SECTION III: Cutting Ratchet Wheels

Cutting ratchet wheels have some similarities to cutting train wheels. The exceptions are noted below along with some side bar discussions. There is one exception, however, that is worthy of a more lengthy discussion. That being, ratchet wheels require an undercut similar to the deadbeat escape wheel, albeit for a different reason. In my research, I found this excellent discussion...“A ratchet wheel, in order for the pawl to lock positively onto every ratchet wheel tooth, should have what is known as an “undercut”. Undercut is achieved when the angle that a ratchet tooth subtends at its root is less than 90 degrees. Anywhere from 45 degrees through to 80 degrees have been used in industrial applications but 60 degrees is commonly found in model ratchets”

Ergo why 60º dovetail cutters are oftentimes used to cut ratchet wheels.

There are occasions when ratchet teeth are cut on center a/k/a radial and presumably its mating click is shaped to allow for positive lock. But in most instances, cutting ratchet wheels will require the cutter to be setup with an offset to produce the needed undercut a/k/a rake angle. Archie Perkins has a thorough discussion on this topic in his “The Modern Watchmakers Lathe And How To Use It”37. It is the only detailed reference on this topic I could find and I have more than my share of books in my library. Let me also acknowledge my nearby Master Clockmaker, Werner Paul, for pointing out the need to include this discussion in my article and being available for my questions on the topic. My horology knowledge is now that much richer. For the benefit of the uninformed, radially cut ratchet teeth have their faces cut on center45. To check for this, draw an approximate 2” vertical line and lay the center hole of the ratchet wheel onto the line. Using the line as a guide, align by eye a tooth tip from the top of the wheel and a tooth tip from the bottom of the wheel onto the line while simultaneously using the wheel center hole (or square as appropriate) to find the centerline of the ratchet wheel and then visualize a straight line from tooth tip to tooth tip. With the wheel hole/square centered on the line, if both the tooth tips and tooth faces are on the line, you are looking at radially cut teeth. Evidently, they are not too common, but it is good to know how to check for them. Again, Mr. Perkins has excellent illustrations in his book45.

Back to the topic at hand. The two likely scenarios for cutting ratchet wheels would be either a new clockmaking project or when you need to cut a replacement wheel. A new clockmaking project is more straightforward as you can use the same approach discussed earlier for cutting a deadbeat escape wheel. It is the same calculation using the same 10º rake angle and steps where the leading edge of the cutter is first centered over the ratchet wheel and then traversed the calculated offset distance. Regards the shape of the face of the fly cutter and the click. The generally agreed to angle for the cutter is 60º and, to achieve positive lock, the click is designed so that its stop face is radial to the click wheel’s center42.
A mainwheel and its click to illustrate how the click’s stop face is designed to be radial to the center of the click wheel which is the same as saying radial to the center of the arbor.

All above said, the more frequent need to cut a ratchet wheel would be the replacement of a damaged original wheel. Some perspective before I get into that. When cutting replacement deadbeat escape wheels, the use of the formula to calculate the offset is a practical approach as one is just seeking to create sufficient undercut. You don’t really need to know the exact rake angle. On the other hand, when the need arises to replace a damaged ratchet wheel, the replacement wheel should emulate the original wheel to ensure positive lock occurs with the original click. However, the original rake angle oftentimes is difficult to measure as the tooth tips are rounded over after many years of services. Given that sharp tooth tips are required for an accurate determination of the rake angle to then perform the offset calculation, we could use an alternative method. Fortunately also the ratchet wheel and its mating click are not precision instruments and there is a certain amount of tolerance, forgiveness with their interactions.

Let’s first prepare the ratchet wheel blank and then discuss some practical methods for determining the offset cut. The recommended material for ratchet wheels is brass or steel round rod, as appropriate, whether it is for a new clockmaking project or to replace a damaged wheel. Select a diameter that will be larger than the wheel’s finished OD. The choice of length is a bit of an iterative process. You want the least amount possible protruding beyond the chuck jaws (1” is recommended), the maximum amount to set down into the chuck so that combined you gain as
much rigidity as possible. This then needs to be balanced against the clearance needed for the cutter. On Sherline chucks, if you are working with either a 5/8” or ¾” round rod, allow for ¼” to set down into the chuck body up to the outside of the chuck jaws. Including the length to protrude beyond the jaws, this gives you an overall finished length of 1 3/4”. However, a 1” round rod will only set onto the chuck body so allow only ½” up to the outside of the chuck jaws for an overall finished length of 1 ½”. All this needs to be considered as you plan your choice of length for your particular need. Once you are settled on the length, insert the round rod in the 3 jaw chuck and bring a 3/8” - 1/2” long section of it to the pre-determined exact ratchet wheel outside diameter (3/8” is plenty for one wheel; ½” for two wheels). Leave the round rod securely in place in the chuck to ensure concentricity. As part of machining the round rod, is the need to drill or bore the pre-determined wheel center hole. Whether the finished center hole is round or square, the wheel is most concentric at this point and the center hole should be drilled, bored at this time. Note that all square holes have a corresponding starting round hole.

There are a couple of methods to determine the offset without first determining the exact angle of the undercut and using the offset calculation. The first method makes use of the original wheel as a pattern and requires the use of two chucks. One for the pattern ratchet wheel and its arbor and one for the round rod blank. Also, be resourceful, if the time side ratchet wheel in need of replacement is damaged beyond use, resort to the strike or chime side ratchet wheel as the pattern wheel.

One chuck to carry the arbor and its pattern wheel and a second chuck to carry the round brass rod.
1. Grind the tooth angle on a standard ¼” x 2 ½” lathe tool blank and then reduce its finished length to 1 ½”. In grinding the tooth angle compare and contrast it to the original tooth angle until it matches. This can be a visual grinding and compare or you can also scribe and measure the tooth angle. Place the ratchet wheel onto paper or note card stock and scribe the angle with needle or pencil. Extend the lines with a ruler and use a protractor to determine the angle. While grinding, check your progress with a machinist protractor. As a point of reference, this angle will most often range between 60º and 75º.

If the correct angle does elude you, a technique that works for me is to fit up the ratchet wheel into a temporary wheelcutting setup and place a lathe tool blank into the cutter holder opposed to each other as shown. Remembering that the cutting surface faces down, compare and contrast the angle of the ratchet wheel teeth to the tool blank to visualize the angle and mark it using a Sharpie pen. Then grind that angle. Leave the wheelcutting setup in place to recheck the angle and grind more as necessary.

2. Fit up the original damaged ratchet wheel or pattern wheel onto a temporary arbor, then into another chuck and snug all up onto the x table. Then fit up the newly made cutter in the mill spindle.

3. Position the cutter horizontal and the cutter face (that which is facing down) on the same plane as the stop face. Compare and contrast the tooth angle with the cutter angle. Match up the cutter with the correct tooth angle by moving the x table and y saddle. Also use the RT handwheel to revolve the wheel until the tooth angle matches, fully fits the cutter angle without engaging the original tooth’s stop face or sliding face. I’ve developed this technique. A reminder that making contact first with the faces effectively places you at zero. With the cutter in the horizontal position and the cutter face on the same plane as the stop face, traverse the x table until the cutter makes contact with the sliding face, zero the x handwheel and then back off .005”. Next, check to see if the cutter face is on the same plane as the stop face. If not, you’ll need to reestablish this position by traversing the y saddle. Stop once you make contact with the stop face, zero the y handwheel and then back off until the cutter comes through freely. This could be as much as .020” or so and has to do with the relief angle. As a final check, bring the cutter through manually to be sure it comes through freely and does not make contact with either of the faces. If you are still making contact, back off another .001” or so. Otherwise you might be too deep and end up with a wheel outside diameter smaller than the original. Being .005” too deep
on the setup equals .010” too deep on the whole wheel. Once you are satisfied, lock the x table and y saddle. In effect, you have just moved it the offset distance. The z axis can and will need to be raised or lowered for the next steps. Another point to make about the wheel outside diameter. If your wheel has very sharp pointed teeth, as some ratchet wheels do, you may want to purposely machine the blank over size and then machine the teeth to size/diameter assuring that all teeth will have very sharp points and the desired wheel outside diameter.

4. Raise the cutter up via z axis, remove the chuck with the pattern wheel from the x table and then fit up the chuck with the round rod blank. Begin the wheel cutting by lowering the cutter via z axis and cutting the first tooth. Assuming the CNC programmer has been programmed for the number of teeth, index the wheel blank to the next tooth and continue cutting the remainder of the ratchet teeth. Note that this changeover of the pattern wheel to the blank works because both are the same diameter.
Some troubleshooting tips:
After all this setup is complete, while your offset is correctly positioned, you may still need to adjust for depths of cut. You’ll know after the first tooth. All is not lost. You still have a chance to save the job as my late father-in-law would say. Have handy the depth of the original stop face and the length of the sliding face. The x table controls the depth of the stop face and the y table controls both the depth a/k/a length of the sliding face and the tooth width. Ideally you’ll have a ruler with 100ths gradations. After the first pass, revolve the wheel blank around with the controller and check these measurements. If you need another .005” or .010” for either face, unlock the table and/or saddle, turn their handwheels accordingly i.e. x table and y saddle need to move inward and then relock the slides. Using the controller, return the wheel blank to its original position and recut the first tooth. Repeat this process until you are satisfied with depth of cut. That said, try to keep within one additional correction pass per face as there is considerable sideways force occurring between the cutter and the round rod wheel blank. Consequently, this can cause a bit of a bouncing effect that could place the cutter on a new path and leave you with ridges in the faces. Not the ideal result. The more passes you make the higher chance of this occurring. All the more reason to keep the length of the blank short to increase rigidity. If you do end up with ridges, leave the table and saddle locked in place. Check the ridges and if you think they will affect the click’s positive lock or if you just don’t like the looks of them, you have the slides in their locked positions with the correct depths established, you could just cut a new wheel (albeit you’ll first need to prepare a new round rod wheel blank).
Only this time you can do it without adjustments or ridges.

Alternately, a method that works very well for me when I need to recut the depths is to first recut the stop face to the correct depth and then recut the sliding face the correction amount. If my depth is good on the sliding face and I just have ridges to remove, I’ll cut the sliding face an additional depth of .010” or so to clean up the ridges. Typically this will remove the ridges without jeopardizing its length (think of it as a clean-up cut) and “save the job”. As mentioned, the ratchet wheel and click are not precision instruments and there is some room for error.

By the way, it is a good idea to periodically check the T-nuts on the RT to be sure they are very snug. If you are like me, I leave the RT on the mill table and use it for various jobs. With use comes the inevitable vibration and this could cause the T-nuts to loosen up and be a contributor to the bounce problem discussed above. A final tip, if you have a 60º angle, then use the 60º dovetail cutter. It is a really nice tool that generally does not leave ridges if you need to go deeper on a recut.
This pattern wheel was a perfect candidate for the 60° dovetail cutter. Nice tool!

Ratchet wheel cut with the dovetail cutter. Very nice job!

On the topic of troubleshooting, here are some words of wisdom from Master Clockmaker David LaBounty…”Fine tuning the setup is something I do often. When cutting a gear, it will be necessary to keep a sharp eye on things in case something goes awry. If you catch a problem soon enough, it is possible to make a small adjustment and salvage the piece. If you blindly go about cutting the gear, you will often end up with something which isn’t useable. Of course, being sure the piece is stable and solid is a must. The piece can end up being unusable if something comes loose or shifts slightly during machining.”

As illustrated in the pictures below, one can work from the right side or the left side. That said, as one is not frequently cutting ratchet wheels, to improve your efficiency, I would suggest getting into the habit of fitting up the wheel one way or the other and settle on that way. From what I can gather, the left side setup is the most commonly used setup. Add to this, on the Sherline mill the 60° dovetail cutter, a frequently suggested cutter for ratchet wheels, can only be used from the left side.
It doesn’t matter which side of the ratchet wheel you decide to use as a pattern. The cutter angle is the same for whichever side you choose. What does matter is to be aware which side of the cutter blank to grind the angle from. In each instance, the cutter face is facing down as it would be when fitup onto the Sherline mill spindle. As a final note the 60° dovetail cutter that is frequently recommended, will only serve as a left side cutter on the Sherline mill. That is not a limitation, one just needs to establish the habit of fitting up the wheel for a left side cutter.

Here is the pattern wheel and cutter setup for the right side cutter.

Here is the pattern wheel and cutter setup for the left side cutter. From what I can gather, this side is the more commonly used side for the setup.
The second method, taught to me by master clockmaker, Werner Paul, provides for a way of measuring the offset and requires just the one chuck to hold the round rod wheel blank. Some insight before I describe the method. Ratchet wheel teeth present two surfaces or faces. One that I will call the stop face and the other the sliding face. The stop face is what the click bangs into to come to a stop. The sliding face is the surface that the click slides on, rests on and its surface shape is what the face of the cutter seeks to match. The sliding face is the correct tooth face to use for this method.

1. Draw a vertical line. Approximately 2” long will do and preferably on white paper. I would recommend using either a mechanical pencil with its .5mm lead or a needle scribe to minimize the error that tends to occur with the line width.
2. Lay the ratchet wheel down on the paper with its teeth near the line.
3. Bring the edge of one of the sliding tooth faces parallel to the vertical line (any one will do), place the edge onto the line and then mark the center of the wheel’s center hole. A method to accomplish this is described below:
   a. As you bring tooth edge parallel, leave a slight space between the edge of the sliding face and the vertical line (you’ll now see the benefit of using white paper). Now, using the space to guide you, eyeball/judge for the parallel position and adjust as necessary.
   b. Once satisfied that the edge is parallel to the line, while maintaining this parallel position, bring the tooth’s edge up to and onto the line. Then lightly mark the center of the ratchet wheel center on the paper.

![Sliding face denoted by arrow. Note the space between tooth sliding face and the vertical line. This simply provides a means to better judge the parallel position. Also notice the rounded tooth tips.](image1)

![Note the edge of the tooth’s sliding face has now been moved onto the line and the center of the wheel center has been marked. I used a regular pencil to clearly show the concept. Normally I draw the line onto notecard stock using a needle scribe to minimize the line width error.](image2)
4. Remove the ratchet wheel and measure the distance from the vertical line to the mark. Ideally you’ll have a ruler with 100th gradations. This distance is the offset i.e. the additional linear distance to move the cutter beyond the center line a/k/a radial position.

Now that you have the offset distance, let’s position the cutter. The second method requires three moves. First move is to center the cutter so that it is radial to the wheel center while the second move is to position the cutter the offset distance and the third move is to account for the width of the cutter. As I use ¼” lathe tool bit squares, .250” translates into five (5) turns of the hand wheel. See below example that uses a ratchet wheel OD of .645” = radius of .3225”, offset of .220” and cutter width of .250”:

- With the wheel blank fit up onto the mill table, use x, y and z handwheels to position cutter at wheel blank’s outside edge. This zeroes the cutter. Using z handwheel, bring cutter up to clear the wheel;
- Traverse the x table .3225” (6 turns + 22.5 gradation) to bring the cutter to center
- Traverse the x table .220” (4 handwheel turns + 20 gradations) for the offset distance
- Traverse the x table .250” (5 handwheel turns) for the cutter width
- Lock the x table
- Traverse y saddle to place cutter in the horizontal position
- Proceed to find depth of cut. When satisfied that the proper depth has been reached, lock the y saddle. The wheel blank is now positioned to begin cutting.
- Bring the z axis down until the cutter is all the way through. Generally this requires bringing the cutter down the round rod blank 1” or so. Note that it’s a bit different cutting
a ratchet wheel on the round rod wheel blank as compared to cutting a single wheel. On a single wheel, the cutting noise stops when you are all the way through. On the round rod wheel blank, there is a continuous cutting noise and thus one is left to a visual check as to whether or not the cutter has been brought down far enough. One ends up using quite a bit of stock so be sure to price that into the job.

To help one visualize this measuring method. I’ve taken a finished ratchet wheel and taken it through the steps of traversing the table to position the cutter at the center position, at the offset position and the final position to account for the cutter width. A good exercise is to try both methods with the same ratchet wheel. You will find that the cutter ends up in the same place (assuming you’ve measured your offset distance accurately 😊).
General Consideration for both methods:

- Calculations: Determine the outside diameter, # of teeth, thickness and wheel center hole of original ratchet wheel.
- Setup the milling machine in the horizontal position and the RT/CNC Controller and ratchet wheel blank as described above and remember to zero the RT table and its handwheel.
- The material for the form tool is the same as described for the EW form tool. M2 lathe tool bits. Once the lathe bit is ground to the correct form, cut it to the 1 1/2” length and sharpen it on the oiled Norton India stone.
- The included angle for the ratchet wheel tooth varies and therefore the form tool will vary. When grinding form tools for ratchet wheels to set the grinder tool rest at approximately a 7º angle.
- All square holes have a corresponding round hole to start. So if you had to replace a ratchet wheel with a square hole, you first would drill the corresponding round hole to start and you would do this on the lathe after machining to size the round rod wheel blank. There are charts readily available that will tell you for any given square hole, the corresponding round hole to start with and ultimately you’ll need to file the hole square or use a square broach of the needed size. The preferred means being a square broach. A common horological design for a square broach is for its end to be round to provide a guide into the hole and then next a square section. The round end is the size of the predetermined round hole for the square while the square is to the size of the square hole. As a final step, slight reliefs are filed/ground onto each corner. These types of broaches can be made from round or square stock that can then be machined, hardened and tempered.
or another ideal choice is a 2 ½” lathe tool blank that is already hardened and tempered, however, it needs to be ground to the finished shapes.

- Square, round stock
  Material needed is stock that is designed to be hardened and tempered. Lots of choices including the ¼” W-1 stock we used for the cutters. I also keep a large supply of O-1 drill rod diameters. Just need a size large enough to satisfy your square broach sizes. Use the Sherline lathe to machine the round end to the desired size. Fit up the RT into the vertical position onto the x table. Fit up the four jaw chuck onto the RT. Insert the stock into your four jaw chuck. Fit up ¼” end mill into the mill spindle. Then enter four divisions into the programmable controller and proceed to mill the square to the desired finished size. When complete, harden and temper the broach.

- ¼” Lathe tool bit stock:
  In this instance, the Sherline mill can function as a surface grinder. Fit up the RT into the vertical position onto the x table. Fit up the four jaw chuck onto the RT. Insert the lathe tool bit in your four jaw chuck. Fit up an appropriate grinding wheel into the spindle. Place the RT into “continuous mode” and grind the end to the desired round size. Then enter four divisions into the programmable controller and grind the square to the desired size.

  In either of the above instances, you could use a spin indexer with collets for both the round and square sections or a four sided collet block set secured by the milling vise for just the squares if you have such tools.

In both instances, the wheel should already have been drilled/bored to the correct hole size. Part the ratchet wheel off the round rod blank. Place the round end of the broach into the ratchet wheel, place a spacer with a larger center hole than the wheel behind the ratchet wheel and then place all endwise into a vise. Use the vise jaws to press the square broach thru the ratchet wheel hole. Naturally this results in a pretty sticky fit when finished. So you’ll need to stake out the broach to finish up the job.

- Final important notes! As always, the shape of the tooth and its tooth tip should be as the original. In some instances that means you will not be leaving the traditional flat or “land” on the tooth tip. Instead you will be cutting teeth to a sharp point on the final pass. And some JK guidance, “Ratchet wheels are not critical and the radius they sometimes have are generally decoration only. As such, it is quite easy to grind a cutter freehand in the same manner as for an escape wheel. Non-critical freehand grinding for non-critical applications is something that should be practiced on occasion. It helps prepare one for other types of grinding.”
Finished ratchet wheel ready to be parted off. The cutter for this angle was 70°.

The ratchet wheel is next parted off. I opted to use my Myford S7 for that task. I look for opportunities to use this sweet machine!

Several successes with ratchet wheels meant the end of my wheel cutting journey. Whoo Hoo!
**Ratchet wheels that perform two functions:**
Ratchet wheels sometimes perform two functions. They provide the means to hold the click and the ratchet wheel body sometimes forms the wheel collet to secure the wheel to the arbor. As a result, the collet body is part of the ratchet wheel. Producing this type of ratchet wheel shares many of the same similarities as a regular ratchet wheel discussed earlier. The exceptions are discussed below.

One of the exceptions is its center hole. It is a critical dimension as it needs to be an interference fit onto the mainwheel arbor. Measure the arbor and subtract .003” for the interference fit. Drill and bore the hole using gage pins to measure progress and the finish measurement. Example: mainwheel arbor measurement .190” minus .003” = .187” for the wheel center hole.

Removing these types of ratchet wheels requires a different approach as well. Following are methods and tips for removing these types of wheels from their arbors. These are applicable for removing mainwheels and other wheels of the trains also and therefore references to these types of wheels are also included. First things first. Make a drawing or take a photograph. Take measurements of all locations of parts on the arbor along with the dimensions of all parts and record them as all parts need to end up back in the same place and be of the same size. Example: measure arbor length pivot end to pivot end and shoulder to shoulder; measure where the ratchet wheel is positioned on the arbor, etc. Observe which end of the arbor carries the mainspring hook. The mainwheel can generally be removed in that direction while the ratchet wheel cannot. “Follow the rivets”. The riveted material a/k/a compressed metal is generally the first place to start when removing wheels as typically this was the last operation to be performed after all other parts had been assembled onto the arbor. Avoid removing material from the arbor to remove wheels be it a ratchet wheel, mainwheel or train wheel. Doing so would reduce the arbor diameter or otherwise spoil a segment of the arbor. Instead, only remove material around the inside edge of the washer or the outside edge of the collet as appropriate. One should not need to stake off the train wheels. They should just “unsnap” or pop off from the collet once the surrounding riveted (compressed metal) material is removed. On the other hand, it is common to need to stake off a wheel collet and the ratchet wheel if it is functioning as a wheel collet. Right hand facing tool (described below) is the best lathe tool for removing material to remove wheels. Its pointed end can be placed precisely where you need to remove the material i.e. inside edge of washer, outside edge of collet and removes the least amount of material.
Always strive to stay away from the arbor and instead concentrate on the riveted area of the collet and the washer... just “nip off the rivets” with the right hand facing tool. Sometimes it is necessary to extend the lathe tool to reach the work. In this instance, it is very light loading and thus of no consequence.

Lathe tools left to right: left hand facing tool, right hand facing tool and round nose a/k/a roughing tool for brass. A round nose tool for steel would require side rake.

Washer, ratchet wheel and its main wheel staked off their arbor.

Producing these types of wheels is a more complex machining process as well and that is discussed next. A collet of this type with its inner and outer dimensions needing to be squared up at 90 degrees to the finished wheel requires right facing and left facing lathe tools along with a round nose lathe tool a/k/a roughing tool as shown above. The illustrations shown below take you through the machining process. It assumes you have chosen your round rod blank with appropriate length and diameter, that you have the right cutter fit up into the mill spindle and that you have used your pattern wheel to establish the mill spindle’s offset position.
Round nose a/k/a roughing tool to make the plunge cut, machine a working distance to allow room for the facing tool to fit in and machine the collet’s rough inner dimension. Round nose tool cuts left to right and right to left very nicely.

Left hand facing tool to finish the collet’s inner dimension and machine the 90 degree cut at the wheel.

Right hand facing tool to machine the collet’s outer dimension, the 90 degree cut at the wheel and machine it’s finish thickness. Wheel center hole is then drilled and bored to finished size.

You are now ready to cut the wheel teeth. The chuck with the wheel blank is fitup onto the RT, teeth are cut as discussed in the previous section and the wheel is then parted off. Referring to your drawing, notes for part locations, the newly cut wheel is then staked onto the mainwheel arbor.