

## TIP 27 — Cutting Bevel Gears on a Sherline CNC/David Lehrian

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### Bevel Gear Cutting Page

2/4/2001

*(Please note that many of the referenced links are out of date and may no longer exist.)*

The following is a description of how I cut bevel gears on my CNC Sherline Mill and Lathe that I purchased from Backtrack CNC. The software that generates the G-code to drive the mill was written by myself in Java 1.1 and is available for download for those inclined to try it themselves. The calculations were taken from *Machinery's Handbook 26th Edition* from "Industrial Press." The software will calculate the correct involute gear cutter number if you wish to purchase the cutter, however I used the Sherline's Gear Tooth Cutter P/N 3217 and learned to grind my own cutters.

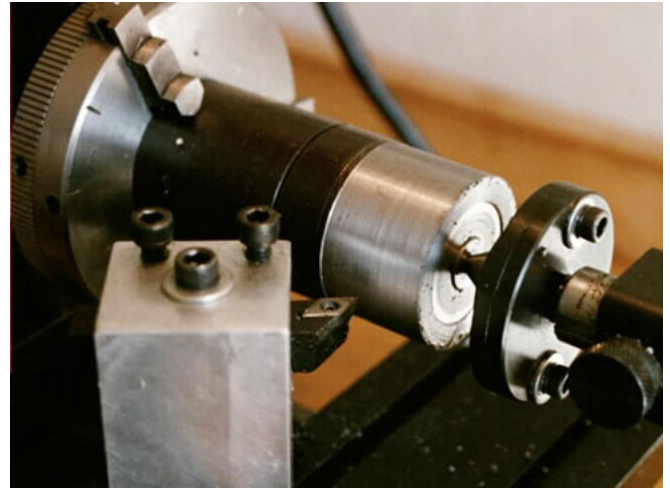
The gears I needed to cut were for my RC Truck by HPI. The front and rear differential gears had become stripped because the soft cast metal used to mass produce the gears just wasn't up to the forces generated by the hopped up 0.15 c.i. Nitro Methane engine. Additionally the stock vehicle had a differential which I wanted to replace with solid axles because the truck is run mainly off road and only used for backyard bashing. It is arguable if the differential would give better performance on a groomed race track, but I tend to believe the solid axles would get the power to the ground more consistently by not allow un-weighted wheels to unload and spin causing a loss of traction. Loss of traction means that power isn't being transferred and would cause a reduced speed, however it may increase handling, like I said, it is arguable. Anyway, back to cutting the gears. Cutting gears from stock metal is a slow process with a steep learning curve. The entire process took me about 3 months to get usable hard steel gears. Hopefully this information will shorten the learning curve for those so inclined to give this a try.

First I needed to determine the pitch angle of the gears I wanted to replace. I used a protractor to determine that the pinion's pitch angle was approx. 20 deg. which meant the gear needed to be 70 deg. to get the 90 deg. total angle needed for the differential. I also measured the diameter of the gear and pinion and counted the teeth on the existing gears. The pinion had 12 teeth and the gear had 36 teeth. The diameter of the pinion was 12.7 mm (0.5 in.) so the diametral pitch of the pinion was 24 (this is calculated by the software and is always in English measurements). Diametral pitch is the diameter of the gear divided by the number of teeth. In order to mate the pinion to the gear, the gear also had to have a diametral pitch of 24. Because it has 36 teeth, this meant that the diameter needed to be 38.1 mm (1.5 in.) These are the basic measurements and calculations from which the rest of the calculations are derived.

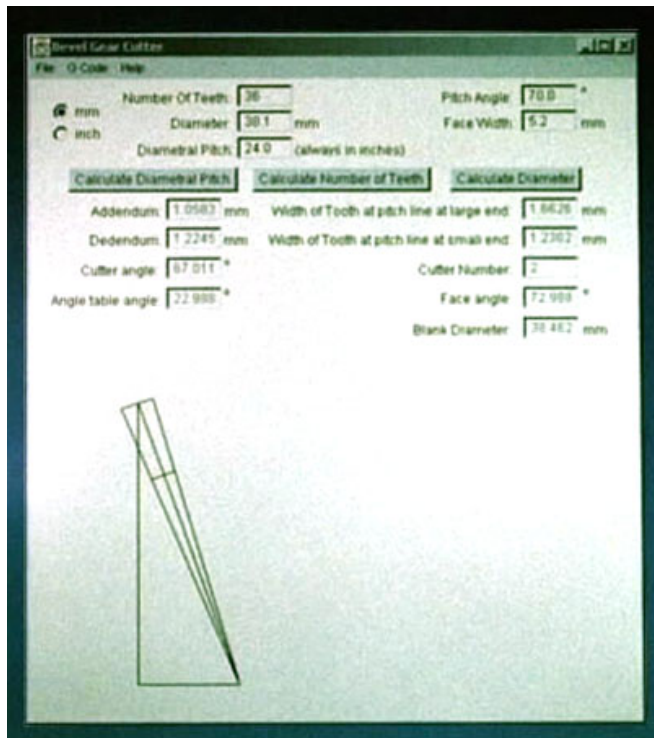
Gears have addendums and dedendums that are the amount of tooth above and below the pitch line. In order to turn a proper blank for the gear, the angle of the blank is greater than the pitch angle (more material must be left above the pitch line to form the addendum of the tooth). This value is known as the "Face Angle" and is calculated by the software. Also because of the addendum and the angle of the bevel gear the actual diameter that the blank needs to be turned to is also larger than the gear diameter. This is labeled in the software as the "Blank Diameter". The more shallow the pitch angle, the greater the difference between the "Gear Diameter" and the "Blank Diameter" (compare the 20 deg. and 70 deg. calculations of "Blank Diameter"). All the calculations are basic trigonometry and are performed by the software.

So to cut the 70 degree bevel gear here is what the software looks like. Notice the "Addendum" and "Dedendum" sizes as well as the tooth widths at the large and small ends along the pitch line. The

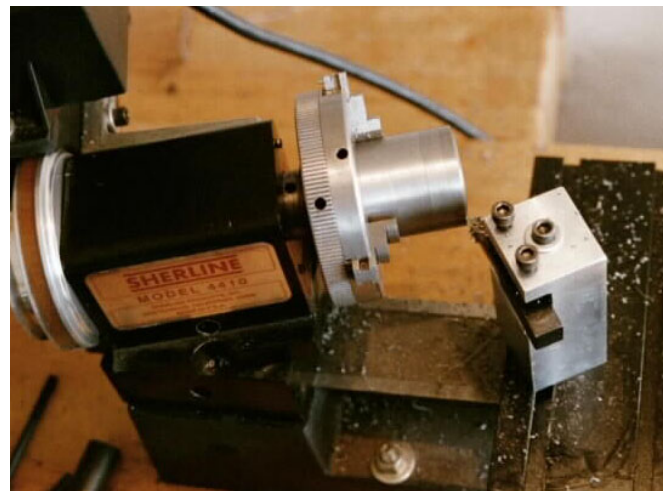
“Cutter angle” is also calculated which is the angle of the cutter path relative to the gear face blank. The “Angle table angle” is the angle that the rotary table needs to be set to. The value is based on the direction of the cut so for this gear the “Angle table angle” equals 90 deg. - “Cutter angle”. If I were to purchase a cutter for this gear I would purchase a No. 2 for 24 Diametral pitch with a 14.5 degree or a 22 degree pressure angle. The drawing is the gear sliced in half looking from the side. The center line is the pitch line and on either side are the addendum and dedendum angle lines (the addendum line is the line of the “Face angle”).



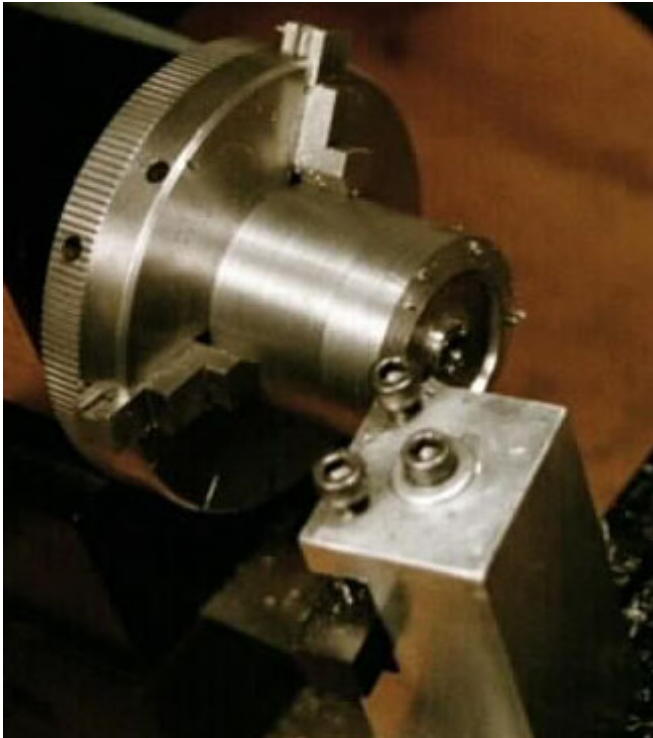
*Here is the face angle being turned.*



*The software shows that the “Face Angle” is 72.988 degree and the “Blank Diameter” is 38.462 mm. Here is a picture of the blank being turned on the lathe.*



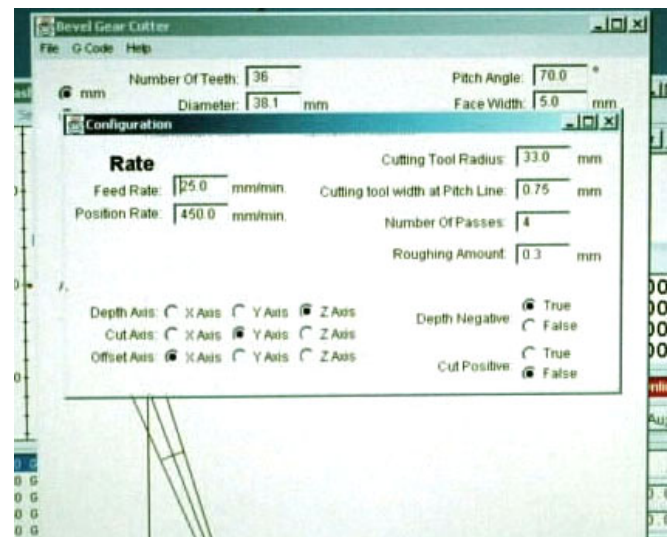
*Here the face being relieved so the teeth stand out from the gear.*



*A 5 mm hole was made through the middle to mount the gear on the 5 mm shaft.*

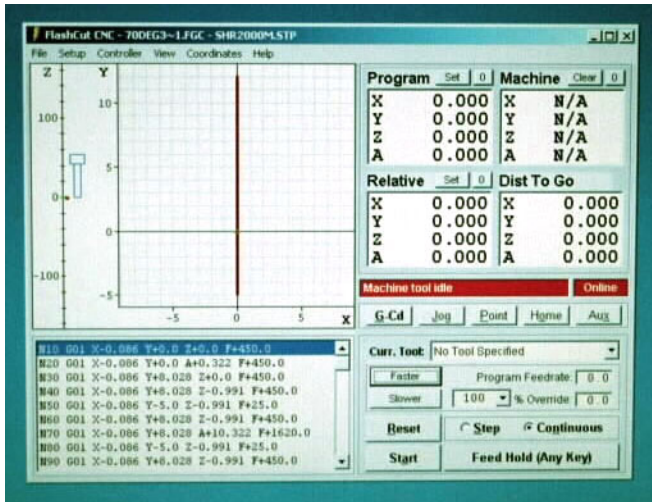
The blank is now ready to have its teeth cut. This is where the software really helps out because it will generate the G Code to control all 3 mill axis and the rotary table. Below is the configuration page to tell the software how to generate the G-code. There are many details on this page that require knowledge of how the gear is going to be cut. There is the “Feed Rate” and the “Position Rate” which are self-explanatory. There is the “Cutting Tool Radius” which is used to know how far away from the gear the cutter must move before turning the gear in the rotary table. If this value is too small, the cutter will strike the tooth edge when the rotary table is rotated (I told you there was a steep learning curve ;-). The “Cutting tool width at Pitch Line” is used to know how much angle offset and linear offset is required to cut each side of the tooth. For a more in-depth explanation see Machinery’s Handbook. The number of passes is used to rough the gear out before making the final 2 passes. A number of 4 actually causes 5 passes around the gear. The first 3 will get the teeth to within the “Roughing Amount” and the final 2 passes make the teeth the actual size required. There is a 5 second delay between the roughing rounds and the finish rounds

so you can stop the machine and sharpen the tool for the final 2 light rounds. The reason there are 2 passes at the end is because cutting teeth requires that each side of the tooth be cut. This isn’t merely a single pass down the middle (like my first miserable attempt). I recommend you learn using brass or aluminum and the number of passes can be set to 1. You only need to make multiple passes when you graduate to tougher materials like 4140 Chrome-Moly steel, which is the material used in these pictures. The “Depth Axis”, “Cut Axis” and “Offset Axis” tell the software which axis is performing which function. The “Depth Axis” is the axis that controls how deep of a cut is made. The “Cut Axis” is the axis that feeds the blank into the cutter and the “Offset Axis” is the axis that controls the linear offset for cutting the teeth. The “Depth Negative” tells the software if the depth is made in the negative or positive direction. And the “Cut Positive” sets whether the blank is fed into the cutter in the negative or positive direction. Knowing how to set up the gear blank and software is critical to the success of this project. If you don’t understand any of this information, don’t press the “Start” button!



*I use Flashcut CNC software to drive the mill. Here is what the G-code looks like in Flashcut CNC software. (Not very interesting, but worth a picture.)*





Here the cutter is being lined up with the edge of the gear blank and centered. This is the beginning position for the cutter. Notice that the table is angled to perform angled cuts. The angle that the table is set to is listed on the main page of the software as “Angle Table Angle” and for this gear is 22.988 deg. This is so larger teeth are cut at the outside of the gear than on the inside of the gear. The pinion is cut with different settings for the depth axis and cut axis and this affects the angle table angle. Before starting you need to visualize the type of cut that is going to be made to make sure the set-up is correct or failure will be dramatic. See the page on grinding your own cutters for more information on how the cutter is shaped.



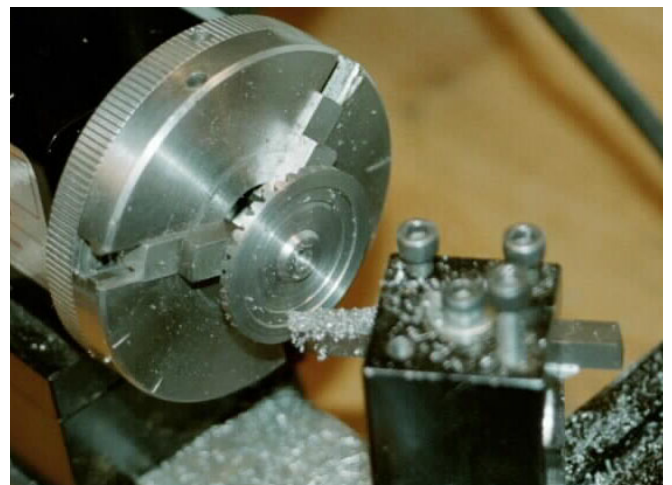
Here is the gear during the second round of roughing (I forgot to take a picture during the first round). The cutter is actually moving, the photograph stopped the action. The brush is applying fresh lube every revolution of the cutter and cleaning off any metal chips that got stuck to the cutter.



*Here is the gear on the final pass.*

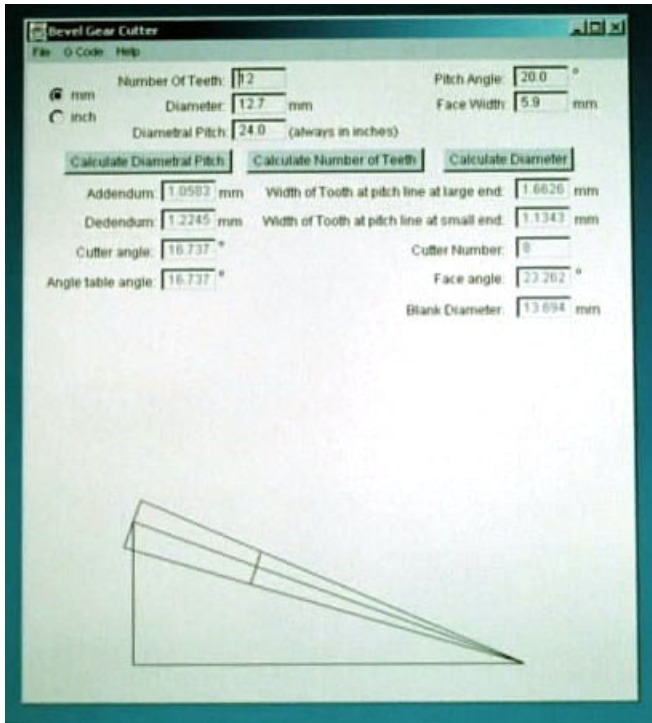


*Here is the gear after I parted it off and am relieving the back of the gear to remove unnecessary metal. You need to be very careful with how deep you cut on the back so you don't cut all the way through (this is more of that steep learning curve I mentioned earlier ;-).*

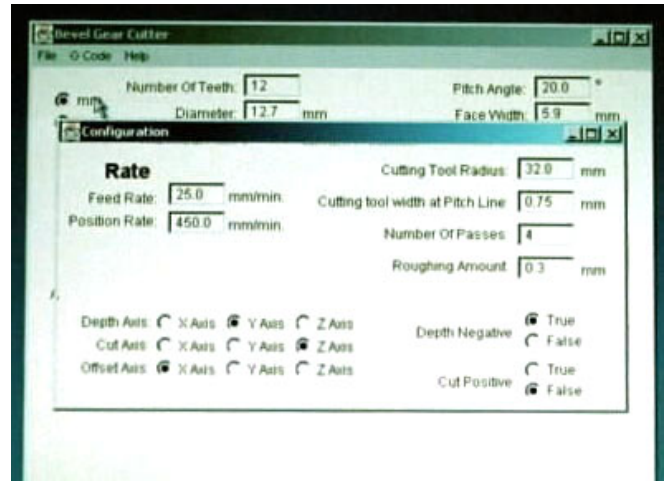


*Now the gear is done and it is time to start the pinion. The pinion is 20 deg. Here is a picture of the software calculations for the pinion.*





The pinion blank is turned on the lathe as the gear blank was. As you see from the above calculations the face angle is 23.363 deg. and the blank diameter is 13.694 mm, somewhat larger than the 12.7 mm which is the diameter at the pitch line. I forgot to take pictures of turning the pinion blank so the first picture is of the pinion G-code software configuration. The geometry of the pinion caused me to have to cut with the Z-axis instead of the Y-axis. The Y axis was the “Depth Axis”. The “Depth” was still done in the negative Y direction and the “Cut” was in the negative Z direction. I also did 4 passes on the pinion. I found that these numbers were about right for cutting 4140 Chrome-Moly steel, but I slowed the Feed down to 21 mm/min using Flash Cut’s feed override capability.



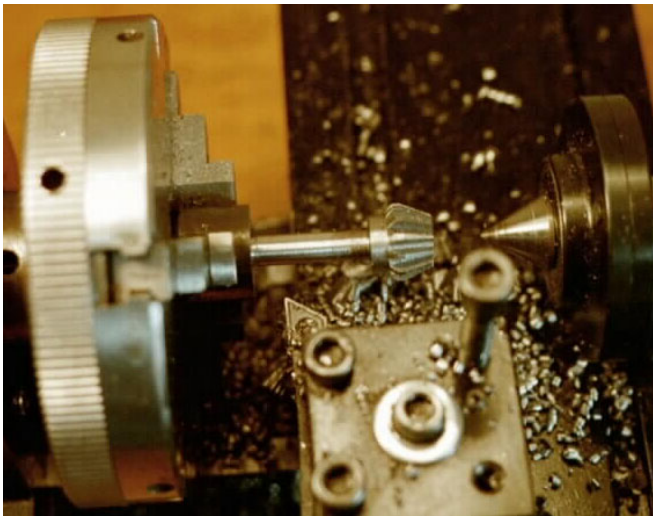
Here is the blank on the mill ready to start cutting the teeth.



Here is the pinion after the first round of cuts.



*Here is the finished pinion back on the lathe with the shaft turned down.*



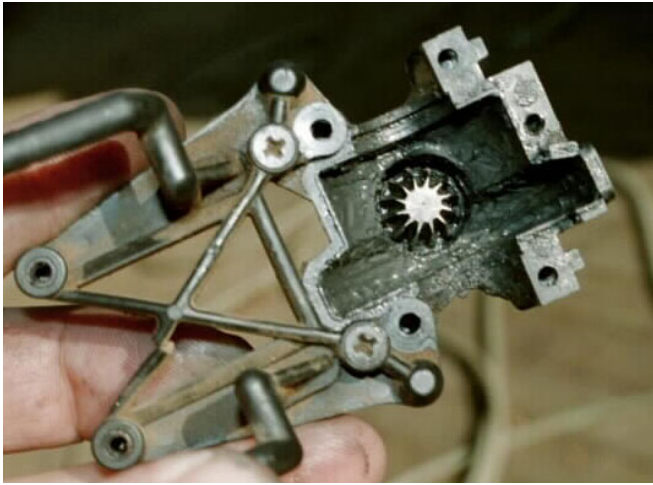
*Here is the finished gear and pinion.*



Here is the gear brazed onto the axle shaft. Also pictured are the out drives, which connect the axle to the Constant Velocity Drives (CVD's) that power the wheels. I will soon include a picture of the CVD's which were originally made by MIP but had to be replaced after they failed. I made new shafts and ends which are significantly thicker and stronger than the aftermarket MIP versions.



*Here is the pinion installed in the RC Trucks differential housing.*



*Here is the entire gear and pinion assembly ready to be greased, closed up and installed in the truck.*

