# **Title**: Making parts of Robonova Legs with PCNC

**Keywords**: PCNC, G-code, Robonova, Milling, Cutting, NCplot, Aluminum plate & block

## Motivation and Audience

These tutorials describe how to make Robonova legs with our own machine, the PCNC, by yourself. By following this, you will learn a procedure for machining parts, the materials you need, and also gain some knowledge about how to use machines and tools in DASL. Also, since you can produce your own parts, you can construct a skeleton of a robot, and further, you can construct your own robot at a low cost. This assumes that you know how to use PCNC, NCplot v2.05, Cut&Mill machines. If you do not know about any of these topics mentioned above, you have to learn how to use them by following these tutorials, http://www.pages.drexel.edu/~rjg48/tutorials_DASL-131.html, which are tutorials of basic CNC operation & and simulation made by Roy Gross, B.S student in DASL.

The rest of the tutorial is presented as follows:

1. Parts List and Sources
2. Construction
3. Programming
4. Final Words

## Time schedule (you may need 4 days to complete this tutorial)

| Task | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Simulation | | | | |
| Cut&Mill patterns | | | | |
| Cut&Mill dies | | | | |
| Fold&Assemble | | | | |

## Parts List and Source

To complete this tutorial, you will need the following items.

| PART DESCRIPTION | PART | VENDOR | PRICE | QTY |
|---|---|---|---|---|
| | | | | |

| | | | | |
|---|---|---|---|---|
| CNC machine | CNC 1100 | Tomarch LLC | ~5,000 | 1 |
| Cutting machine | Orbital jig saw | Black & Decker | quot. | 1 |
| | Metal cutting band saw | http://www.everising.com | quot. | 1 |
| Trimming machine | Multipro | DREMEL | quot. | |
| Simulation program | NCplot v2.05 | http://www.ncplot.com | 299.00 | 1 |
| Aluminum Plate<br>Aluminum Block | Alloy 6061, 24” X 48” | http://www.mcmaster.com | 50.00 | 2 |
| Tool box | Hammer,etc.. | | quot. | |
| Parts | 4mm Metric bolt & nut | http://www.mcmaster.com | quot. | MOQ |
| | 5mm Metric bolt & nut | | quot. | MOQ |
| | | | | |

TABLE1: Parts needed to follow this tutorial

## Construction

This section gives step-by-step instructions along with photos to make parts of Robonova Legs. This section is consists of 8 steps as follow:

**Step1: G-code simulation**

**Step2: Cut Aluminum Plate with Orbital jig saw**

**Step3: Cut & Mill plate for patterns with CNC**

**Step4: Cut Aluminum Block with Metal cutting band saw**

**Step5: Cut & Mill block for dies with CNC**

**Step6: Trim patterns with trimming machine**

**Step7: Fold patterns on dies**

**Step8: Assemble patterns on Robonova**

Warning: Before you start, you have to make sure that you know how to use the CNC. The CNC is very dangerous and sensitive machine so you must ask Rob or Youngbum if you do not know something about the operation of the CNC, are in trouble with CNC, or cannot understand the next step.

### Step1: G-code simulation

Preparation: NCplot v2.05, G-codes for all patterns & dies

This step is about simulation. You can download all G-codes for patterns and dies here. This file includes as follow:

U_shaped_universal_bracket.txt

U_bracket.txt

Knee_bracket.txt

Foot_bracket.txt

U_die.txt

Foot_die.txt

Sizeandreference.txt

Skeleton of G-codes for U_shaped_universal_bracket and knee_bracket were made by Roy Gross, B.S students in DASL. Also skeleton of G-codes for U_bracket and foot_bracket were made by Robert Ellenberg, Ph.D student in DASL. The other G-codes were from Youngbum, Ph.D student in DASL. All files have been modified to be 100% accurate, Youngbum has modified all G-codes which are changing hole positions.

All text files except for “Sizeandreference.txt” are Real-Operated codes so you do not need any modification and it does not need to be corrected. If you want to change some code, let Youngbum know before correction.

“Sizeandreference.txt” is about the size of plate and block you will cut and mill. And it includes reference position you will need for real cutting and milling.

Next, you need to run the simulation program to simulate these files. I recommend downloading NCplot v2.05 which is a trial version for 15 days. If you have another simulation program, you can use it but this section assumes that you use NCplot v2.05.

Now, you have G-codes for all patterns and dies and NCplot v2.05. First, you should run simulation program on your computer. It looks like below.

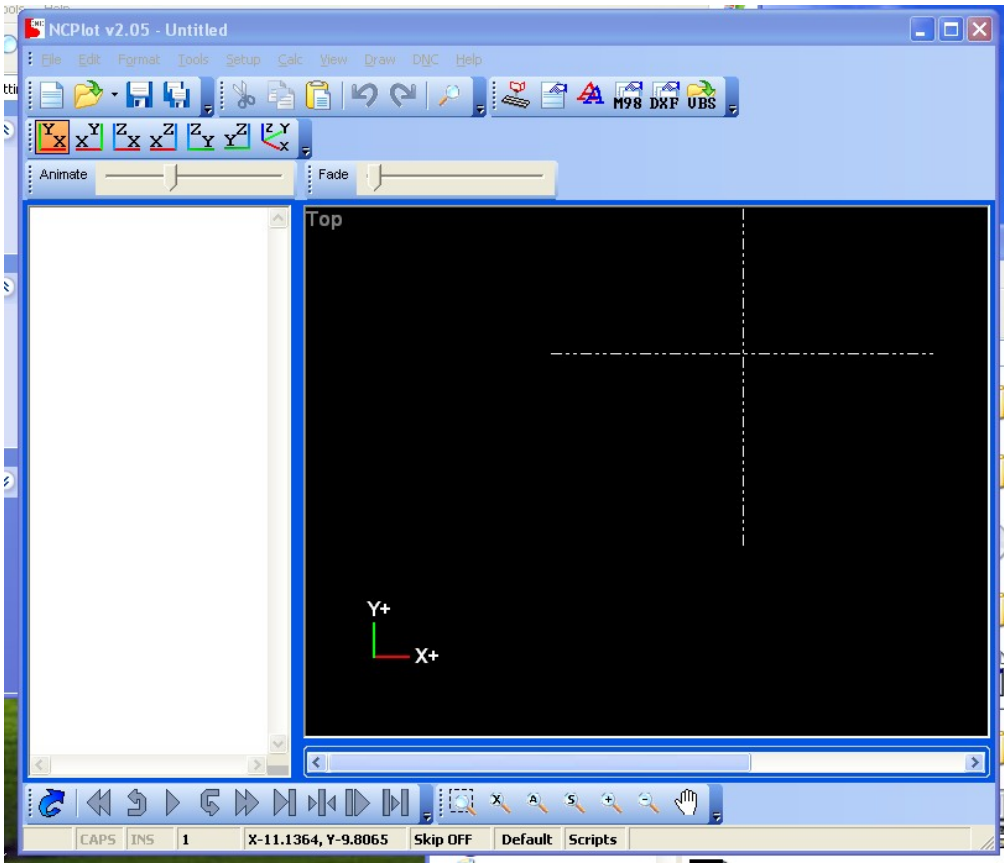



Figure1: Getting start with NCplot v2.05

Now, you need to open “U_shaped_universal_bracket.txt” with notepad. Then, you need to copy all the text and then paste them into left window in NCplot. You can use a hot key to do this; Ctrl + a: select all -> Ctrl + c: copy in notepad => Ctrl + v: paste in NCplot.

It looks like below.

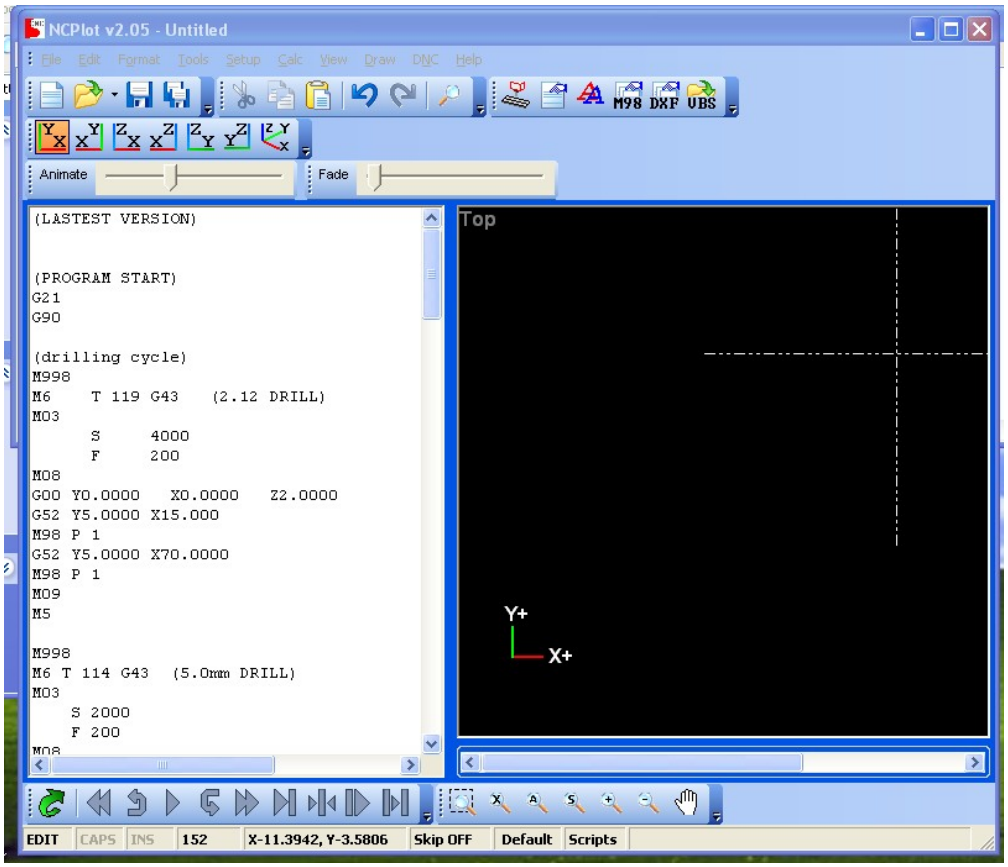



Figure2: U_shaped_universal_bracket.txt in NCplot

Now, you need to check “Absolute arc”. You can click “Draw” in popup menu, then you need to unselect “Absolute arc”. Then, you need to click the “refresh” button left side on the bottom menu. NCplot will read this code and show you a shape it read last. Do not worry about it show you something you do not understand because this program is not perfect program for simulation. This program cannot understand sub-program and tool change codes. It will show you something, just what it read last. You can see Video below, and if it shows you image the same as you did, you can go to next.

Video1: Simulation of U_shaped_universal_bracket.txt in NCplot v 2.05

If you have done the steps before correctly, it means that you have correct G-code for U_shaped_universal_bracket. Now, you need to simulate the other program to check whether you have correct codes or not with the same procedures above. But when you run a simulation for U_bracket and Foot_bracket, you have to select “Absolute arc”. Also you can compare your progress with the Video below.

Video2: Simulation of rest of G-code in NCplot v 2.05

**Step2: Cut Aluminum Plate with Orbital jig saw**

Before you get start, open “Sizeandreference.txt” in G_code.zip. You can see proper size of plate you will cut & mill. It means that, for instance:

Ex) `Width = 97mm + 35mm + 40mm = 172mm`
`Height = 114mm + 35mm + 40mm = 189mm`

The first value is the actual size of pattern. The second value is the diameter of End Mill, the third value is the size of clamp. Insufficient size of plate can cause very dangerous situation during cutting & and milling because it can cause end mill collision with clamp. Reversely, very large size of plate can cause coarseness to the cut. So you need proper size of plate. Following images will show you how to do it.

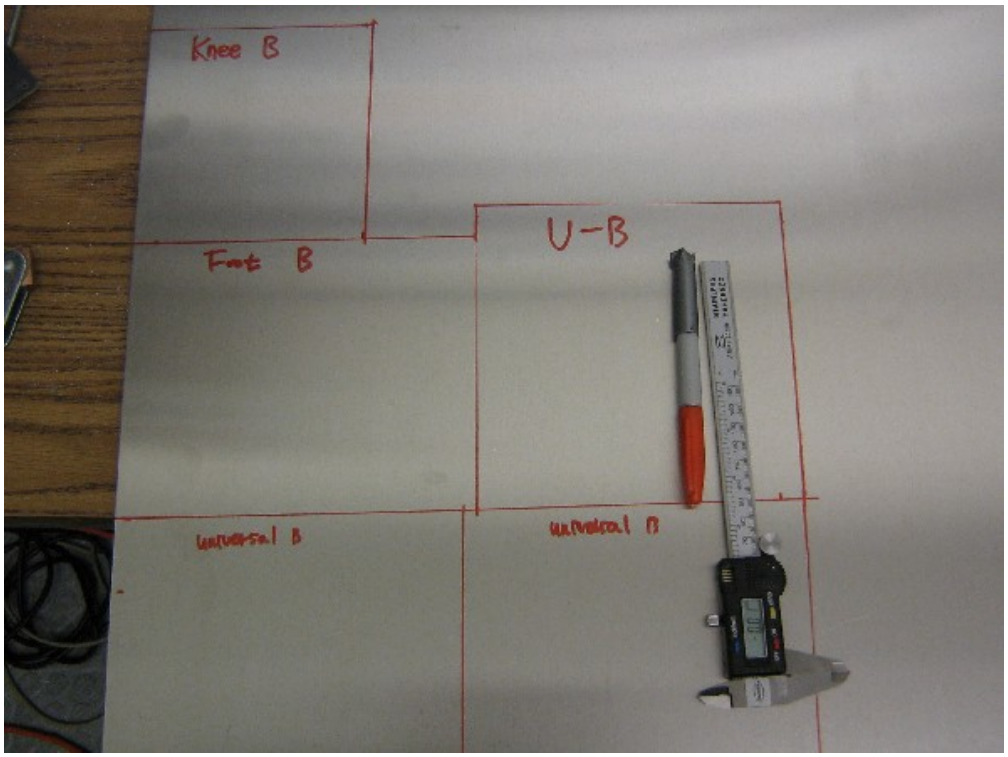
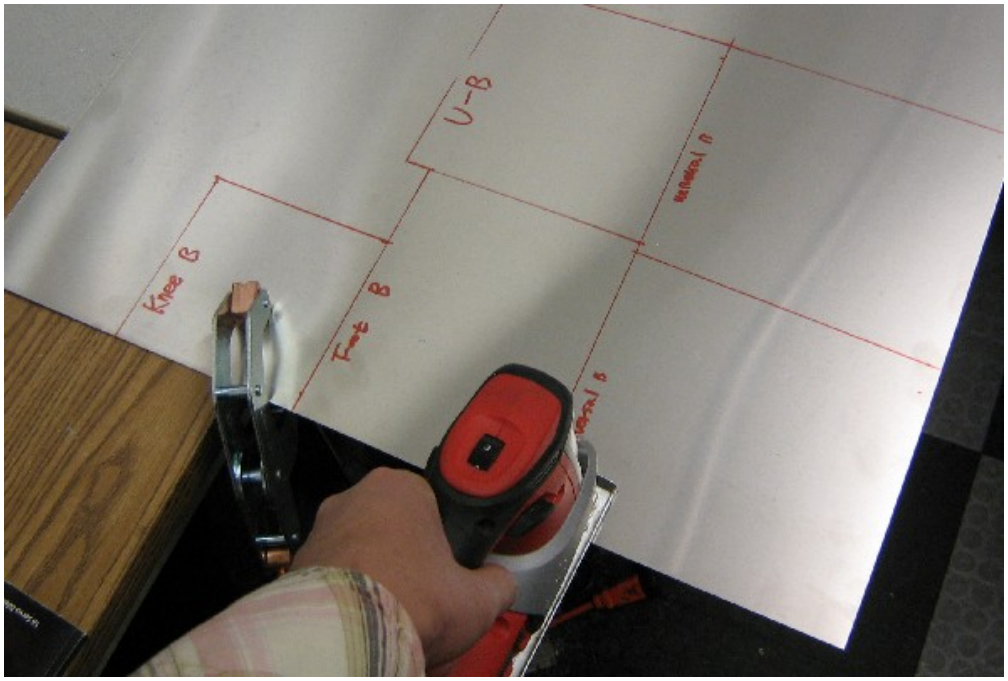



Figure3: Proper size of Aluminum plate

If you did the above, you can cut an aluminum plate with the proper size. Before you start, you have to learn how to use the jig saw. If you are ready to cut, cut aluminum plate as much as you need by the jig saw. An image below will show you a method to cut properly and safely.



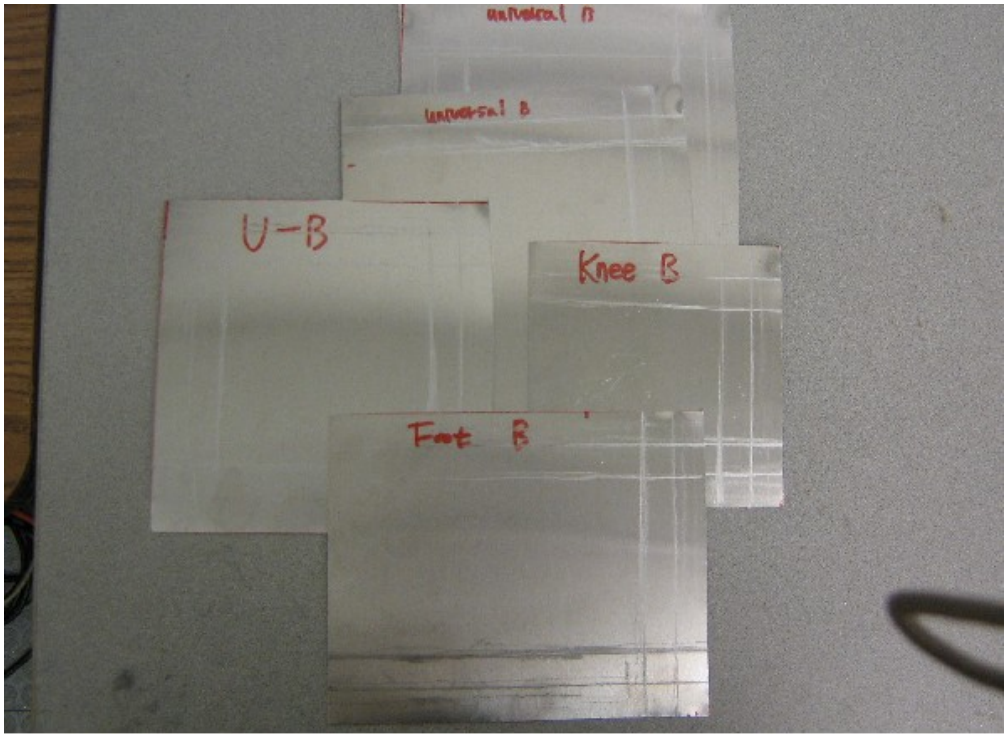




Figure4: A method of cutting Aluminum plate and All plates

**Step3: Cut & Mill plate for patterns with CNC**

Now, you will do real cutting and milling with CNC. Even if you are learning how to use CNC and are not an expert with CNC, just follow the procedure mentioned below with the images. It will help you to use CNC safely.

The first push the start button to run CNC.


Figure5: Push the start button

Next insert your own USB memory into CNC computer.  Your drive has to have all text files for all patterns and dies.

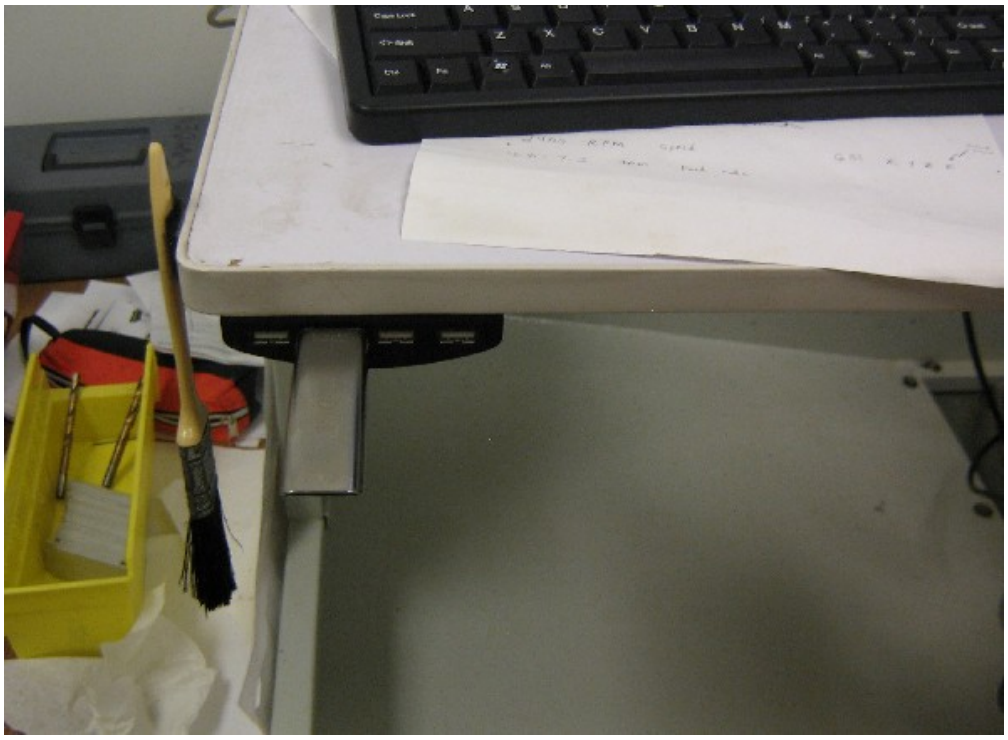


Figure6: Insert memory into CNC computer

Then make your own folder in CNC computer.  Also copy all files to new folder you made.

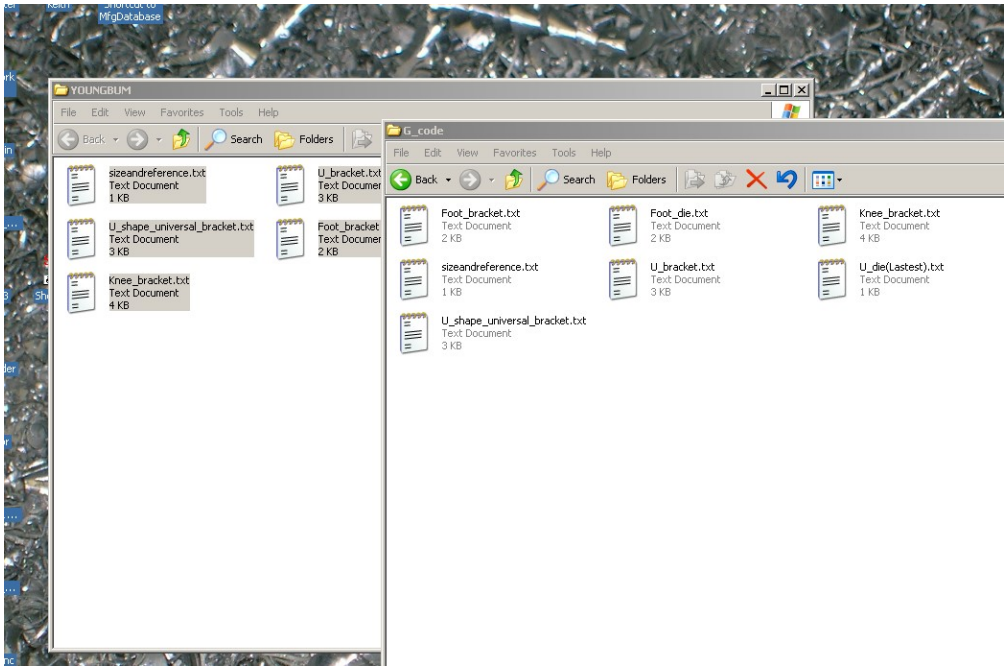



Figure7: Making folder and copy all files into new folder

Next step, you need to change the name of all text files for patterns and dies to .nc files. CNC can read just files which have .nc expansion.

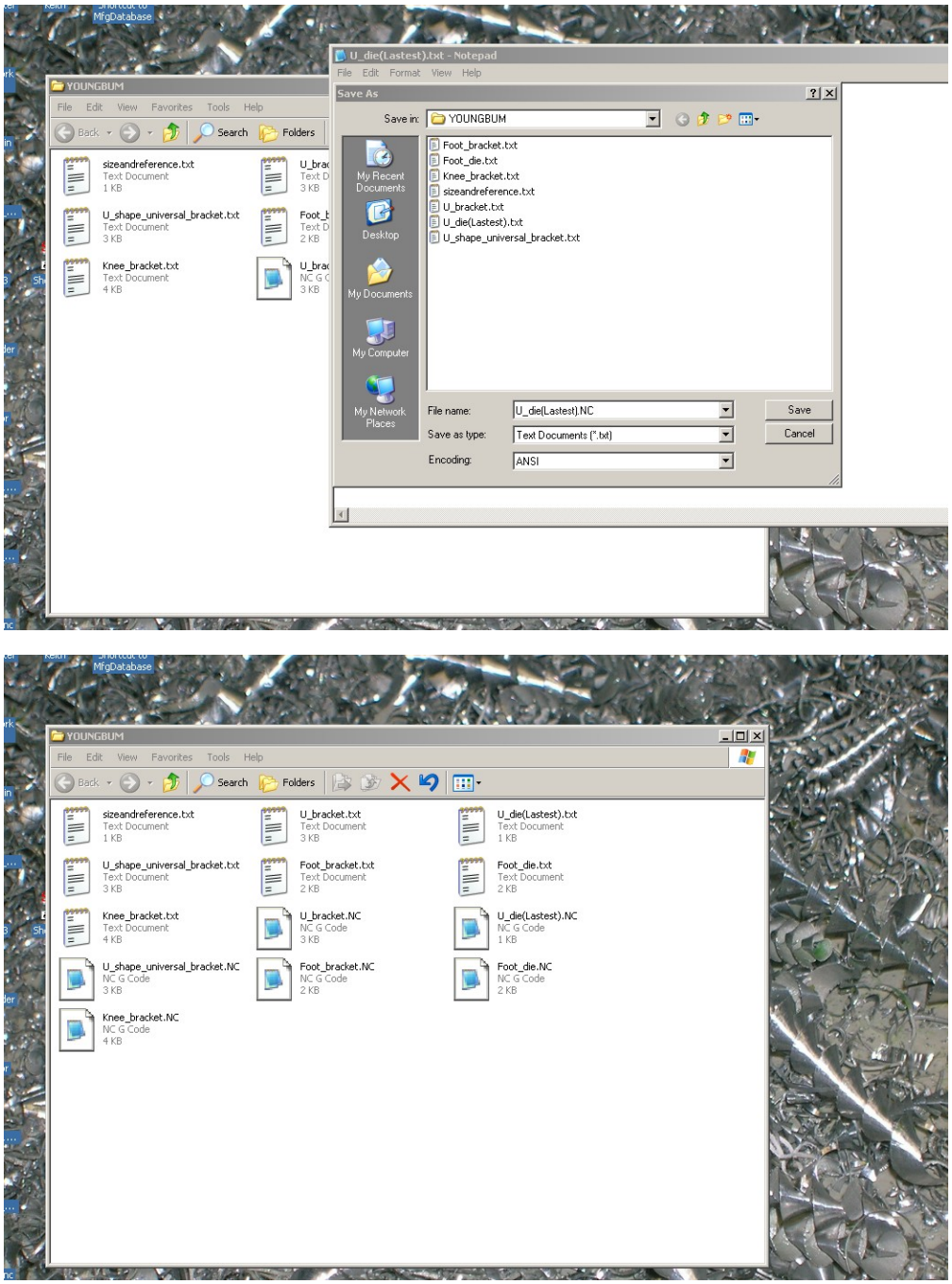



Figure8: Change files name which have .txt to .nc

Until now you have done presetting for program. Now you need to preset for CNC. Double click CNC icon on desktop screen to run program for CNC.

Then click “reference all” button on CNC program and pull oil lever in the CNC at the same time to make machine tool cut smoothly. After clicking “reference all”, CNC table, XYZ, will move to

reference automatically.  At this time, after pulling oil lever, machine tool will get oil which will make movement of the table smooth.

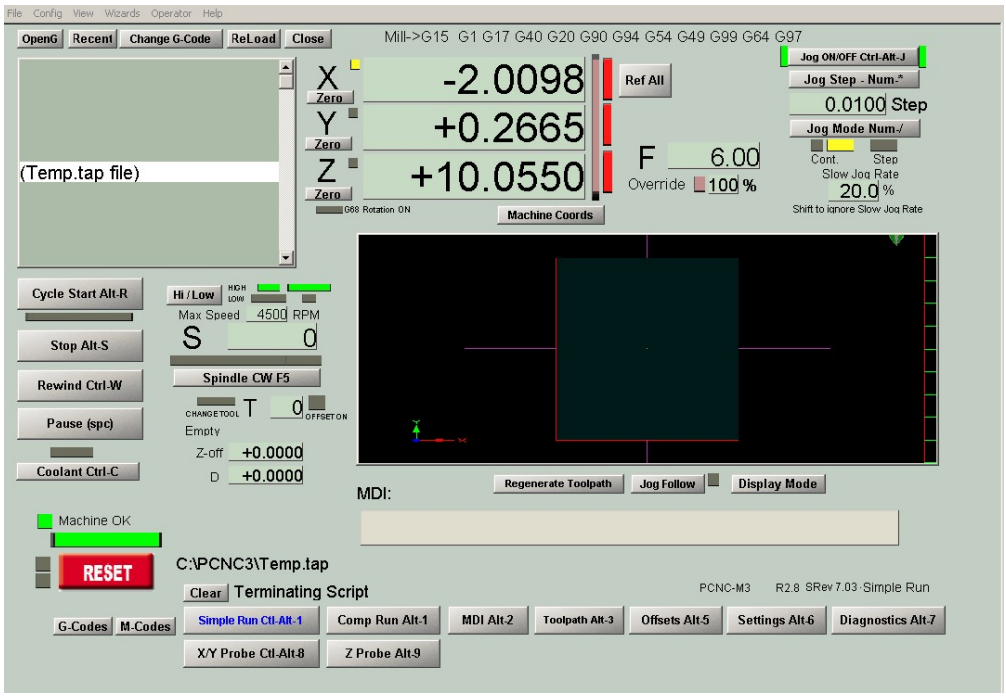



Figure10: Click “reference all” button

Figure11: Pull the lever in CNC to supply oil for machine tool

If you followed steps above correctly, you should have done all pre-setting for real cutting with CNC. Finally you are ready to cut the aluminum plate to produce your own patterns. You have proper rectangular size of aluminum plate, correct G-code, and CNC pre-setting. Now you need to put your aluminum plate in place held firmly by using clamp. The aluminum plate you have now may be bent, even if it is not, it is thin. You will cut it so you need a prop for cutting your Aluminum plate. A prop must be flat and has proper thickness for CNC table not to be damaged. The image below will show you props I used.

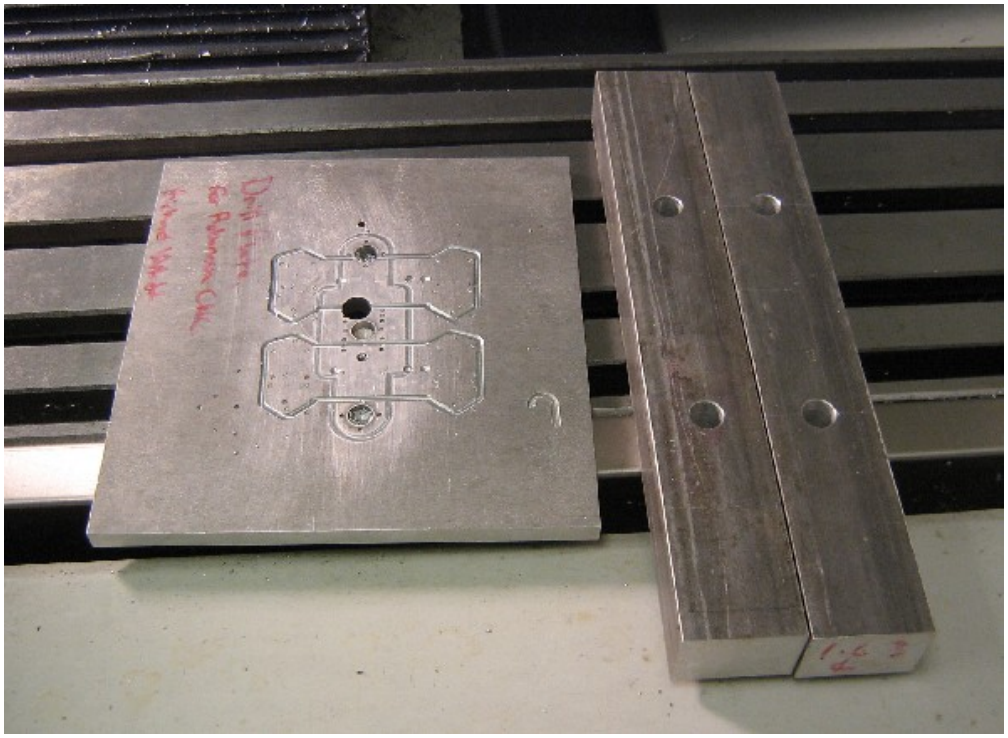


Figure12: Props for cutting Aluminum plate

If you prepared a suitable prop(s), then you need to tight the aluminum plate on the prop by clamp. The image below is the image after the plate is tightened on the prop.

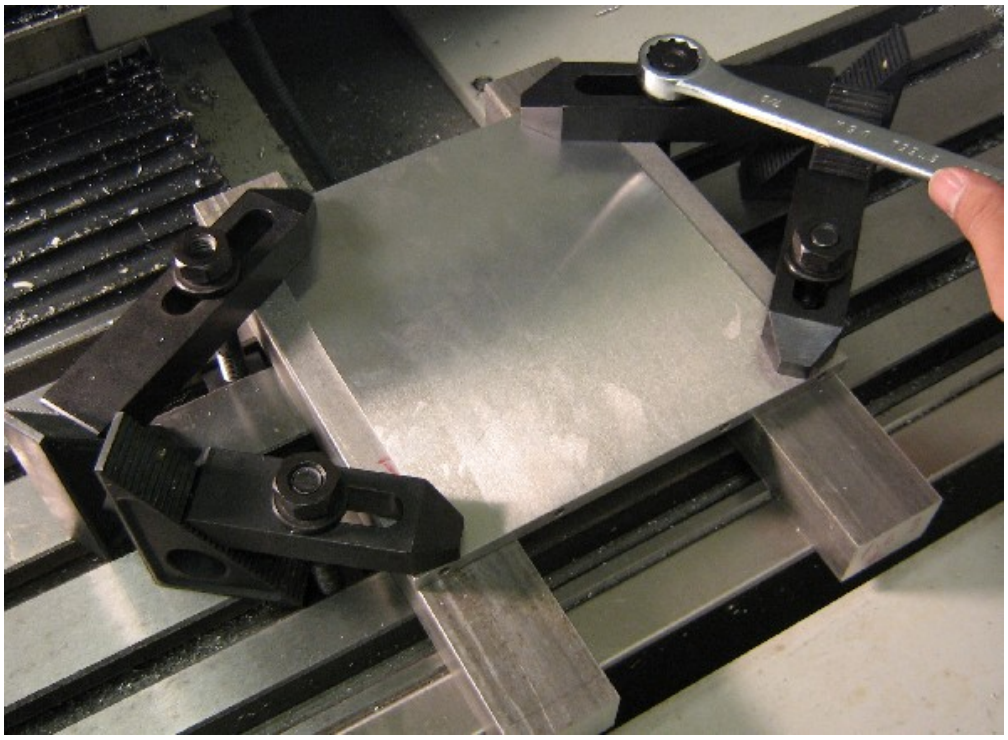
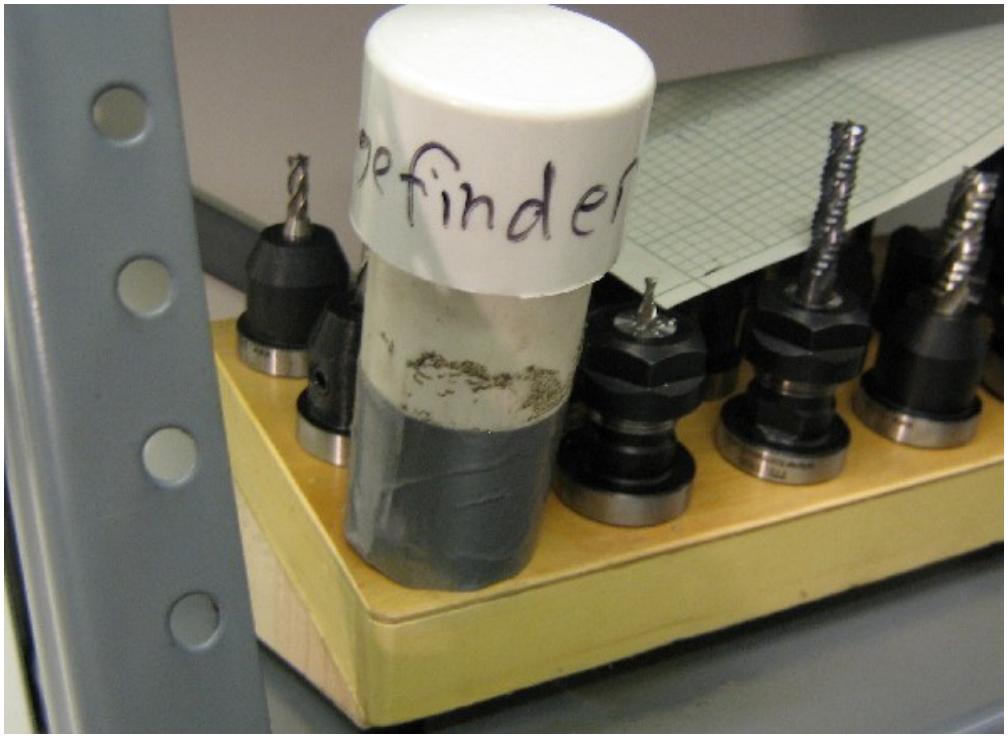


Figure13: Being tighten on the prop on CNC table

The next sequence is to set the reference. You need to use Edge Finder which is one of CNC tools. It informs you when it is touched with materials. The image below is about Edge Finder.



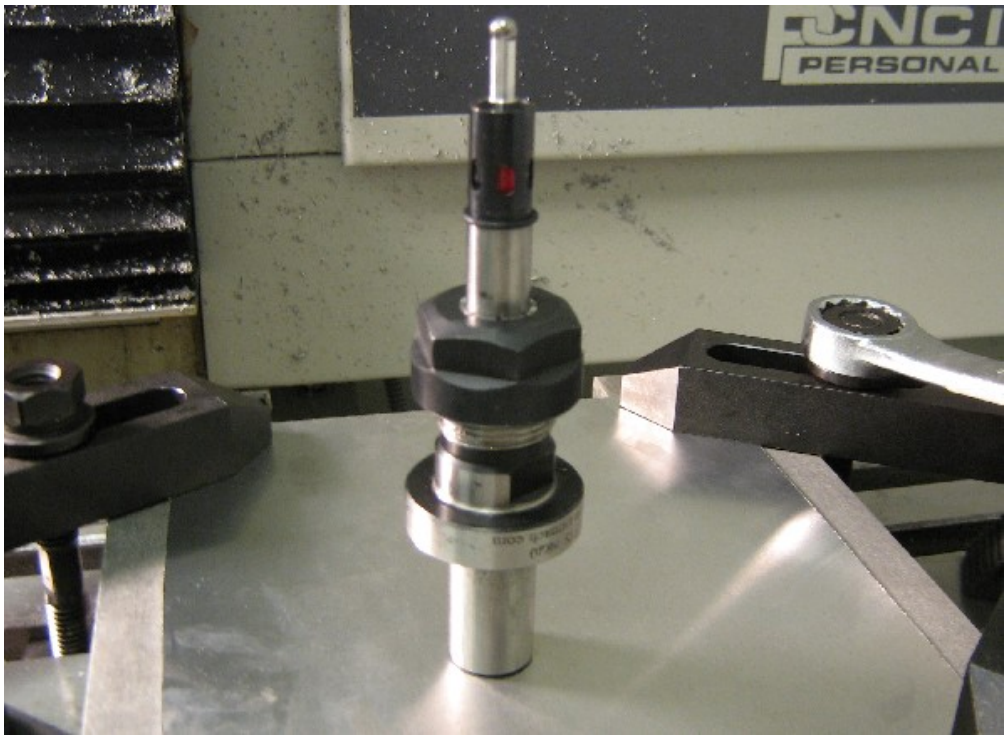



Figure14: Edge Finder

You can see position of the reference in “Sizeandreference.txt”. For example:

Ex) reference x = 38mm, y = 38mm

The standard is left bottom corner. The image below will show you what that means.

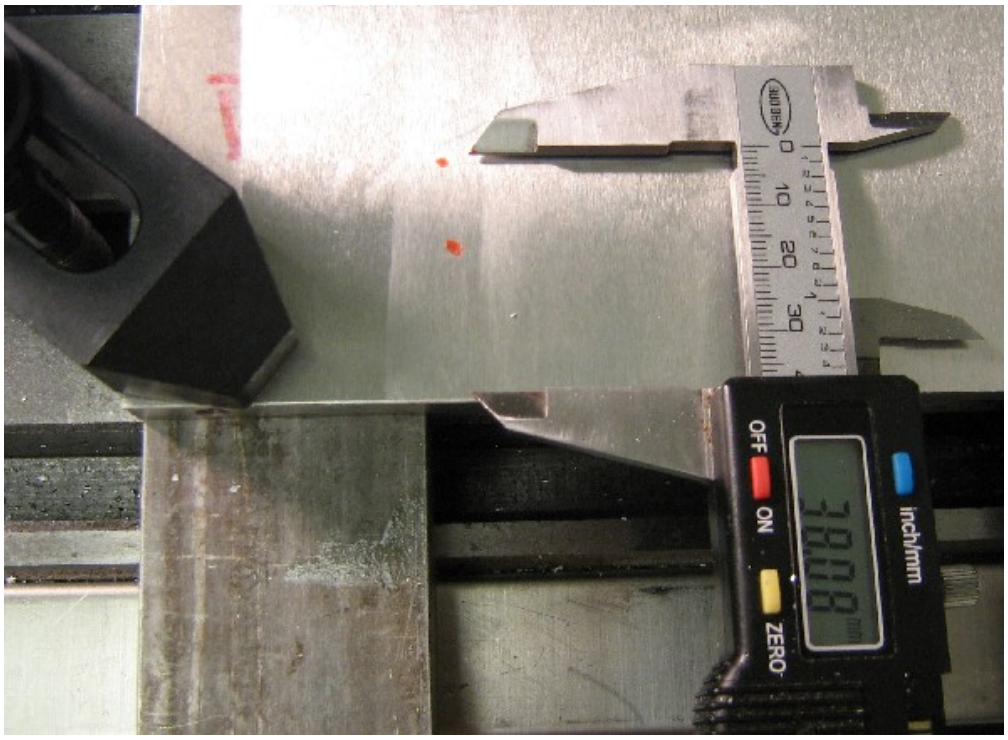



Figure15: Reference presetting

Then you put Edge Finder into CNC.  It assumes that you know how to change tool.  We call doing this “tool change”.

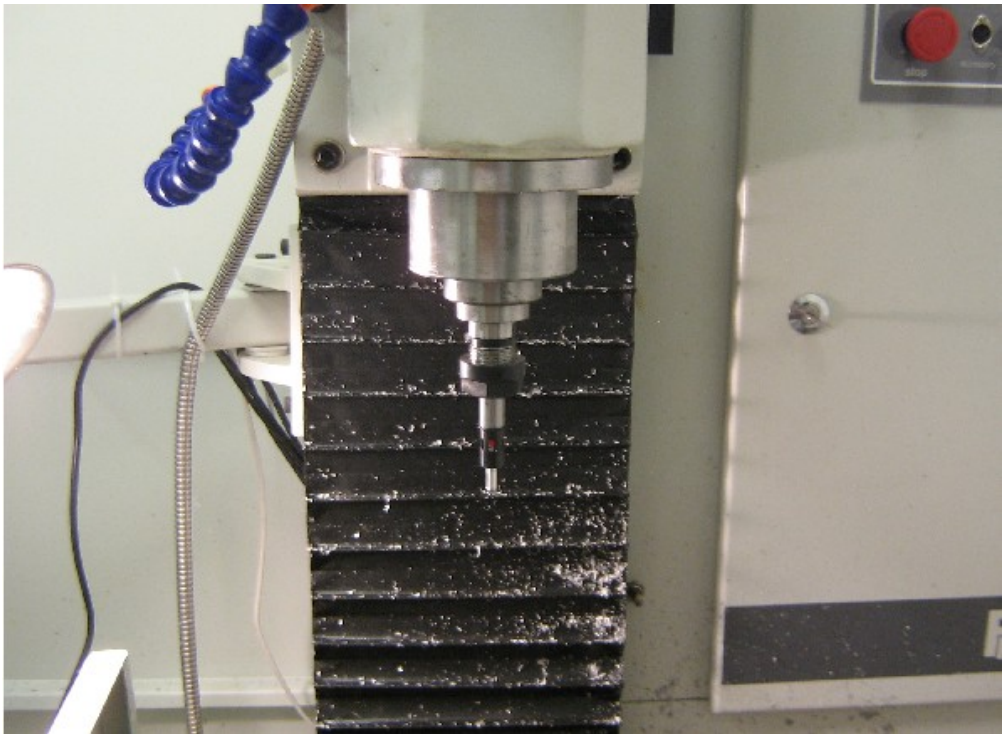


Figure16: Tool change, Edge Finder

the Before you set reference, you must put “M6 T0 G43” into the command window on program. It means that you set tool position of Edge Finder. Tool number of Edge Finder is T0. You can find information what these G-codes mean in the CNC reference book, guide book.


Figure17: Enter “M6 T0 G43” in the command window

Now you need move CNC table (X, Y) and tool position (Z) manually to set the reference. You check your reference by following sequence above. It is easy to set reference. You should move tool to the position you set.

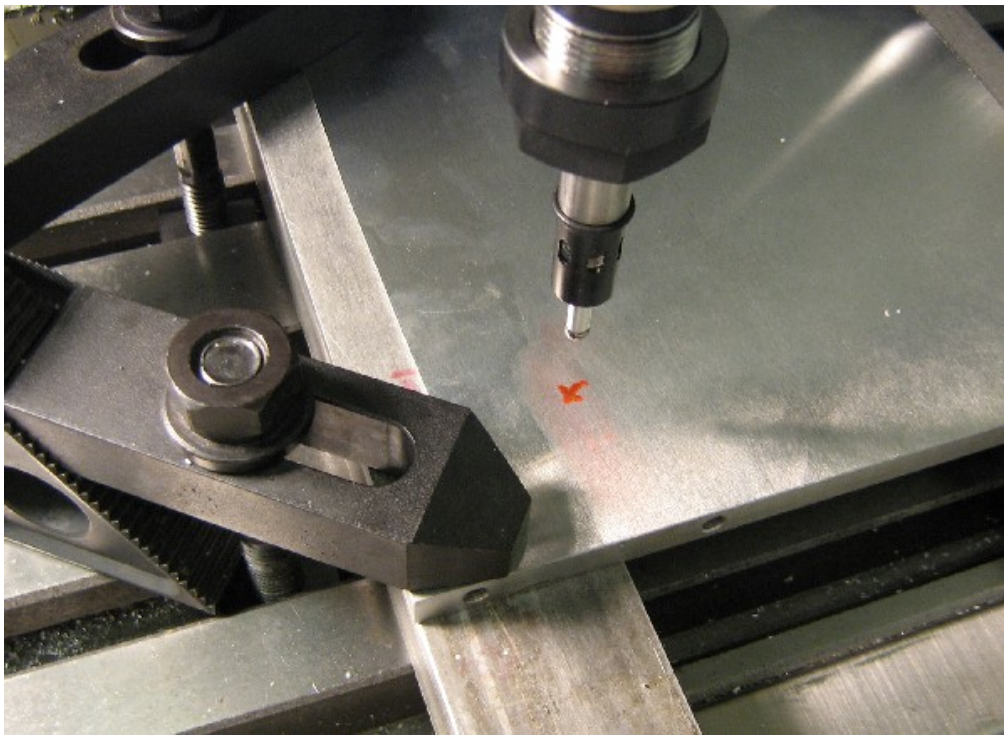


Figure18: Reference position setting

At This time, you can push “zero” button in the screen.

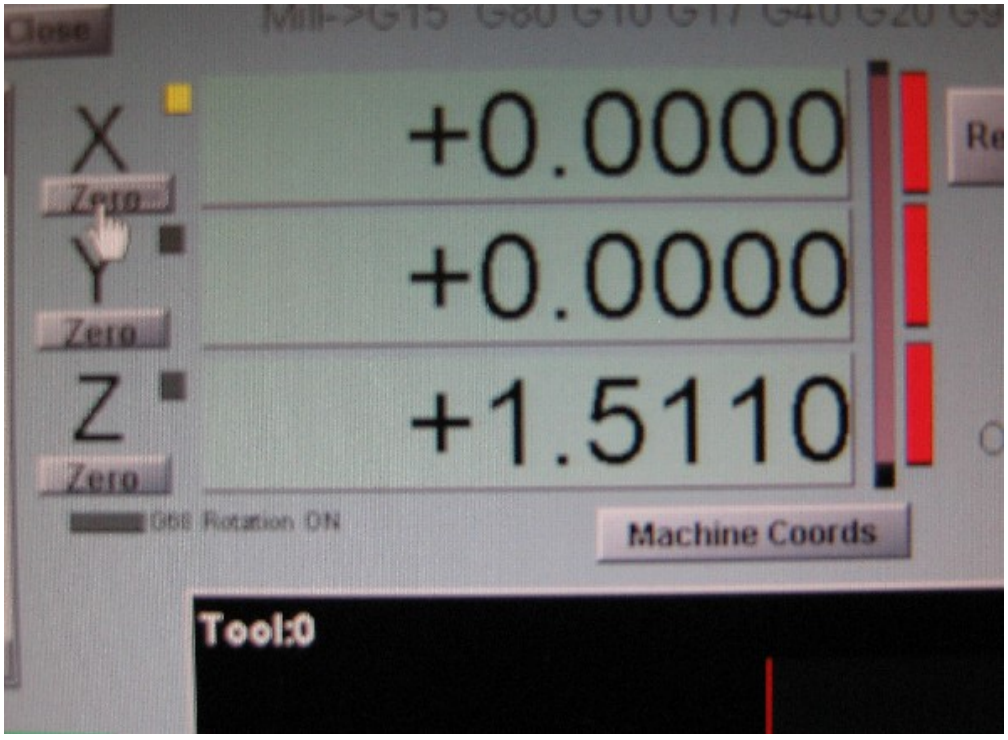



Figure19: Set X, Y to be zero

Now you have reference positions of X, Y direction.  You need to set the Z reference.  The method of how to set Z reference is in CNC reference book.  You can read the method in the book.  We usually use cylindrical metal with 6.34mm diameter.  The images shown below will show you how to set the Z reference.

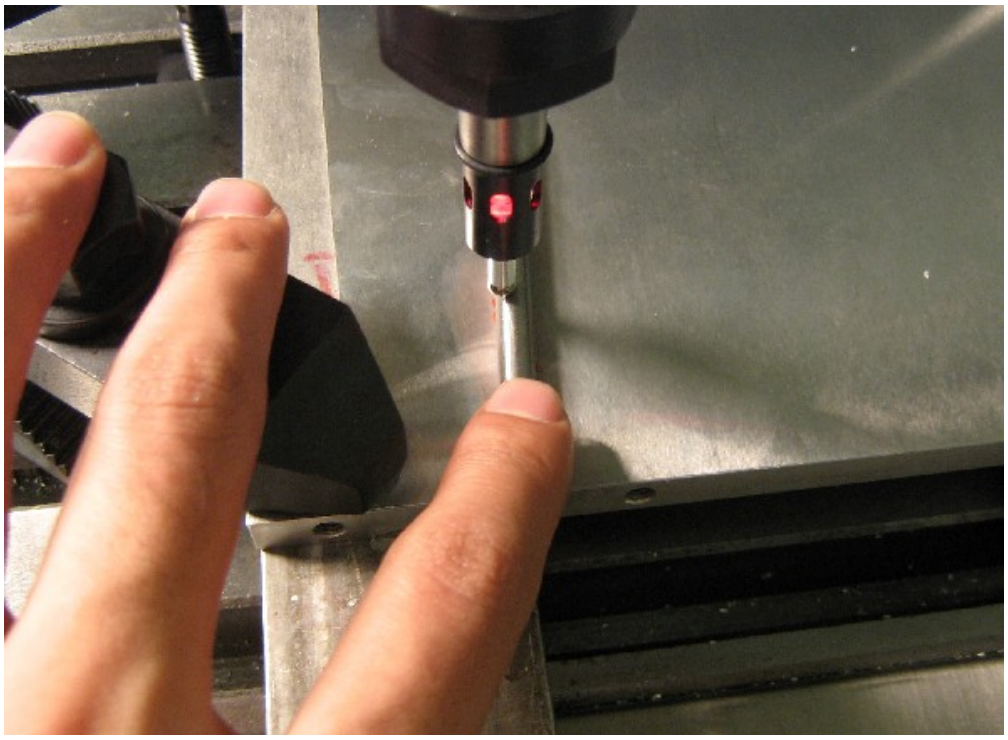


Figure20: Set Z reference with 6.34mm diameter

Figure21: Finding Z position

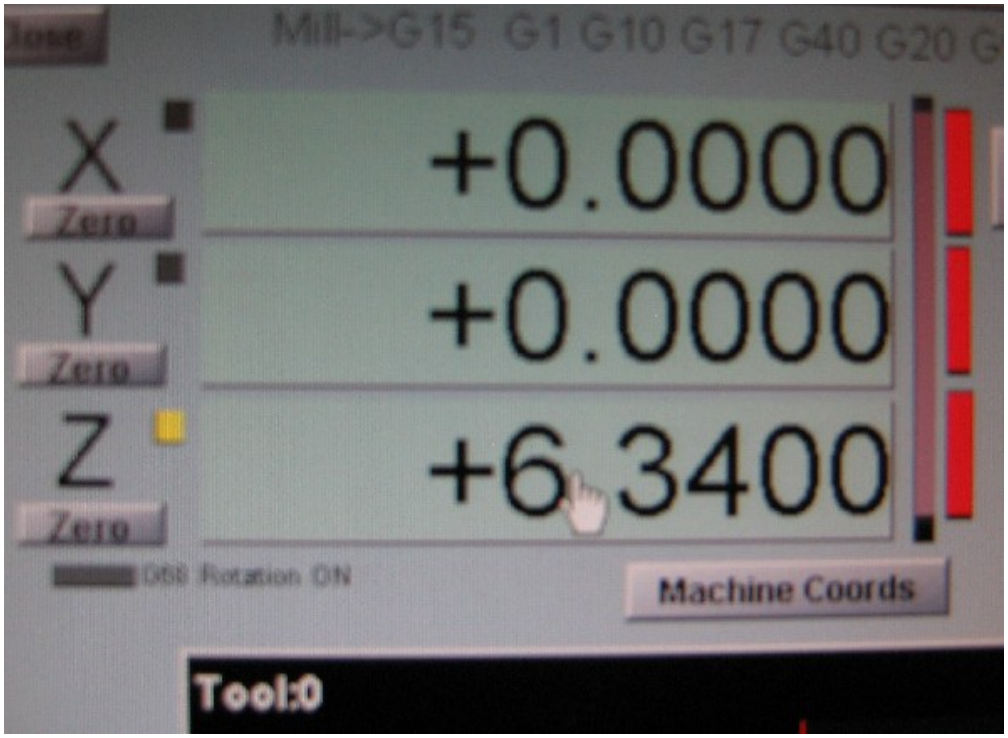



Figure22: Set Z to be 6.34mm

Then you need to move the tool to change its position. Edge Finder is very sensitive tool so you have to handle it very carefully. You enter “G0 z200" into command widow. After that, you can see movement of tool toward Z direction.

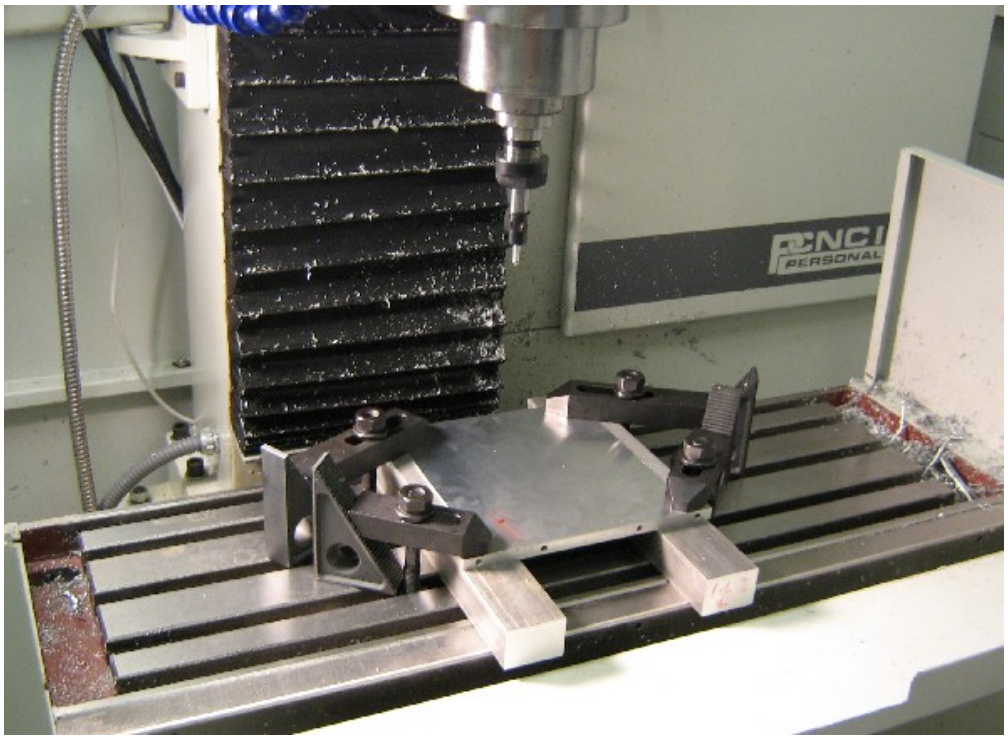


Figure23: Tool change position by G0 Z200

Now you are really ready to cut.  Push “open-G” button to open your file.

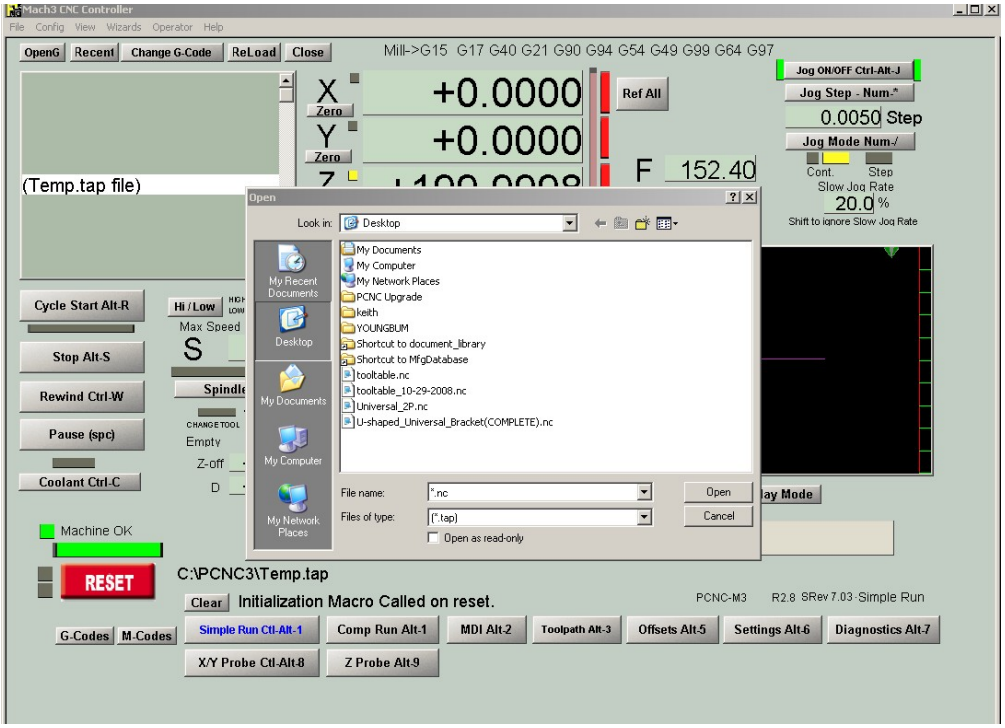



Figure24: Open the file

Click your code (.nc) you want to cut, after this the CNC program will read (or load) it automatically.  First it is better to load “U_shaped_universal_bracket.nc”.

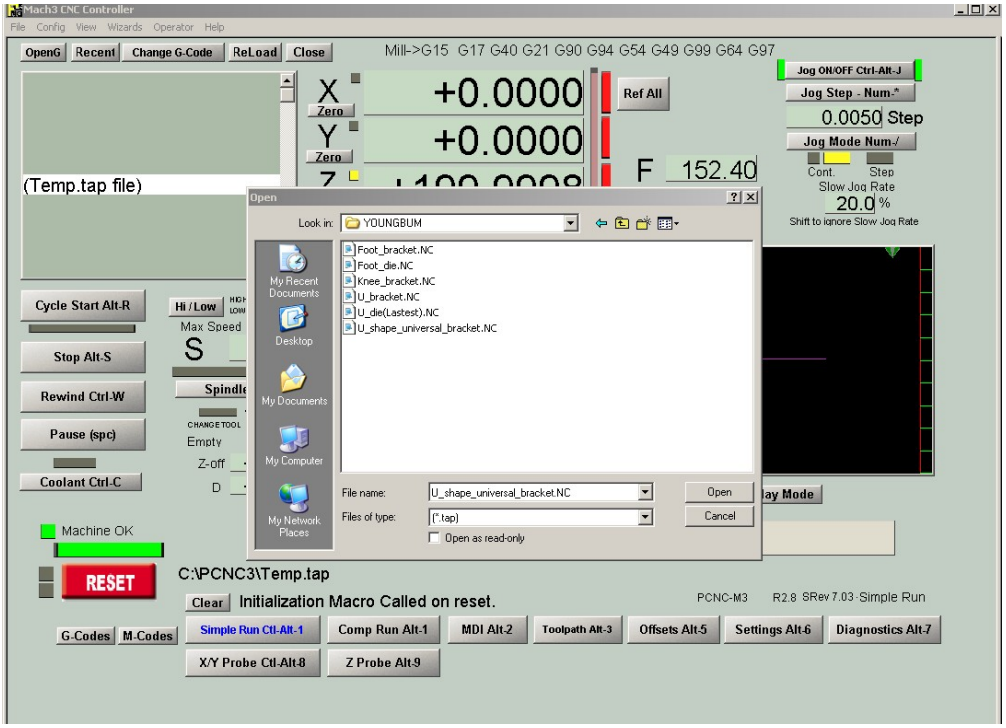



Figure25: Loading “U_shaped_universal_bracket.nc”

You are entirely prepared for operating CNC and cutting.  Now you can click “Cycle start Alt +R” button to execute CNC.  You can see CNC machine now operating.  What you have to do is to change tool to the exact tool the CNC will use.  You can see what kind of tool the CNC requires.  The images shown below will show you how to start, and how to change the tool to the exact tool machine needs.

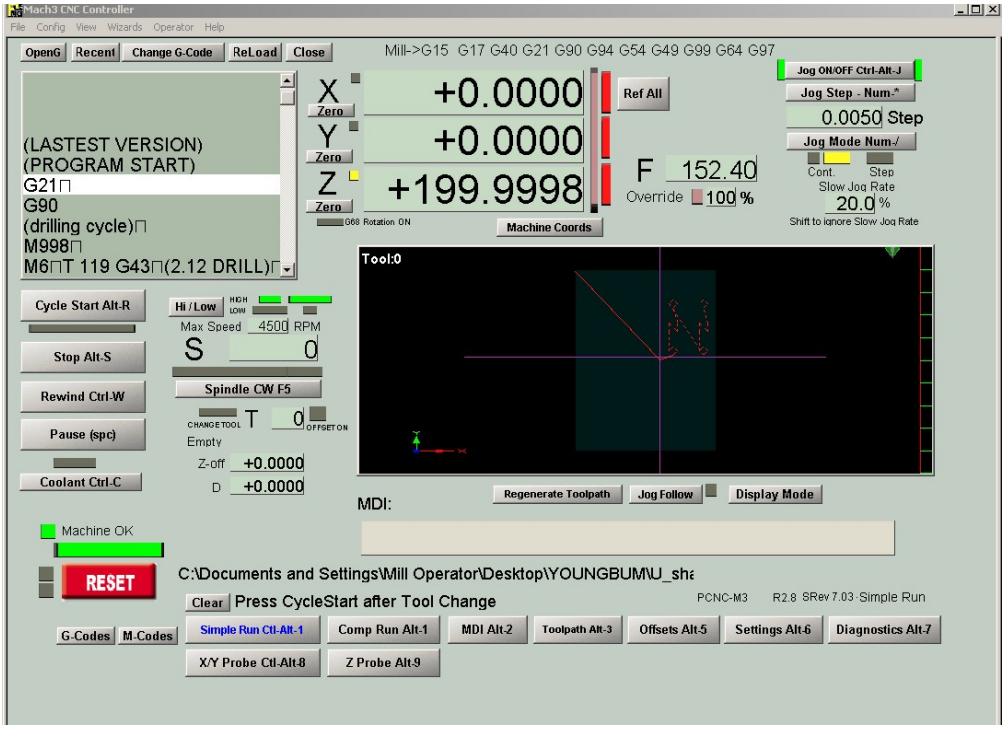



Figure26: Running CNC machine

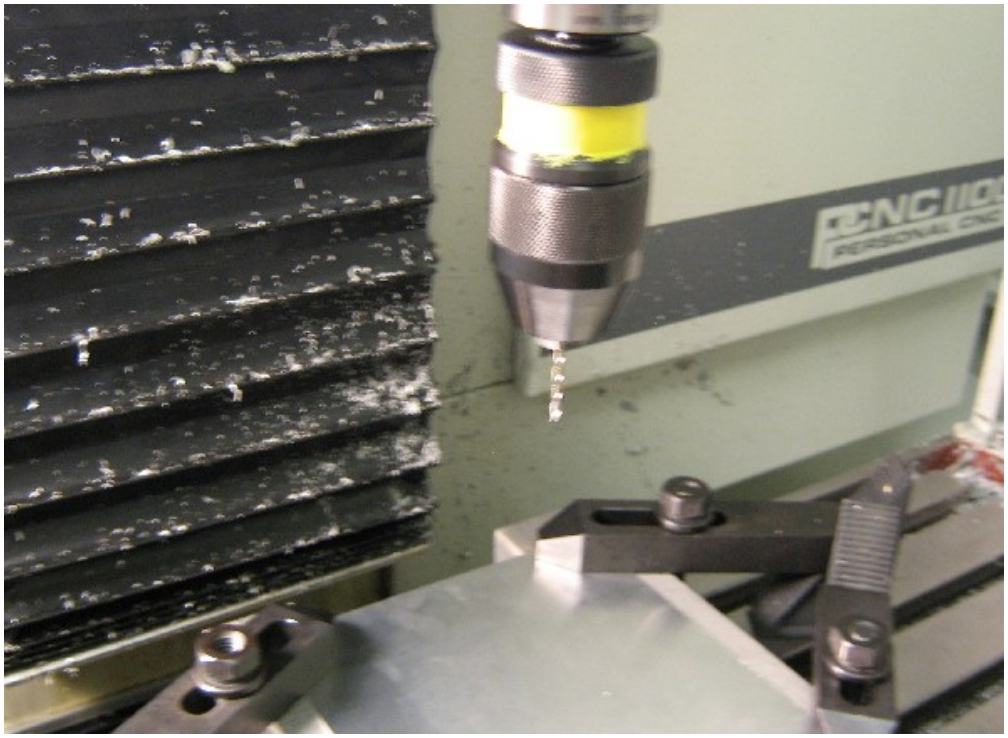


Figure27: Tool change to 2.12mm tool

You may have cut “U_shaped_universal_bracket”. Now you can cut other patterns except for dies with the same procedure explained above.

Warning: when you cut U_bracket and Foot_bracket, you must disable "Abs I/J" effect as shown below.

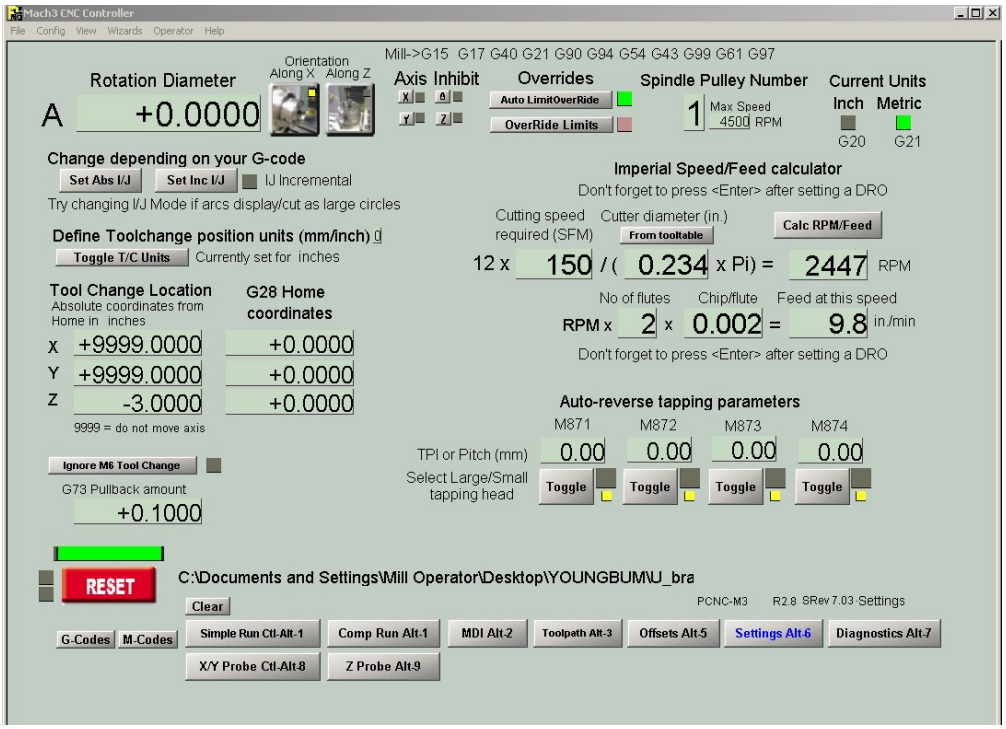



Figure28: Disable Abs I/J

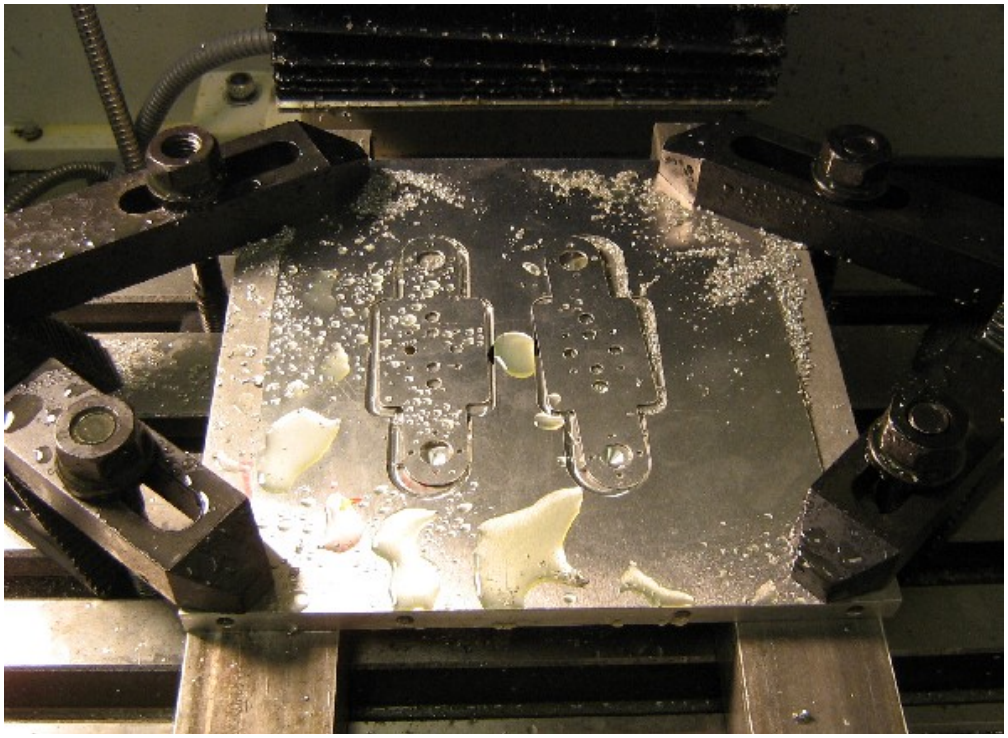


Figure29: When CNC have done cutting

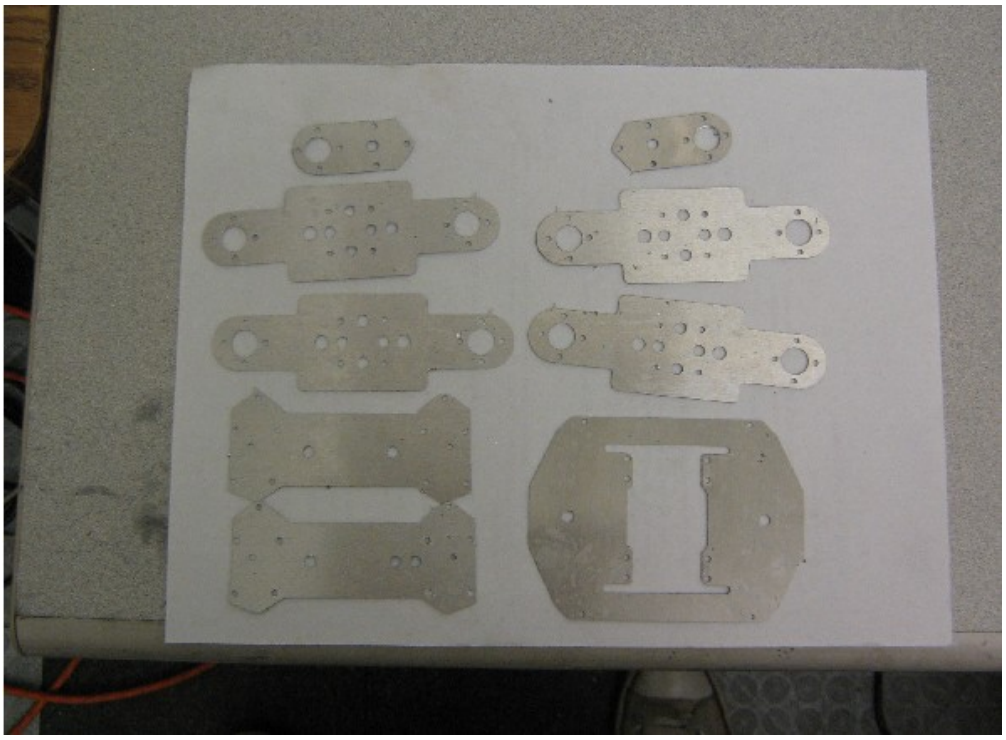


Figure30: All patterns as an output

**Step4: Cut Aluminum Block with Metal cutting band saw**

This step has a very similar procedure to step2 except for the machine you use. You will cut an Aluminum block with proper size. You can open “Sizeandreference.txt”, and see the proper size of dies for each pattern. The size of dies in the file will be little bigger than actual size you need because you have to make it flat by using Face Mill. So you need extra space. Next, draw a line on the block. The line will be cut end.

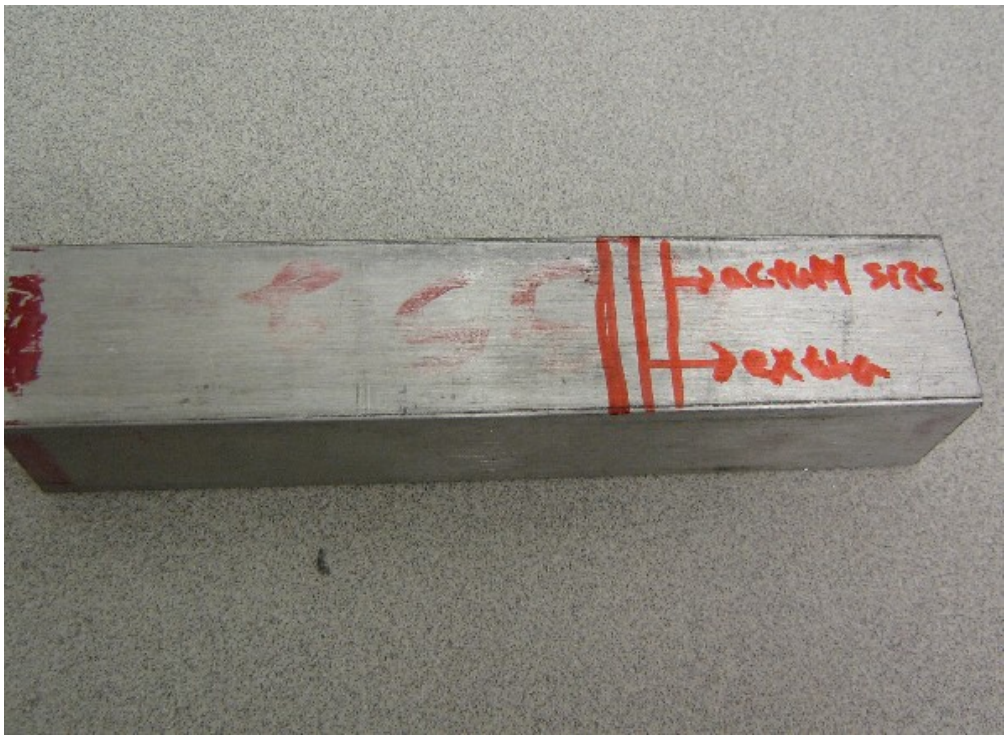


Figure31: Drawing the line on the block

Now you can use the metal cutting band saw to cut the aluminum block. The image below shows the machine you will use.

Figure32: Cutting machine

The way to use this machine is very simple but very dangerous. You need to ask one of Ph.D student in DASL to learn how to use it. The image below shows you pre-setting for cutting an aluminum block.

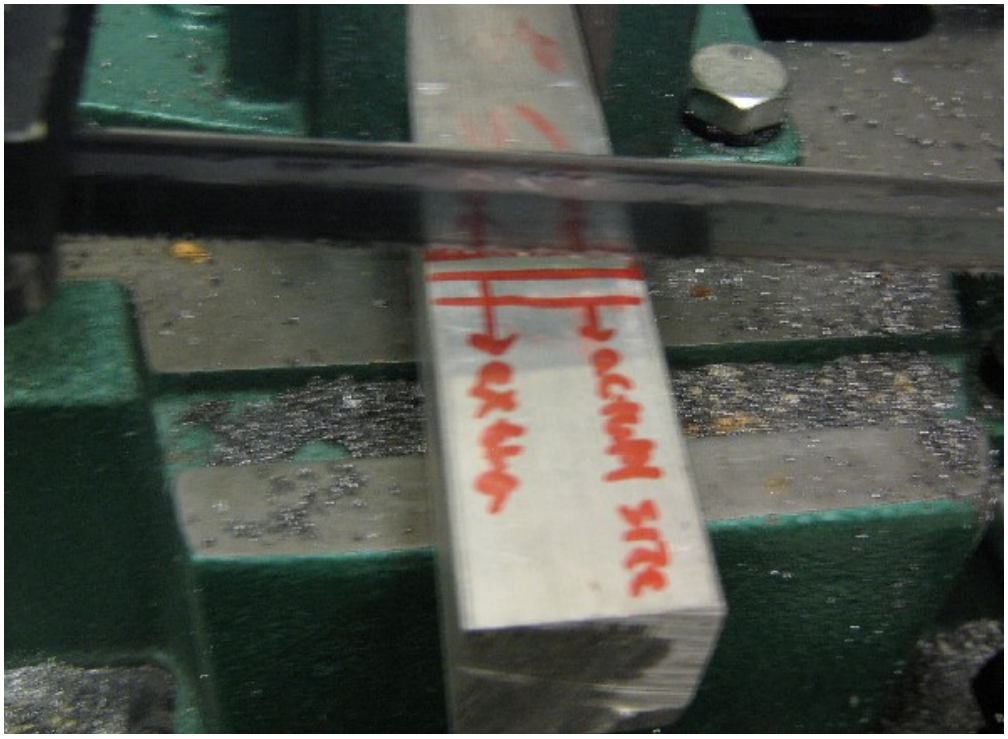


Figure33: Pre-setting for cutting Aluminum block to get proper size to cut

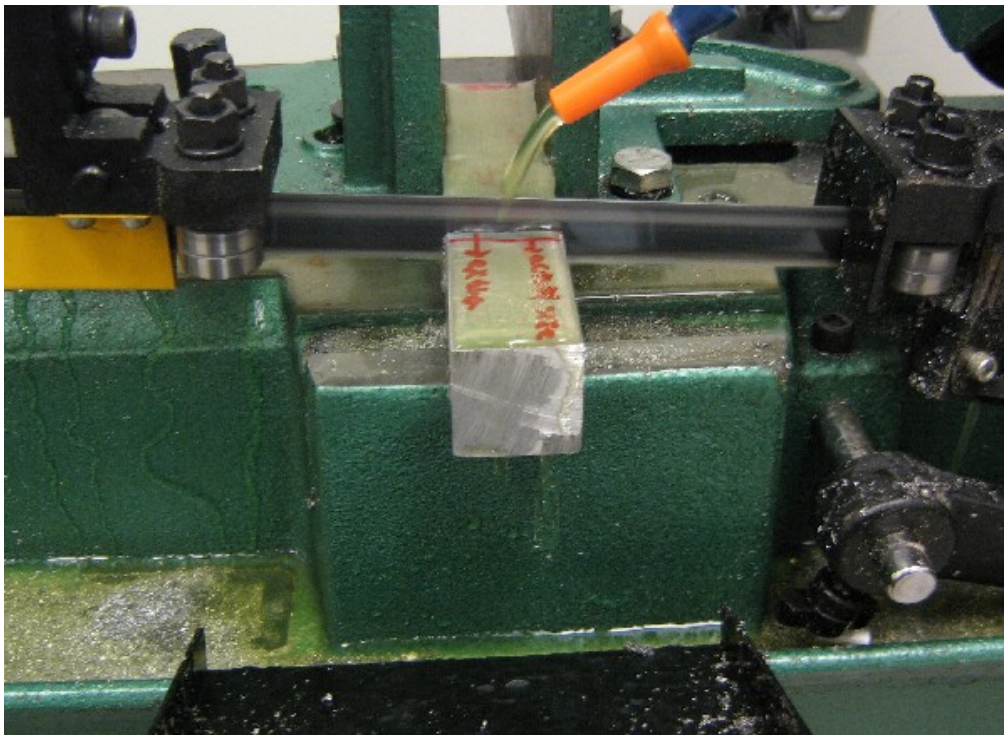


figure34: Cutting Aluminum block

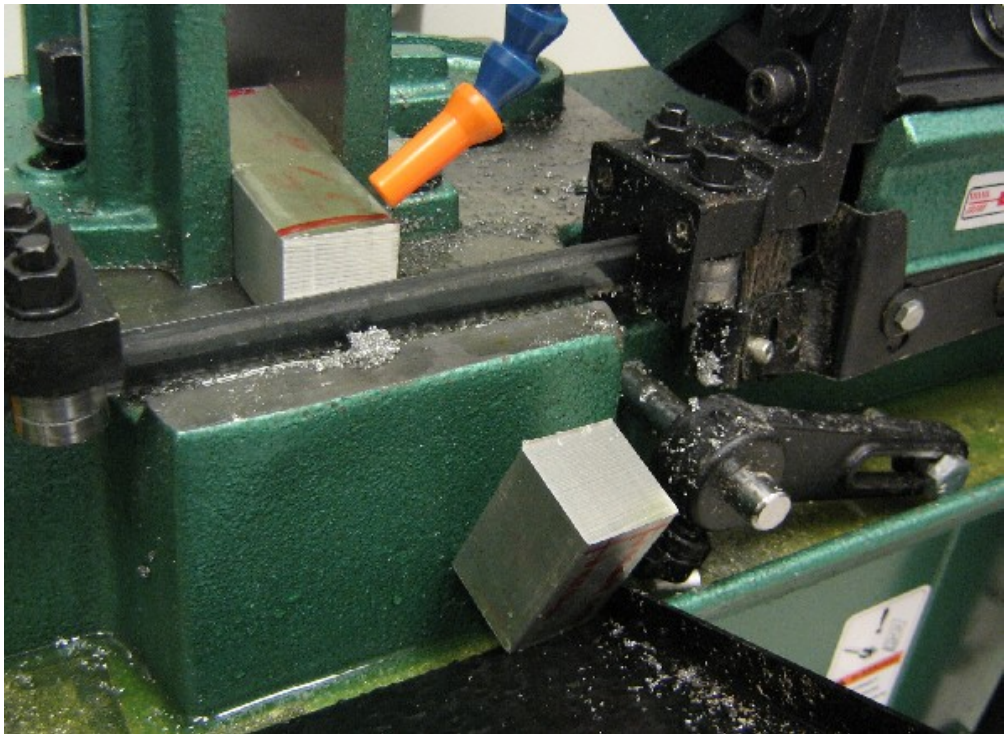


figure35: After cutting

**Step5: Cut & Mill block for dies with CNC**

The procedure of this is very similar with step3 and it has the same procedure as step3 to preset CNC machine.  Before you start, read step3 and remember how to preset the CNC and G-code.

Now you got the suitable size of Aluminum block.  You need to clamp tool which is for block. The image below shows you what it is.

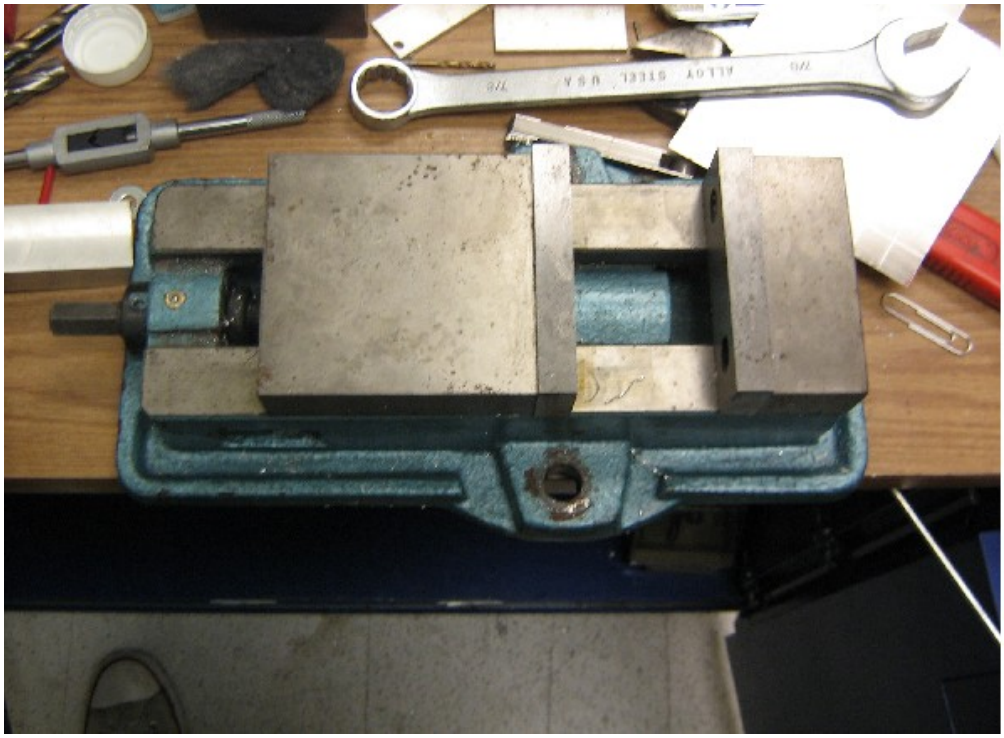


Figure36: A die for block cutting

Then you can clamp it on the CNC table.

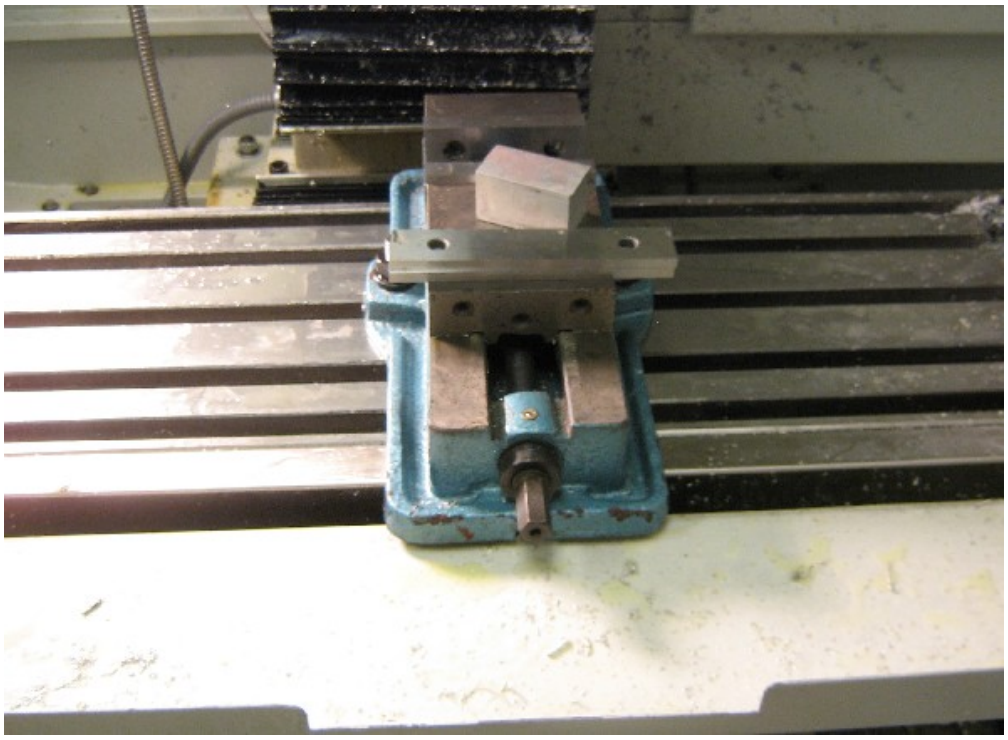


Figure37: Being tightened to the CNC table

Now you need to put your aluminum block to be cut on the die and clamp it.

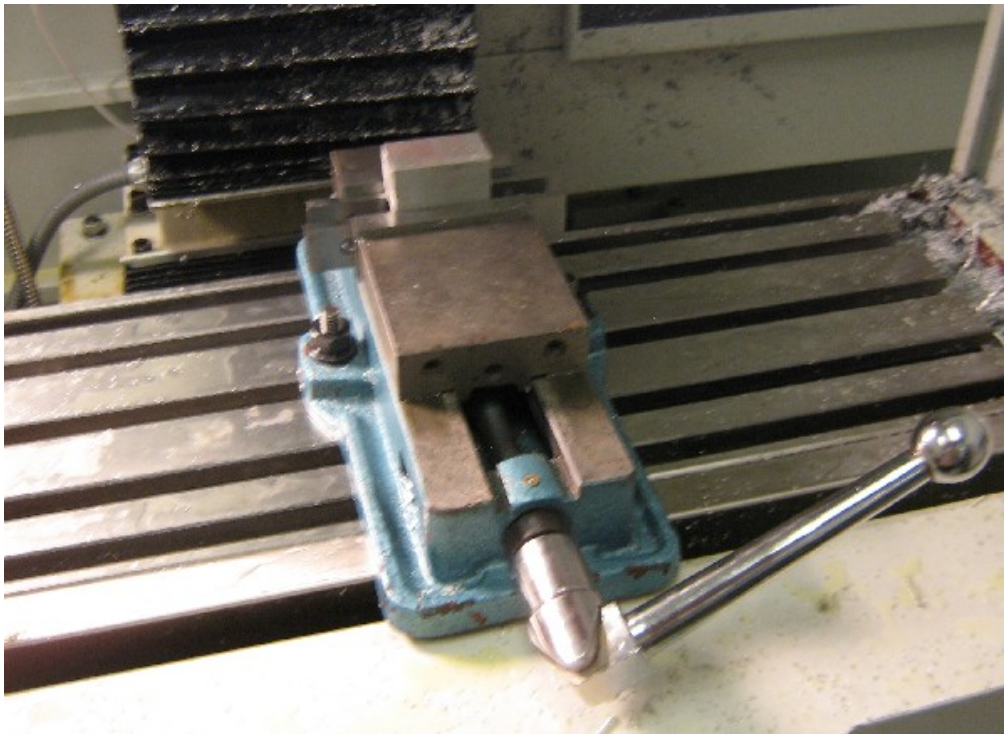


Figure38: Aluminum block tighten on the die

First you need to make your aluminum plate a cube.  You can use Face Mill to make it flat and square.  The image below shows the tool you need.


Figure39: Face Mill

Now you have the CNC program running on the computer, aluminum block clamped on the die, and you have used Face Mill.  At this time, you do not need to set X, Y reference for trimming the surface of block.  You need to set just Z reference.  The way to set the Z reference is the same way you did in step3.  Follow instruction in step3 to find Z reference.  Make sure that you enter “M6 T0 G43” into command window before setting reference.

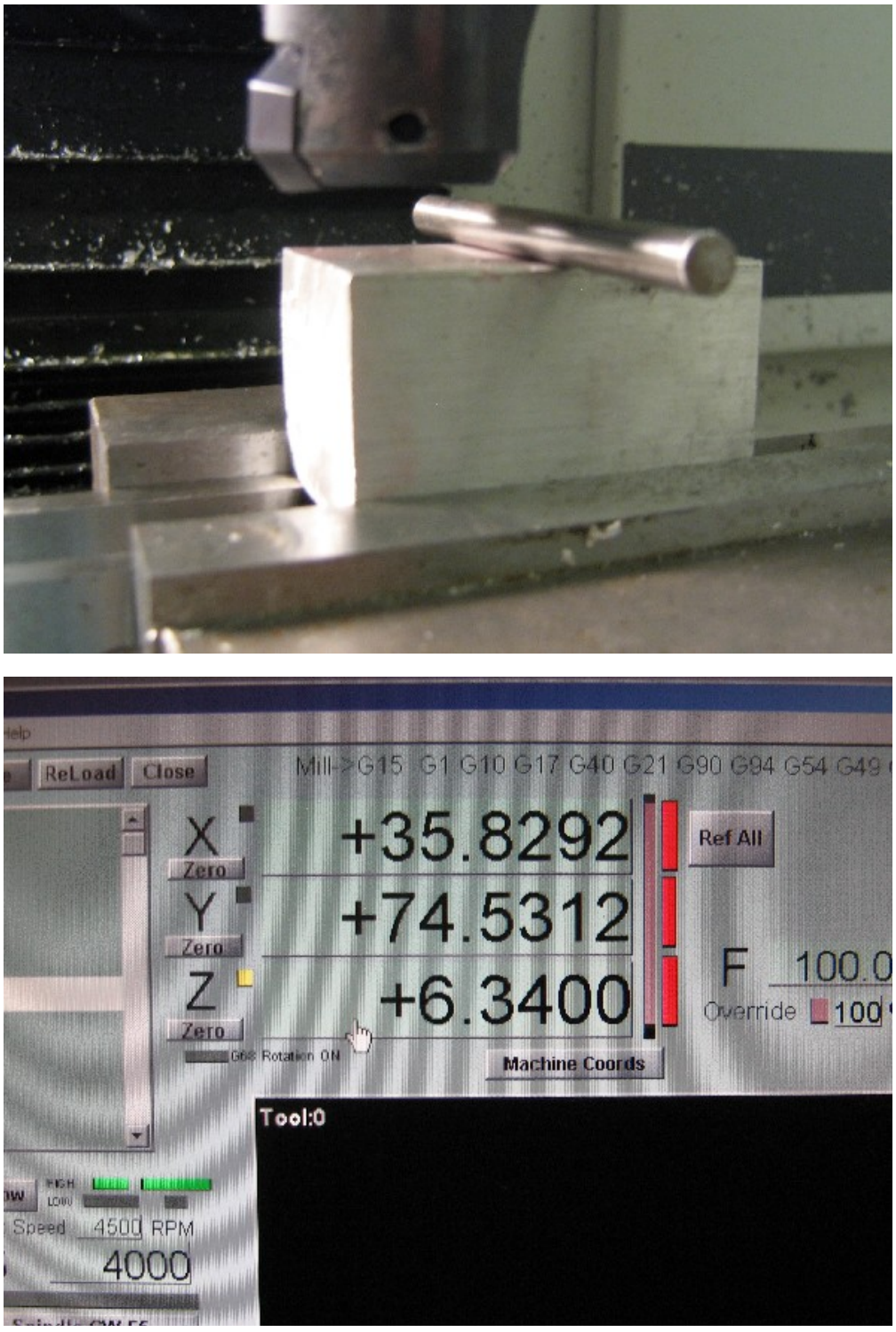



Figure40: Find Z reference

Now you have the Z reference.  You need to move the tool to be at the side of block.

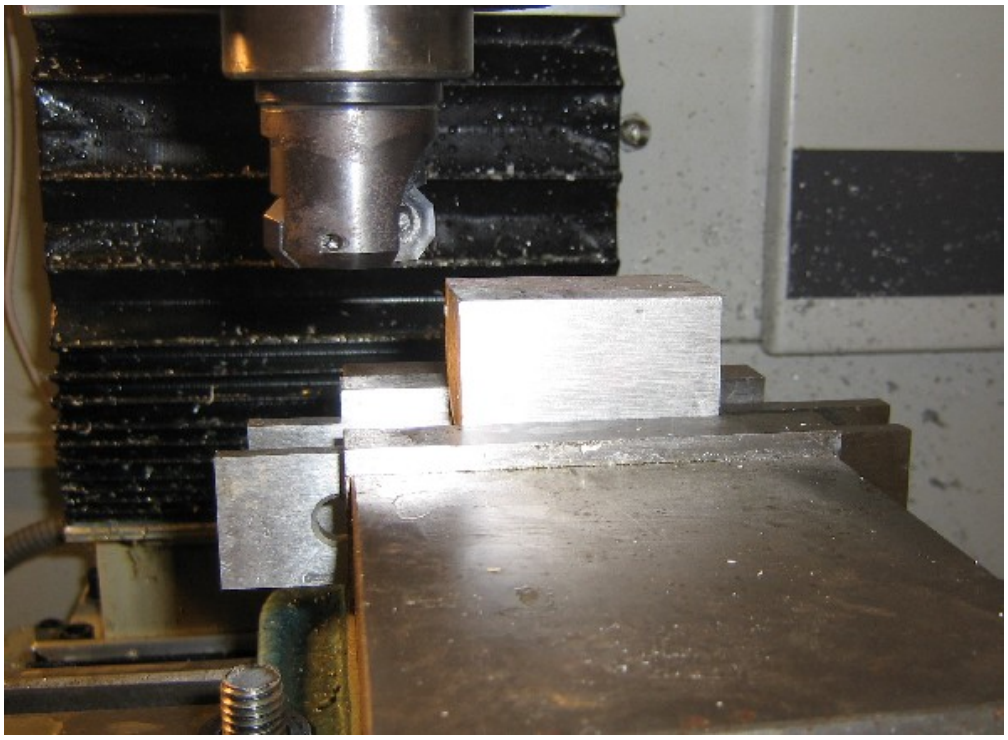


Figure41: Ready to trim

Be careful that you follow the instructions and keep the sequence below.

Before following instruction below, you have to calibrate the width of the block. And you will move the Face Mill to X direction as much as width + Face Mill diameter which is 38mm.

Enter “G0 -1.0”

Enter “M3 S3000 F100”

Enter “G1 X width + Face Mill diameter”

Enter “M5”

After performing this operation, you can see the block trimmed. You need to repeat commands above to wholly trim the block. And you can repeat the commands above until block has proper size. Do not cut more than 1mm deep because cutting more at one time will cause a dangerous situation. Also you can apply commands above to make the block into a cube. The images shown below are about trimming the block.

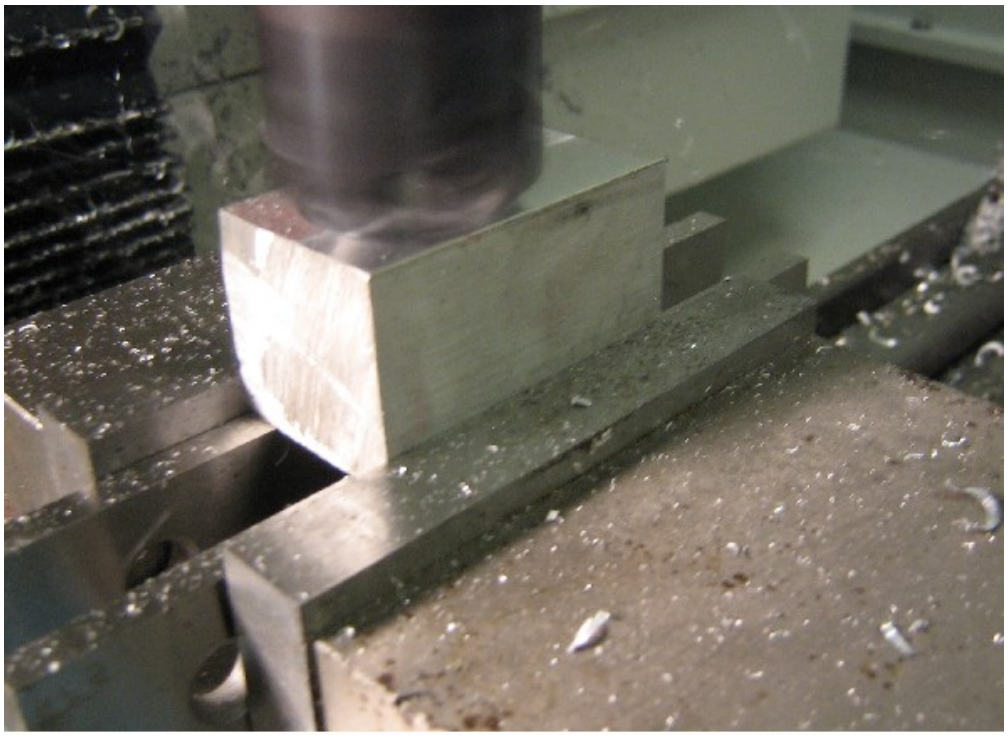


Figure42: Trimming


Figure43: Move tool to Y direction to trim other side

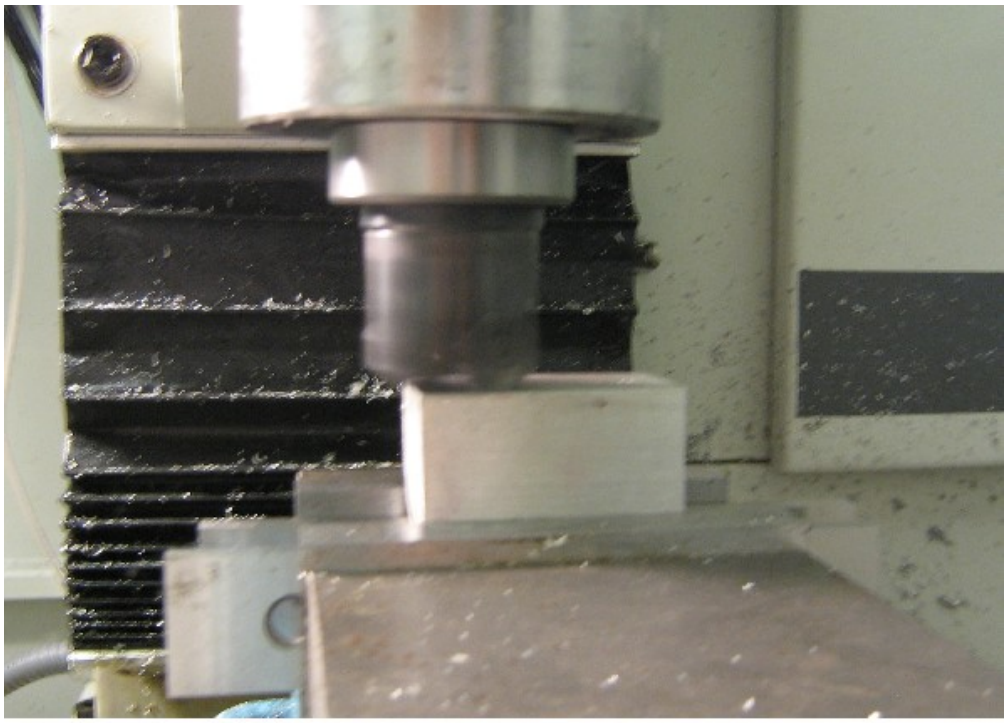


Figure44: Trimming other side

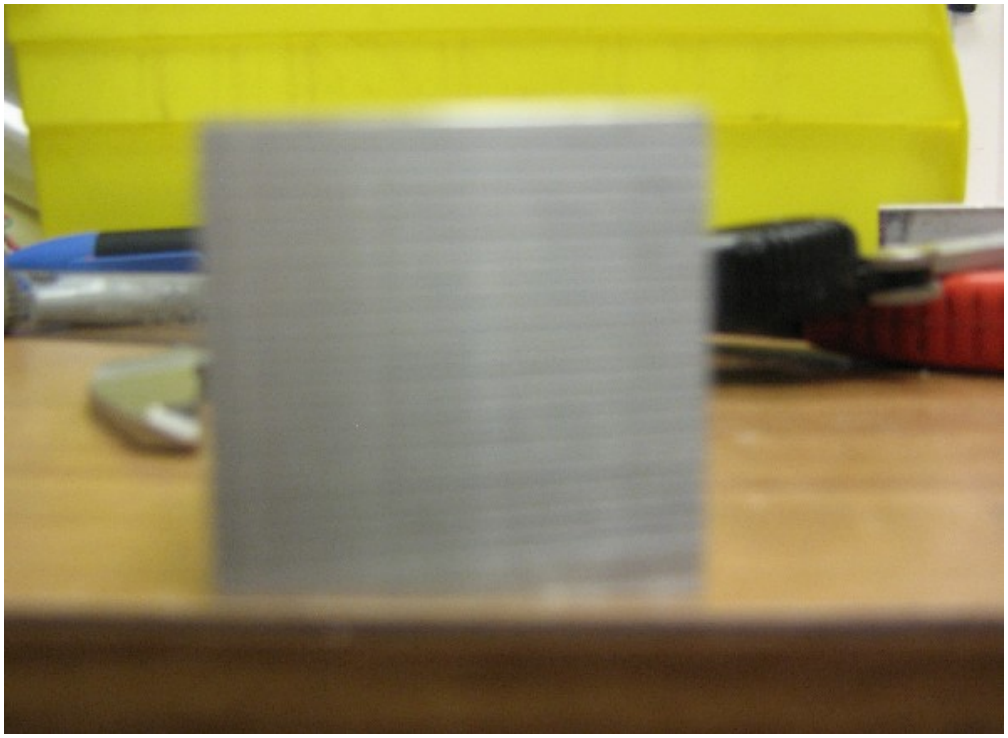


Figure45: The result which is perpendicular to ground

Now you made a cube for a pattern and which has the proper size for a pattern. You need to make one more cube for another pattern. You can repeat step4 and 5 to make one more cube because you need 2 dies for U_bracket and Foot_bracket.

After making two cubes, you need to drill holes on the cube or gouge the cube. We will first make a die for Foot_bracket. You put the cube for Foot die in place where it is on the die for the block. The image below shows you what you will do.

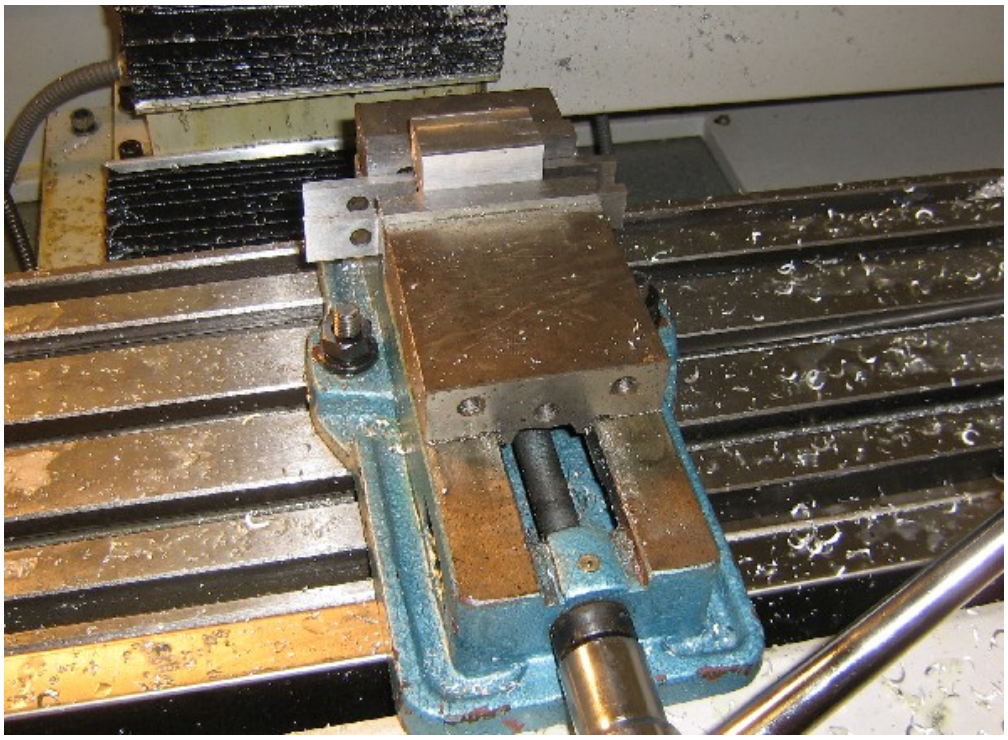


Figure46: Put the cube for Foot die in place and clamp it

Now, you can follow a part of step3. You need to set X, Y, X reference. Then you need to load “Foot_die.nc”. The CNC will automatically read this file after loading. And then what you have to do will be to change tool exactly. The image below shows you the output.

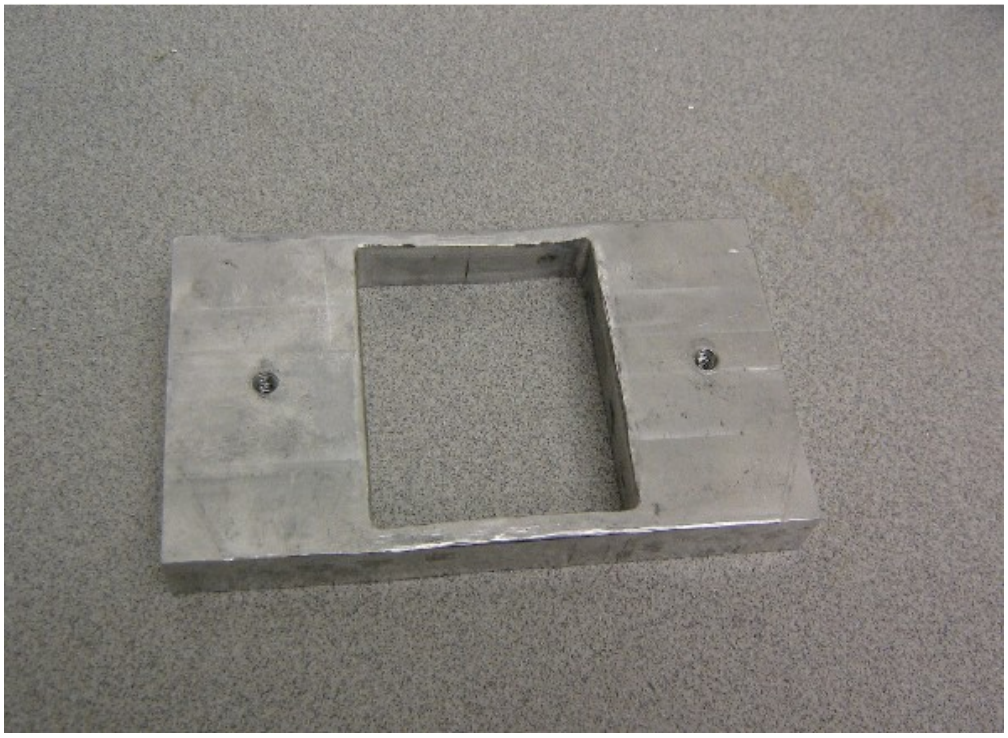


Figure47: Foot Die

Now you need to make a die for U_bracket. It will be easier because you need just two holes. Already the cube for U_bracket has the right size so you just need to drill for two holes. Repeat step mentioned above which are set X, Y, Z reference, load “U_die.nc” file, and change to the correct tool. The image shows the result for U_bracket.

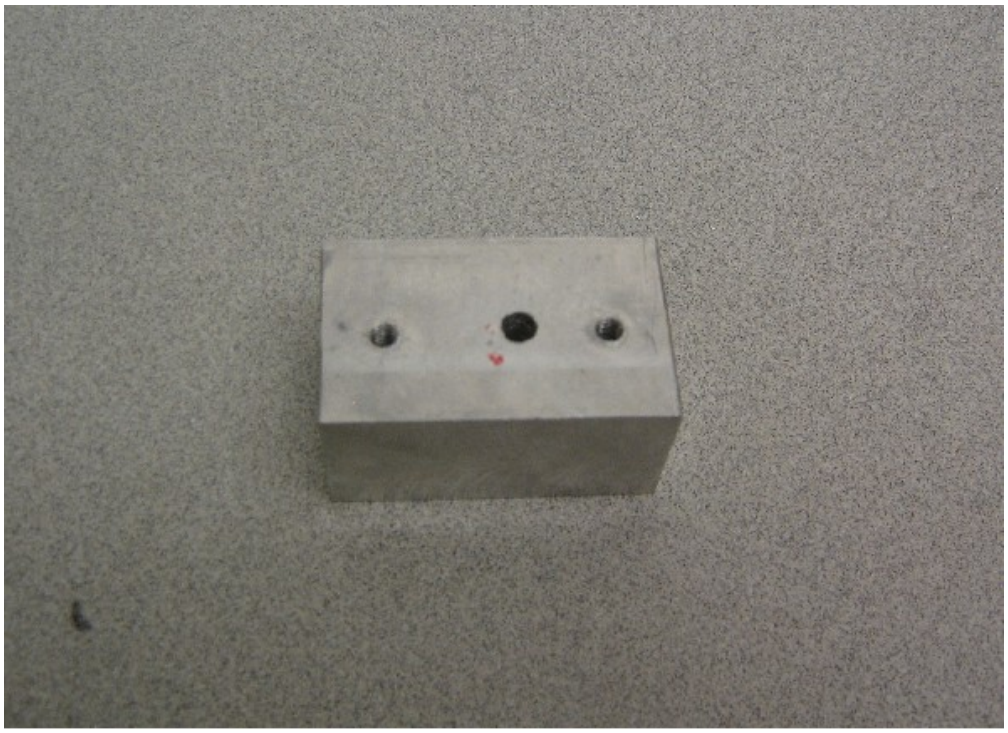


Figure48: U Die

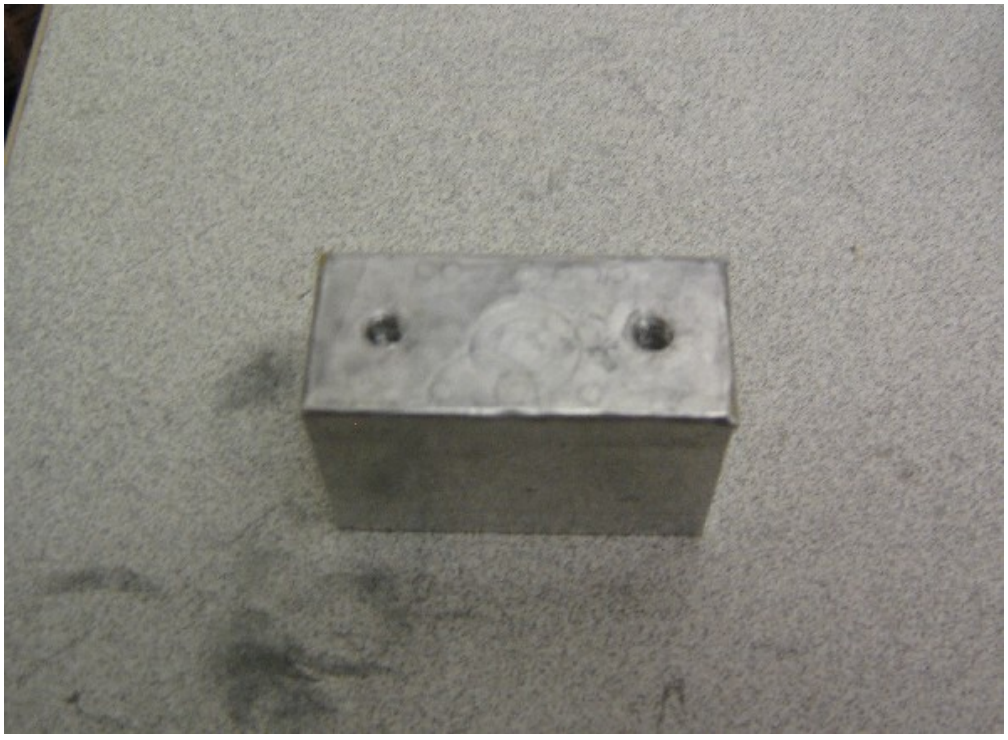


Figure49: U Shaped Universal Die

**Step6: Trim patterns with trimming machine**

Now you have all the patterns and dies.  But you can see the rough edge milled in each pattern.  You need to trim this rough edge to be smooth.

Figure50: rouge Edge of each pattern

You can use MultiPro to trim this rough edge.  Set it like the image shown below.

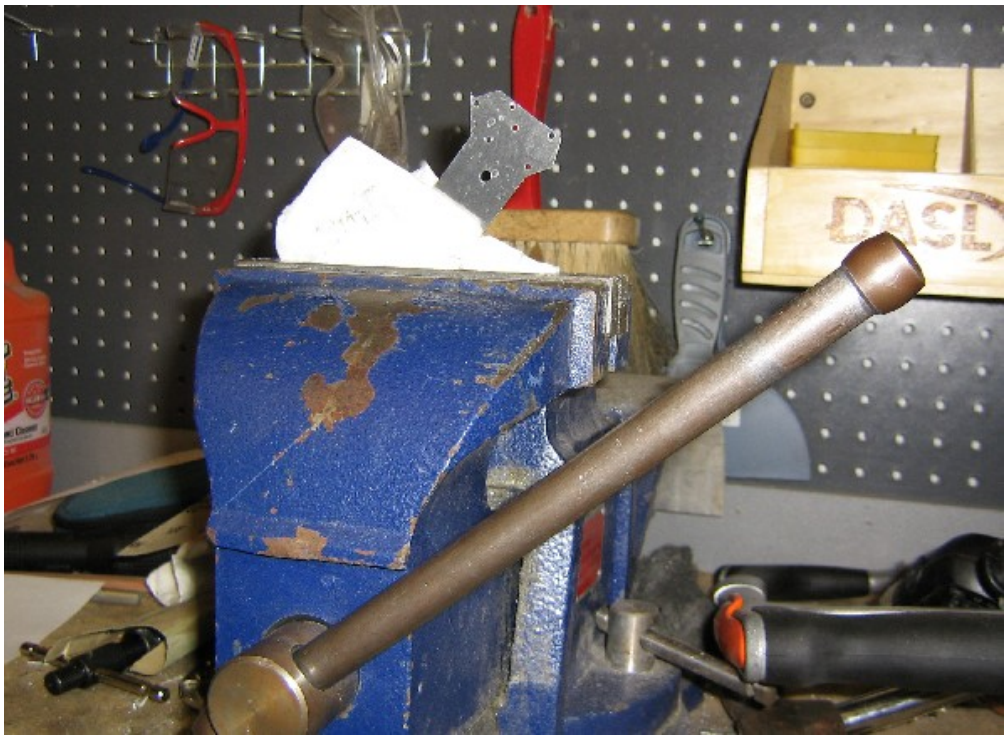


Figure51: Pre-setting for trimming edge

Then you can trim by MultiPro for trimming edge.  The image below shows you how to trim.

Figure52: Trimming edge

You need to trim rough edge in all pattern by repeating the procedure mentioned above.

**Step7: Fold patterns on dies**

Now you have all the trimmed patterns and dies. The image below shows you all the trimmed patterns and dies.

Figure53: All patterns and dies

Now you need to fold all patterns on the dies you made. First we will fold U_shaped_universal_bracket. At this time, you need two 4mm metric bolts to fix this pattern on U_shaped_universal_bracket. The image below shows you presetting for folding.

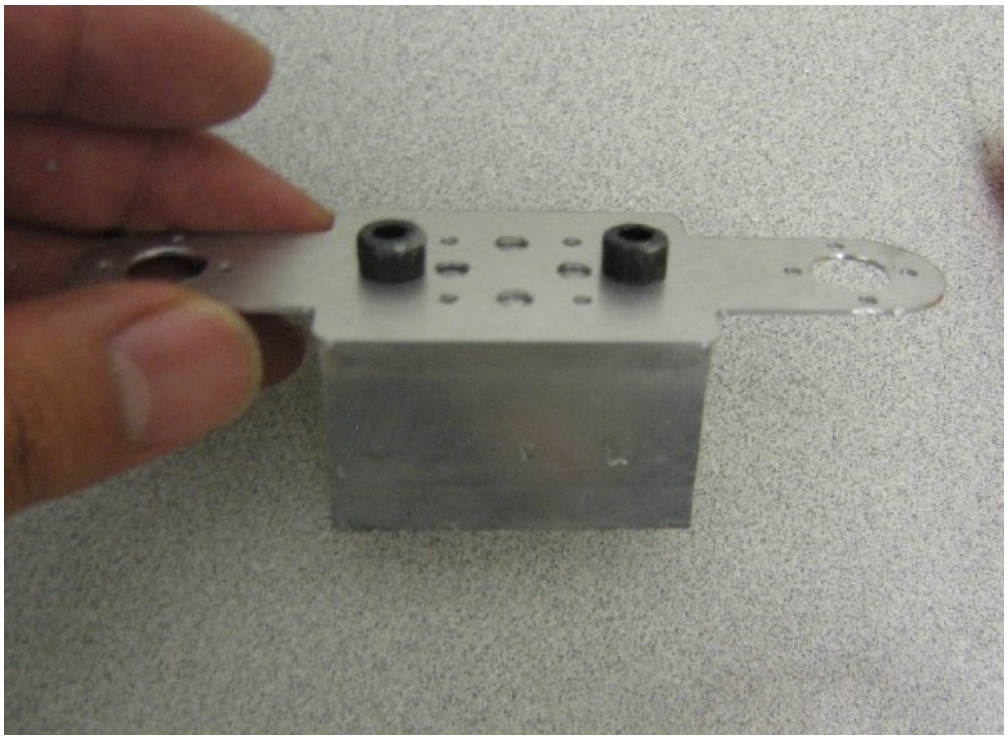


Figure54: First tighten on U_shaped_universal_bracket

Then you can clamp it on a bench.  And you need a hammer to fold it.  The image below shows you how to tighten it to the bench.

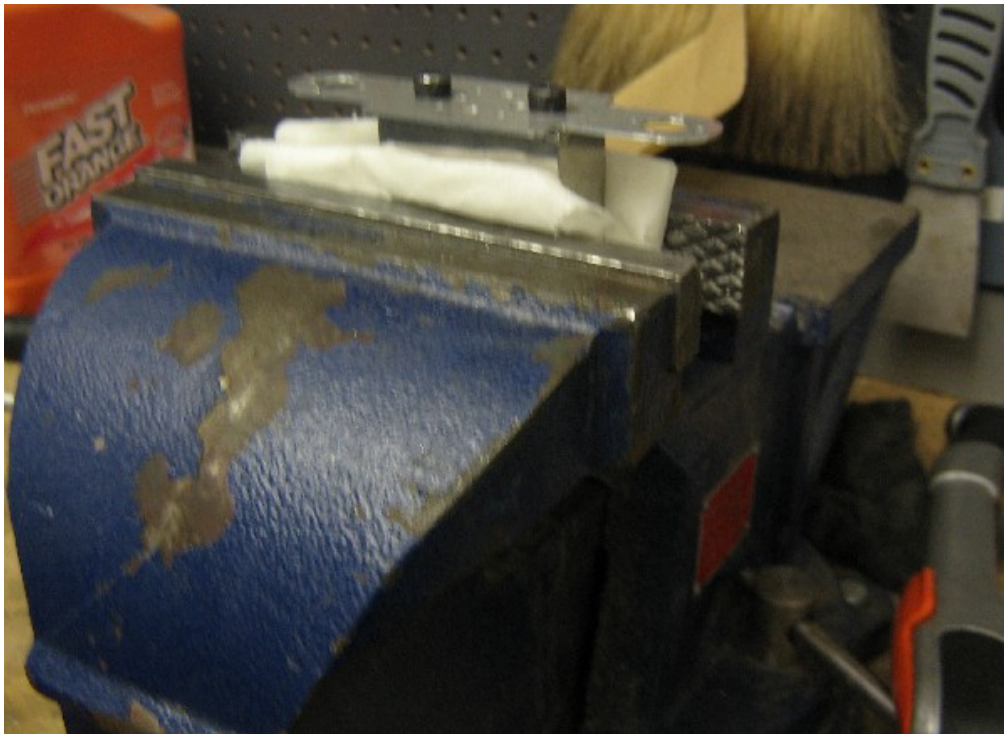


Figure55: Being tightened on the bench

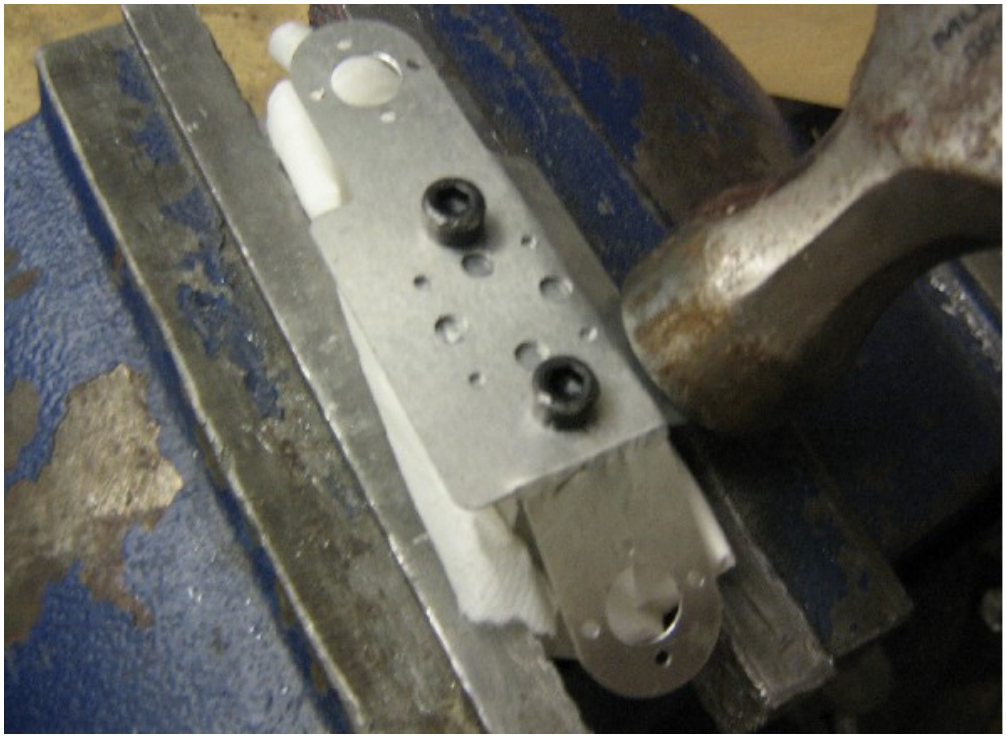


Figure56: Folding

Now you have to hit it with a hammer to fold it by hand.  The output is shown as below.

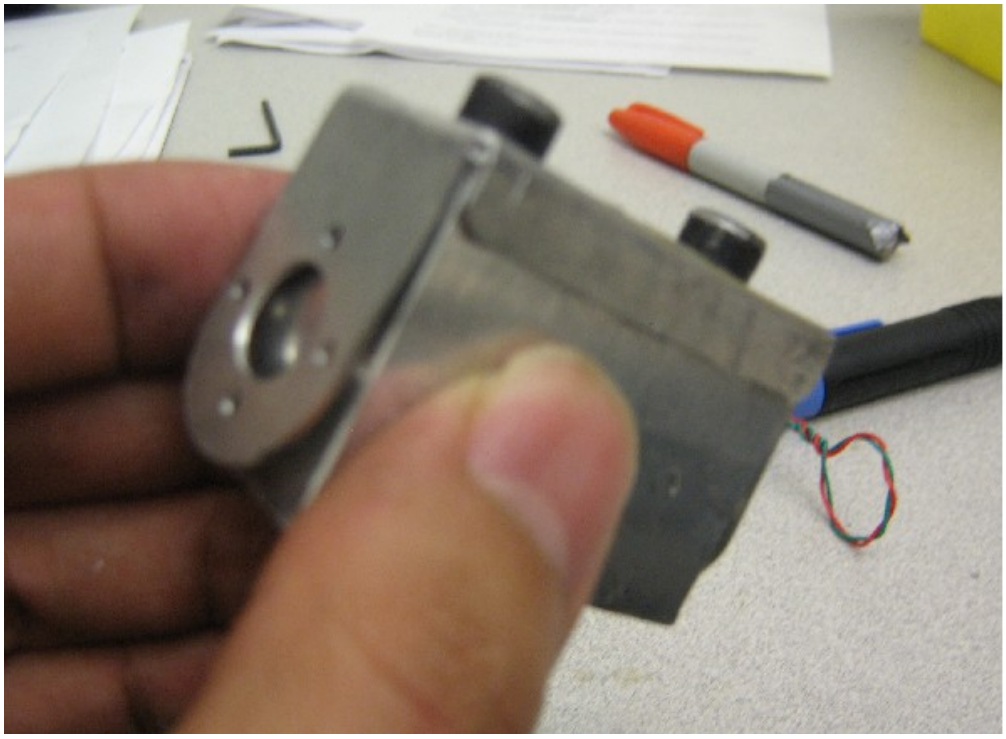


Figure57: Folded U_shaped_unversal_bracket.

Now you can repeat the procedures mentioned above for all patterns with their dies. If you fold all the patterns, you can go next step.

**Step8: Assemble patterns on Robonova**

Now you have all folded patterns. At this time, you need to assemble it on real Robonova. You can get information about how to assemble by observing real Robonova legs. You can use bolts and nuts from a Robonova to assemble. The best way to assemble it is first, separate one pattern from Robonova, and then assemble your pattern with bolt and nuts from a Robonoba. The final result for the legs is be shown below.

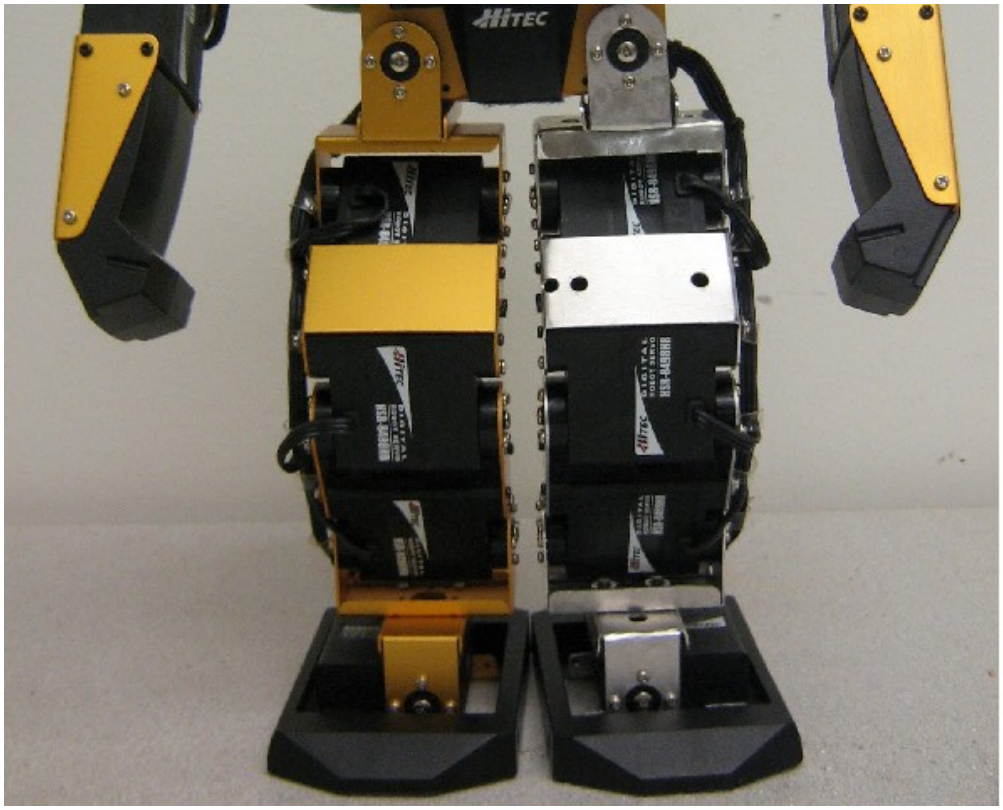



Figure58: Final result

**Step9: Additional step**

This tutorial's object

You have learned how to make a legs of Robonova. Now you can make your own biped Robonova. To connect the legs together, you should make a bridge. G-code is below. All

sequences are the same as above.  You can copy this code and paste to notepad, and then change the name of this file to .nc file.  Next you can use the CNC with this .nc file to make a bridge.  There will be two images and a video below.  The first image is a result of bridge pattern, the second image is a result of biped Robonava, and last video is walking Robonova.  To enable biped Robonova to walk or to move, you should follow Rob's tutorials, which is on http://prism2.mem.drexel.edu/tutorials/ellenburg.php.

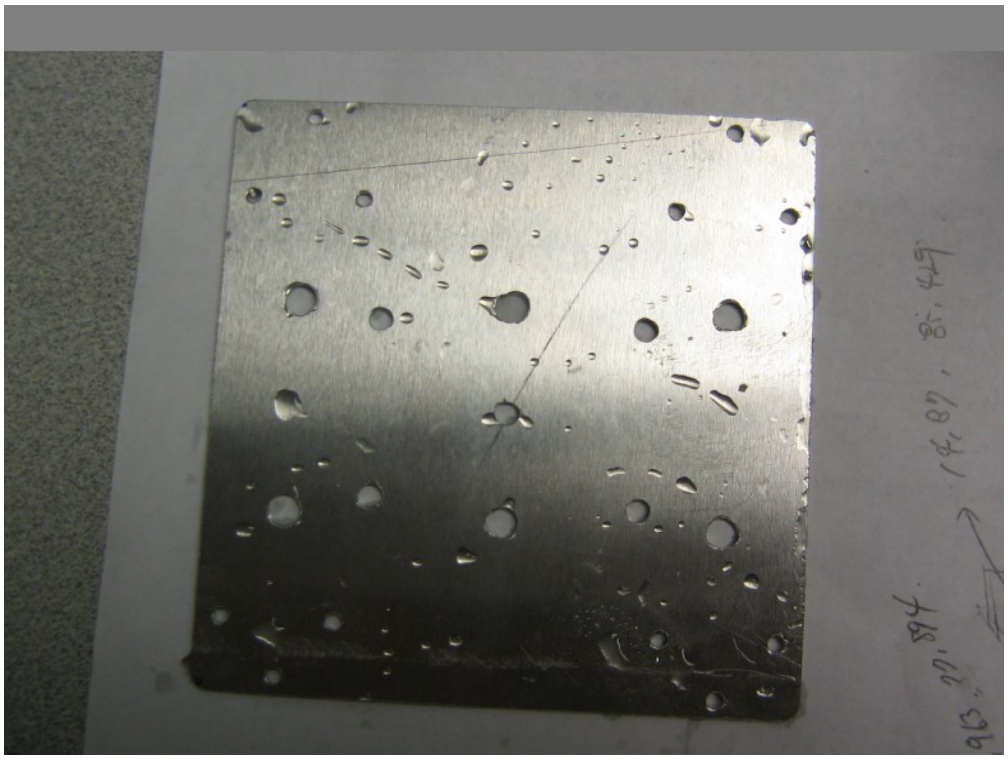


Figure59: The result of the bridge pattern

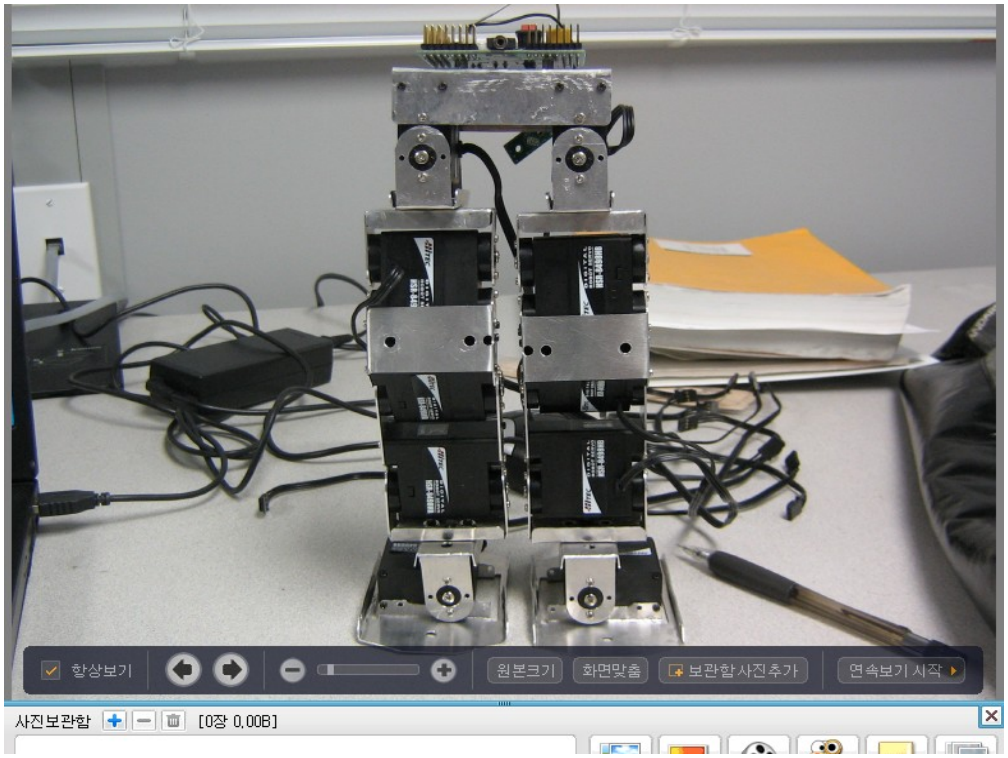


Figure60: The biped Robonova

Video3: The walking biped Robonova

**Final Words**

This tutorial's objective was to make Robonova legs and get familiar with many kinds of machines in DASL. After completing this tutorial, you may have ideas to construct or improve something with the CNC machine and other machines. Possible future work, derived from this tutorial, includes building your own Robot, or changing a Robot's shape to be more effective. T

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