Feeney Construction Log Page 2:
Cutting the Skew Gear

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The concepts for skew gears as applied to cam shafts in model four-stroke engines has been fully explored in Model Engine News for December 2003. The challenge here was to make a 30 degree, 40 DP, 20 tooth skew gear without spending millions on cutters and universal dividing heads and change gears. I very much doubt that I'd have managed to do this without the copy of an article by J Cooper that appeared in the US magazine *Machinist's Workshop* of June 1999 and I'm greatly indebted to Dan Bousman for locating it for me. Thanks Dan!

Forming spur gears with a very close approximation to the ideal involute form tooth using a "rack form" cutter is simple and has been covered again, again and again in all the model press. Cooper's revelationary article showed that it will also make skew gears if the gear blank axis is inclined to the skew angle, relative to the axis of the cutter.

Photo 1

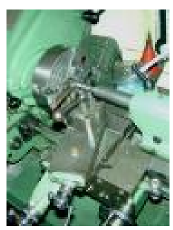

Photo 2

Photo 3

First, we must make the cutter. It's wrong to call this a hob even though the cutter tooth form is the same. A hob's teeth have lead, this cutter's teeth have none. First we need a cutter to make the cutter. This is ground to the very precise form of a 40 DP rack tooth. The two short lengths of 1/4" steel rod above the mandrel at the bottom of Photo 1 are used for this.

One has a tongue on it that is precisely the width of the 40 DP rack form at the Pitch Circle, This is used as a go/no-go gauge when cutting a slot into the other. This slot, made with multiple passes of a thin slitting saw, must be precisely the width of the gauge, cut to a depth of precisely the distance from rack tooth crown to the pitch circle (ie, the "addendum").

Using this gauge, the cutter is ground with the sides at the 20 degree pressure angle (relieved with 3 degrees of side rake). When the tip of the cutter bottoms in the gauge with no horizontal play, the tool form is correct. Simple and effective (that's Mr Cooper's idea; I'm not that smart—last time I made one of these tools, I tried to measure the tool tip width with a Vernier and maybe I got within cooee of correct—who knows?).

Photos 2 and 3 show the circular rack being formed. Each space is cut to the rack form tooth depth. The spacing is the pitch of a 40 DP rack. A 40 DP cutter is quite tiny. The overall tooth depth is a mere 0.055", but a plunge cut of a tapering tool into water hardening drill rod of even this distance is not fun. Hence, the compound slide is set over to one half the incuded angle. This causes the tool to chase down the right hand flank. The cutter is advanced using the calibrated handwheel on the Myford lead screw (see Photo 2). Photo 3 shows a close up of the finished rack before tooth gashing.

The finished cutter appears at the top of Photo 1. A milling cutter has been run up the blank forming six teeth. The blank has then been drilled for a 3/8" shank and secured with a 4-40 grub screw against a flat on the shank (American texts call these "set screws", which is probably more correct. I'll leave the derivation of the term "grub" to your imagination). If I was doing this over, I'd make two changes. First, I'd mount the blank on the shaft before cutting the rack to assure concentricity, and second, I'd drill and tap for two grub screws at 90 degrees to each other. One screw may come loose, two—acting against each other at 90 degrees—won't. It was too late for me when I discovered/remembered this, as after forming, the cutter is hardened and tempered to light straw. The faces of the teeth were then stoned as well as possible given the tight constraints.

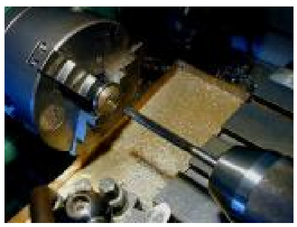
Photo 4

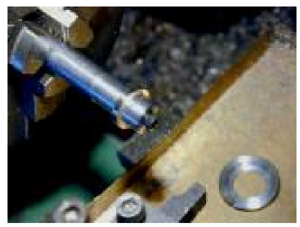
Photo 5

The grear blanks must now be prepared. For the gear to have 20 teeth, cut at 30 degrees at 40 DP, they will be .627" in diameter. The drawings call for them to be 0.093" thick, with a 0.250" hole. I cut of a batch of blanks from 0.750" brass rod to just less than 1/8" thick in the band saw. Call me cheap, but this wastes less material than parting off in the lathe (and creates less of that annoying brass swarf that laps itself into the bed ways if you're not meticulous about cleaning up). Each blank is mounted in a pot-chuck to face each side, then drill and ream (see Photo 4).

Following this, the blank is mounted on the mandrel seen at the bottom of Photo 1. The mandrel has a very precise 0.250" stub that is clocked true in the three-jaw chuck. A counter-bored end cup clamps the blank so it can be turned to the required OD concentric with the reamed hole. Photo 5 shows this step. The pot-chuck is also shown in this photo, and in Photo 1.


Photo 6


Photo 7

The three jaw chuck is transferred to the rotary table under the mill. This has been mounted on a substantial plate with its axis true to the mill Y axis. The plate has been jacked up to 30 degrees for a left-hand spiral (ie, the tooth must slope down to the left as viewed when held vertically). Cooper's article used a sine-bar arrangement to achieve this. I think that's overkill. The sum of the two angles gives the theoretical alignment of the two shafts, but my reading on skews say a slight discrepencies can be allowed for by increasing the center distance. So Photo 6 shows a shop made but accurate 30/60 square being used to set the plate.

Photo 7 give the idea of the Heath-Robinson lash-up. The 3/8" plate has two edges milled 90 degrre to each other. The rotary table is bolted to the plate and set 90 degrees to the long edge. A stop is clamped to the mill table at right angles to the Y axis. The other milled edge of the plate butts against this stop. Bits and pieces from the mill clamp kit hold the whole thing rigid. Ugly, but finctional.


Photo 8


Photo 9


Photo 10

Photos 8 through 10 show the teeth being formed. The cutter is lowere until the center tooth ring is aligned with the center of the blank at mid-point (think about it). The quill is locked and the X axis wound out until the cutter just kisses the blank. With the cutter clear of the blank to the left, the X axis is wound another 0.055" — ie full depth of cut for the tooth. The first pass is now made, winding back and forth a few time to allow for any cutter spring-back. Photo 8 shows the blank after pass #1. No pass is going fully form any tooth. The one in the middle will be less than full depth at either end. Those above and below will be full depth at one end, but light at the other. All will be rack form; none will yet be approaching the involute shape.

In photo 9, we've indexed around the blank 19 times to the last tooth. Depending on which way you index, the cutter teeth above (or below) will be correcting the depth of cut problem and further shaving the rack-form teeth closer to the involute. The shape will be formed by a series of flats depending on how many cutter teeth "mesh" with the blank—3 flats in this case. Note that when tooth #20 is cut, the job will not be complete! We must continue at least two more to ensure all profiles are cleaned up as best possible.

In Photo 10, the gear is full formed and the cutter has been raised. Cooper points out that is is possible to further refine the tooth towards the involute by alternately raising and lowering the cutter by a fraction of the rack pitch, rotating the blank to re-achieve mesh, then making another pass. This would probably be essential for large teeth—say in the 20 DP and below range, but my tests showed this was not required. The gear at this time is rather furry, especially at the exit side of the cutter passes. After removal from the mandrel, a few light rubs against a large fine-cut file cleans up the worst of it, and a buff with a fine wide brush does the rest.

The big moment: Would my gear mesh and spin, and how would the center distance for "sweetest" running compare with the theoretical center distance? To try this, the professionally made drive gear was mounted on a stub and driven by the lathe. my gear was mounted on an axel stub spinning at 90 derees to the driver, running in a bearing clamped to a vertical slide that would allow the center distance to be adjusted. My plan was that if I did not like the freeness, or if it made a lot of noise, I could drop some valve grinding paste into the mesh and let the gears modify each other. This turned out to be completely unnecessary. The gears meshed freely, so the distance was lowered until they sounded "unhappy", then raised just enough to achieve free running again. Then, by measuring the vertical distances between the shafts and adjusting for the (drill rod) shaft diameters, the center distance was calculated, and—well blow me down! It was just 0.001" lower than the theoretical distance! The extra thou of backlash (roughly 2% of tooth depth) will give a little extra freedom, if I can bore the crankcase that accurately.

During this process, I learnt that I'd got it half wrong (again, dammit) about the end-thrust of the Feeny gears. Looking the the previous photo, the driver gear end-thrust when the gears are running in normal model engine direction (ie, the lathe spindle sunning reverse) is towards the tail stock. The driven gear end-thrust is into the vertical slide. This is the best we can do for the Feeney. The cam shaft will be being pushed into its cavity, so there will be no thrust load on the cavity cover bearing. The driver gear will be trying to lever itself off the crankshaft though. As mine is a real tight press fit, this will not pose a problem. It does show however that we can't use right-hand spiral gears without a casting re-design.

So, the method works. All the cutters, jigs and gears were made from existing stock, or the scrap bin. Looking back at Photo 1 (reproduced here), to the left of the pot-chuck are two tried and proven good gears. To the right are five unusable stuff-ups. My 90:1 Vertex rotary table needed 4.5 turns per tooth for the 20 tooth gear. Concentration (I've learnt) is paramount when indexing. Turn off the radio, unplug the phone, put the cat out. Count out loud and develop a rythm to the process (eg, always move the sector arms first, or last. Never change!) Above all, don't let your mind wander. One of the stuff-ups happened when my single grub screw cutter came loose on the shaft and the cutter shifted its vertical position a few thou. Grrrrr. Next time, two screws, or glue the cutter to the shaft. Another stuff-up was caused by cutting the teeth 0.110" deep. Don't ask me why, it was late at night and I was tired (perhaps that's why?). Another was an indexing mistake and another, the first, was indexing by 4.45 instead of 4.5!!! But I've learnt. After this shot was taken, I produced a further 4 gears for Art's next run of Feeney kits with no mistakes.

But all's not roses. If I'd had to make the 60 degree gear, I'd have been in trouble. Have a look at photo 7 and imagine the plate and rotary table raised another 30 degrees. The top would hit the mill quill. If I spun the plate around 180 degrees, I'd be clear of the quill, but now the division plate and handle are at the back of the mill and indexing would be very slow, difficult and error prone (in my shop). Cutting right-hand gears would pose no great difficulty however. One possible solution appears to be to mount the rotary table horizontally on the plate, and angle the plate at 30 degrees with the opposite slope. This looks like it would produce the left-hand 60 degree gear, maybe.

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