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SHAPING RATCHET TEETH

Technological Spinoff Report

R. W. Stiles, Project Leader

Project Team:
G. E. Volkland

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**Kansas City
Division**

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SHAPING RATCHET TEETH

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August 1973

Prepared by R. W. Stiles, D/822

Gear shaping as a method of cutting teeth offers advantages not available in hobbing, form milling, and blanking. Bendix conducted cutting tests on a gear shaping machine; as a result, a mathematical model and computer program for generation shaping were developed. The mathematical model has advanced generation shaping of non-involute forms from trial and error to mathematical exactness.

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THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

A prime contractor for the
Atomic Energy Commission
Contract Number AT(28-1)-613 USAEC

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SUMMARY

Bendix manufactures a wide variety of ratchet wheels for electromechanical devices: hobbing, blanking, and form milling are most commonly used. But because of disadvantages associated with each, gear shaping was studied as an alternate, more versatile method of making ratchet teeth.

In gear cutting, the reciprocating action of the cutter permits cutting internal teeth and features that are closely banked against obstructions. In addition, irregular, segmented, noncircular, or interrupted configurations can be produced.

Initial investigations, using the trial-and-error layout cutter design technique, were found to be too inaccurate for Bendix purposes. Therefore, a mathematical model and computer program were created that will accurately predict whether a desired ratchet tooth geometry can be produced, and will also design the cutting tool.

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DISCUSSION

SCOPE AND PURPOSE

Bendix manufactures a wide variety of ratchet wheels for electromechanical mechanisms (Figure 1).

Figure 1. Samples of Bendix-Made Ratchet Wheels

The ratchet wheel teeth are produced by hobbing, blanking, or by form milling one tooth at a time on a vertical or horizontal milling machine. The last is the most common process but all have some limitations or disadvantages. Hobbing at Bendix is presently limited to a 0.625 inch (15.8 mm) diameter blank because of machine capacity, and the teeth must be equally spaced about the entire periphery of the blank. Dies for blanking ratchet teeth are expensive and production quantities must be high to justify the initial tooling costs. Material selection is another important factor in blanking: 6061 aluminum, for example, tears when blanked. Form milling is slow, requires large numbers of cutting tools, and does not have the accuracy or repeatability of the other two processes. None of these processes can produce banked or internal ratchet teeth.

This study was undertaken to develop gear shaping (Figure 2) as a method of producing ratchet teeth. Gear shaping offers considerable flexibility as a metal cutting process: the cutter, which has suitable relief to provide cutting edge clearances, rotates in timed relationship with the workpiece and cuts by reciprocating. The cutter's reciprocating action permits cutting features that are closely banked against obstructions and internal teeth. Irregular, segmented, noncircular, or interrupted configurations can also be produced.

Figure 2. Gear Shaping Operation

In comparing gear shaping to the other ratchet teeth manufacturing processes, the cost of the process has to be taken into consideration (Figure 3). In production quantities in excess of 2000, fine edge blanking is the most economical process. Hobbing is the most economical at any production run size and form milling is the most expensive. Cost, however, is not the only consideration in process selection. Gear shaping offers the greatest versatility of the four.

Bendix obtained two gear shapers in 1969: a Fellows Number 3 Gear Shaper for fine pitch gear teeth (40 DP and finer) up to 3 inches (76.2 mm) pitch diameter, and a Fellows Number 712 Gear Shaper for coarse pitch (7 DP maximum) gear teeth up to 7 inches (177.8 mm) external and 5.5 inches (139.7 mm) internal pitch diameter.

Figure 3. Unit Dollar Cost Versus Production Quantity for Making Ratchet Teeth on a 20-Tooth Stainless Steel Ratchet Wheel

ACTIVITY

Initial Gear Shaping Attempts

A ratchet wheel (Figure 4) used in a production part was selected to study generation shaping using Fellows tooling. This part is a positive rake ratchet wheel with a large radius at the root of the tooth.

The first efforts were too inaccurate. Test specimens were cut on the Fellows Number 712 Gear Shaper (Figure 5) and the tooth form inspected on an optical

Figure 4. Ratchet Wheel Selected for Study

Figure 5. Fellows 712 Gear Shaper, Showing Reciprocating Cutter and Ratchet Wheel

comparator with an overlay chart. The back side of the tooth was within the required 0.004-inch (0.1 mm) tolerance band, but the face was about 0.008 inch (0.2 mm) too large (Figure 6). When the cutter was fed deeper into the blank to remove the excess material, the total tooth thickness was reduced, creating an undersized back side of the tooth.

Figure 6. Generated Tooth Profile

Fellows could not determine how the cutter could be altered to eliminate the unwanted material; in their judgement, no further refinements could be made because they had already optimized the cutter's design.

Bendix engineers discovered that Fellows used layout techniques for cutter design on non-involute applications. Layout, a trial-and-error technique, depends on the experience of the layout draftsman and can only approximate the ratchet tooth and cutter tooth geometry. Therefore, the scope of Bendix's study was expanded to develop a mathematical model and computer program for generation shaping.

Development of Mathematical Model

Theory of Gear Shaping

To create a profile on a gear shaper, both members (cutter and workpiece) must have pitch line movement: two pitch circles rolling together, or a combination of a pitch circle and a pitch line movement, as in cutting a rack. The cutter's tooth curve is driven in unison with a mating blank, generating a

tooth profile in the blank that will mesh with itself as shown earlier in Figure 2. In shaping involute gear teeth, the cutter tooth is also an involute form of the same pressure angle and pitch. In the case of a ratchet tooth, however, the cutter tooth must be an arcuate contour that will roll with the straight sides of the ratchet tooth (Figure 7).

Figure 7. Shaper Cutter Tooth Action During Ratchet Tooth Generation

Ratchet wheel tooth geometry is divided into these three classes (Figure 8):

- A radial tooth form in which the tooth face lies on a radial plane from the centerline;
- A positive rake tooth form in which the tooth face lies from radial to below radial;
- A negative rake tooth form in which the tooth form lies from below radial to radial.

As the pitch circles of the cutter and the workpiece are rolled together, the cutter's locus is an infinite number of cycloidal curves (Figure 9): an epicycloidal curve, a curtate epicycloidal curve, or a prolate epicycloidal curve. Therefore, the cutter tooth's path as it generates the mating ratchet tooth will be made up of one, two, or a combination of all cycloidal curves.

Figure 8. Three Types of Ratchet Teeth

The cycloidal curve(s) describing the cutter tooth loci will depend upon where the pitch circles intersect the ratchet tooth; the ratchet tooth geometry is in turn determined by the loci the cutter follows. A direct relationship therefore exists between the tooth geometry and the pitch circles.

Figure 10 shows the locus of each of nine points selected along each side of a negative rake ratchet tooth as the two pitch circles roll together. The envelope formed by these loci define the cutter tooth profile that will produce this ratchet tooth.

Figure 9. Three Types of Epicycloidal Curves

These manipulations can be made to the pitch circles to influence the ratchet tooth geometry.

- The workpiece's pitch circle will intersect the ratchet tooth's root diameter. The resultant pitch circle of the shaper cutter will intersect the major

Figure 10. Locus of Negative Rake Ratchet Tooth

diameter, or crest, of the cutter tooth. The locus of the cutter tooth's leading edge will follow an epicycloidal curve and the loci of all other surfaces on the cutter tooth will follow curtate epicycloidal curves. With this type of cutting action, the point at the cutter's tip on the ratchet wheel tooth can be reproduced and thereby produce a "sharp" fillet radius. The only ratchet tooth applicable to this type of cutting action is the negative rake one, shown earlier in Figure 8.

- The workpiece's pitch circle will pass through a plane somewhere between the crest and root of the ratchet tooth. The shaper cutter's pitch circle will pass through a corresponding plane on the cutter tooth. The cutter's loci will be a series of epicycloidal, curtate epicycloidal, and prolate epicycloidal curves. This type of cutting action will produce a radial, negative, or positive rake tooth with a large fillet radius at the root.
- The workpiece's pitch circle will be extended beyond the crest of the ratchet tooth. All of the cutting edges will move in a plane below the cutter's pitch diameter. The locus of all points on the cutter will be a prolate epicycloidal curve. This looping action will undercut the face of the ratchet tooth and create a positive rake tooth as shown earlier in Figure 8.

Using this gear shaping theory, a mathematical model of generation shaping was developed to provide precise data on cutter tooth design and ratchet tooth geometry obtainable with this cutter.

These mathematical formulas calculate the locus of the cutter tooth:

- Epicycloidal Curve (Figure 11):

$$X = (R + r) \cos \theta - r \cos \frac{R + r\theta}{r} \quad Y = (R + r) \sin \theta - r \sin \frac{R + r\theta}{r}$$

- Prolate Epicycloidal Curve (Figure 12):

$$X = (R + r) \cos \theta - r' \cos \frac{(R + r\theta + \ell)}{r}$$

$$Y = (R + r) \sin \theta - r' \sin \frac{(R + r\theta + \ell)}{r}$$

$$r < r'$$

- Curtate Epicycloidal Curve (Figure 12):

$$X = (R + r) \cos \theta - r' \cos \frac{(R + r\theta + \ell)}{r}$$

$$Y = (R + r) \sin \theta - r' \sin \frac{(R + r\theta + \ell)}{r}$$

$$r > r'$$

Figure 11. Epicycloidal Curve

Figure 12. Prolate or Curtate Epicycloidal Curve

Data Input

To use this mathematical model for a specific application, a sufficient number of points (radial distance and angle from the ratchet wheel centerline) on the ratchet tooth must be described so that when these points are connected with straight lines, a complete tooth is defined. These points are entered in the data deck of the computer program. The pitch radius of both the ratchet wheel and the cutter are also entered in the data deck along with the total angle selected to roll the pitch circles through angle θ and the number of divisions that θ will be divided into $\Delta\theta$.

Data Output

The computer calculates the X and Y coordinates defining the cutter tooth and then draws the profile on the plotter. The plotted cutter tooth is then rolled through angle θ and redrawn every 2° (0.03 radians) ($\Delta\theta$) over the previously drawn ratchet wheel. The generated envelope will show any departures in tooth definition from the input tooth. By manipulating the pitch (rolling) circles, the best condition that can be generated on a gear shaper can be created.

The plotter will also draw a two-dimensional line definition of the cutter tooth at any desired magnification for manufacturing and inspection of the cutter.

The tooth form on the previously selected production part ratchet wheel was entered in the computer program and the plot (Figure 13) showed that this tooth profile could have been created by gear shaping, and that incorrect cutter design (and not process limitations) prevented it.

A radial ratchet tooth (Figure 14) was also entered into the program to determine if it could be generated on a gear shaper. This ratchet tooth is typical of those manufactured at Bendix for use in several electromechanical assemblies. The computer plot in Figure 15 shows the optimum tooth form that can be produced by generation shaping. The face of the tooth can be held on the radial for approximately half its total depth and the smallest fillet radius obtainable in this particular case is a 0.015-inch (0.4 mm) radius, about twice that required.

ACCOMPLISHMENTS

The creation of a mathematical model and computer program has advanced gear shaping from trial-and-error to mathematical precision.

Figure 13. Computer Generated Ratchet Wheel

Figure 14. Typical Radial Ratchet Wheel Manufactured at Bendix

From the study, some general observations can be made about generation shaping ratchet wheel teeth.

- A "sharp" fillet radius can only be generated on a negative rake tooth.
- A radial tooth can be shaped if sufficient fillet radius is allowed. Only a third to a half of tooth depth can be held radial.
- To produce a positive rake (undercut face) tooth, the pitch circles must be in a plane at or beyond the crest of the ratchet tooth.
- The cutter's pitch circle should be made as large as possible. Enlarging the cutter increases the generating pressure angle allowing the cutter tooth to enter and withdraw from the blank at a steeper angle, reducing

Figure 15. Computer Generated Radial Ratchet Wheel

the undercutting and topping effect. The cutter used to shape the Coded Enable Switch ratchet wheel was four times larger than the ratchet wheel blank.

- The relative position of the theoretical pitch circles can be manipulated to influence the ratchet tooth geometry.

A radial tooth form like that shown in Figure 14 can be produced by hobbing if the teeth are not obstructed and are equally spaced about the periphery of the ratchet wheel. A single position hob can be used for these applications with the hob offset from the ratchet wheel centerline (Figure 16).

The computer program developed is a useful tool to the process engineer investigating gear shaping as a metal cutting process. The program will tell if a desired geometry can be generated on a gear shaper, and will also design the cutting tool. An optical comparator overlay of the cutter tooth at any desired magnification can be obtained through the Calcomp plotter.

PARTS HAVING SPECIAL FORMS

Figure 16. Single Position Hob Applications

The overlay can be used to both manufacture and inspect the cutting tool. Although the study was directed toward ratchet teeth, the theory and computer program are applicable to any geometry.