Laboratory Assignment Number 2 for MEAM247
Due by February 23, 2007

Purpose: In this lab you will customize an elliptical machine to a team member's physical dimensions. It is intended to better acquaint you with autoCAD/SolidWorks and the laser cutter. In addition, you will have a chance to design a simple mechanical system with a four bar linkage.

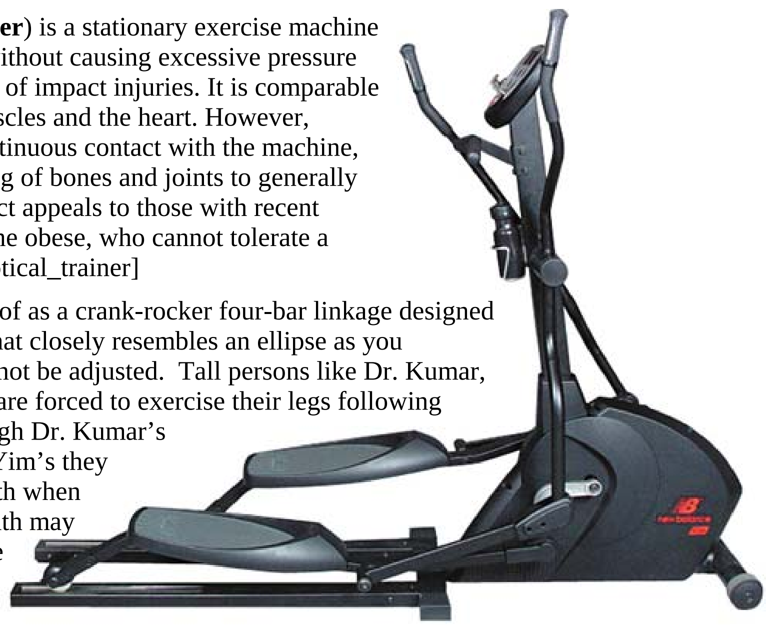
Minimum Parts Required: 12"x18" acrylic sheet, 7 plastic shoulder bolts w/ matching screws. You may want small amounts of 1/8 acrylic to make washers. Limited amounts of additional acrylic are available (or you may acquire your own if necessary).

References: `synthesis.pdf`

Part 1: The standard elliptical machine

Reading: Before starting this lab, read all of the assignment. Read linkages slides from MEAM 211.

Background: An **elliptical trainer** (also **cross trainer**) is a stationary exercise machine used to simulate walking or running without causing excessive pressure to the joints, hence decreasing the risk of impact injuries. It is comparable to a treadmill in its exertion of leg muscles and the heart. However, because the user's limbs remain in continuous contact with the machine, its operation limits the dynamic loading of bones and joints to generally harmless levels. This non-impact aspect appeals to those with recent injuries, chronic knee problems, and the obese, who cannot tolerate a treadmill. [en.wikipedia.org/wiki/Elliptical_trainer]



The elliptical machine can be thought of as a crank-rocker four-bar linkage designed to guide your foot to travel in a path that closely resembles an ellipse as you exercise. Unfortunately this path can not be adjusted. Tall persons like Dr. Kumar, and 'not so tall' persons like Dr. Yim are forced to exercise their legs following the same exact leg motion. Even though Dr. Kumar's natural leg strides are larger than Dr. Yim's they are forced to execute the same foot path when they exercise on the elliptical. This path may feel natural for most people of average size, but may feel awkward for Dr. Kumar and Dr. Yim. Dr. Kumar is forced to take smaller strides than he's used to and Dr. Yim has to take bigger strides than he usually takes when he walks. Obviously the design of the elliptical machine is compromised.

In this lab you will customize an elliptical machine to a team member's dimensions in which the path of the elliptical machine will match as close as possible the actual stride of your legs during walking.

Assignment: Complete the following exercises.

☐ 1.1) Draw or take a picture of an elliptical machine and denote the crank, coupler, follower and frame. Take the important measurements of this machine and analyze the motion with the fourbar linkage program that has been provided to you in MEAM 211. You can edit `fourbario.dat` and plug the values in there.

☐ 1.2) While you are taking the picture of the elliptical machine, try it out. Note how far your legs must move. Measure the angles your joints take using your goniometer. Note how much the rest of your body moves. Are there any parts of this machine that are particularly badly designed? well designed? Why is each structural part of the machine there?

In the report: Include a drawing of the of the elliptical machine with measurements and provide the plots as shown by `fourbar_analysis.m`

Part 2: Design the linkage

Reading: `synthesis.pdf` from MEAM 211

Goal: You will design a linkage that will match the path of your foot during exercise of the elliptical machine with the path of your foot during an actual walking motion.

Assignment: Complete the following exercises.

☐ 2.1) Read the MEAM 211 four-bar analysis and synthesis documents.

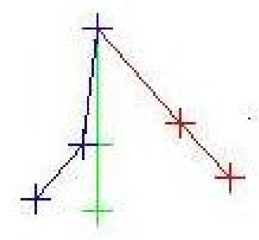


Figure 1: A stick figure of legs is shown in three extreme positions during stride: minimum (blue), neutral (green) and maximum (red). The minimum position is defined as the position of the leg when the joint angles are smallest. In the neutral position the joint angles of the hip and knee are 0 degrees and in the maximum position the joint angles are greatest. Angles are measured in the local frame.

☐ 2.2) In the previous lab you have plotted the path of your heel over time during a natural walking stride. For *three position synthesis* (described later) you will need to pick three different positions of your foot. For example you could take the three positions of the heel as shown in Figure 1.

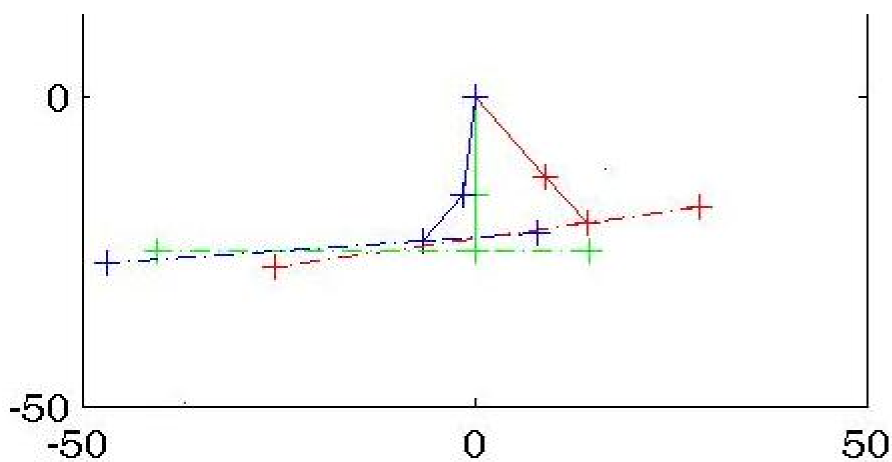


Figure 2: Plot of leg with platform attached to the foot in three different positions.

☐ 2.3) The bar that the user will be standing on will be called *the platform*. See Figure 2. The platform will give you the three positions of the coupler from which you will determine the fourbar linkage for your customized elliptical machine. The position of the ankle gives you three positions of a point on the platform, but not the angle of the platform relative to the ground (or heel). You will need to determine the three angles that will allow you to create a feasible elliptical machine.

☐ 2.4) After you have designed your fourbar linkage, analyze and plot this linkage by using `fourbar_analysis.m`. Compare the output motion of the platform with the plotted path taken from the previous lab. Iterate between part 2.2 and 2.4 to get your four bar linkage to follow actual path of the foot as close as possible. Plot both the motion of the foot from the four bar and the actual data on one graph.

In the report: Include the plot from 2.4, the linkage design, the angles of the three positions from the measured leg data. Discuss how you chose the platform angles.

Part 3: Making the prototype

Background:

Prototyping is an important part of the design process. It allows you to quickly check your design for feasibility, functionality manufacturability and other factors for very cheaply and gives you a physical intuition of the kinematics of the device.

In addition to physical intuition, semi-functional mockups are often used to explain to concepts to people (to venture capitalists if you're pitching an invention, management of a company you may be working at, customers who may want to buy a machine etc.) In these cases, besides getting the kinematics right, there are several other important aspects of the prototype.

- **Aesthetics**. The device should look appealing.
- **Robustness**. Having the device fall apart during a demonstration is disastrous.
- **Features**. The device should have a reason for everything on it.

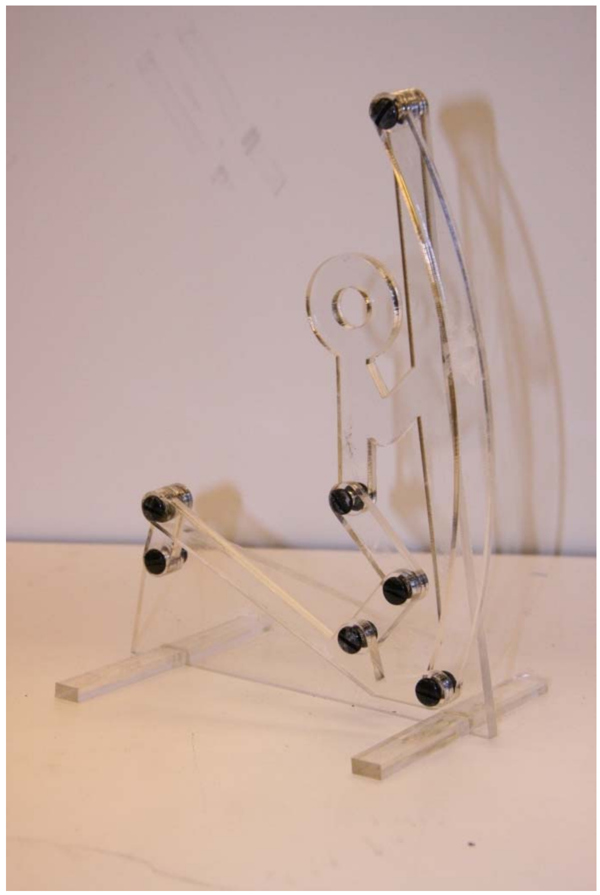


Figure 4: Photograph of an elliptical machine prototype. Note that the main frame serves as a main stand and the body of the person is rigidly attached to this stand.

Assignment:

Complete the following exercises.

☐ 3.1) Using the previous section of this lab you will build a functional mockup of a new an improved elliptical training device. It must, at a minimum.

- allow constrained motion of the legs in some optimal pattern (**you choose what optimal means**)
- be able to fit in a 11" x 35" x 35" box,
- be able to show the intended motions for a miniaturized person using it (e.g. a working four bar linkage).

Based on your observations of current elliptical machines (or other exercise machines you may have seen), you may wish to add functionality to your device.

☐ 3.2) You will present your device in a 2 minute presentation to the class as if you are selling the concept to potential investors. You should highlight the features that make your device unique, useful and desirable.

Professor Kumar will choose one or two designs he likes best, which will receive a prize and be displayed in the MEAM display case outside Town229.

☐ **Extra Credit:** Most exercise machines can be adjusted to a person's dimensions by adjusting prismatic or revolute joints to change the height or angle of the seat for example. The elliptical machine however does not offer such a feature (as far as we know). Can you add a joint in which the path of the elliptical could be tuned to fit your natural strides? Build a prototype of your design. Are there any elliptical machines out there with such a feature. Are there any patents on such a design?

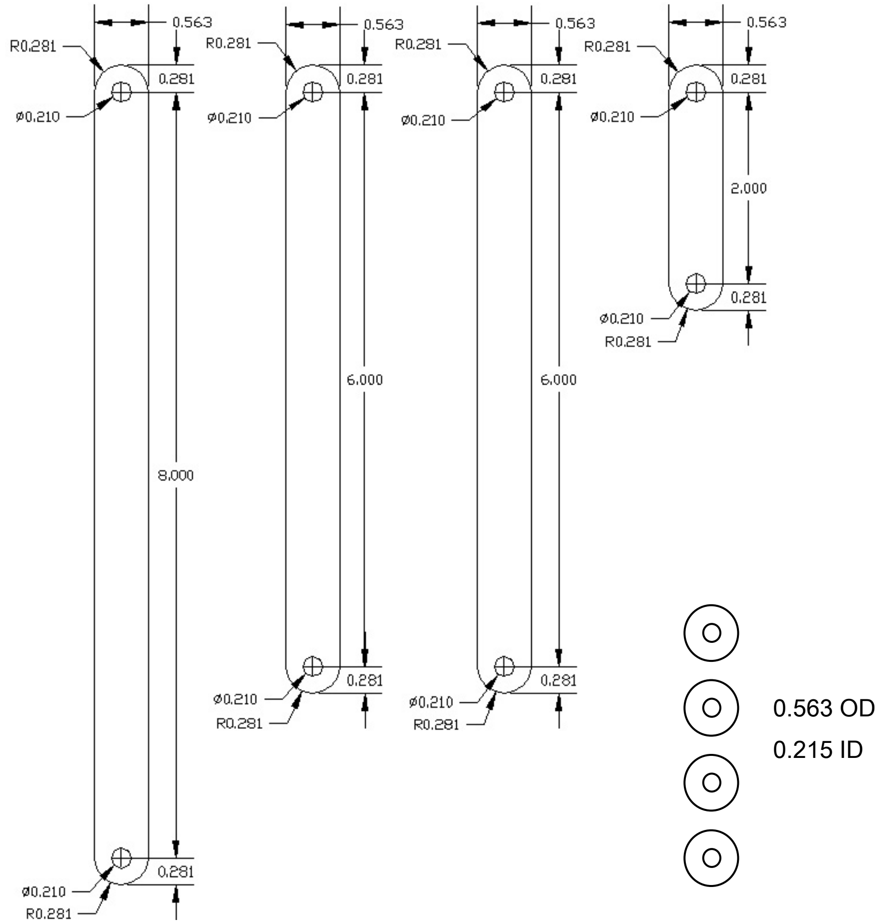
In the report: Include pictures of your creation, the important properties chosen, a description of the features of your design and the rationale for each. Describe what you have chosen for your optimality metric in section 3.1. Include print out of CAD files used to cut the pieces and the scale (ratio) of the model versus reality.

Appendix: Sample linkage using the laser cutter

Background: There is a Universal Laser Systems laser cutter in in the Towne Rm169 MEAM machine shop. There will be a signup sheet for hours from 9AM-5PM with 1 hour slots. Please sign up for only 1 hour at a time. Come prepared with your finished files. If there is no sign up sheet, usage of the laser cutter will be first come first served. The instructions below are a sample of how to create a four bar linkage on the laser cutter.

☐ A.1) Draw the parts using AutoCAD. AutoCAD is available on all CETS computers in the computer labs. Use the following steps to create your drawing:

1. From the "File" menu select "New".
2. Select "English Units" and a new drawing area will open. The laser system requires all units in English.
3. Go to the "Format" menu and select "Lineweight", set the line weight to 0.002". The laser system requires that the line width (weight) be less than 0.008" for vector cutting.
4. Go to the command prompt at the bottom of the drawing window, enter the following commands,
   _rectang
   0,0
   12,-12
   This will draw a rectangular box that defines the maximum cutting area of the acrylic sheet that you have. Note for future reference, the maximum cutting area of the laser system is 18"x32". The line color of the rectangle should be set to white, the laser will not cut any lines in your drawing that are white, they will be for reference only.
5. Go to the "Format" menu and select "Color", set the color to red. As noted in step 4, the laser will not cut any line that is drawn in white. By changing the line color to red, the laser can be configured to cut any part drawn in red.
6. Begin to create your linkage parts on the drawing. See Figure 1 for an example of linkage components, this is only a example, you don't need to use these parts dimensions. A couple of things you should keep in mind when laying out your parts. First is to locate the parts strategically to conserve your 12"x12" material. . It is recommended that the upper left corner of the first part in your drawing be located at 0.75",-0.75". Note that there is a discrepancy of ~0.2" between the Y axis on your drawing and the Y axis on the laser system (no X axis discrepancy). If you have your part located 1.0" from the X axis (the Y axis setting), the laser will actually begin cutting at ~0.8" from the X axis.
7. When drawing the holes for the pivot points, make all pivot holes 0.215" in diameter to fit the plastic shoulder bolts that will be provided. The head diameter of the shoulder bolt is 0.4". Depending on how you design the four bar linkage you may need the links to ride on top of each other. You may need spacers to give clearance for the shoulder bolts. These spacers are essentially like washers with an ID made to fit the shoulder bolt.

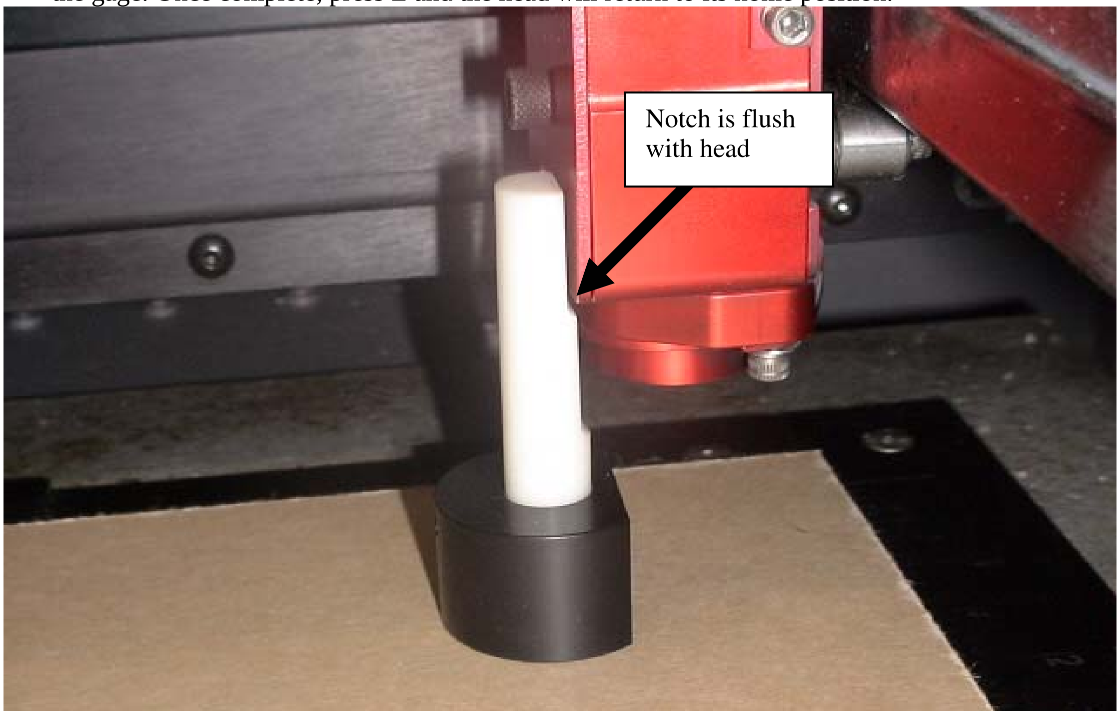


8. Print out your drawing to include in the lab report.

☐ A.2) Cut the parts on the X-660 laser system. Note that you will need to have your AutoCAD parts file (“name”.dwg) saved on floppy disc, or transferred on the network.

1. Start AutoCAD on the computer connected to the laser system and open your parts file via the floppy drive.
   VERIFY THAT ALL PARTS THAT ARE TO BE CUT ARE DRAWN WITH RED LINES, the laser will be setup to vector cut only those lines that are in red.
2. Turn on the laser system, the switch (yellow) is located on the lower right side of the laser, bottom towards the back.
3. In AutoCAD, go to the “File” menu and select “Page Setup”.
4. Select the “Layout Settings” tab and only set the following parameters, all others should remain the same,
   Plot area - Extents
   Plot scale - Scale - 1.1
5. Select the “Plot Device” tab and set the following parameters,
   Plotter configuration - Name - X-660.pc3
   Plot style table – Name – acad.ctb
6. On the same “Plot Device” tab, select the “Properties” icon and select the “Device and Document Settings” tab. Select the “Custom Properties” icon.
7. Select the “Laser Settings” tab. Set the “Pen Mode” for red to “VECT” by clicking on the icon. The “Pen Mode” for all other colors should be set to “SKIP” (including black which applies to the white lines in AutoCAD), this is default.
8. Highlight the red settings by clicking once on the word “red”. Set the following parameters for red,
   Power – 100%
   Speed – 3.0% (note for thicker plastics this number will need to be smaller)
   PPI – 500 PPI
   then select the “Set” icon, all parameters for red should then be updated. Select the OK icon at the bottom of the window.
9. In “Plotter Configuration Editor – x.660.pc3”, select OK.

10. In “Page Setup-Model” select the “Plot” button. This will download your plot file to the laser system. Press the NEXT FILE button on the laser panel to verify that your file has downloaded correctly, specifically check the power setting and feed rate (100%, 3.0%,), if these are zero then the file didn’t download correctly. Check the color, pen thickness and try to download again. (If problems persist, see the TA).
11. The laser now needs to be setup to cut your material. Open the lid on the laser and place your 12”x12” acrylic sheet on the bed with upper left corner touching the scales. Make sure the material is resting on the four flat washers provided, this will allow heat to dissipate from under the material when cutting.
12. Press the Z button on the laser front panel. The laser head will move to the left for Z axis setup. Press the SELECT button once to get 0.01” resolution. Place the height gage under the laser head, **MAKE SURE THE GAGE IS NOT DIRECTLY UNDER THE CAP SCREW STICKING OUT OF THE LASER HEAD.** Press the <> buttons until the laser head is at the height that just pushes away the gage. Once complete, press Z and the head will return to its home position.



13. Move the piece to the lower left corner of the bed. This is the default location that AutoCAD will plot to (see the Plot Preview for where the laser will cut).
14. **IMPORTANT** Turn on the exhaust fan, the switch is on the wall behind the laser. Press the START button on the laser and the cutting will begin. When the laser is done cutting it will make an audible beep and the laser head will return to the home position. Turn off the exhaust fan and remove your parts.
15. You may wish to wipe the parts with a damp cloth to remove smoke and particles from the ablated plastic.

Assembling the linkage

The links are joined using the plastic shoulder screw and the mating plastic screw. The plastic screw is self-tapping into the shoulder screw so you shouldn’t screw and unscrew it too many times as it will become loose.

Grading

60% **Implementation**. This will include:
- Functionality (how well it follows your optimality criterion from 3.1).
- Robustness
- Aesthetics

20% **Presentation**. February 23rd at ME211 recitation and 26th at ME247 lecture.

20% **Report**. due February 23th 2007 at ME211 recitation

Lab #2

Time Summary

Be sure to turn this in with your lab report

This information is being gathered solely to produce statistical information to help improve the lab assignments.

Part 1 Preparing Outside of the lab ____________ In the lab working this part__________

Part 2 Preparing Outside of the lab ____________ In the lab working this part__________

Part 3 Preparing Outside of the lab ____________ In the lab working this part__________

Report Preparing the Lab Report ______________