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Book

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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

This Issue

MACHINE TOOLS—I

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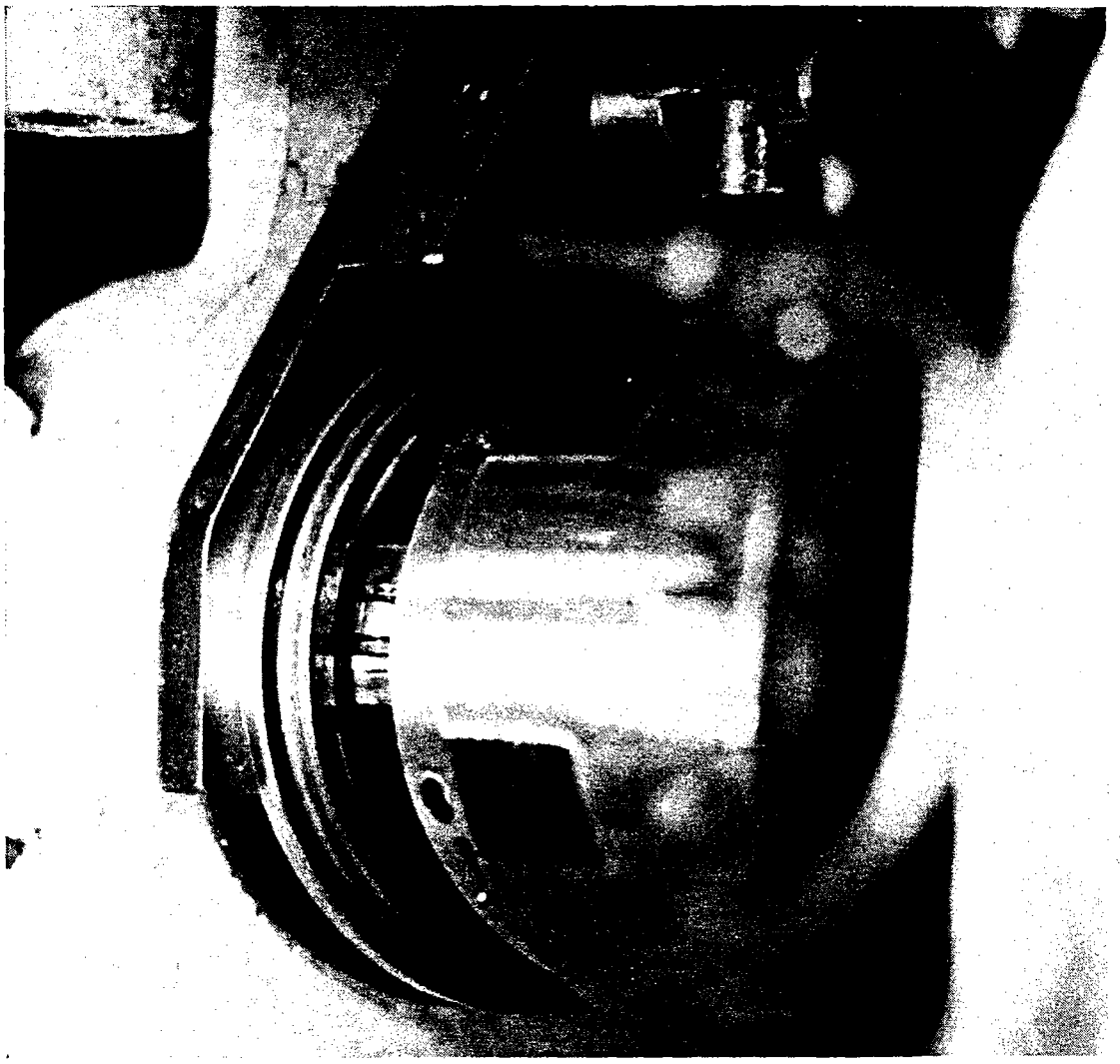

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MACHINE TOOLS—I

ONE dictionary[1] defines a machine tool as: "a non-portable power driven machine partly or wholly automatic in action for milling, plowing, turning, grinding, boring, drilling or otherwise changing the shape of material by removing metal in the form of blocks, fragments, spiral shavings or the like; a machine for making machines or machinery, for example, a lathe."[1]

"Machine tools form the basis for all modern industrial production: not only are they necessary in the manufacture of every type of engine and kind of mechanism, but they are essential for making the plants for processing textiles, chemicals, foodstuffs, metal goods and virtually every other commodity."[2]

A machine tool removes unwanted material by using power to force one or more much harder and precisely-shaped *tools* into the *workpiece* and moving the two relative to each other in one or more directions. There are only a few basic general-purpose machine tools, but literally thousands of adaptations of them which perform highly specialized operations at high production rates on specific workpieces, but frequently have little adaptability to anything else. The general purpose machines are operated by skilled machinists and produce only one or a few workpieces at leisurely rate: the specialized adaptations, however, are usually completely automatic high-production machines which need to be supplied only with power, working pieces or stock, lubricants, cutting fluids, and the occasional replacement or adjustment of tools by a skilled set-up man who may supervise the work quality on several machines.

This article will sketch the construction, operation and lubrication of the principal basic general purpose machines (like the lathe, milling machine, grinders, broaches, drills, planers, and shapers) and a few of such widely used high-production adaptations of the lathe like single, multiple spindle, and chucking automatics.

LATHE

As the dictionary definition[1] correctly suggests, the lathe is usually regarded as the primary machine tool and the principal progenitor of all the others.

"Leonardo da Vinci's records show a lathe with a pole drive apparently in use in the 1500's. ...In 1794 Henry Maudslay developed his first all-metal lathe with a sliding tool rest. John Wilkinson improved the lathe for boring purposes in 1776 for James Watt. Maudslay's adaptation of the lead screw to his lathe in 1810 made possible the construction of lathes, planers and milling machines in quantity and really laid the basis for the modern family of machine tools. By 1840 these tools were

[1] Webster's New Collegiate Dictionary (1956)
[2] Encyclopedia Brittanica

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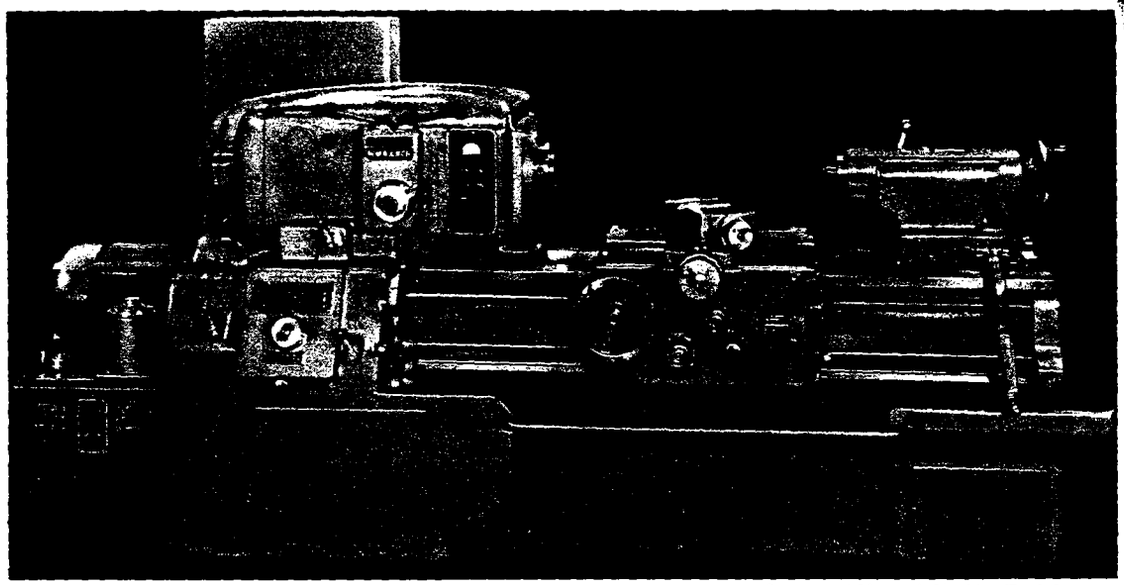

Courtesy of Monarch Machine Tool Company

Figure 1 — A modern general purpose screw-cutting engine lathe with refined controls, a quick change gear box, power feeds, removable chip and splash pan and (at lower left) the driving motor, a cutting fluid tank and pump.

fairly well established as productive machines for industrial use. Their objective is two-fold, namely: to provide much greater power than man himself can furnish to form and shape certain of his materials of construction; and to give him skill and precision in this work which man alone cannot provide."[2]

The ancestor of the lathe cannot be positively identified, but the wheel and especially the potter's wheel are possibilities.

The modern lathe obtains the necessary relative movement between workpiece and tool by rotating the workpiece against a more or less stationary tool. (Wilkinson's "lathe" of 1776 would probably be called a "horizontal boring mill" today because the large workpiece—a cylinder casting for one of Watt's steam engines—was held stationary while the tool was spiraled through it.)

As illustrated from left to right in the highly developed modern machine shown in Figure 1, the basic screw-cutting engine lathe consists of: (1) a *headstock* with bearings and adjustable-speed drive for the hollow *spindle;* (2) a *carriage* with *cross-feed* and angularly-adjustable *compound* carrying the *tool post;* (3) a movable *tail stock,* all mounted on and accurately aligned horizontally and vertically by means of the *ways* on top of the *bed* or basic frame of the lathe; (4) drive gearing, belting and a drive motor or other power source. The *workpiece* may be held either in a *chuck, collet,* or *faceplate* on the headstock spindle or between a pointed *live center* in the spindle and a similar *dead center* visible in the tail stock of Figure 1. The position and cutting depth of a rigidly-mounted single-pointed tool in the tool post is controlled by micrometer handwheels on the compound and crossfeed: the fact that the tool is held by the lathe is responsible for its designation as an *engine* lathe. The engine lathe in Figure 1 is also of the *screw cutting* type since it contains a long longitudinal accurately-machined *lead screw* which can be quickly geared to the spindle with any of numerous ratios, and can also be connected to the carriage by means of an easily-engaged *split nut.* This arrangement enables the tool and carriage to be adjusted to traverse a definite distance or *lead* along the ways for each revolution of the spindle and to cut a spiral groove or *thread* of the desired *pitch* on either the interior or exterior of the workpiece and in either a right-hand or left-hand helix. If the workpiece is held entirely by some device on the spindle, inner, end and outer surfaces may be machined with one setting and perfect concentricity. Drilling a central hole through the revolving workpiece is easily accomplished by holding a drill in a stationary chuck on the tail stock. Small-angle external tapers of considerable length can be cut on a workpiece that is mounted between centers by moving the dead center horizontally a suitable distance. Either male or female tapers may be turned by disconnecting the cross slide from its feed screw and causing it to follow a stationary adjustable *taper attachment* bolted to the back of the lathe bed. Steep or large-angle tapers are cut by setting the compound at the desired angle, but are limited in length by the compound screw travel. Light milling operations,

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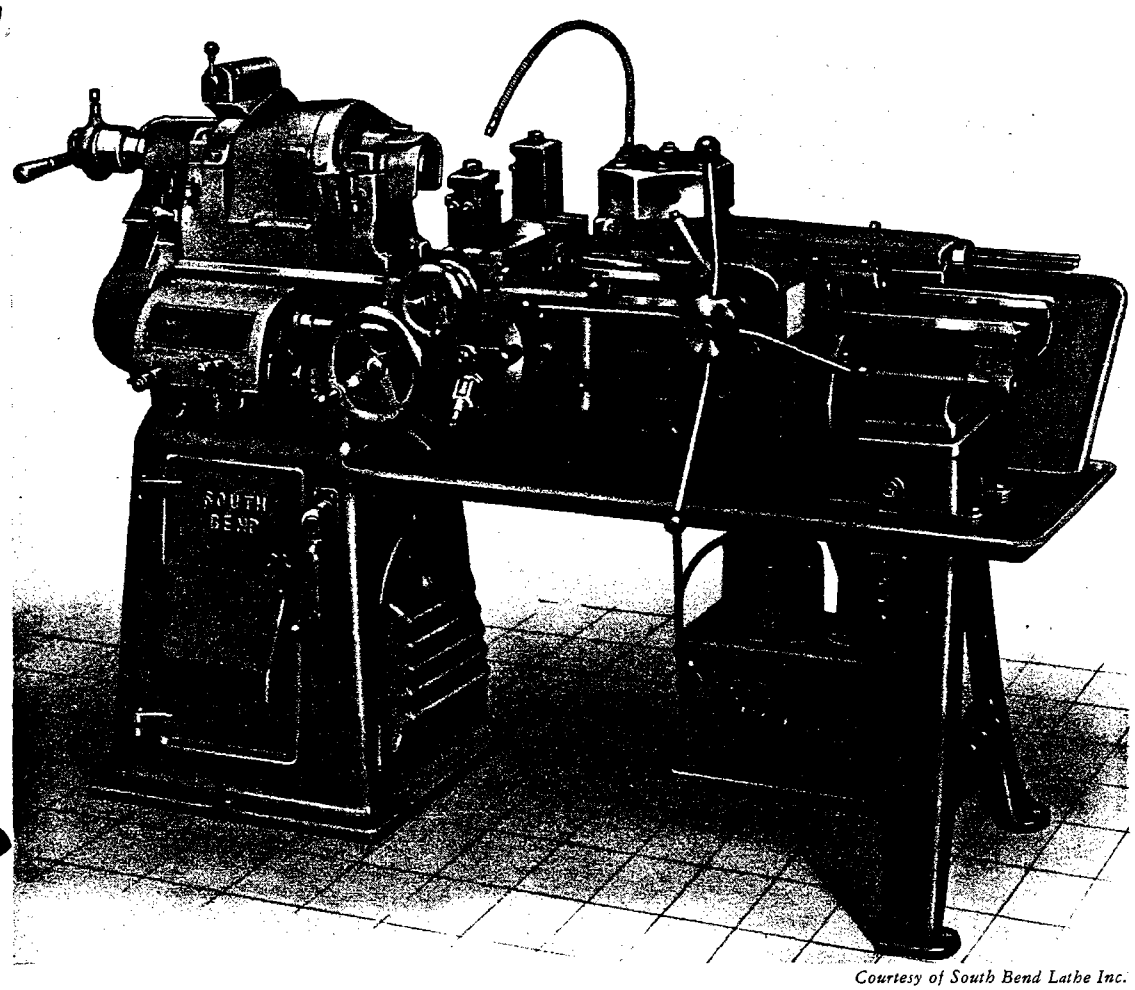

Courtesy of South Bend Lathe Inc.

Figure 2 — A manually-operated 13 inch precision turret lathe equipped with a quick-acting 1 inch collet, twin cross-slide tool holders, a quick change gear box and a six position automatically-indexed turret with individual stops.

like slotting and external keyways, are accomplished by mounting a vertically-adjustable workpiece vise on the tool post and a suitable milling cutter on the spindle. A small workpiece fastened at proper height on the cross slide or compound can be milled or bored with a fly cutter mounted in an arbor between centers. Both open and closed helical springs can be formed without heat treating by setting the change gears to the desired lead, then drawing piano wire through a tool post tensioning device and around a spindle-driven mandrel of smaller diameter. A small motor or belt-driven abrasive wheel can be mounted on the tool post, thus adapting the lathe for use as a cylindrical grinder.

These few examples demonstrate the remarkable versatility of the general purpose lathe and illustrate that its usefulness is principally limited only by the knowledge, skill and ingenuity of the machinist who operates it.

Since early lathes employed only manual adjustments, single tools, limited speeds and restricted power supplies, their abilities as production tools—i.e. to produce many identical pieces quickly and accurately—were also limited. Mechanisms and materials to correct these deficiencies were developed rapidly during the last 100 years to include: adjustable stops on feed mechanisms to permit quick and accurately-repetitive production by relatively unskilled operators; speed changing mechanisms ranging from multi-step pulleys and drive motors to quick-change gears and infinitely variable mechanical, electrical and hydraulic drives; power feeds, both mechanical and hydraulic; automatic chucking and gaging mechanisms; new cutting fluids and tool materials like high-speed steels and cemented tungsten carbide that permit higher speeds and feeds, i.e. the removal of more unwanted material in a given time; multiple tools and tool holders; massive, rigid constructural details; much more powerful driving motors; automatic mechani-

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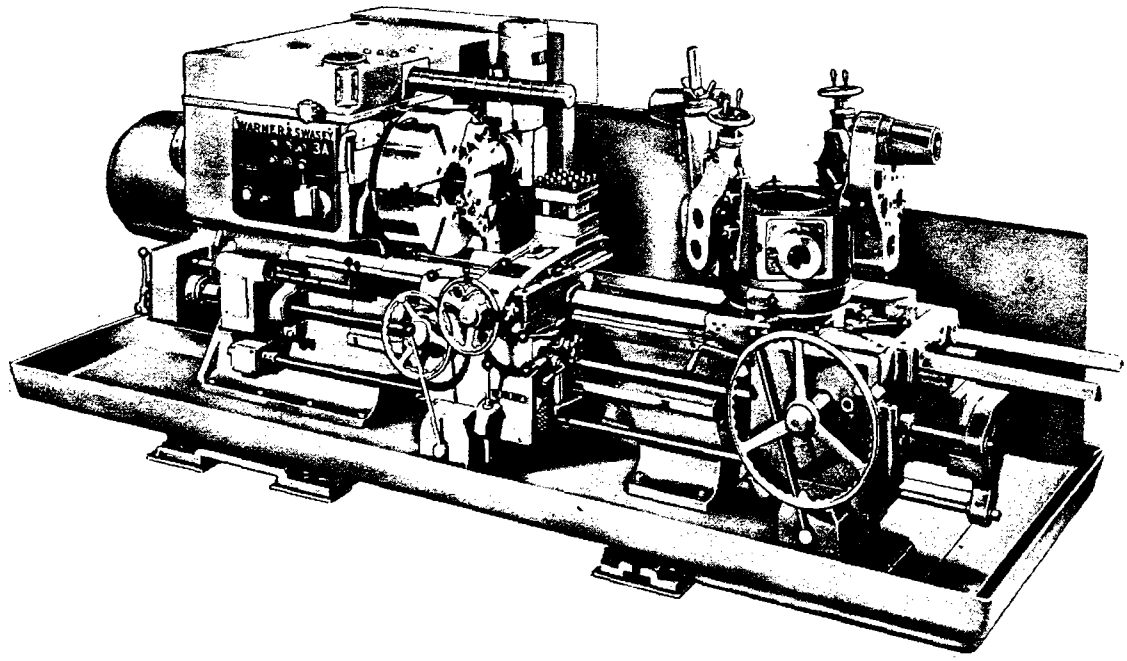


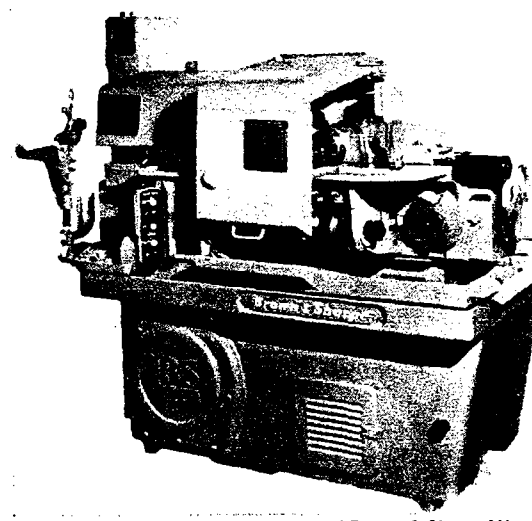
Courtesy of The Warner & Swasey Company

Figure 3 — An extra heavy duty saddle type turret lathe with 23½" swing and spindle bore of more than 6 inches. Note large "universal" scroll type three-jaw chuck on spindle, heavy tool holder on cross slide and six position turret with two steady rests to brace tools during especially heavy operations.

cal and electronic mechanisms which can be pre-set or programmed to take over almost complete control of the machine.

When machining a complex workpiece in a general purpose lathe, considerable time is spent in changing and adjusting the several tools that are required, and in feeding them only the required distance into the workpiece. Thus, one of the earliest and most effective adaptations of the lathe was the substitution of a multi-tool turret for the tail stock as illustrated in Figure 2. In this instance, the turret is capable of mounting six different tools, and is advanced towards the workpiece in the headstock collet, either manually by rotating the four-armed hand "wheel," or under any of 144 power turret feeds that are provided by the quick change gear box. As the turret is withdrawn, it is indexed automatically to the next tool while the corresponding stop-rod (of the six projecting from the rear of the turret) is similarly rotated into working position. Two tool holders on the cross slide are provided for forming and cutoff tools which must be advanced radially into the workpiece.

Figure 3 shows a considerably larger extra-heavy duty turret lathe with special steady-rests for at least two of the six turret positions. Though not apparent in the picture, this lathe is equipped with Bijur lubricant pumps drawing from the headstock reservoir and a very complete system of oil distribution tubing to the cross slide, turret saddle and headstock gearing. The headstock reservoir contains 18½ gallons of an oxidation and corrosion inhibited premium hydraulic oil having a viscosity of approximately 215 Saybolt Universal Seconds at 100° F.



Courtesy of Brown & Sharpe Mfg. Co.

Figure 4 — A compact highly developed single spindle automatic screw machine for high speed turning, boring or threading workpieces up to 1½" in diameter and 3½ inches long. Automatic changes in spindle speed are made, and complete reversal is accomplished in 6 seconds.

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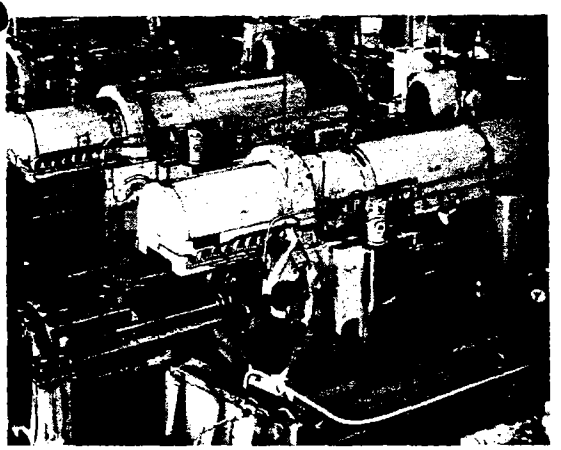

Courtesy of Lincoln Engineering Co.

Figure 5 — Two of a battery of six spindle automatic screw machines manufacturing deep-groove ball bearing races from seamless steel tubing. Note tubing for automatic measured grease lubrication of each point every 4 hours at a pressure of 2450 psi.

AUTOMATIC SCREW MACHINE

Screw machines are similar to turret lathes in construction except that the head is designed to hold and feed long bars of stock instead of castings or forgings. A variety of machining operations can be performed on both the end and side of the bar, and the machine movements are so actuated that identical parts are made continuously without the constant attention of an operator. Bars are fed into the machine, the machining operations are accomplished, and the finished parts are removed without being handled. Figure 4 illustrates a single-spindle automatic screw machine capable of machining work pieces up to 3½ inches long from 1½" diameter bar stock.

The first automatics were limited to the performance of the few simple machining operations necessary to produce small screw parts; hence the name "Screw Machines." By contrast, the present day machines can make practically any part that can be machined from bars of steel, iron, brass, aluminum or any of the special alloy metals. The name "Screw Machine" as applied to the present automatics is much too limiting and not sufficiently descriptive to indicate the scope of operations that can be performed. Consequently some manufacturers are now identifying these machines by the more general term of "Automatic Bar Machines."

Standard models of automatics are available for machining bar stock of all diameters up to and including 7¾ inches and of all shapes whether round, square or hexagonal. Some machines can turn out finished parts as long as 30 inches, although usually the length of the stock machined is appreciably less than that. There are two distinct classifications or types of machines: namely, the single spindle and the multiple spindle. A brief discussion of the general operating principles of each follows:

Single Spindle Automatic

As the name implies, these machines work on only one bar of stock at a time. A bar up to 16 or 20 feet in length is suitably supported and extends through a hollow spindle, where it is held firmly by a collet. The machining operations are accomplished by cutting tools mounted on the turret and on the cross slides. The turret, or end tool slide, is directly opposite the spindle and normally will have five or six positions equally spaced around its circumference for holding tools which perform cutting operations on the end of the bar. The cross slides, of which there are usually two on a single spindle machine, are located at right angles to the spindle and carry the tools which machine the side of the bar.

When the machine is operating, the spindle and the stock are rotating at a given, predetermined speed, and provision is made for quick reversal of the direction of rotation whenever the nature of the operation so requires. A specified length of stock is automatically fed through the spindle into the machining area, and the turret and cross slides move in from their positions to start the cutting operations. When the tool or tools located in the first position of the turret have finished their job, the turret withdraws from the bar, is indexed to bring the second tooling position in line with the work, and is again moved forward toward the bar so that the tools in this position can perform their operation. This process continues until the turret has indexed through all of its positions and all of the tools have contacted the stock. In the meantime, the tools held on the cross slides have been doing their job simultaneously with the end working tools. The movements of the cross slides to and from the work are independent of those of the turret but usually are so controlled that the side machining operations are completed by the time the last end working tool has been completed. The piece is then cut off, stock is again fed into the machining area and the cutting operations are repeated.

Multiple Spindle Automatic

Multiple spindle machines like those shown in Figure 5 may have four, five, six or eight spindles spaced equally around a spindle carrier. As in the single spindle machines, long bars of stock supported at the rear of the machine pass through hollow spindles and are gripped firmly by a collet. The turret opposite the spindle carrier is equipped with as many tool mounting positions as there are spindles, and each position is such that an end work-

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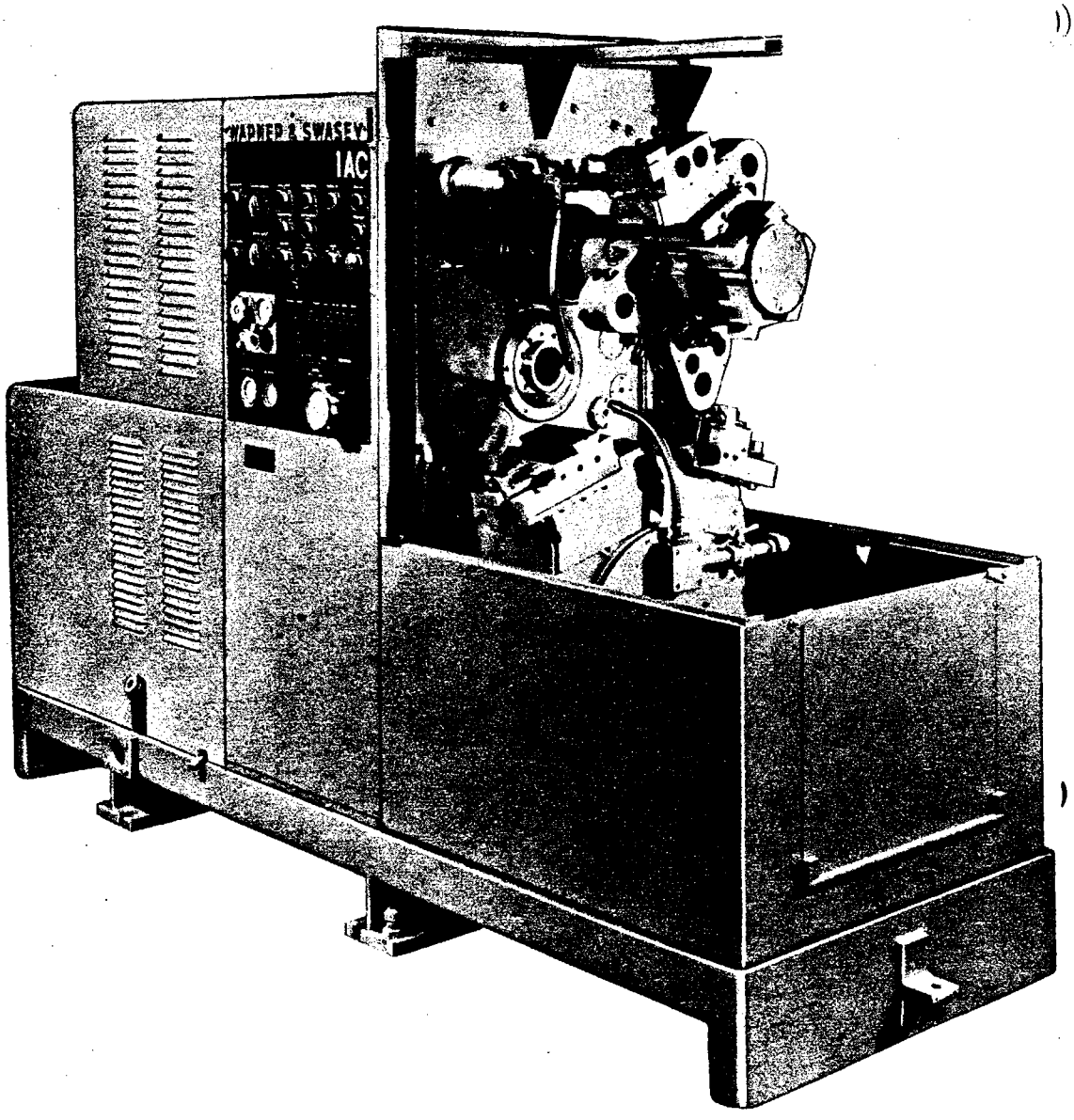

Courtesy of The Warner & Swasey Company

Figure 6 — A single spindle chucking automatic with five-position turret and two cross-slides.

ing tool is in direct line with a spindle. The cross slides holding the side working tools are placed at right angles to the spindles. All machines will have at least four cross slides and those with six or eight spindles may have two additional slides.

Construction and Operation

With the single spindle machine the turret indexes around the spindle, bringing the end working tools successively in position to perform their operations. When the tool or tools mounted in one position on the turret are working, those in the other turret positions are at rest. With the multiple spindle machines, the spindle indexes around the turret, carrying the bars of stock to the various end working and side working tools. In these machines each tool operates in only one position, but all tools are operating simultaneously.

For purposes of identification, the spindle positions are numbered consecutively in the direction of indexing, which may be clock-wise on some machines and counter-clock-wise on others. The position at which numbering begins also varies with different machine manufacturers. Stock is fed into

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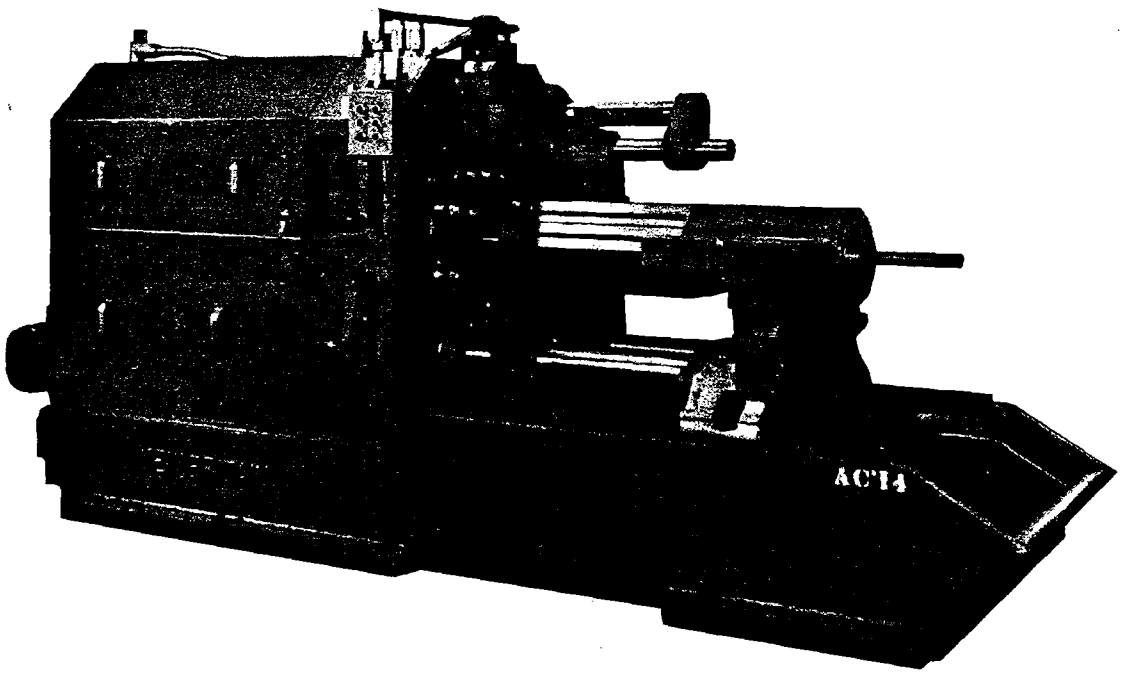

Courtesy of New Britain Machine Div. The New Britain Machine Company

Figure 7 — A six-spindle automatic chucking machine without tooling. Note massive six-sided turret at right center and three cross-slides.

the machine at a given spindle position, and as the spindle carrier indexes, the bar progresses from one tooling position to another. The end and side cutting tools at each tool position are so arranged that when the bar completes the circuit, the machining operations on the part are completed. Each time the spindle carrier indexes, a part is completed and cut off, a new length of stock is fed into the machining area, and the other pieces in the spindle are in various stages of completion.

Two-Speed Operating Cycle

The operating cycle for both single and multiple spindle machines consists of two parts, a high speed cycle and a low speed cycle: the latter begins when the turret and cross slides have advanced at high speed to within a hair of the point where the tools contact the stock and begin to cut at a lower speed. Immediately upon completion of the cutting operation, the machine again shifts into its high speed cycle. The turret and cross slides then withdraw rapidly, the turret or the spindle carrier indexes (depending upon whether the machine is a single or multiple spindle), the stock is fed and the turret and cross slides advance rapidly into the work while speed is decreased to the proper one for cutting.

Tooling

Automatics are inherently high-production machines, but their most efficient utilization on any given job depends largely on a satisfactory tooling set-up. This includes not only the proper choice of tools, but also the most suitable arrangement of the sequence in which they are used. Coupled with this, of course, is the selection of the feeds and speeds best suited to the material being machined and the use of a satisfactory coolant. In the interest of the best overall production rate, the machine usually is tooled and operated so that the production cycle is as short as possible without imposing such a heavy load on the cutting tools that the machine must be shut down frequently to replace or regrind them.

Several basic principles can be observed in tooling up an automatic. From the foregoing discussion it is apparent that one of the features of these machines is that of taking successive cuts on a bar of stock. The combinations of successive machining operations that can be performed are almost infinite. Multiple-spindle machines also take combined cuts; consequently, their frames are usually constructed from rugged alloy castings to minimize vibration obtained with heavy cuts and high speeds and to insure accurate performance, better finish and the maintenance of closer limits.

Large tooling areas are provided which permit free access to the tools and facilitate job set-ups and tool changes. This also allows ample space for coolant lines and enables the chips to drop rapidly from the machining zone and thus avoid interference with the cutting operations.

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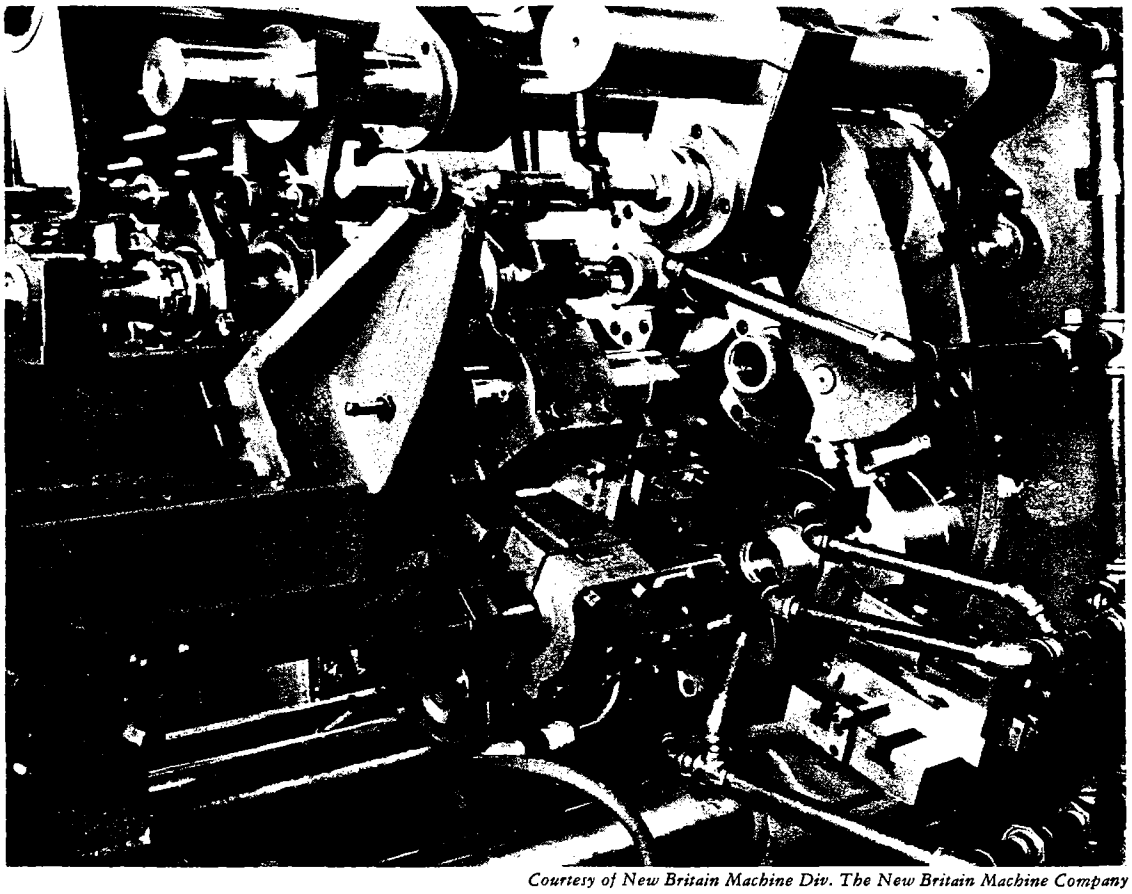

Courtesy of New Britain Machine Div. The New Britain Machine Company

Figure 8 — Closeup of tool and chucking area in the six-spindle machine of Figure 7 while actually machining male wing-nut unions. Note general massiveness and rigidity of tool holders and provisions for flooding each workpiece with cutting fluid.

Spindles

Spindles are made from precision ground, alloy steel tubes, and both ends are mounted in anti-friction bearings. All machines feature a wide range of spindle speeds and changing from one speed to another is accomplished readily by merely changing pick-off gears.

With the multiple-spindle automatic, however, the spindle speed is constant for any given set-up and is the same for all spindles. The spindles may be driven from a central gear on the spindle drive shaft to gears on each spindle.

Spindle Carrier

In multiple-spindle automatics the spindles extend through holes precisely and accurately spaced around a spindle carrier, which is made from a heat-treated and precision-ground casting and is usually shrunk onto the carrier stem. Both the stem end and the carrier itself are mounted on heavy, firmly supported bearings.

Indexing of the spindle carrier through the various positions is accomplished by a modified Geneva mechanism driven by suitable gearing. This permits rapid acceleration of the carrier in going from one position to another but provides a smooth, shock-free stop. After each indexing the carrier is automatically locked in place so that it cannot move during the cutting operations.

Stock Feed Mechanism

Bar stock is fed into the machining zone during the high speed cycle, and the process is accomplished by coordinated activation of the collet holding the bar in the spindle, a feeding device which advances the stock through the spindle, and a stock stop which accurately controls the length of stock fed.

Various types of spring collets located in the front of the spindle and held by a nose cap are available which can accommodate any shape of bar stock. The "grip" which the collet exerts on the bar is easily adjusted.

Numerous means are employed to feed the stock. Usually a feed tube supported on long bearings is located in the spindle behind the collet and is at-

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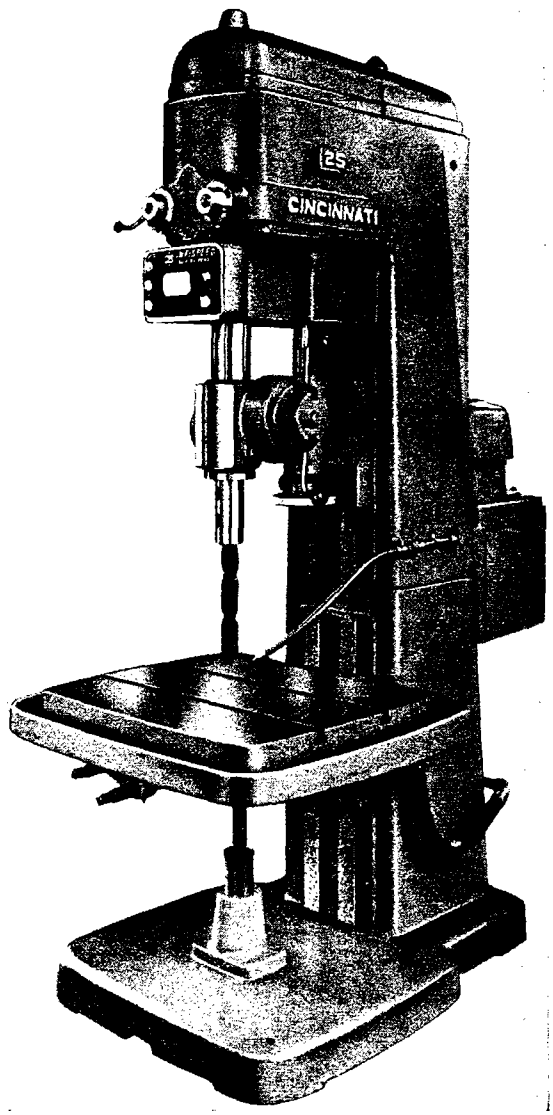

Courtesy of Cincinnati Lathe and Tool Company

Figure 9 — A 25 inch box-column sliding head drill press with infinite step speed control and indication between 60 and 1825 rpm. 1½" hole capacity in cast iron.

tached to a friction feeding finger. The assembly is operated by a cam, and during the machining cycle it is drawn back over the stock and the feeding finger grips the bar. During the idling cycle the collet automatically opens and the feed tube moves forward, forcing stock through the spindle and against a positive stock stop, which insures accurate reproducible feeding. The stop is cam operated and may be either the swing or receding type. It moves into position during the high speed cycle, and after the stock has been fed, it moves out of the machining area so as not to interfere with the cutting tools. All of the movements associated with feeding the stock must be very rapid but at the same time they must be smooth, shock-free and accurate, to prevent the stock from rebounding when it contacts the stop.

Turrets

The turret in a single spindle machine is made from a high alloy casting, accurately ground and fitted in large scraped bearings. Holes bored in the turret are fitted with clamped bushings to hold the cutting tools. Smooth and rapid indexing is accomplished by a Geneva mechanism, and the horizontal motion to and from the bar of stock is controlled by cams.

The turret in a multiple-spindle automatic is usually mounted on the spindle carrier stem and thus forms an integral unit with the spindle assembly. This assures permanent alignment of the turret with the axes of the spindles. In addition, the turret is further supported by a rugged guide arm which travels on a heavy guide plate. The horizontal motion is activated by cams or by intermittent gearing with clutches to shift back and forth from the high and low speed cycles.

The length of travel during the cutting cycle is easily fixed, and to insure accuracy and reproducibility, the turret operates against a positive stop.

Cross Slides

The cross slides are wide and long, of rugged construction and are mounted in such a manner that the bearing surfaces are protected from chips and grit. Their movements are controlled by cams, and the operation of each cross slide is separate and distinct from the others and also from that of the turret. The length of the cutting stroke is easily set, and like the turret, the cross slides operate against a positive stop.

The mutiple spindle machine will always have four cross slides and sometimes as many as six. It is general practice to use the lower slides for heavy work such as forming and the upper slides for finishing cuts. This reduces the chance of having finishing operations interfered with by falling chips.

Chucking Automatic

A *chucking automatic,* like that shown in Figure 6, has many of the features of the previously described automatic screw or automatic bar machines: in addition, it is capable of chucking and machining individual workpieces like castings or forgings.

Figure 7 illustrates a six-spindle automatic chucking machine designed to hold and successively machine six such pieces at a time. Figure 8 presents a close-up of the tooling area from the opposite side of the machine, showing three of the chucks holding three male wing-nut union workpieces which (from

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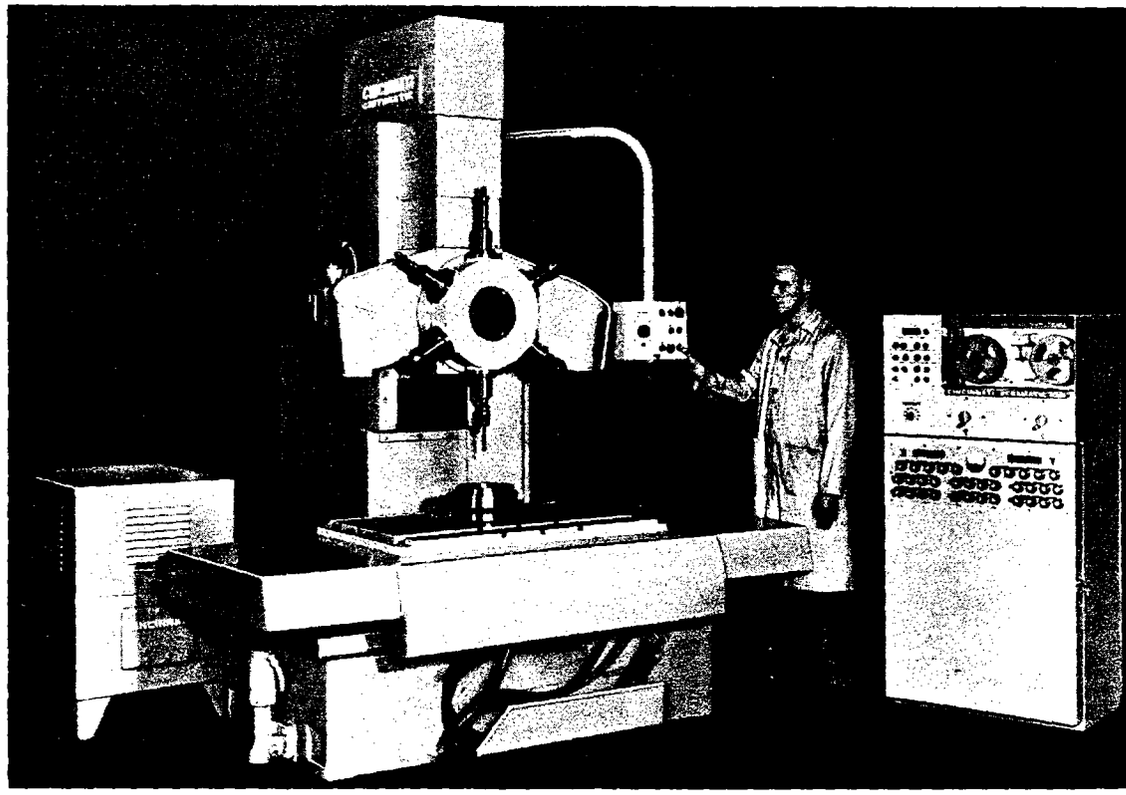

Courtesy of Cincinnati Lathe and Tool Company

Figure 10 — A numerically controlled turret drill with automatic simultaneous "X" and "Y" axis table movements at 200 inches per minute.

bottom to top) have been: (1) bored and faced; (2) taper-reamed internally and knurled externally and (3) tapped or threaded internally.

DRILL PRESS

As a hand tool, the drill is one of the oldest of implements; however, the application of power and either simple pressure or a regulated power feed to rotate and force a large drill into tough or hard materials is relatively recent. In size, they range from table-mounted high speed *sensitive drills* used to drill holes as small as only one thousandth of an inch in diameter to huge radial drills with a capacity of three inches or more. Large and deep holes like naval gun bores are drilled horizontally. The basic drill press consists of a heavy metal base and an upright column to which are attached the drillhead and the work table: beginning with this basic design, there are numerous modifications and attachments which greatly increase its versatility. For example, the modern floor drill illustrated in Figure 9 includes such refinements as: (1) a sliding head which supports the drill driving-spindle and its *quill* close to the workpiece, thereby increasing its rigidity and accuracy; (2) a massive work table, adjustable in height by screws and capable of being clamped rigidly to the column; (3) a self-contained motor and variable-speed spindle drive; (4) a power feed adjustable from 0.002 to 0.015 inches per spindle revolution; (5) a pump and reservoir for circulating cutting oil to the drill.

In a *radial* drill, the drillhead can be moved along the radial arm which can be rotated entirely around its massive vertical column, the combination thus permitting a number of holes to be drilled in a large workpiece without having to move it.

Figure 10 illustrates a numerically-controlled *turret drill* which can be adjusted and "programmed" with the tape mechanism to automatically drill any number of accurately located holes of six different diameters. The operator merely replaces workpieces and restarts the machine; consequently, he can supervise the operation of several.

Tapping attachments are available which drive the tap into the workpiece (with or without the assistance of a lead screw) to the pre-set desired depth, then automatically reverse and back out the tap.

Drillheads, complete with self-contained drive motors and automatic feed and withdrawal mechanisms, are frequently used as components of special machines to drill or tap the numerous holes at

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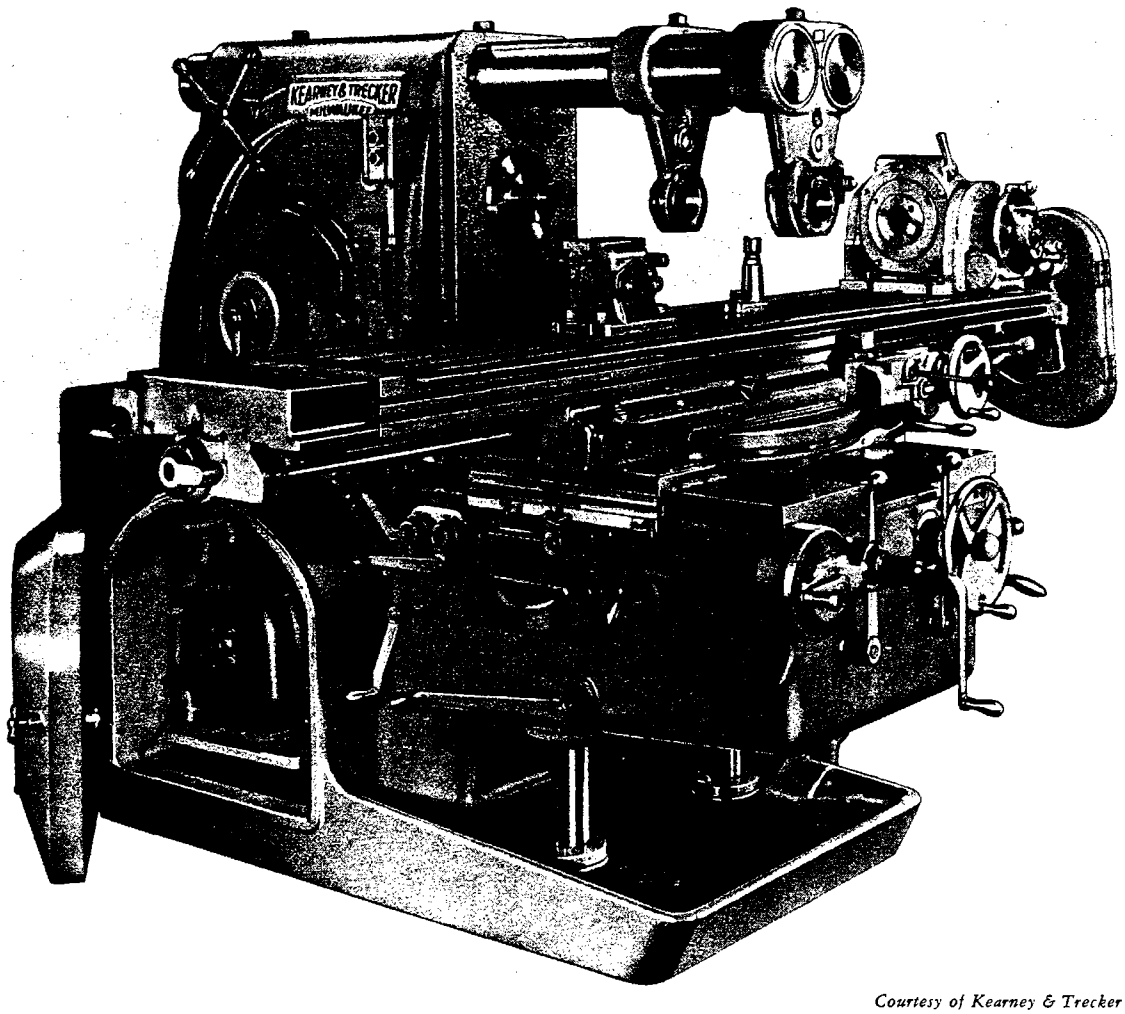

Courtesy of Kearney & Trecker

Figure 11 — A universal milling machine. Note horizontal spindle, twin cutter arbor supports, the massive knee carrying the universal table, the gear-driven dividing head attachment at right end of table.

unusual angles that workpieces like automobile engine blocks require.

MILLING MACHINE

The *milling machine* (usually shortened to "mill") removes metal by means of a multi-toothed cutter which is rotated relatively slowly, but most powerfully against the workpiece. The most common and versatile type is the *universal mill* shown in Figure 11 which employs a horizontal spindle driving the cutter arbor and a table carrying the workpiece which can be accurately moved longitudinally, crossways and vertically either manually or by power. Because of its rigid construction and high cutter torque, the mill can employ heavy cuts to remove large amounts of metal and (unlike the ordinary lathe) can machine large plain surfaces, slots, splines, keyways, irregular curved shapes like propellers and wing struts, cams, heavy low-pitch threads, worm and both spur and helical gears. The dividing head attachment shown in Figure 11 is used not only to space splines and gear teeth, but (when correctly geared to the table) to rotate the workpiece proportionally to table movement and thus permit machining of helical surfaces. Such a mill can be controlled by a tape or other automatic mechanism to machine complex surfaces with minimum human supervision.

As indicated by its name, the general purpose *vertical milling machine* shown in Figure 12 employs a vertical spindle with a cutter having multiple teeth on both its lower end and periphery. Thus, the vertical mill is especially adapted to machining the bottoms and sides of holes or depressions that could not be reached with the ordinary universal mill, for example, the work-holding

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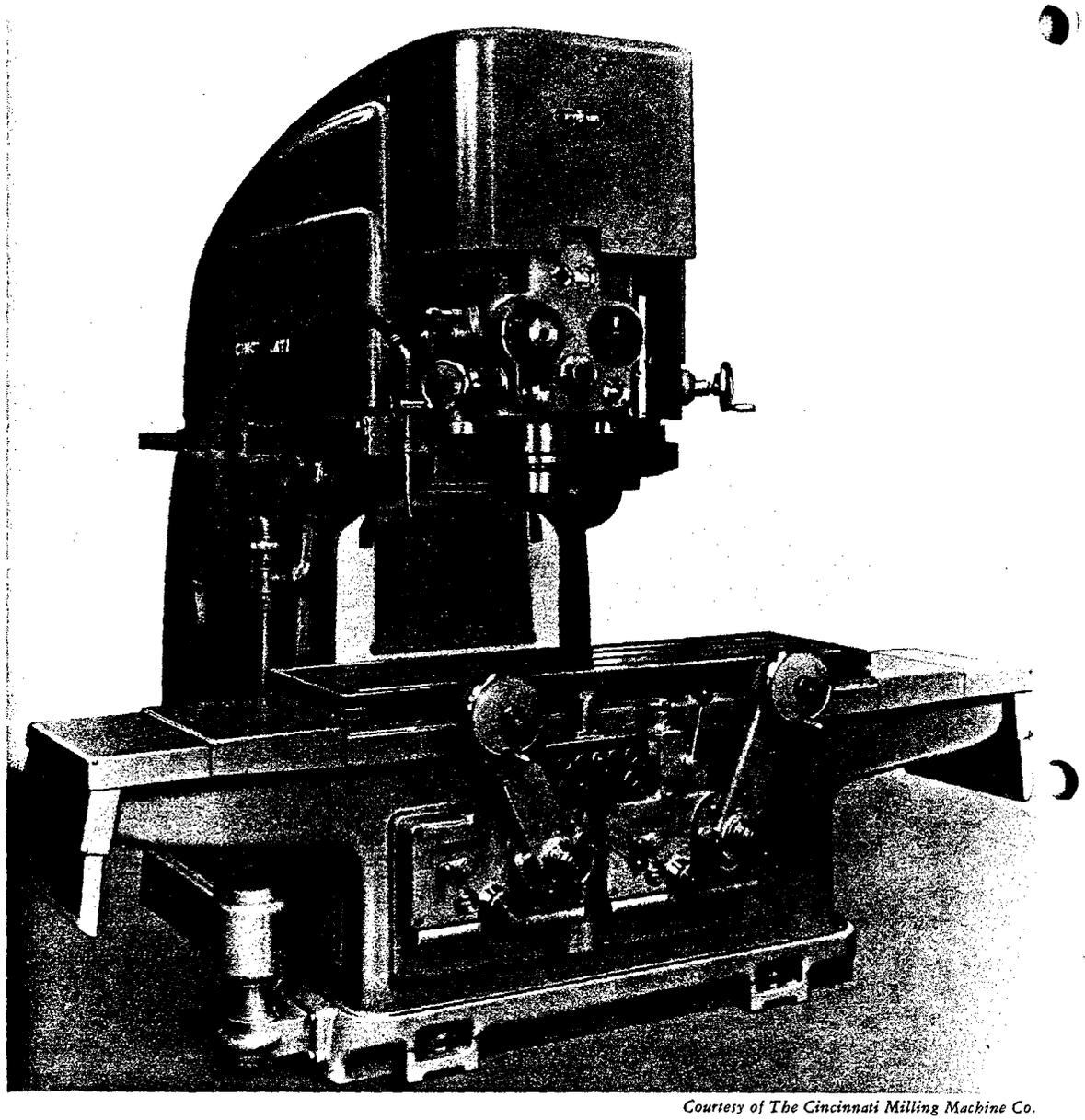

Courtesy of The Cincinnati Milling Machine Co.

Figure 12 — A general purpose vertical milling machine with bed carrying a plain table.

"T-slots" in the tables of most machine tools. (Vertical-mill attachments are available, however, for some universal mills.)

SUMMARY

Machine tools form the basis of all industrial production: not only are they necessary in the manufacture of every type of engine and kind of mechanism, but they are essential for making the plants for processing textiles, chemicals, foodstuffs, metal goods and virtually every other commodity.[2] This issue has discussed the construction and operating principles of the lathe, its automatic screw machine descendants, the drill press and the milling machine. The succeeding issue of this publication will continue this study with the shaper, planer, broach, and grinders and will discuss the general principles for lubricating all general-purpose machine tools.

[2] Encyclopedia Brittanica

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