Current Practise in Surface Broaching

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One of the most revolutionary developments in mass production in many years is the introduction of surface broaching as a major metal-cutting process. Its greatest acceptance has come in the automotive industry, supplanting many well-intrenched milling-machine operations.

This paper is concerned with a detailed discussion of surface broaching in the automotive industry, covering the general applications, design of broaches, description of broaching machines, etc. The paper also includes tabular material giving production data such as broach speeds, broach life, productivity.

Wherever possible, attention has been given to general applications of the method so as to be of interest to those concerned with metal cutting in various industries.

WIDESPREAD adoption of external or surface broaching by a number of important mass-production industries has met with such marked success as to make it worthwhile for those concerned with machine-shop practise to investigate the subject.

Needless to say, it is not a new method; it has been known for a great many years, but it has been only within the last two years that the possibilities of surface broaching have been seriously considered. Within the last 15 or 18 months unique equipment has been designed specifically for economical surface broaching which has almost caused a revolutionary change in machine-shop practise in mass production.

What Is Surface Broaching?

Surface broaching is a method of removing metal from the exterior surfaces of machine elements whether the surfaces be plane, irregular, or a combination of the two. It is essentially a "copying" method employing a long broach with a multiplicity of cutting teeth, the number of teeth and, consequently, the length of the broach being dependent upon the requirements of the specific job.

The outstanding advantage of the method lies in the ability to remove a comparatively large amount of metal in a single pass of the broach from the rough surface to the final finish. Wherever an extremely fine surface finish is required, the broach may be equipped with an extra section of cutting teeth to serve the function of a burnishing tool.

Applications of Surface Broaching

In its present development the greatest impetus to surface broaching has come in the field of mass production, particularly in the automotive industry. A variety of operations which formerly have been handled exclusively by various forms of milling are now accomplished by surface broaching. These include such operations as cutting slots, serrations, grooves, bearing joints, recesses, etc. The method also has encroached on certain applications of surface grinding, gear roughing, and gear finishing, particularly in the formation of straight gear teeth and the roughing of bevel and helical gear teeth.

Equipment is being developed to finish by surface broaching extremely wide, plane surfaces, such as may be found on engine-cylinder blocks and cylinder heads, now exclusively finished on huge drum- and table-type milling machines. Another important development is the finishing of cylindrical surfaces, such as crankshaft journals. This process has already been adopted, experimentally, by one of the largest automobile manufacturers.

The growth of the present movement is undoubtedly due to the cooperative effort and the friendly exchange of experience among a group of broach manufacturers and builders of broaching equipment whose chief objective has been to advance the knowledge of the art.

Broaches and Broach Design

On the basis of available data, the author has found that practically all broaches used at present are of high-speed tool steel and generally built up of individual sections which provide for simple and economical replacement. Broach length varies widely according to the requirements of the individual part, also within the limitations of the broaching machine. For example, at least one operation (Chevrolet transmission case) uses a broach only $6^1/_2$ in. in length, while a continuous horizontal machine has been tooled up with a broach 75 in. long. Only experience will show whether further advantage may be gained from the use of other types of tool materials as well as the practicability of using inserts of some of the cemented carbides for certain classes of work.

Cemented-carbide broaches have been in use for several years in machining cast-iron (split), valve-guide bushings for one of the large car manufacturers. These are machined from rough castings on the split face and the half-round slot, in one operation. High-speed steel showed a high run of about 150,000 pieces between grinds. Cemented carbide has made a high run of 800,000 pieces between grinds and a record run of more than 1,000,000 pieces. The cemented-carbide broach has been adopted as standard on this operation.

The broach must be designed to suit the need of each individual job since tooth-spacing, thickness of the chip, clearance angles, height and width of the insert, and other factors can be determined only after a careful study of the part. Within these practical limitations, the length of sections in sectional broaches varies rather widely between 6 and 14 in.

If the same broach is used on two slightly different parts, something will be sacrificed; it may be the type of finish or the life of the tool or floor-to-floor time. The latter particularly will be sacrificed when a more or less standard broach is used as in small-lot production. It is suggested that the best design of a broaching-tool unit is one which would allow for a minimum time for replacement or a maintenance operation. This construction is

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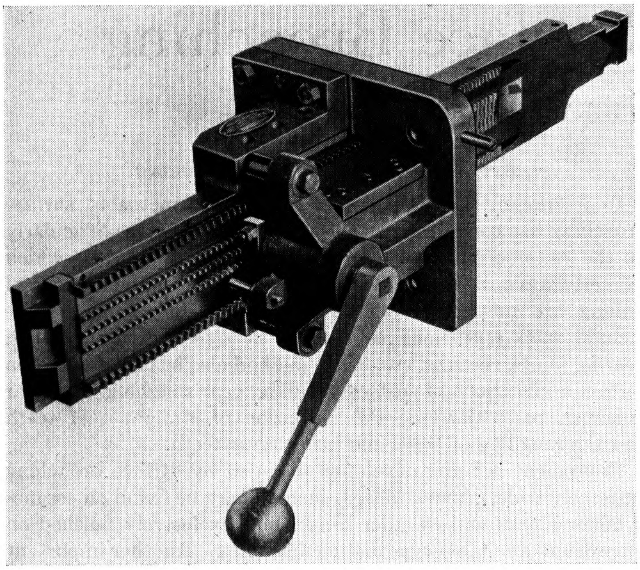

Fig. 1 Insert-Type Broach With Simple, Quick-Acting Fixture for Use in a Horizontal-Type Broaching Machine

said to be approached by designing the broach with inserts which are mounted on a small subplate or several smaller subplates, each as light as possible. The insert unit and the subplates are then connected to a larger holder which is mounted stationary on the ram slide and acts as a support and locater for the smaller unit. Fig. 1 is an example of a broach of the insert type with a simple quick-acting fixture designed for use on a horizontal-type broaching machine.

Fig. 2 shows the tooling for broaching the teeth in a cast-iron segment. The broach is concave to conform with the arc of the segment and is made in three sections bolted to a massive guide. The graduations from the forming of the arc to the finish-form of tooth profile are clearly seen. This job is set up on a vertical machine, the same machine being used for two other parts. The production rate is 225 pieces per hour.

The more complex sectional broach shown in Fig. 3 was designed for automobile-engine connecting-rod operations. In operation 1 it is used to broach the large bore of the connecting-rod end and the two faces across the end of the rod. The broach is also used for operation 3, which finishes the corresponding surfaces on the bearing cap. As indicated in section *BB*, the center section of the broach is of semi-circular form, while the two outer broaches, *C* and *D*, are flat. The three sections are of the same length so that as the finishing insert is worn undersize, the first section on the roughing end is removed and all inserts are moved forward one section while a new finishing section is inserted. After this the entire broach is reground.

Round broaches are so designed that they are interlocking, as shown in section *AA*. Two male projections are provided on each end, located in a bearing mounted on the broach holder. When two sections are joined together, a locking screw is inserted which draws the two round sections together and locks them

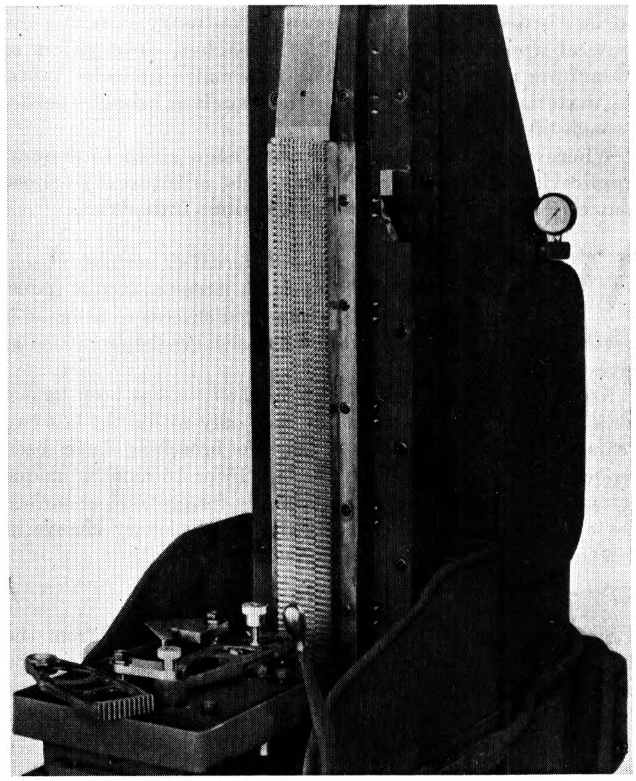

Fig. 2 Tooling for Broaching the Teeth in a Cast-Iron Segment

(The broach is concave to conform with the arc of the segment and is made in three sections bolted to a massive guide.)

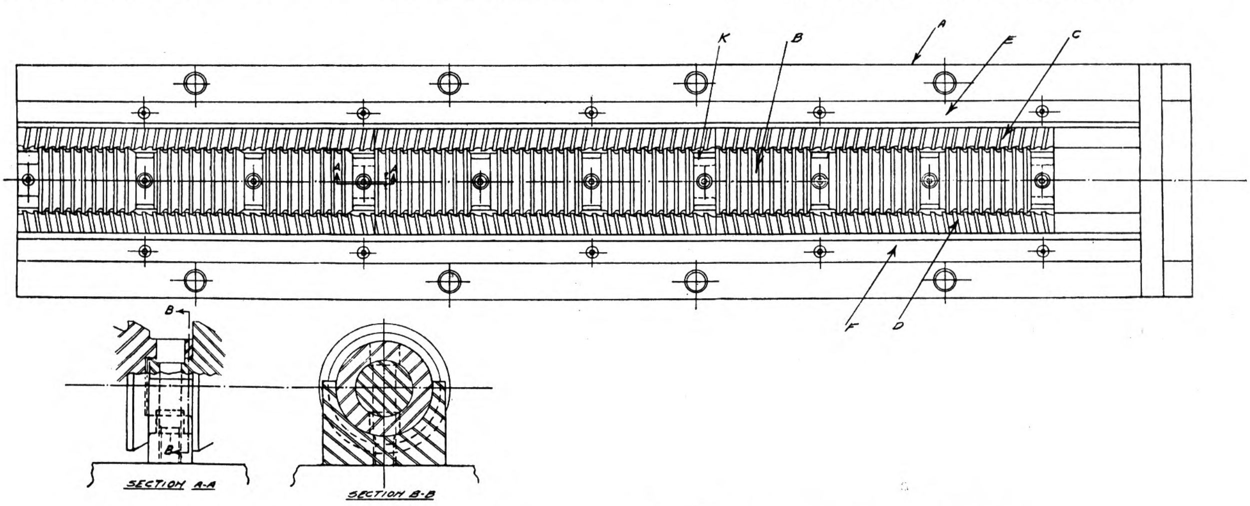

Fig. 3 Sectional Broach Designed for Automobile-Connecting-Rod Operations

against the main channel of the broach. The broach inserts are provided with cutting teeth around the entire diameter, and as the teeth become dull on one side the locking screws are removed and the broach is turned 180 deg and locked as before.

Each broach requires 18,000 to 22,000 lb pull as it removes about $^7/_{32}$-in. of metal per side from the half-round surface, both the rod and cap being broached from the rough forging. The estimated rate of production is about 300 pieces per hour per broach; the estimated number of pieces per sharpening is about 15,000.

Broaching Machines

In investigating the development of surface-broaching equipment, it is interesting to find that initial applications, experimental runs, and small-volume production were formerly worked out on obsolete screw presses, rack-and-pinion punch presses, and, in fact, on any equipment capable of pushing a broach mounted on a ram slide. As a matter of fact, some jobs were handled on a planer with the work mounted in a fixture on the tool-post rail.

For mass-production work today, the market affords a great variety of surface-broaching machines, chiefly of the vertical and horizontal types, with perhaps a greater preference for vertical types. Many of these machines operate hydraulically; some are of the rack-and-pinion type. Production machines are built with either single or double-ram slides, the latter being preferred in high production because of the utilization of idle time, inasmuch as the operator can load one ram while the other is cutting. Examples of typical vertical machines follow:

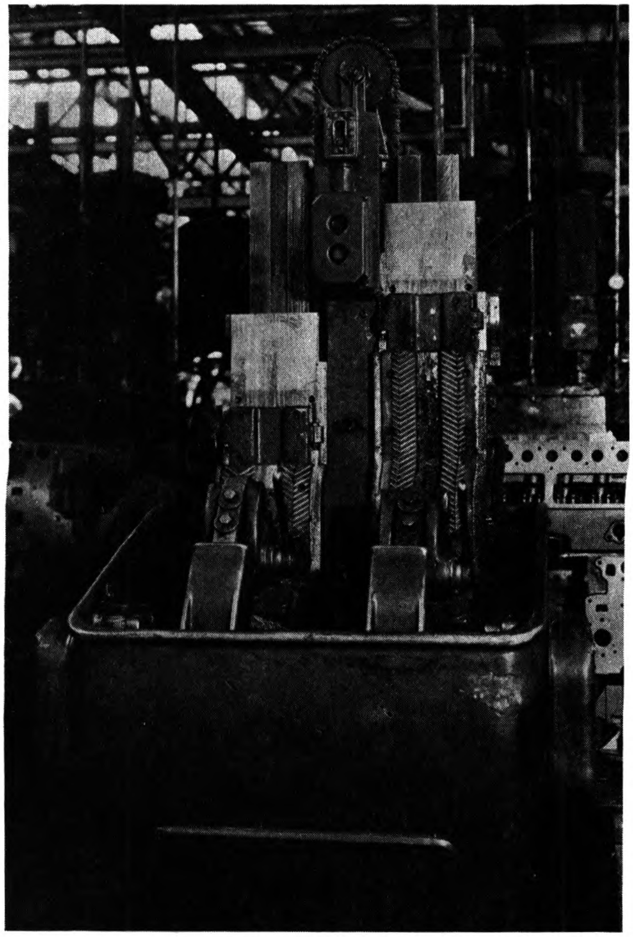

Fig. 4 Duplex Surface-Broaching Machine for Broaching to Size the Joint Face and Ends of Crankshaft-Bearing Caps

Fig. 4 is a duplex surface-broaching machine for broaching to size the joint face and ends of crankshaft-bearing caps. These caps are of gray cast iron with a maximum Brinell of 157. Two tilting fixtures are used in which the part is locked in place by a lever-operated cam. The average material removed is 0.6212 cu in. per cap, the average rate of production is 398 caps per hour, and the average number of caps per grind of the broach, 31,500.

Fig. 5 shows a new vertical, hydraulic machine which has been developed. A number of these machines have been installed in the Newcastle plant of the Chrysler Corporation. This machine features a one-piece, welded-steel structure and can be built with suitable tonnage capacity and width, height, daylight, stroke, etc., as required. Chips are readily removed through a chute at the left of the machine and the cycle may be controlled by hand or foot and semi-automatically or fully automatically.

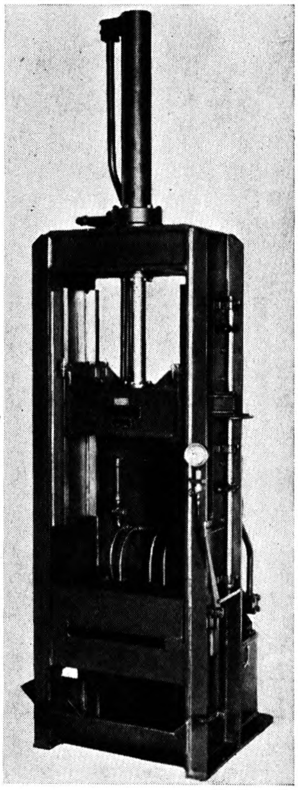

Fig. 5 Vertical Hydraulic Machine

Fig. 6 shows a vertical surface-broaching machine. This machine is hydraulically operated, of the pull type, and will handle broaches up to 44 in. in length. As shown in Fig. 6*a*, the machine is equipped with an automatic tilting fixture arranged for handling two pieces at a time. The work is yoke-shaped, $2^1/_8$ in. wide; the cut is $1^1/_4$ in. deep; and an average of $^1/_8$ in. of metal is removed from each surface. On this particular job the machine is tooled up for a semi-automatic cycle. The cutting stroke is started by pulling the operating lever. When the broaches complete the cutting stroke, the fixture automatically rises *and the broach starts on its upward or return stroke.* During this portion of the cycle the operator removes the pieces and puts in two more for the next cycle. The floor-to-floor time for two pieces is 18 sec. This machine can be fitted with any type of fixture—tilting, sliding, or indexing.

Fig. 7 shows a vertical, hydraulic, duplex broaching machine with an automatic indexing table designed to reduce idle time. This machine is so arranged that one ram goes up while the other moves down, one broach cutting during the cycle. The indexing of the table is controlled by a hydraulic mechanism interlocked with the operation of the vertical rams. The broach on the descending ram engages the work in the fixture which has been indexed to the cutting position, while the fixture on the opposite side of the table has been indexed to clear the broach on the ascending ram. At the completion of the cutting stroke of one ram and the return stroke of the other, the rams stop, the work table indexes, the rams reverse their direction of movement, and the cycle of operations repeats itself.

For very high rates of production, ranging upward of 1800 pieces per hour, several different types of fully automatic, continuous broaching machines have been developed. Such a horizontal, continuous surface-broaching machine is shown in Fig. 8. In this machine the individual fixtures are mounted on the chain which wraps around the driving and the idler sprockets. The number of fixtures is governed by the production desired and the size of the work. Power is transmitted to the chain through a worm set connected directly to an individual-motor drive. The fixture tunnel is mounted on the bed of the machine, providing hardened-steel guides for the fixtures.

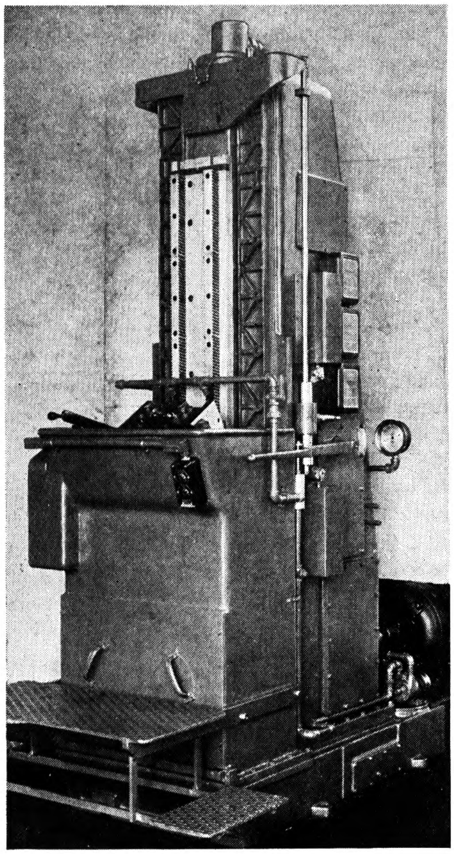

FIG. 6 VERTICAL, HYDRAULICALLY OPERATED, SURFACE-BROACHING MACHINE OF THE PULL TYPE

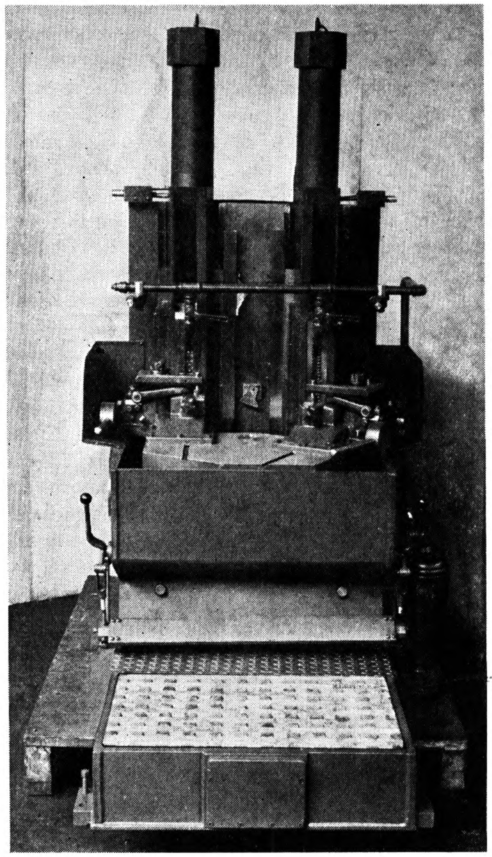

FIG. 7 VERTICAL, HYDRAULIC, DUPLEX BROACHING MACHINE WITH AUTOMATIC INDEXING TABLE

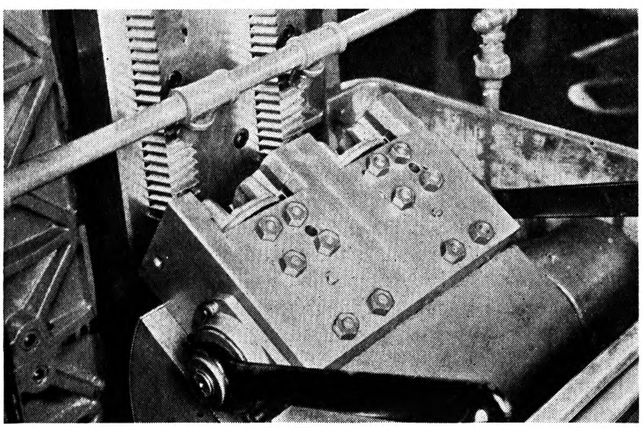

FIG. 6a AUTOMATIC TILTING FIXTURE USED ON THE MACHINE SHOWN IN FIG. 6

This machine is very flexible and can be designed with a broach holder at the top as shown or with a combination of broach holders, one at the top and one underneath, where the nature of the work requires operations on both ends. The fixtures usually are of the automatic-clamping type. The operator places the work in the fixtures where it is equalized by a cam guide at the point where the fixtures automatically lock by means of a built-up pressure from a cam hammer blow. After the fixtures pass through the broach, they are automatically released by a cam and at the unloading position the work drops out of the fixture into the chute.

More recently this machine has been designed to handle work with indexing fixtures; Fig. 8 is an example of this type. This particular machine is arranged for squaring both ends of a shackle pin. In operation, the pins pass through the first set of broaches machining two flats at each end; a second set of broaches is located directly beneath the fixtures and performs a similar operation on the other end of the pin. After this cut the groove on the top plate of the fixture engages the indexing pin, and gives the work-holding spindles one-quarter of a turn. The work then proceeds through the remaining straddle broaches completing the square, after which the pin is automatically ejected from the fixture.

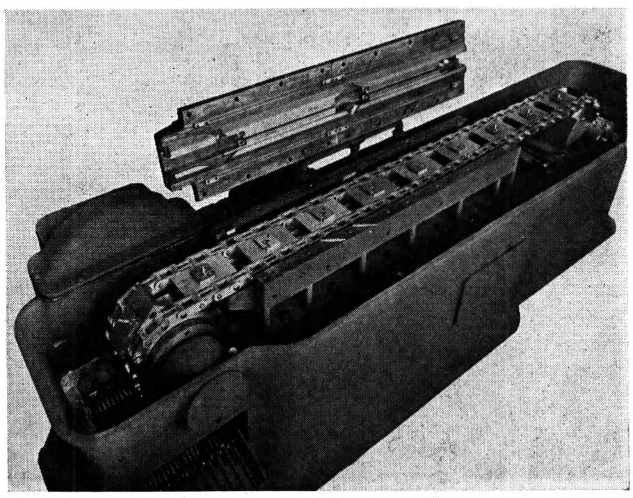

FIG. 8 HORIZONTAL, FULLY AUTOMATIC, CONTINUOUS BROACHING MACHINE, DESIGNED FOR HIGH-PRODUCTION WORK RANGING UPWARD OF 1800 PIECES PER HOUR

A rotary, continuous surface-broaching machine is shown in Fig. 9. The machine is so designed that a considerable length of broaching-tool surface can be used, the broaching tools being made up of various sections so that any section can be replaced or reground with little expense. The tools are mounted around the rim of the column on the finished platen which extends 190 deg around the column. The machine illustrated is equipped with fixtures for broaching yokes, the operation consisting of finishing the four bearing surfaces. It has a total of ten work fixtures with a table rotation of one revolution per minute or a production of ten finished pieces per minute.

The rotary action of the machine in combination with stationary broaches and a certain type of broach tooth is said to give a unique shear action that is very desirable in removing metal. The chips removed by this machine are said to be different from those produced by any other broaching method. The life of the tool is said to be prolonged by this shear effect to the extent that a production of more than 200,000 pieces can be obtained from a set of tools. The machine is fully automatic, the function of the operator being confined to loading and pulling a starting lever. As the work comes out from the final cutting operation, it is automatically loosened by means of a roll that comes in contact with the lever.

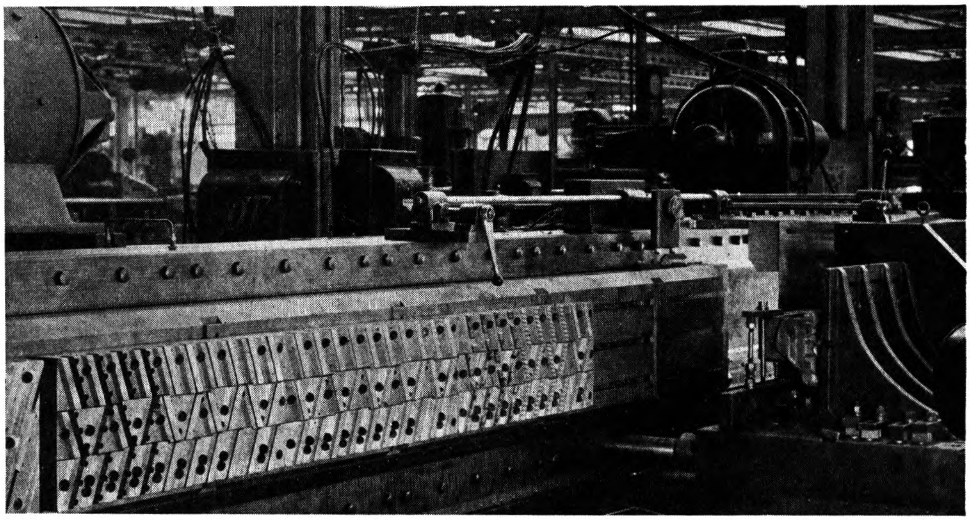

Fig. 10 Large, Horizontal Broaching Machine for Finishing the Entire Top or Bottom Surface of Cylinder Blocks in One Pass of the Broach

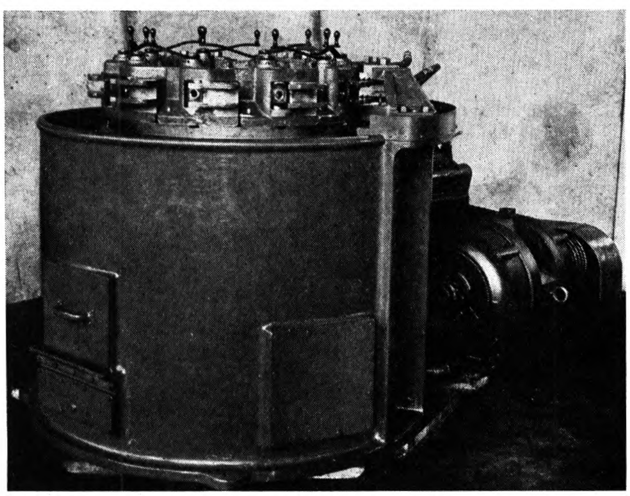

Fig. 9 Rotary, Continuous Surface-Broaching Machine

In addition to the production machines described, there are other developments still in the experimental stage but of great interest nevertheless. One of these is the huge horizontal machine shown in Fig. 10 which was built experimentally for finishing the entire top or bottom surface of cylinder blocks in one pass of the broach. As shown in the illustration, the broaching tool is of built-up construction using inserted single-blade teeth.

Details of Application

Fig. 11 shows parts being finished by surface broaching at the Chevrolet transmission plant, Toledo. Materials include cold-rolled steel, cast iron, and alloy steel. Production figures on each of the parts are given in Table 1. While space does not permit a detailed examination of each of the parts shown in Fig. 11, Figs. 12 and 13 have been selected as being typical of the practise at this plant.

Fig. 12 shows the formation of the tongue on the end of the countershaft. The operation is handled on a horizontal broaching machine finishing four shafts at a time. This view shows the detail of the 48-in. broach which is pulled hydraulically under the fixture.

One of the most interesting applications of surface broaching is the cutting of gear teeth or sector notches as in Fig. 13. Here is a horizontal, hydraulic broaching machine set up for forming the notches in the brake-sector stamping. Six stampings, $^1/_4$ in. thick, each with seven notches, are finished in one pass of the broach. Five of the stampings are ready for use directly after broaching, while the sixth, the one near the power end of the

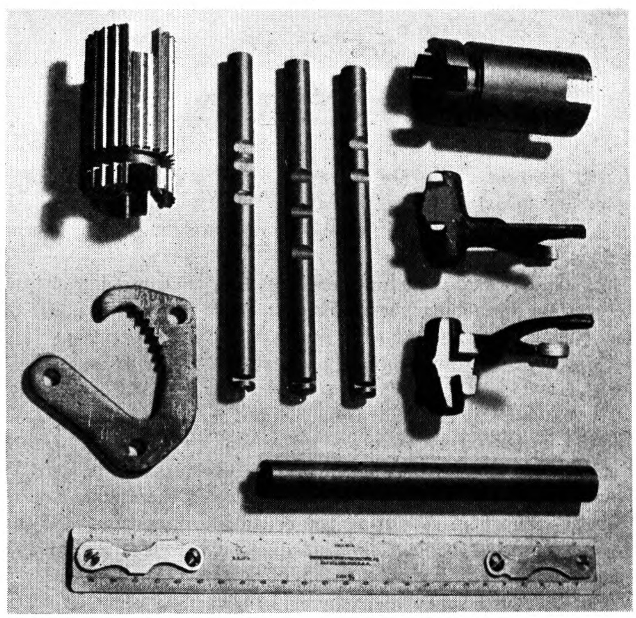

Fig. 11 Various Cold-Rolled-Steel, Cast-Iron, and Alloy-Steel Parts Being Finished by Surface Broaching

(The operations of broaching some of these parts are shown in Figs. 12 and 13, and production figures on each of the parts are given in Table 1.)

TABLE 1 DETAILS OF CHEVROLET BROACHING PRACTISE

Description	Operation	Material	Broach length, in.	Broach surface speed ft. per min.	No. of pieces per grind	Life of broach	Cutting compound
Countershaft	Forming tongue on one end	1020 C.R.S.	48	30	7,000	42,000	Soluble oil (10-to-1 mixt.)
Shifter Shafts	Cutting notches and locater slot in one operation with two separate broaches	1020 C.R.S.	32	30	7,500	37,500	Soluble oil
Hand-brake sectors	Cutting teeth (61,010 $^1/_4$-in. pieces per cut) stampings	......	24	25	6,500	39,000	4% sulphurized mineral oil, full strength
Second and third speed clutch sleeve	Cutting slots (3 in. one end broached on one machine. 3 in. in other end on another machine)	Vanadium 6150-A	62	36	8,400 (slots)	11,200 (3 slots in each piece)	Soluble oil (10-to-1 mixt.)
Transmission housing	Shift-rail slot	Cast iron	6$^1/_2$	12	70,000	150,000	None
Shifter fork	First operation, Broach slots, both sides	1035 Forging	46	27	2,500	15,000	Soluble oil (10-to-1 mixt.)
	Second operation, finish pads and cut clearance	......	47	27	2,600	15,000	Soluble oil (10-to-1 mixt.)

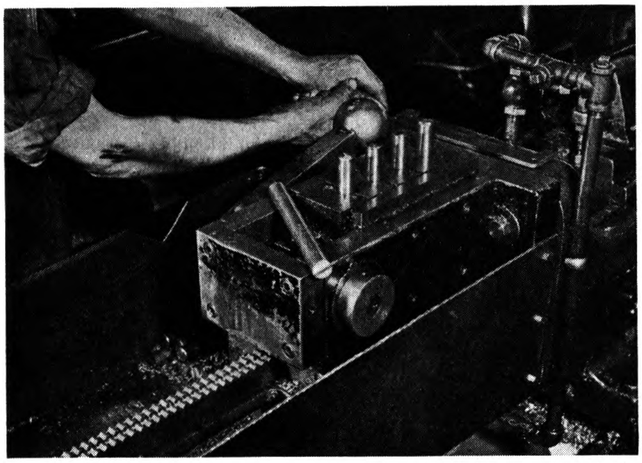

FIG. 12 FORMATION OF TONGUE ON THE END OF THE COUNTERSHAFT, HANDLED ON A HORIZONTAL BROACHING MACHINE

broach, requires a separate operation to remove burrs. Finished pieces are stored in a tote pan at the left; stampings ready for the loading in the fixture are shown in place on the bar in the background.

Fig. 14 shows two machines used by a large automobile manufacturer for broaching the bearing face and the parting line of steel-backed, connecting-rod bearings. Both operations are performed prior to final boring and are considered truing operations.

The machine at the right broaches the surface of a half-round hole in two half-bearings in one operation. The holding fixture which is self-contained is hydraulically operated. The part is inserted in the fixture and held in position by a spring action which is cam operated during the broaching operation. As the broach returns to the loading position the fixture is automatically opened for unloading and reloading of new parts.

The broaching ram which travels in a vertical plane slides in ways incorporated in the fixture. The broaches are made in sections, adjustable for depth of cut by the use of tapered wedges. When the broach becomes dull it can be rotated 180 deg to make available a new set of cutting teeth.

Following this operation the parting line of each bearing is broached on the machine at the left. The fixture used for holding the two half-shell bearings is hydraulically operated. After the parts are inserted into the fixture, a clamp exerts a light pressure allowing them to become equalized for the amount of stock to be removed on each parting line.

As the broach ram starts, a roller in contact with the cam operates a hydraulic cylinder, locking the parts rigidly in position while they are being broached. At the completion of the stroke the fixture releases the parts for unloading. Four separate surface broaches are suitably located on the broach holder to complete this operation. The broach holder is self-contained in the fixture, operating in its own ways, the broaching-machine ram being used only to move the broach holder the length of the stroke. Approximately 0.004 in. of stock is removed per side on each operation.

An interesting application is the cutting of deep, narrow, radial slots in speed-reducer rings. The slots are 18 deg apart, 0.153 in wide by 1$^1/_{16}$ in. deep. Broaching is done on a horizontal, hydraulic broaching machine at a cutting speed of 27 fpm. Each slot is cut singly and the fixture is indexed. The material is cast iron. The production rate on this machine runs 14 pieces against four pieces per hour, the previous milling time.

The life of the broach is 10 to 12 grinds and tool life between grinds runs about 3800 to 4000 finished pieces.

Another interesting job is the broaching of two diameters on the ring wing for hydraulic shock absorbers made by Houde Engineering Corporation as shown in Fig. 15, the operation is performed on a horizontal broaching machine with a 15-hp drive. One broach is cutting while the other is returning to the loading position. The details of the operation follow.

The operation shown here is the rough broaching of the small-radius segments to a diameter of 1.261 in. from the rough forging. The diameter of the forging before broaching is 1.295 to 1.340 in.

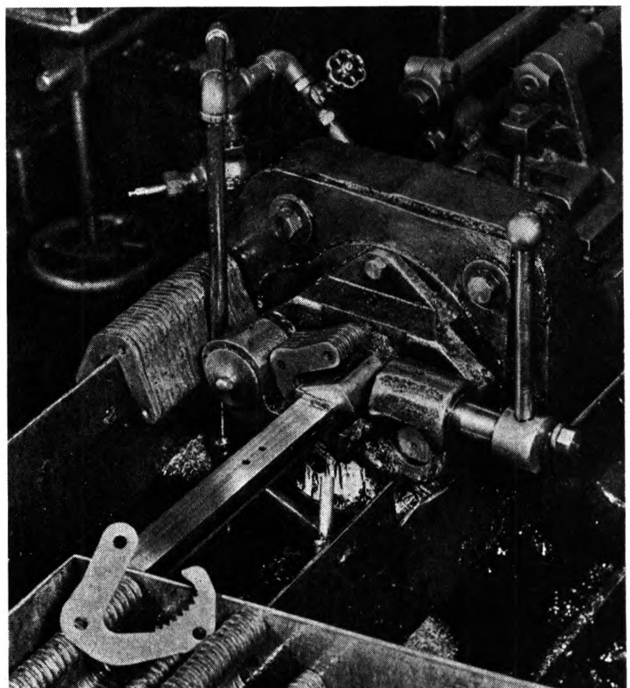

FIG. 13 CUTTING GEAR TEETH OR SECTOR NOTCHES ON A HORIZONTAL HYDRAULIC BROACHING MACHINE, SET UP FOR FORMING THE NOTCHES IN THE BRAKE-SECTOR STAMPING

One man operates one machine with two broaches and performs 500 broaching operations per hour. A pull of approximately 9000 lb is required for each broach. The material is a 0.10 to 0.20 silicon, heat-treated carbon steel with a Brinell hardness running about 285 to 321.

A really outstanding, specialized application is that of broaching the bearing-cap slots or the bearing lock in the bottom of a cylinder block at the Plymouth Motor Co., producing 110 cylinder blocks per hour with one handling of the work. Only one operator is employed.

As shown in Fig. 16, the machine is of the horizontal-type, hydraulically operated, and is in the conveyer line. The work is rolled off the conveyer into a fixture rigidly fastened to the bed of the machine. The operator throws the air valves which lower the piece firmly on to locating blocks fastened rigidly to the bed, where it is lined up by dowel pins, throws an air valve, controlling wedge-operated, end stopping members, rigidly to support the work against the end thrust of the broach, and then throws the lever to start the machine. The broaching table carrying the broach cutter moves forward under the work, broaching the four slots at one pass. At the completion of the cut the air valves are thrown in the reverse direction, the piece is raised out of the path of the broach, and the cutter then returns to its starting position. The temporary end stop is removed, and the operator pushes the work out of the fixture.

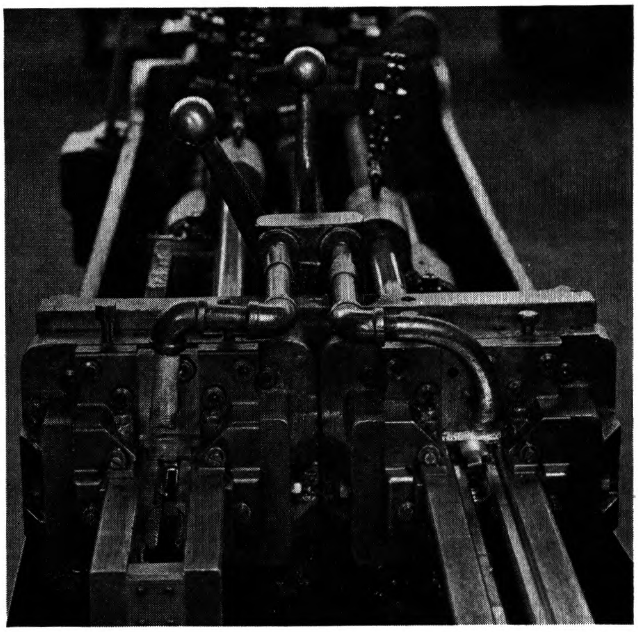

FIG. 15 BROACHING OF TWO DIAMETERS ON THE RING WING FOR HYDRAULIC SHOCK ABSORBERS

TABLES AND PRODUCTION DATA

While it would be rash to generalize as to the probable life of the broaching tools, some conclusions may be drawn from the available production experience. Some of the early performance figures were given in the author's 1934 S.A.E. Annual Meeting paper.[1] The higher values of tool life between grinds of the broach are corroborated by experience at the Plymouth Motor Car Corporation where the tool life in finishing bearing caps is 31,500 pieces between grinds and for drop-forged connecting rods, 21,600 pieces between grinds. On the cylinder-block operation with the broach taking four widely separated intermittent cuts, the broach life between grinds runs about 7000 blocks.

From available data it appears that the surface speed of a broach generally varies from 18 to 33 ft per min and in one case, that of the clutch-sleeve operation at Chevrolet (Table 1), the surface speed is 36 ft per min. The difficulty in attempting to rationalize such data lies in the fact that few of the applications are comparable on a common basis. For instance, much of the early work was done on obsolete or make-shift machines and obviously the production figures can be greatly improved. Then again, there are the variations that result from the machining of totally different kinds of metals, as well as the profound differences which may come about through the use of special broaches and fixtures.

It seems most significant, however, that even the lower production figures quoted here are presumed to be a vast improvement over previous methods of metal cutting. However, these results bid fair to be greatly surpassed by the performance of the new high-production equipment that has been made available recently.

[1] "External Broaching Future Visioned From Study of Current Practise," by Joseph Geschelin, published in the *S.A.E. Journal*, February, 1934.

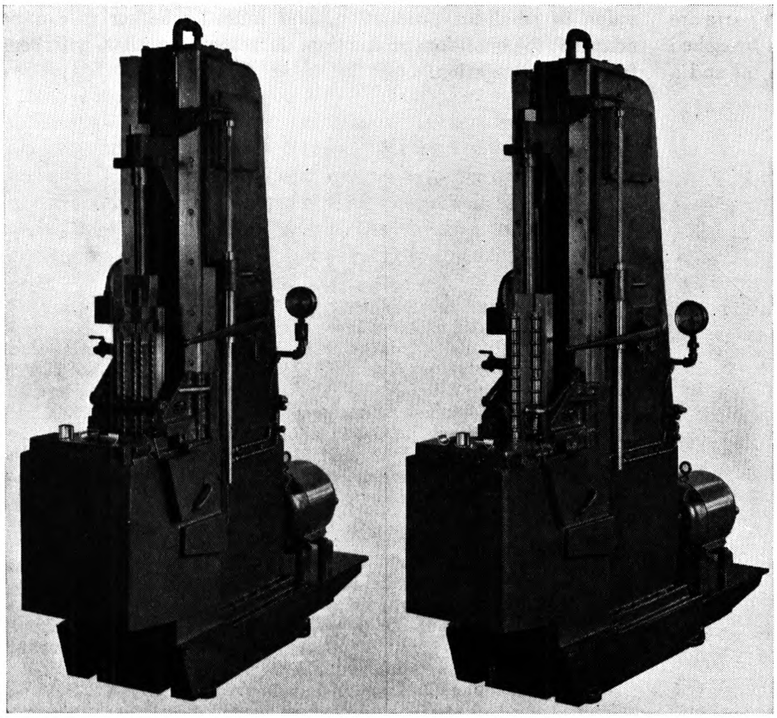

FIG. 14 MACHINES FOR BROACHING THE BEARING FACE AND THE PARTING LINE OF STEEL-BACKED, CONNECTING-ROD BEARINGS

(The machine at the right, surface broaches the half-round hole in two half-bearings in one operation. The parting line of each bearing is broached on the machine at the left.)

CUTTING FLUIDS

Current practise in the utilization of cutting fluids for surface-broaching operations shows how difficult it is to generalize from previous metal-cutting experience. For example, since surface broaching is partly a shearing action accompanied by the liberation of considerable heat, it was thought at the outset that the only suitable cutting fluid would be one possessing extreme-pressure characteristics and exhibiting to the greatest degree

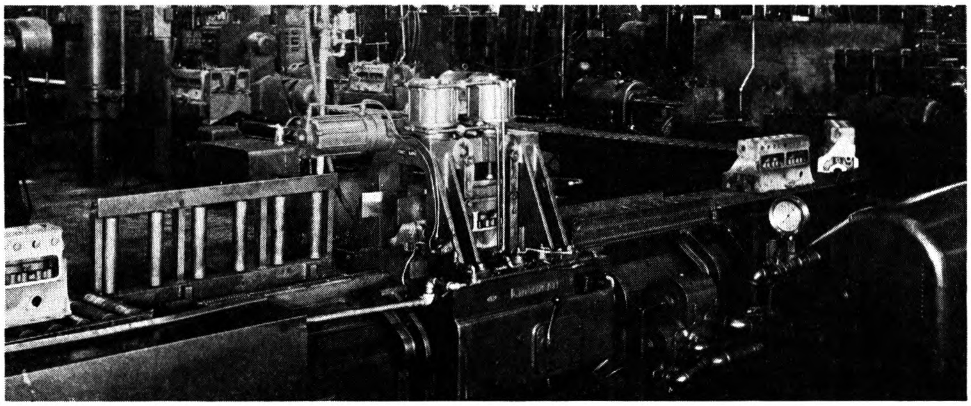

FIG. 16 HORIZONTAL TYPE, HYDRAULICALLY OPERATED MACHINE BROACHING BEARING-CAP SLOTS

the properties of an efficient refrigerant as well as one with good lubricating and wetting-out properties.

As a matter of fact, many applications have been successfully handled with a suitable sulphurized cutting fluid. One specification where surface finish is not very important, is the use of a mineral oil of Saybolt viscosity ranging between 150 to 170, containing not less than 2 per cent sulphur. For fine finish the same material is used with the addition of 10 per cent of lard by weight.

However, during the past year, with the increasing experience in large-quantity production, some of the largest users of surface broaching have found that the majority of operations can be handled economically with an inexpensive, soluble-oil mixture. One example is the Chevrolet transmission plant (see Table 1) where a 10-to-1 soluble-oil mixture is being used for all operations including the machining of alloy-steel forgings. The only exception here is the cutting of teeth in the hand-brake sector, where it is found necessary to use a 4 per cent, sulphurized mineral oil, full strength.

At Chevrolet and elsewhere, the fairly large cast-iron parts are machined dry. Some small cast-iron parts have been broached with a cutting fluid consisting of a mixture of paraffin oil and a small quantity of kerosene. This mixture is said to work equally well on brass and bronze, producing a fine finish as well as giving long life to the broach.

CONCLUSION

To summarize, surface broaching has created a distinct revolution in machine-shop practise, supplanting in many cases certain familiar processes which have been used for a great many years.

For obvious reasons it has been impossible to get any figures on comparative production costs. However, it is safe to assume that the successful manufacturers who have adopted this method in recent months would not have made so significant a change, entailing as it does a considerable capital investment, without having first demonstrated the overall economies of the method.

At present, the art of surface broaching seems to be best suited for large-volume production and all of the new equipment which has been announced during the past year is designed for high production. Whether this new method can be of economic value in small-lot production, and indeed whether it can be adapted to small-lot production, is something that will bear further investigation.