysis of this beam will be done, and submitted, with appropriate documentation. Then, using the section used in Assignment 6, perform adaptive meshing, and produce print-outs of the mesh as it is refined. Examine the mesh, and using your knowledge of FEM, discuss any irregularities in the mesh, and the possible effect.
b) (Dynamics) Create and analyze an antenna from a car. The main shaft should be tapered from bottom to top, and a small ball should be mounted on top. The student may select dimensions, and masses. A complete modal analysis is to be performed.

DM:4.2.7 Simultaneous and Concurrent Engineering

Objective: To make use of the computers to perform team design projects. It should become obvious in the assignment what the advantages, and disadvantages of computer support for these project are. One example of a system like this is an international design company who develops one part in Toronto, and another part in Singapore. email is their communication medium.

Background: Assignments 2 to 5, The SGI Users Guide, and Class Notes

Evaluation: Teams of 5 are to be selected (you must match up with 4 other students), and you will select a team leader. The group will design a simple product with six parts. The parts will be designed, and then analyzed for important design considerations such as stress, kinematics, dynamics, deflection, etc. E-mail will be used for communication between team members via the team leader for all design details, and the team leader will be responsible for keeping this mail as a record of design If you communicate without e-mail, you will be penalized. Files may be swapped between users using'FTP' (See section 4 in notes for intro). A final report is to be submitted which describes the product selected, the team structure, the ideas output, and an e-mail log which shows how the design decisions were made. The only verbal communication allowed is in the planning stages when the product is selected, and the components allocated. A possible structure for this project is 1 team leader/documentation/email specialist, 2 design engineers, 2 analysis engineers for FEM, etc.

DM:4.2.8 Evaluation of Software

Objective: The student will use a design package, as indicated below, unless otherwise arranged with the instructor. The student will learn how to use their assigned package, do a simple design, and prepare a short report describing the software. This report should be of a form useful to a manager making decisions about selection of software packages.

Background: Depends upon source of software

Evaluation: Each student will learn how to use each software package fully. A simple design or analysis problem will be selected by the student, and then used to demonstrate the software. A short report will be written that summarizes the features of each software package, and critically reviews it. Concise reports will be used as indications that the student clearly understands the software, and its relative value to other packages. Overly verbose reports will be given lower marks.

4th digit of student number	Package
0	
1	Protocad
2	Beam CAD
3	
4	
5	
6	
7	
8	
9	

DM:4.3 PROJECTS

DM:4.3.1 Description

Objective: To expand the students understanding of various aspect of CAD/CAM which they find interesting, or of potential career value.

Evaluation: The student is welcome to suggest a project in written form, or choose from the list below. The projects will be marked in terms of completeness, usefulness, conciseness, etc. The student is expected to submit a report, and an informal 4 minute presentation.

a) Design a bicycle in teams of up to 6. The final design should include production drawings, stress and, kinematic analysis. Previously done bicycle designs may be used if available, as long as the analysis results in design improvement).
b) Write a software package for the design, or analysis of a reasonably simple engineering problem. A graphical interface is expected.
c) Select a project of your own which is approved by the course instructor. This project may be BASED on the ES400 work, but if so it must be a large addition (if not sure, submit a proposal).
d) Use ray tracing to produce some graphics images of high quality, and of use in sales, or marketing. This should be a high quality drawing, using textures, many objects, etc.
e) Prepare an entry for the Ideas competition. This entry will be judged as to how well it satisfies the contest conditions.
f) Select a part from the Sunstang (with approval of Mr. Jack). The part will be modelled, analyzed (FEM, and dynamics if required), and improvements suggested, remodelled, and tested.
?) Pick an interesting project and submit a proposal.

Note: The proposal should only be at most half a page, there are no marks for it, but it protects you if something goes wrong.

DM:4.3.2 Project Ideas

Group 1:Greg Squires	Raytracing and Animation
Ed Hoskins	
Marie Malyj	
Allan Zander	
Tara Hillebrandt	
Group 2:Neil Babcock	NC Machining with SmartCAM
Group 3:James Barr	A graphical computer program for flow analysis on PC's
Group 4:Joseph Lem	Ideas - Optimization of Uni-member Bicycle frame with FEM
Jeff Bax	
Shawn Bremner	
Group 5:Charlie Chan	Ideas - Design and analysis of step exercise machine
Arthur Leung	
Bob Lee	
Group 6:Ray Smith	Design and analysis of oil well pump
Chris Vanderploeg	
Dave Jenkins	
Scott Everest	
Henry Lanting	
Ray Smith	
Group 7:Sebastian Van Nooten	Design and analysis of folding bike frame
Charles Halasz	
Tim Fielding	
Jeff Burney	
Group 8:Viliam Glazduri	Design of Sunstang
Matt Butson	
Kyle Frew	
Dave Tomsic	
Ben Berkmortel	
Ed Gebal	
Group 9:Bill Gindner	Composites (?)

DM:4.4 PRACTICE QUESTIONS

1. List at least five basic methods of geometric modelling, and provide a simple example of each.

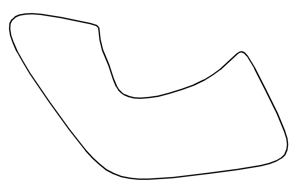
2. With reference to the Ideas package used in the laboratory, discuss some computer graphics rendering and display methods, and when they should be used.

3. Describe how you would model the part below using solid modelling techniques Hint: forget dimensions, sketches may help.

4. Short answer problems

a) List at least 10 Input, and output devices used for CAD systems

b) Suggest two approaches to find the mass properties of the irregular shape below and list some mass properties that could be calculated.



c) Give two examples of problems which may result from numerical accuracy in a CAD system. A drawing may help your explanation

d) Give an example of dithering which you have seen, and describe why it was used.

e) What are some of the important features of UNIX and the SGIs

f) Define CAD, CAM, and CIM, then describe what they mean to each other.

g) List the advantages of a CAD system

h) Show in a diagram how computers may be used to enhance the traditional design methods.

i) Describe the roles elemental, surface, and CSG design techniques play in a CAD system like

Ideas

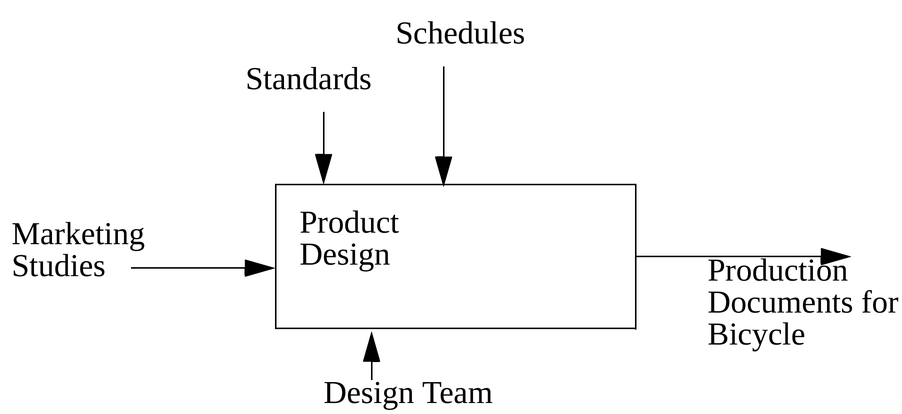
j) Give an example of a surface using a spline (a.k.a. skins), and describe how to fit a method of fitting a spline to the surface.

5. You are working for a company that designs CAD/CAM software for specialized tasks. A customer has approached the company about developing a new CAD system for shoe design. Your manager has asked you to develop a short document which outlines the proposed CAD package. With great enthusiasm you accept the job, and decide to produce a document with the following layout.

Section	Title	Page
1	Executive summary	1
2	Computer Hardware requirements	1
3	Summary of internal geometric model	2
4	Summary of design input	2
5	Summary of display methods	4
6	Suggested analysis techniques	4
8	New corporate communications	5
9	Implementation schedules	6

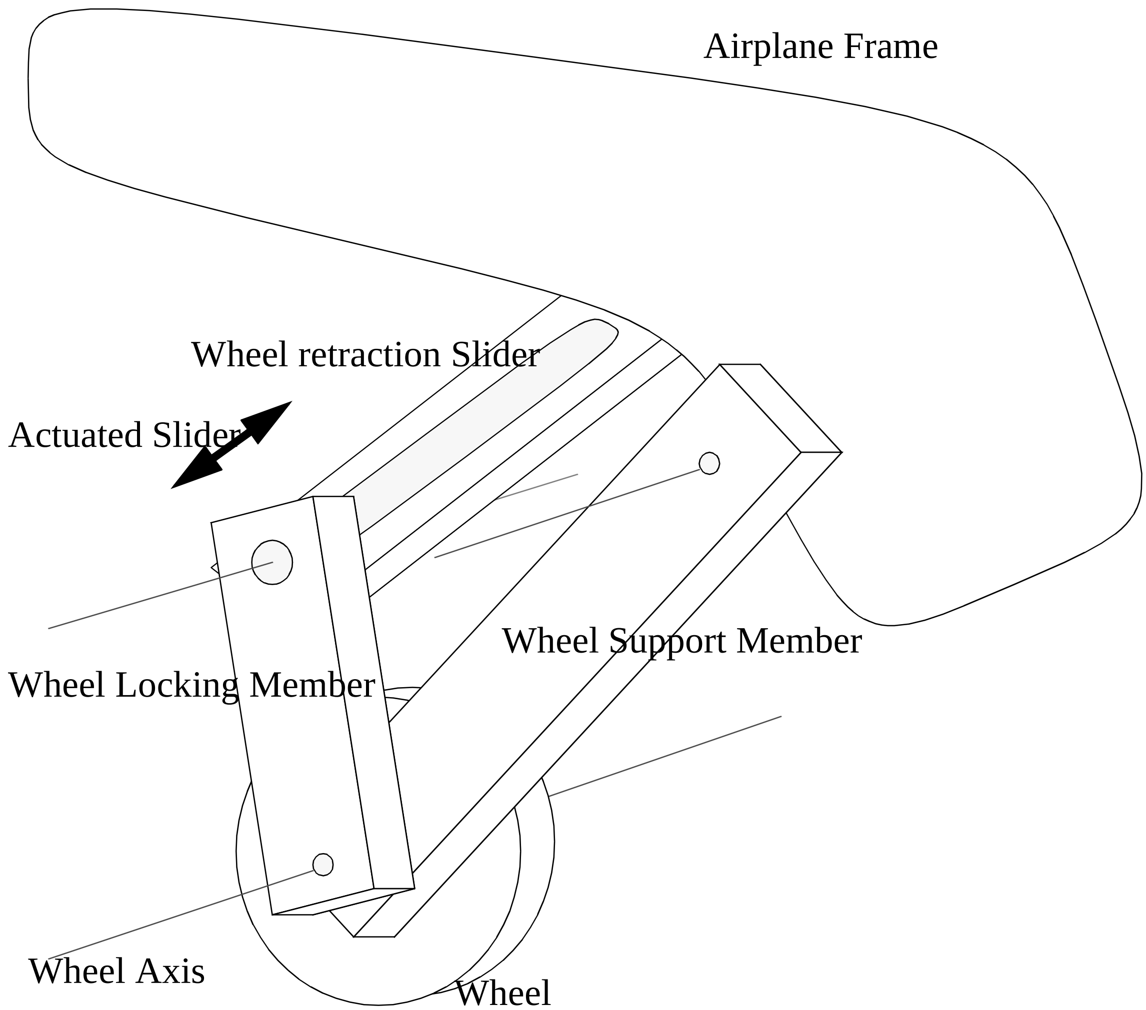
You should keep in mind that your boss dislikes verbose reports which don't get to the point quickly. Therefore point form lists, and figures will make your boss happier. Your boss also dislikes reports that are longer than 7 pages. In fact your boss refuses to read past the 7th page.

6. Draw an IDEF0 diagram which outlines the processes used by a team designing a product, such as a bicycle. The basic level 0 diagram is given below.



7. If we are designing an aircraft landing gear we would have to perform some Computer Aided Engineering tasks. Briefly describe the tasks you would have to perform to model, and evaluate the model. For each phase describe why the tests would be done, and how the test results would be used to improve/correct the design.

The Design below represents a hypothetical mechanism for a retractable landing gear on an airplane. We can assume that the wheel retraction slider is fixed in position. Some device to be chosen later (probably a hydraulic cylinder) will be used to push the Wheel Locking Member along the Wheel Retraction Slider. Obviously this will raise and lower the wheel. The wheel support member is pinned on either end, as is the Wheel Locking Member.



8. These short answer questions are testing general knowledge of CAD/CAM.

a) Describe how a shape can be analyzed for Mass Properties using a 2D case for discussion. Describe an alternate method.

b) Assuming you are designing a new hull for a nuclear sub (not the construction of it), describe at least five factors you would want to examine with CAE.

c) What is the fundamental concept behind Concurrent Engineering? List at least three reasons why Concurrent Engineering is gaining popularity. Describe at least two advantages computers provide for Concurrent Engineering.

d) Describe what trimming is and how it differs from at least one other similar method.

e) Although dithering is sometimes necessary, it is not always desired. Why?

f) When would it be useful to use IDEF0 models? What steps would normally be followed when using the IDEF0 methodology? What are some problems that IDEF0 diagrams can reveal?
g) Why are the uses of MRP and Capacity Planning different? What class of scheduling problems do MRP and Capacity Planning not consider?

9. Describe what the output from the following C program will be.

```
main()
{
    int i;
    double x, y;
    for(i = 0; i < 2; i = i + 1){
     printf(“number %d \n”, i);
    }
    x = i * 2;
    y = x + 2;
    printf(“it costs $%f to be an engineer \n”, y + 4);
}
```

10. What does the IGES file below show? Note: the columns are not exactly placed.

```
This IGES file has been specially constructed for the ES488 S0000001
Final Exam 1993.                                             S0000002
CIRCLE 1,1,1                                                 S0000003
,,8Hexam.prt,8Hexam.prt,6HCADMAN,5HXXYYZ,16,8,24,11,53,8Hexam.prtG0000001
1.,2,2HMM,1,1.,13H911001.075746,.0005,,9HHugh Jack,          G0000002
33HThe University of Western Ontario,4,0;                    G0000003
110 1      1     0     0     0           0000000             D0000001
110 0 1    1     0     0     0     line                      D0000002
110 2      1     0     0     0           0000000             D0000003
110 0 1    1     0     0     0     line                      D0000004
110 3      1     0     0     0           0000000             D0000005
110 0 1    1     0     0     0     line                      D0000006
110 4      1     0     0     0           0000000             D0000007
110 0 1    1     0     0     0     line                      D0000008
110 5      1     0     0     0           0000000             D0000009
110 0 1    1     0     0     0     line                      D0000010
110,40.,15.,0.,50.,45.,0.;                               1    P0000001
110,30.,45.,0.,50.,45.,0.;                               3    P0000002
110,30.,80.,0.,70.,15.,0.;                               5    P0000003
110,50.,80.,0.,70.,80.,0.;                               7    P0000004
110,70.,80.,0.,60.,50.,0.;                               9    P0000005
S3  G3D10   P5                                               T0000001
```

11. These short answer questions involve application of concepts to practical problems.
a) List some benefits the network (in the computer lab) provides that are not available on stand

alone computers.

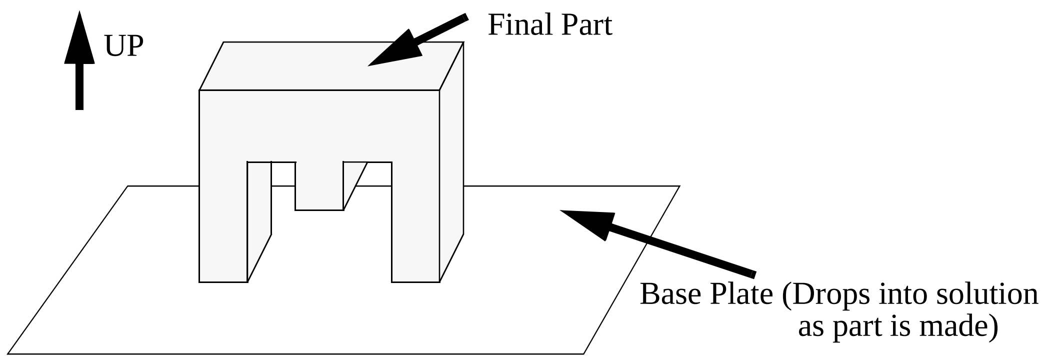
b) Describe the components and operation of an Automated Manufacturing Workcell you have seen.

c) We often discuss when CAD systems should be used. When should they not be used? Give an example.

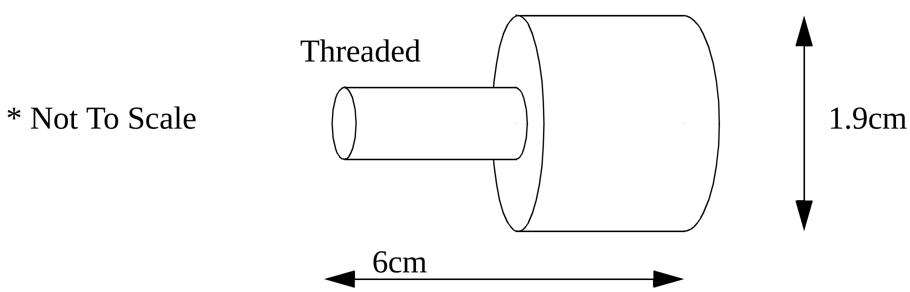
d) Identify one stage of product development that CAD is not commonly used for, and describe why it is not.

e) Describe one application for which a CAD package like CADKEY would be a better choice than a package like IDEAS. Justify your choice.

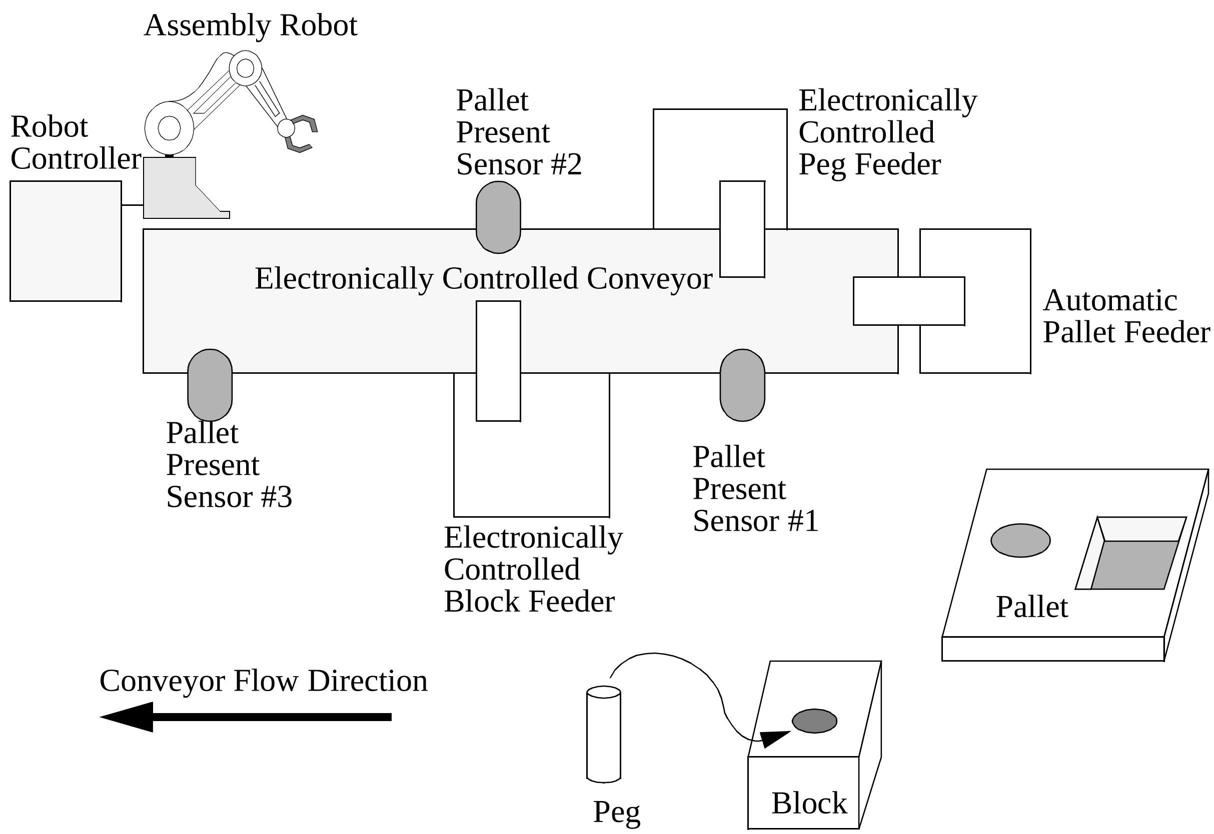
f) I was about to produce the part below with stereolithography, but when my boss double checked it he said there was a serious problem that would result in failure. What is the problem? Suggest ways to solve it.



12. You are just about to design a new part, but first you want to look for a similar part on your companies GT system (It uses an OPITZ code). a) Develop the form code for the part below. b) If we find a close match, what other types of useful information could the GT system provide?

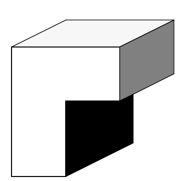


13. The workcell below has been designed to put parts on a pallet, and then a robot will assemble them. Suggest how a PLC would be connected, and programmed. If you need other sensors, or other devices state what they are, and how they would be used. (Assume that all the feeders just need a single electrical input to issue one part correctly). The pallets are issued automatically, and the feed rate is set manually.

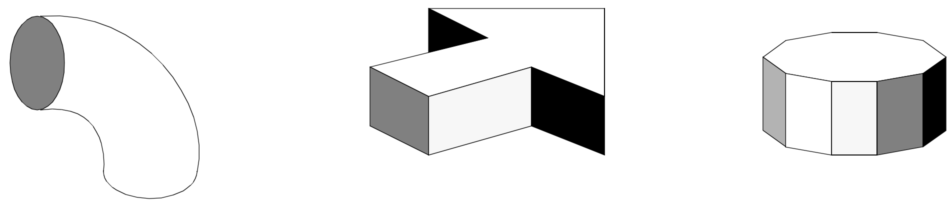


14. You are the designer at a tent making company that has 100 employees. The basic components of the tents are the frame, and the canvas covering. Some of the larger tents can be hundreds of feet long. As a result there are a number of design problems. When the canvas is hung on the frame, it does not maintain the initial shape of the material, for example drooping under the effects of gravity is one problem. You have just completed an interesting course on CAD and CAE, and you have decided to contact a software company to ask them to write a software package for you. Before meeting the software analyst from the company you must sit down and decide what you want the software to do. For example, rendering and some various forms of FEM would be required. Be more specific than this, and consider other options. Discussion should refer to tents when appropriate. a) List possible computer graphics outputs of the stored design. b) List possible input methods. c) List and justify some CAE options.

15. Describe how the part pictured below would be represented in five different geometric model types (eg. CSG, Surface).



16. Describe which modelling methods are suited to the parts below (how and why).



17. Suggest a method for constructing the parts below using any or all of the Solid Modelling techniques (eg. create cylinder, cut part with cylinder)

18. Data structures form the backbone of every computer program. A data structure is basically a set of well thought out variables and arrays. These structures are designed to hold information, and allow easy use. An example would be a data structure for holding information about the location of office furniture. The figure below shows a list of offices, these each point to a 'linked-list' of furniture. The Furniture List stores a list all the furniture, and the use of the 'next' field allows many different sub-lists to exist in the larger list.

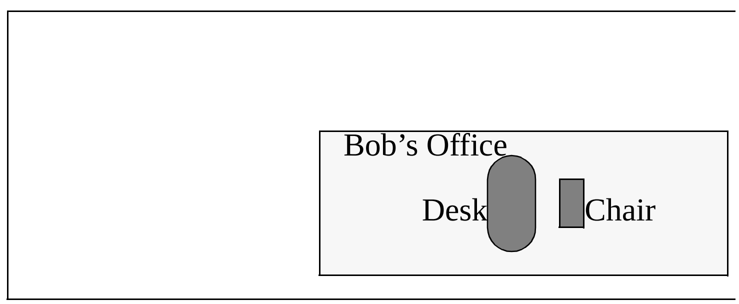
OFFICE LIST

	Office Desc.	Location (x,y)	Pointer
1	Bob's Office	100, 20	3
2			
3			
4			
5			

RNATURE LIST

	Furn. Desc.	Position (x,y)	Rotation (deg.)	Width	Depth	Next
1	Desk	16, 2	270	6	3	LAST
2						
3	Chair	20, 5	90	2	2	1
n						

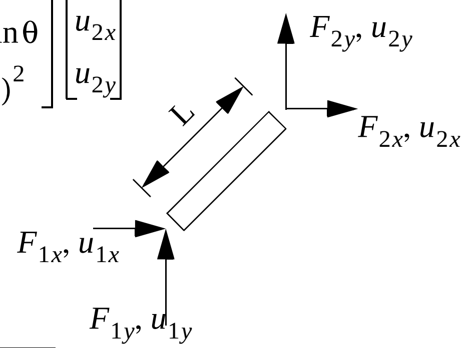
XYZ Company

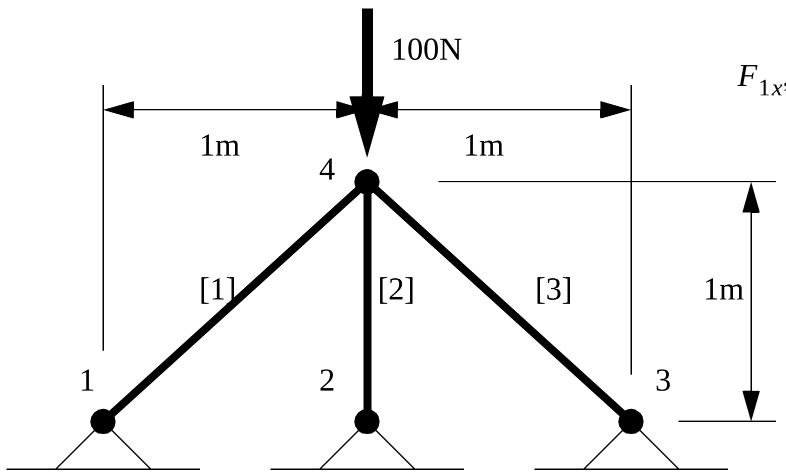


Your problem involves suggesting a data structure which can store information about a few parts each made with spheres stuck together, like a Mickey Mouse head. The structure should allow for the obvious, as well as color. (Hint: The structure you use may be similar to the one above, but the data fields will definitely have to be customized for your structures)

#4 a) Given the following problem, and the stiffness matrices for the elements, set up the global stiffness matrix. (15%)

$$\begin{bmatrix} F_{1x} \\ F_{1y} \\ F_{2x} \\ F_{2y} \end{bmatrix} = \left(\frac{AE}{L}\right) \begin{bmatrix} (\cos\theta)^2 & \cos\theta\sin\theta & -(\cos\theta)^2 & -\cos\theta\sin\theta \\ \cos\theta\sin\theta & (\sin\theta)^2 & -\cos\theta\sin\theta & -(\sin\theta)^2 \\ -(\cos\theta)^2 & -\cos\theta\sin\theta & (\cos\theta)^2 & \cos\theta\sin\theta \\ -\cos\theta\sin\theta & -(\sin\theta)^2 & \cos\theta\sin\theta & (\sin\theta)^2 \end{bmatrix} \begin{bmatrix} u_{1x} \\ u_{1y} \\ u_{2x} \\ u_{2y} \end{bmatrix}$$





#4 b) Assuming that the beams have a cross sectional area of 2cm2, and a Modulus of Elasticity of 50MPa, find the new position for joint 4. (15%)

DM:4.5 REFERENCES

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MEC 015 - Basic Manufacturing

5. INTRODUCTION

5.1 PEOPLE

5.1.1 Lectures:

Dr. Hugh Jack, P.Eng.
Office: S45A
Phone: Ext. 6429
Office Hours:

5.1.2 Laboratories:

Mr. Peter Dimitriu, P.Eng.
Office: S49
Phone: Ext. 6422
Office Hours:

5.1.3 Teaching Assistants:

5.2 AKNOWLEDGEMENTS

There are a number of faculty who have contributed to this course in the past. And, in particular, there are two faculty members who have made particular contributions of note.

Professor Roger Lewis developed a set of course notes that are essentially the basis of these notes. His efforts were not trivial and should not be overlooked.

Professor Norm Ferguson developed a handbook called “Metrology; The science of precise measurement”. This was also of invaluable assistance when assembling these notes.

5.3 SCHEDULE FOR THE COURSE

Week	Topic	Sections
F1	Metrology	
	Standards	
	Standards and Comparators	
	Metrology tools	
	Assembly and limit gauges	
F5	Drilling	
	Cutting Tools	
	Milling/turning	
	Grinding	
F9	Cutting speeds/feeds	
	Cutting mechanics	
	Tool materials	
	Merchant’s force circle	
	Velocity and power requirements	
W1	Surface texture	
	Roundness testing	
W3	Interferometry	
W5	Tool temperature	
	Tool life	
	Economics of machining	
W8	SPC	
	Probability and acceptance sampling	
	Process capability	
	attribute control charts	
	automated data collection systems	

5.4 ASSIGNMENTS/LABORATORIES

5.4.1 Laboratories

• There are a total of eight laboratories to be submitted, others are included for the benefit of the student,
  - basic measurement (no formal submission)
  - dimensional measurements
  - comparators
  - optical metrology
  - Manufacturing Processes (demonstration only - no formal submission)
  - cutting forces
  - surface texture
  - roundness measurement
  - interferometry
  - SPC analysis with gauge talker III
  - laser measurement (demonstration only, no formal submission)

5.4.1.1 - Lab Rules

• The general rules are simple,
  1. Students must attend ALL labs, attendance at the demonstrations is also mandatory. missed laboratories will result in a loss of a mark.
  2. Each laboratory must be done independently or in groups only when specified. COPYING WILL NOT BE TOLERATED, AND WILL BE DEALT WITH SEVERELY.

5.4.1.2 - How To Prepare for and Write-Up an Experiment

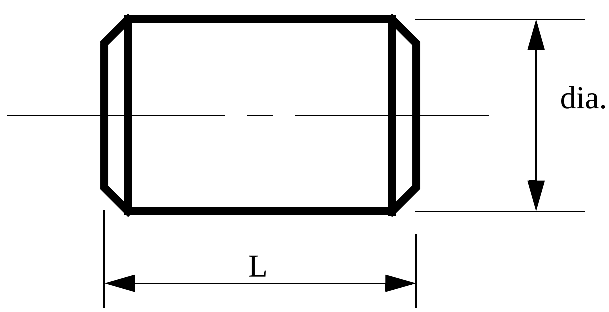
See the laboratory instructor.

5.4.1.2.1 - Basic Measurements

Purpose:

a) To determine the length of a component.
b) To introduce students to some fundamental measuring instruments
c) To determine possible causes of variation in measurement.
d) To introduce the concept of Standards, used in manufacturing

Component Drawing:



Procedure:
Use different instruments and different operators to measure the component length ‘L’.

Results:
Units -> Decimal inches

Tabulated Results:

Instrument Used	Dimension ‘L’		
	Operator #1	Operator #2	Operator #3
steel graduated scale			
vernier caliper			
1-2” std. micrometer			
bench micrometer			
electronic comparator	maximum =	minimum =	

Analysis of Results:

Which of the results is correct?
What accuracy is required?
What does accuracy depends upon?

Possible Causes of Variation:

- The Instrument - design, magnification (def. output/input), sensitivity (def. smallest input to provide a reliable output), condition & calibration.
- The Operator - experience, judgement, attitude, sense of touch or feel.
- The Component - flatness, parallelism, surface texture.
- Temperature - standard temperature (20°C or 68°F), different materials have different coefficients of linear thermal expansion.
- The Standards - grade & original accuracy, condition, traceability to primary standard.

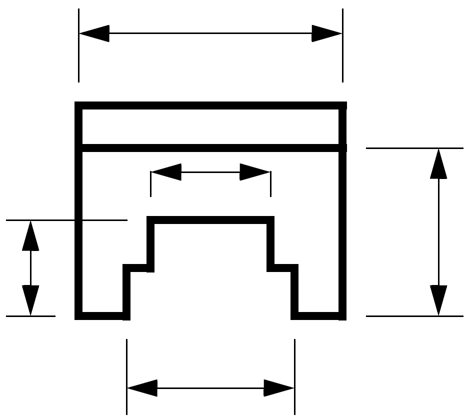
5.4.2 Line Graduated Instruments

Purpose: To become familiar with the fundamental forms of measuring instruments. In particular scales, micrometers, vernier instruments, and transfer tools.

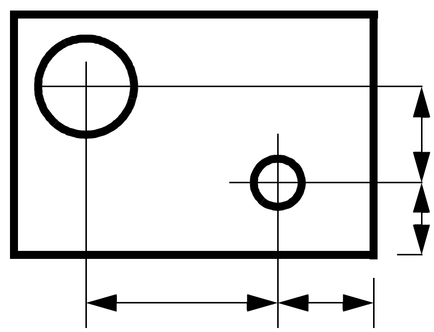
Procedure:

1. Record the measurements for the two parts below using scales (i.e., rulers) and transfer tools (e.g., calipers). Record the answers to the nearest 0.5mm or 0.02"

a) Vice Body (metric)

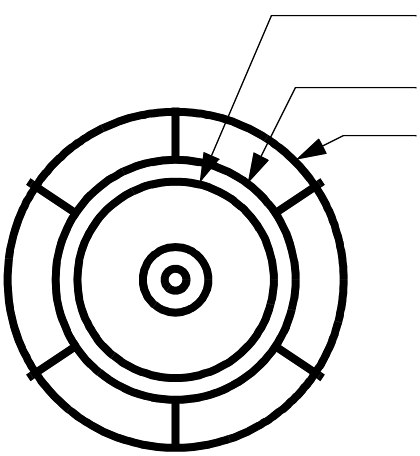


b) Layout Plate (inches)

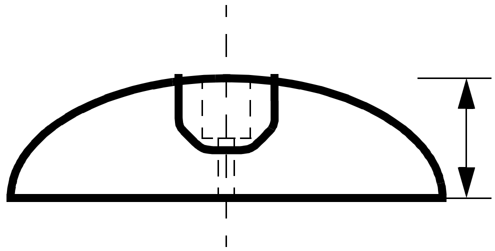


2. Use vernier instruments to measure the following parts. Record all lengths to the nearest .001", or .02mm.

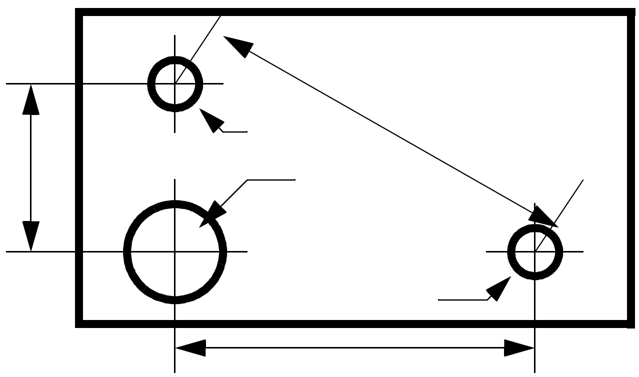
c) Turbine Fan (Inches)



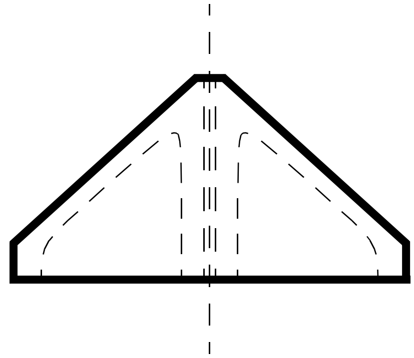
d) Cast Part
(Use metric Vernier)



e) Drilled Plate (only larger holes are shown) (mm)

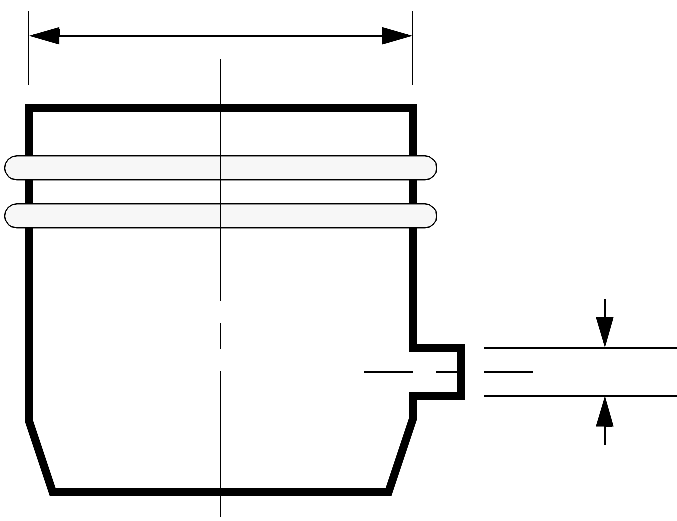


f) Cone - Use the vernier protractor to measure angle.

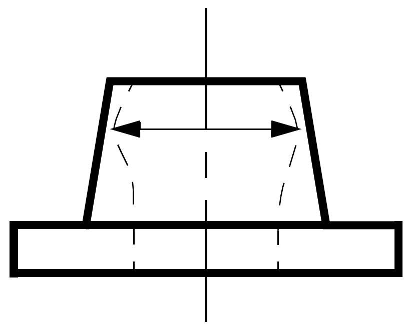


3. Using the instruments specified below, measure each of the parts. Record the dimensions to the appropriate number of decimal places. Where feasible, instruments may be checked against gauge blocks.

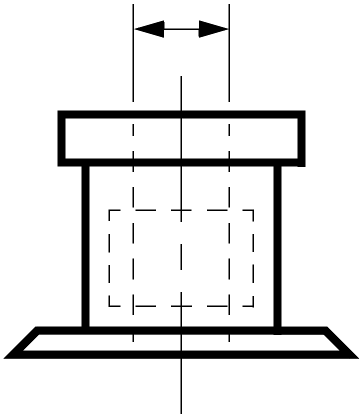
g) Piston - use outside micrometer (mm)



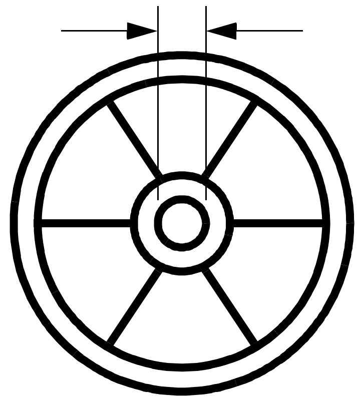
h) Housing - measure inside diameter in inches



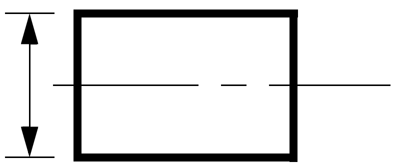
i) Geared Shaft - use telescopie gauge



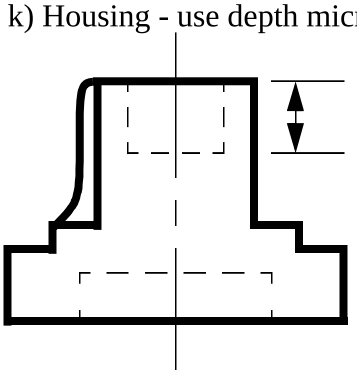
j) Pulley - use small hole gauge



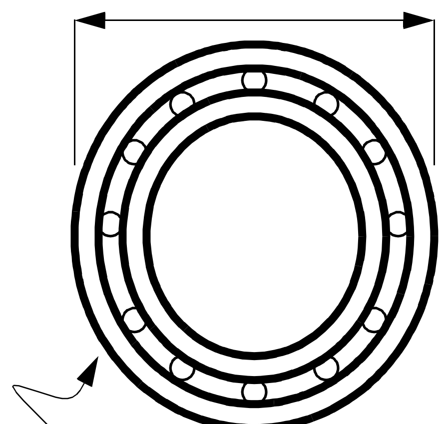
l) Polished Cylinder - use ETALON micrometer (4 decimal places, inches)



k) Housing - use depth micrometer (in)



m) Bearing - use bench micrometer (in.)



**Only the outer housing is provided

<u>Questions:</u>

1. Discuss the term ‘parallax error’, associated with the steel scale measurements.
2. Draw to some reasonable scale, a metric depth vernier set at a reading of 36.64mm.
3. A micrometer type instrument achieves magnification by two basic principles, explain these.
4. Explain the purpose of either Standard Rollers, or Hoke Gauge Blocks, used with a bench type micrometer.
5. List in order, the corrective adjustments necessary to calibrate a micrometer.

5.4.3 Comparators & Surface Plates

Part A - Comparators

Purpose: To give the student an understanding of the principals of measurement by comparison, and to be able to set up and use the comparators in the lab.

1. Set up the Valenite electronic column gauge to the master ring gauge. Then determine the actual diameter of the holes A, B, C in the test piece marked 2a.

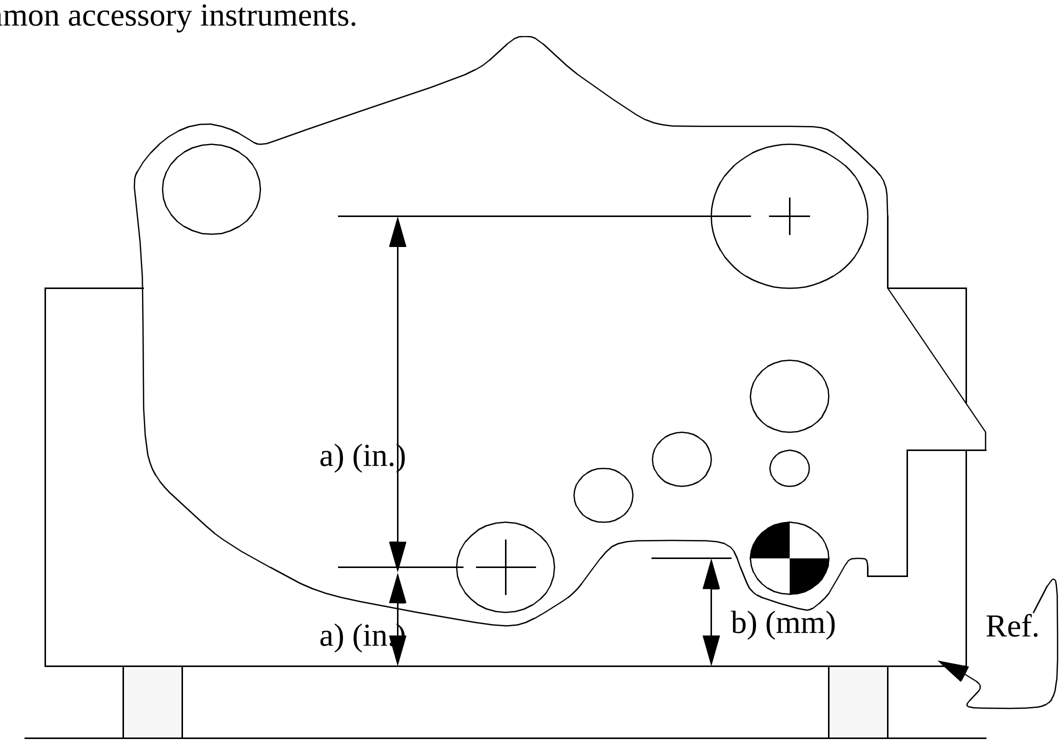
2. Set up the Sheffield flow type pneumatic gauge using master pin gauges 0.7310” and 0.7292” (make one scale division equal to 0.0001”). Then determine the actual diameters of the brass pins A, B, C.

3. Set up and adjust the Sigma pressure drop pneumatic gauge to the master gauge 12.74mm. Then determine the actual diameters of the holes in the test piece marked 2b.

4. Set up and use the Sigma electronic comparator (set on a metric scale) to determine the length (ins.) of the other given component (cylinder)

Part B - Surface Plate

Purpose: To become familiar with the use of the surface plate as a reference plane, the use of the common accessory instruments.



5. a) Using the Mitutoyo electron height gauge, determine the two dimensions required, refer-

enced from the base of the fixture. The units are inches.

b) Using the vernier height gauge with the test indicator attached, transfer the heights to the micrometer height gauge to determine the dimension from the reference line to the hole marked. The Units are millimeters.

Questions:

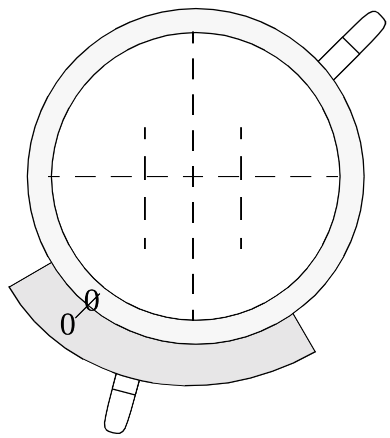
1. What advantages do electronic comparators have over mechanical comparators?
2. State one advantage, and one disadvantage of the air gauge compared to other principles of magnification.
3. In your own words, define “sensitivity” as applied to comparator type instruments.
4. List two important advantages of the granite surface plate over the cast iron plate.
5. What factors limit the accuracy in determining the dimensions, in exercise #5 b).

5.4.4 Toolmaker’s Microscope and Optical Projector

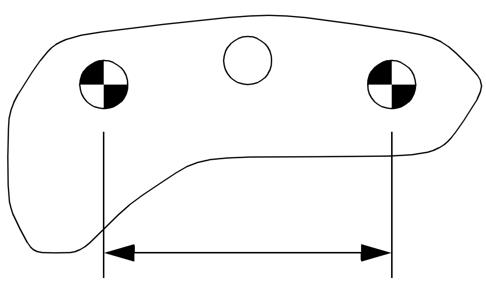
Purpose: To become familiar with measuring tools with optical magnification.

Part A: Toolmaker’s Microscope

1. Check the zero of the vernier protractor (under the eyepiece) as follows: - Set the protractor scale to zero. Then verify that the horizontal cross line (a) is parallel to the cross travel of the stage. To do this rotate the side micrometer knob and note that any object viewed through the eyepiece runs parallel to the cross line. If this is not correct see the instructor.



2. Set up the watch plate and measure the pin centre to centre distance. Record your measurements in decimals to four places. WARNING - If either micrometer head is turned to the full extent of its travel, it may become jammed.



3. Measure and record the pitch (axial spacing of the threads) of tap #1. Also measure and record the lead angle of the same tap. This will be the mean of the lead angles at the thread crest and root.

Add sketch from old labs

Part B - Optical Projector

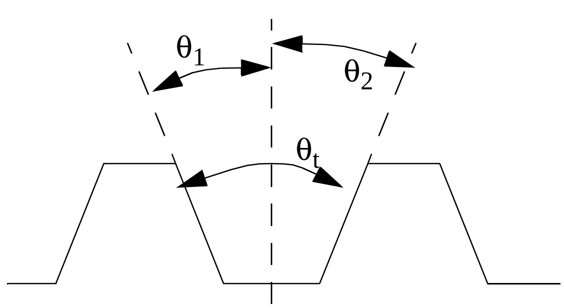
4. a) Check the zero of the vernier protractor around the screen.

b) Check the magnification of the system. First set the protractor scale on zero. Then using the test pin gauge on the table, project the image (shadow) of the rod (you must measure the diameter of the pin by using the micrometer on the projector) onto the screen and adjust the table vertically until the tip of the shadow just contacts the horizontal cross line. Traverse the table horizontally with the micrometer. Note if the shadow moves in contact with the cross line. Then with the scale measure the width of the shadow. The width of the shadow divided by the actual diameter of the rod is the magnification.

5. Using the scale and tap #2, measure directly from the image on the screen the following thread dimensions.
    a) major diameter
    b) minor diameter
    c) average pitch

6. For the given tap #3, measure the pitch (thread spacing) and the pitch diameter E using the micrometers on the projector. Calculate the lead angle. (see the text for descriptions of these terms).

7. Set up the Acme thread supplied, part #4, and measure the flank angles as shown below. Use the protractor on the screen. Record these angles and calculate thread lean.



Questions:

1. Suggest the reason why the cross lines on either instrument are broken lines and not solid lines.

2. Why, in exercise 3 above, is the lead angle calculated as the mean of the angles taken at the crest and root of the thread?

3. Provide a practical application to illustrate the importance of question #1.

4. Suggest reasons for errors in the total of angles θ_1 and θ_2 and the total angle θt

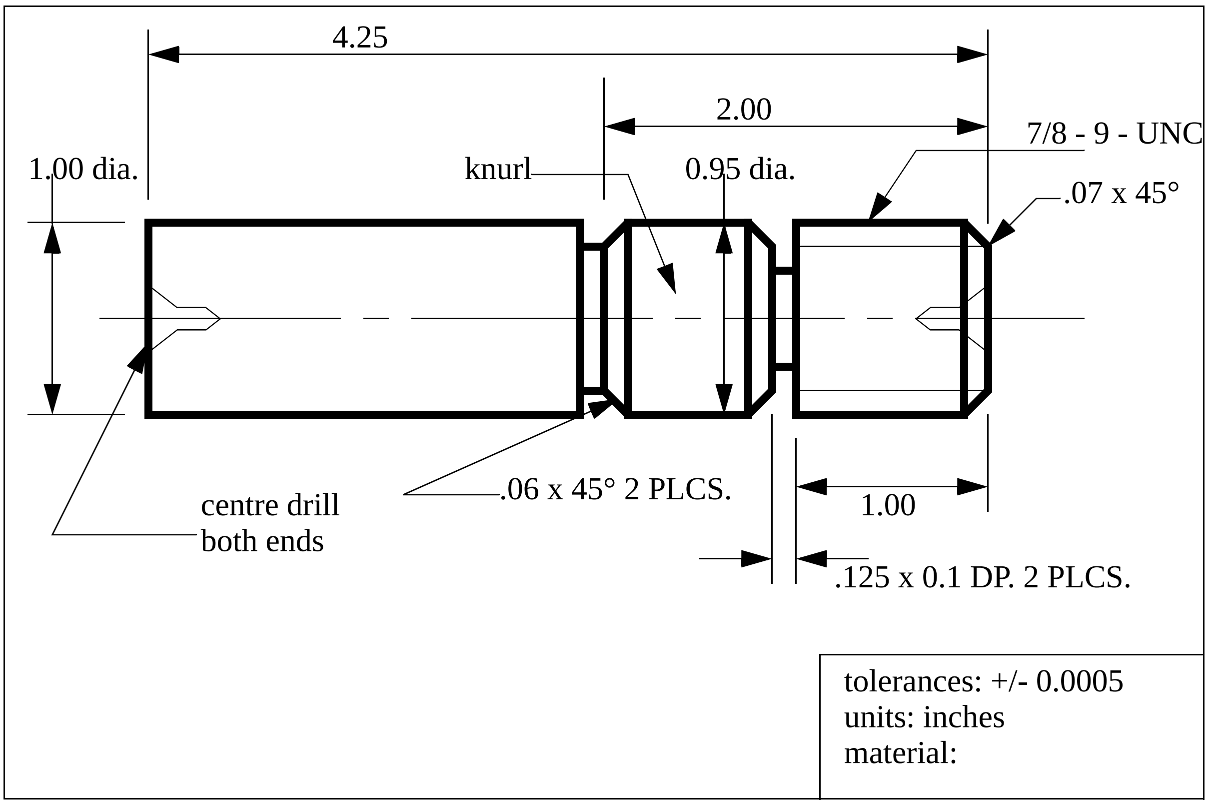
5.4.4.1 - Process Planning and Machining Demonstration

Purpose:

a) to observe a series of Machine Tool operations, in the manufacture of the component shown.

b) To introduce the students to the concept of Process Planning

Component Drawing:



Procedure:

1. Study the component drawing and the process planning sheet
2. Proceed to the machine shop to observe the part being made

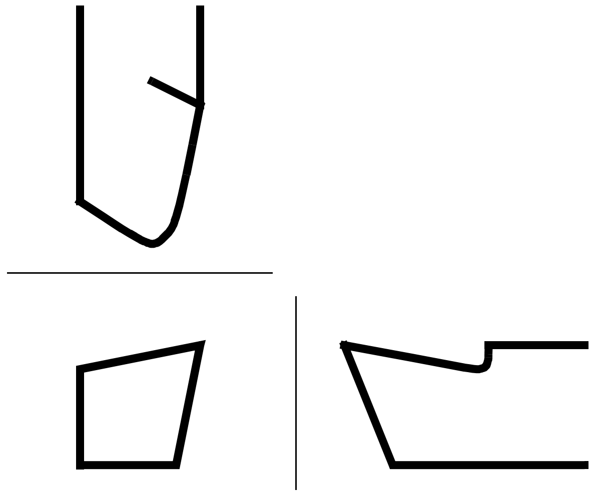
CAUTIONS:

1. Power will be on in the machine shop.
2. For your safety, refrain from touching any machine buttons or levers.
3. Do not handle swarf (metal chips) from the cutting processes, they are hot, and sharp and WILL cause at least some harm.

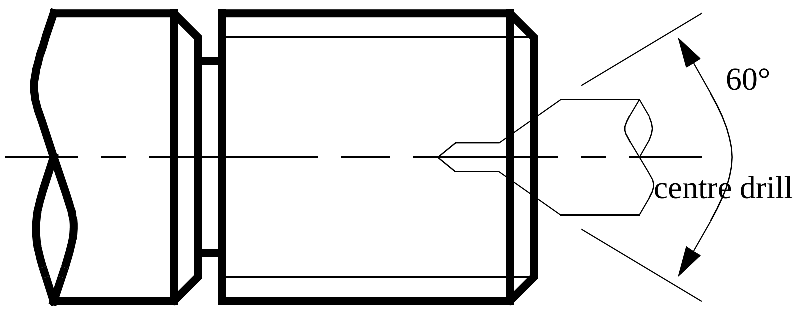
Cutting Tool:

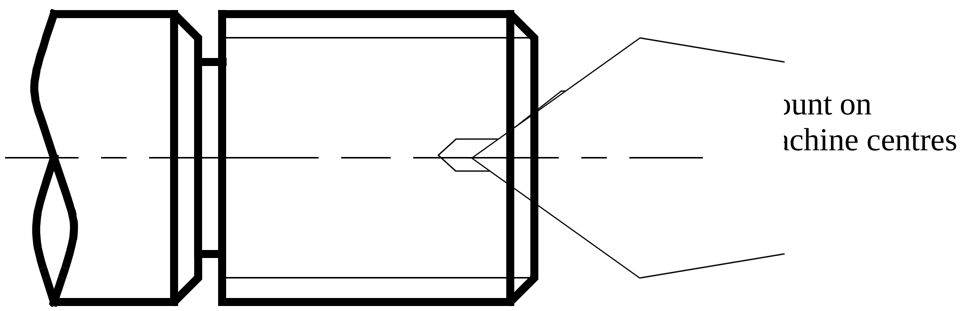
- High Speed Steel 3/8” tool bit

• Orthographic Views are shown (refer to text also, fig. 27-2)



Centre Drill & Machine Centre:





Surface Cutting Speed:

Recall from the notes,

$$CS = \frac{\pi D}{12 \times RPM}$$

CS = 100 fpm for optimum cutting conditions with mild steel work, and high speed steel tools

Process Planning Sheet:

OP #	Description	Department
05	cut off bar stock 1” dia. 4 3/8” long.	cut off saws
10	deburr with a file	bench
15	hold in a 3 jaw chuck fack and centre drill both ends	lathes
20	turn two diameters hold between centres	lathes
25	Under cut grooves using a 0.125” parting tool	lathes
30	chamfer 2 @ 0.06” & front @ 0.07”	lathes
35	cut thread 7/8 - 9 - UNC	lathes
40	Knurl 0.95” dia.	lathes
45	Inspect part to drawing	inspection

5.4.5 Cutting Forces

Purpose:
To investigate the relationship of the cutting variables,
a) cutting velocity.
b) undeformed chip thickness (feed rate) to cutting force (tangential) F_c and lateral force (feed) F_t.

Procedure:
a) Take several cuts at different cutting speeds and note the readings of F_c and F_t and measured R.P.M. for each cut.
b) Take several cuts at different feed rates (undeformed chip) and note the readings of F_c and F_t for each cut.

Results:
a) Tabulate the results in the tables provided, and any other observations should also be written down.
b) Make graphs for the measured data.
c) Analyze and discuss the results (i.e., point out the obvious and subtle).
d) Write conclusions based on the analysis (i.e., draw some general conclusions based on the facts).

Questions:

1. Explain which of the test cuts requires the greatest H.P. at the tool.

2. If the machine efficiency is 60% calculate the minimum motor size required. For one of the cuts measure the deformed chip thickness t_2, draw the merchants force circle diagram for that condition, determine the shear force F_s and calculate the co-efficient of friction on the tool face.

RESULTS - LAB #4 - CUTTING FORCES

Material: Aluminum /alloy - Dia. = inches

Depth of cut = inches

Mean diameter = inches

Tool: Material: High Speed Steel

Rake Angle α = degrees

Feed Rate = 0.005 inches/second

Initial feed setting 20 TPI/(1/4)/B/5 (low speed H)

For a) variable velocity *** Plot graphs for F_c/V and F_t/V on the same graph.

	RPM Settings	RPM Measured	Velocity (ft/min.)	F_c (lbs.)	F_t (lbs.)	
H	63					
H	100					
H	160					
V	200					change feed to A
H	250					change feed to B
V	315					change feed to A
V	400					
V	500					

For b) variable feed *** Plot graphs for Fc/feed and Ft/feed on the same graph.

RPM setting: Set = 315 RPM, actual = , velocity = ft/min.

Feed (in./rev.)	Machine feed settings				F_c (lbs.)	F_t (lbs.)
	T.P.I.	1/1 1/2 1/4	A or B	#		
.0005	192	1/4	B	7		
.0010	96	1/2	B	7		
.0021	48	1/1	B	7		
.0031	32	1/1	B	2		
.0042	24	1/4	A	7		
.0050	20	1/4	A	5		
.0062	16	1/4	A	2		
.0071	14	1/2	A	9		
.0100	10	1/2	A	5		

NOTE: Maximum load on dynamometer is 400 lbs. Use caution at feeds above .008

5.4.5.1 - Surface Texture

Purpose:

a) To observe a stylus type machine (Brown & Sharpe Surfcom 110B) in action, for the assessment of surface texture.
b) To evaluate the influence of machining variables, on the surface produced.
c) To analyze surface quality on different types of work material.

Exercises:

1. Test the calibration of the Brown & Sharpe Surfcom, using test specimens with known R_a values.
2. Investigate the effect of changes in the following machining variables on surface finish. The samples were produced on a 1.50 inch diameter bar of Mild Steel, turned between centres, using Tungsten Carbide tools. Note: typical results are provided. Plot graphs to show the relationship of each variable, to the surface texture produced. Analyze and comment on these results.

a) Cutting Speed
b) Tool Nose Radius
c) Feed
d) Depth of Cut

3. Take meter readings for the six specimens provided, i.e., Low carbon steel, aluminum, Brass, Bronze, Stainless Steel and Copper. Note: these surfaces were all machined using the same machining parameters. Discuss possible causes of significant differences in the readings obtained.
4. On the cylindrical part, the three surfaces were turned at different feed settings.

a) Find the meter reading for each surface.
b) Take a graphical trace of the “roughest” surface and determine the feed per revolution used to produce it.
c) Determine the value of ‘tp’ the bearing ratio, at a cutting depth of 50% of Rmax. (The distance between the highest peak and the lowest valley within the assessment length L).

Sample Results:

Example # 1 Calibration

118 μin. standard.
cutoff = 0.03” traversing length = 0.18” magnification = 2000 R_a = 123 μin. R_{max} = 490 μin.

18.1 μin. standard.
cutoff = 0.03” traversing length = 0.18” magnification = 2000 R_a = 19 μin. R_{max} = 83 μin.

Example # 2 Machining Variables

Spindle (RPM)	CS (fpm)	Surf. Text. (R_a)
180	70.7	350 µin.
290		180
360		150
480		105
550		90
875		110
1100		115
1750		115
Plot Surface Texture/Cutting Speed		

Vary Cutting Speed
feed 0.007”/rev.
depth 0.050”
work dia. 1.50”
nose radius = 1/32”

Feed (in./rev.)	Surf. Text. (R_a)
0.0035	35 µin.
0.007	90
0.010	120
0.014	230
0.020	305
0.025	375
Plot Surface Texture/Cutting Speed	

Vary Feed Rate
work dia. 1.50”
spindle RPM 550
depth 0.050”
nose radius = 1/32”
CS = ________ fpm

Nose Rad. (in.)	Surf. Text. (R_a)
1/64	105 µin.
1/32	90
3/64	155
1/16	190
Plot Surface Texture/Cutting Speed	

Vary Nose Radius
work dia. 1.50”
spindle RPM 550
feed 0.007”/rev.
depth 0.05”
CS = ________ fpm

Cut dpeth (in.)	Surf. Text. (R_a)
0.100	100 µin.
0.075	85
0.050	90
0.025	95
0.010	95
0.005	115
Plot Surface Texture/Cutting Speed	

Vary Depth of Cut
work dia. 1.50”
spindle RPM 550
feed 0.007”/rev.
nose radius = 1/32”
CS = ________ fpm

Example # 3 Different Materials

mild steel
cutoff = 0.03”
traversing length = 0.18”
magnification = 2000
R_a = 104 µin.
R_{max} = 610 µin.

aluminum
cutoff = 0.03”
traversing length = 0.18”
magnification = 2000
R_a = 107 µin.
R_{max} = 528 µin.

brass
cutoff = 0.03”
traversing length = 0.18”
magnification = 2000
R_a = 109 µin.
R_{max} = 1046 µin.

bronze
cutoff = 0.03”
traversing length = 0.18”
magnification = 2000
R_a = 115 µin.
R_{max} = 614 µin.

stainless steel
cutoff = 0.03”
traversing length = 0.18”
magnification = 2000
R_a = 175 µin.
R_{max} = 843 µin.

copper
cutoff = 0.03”
traversing length = 0.18”
magnification = 2000
R_a = 107 µin.
R_{max} = 677 µin.

Example # 4 Specimens Turned at Different Feed Rates

surface 1
cutoff = 0.03”
traversing length = 0.18”
magnification = 2000
R_a = 19 µin.
R_{max} = 304 µin.

surface 2
cutoff = 0.03”
traversing length = 0.18”
magnification = 2000
R_a = 30 µin.
R_{max} = 214 µin.

surface 3
cutoff = 0.03”
traversing length = 0.18”
magnification = 2000
R_a = 72 µin.
R_{max} = 439 µin.
T.P.
C-Level 0.0 µin. 0%

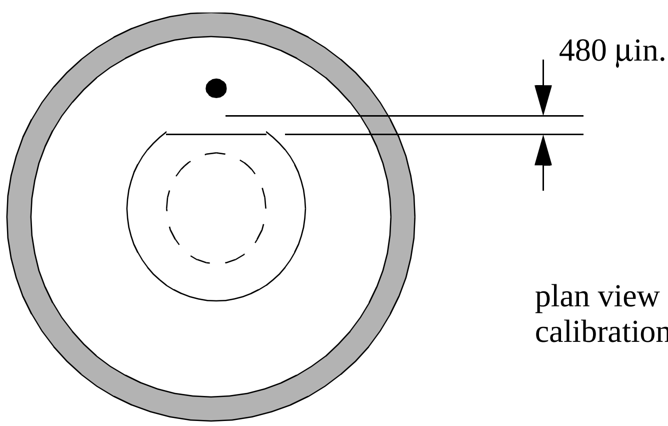
*************** INCLUDE TRACES FROM OLD LAB HERE

5.4.5.2 - Roundness Testing

Purpose:
a) To examine different methods of assessing Roundness and Concentricity.
b) To observe the Rank Taylor Hobson Talyrond in action and learn how to analyze the Polar Traces produced on this type of machine.

CAUTION: The Talyrond must never be started until the Professor or Technologist has lubricated the spindle bearing or expensive damage to the bearing may result.

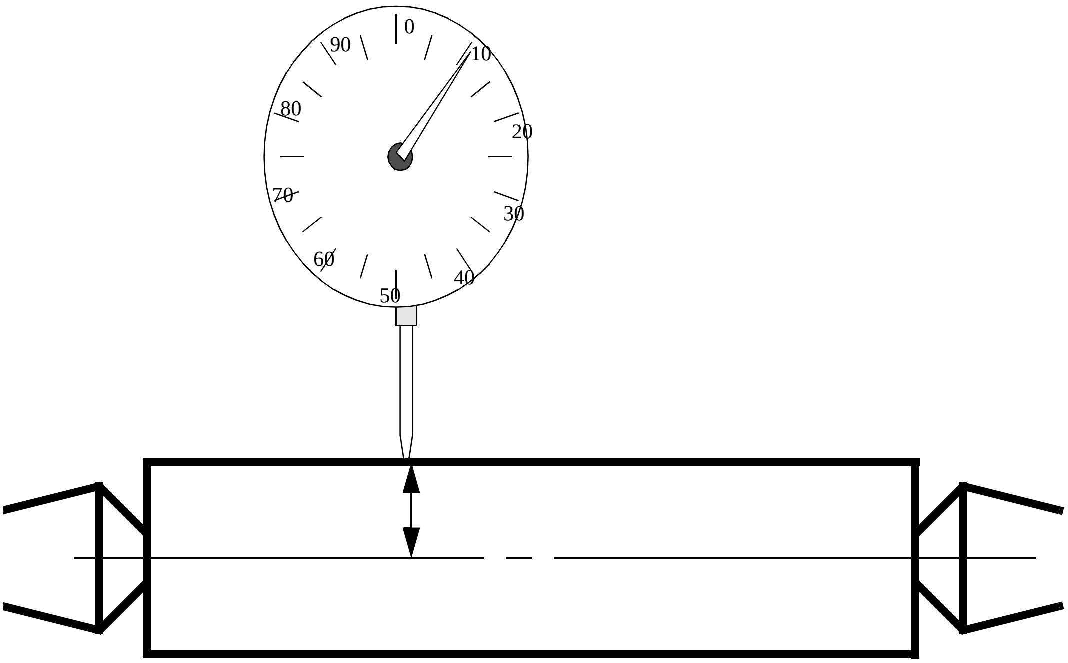
Exercises:
1. Set-up the Talyrond with the 480 μin. reference "Radial Calibration Standard". The standard should be centered visually using the annular rings on the table as the reference. After this, the coarse and fine centering knobs are used, to align the part axis with the machine bearing axis. This process is monitored on the machine head. When the magnification has been increased to a maximum, consistent with the entire trace remaining on the chart (x 2000 in this case) a polar graph is traced. The 2 1/2 inch stylus arm should be used for this. The "spike" length is measured using the transparent template, this value being compared with the standard value, to verify the correctness of the Talyrond.



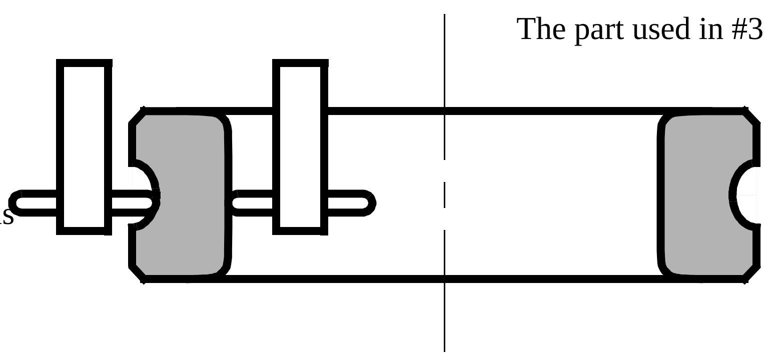
plan view of radial calibration standard

2. a) Mount the stainless steel bar between the bench centres. Position the dial indicator to be in contact with the part at end A. Rotate the part and observe the Full Indicator Reading (F.I.R.). Repeat for end B.

b) Align the same part on the Talyrond, producing a polar trace for end A. Repeat for end B. Compare F.I.R. values obtained in part a) with the out of round values revealed in part b), explain any differences.



3. Align the inner bearing component on the Talyrond for testing the inside part diameter. At a high magnification setting, produce a polar trace to show not only out of roundness but also the magnified surface roughness. Leave the trace in position and change from normal to filter 'B' and trace over the original graph. Analyze the resulting traces and comment on the influences of filter 'B'. Note: See the lecture notes for more details.
4. For the same component used in #3. Provide two traces on one graph, the first from the outside diameter the second from the inside diameter of the part. Show the calculation for eccentricity.



Questions:
1. Does the diameter of the trace on the chart have any relationship to the diameter of the part being checked?
2. Explain why the appearance of a polar trace involves considerable distortion, relative to the circular part it represents.
3. In exercise #4 the inside and outside profiles of the part shown, were examine for concentricity.

Why is it necessary to adjust the Talyrond table levelling screws, before the two polar traces are produced?

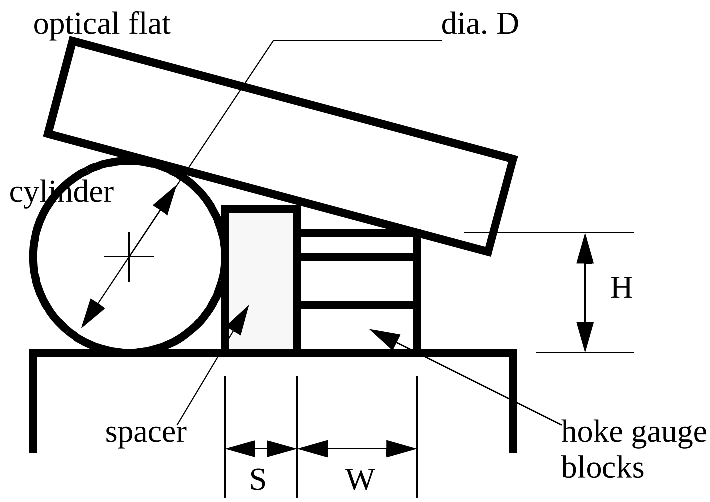
******************* ADD IN SHEETS WITH POLAR TRACES

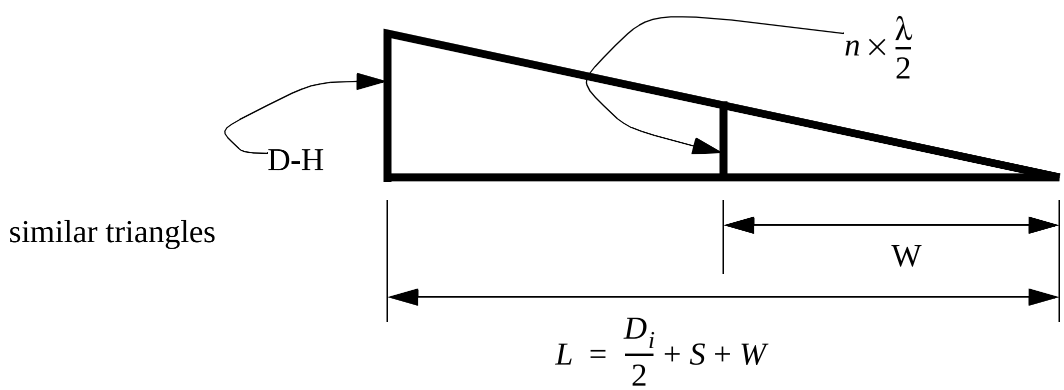
5.4.5.3 - SPC Analysis with GaugeTalker

5.4.5.4 - Interferometry

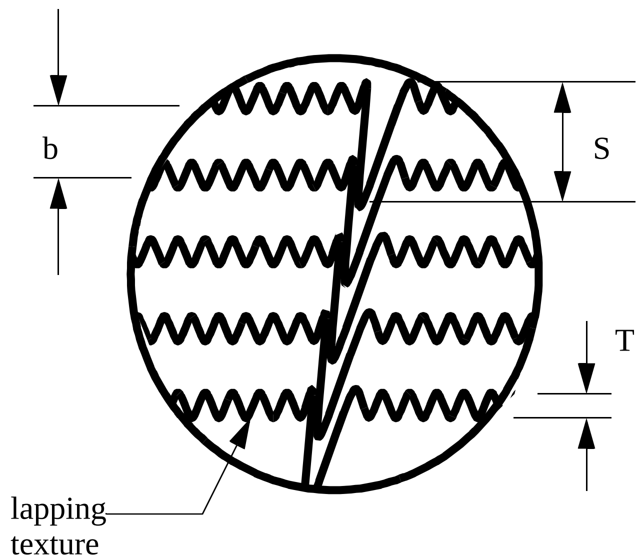
Purpose:
a) To understand the formation of interference bands.
b) To gain experience interpreting interference fringe patterns.
c) To assess Surface Texture using the Interference Microscope

Exercises:
1. Examine the lapped surfaces of old and new supplied gauge blocks, using an optical flat under a helium light (monochromatic light). The wavelength for helium = 23.2 μin. Sketch and explain the observed fringe patterns, evaluating the departure from flatness.
2. Determine the diameter 'D' of a cylinder, using an optical flat and the hoke gauge blocks. Set-up the items as shown in the sketch below. Obtain an interim dia. Di by measuring the cylinder on a bench micrometer. Select Hoke gauge blocks to build-up the height 'H' this being 0.0002" less than the measured value Di. Observe and count the number of fringes 'n' seen through the optical flat, over the width W of the Hoke gauge stack. Derive an equation by similar triangles and use this to calculate the cylinder diameter 'D'.





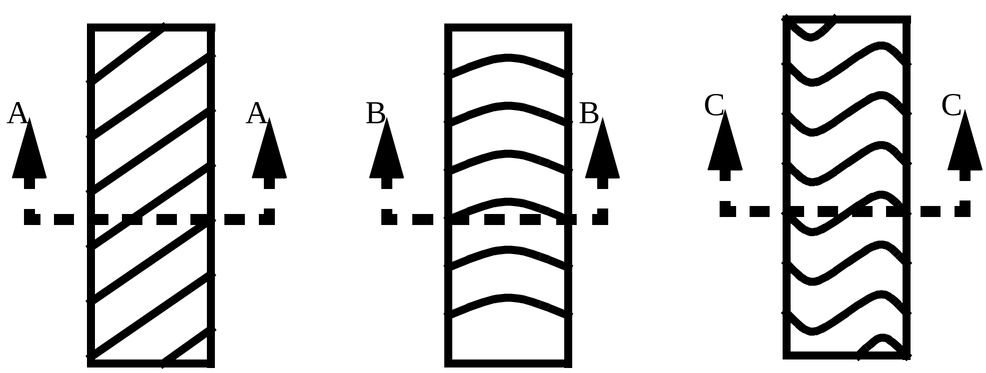
3. Examine a “scratched” gauge block surface with the Interference Microscope. The view should be similar to the sketch on the next page. Estimate the depth of the scratch “S”, and the Surface Texture Ra by first calculating the full texture height “T”. Note: lambda for the Mercury light source = 20 μin.



Questions:

1. List the three characteristics of the fringes in a band pattern, from a flat surface, viewed through an optical flat under a monochromatic light.

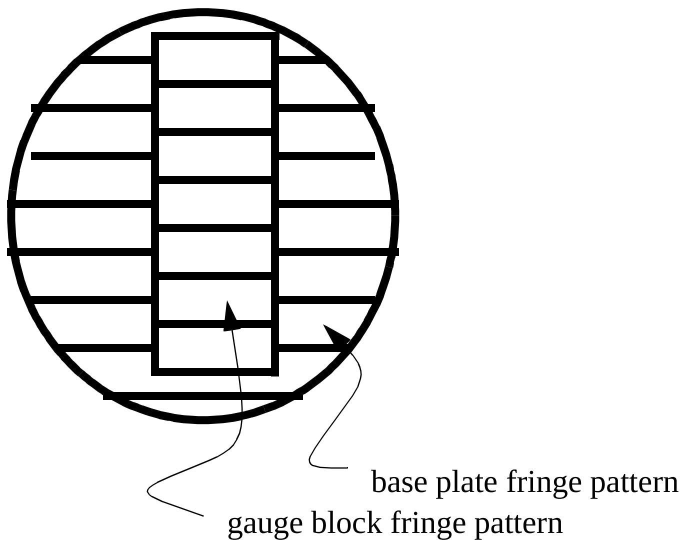
2. The three examples shown below are views seen through an optical flat. Assume the optical flat makes contact with the LEFT ENDS of the surfaces. Draw the three sectional surface views A-A.

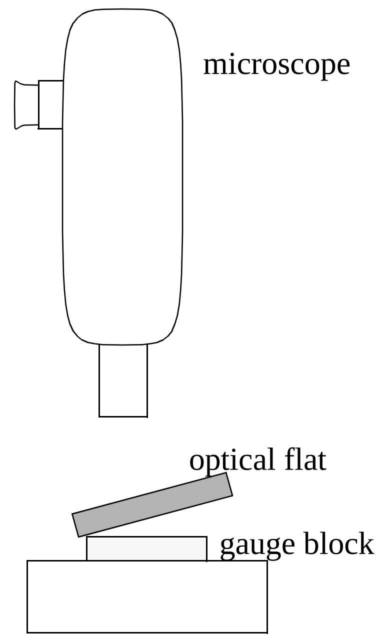


3. The sketches below are the Gauge Block Interferometer and the typical view seen through the eye piece of such an instrument. The height of the gauge block under test “G” is shown in the following equation:

$$G - G_N = \frac{\lambda_1}{2}[(n_1 - N_1) + (f_1 - F_1)]$$

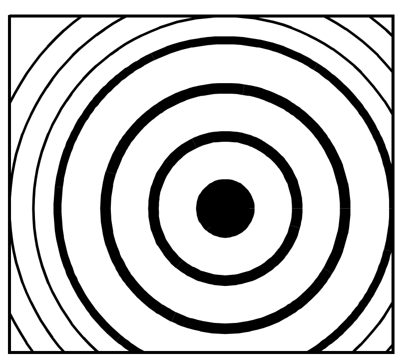
Define the other terms.





Because the fringe patterns for the gauge block, and the base plate have the same spacing, the two sides of the gauge block are parallel.

4. Describe the nature of the surface being viewed through an optical flat, in the sketch below.



5.4.6 Assignments

5.4.6.1 - Metrology and Assembly

1. From the same set of gauge blocks build up the dimensions 3.2452” and 3.2462”. You must not use the same gauge blocks twice. Use the 83 piece gauge block set.

2. Determine what height is required to set up a 5” sine bar for an angle of 11°34’. Specify the gauge block stack required.

3. Design GO/NO GO gauges for an equilateral triangular hole that is to have each side 2.025”±0.002”.

4. Do complete drawings for a 3.000” hole shaft pair if they have a RC3 fit.

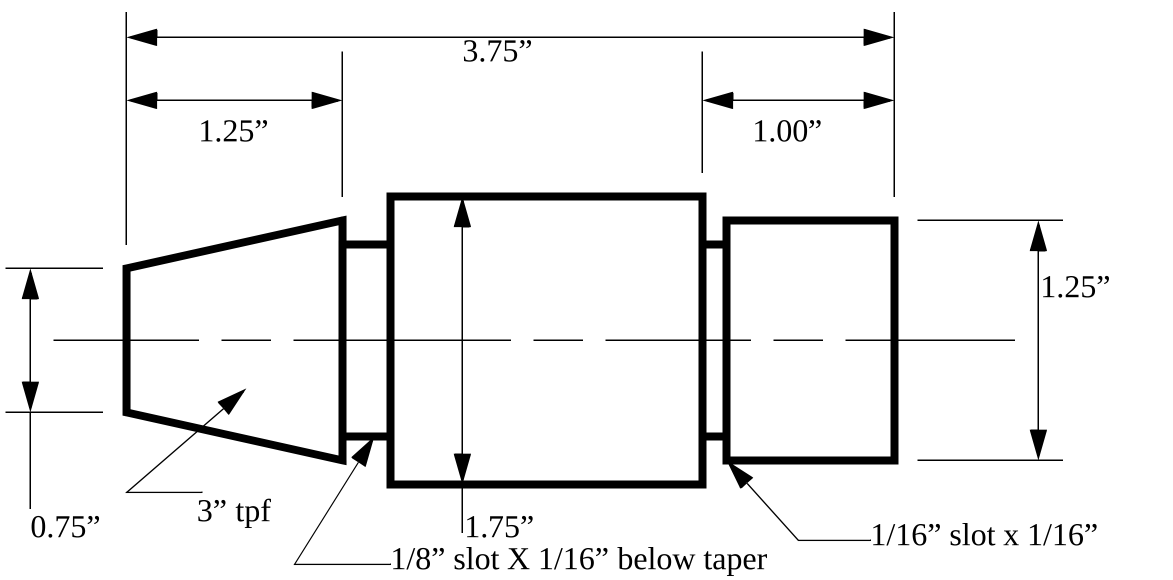
5.4.6.2 - Machining - Revised Assignment - Due First Class in January

1. A new lathe tool is to be used on cast iron work with a 6” diameter to make a 5” long rough cut in 3 passes. The operation conditions listed below were provided by the supplier or assumed. Calculate the parameters a) to e) as requested.

   Cutting Speed = 300 fpm
   Feed Rate = 0.008 ipr
   Depth of Cut = 0.125”
   Idle Horse Power = 0.25
   Machine Efficiency = 0.90

   a) Spindle RPM
   b) Time to make the cut (min.)
   c) Metal Removal Rate Q (in.^{3}/min.)
   d) Cutting Horse Power (HP_c)
   e) Minimum Machine Tool Motor HP.

2. The aluminum component below is to be turned on a lathe using a HSS tool. Develop a process plan, including offset for the taper, speeds, feeds, etc. Put the process plan in a list similar to the format shown. Assume a cost of $45.00/hr. for the lathe, and $25.00/hr. for all other pieces of equipment. State all assumption clearly, and justify numbers in the process plan with calculations or references.



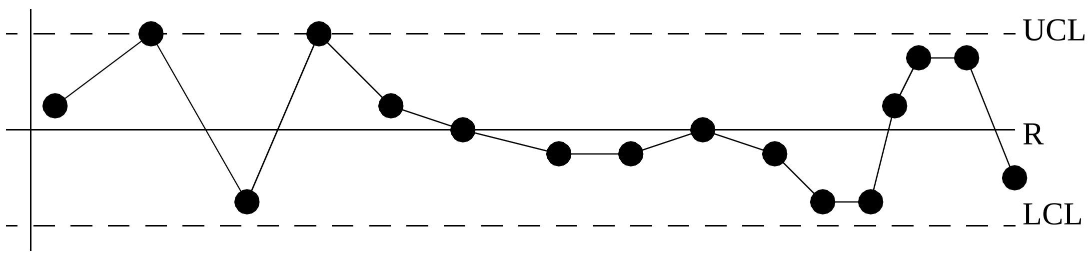
Operation Number	Operation Description	Time	Cost
0010	Cut off Stock to 4”	6 min.	$5.00
0020	Mount in lathe chuck, face and centre drill	12 min.	$9.00

5.4.6.3 - Quality Control

#1 Draw the detailed $\overline{X}$, R, and s charts for the data below.

Sample 1	Sample 2	Sample 3
1.6	0.1	2.7
1.3	2.5	2.7
1.9	2.1	4.9
1.9	3.3	1.5

#2 What problems can be seen in this control chart?



#3. Draw the Pareto diagram for the data below. The data indicates the number of reported errors made when taking fast food orders by telephone

Day \ Operator	Tom	Dick	Harry
Monday	12	8	3
Tuesday	9	7	7
Wednesday	7	9	9
Thursday	8	4	2
Friday	21	9	24
Saturday	28	12	9

5.4.6.4 - Inspection Planning

#1.

a) Develop a double sampling plan OC curve given that,

N = 1000

n1 = 50
c1 = 2
r1 = 4
n2 = 100
c2 = 3

b) What is the AOQL?

5.5 BIBLIOGRAPHY

Armarego, Brown, Machining of Metals, Prentice Hall

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Boothroyd, G., Fundamentals of Metal Machining, McGraw-Hill

Busch, E., Fundamentals of Dimensional Metrology, Delmar/Nelson

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Juran, Gryna, Quality Planning and Analysis (2nd edition), Wiley & Sons

Krar, O., St. Amand, Technology of Machine Tools (3rd Edition), McGraw-Hill

ShotBolt, G., Metrology for Engineers, Cassell & Company

5.6 REFERENCES

MEC 121 - STATICS

6. INTRODUCTION

6.1 PHILOSOPHY

6.1.1 Tips When Solving Statics Problems

1. Even when problems seem impossible keep trying, it will help you learn to solve problems (This is like learning a new sport, except here you are building strength and coordination for problem solving). Solving problems is mainly a skill of recognizing patterns and then using techniques you have seen before.
2. If there is a topic you do not understand in a previous section, it will make it hard to solve problems in more advanced sections.
3. As you solve problems, you will find that you work faster.
4. Avoid shortcuts, they always take longer.
5. Try alternate ways of solving problems, this will strengthen your skills.
6. If you are really stuck on a problem leave it until the next day, then try again.
7. Solve problems with variables, and units, this will reduce errors, and makes errors easier to find and fix.
8. Solving problems is the only way to do well.
9. Always look at your answer to see if it makes sense, and find ways to check the results.
10. Always use Free Body Diagrams, and list assumptions, this will reduce assumption based mistakes in simple problems, and give you clues for solving complicated problems.
11. Carefully read any question before starting. If it is confusing, underlining or writing out the details in point form can help.

6.2 RESOURCES

6.2.1 How to Find Additional Resources

1. A tutorial disk is included with the text. It seems reasonable if you are having problems with a particular section of the text.
2. Books may be found in the library.
3. Books can be purchased, but read a few problems in any book you are considering to make sure they are to your liking before buying.

4. Read the textbook chapters as indicated, and try suggested problems.

6.2.2 Problems to try in Book (6th Edition)

Topic	Section	Page	Practice Questions
Introduction	1.1-1.6	13	1,2,7,11,12,19
Newtons Laws	2.1-2.3	23	2,3,6,7,10,13,17,19,22,25
Vectors and Scalars	2.4	34	29,30,33,39,41,49,50
	2.5-2.6	49	55,57,61,65,69
	2.7-2.8	58	74,77,78,81,87,89,95
	2.9	68	103,105,109,113
Particle Equilibrium	3.1-3.3	82	1,3,5,9,15,18,29
Free Body Diagrams	3.4	94	31,34,38,42
2 & 3 D Force Systems			
Support Reactions			
Moment of a Force	4.1-4.4	116	5,7,10,13,14,17,27,34
Scalar and Vector Forces	4.5	127	45,51,53,54,55
Cross Products	4.6	137	61,63,70,73,74,77
Principle of Transmissibility	4.7	155	82,85,95,106
Moments about an Axis			
Rigid Body Equilibrium	5.1-5.2	187	2,3,6,10
2 & 3 Force Members	5.3-5.7	224	66,67,69,79,82,87
2 & 3 Dimensional Equilibrium			
Structures	6.1-6.3	245	1,2,3,9,11,14,15.18,19
Forces in 2 Dimensions	6.4	255	21,23,26,30,34,37,39
Method of Joints			
Method of Section			
Frames	6.6	279	49,55,57,59,65,73,77,81,
Method of Members			85,87,91,98
Centre of Mass	9.1-9.2	413	9,11,14,21,29,31
Centroids of Lines/Areas/Volumes	9.3	424	35,47,50,55,63,71
Composite Bodies			
Dry Friction	8.1-8.2	359	1,2,3,5,7,19,21,27,33,34,42
Friction Angle			46,47
Friction on Particles and Rigid Bodies	8.3	375	53,54,58,59,62,63

Wedges

6.2.3 Problems to try in Book (7th Edition)

Section 1.1 to 1.6 - Basic Units, Calculations and Statics

pg. 15

#5	/10	#6	/10	#7	/10	#10	/10
#12	/10	#13	/10	#	/10	#	/10

Section 2.1 to 2.3 - Newton's Laws

pg. 25

#2	/10	#3	/10	#6	/10	#7	/10
#11	/10	#13	/10	#14	/10	#15	/10
#24	/10	#26	/10	#31	/10	#	/10
#	/10	#	/10	#	/10	#	/10

Section 2.4 to 2.9 Vectors and Scalars

pg. 36

#34	/10	#38	/10	#39	/10	#47	/10
#50	/10	#54	/10	#55	/10	#	/10

pg. 50

#66	/10	#70	/10	#71	/10	#74	/10
#75	/10	#	/10	#	/10	#	/10

pg. 60

#85	/10	#90	/10	#91	/10	#93	/10
#110	/10	#114	/10	#115	/10	#	/10

pg. 71

#123	/10	#125	/10	#126	/10	#134	/10

Section 3.1 to 3.3 - Particle Equilibrium

pg. 87

#1	/10	#3	/10	#5	/10	#7	/10
#10	/10	#17	/10	#39	/10	#	/10

Section 3.4 Free Body Diagrams, 2/3D force Systems and Support Reactions

pg. 99

#41	/10	#43	/10	#50	/10	#58	/10
#	/10	#	/10	#	/10	#	/10

Section 4.1 to 4.4 - Moment of a Force

pg. 123

#6	/10	#7	/10	#14	/10	#15	/10
#17	/10	#22	/10	#35	/10	#37	/10
#	/10	#	/10	#	/10	#	/10

Section 4.5 - Scalar and Vector Forces

pg. 135

#51	/10	#53	/10	#59	/10	#61	/10
#65	/10	#	/10	#	/10	#	/10

Section 4.6 - Cross Products

pg. 144

#69	/10	#73	/10	#74	/10	#77	/10
#79	/10	#87	/10	#	/10	#	/10

Section 4.7 - Principle of Transmissibility and Moments about an Axis

pg. 162

#93	/10	#99	/10	#103	/10	#110	/10
#	/10	#	/10	#	/10	#	/10

Section 5.1 to 5.2 - Rigid Body Equilibrium

pg. 193

#3	/10	#4	/10	#6	/10	#7	/10
#	/10	#	/10	#	/10	#	/10

Section 5.3 to 5.7 - 2 and 3 Force Members and 2/3D Equilibrium

pg. 231

#66	/10	#71	/10	#75	/10	#78	/10
#87	/10	#89	/10	#	/10	#	/10

Section 6.1 to 6.3 - Trusses and Method of Joints

pg. 253

#1	/10	#2	/10	#3	/10	#9	/10
#11	/10	#14	/10	#22	/10	#27	/10
#29	/10	#	/10	#	/10	#	/10

Section 6.4 - Trusses and Method of Sections

pg. 263

#31	/10	#34	/10	#39	/10	#43	/10
#49	/10	#50	/10	#57	/10	#59	/10

Section 6.6 - Frames and Method of Members

pg. 287

#70	/10	#71	/10	#75	/10	#90	/10
#95	/10	#97	/10	#99	/10	#106	/10
#110	/10	#114	/10	#121	/10	#123	/10

Section 9.1 to 9.2 - Centre of Mass by integration

pg. 427

#9	/10	#13	/10	#18	/10	#23	/10
#30	/10	#35	/10	#	/10	#	/10

Section 9.3 - Centroid of 1/2/3D volumes by integration and composite bodies methods

pg. 438

#41	/10	#50	/10	#53	/10	#62	/10
#65	/10	#71	/10	#	/10	#	/10

Section 8.1 to 8.2 - Basic Friction

pg. 369

#1	/10	#2	/10	#7	/10	#9	/10
#10	/10	#11	/10	#15	/10	#19	/10
#25	/10	#29	/10	#33	/10	#53	/10
#54	/10	#55	/10	#	/10	#	/10

Section 8.3 - Friction and Wedges

pg. 385

#61	/10	#62	/10	#63	/10	#66	/10
#67	/10	#71	/10	#	/10	#	/10

6.2.4 Bibliography

Bedford, A., Fowler, W., “Engineering Mechanics Statics”, Addison-Wesley Publishing Co., Inc., 1995.

Beer, F.P., Johnston, E.R., Statics & Mechanics of Materials, McGraw-Hill, 1992.

Hibbeler, R.C., Engineering Mechanics: Statics and Dynamics, 6th edition, MacMillan Publishing Co., New York, USA, 1992.

Pytel, A., Kiusalaas, J., Engineering Mechanics; Statics and Dynamics, Harper Collins, 1994.

6.3 ASSIGNMENTS

• The assignments are to be done individually from beginning to end. My experience shows that study groups are of great help, and will help a student get by many small problems quickly. But students who never do any problems individually (i.e., assignments) always do poorly when they must solve problems themselves on exams.

• Stassen's Ten Commandments for Assigned Calculations

The following format requirements must be met before an assignment will be accepted or given credit.

1. The problem Assignment Sheet must be attached to the front of the report. The name of the author and the Section Number must be placed at the upper right-hand corner of the front page.
2. All calculations must be shown and a clear "heading" must be given with each step of the calculations.
3. All units must be attended to properly in balanced equations. Answers without units are not valid, except 0 or unitless values such as ratios.
4. Where applicable references must be given for all relationships obtained from text-books.
5. Clear diagrams must be provided where necessary.
6. Do not use unnecessary terms like "I" or verbose terms such as "to find", etc. It is expected that proper and concise statements are made where needed.
7. At the conclusion of each problem the final result must be clearly summarized and high-lighted.
8. Where necessary a conclusion should be drawn or a final comment made. Sometimes a recommendation is necessary and should be included in the report.
9. Reports must be written on one side of letter size paper. Only in the case of graphic solutions can "odd" paper sizes be used, but these must be folded to size.
10. Calculations should progress in a logical and sequential manner to the final result.

NOTE: A good maxim for overall appearance is that the work should be ready for typing.

6.4 BRIDGE BUILDING COMPETITION

Objective: To use simple materials to construct a bridge with the highest strength to weight ratio.

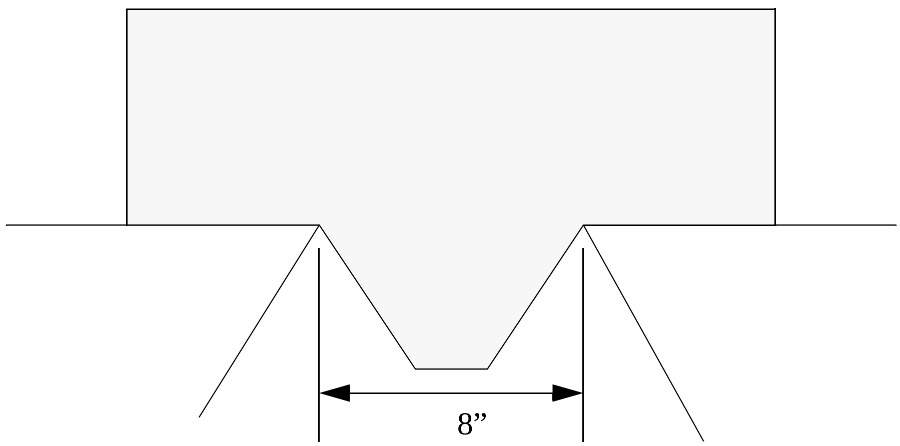
Rules:

1. The materials that may be used are listed below. If there are any questions regarding

acceptable materials the course instructor can be consulted. Any questions must be resolved before the judging. The total weight must be below 500g. Use,

- common toothpicks, such as the tapered wooden or round variety (< 1/16”).
- white glue, balsa glue, 5 minute epoxy, super-glue, or a similar adhesive is to be used only for joining the toothpicks or thread.
- common sewing thread that can be used on a common sewing machine or serger.

2. The bridge will be mounted between two flat surfaces 8” apart, assume the maximum length of the edges will be 24 inches or less.



3. The bridge will be loaded on the upper surface until failure. The loading area must be at least 8” by 8” square.

Evaluation:

1. The bridge will be weighed and checked for conformance to the rules.
2. A water vessel will be placed on top, and slowly filled with water until the bridge fails. Failure will be determined by the P.Eng. judges to be when the structure is no longer operating as originally anticipated, or 1cm below the original height of the load.
3. The water container, with water, will be measured to give the failure load.
4. A ratio of failure load to weight ratio of the bridge will be used to rank the performance.

Hints:

1. Heavy is not necessarily better (an ant would outperform a human with the characteristics used here)
2. Equilateral triangles form good supports in a solid structures.
3. Consider the Golden Gate Bridge in San Francisco for support structures.
4. Try building prototypes first to test the structure.

MEC 706 - SOUND AND VIBRATION CONTROL

7. OVERVIEW

7.1 PREFACE

The notes are based on the book “Industrial Noise and Vibration Control” by Irwin and Graf. Whenever figures, table, questions, etc. are referred to that are not in these notes, they may be found there. The notes generally follow the order of the text, except for the vibration component of the notes. Sets of questions follow the applicable note sections, these are from previous assignments, midterms, and finals. Where available answers are provided, but at this point the only promise about their value is that they will contain mistakes (hopefully many of these mistakes will be corrected in future revisions). Please take note of mistakes in the notes, and indicate them to me later. I will upgrade the notes for the benefit of future years. Please keep track of additional topics you think would be of value, and I will endeavor to add those if possible. A set of log graph paper sheets are provided near the front of the notes. These can be used for some of the vibration, and sound problems.

A note of value is that the problems do tend to focus on industrial noise and vibration control, but the approaches discussed are directly applicable to other areas, such as vibration in an airframe.

The selection of topics, first vibration then sound might apparently seem distant at best. But, when considered, these phenomenon are natural complements. In fact the underlying mathematical concepts are identical, the major difference is that the transmission medium is varied. This rationale leads the review of vibrations concepts, to lay a familiar basis for the student to consider the nature of sound. The essential nature of these problems cannot be underplayed, as environmental issues are becoming an essential component of all engineering design. It is for this reason that the scientific properties of sound will be related to various existing legal statutes for noise control.

7.1.1 Theoretical Fundamentals

The student is expected to have a grasp of a number of basic topics,

- Properties of logarithms
- Laplace and Fourier transforms
- Wave properties
- A knowledge of statics and dynamics
- A basic background in material properties

- A previous course in vibration

7.2 EVALUATION

The student will be evaluated throughout the year with two midterm tests, tentatively schedules for,

Midterm #1 - February _____, 1995
Midterm #2 - March _____, 1995.

In addition there will be a total of four assignments that will be assigned throughout the term as material is covered. These assignments descriptions will be given later.

7.3 RESOURCES

7.3.1 Library

• There are a number of resources available to the student. In many cases older textbooks will contain valuable information.
*********** Get a List of useful books

7.3.2 Computer

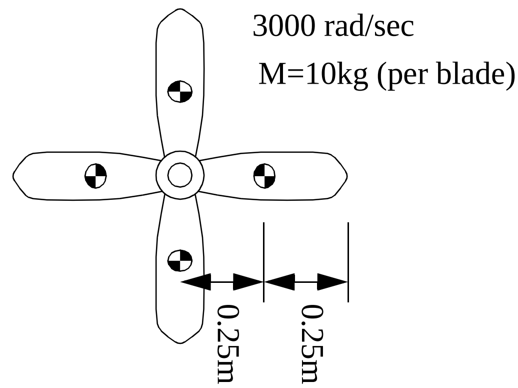
*********** Check for public domain, WWW, gopher, etc.

7.3.3 Conversion Table

A conversion table is attached to the end of these notes for many common unitary translations that may be required.

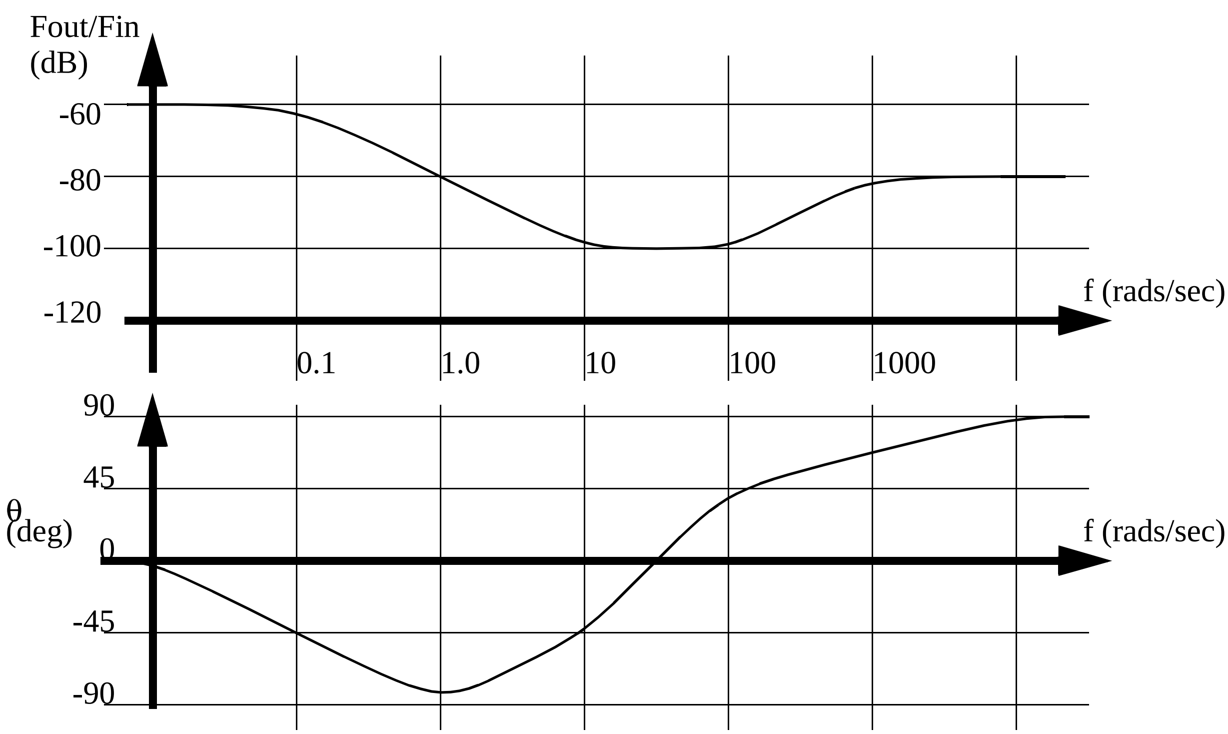
7.4 PRACTICE QUESTIONS

#1 a) A worst case analysis is being done on a four bladed propeller. Given the properties below, estimate the maximum force that will be applied to the engine mount if one of the blades falls off. (5%)



b) Describe how we would practically find the relationship between vibration at the engine mount, and a point in the cockpit. (5%)

c) Assuming the Bode Plots below was obtained in the test in part b), what would the transfer function be? (5%)



d) Given that the engine generates a vibration force of 100N at 6000 rad/sec, use the bode plots to estimate the vibration force in the cabin, with the missing propeller blade. (10%)

e) Using the conditions described in d), use a Fourier transform to find the vibration force in the cabin, with the missing propeller blade. (15%)

f) Given that the main source of sound in the cabin is a panel that shakes, and experimentally we determine the force to sound power to be related by the equation below. Find the sound power levels in the cabin. (5%)

$$W_{sound} = \frac{F}{20000}$$

g) Given that the cabin (2m by 2m by 2m) is finished with wood walls (alpha = .1), and 4 glass windows (40cm by 40cm each and alpha = .12). Find the reverberant sound pressure level in the cabin caused by the motor, and the missing propeller blade. (10%)

h) What is the total loudness in sones, based on the values found in g)? (5%)

i) What is the voice level that may be used from the curves below if the pilot and copilot sit 3 feet apart? (5%)

j) Outside, the aircraft engine is running, and noise POWER levels are as listed below. If the nearest neighborhood is 50m away, what are the sound pressure levels? What is the total sound pressure in each time period (add the A-weighted pressure values)? (10%)

f (Hz)	7am-10pm Lw(dB)	10pm-7am Lw(dB)
125	93	83
250	98	91
500	115	110
1000	109	103
2000	101	97

k) What is the noise pollution level if a 10dB penalty is in place from 10pm to 7am? (5%)

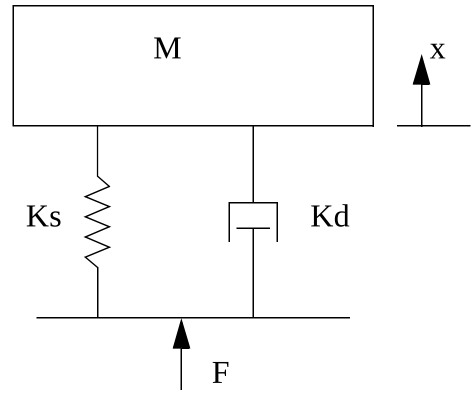
l) A hangar is to be built to house the aircraft, and reduce the noise levels. (In effect this is a large hood.) If the hangar is to be built 100m by 100m by 20m, with a 1/4” plywood wall with insulation, what will the 1000Hz sound pressure level be near the hangar during the day? (10%)

m) As another alternative, a resonant muffler (an expansion chamber) is to be designed to reduce the 1000Hz sound. If the exhaust pipe has a 30cm radius, select the width and length for a Transmission Loss of 20dB. Assume c=300m/s. (10%)

7.5 OLD EXAM PROBLEMS

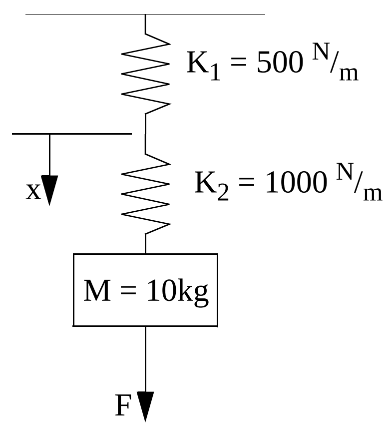
1. When a force ‘F’ is applied to the spring-mass-damper system below, the result is a motion ‘x’.

If the spring-damper pair should have a static spring coefficient of 500 KN/m, but at 100Hz we want an isolation of 99.9%. What is the required damper value. Clearly state any assumptions made.



2. The applied force ‘F’ is the input to the system, and the output is the displacement ‘x’.

a) find the transfer function.



3. Given the transfer function below,

$$\frac{y(s)}{x(s)} = \frac{(s+10)(s+5)}{(s+5)^2}$$

a) draw the straight line approximation of the bode and phase shift plots.
b) determine the steady state output if the input is x(s) = 20 cos(9t+.3)

4. Given the following time response to a step input of F=5N for t >= 0, find the transfer function x/F.

$$x(t) = \{5 - 5e^{-10t}\}m$$

1. Given the transfer function below, find the isolation at 2Hz. (25%)

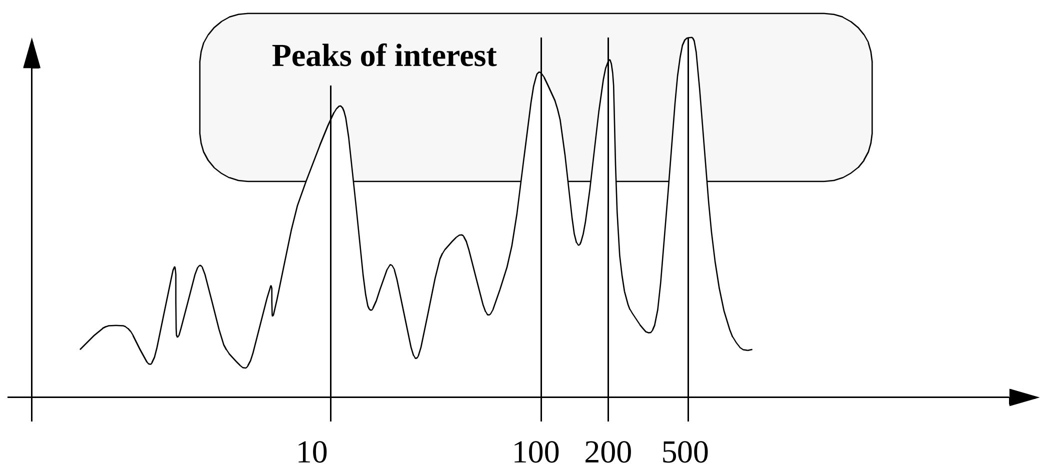
$$H(s) = \frac{(10 + 5s)}{(2s^2 + 20s + 4)(6 + 3s)}$$

2. Describe how an active vibration control system might work. (5%)

3. A 160lb sign is to be mounted onto the side of a building. One significant problem is that the sign vibrates at about 100 radians per second. Therefore isolators will be used between the sign and the side of the building. Using the specifications sheet that was supplied by a local sales office, select a suitable isolator. (10%)

4. Two identical sources have a combined amplitude (Lp) of 104dB. What would be the value of the root mean square pressure for just one of the sources? (5%)

5. The sound spectrum below is known to exist for an industrial machine. Keeping in mind the proximity of some of the peaks, what bandwidth would our sound instrumentation require to tell them apart? (5%)



6. There is a small room that contains an average 100 hp diesel engine turning at 7200 rpm. The room is 2.5m by 2.5m and has a ceiling height of 2m. The walls and ceiling of the room are coverered by a sound absorbtion coating (with a coefficient of 0.92). There are two 50cm by 30cm heavy plate glass windows in the walls for safety, and the floor is unpainted concrete. (50%)
a) determine the sound power level of the sound source (in dB).
b) assuming uniform directivity, what would be the direct sound pressure level (in dB) would we hear standing 0.5m and 2m away?
c) what is the reverberant sound pressure level (in dB) we would hear standing 0.5 and 2m away?
d) assuming the noise from the engine is relatively uniform in intensity from 200 Hz to 4 KHz, how far apart would two people in the room have to stand to hear each other shouting based on reverberant sound only?
e) what would the longest period of time a worker could be in that room each day based on rever-

berant sound only?

1. Given the transfer function below,

$$\frac{y(s)}{x(s)} = \frac{(s+10)(s+1000)}{(s+1000)^2}$$

   a) draw the straight line approximation of the bode and phase shift plots.(8%)
   b) determine the steady state output if the input is x(s) = 20 cos(100t+.3). (4%)

2. Given the following time response to a step input of F=5N for t >= 0, find the transfer function x/F. (6%)

$$x(t) = \{5 - 5e^{-10t}\}m$$

3. A spring damper system supports a mass of 34N. If it has a spring constant of 20.6N/cm, what is the systems natural frequency? (4%)

4. A large machine weighs 1000kg and vibrates at 20Hz, design an inertial damper. (4%)

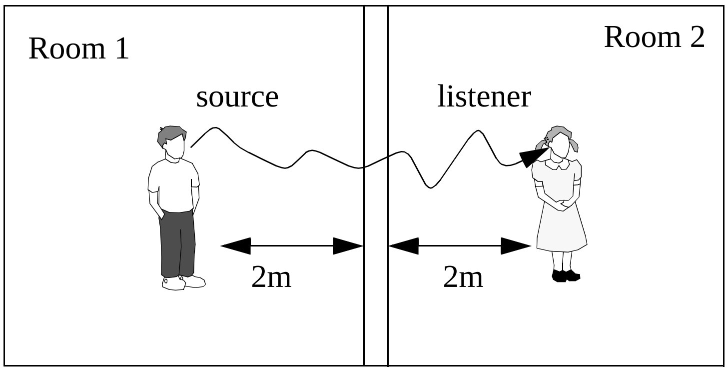
5. If we had two sound sources at 120 Hz and 142 Hz that we wanted to measure separately, what would be the bandwidth of the analyzer? (4%)

6. A design is specified so that it should have a maximum preferred noise criteria value of 35. When tested, the sound values measured at half octaves from 63Hz are, (4%)

   41dB, 43dB, 46dB, 51dB, 48dB, 48dB, 35dB, 33dB

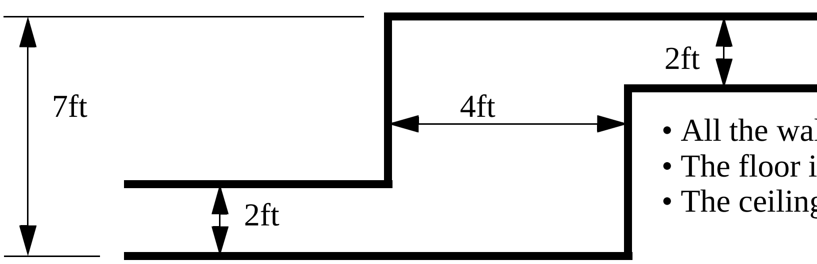
7. Expecting an increase in business, the Boris and Natasha Detective Agency has hired you to build a soundproof wall to divide their cork lined interrogation room. The dimensions and location of the new rooms are shown below. The loudest voice expected in either room will be 80dB, and a listener can hear voices at pressure levels above 20dB.Will a 2x4” stud wall with

gypsum on both sides prevent a listener from hearing another interrogation? (15%)



Each room is 4m by 4m by 4m and has carpet on the floors walls and ceilings.

8. You think that a bend in a hallway of your house reduces noise levels. This “plenum” has the dimensions below. Determine the Transmission Loss for 500 Hz. (10%)



- All the walls and ceiling are gypsum
- The floor is carpet with underpad
- The ceiling height is 7ft.

9. The following data was recorded for a non-isotropic source. What would be the directivity factor (Q) in direction θ = 60° (use appropriate approximation for calculation of the average value). (6%)

θ(deg):	0,	60,	120,	180,	240,	300
Lp(dB):	77,	71,	69,	70,	69,	73

10. Given the transfer function below, find the isolation at 2Hz. (15%)

$$H(s) = \frac{(10 + 5s)}{(2s^2 + 20s + 4)(6 + 3s)}$$

11. There is a small room that contains an average 100 hp diesel engine turning at 7200 rpm. The room is 2.5m by 2.5m and has a ceiling height of 2m. The walls and ceiling of the room are covered by a sound absorption coating (with a coefficient of 0.92). There are two 50cm by 30cm heavy plate glass windows in the walls for safety, and the floor is unpainted concrete. (20%)
a) determine the sound power level of the sound source (in dB).
b) assuming uniform directivity, what would be the direct sound pressure level (in dB) would we hear standing 0.5m and 2m away?

c) what is the reverberant sound pressure level (in dB) we would hear standing 0.5 and 2m away?
d) assuming the noise from the engine is relatively uniform in intensity from 200 Hz to 4 KHz, how far apart would two people in the room have to stand to hear each other shouting based on reverberant sound only?
e) what would the longest period of time a worker could be in that room each day based on reverberant sound only?

7.6 REFERENCES/BIBLIOGRAPHY

Irwin, J.D., and Graf, E.R., Industrial Noise and Vibration Control, Prentice Hall Publishers, 1979.

MEC 708 - SOUND AND VIBRATION CONTROL

8. OVERVIEW

8.1 PREFACE

The notes are based on the book “Industrial Noise and Vibration Control” by Irwin and Graf. Whenever figures, table, questions, etc. are referred to that are not in these notes, they may be found there. The notes generally follow the order of the text, except for the vibration component of the notes. Sets of questions follow the applicable note sections, these are from previous assignments, midterms, and finals. Where available answers are provided, but at this point the only promise about their value is that they will contain mistakes (hopefully many of these mistakes will be corrected in future revisions). Please take note of mistakes in the notes, and indicate them to me later. I will upgrade the notes for the benefit of future years. Please keep track of additional topics you think would be of value, and I will endeavor to add those if possible. A set of log graph paper sheets are provided near the front of the notes. These can be used for some of the vibration, and sound problems.

A note of value is that the problems do tend to focus on industrial noise and vibration control, but the approaches discussed are directly applicable to other areas, such as vibration in an airframe.

The selection of topics, first vibration then sound might apparently seem distant at best. But, when considered, these phenomenon are natural complements. In fact the underlying mathematical concepts are identical, the major difference is that the transmission medium is varied. This rationale leads the review of vibrations concepts, to lay a familiar basis for the student to consider the nature of sound. The essential nature of these problems cannot be underplayed, as environmental issues are becoming an essential component of all engineering design. It is for this reason that the scientific properties of sound will be related to various existing legal statutes for noise control.

8.1.1 Theoretical Fundamentals

The student is expected to have a grasp of a number of basic topics,

- Properties of logarithms
- Wave properties
- A knowledge of statics and dynamics
- A basic background in material properties
- A previous course in vibration

8.2 RESOURCES

8.2.1 Library

• There are a number of resources available to the student. In many cases older textbooks will contain valuable information.

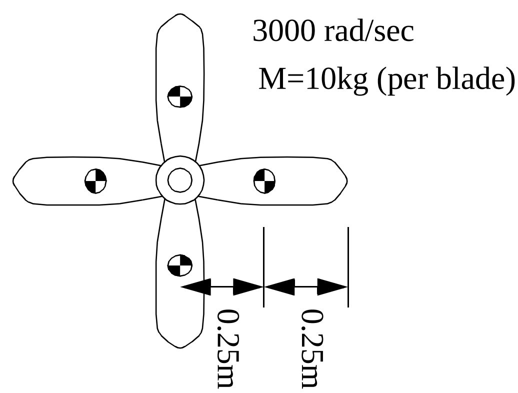
*********** Get a List of useful books

8.2.2 Computer

*********** Check for public domain, WWW, gopher, etc.

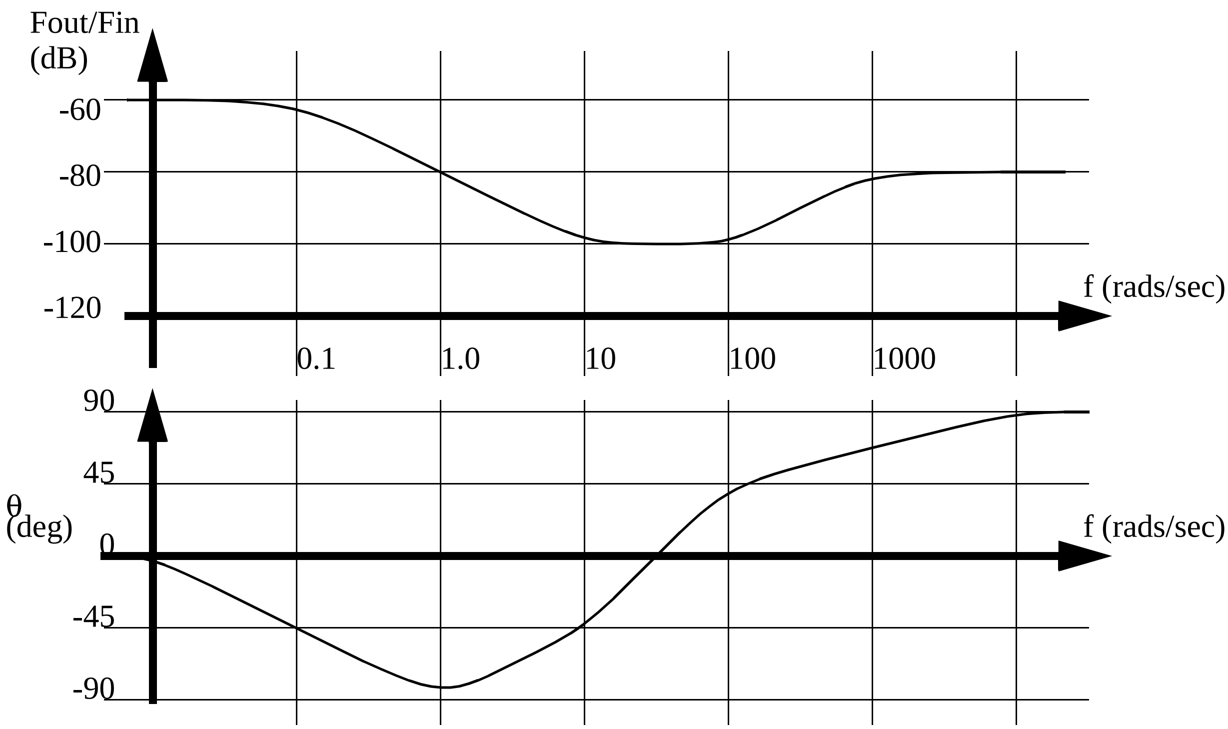
8.3 PRACTICE QUESTIONS (from MEC 702)

#1 a) A worst case analysis is being done on a four bladed propeller. Given the properties below, estimate the maximum force that will be applied to the engine mount if one of the blades falls off. (5%)



b) Describe how we would practically find the relationship between vibration at the engine mount, and a point in the cockpit. (5%)

c) Assuming the Bode Plots below was obtained in the test in part b), what would the transfer function be? (5%)



d) Given that the engine generates a vibration force of 100N at 6000 rad/sec, use the bode plots to estimate the vibration force in the cabin, with the missing propeller blade. (10%)

e) Using the conditions described in d), use a Fourier transform to find the vibration force in the cabin, with the missing propeller blade. (15%)

f) Given that the main source of sound in the cabin is a panel that shakes, and experimentally we determine the force to sound power to be related by the equation below. Find the sound power levels in the cabin. (5%)

$$W_{sound} = \frac{F}{20000}$$

g) Given that the cabin (2m by 2m by 2m) is finished with wood walls (alpha = .1), and 4 glass windows (40cm by 40cm each and alpha = .12). Find the reverberant sound pressure level in the cabin caused by the motor, and the missing propeller blade. (10%)

h) What is the total loudness in sones, based on the values found in g)? (5%)

i) What is the voice level that may be used from the curves below if the pilot and copilot sit 3 feet apart? (5%)

j) Outside, the aircraft engine is running, and noise POWER levels are as listed below. If the nearest neighborhood is 50m away, what are the sound pressure levels? What is the total sound pressure in each time period (add the A-weighted pressure values)? (10%)

f (Hz)	7am-10pm Lw(dB)	10pm-7am Lw(dB)
125	93	83
250	98	91
500	115	110
1000	109	103
2000	101	97

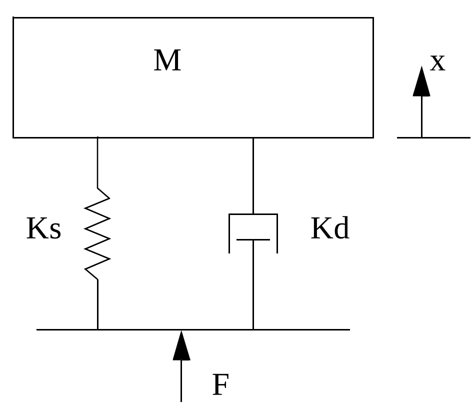
k) What is the noise pollution level if a 10dB penalty is in place from 10pm to 7am? (5%)

l) A hangar is to be built to house the aircraft, and reduce the noise levels. (In effect this is a large hood.) If the hangar is to be built 100m by 100m by 20m, with a 1/4” plywood wall with insulation, what will the 1000Hz sound pressure level be near the hangar during the day? (10%)

m) As another alternative, a resonant muffler (an expansion chamber) is to be designed to reduce the 1000Hz sound. If the exhaust pipe has a 30cm radius, select the width and length for a Transmission Loss of 20dB. Assume c=300m/s. (10%)

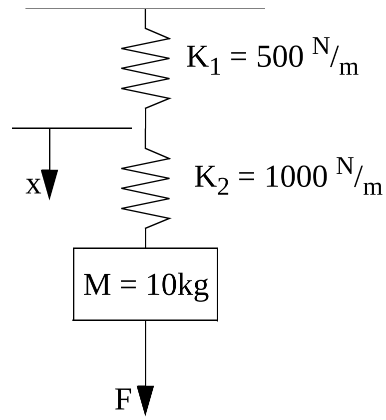
8.4 OLD EXAM PROBLEMS (from MEC 702)

1. When a force ‘F’ is applied to the spring-mass-damper system below, the result is a motion ‘x’. If the spring-damper pair should have a static spring coefficient of 500 KN/m, but at 100Hz we want an isolation of 99.9%. What is the required damper value. Clearly state any assumptions made.



2. The applied force ‘F’ is the input to the system, and the output is the displacement ‘x’.

a) find the transfer function.



3. Given the transfer function below,

$$\frac{y(s)}{x(s)} = \frac{(s+10)(s+5)}{(s+5)^2}$$

a) draw the straight line approximation of the bode and phase shift plots.
b) determine the steady state output if the input is x(s) = 20 cos(9t+.3)

4. Given the following time response to a step input of F=5N for t >= 0, find the transfer function x/F.

$$x(t) = \{5 - 5e^{-10t}\}m$$

1. Given the transfer function below, find the isolation at 2Hz. (25%)

$$H(s) = \frac{(10 + 5s)}{(2s^2 + 20s + 4)(6 + 3s)}$$

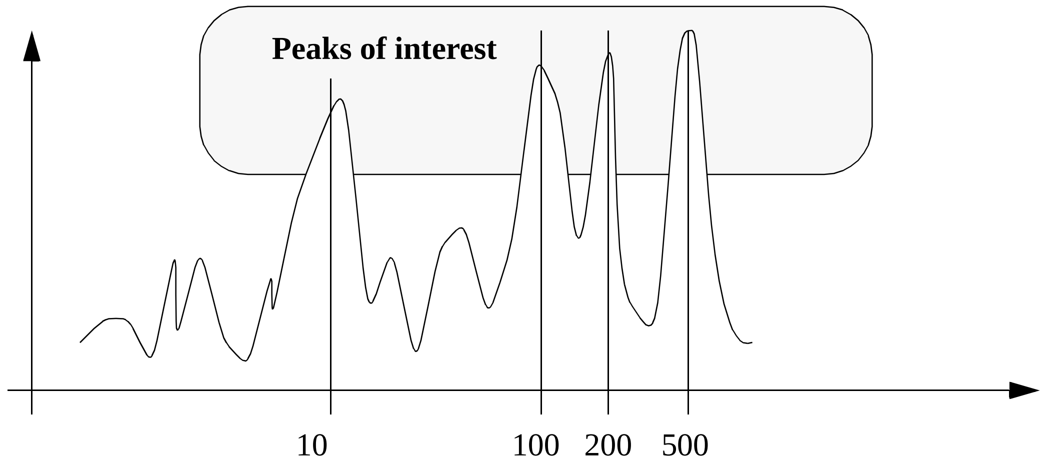
2. Describe how an active vibration control system might work. (5%)

3. A 160lb sign is to be mounted onto the side of a building. One significant problem is that the sign vibrates at about 100 radians per second. Therefore isolators will be used between the sign and the side of the building. Using the specifications sheet that was supplied by a local sales office, select a suitable isolator. (10%)

4. Two identical sources have a combined amplitude (Lp) of 104dB. What would be the value of

the root mean square pressure for just one of the sources? (5%)

5. The sound spectrum below is known to exist for an industrial machine. Keeping in mind the proximity of some of the peaks, what bandwidth would our sound instrumentation require to tell them apart? (5%)



6. There is a small room that contains an average 100 hp diesel engine turning at 7200 rpm. The room is 2.5m by 2.5m and has a ceiling height of 2m. The walls and ceiling of the room are covered by a sound absorbtion coating (with a coefficient of 0.92). There are two 50cm by 30cm heavy plate glass windows in the walls for safety, and the floor is unpainted concrete. (50%)
a) determine the sound power level of the sound source (in dB).
b) assuming uniform directivity, what would be the direct sound pressure level (in dB) would we hear standing 0.5m and 2m away?
c) what is the reverberant sound pressure level (in dB) we would hear standing 0.5 and 2m away?
d) assuming the noise from the engine is relatively uniform in intensity from 200 Hz to 4 KHz, how far apart would two people in the room have to stand to hear each other shouting based on reverberant sound only?
e) what would the longest period of time a worker could be in that room each day based on reverberant sound only?

1. Given the transfer function below,

$$\frac{y(s)}{x(s)} = \frac{(s+10)(s+1000)}{(s+1000)^2}$$

a) draw the straight line approximation of the bode and phase shift plots.(8%)
b) determine the steady state output if the input is x(s) = 20 cos(100t+.3). (4%)

2. Given the following time response to a step input of F=5N for t >= 0, find the transfer function x/F. (6%)

$$x(t) = \{5 - 5e^{-10t}\}m$$

3. A spring damper system supports a mass of 34N. If it has a spring constant of 20.6N/cm, what is the systems natural frequency? (4%)

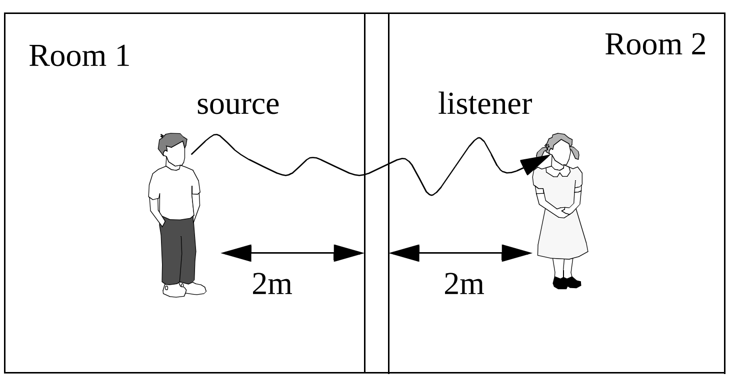
4. A large machine weighs 1000kg and vibrates at 20Hz, design an inertial damper. (4%)

5. If we had two sound sources at 120 Hz and 142 Hz that we wanted to measure separately, what would be the bandwidth of the analyzer? (4%)

6. A design is specified so that it should have a maximum preferred noise criteria value of 35. When tested, the sound values measured at half octaves from 63Hz are, (4%)

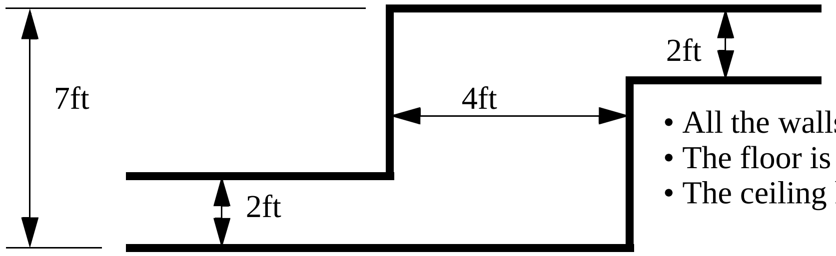
41dB, 43dB, 46dB, 51dB, 48dB, 48dB, 35dB, 33dB

7. Expecting an increase in business, the Boris and Natasha Detective Agency has hired you to build a soundproof wall to divide their cork lined interrogation room. The dimensions and location of the new rooms are shown below. The loudest voice expected in either room will be 80dB, and a listener can hear voices at pressure levels above 20dB.Will a 2x4" stud wall with gypsum on both sides prevent a listener from hearing another interrogation? (15%)



Each room is 4m by 4m by 4m and has carpet on the floors walls and ceilings.

8. You think that a bend in a hallway of your house reduces noise levels. This "plenum" has the dimensions below. Determine the Transmission Loss for 500 Hz. (10%)



- All the walls and ceiling are gypsum
- The floor is carpet with underpad
- The ceiling height is 7ft.

9. The following data was recorded for a non-isotropic source. What would be the directivity factor (Q) in direction θ = 60° (use appropriate approximation for calculation of the average value). (6%)

θ(deg):	0,	60,	120,	180,	240,	300
Lp(dB):	77,	71,	69,	70,	69,	73

10. Given the transfer function below, find the isolation at 2Hz. (15%)

$$H(s) = \frac{(10 + 5s)}{(2s^2 + 20s + 4)(6 + 3s)}$$

11. There is a small room that contains an average 100 hp diesel engine turning at 7200 rpm. The room is 2.5m by 2.5m and has a ceiling height of 2m. The walls and ceiling of the room are covered by a sound absorption coating (with a coefficient of 0.92). There are two 50cm by 30cm heavy plate glass windows in the walls for safety, and the floor is unpainted concrete. (20%)
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8.5 REFERENCES/BIBLIOGRAPHY

Irwin, J.D., and Graf, E.R., Industrial Noise and Vibration Control, Prentice Hall Publishers, 1979.

MEC 732 - Automated Manufacturing Systems

9. OVERVIEW

9.1 RESOURCES

9.1.1 Library

• The library has an excellent selection of journals, reference books, trade magazines, and textbooks. (Other local libraries could also be used)

9.1.2 Internet

9.1.2.1 - Mosaic documents:

• Using workstations, or IBM PCs equipped with mosaic software, run the software, and open the files below.

• Rapid Prototyping:
    http://www.cs.hut.fi/~ado/rp
    http://www.arc.ab.ca/~morgan/RP.html
    http://sffoffice.me.utexas.edu/
• VR In manufacturing
    http://nemo.ncsl.nist.gov/~sressler/projects/mfg/mfgVRcases.html

9.1.2.2 - Telnet

• Telnet allows free connection to sites, and is available on all UNIX machines
    • AWS Caucus (amweld.org), Sponsored by the American Welding Society. Topic; Flux-cored-arc-welding, ISO9000, technical help, certification, a database of Welding Journal articles.
    • FEDWORLD (fedworld.gov) Sponsored by National Technical Information Service. Gateway to over 130 government bbs'
    • TMS Online (online.tms.org), Sponsored by The Minerals, Metals, Materials Society. Has conference proceedings, announcements, calendar. (see telnet above)

9.1.2.3 - Modem

• A list of Bulletin boards, etc. are given below for phoneup access to information (Note: you will at least pay long distance for these, and possibly user charges also)

    • AWS Caucus (800) 447-9915, 9600 baud (see telnet above), Sponsored by the American

Welding Society. Topic; Flux-cored-arc-welding, ISO9000, technical help, certification, a database of Welding Journal articles.

- Business Gold--NTTC Online (304)243-2560, 9600baud 7bit, Even parity, 1 stop, Sponsored by the National Technology Transfer Center. Access to the directory of federal laboratories, federal technology available for licencing, and small business innovative research solicitations. Current technology transfer news, events calendar, and publications list.
- Computer Plumber BBS (319)337-6723, 19,200 baud. Devoted to engineers who work with industrial applications of computers. Shareware files. System operator maintains extensive bbs list.
- The Depot BBS (717)853-3599, 14.4 kbaud. Extensive collection of CAD, CAM, and CAE related shareware and discussion groups (conferences).
- Digital X-Connect BBS (214)517-8443 9600 baud. General information of interest to engineers, technicians, and technical managers. Free on-line resume service and job postings.
- EBB--Economic Bulletin Board (202)482-2584, 9600 baud, $45 annual subscription fee and per minute charges. Operated by US department of commerce. topics: economic data, export leads, and market research, press releases from various US government agencies.
- FEDWORLD (703)321-8020, 9600 baud, Sponsored by National Technical Information Service. Gateway to over 130 government bbs'. (see telnet above)
- Finishing TEchnology Hotline (201)838-0113, 2400 baud, Sponsored by Metal Finishing magazine, Topics: painting, anodizing, pickling, powder coating, commercials suppliers, etc.
- HMIX BBS Hazardous Materials Information Exchange (708)972-3275, 9600 baud. Topics: material lists, instructional material, laws, regulations, US govt. contacts.
- Industrial Forum (209)267-9379, 14.4 kbaud, Sponsored by CCI Training Services. Topics: surface preparation, painting, coating, paper and pulp mills, pipelines and tanks, inspection and quality control, environmental control, govt regulations.
- MatChat BBS (510)655-1753, 14.4 kbaud. A materials oriented bulletin board system.
- MechEng (ASME) (608)233-3378, 9600 baud Basically a very wide range of discussion topics, and software for IBM PCs and MacIntoshes.
- MIC-NET (Manufacturing and Inventory Control Network) (719) 687-7222, 28kbaud, Software: MRP, Inventory control, mechanical engineering, TQM, SPC.
- SME On-Line (313)271-3424, 14.4 kbaud. Manufacturing related freeware and shareware, discussion groups, etc.
- Statistics BBS (316)687-0578, 9600 baud, Topics: reliability, quality, experiment design, SPC, industrial statistics.
- TMS Online (412)776-2040, 2400 baud, Sponsored by The Minerals, Metals, Materials Society. Has conference proceedings, announcements, calendar. (see telnet above)

9.1.3 Other Ideas

- Contact equipment manufacturers, they might help you, or even provide technical details.
- Contact manufacturers that use the process, their production engineers may be able to help.
- Trade shows.

• Be creative!

9.1.3.1 - Gopher

9.1.3.2 - ReadNews

9.1.3.3 - ftp

• Popular Sites,
  wuarchive.wustl.edu - massive archives of software, a very old site.
  sunsite.unc.ca - a site sponsored by Sun Microsystems, with a good selection of software for all platforms

9.2 PROJECT

Option A - Case Study (Subject to change)

A commercial product will be selected (the chosen product must be approved by the course instructor) by a team of students (4 is reasonable). The project will be an existing product that is disassembled, and examined. In detail, all methods for automated production will be suggested, including some changes to the product to make it easier to manufacture. After this is complete, a manufacturing facility will be proposed by the team, including equipment selection, layout, connections, estimates for cycle time, testing/inspection, etc.

The form of the case study will be left up to the students, and the evaluation will be based on a final report, and a presentation. Creativity and completeness are a must, mediocre work will receive mediocre marks. Detailed drawings, specific equipment to be ordered, reasons and justification for the design are some of the elements required.

Option B - Project (Subject to change)

This section will allow for students to gain NEW exposure to some aspect of manufacturing technology. The projects should be related to some aspect of automated manufacturing. The list of topics below suggests some possible ideas,

- Build a small robot
- Investigate some manufacturing software critically
- Write a program for some manufacturing task
- Use Ideas for design of a product.(cate)
- Suggest a topic.......

The nature of this project is arbitrary, and any topic suggested should be discussed with the course instructor, and a short (1 paragraph) description should be given to the course instructor for the benefit of the student. The project will culminate with a report, and presentation, and demonstrations where applicable.

Special Notes: Students are expected to declare their intentions by Sept., 23, 1993. This includes topics, teams, and a tentative deadline schedule. The outline should be less than1page. (no marks are assigned for this)

9.2.1 Old Projects

MEC 732 Project Summaries (Final) - October 17th, 1995
NOTE: Any deviations from the project details printed here are the full responsibilities of the students.

Group Project

Alex Wong“Hole in Sphere Project”
Robert Krygier
Andre Cargnelli
Ahmed NenseyDescription: A mechanism will be designed and built for orienting spherical balls with small through holes. This will be done with a mechanism that uses three rollers for orientation, and an optical pair to detect the hole. An electromechanical control system will be used.
Deliverables: Working model and detailed report describing design.

Constantine Roumanis“Drink Mixer”
John Leung
Dan DellosaDescription: A system will be designed and built to mix various drinks. This will include a conveyor, sensors, actuators, and drink dispensers. The system will be controlled with a PLC. Note: This project will have a number of design complications that must be identified early in the term.
Deliverables: Working model and detailed report describing design.

Lev Mordichaev“Automated Robot Arm”
Karl Fung
Dennis Ngo
Nikko Chan
Edwin Wen
Elaine RodriguesDescription: A robot arm will be designed and built that can move up/down, left/right, and has a gripper that will open/close. The robot will be controlled via a computer program, and electrical connections to the robot.

Deliverables: Working model and detailed report describing design.

Nima Jahangir“Automated Impression Stamper”
Tricia Buenbrazo
John Tran
Koorosh Eslami
Dieu Ban Dang
Shahram BineshDescription: Parts will be transported to a stamping station in the workcell. Once there they will be fixed in a jig, and a rubber stamp will be used to make an ink impression. The part will then be ejected from the jig, and travel down another path.

Deliverables: Working model and detailed report describing design.

Keith Lou“A Manually Controlled Robot”
Sue Lee
Richard Dankworth
Phat N. Huynh
Howie Lam
Tarius MakmurDescription: To build a manually controlled robot to perform a certain task using a joystick for control. This small scale robot will be capable of picking up an object, and positioning it in another location. And, for proof of concept, a set of fixtures, jigs or feeders will be constructed for a simple robotic task. Note: This project has too many people for construction of a robot only.

Deliverables: Working model and detailed report describing design.

Zulfiqar Rajper“A Wedding Video Cassette Holder”
Azim Habib
Mehraj Saju
Rajeev Gupta
Ainsley Mills
S. Ahmad Majidi TehraniDescription: Development of a design, and selection and design of an automated facility for manufacture of a video cassette holder specifically for wedding videos. Note: The final design should focus on detailed drawings, selection of specific machines, plans for implementation, etc.

Deliverables: Report, Quotations, Drawings, Implementation Plans, Layout, etc.

Dave TuftsTentative: “Automation of Office Partition Production”
Augustin Garcia DeParedes
Mickey Obradovich
Michael NicolaDescription: A line will be examined for the production of office dividers. These partitions are currently assembled in a manual process, but this should be automated for quantities of 400-600. Note: The final design should focus on detailed drawings, selection of specific machines, plans for implementation, etc.

Deliverables: Report, Quotations, Drawings, Implementation Plans, Layout, etc.

Joey Aprile“A Box Sorting System”
Don Christie
Gabe Fusco
Mike PoczoDescription: A conveyor based system will be designed and built for sorting boxes by a switched conveyor path. This will include construction of the conveyor, sensors, actuators, and control system.

Deliverables: Working model and detailed report describing design.

Brad Southon“Automated Paint Line”
Sebastian Mallia
Robert PoundDescription: A current design for a ceiling fan will be examined for assembly efficiency, and a new automated assembly line will be designed. Note: The final design should focus on detailed drawings, selection of specific machines, plans for implementation, etc.

Deliverables: Report, Quotations, Drawings, Implementation Plans, Layout, etc.

Lee Wright“A New Clipping System at NR”
Mike CecchiniDescription: At NR they currently use workers to manually insert clips one at a time, by hand, into a flat rubber part. This procedure is slow and has created a couple of Repetitive Motion Injuries. There have been unsatisfactory attempts by NR to resolve the problem. This groups will examine possible solutions (with NR’s permission) including, a clipping gun or tool, a cartridge loading system, a bowl feeder based reloader.

Deliverables: Report, Quotations, Drawings, Implementation Plans, Layout, etc.

Keith German“Automated Drink Dispenser”
Dave Van Den Beld
Jeff Kempson
Brent Rubeli
Michael StaplesDescription: Glasses on a conveyor belt (?) will be transported to/from a dispensing station where they will be filled by an automated mechanism. The system will be designed and built, possibly using a PLC, or a PC for control.

Deliverables: Working model and detailed report describing design.

Romeo Calibuso“Flush Valve Automation System”
Naren Arcot
Nick Chung
Monica Skulj
Chinh N. HuynhDescription: A flush valve system for use in porcelain toilets will be examined, redesigned, and a partially automated assembly line will be designed. Note: The final design should focus on detailed drawings, selection of specific machines, plans for implementation, etc.

Deliverables: Report, Quotations, Drawings, Implementation Plans, Layout, etc.

Gerard Biasutto“Self Leveling Platform”
Mario Borsella
Dino Farronato
Marco Gaetano
John YuemDescription: An actuated system will be designed and built to level a platform under tilting conditions. This will involve actuators positioned at four corners. A control system will be constructed to drive the actuating cylinders.

Deliverables: Working model and detailed report describing design.

Tomer Shahaf“Medical Film Lamination Machine”

Description: A pressure adjustment mechanism will be added to reduce waste, and coating of rollers.

Deliverables: Report, Quotations, Drawings, Implementation Plans, Layout, etc.

Joel Ramos“IBM Robot Simulation To Support Simulation”

Description: The IBM Robot simulators (for the AML language) will be used to simulate an assembly process, with the objective of optimizing layout of the assembly stations. Note: the assembly task should be specified.

Deliverables: AML programs, A Detailed Report including well justified conclusions.

NOTES:
1. All teams constructing equipment have been advised to start early.
2. Students have been advised that topics that have been listed here are of adequate scope, if other topic choices are made, it is at the discretion (and risk) of the individual students.

9.3 OBSOLETE PRACTICE PROBLEMS

5. The main advantages of GT is,
   a) labelling drawings.
   b) locating similar drawings.
   c) sorting drawings by name.
   d) none of the above.

(ans. b)

9.4 OLD ASSIGNMENTS

Assignment #1

Purpose: Conceptual design of a robot for a manufacturing task.
Reason: This will help the student realize why different robots are chosen for different tasks.
Method: The assignment is to be done in teams of 4 students.
Problem: Each group will design a robot for a task, as described below. This will include analysis of the task requirements including AT LEAST, degrees of freedom, workspace, actuators, sensors, kinematics, path planning, and programming. The final design should include a clear and concise report between 5 to 10 written pages in length, describing in detail the design decisions. This report should also have drawings, or good quality hand sketches of the basic robot configuration.

(The various topics can be signed for by students on the board by S49)

1. assembly of car body panels on an automotive assembly line.
2. assembly of beams in the new space station, in orbit.
3. removal of injection molded parts from an open die.
4. mixing of radioactive solutions in test tubes.
5. an automatic CD changer in a juke box.
6. for the insertion of glass for car windshields.
7. to pack flourescent light tubes in shipping cartons.
8. to point and fire a weapon for destruction of incoming missiles.
9. to make pizzas.
10. for cutting hair.
11. for delivering mail in an office.
12. to perform house painting.
13. for cleaning office windows on high rise buildings.
14. a robot that it used to test car doors by repeatedly opening and closing them.

15. a robot to crawl through sewer systems and look for blockages.
16. a robot that is inserted into the body to perform surgery.
17. a robot that is capable of writing like a human.
18. a sculting robot.
19. a robot that can “wiggle it’s nose” for Walt Disney.
20. a robot for building ships in bottles.

Evaluation: Marks will be awarded on the basis of completeness of the design, and suitability of the robot to the assigned task. Marks will be deducted for unclear, vague reports and drawings.

Assignment #2

Purpose: To do detailed design/analysis of the robot concept designed in Assignment #1.

Reason: To ensure that the shortings of the design are revealed (and overcome if possible), and that the various technologies involved are explored at a professional level.

Method: Each of the four team members that cooperated on the first assignment will now select and do 1 of the four problems below. These are to be individually labelled so that individual marks can be assigned. Note: sections that are not done individually will simply not be marked.

Problem(s):

1. Do a kinematic analysis of the robot including, the forward/inverse kinematics, the workspace boundaries, singularities, and the jacobian. The kinematic analysis should be done with both simple homogenous transforms and the Denavit-Hartenberg to verify the results.

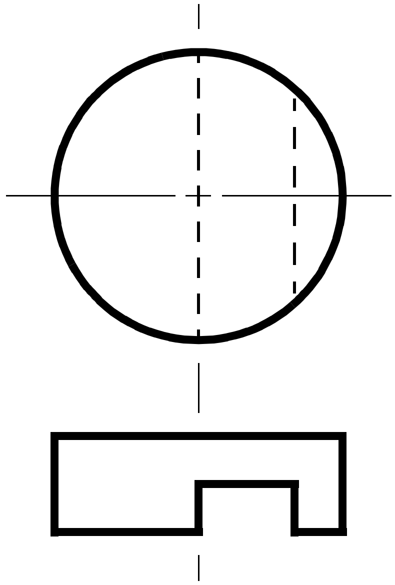
2. Develop a flowchart of the actions that must occur for the robot. Associate these to the sensors, and actuators of the robot. Develop a control program using either a PLC, or AML. If necessary, you may add new commands to assist you, as long as they are very clearly defined.

3. An analysis of the robot to find the accuracy, repeatability and spatial resolution must be done based on the sensors selected, actuators chosen, flexibility of joints, payload, maximum velocities, etc.

4. The end of arm tooling must either be fully designed, including drawings, or commercially selected with alternatives, and costs. In both cases the suitability of the design should be verified using suitable engineering calculations.

9.5 PRACTICE PROBLEMS

1. For the part shown below, design a part feeder.

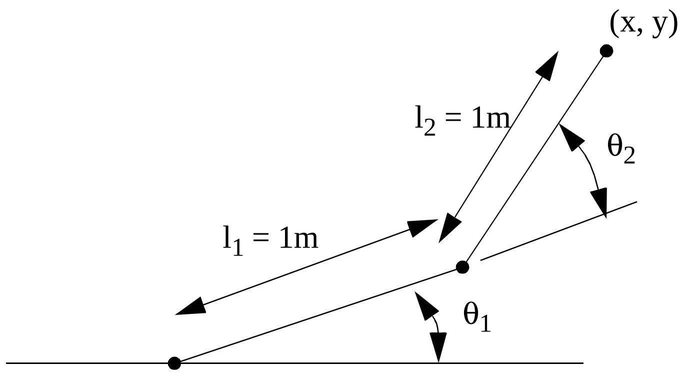


2. For the product below describe the various DFA problems and suggest solutions.

DFA problem

3. Design a system for making coffee and pouring it into styrofoam cups. Lids must be put on after the coffee is complete. The user should be able to select 1 or 2 creams and/or sugars by pressing buttons. This should include rough mechanical layout, electrical connections, actuators and sensors, feeders, etc.

4. For the robot pictured below,



a) calculate 5 (x,y) points along a straight line path from (0.5,0.5) to (-0.5,0.5).

b) Develop the inverse kinematic equations and calculate the joint angles at each of the points in part a)

10. Briefly describe the relationship between CAD, CAM and CIM. (3%)

11. Show graphically how we would choose between manual labor and fixed automation. (3%)

12. What technological limitations reduce the chance of success when implementing a new CIM/FMS system? (2%)

13. Give examples of equipment for each of the four levels of the Shop Floor Production Model. (4%)

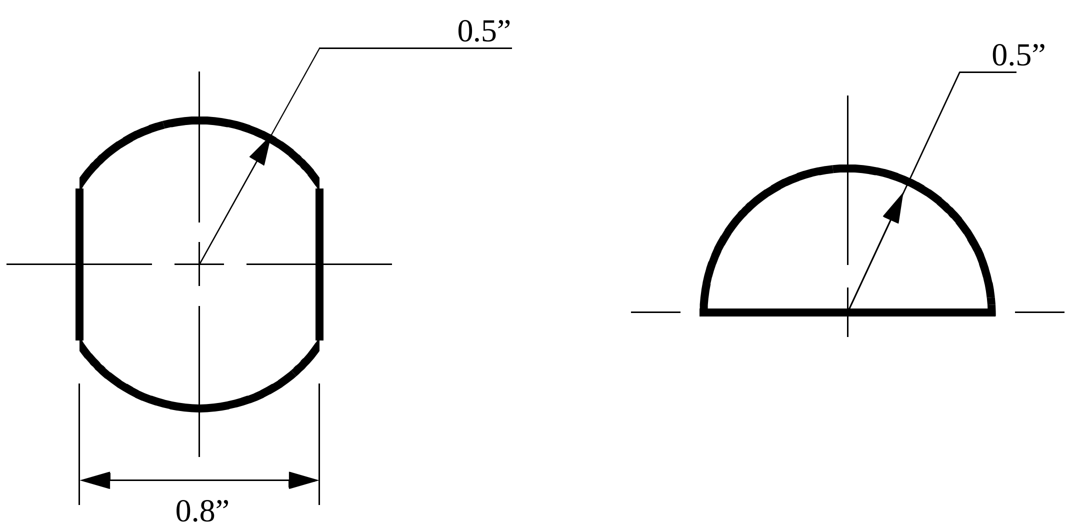
14. What use would the $IDEF_0$ model have in an automated factory? (2%)

15. What use would a graphical user interface (GUI) have in workcell control. Use an example to illustrate your reason. (3%)

16. What robotic configurations (e.g., SCARA) and number of degrees of freedom are suitable for the following tasks. If needed write any assumptions made as footnotes below the table. (6%)

TASK	ROBOT CONFIGURATION	DOF
spray painting		
painting with a brush		
welding with a torch		
electronic assembly		
assembly of automotive engines		
an automatic CD changer		

17. Design a material handling system based on vibratory feeders to sort the parts below. Assume the parts are mixed together in the same bin, and the parts will emerge from the same vibratory feeder in two separate tracks. (8%)



18. The part below is to be assembled in an automated facility. We want to apply design for assembly principles to reduce our assembly time and cost.

* A sketch of a simple assemblyXXXXX

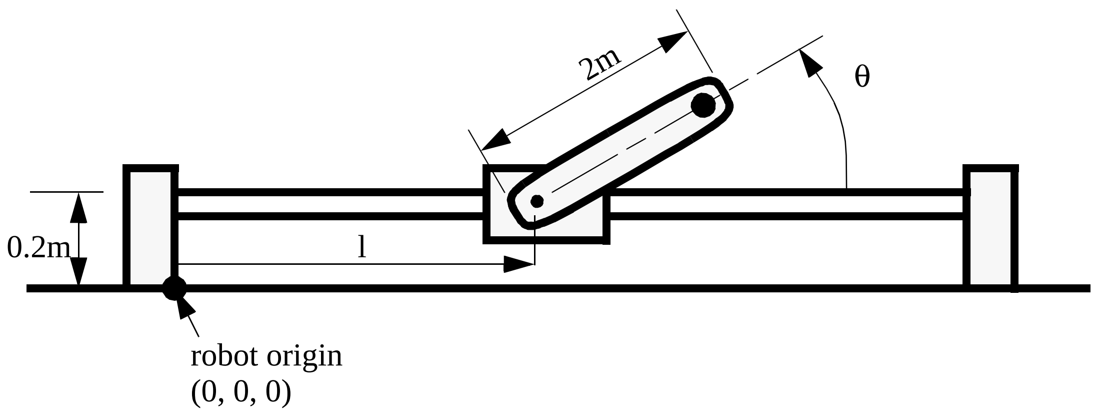
a) what is the theoretical minimum number of parts? (2%)

b) for each of the parts in the assembly describe DFA oriented problems. (4%)

c) select parts that are candidates for redesign, combination or elimination. (3%)

d) develop a new design based on your analysis. Rough sketches are required. (8%)

19. We want to design a 2 d.o.f. robot for gluing on continuous paths. The robot will be articulated, as shown below. We want to do some high and low level design before ordering components, fabricating parts and writing software.



a) What are forward kinematic equations? (6%)

b) What are the inverse kinematic equations? Give all possible solutions. (6%)

c) Develop the Jacobian matrix for the robot, also find the Inverse Jacobian. (6%)

d) select suitable actuators for positioning the robot. (3%)

e) select suitable sensors for determining joint positions. (3%)

f) roughly design the EOAT for picking up spherical objects. (6%)

g) Develop the equations needed to find points on the robots straight line (point to point) motion paths. The robot should start and stop smoothly. (6%)

h) Develop a complete block diagram of the robotic system. Clearly name all of the boxes and label the inputs and outputs. (10%)

i) Assuming that the robot uses the AML programming language, write a program to track a square with the bottom left corner at (2m, 1m), and the top right corner at (3m, 1.5m). Make any reasonable assumptions needed. (6%)