BACK TO BASICS...

Gear Manufacturing Methods – Forming The Teeth

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Fig. 1 – Hobbing an external helical gear on a vertical gear hobber. Cutting action is produced by feeding the angular, gashed, worm-shaped hob through the gear blank in proper timed relationship. *Courtesy Liebherr Machine Tool Div.*

The forming of gear teeth has traditionally been a time-consuming heavy stock removal operation in which close tooth size, shape, runout and spacing accuracy are required. This is true whether the teeth are finished by a second forming operation or a shaving operation.

Originally gear teeth were produced with form-milling cutters on milling machines equipped with index heads. Later the popular gear hobbing process, Fig. 1, was developed to produce external gears. The shaper-cutting method was developed primarily to produce internal gears and gears on blanks that would not permit passage of a hobbing tool.

Today internal gears are being broached at high production rates. External gears are also being produced at high production rates by pot broaching methods. Other methods such as high energy rate forming and rolling of fine-pitch teeth from the solid are being applied and investigated.

Gear Hobbing and Shaping

One of the key problems in hobbing and shaping of gear teeth is the specification of a properly proportioned tooth form. Most of the problem occurs in the fillet area. However, when semi-topping hobs or shaper cutters are used to produce tip-protective chamfers, Fig. 2, a loss of active profile can result if the outside diameter of the blank has not been increased beyond the theoretical outside diameter to provide additional stock for the chamfer.

If the fillet produced by hobbing or shaping is too high, finishing tool interference and breakage can result, and the accuracy of the produced profile can be affected. If the hob or shaper cutter tooth has a full radius form on the tip, maximum wear life of the tools is provided.

Referring to Fig. 3, it can be seen that forming of the teeth with a gear-shaped shaper cutter or a rack-shaped hobbing tool differs considerably from the in-fed form tool operation. Hobbing, gear-shaping, and rotary gear shaving have tooth tip paths which produce fillets that are actually trochoidal curves generated by the tip corner of each tooth.

As a result, the point of tangency between this curve and the generated involute profiles is higher than that of the radius on the form tool. The shaper-cut fillet tangency point is slightly higher than that produced by a hob of the same working depth. Thus, the shape of a fillet on a gear drawing is correctly specified as that produced by a specific hob or shaper cutter tooth form with a specific tip radius or form.

The generating action of hobs and shaper cutters with and without protuberance to provide necessary shaving cutter tip clearance is illustrated in Fig. 4.

The amount of total undercut (shaving stock plus 0.0005 to 0.001-in.) produced by pre-shaving, protuberance-type tools, Table 1, varies with the pitch of the gear teeth. Posi-

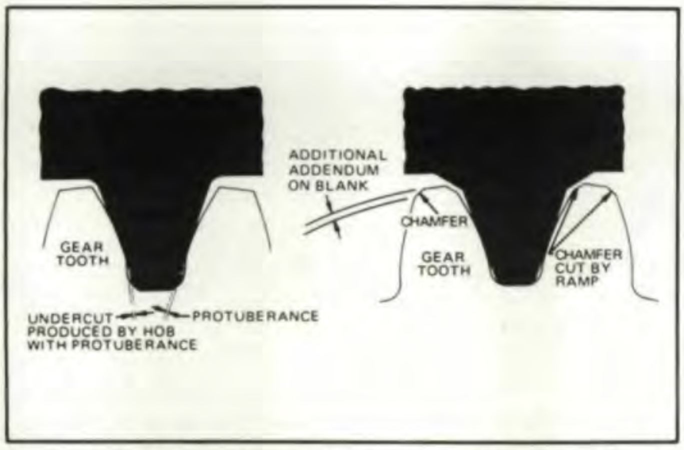

Fig. 2 – Typical hob tooth shapes. Protuberance type is at left, semi-topping type at right. *Courtesy Star Cutter Co.*

Table 1 – Recommended Shaving Stock and Total Undercut for Pre-Shave Gear Cutting Tools

Normal Diametral Pitch	Shaving Stock (In. per Side of Tooth)	Total Undercut (In. per Side of Tooth)
2 to 4	0.0015 to 0.0020	0.0025 to 0.0030
5 to 6	0.0012 to 0.0018	0.0023 to 0.0028
7 to 10	0.0010 to 0.0015	0.0015 to 0.0020
11 to 14	0.0008 to 0.0013	0.0012 to 0.0017
16 to 18	0.0005 to 0.0010	–
20 to 48	0.0003 to 0.0008	–
52 to 72	0.0001 to 0.0003	–

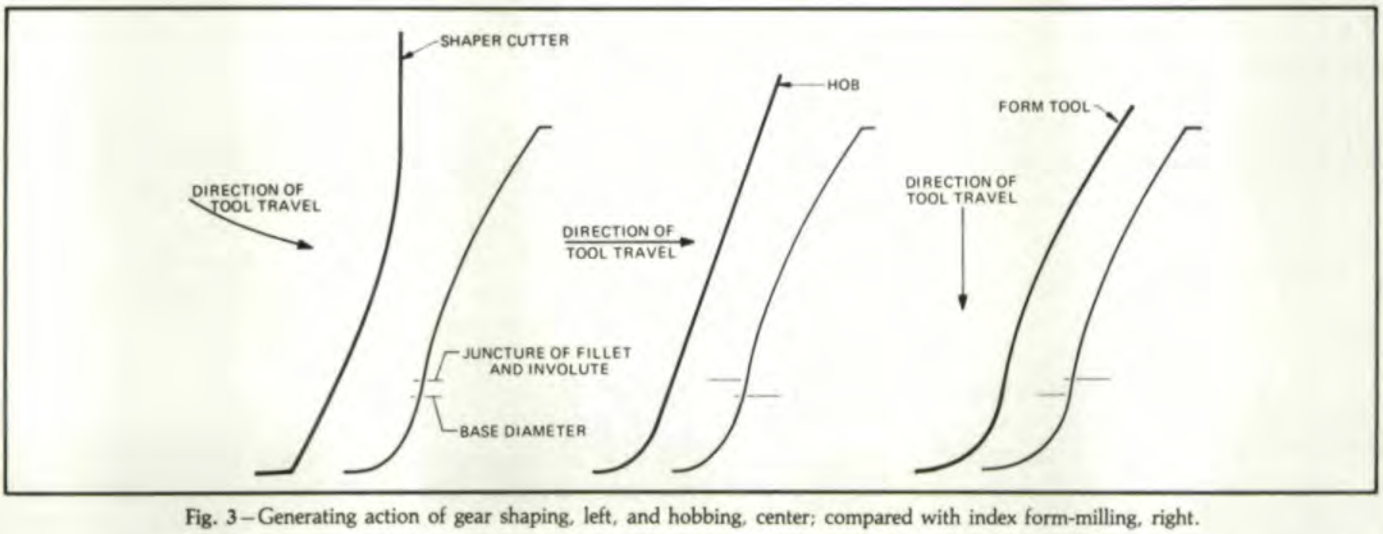

Fig. 3 – Generating action of gear shaping, left, and hobbing, center; compared with index form-milling, right.

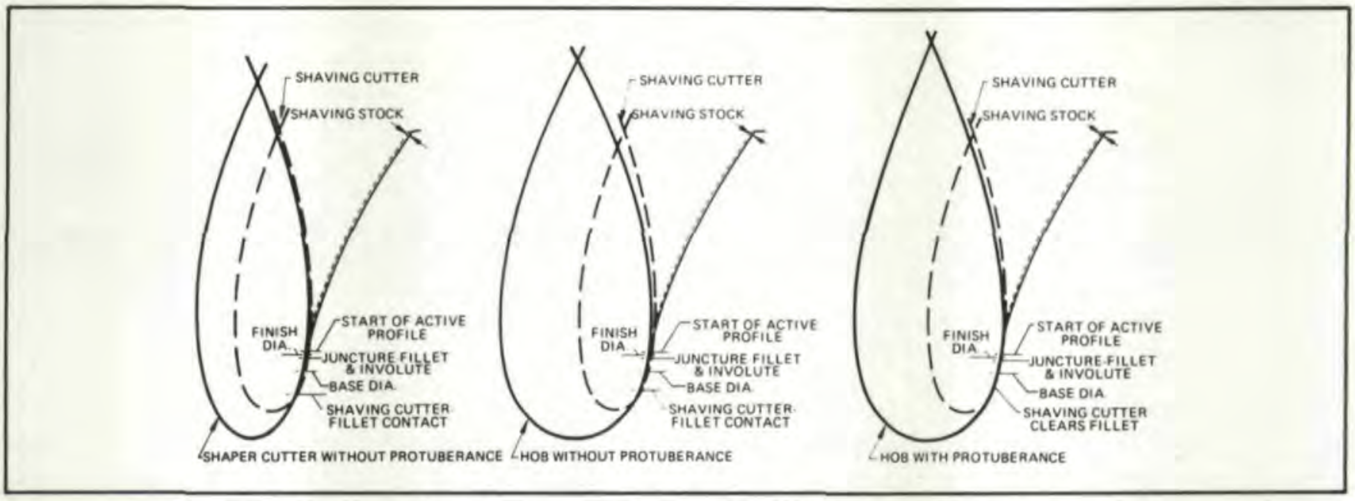

Fig. 4 – Generating paths of shaper cutter, hobs and rotary-shaving cutters in fillet area on same tooth.

tion of the protuberance-produced under-cut fillet produced by a specific hob or shaper cutter varies with the number of teeth in the gear. Usually the undercut will generate too high on gears with small numbers of teeth and reduce the necessary amount of involute profile. Use of the same tool on gears with large numbers of teeth will provide an undercut too low to serve any useful purpose.

Theoretically protuberance-type hobs and shaper cutters should be designed for a gear with a specific number of teeth. However, this method is not economically feasible when a variety of gears with different tooth numbers are being processed. Often a tool with no protuberance may be used for gears with small numbers of teeth. This method makes use of the natural undercut produced by generating-type tools that extend below the base circle on gears with small tooth numbers. Fig. 5 left illustrates this condition.

On long and short-addendum gears, the amount and position of protuberance on hobs and shaper cutters must be carefully specified because of the different generating action in producing the teeth.

The fillet shapes of typical hobbed and shaped gears are shown in Figs. 6 and 8. The finish produced by these two generating forming methods is shown in Figs. 7 and 9.

The effect of the generating action of hobs and shaper cutters on the finish in the fillet area is shown in the two enlarged sketches in Fig. 5.

Applying the Processes

Careful consideration should be given to the tooling for hobbers and shapers. Where possible this tooling should locate on the rim or side of the gear blank, just below the root diameter of the teeth. Proper mounting of hobs, including indication for runout within 0.0005-in., and careful machine setup for tooth size are most important for good results in the subsequent shaving operation.

Optimum machine performance and economy results when only sufficient stock is left for shaving to clean up the gear and assure the removal of semi-finishing errors or their reduction to specified tolerance limits. Leaving an excessive amount of stock to be removed by shaving unduly reduces cutter life, increases shaving time and may result in the shaving cutter hitting the fillet.

Table 1 shows the amount of stock left on each side of a tooth under average conditions for removal in the shaving operation.

It is also important that the involute profile and lead of a hobbed or shaped helical gear be held as close as possible to that of the gear as shaved if maximum shaving cutter life is to be attained. Uniform stock removal in the shaving operation equalizes cutter wear and results in more pieces shaved before the cutter has to be reground. This is not the case when the cutter has to correct too great an error in involute profile and excessive wear is concentrated on only part of the tool. This results in hollow spots on the cutter which in turn leave high spots on the shaved gear tooth profiles.

It is good practice to process a pilot group of gears to the desired lead, heat treat them and then carefully check the amount of distortion caused by the heat treatment. The resulting average of this check will serve as a guide for compensating the lead in processing the remainder of the lot.

Changes in helix angle also produce changes in involute profiles. Thus, both must be adjusted in machining gears which are to be heat-treated. The gears should be hobbed or shaper cut as closely as possible to the adjusted lead. This is particularly true if maximum shaving cutter life is desired in producing wide face gears.

Clutch gears having rounded or pointed teeth should have all chips and burrs removed from their ends before they are shaved. Otherwise, these chips can become imbedded in the serrations of the cutter teeth and cause breakage.

Blank machining, hobbing or shaping speeds and feeds should not be so excessive that they cause cold working or burnishing of gear tooth surfaces. This practice will prolong shaving cutter life and avoid excessive heat treat distortion.

The selection of the type of hobbing tool has an important economic effect on the overall cost of gear processing. At one time, because they were used on finish-hobbing operations before the development of rotary gear shaving, only single-thread, Class "A", ground-form hobs were used as preshaving tools. With the advent of shaving, less-expensive

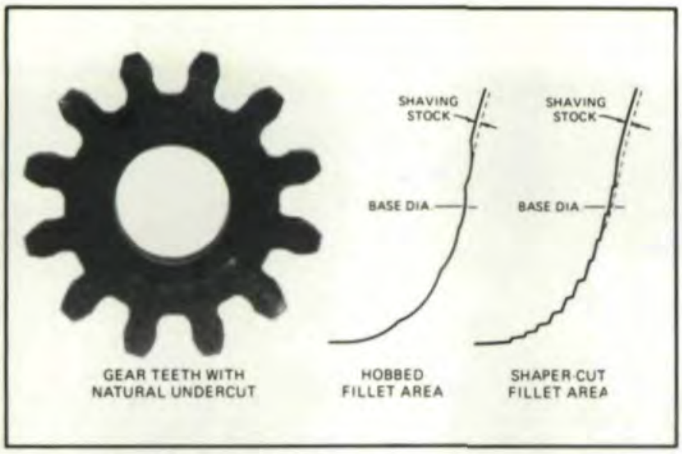

Fig. 5 – A 12-tooth pinion, left, showing natural shaper-cutter undercut. Enlarged fillets, right, show type of finish generated by hobbing and shaping.

Fig. 6 – Hobbed 4-DP, 5-in. PD, 20-tooth gears with 20°-PA, left, and 30°-PA, right.

single-thread, Class "B", ground-form pre-shaving hobs were successfully applied.

Today even lower-cost Class "C", accurate unground-form hobs are widely applied as preshaving tools. To reduce the required number of hobbing machines for roll-finished, fine-pitch helical transmission gears, multiple-thread, Class "C" accurate unground-form hobs are also being utilized as pre-shaving tools.

Multiple-thread hobs with straight gashes are usually larger in diameter than single-thread hobs because of the requirement for a low thread-angle. In actual production of 14 and 16-NDP helical transmission pinions, high production hobbing rates are being achieved by using 3-thread, 3-in. dia., Class "C" hobs instead of 2½-in. dia., single-thread hobs of the same class. The number of threads in multiple-thread hobs should not be prime with the number of teeth in the work gear.

Accurate unground-form, Class "C" single and multiple-thread hobs can be produced by rack form-tool methods to provide extremely close tolerances for such features as protuberance, semi-topping and full-radius fillet design.

Broaching Internal Gears

Internal spur and helical gears can be most economically produced in high production by a single pass of a full-form finishing broaching tool assembly as shown in Fig. 10. A wide variety of automotive transmission internal running gears up to 6-in. pitch dia. with 6 to 20-DP teeth can be produced by

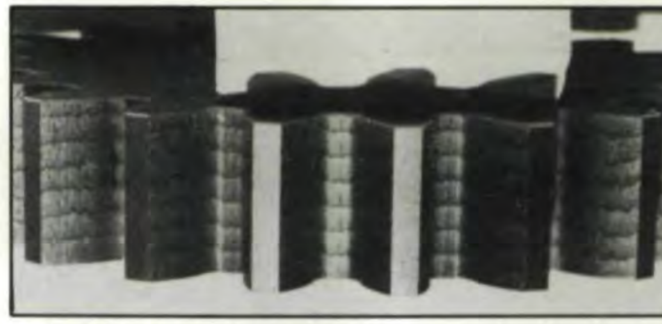

Fig. 7 – Hobbed finish of left-hand gear in Fig. 6 as produced by a 4-in. dia., 10-flute, single-thread hob rotating at 71-rpm and fed at 0.150-in. per revolution.

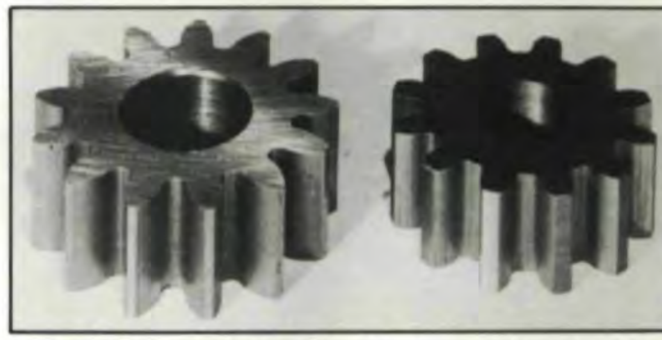

Fig. 8 – Gear-Shaped 5-DP, 20°-PA, 13-tooth gear, left, produced by a 20-tooth, 4½-in. OD shaper cutter; compared wth a 5/7-DP, 20°-PA, 12-tooth gear, right, produced by a 15-tooth, 3.325-in. OD cutter.

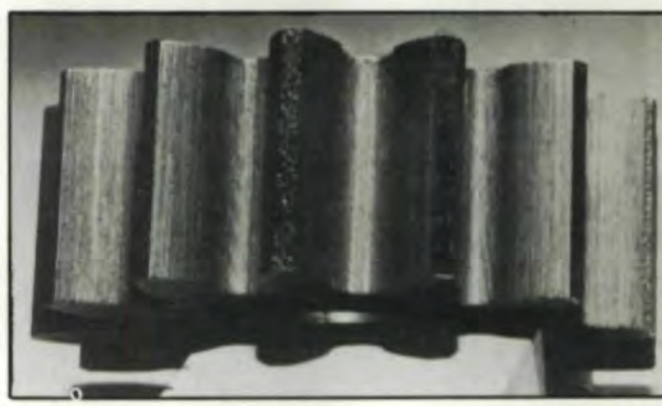

Fig. 9 – Shaper-cut finish of left-hand gear in Fig. 8 as produced with the cutter making 121 strokes per minute and feeding at a rate of 0.001-in. per stroke.

Fig. 10 – Full-form finishing broach showing roughing section, finishing shell, tailpiece and broached gears.

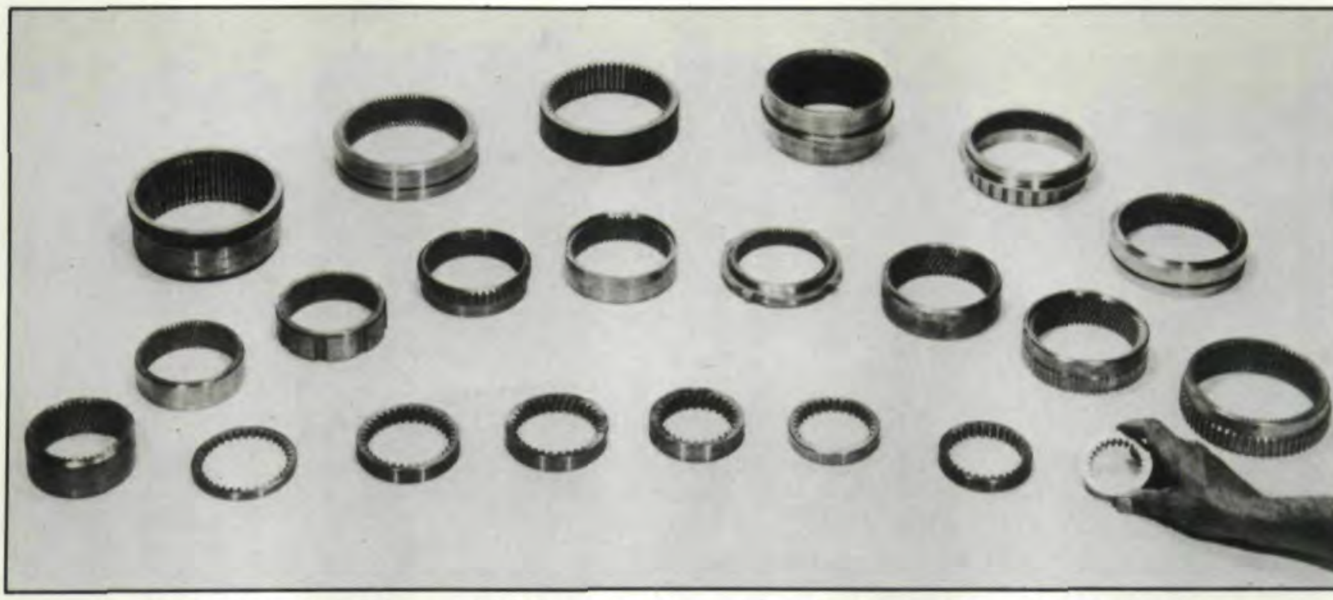

Fig. 11 – Internal-broached spur and helical transmission pump and running gears ranging from 2 to 6-in diameter.

this method. See Fig. 11.

Full-form finish broaching provides fine surface finishes, precision involute form, accurate tooth thicknesses and precision tooth spacing and lead.

Internal helical gears are usually broached on vertical broaching machines. Accurate leads are produced by the action of a precision lead bar, follower nut, and associated gearing, which rotate the broach as it is pulled through the blank. See Fig. 12

Where close control of internal gear tip contact with mating pinions is desired, the broached tooth form can be notched as shown in Fig. 13 to provide absolute control of length of roll.

In one application, two fully-automated full-form finishing broaching machines produce internal helical gears at a rate of 180 pieces per hour. The internal gear has 72, 15.5-DP, $17\frac{1}{2}°$-PA teeth with a 22° 11', 30" right hand helix angle. The gear blank has a 6-in. OD and is about 1-9/16-in. wide. Brinell hardness of the SAE 4028 blank is from 179 to 217.

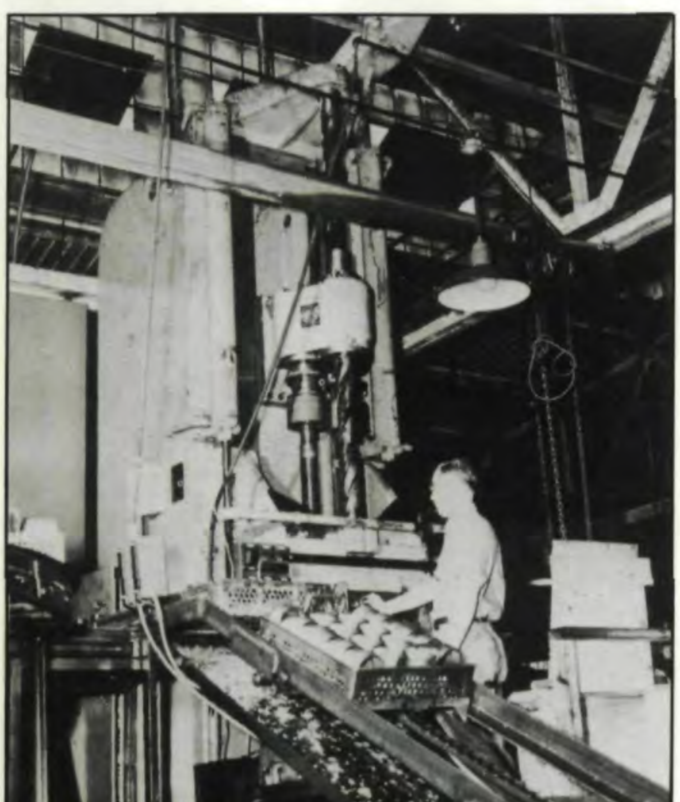

Fig. 12 – Full-form finish broaching of internal helical gears two-at-a-time on a vertical broach.

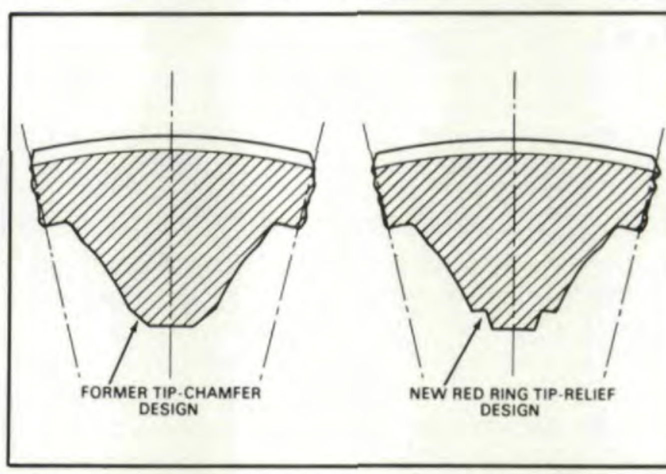

Fig. 13 – Conventional broached internal gear tip chamfer and improved tip relief, length-of-roll-control design.

Fig. 14 – Large internal spur differential running gears that are broached to precision tolerances.

Fig. 15 – A variety of external cast iron and steel clutches, cams and splines produced by push-up pot broaching.

The broaching tool is 82-in. long and has a chip load of 0.0036-in. per tooth.

Originally the gear was shaped and shaved. It took 3 minutes to shaper-cut the teeth and 1¼ minutes to shave it. Each broaching machine makes a finished gear every 40 seconds. The former method required 28 gear shaper spindles and six rotary gear shavers. Total life of individual broaching tools is about 100,000 pieces.

Internal spur differential running gears with 5/7-DP teeth up to 9.400-in. pitch diameter have been produced by nibbling-type broaching tools, Fig. 14.

Broaching External Gears

The fastest way to produce medium and high production external gears, splines and parts with specially formed teeth like those in Fig. 15, is by pot broaching. A new process called push-up pot broaching uses a machine, Fig. 16, in which the part is pushed upward through a fixed pot broaching tool of either stick-type or wafer-type design to produce external teeth under ideal conditions that assure quick and complete chip removal from the broach teeth. Coolant is flushed into the tool area through a quick-disconnect coupling.

Fine finish and precision tooth form, size, and spacing are provided in gears and splines produced by push-up pot broaching.

The process is ideally adapted to full automation. Finished parts are ejected at the top of the pot broach where gravity force can help move them on to the next operation.

The 60-tooth, 12-DP, 14½°-PA, SAE 5130 involute spline (second from the right in Fig. 15) has a 5-in. PD and is 0.800-in. long. The teeth are broached and the outside diameter finished with a ring-type broaching tool at a rate of 240 pieces per hour by pot broaching. Total life of the tool in this application is about 600,000 pieces.

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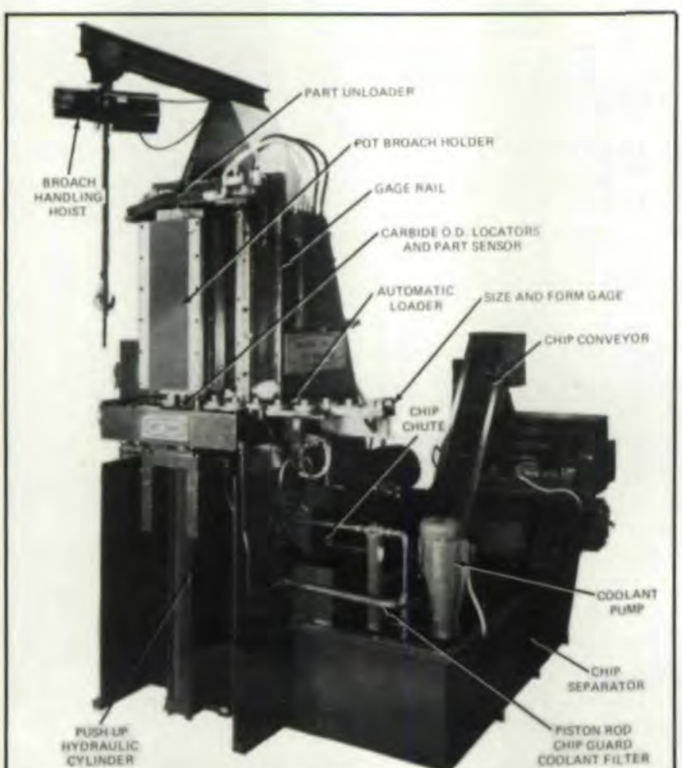

Fig. 16 – A 25-ton automated push-up pot broaching machine that can produce external gears, splines and tooth forms at rates up to 450 pieces per hour.

IMPROVEMENT IN LOAD CAPACITY . . .
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The ordinary gear sets of the same material and hardness are also tested. The wear of the sets is several times that of the modified one, and after 200 hours run, the wear still advances. When the highest load is applied, the advance of wear is too rapid to measure the over-ball diameter.

Conclusion

A new method to improve load capacity of crossed helical gear sets is introduced. The method is based on kinematic consideration of skew gears. Results of a running test show that the wear of the improved gear set is far less than that of the ordinary crossed helical gear set. The method is worthy of further practical development.

Nomenclature

a,b,h	parameters for expressing the cutting edge position
A	center distance
m_n,	normal module
$\bar{n}_1$,	a unit normal vector to $\bar{r}_1$,
$\bar{n}_f$	a unit normal vector to cutting face $\bar{r}_f'$
r_a	outside radius of a cutter
r_b,	base circle radius of an involute
$\bar{r}_l$,	vector representing an involute helicoid
r_c	vector representing an involute side flank
u,v	angular parameters for expressing an involute
α_n	normal pressure angle
β	helix angle
γ	rake angle
η	parameter for expressing an involute
ϕ	rotation angle of an unmodified gear
Δ, Δ_n	difference between two side flanks

References

1. MERRITT, H.E., *Gear Engineering*, Pitman, 1971.
2. SHIMOKOHBE, A., et al., "Line of Contact and Relative Curvature of Hourglass Worm Gears", Bull.T.I.T., No. 123, 1974, p131.

This article was previously presented at a 1984 ASME conference. Paper No. 84-DET-206.

GEAR MANUFACTURING METHODS . . .
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External helical gears can also be produced by pot broaching. (See Fig. 17) The 4-in. O.D., ¾-in. wide cast iron helical gear has eighty-seven, 24-DP 22°-HA teeth.

The gears are produced on a special lead-bar-equipped vertical press by a solid HSS pot broaching tool in 15-sec. floor-to-floor time. Total tool life is 1,250,000 pieces.

Forming Teeth in Solid Blanks

Forming of fine-pitch gear teeth from the solid with gear rolling dies before roll-finishing is a process method that

Fig. 17 – A solid HHS pot broaching tool that produces external helical cast iron running gears.

shows considerable promise. It is currently in the development stage.

High energy rate forging machines use high-pressure gas to drive a forming punch or die at speeds of up to 1,100-in. per second, Gears produced by this process are said to be 10 to 50-times stronger than those made by conventional forging and tooth-cutting methods.

To produce a blank with integrally-formed teeth, a raw billet is put in a blocker die to convert it into a preform. Then the preform is put into a finish die and is HERF-forged into a gear in a single blow. The gear is then trimmed to remove flash. Dies are 63Rc high-nickel, high-chrome, hardened steel.

Tooth grinding or rotary-shaving operations are performed after the forged blanks are machined. A typical HERF process makes thirty SAE 9310 gas turbine engine spur gears per hour. The gears have 10-DP, 25°-PA teeth on a 4½-in. pitch diameter. HERF forging tolerances for the gears are plus or minus 0.005-in. with stock left for finish-shaving.

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