

MULTIFUNCTION MACHINES

Many of the machine tools previously described in this volume often perform multiple operations. A good example is lathes, discussed in Chapter 8, "Turning and Boring." These machine tools can be used for turning, facing, drilling, boring, and thread cutting, and for other operations. However, when several operations must be performed on identical parts, with high production requirements, it is generally more practical and economical to use multifunction machines such as those discussed in this chapter. Multifunction machines perform a number of operations consecutively and/or simul-

taneously, often permitting complete machining in one setup.

A Machine Tool Task Force, supervised by the University of California, Lawrence Livermore Laboratory, released a report to industry late in 1980 predicting that more multifunction machines, special-purpose machine tools, and machining systems will be required in the future. Reasons for this include the continuing increase in labor and material costs, the shortage of skilled labor, and changes in customer demands.

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SINGLE-SPINDLE AUTOMATIC LATHES

Single-spindle automatic lathes basically are similar to many of the lathes discussed in Chapter 8, "Turning and Boring." Features of these machines include (1) the capability to use multiple tools mounted on two or more independent, synchronized slides and (2) automatic cycling. The machines can be single-cycle automatic, with manual loading and unloading, or fully automatic, equipped for mechanical loading and unloading.

A major advantage of single-spindle automatic lathes is high-speed production, resulting from having a number of tools cutting simultaneously, with no time lost for tool indexing or positioning. Customarily, as many tools as possible are used without exceeding the power of the machine and within the rigidity constraints of the workpiece.

Single-spindle automatic lathes generally are best suited for high production requirements in turning and facing multiple-diameter or long workpieces. The more complex the setup, the longer the production run should be for minimum cost because setup and changeover is time consuming.

When these machines are used for shorter production runs, consideration should be given to reducing the number of tools, thereby increasing the cycle time and decreasing the setup time. Setup time can also be reduced by sequentially scheduling the production of families of parts, thus minimizing changeover time. Lathes and turning centers

equipped with NC/CNC, discussed in Chapter 8, are being used extensively for short production runs and increased flexibility.

MACHINE DESIGN

Most single-spindle automatic lathes are arranged to turn workpieces held between centers, but some are designed for chucking work, with the workpiece held in a chuck, collet, or special workholding fixture. Most machines are of horizontal configuration, but some are built with vertical spindles. Depending upon the manufacturer, feed of the slides is accomplished with hydraulics, air/hydraulics, leadscrews, or cams. Figure 15-1, view *a* illustrates a machine with cam feed for the front slide; view *b* shows a machine with a leadscrew fed front slide.

Single-spindle automatic lathes are available in a range of capacities. Table 15-1 lists the capacities of four standard machines offered by one builder.

The basic machine consists of a headstock, a bed with front and rear ways mounted on a suitable base, a tailstock, a carriage with both longitudinal and crossfeed mounted on the front ways, and a squaring attachment clamped to the rear ways that provides crossfeed only.

On single-spindle automatic lathes made by this builder, the headstock contains both the spindle drive and the mechanical feed unit. Both the spindle speed and feed rate (in ipr or mm/rev) are

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CHAPTER 15

SINGLE-SPINDLE AUTOMATIC LATHES

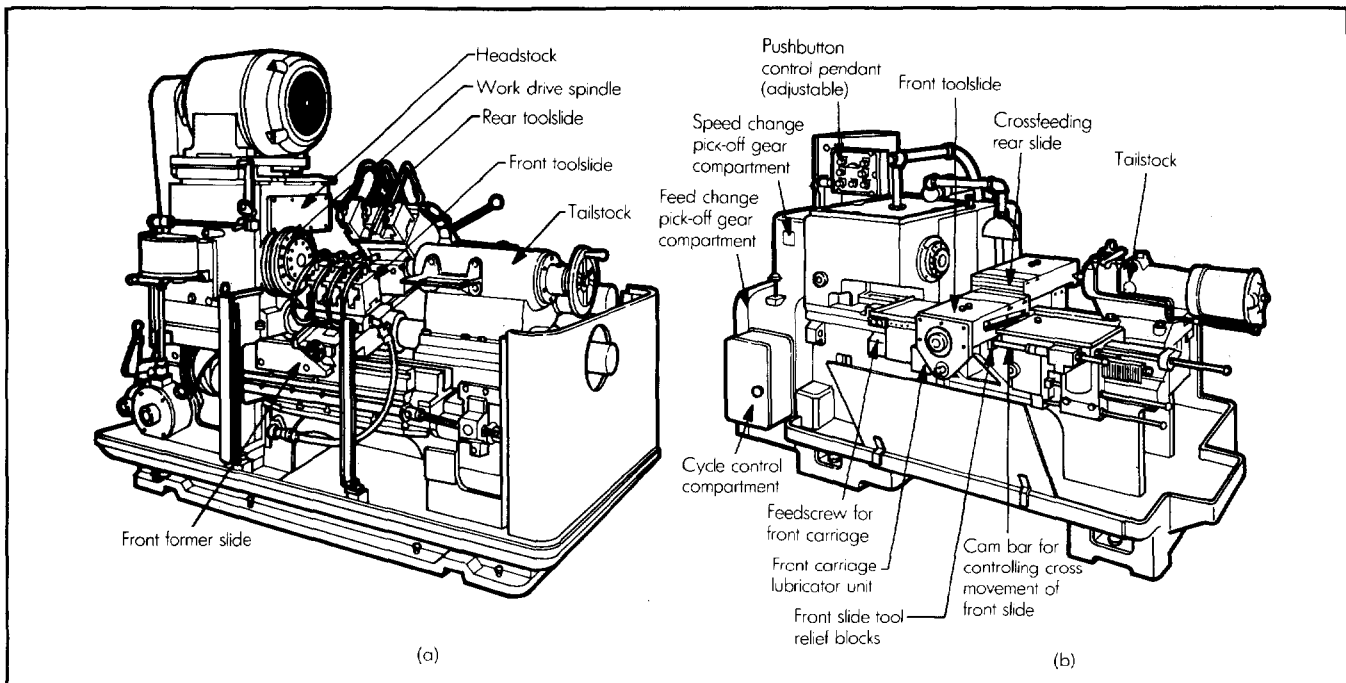


Fig. 15-1 Single-spindle automatic lathes: (a) cam feed for front slide, and (b) leadscrew-fed front slide.

selected by means of pick-off gears. More flexibility is generally not required on these high-production machines. In the rare case when a spindle speed change is required during the cycle, either a two-speed a-c motor or a d-c variable speed drive can be used. Since the feed is driven from the spindle, varying the spindle speed does not affect the feed per revolution. Special cams are available for situations in which feed variation during a cut is required.

All the cutting attachments are driven by cams which are connected to the feed unit without the use of clutches. This design prevents any possibility of the machine getting out of time after being set up. All the cams make one revolution per machine cycle.

Rapid traverse is provided to reduce nonproductive cycle time to a minimum. The points in the cycle at which the machine shifts from rapid approach to feed and from feed to rapid retraction are adjustable.

The front carriage is moved along the bedways by a pull-bar driven by the main cam. Any desired stroke (up to the total rise

of the cam) can be attained by adjustment of the device which connects the carriage to the pull-bar. The carriage cross slide is moved in and out by means of a cam driven by an adjustable, intermittent gear drive. This adjustment allows the cross slide to be in cutting position during any desired portion of the

TABLE 15-1
Capacities of Single-Spindle Automatic Lathes

Maximum hp (kW)	Maximum Length Between Centers, in. (mm)	Swing Over Ways, in. (mm)	Swing Over Slides, in. (mm)
7 1/2 (5.6)	12 (305)	11 (279)	4 1/2 (113)
25 (18.6)	40 (1016)	11 (279)	5 1/2 (140)
60 (44.8)	100 (2540)	16 (406)	7 (178)
150 (112)	120 (3048)	23 1/2 (597)	14 (356)

(Seneca Falls Machine Co.)

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longitudinal travel. In addition, by appropriate simultaneous adjustments of the longitudinal and transverse motions, the front tools can be made to approach the work either straight in or at an angle. Angular approach is desirable for feeding tools into stock to be removed by multiple tools.

ATTACHMENTS

Many attachments are available to tailor single-spindle automatic lathes for requirements of specific applications. These include modifications of the front turning carriage, rear and overhead squaring attachments, a headstock turning attachment, various tailstocks, double-end and center drives, steadyrests, and automatic loaders.

Front Turning Carriage

The carriage of a single-spindle automatic lathe is available with one to four slides. On long-bed machines, more than one carriage can be installed.

Rear and Overhead Squaring Attachments

A squaring attachment mounted on the rear way provides transverse motion only. It is readily timed to cut before, during, or after turning. Rear squaring attachments are used for facing, grooving, chamfering, forming, and other operations which lend themselves to straight infeed. More than one attachment can be mounted on a machine. Overhead squaring attachments, mounted on top of the headstock, are identical in function to the rear squaring attachments.

Headstock Turning Attachments

This attachment is made in two versions: one to mount on the front ways and one to mount on top of the headstock (see Fig. 15-2). The attachments are used for short-stroke turning, boring, chamfering, or similar operations toward the tailstock.

Tailstocks

Many varieties of tailstocks are available for use on single-spindle automatic lathes. The standard unit has a live spindle to accept the center and is mounted in an air-actuated quill. A variation of the quill-type tailstock is the relieving-type in which the tailstock body swings away from the machine centerline to permit insertion of a workpiece deep into a headstock collet.

In a variation of the relieving tailstock, the body relieves transversely. This is useful for use with large diameters such as

shaft-mounted electric motor rotors and for use in conjunction with automatic loading devices.

When the tailstock tooling (such as a chuck or collet) requires air actuation, a tailstock having a body that slides longitudinally is used. The body carries a spindle similar to the headstock spindle to facilitate mounting the tooling and rotating cylinder.

Double-End Drive

When the workpiece requires machining near the tailstock that produces objectionable torsional deflections, it is necessary

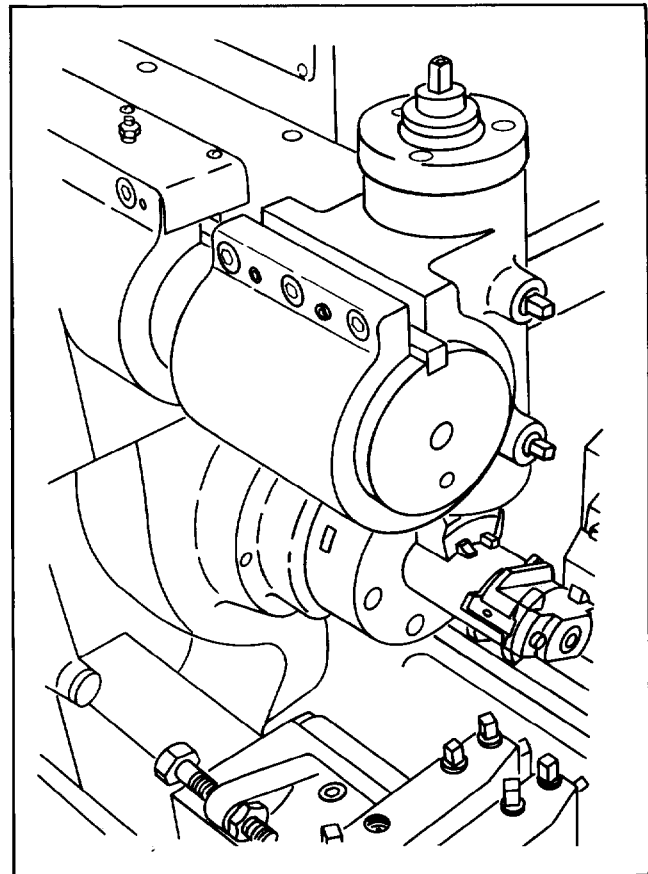


Fig. 15-2 An auxiliary overhead slide powered by a lever arm from movement of the front carriage and arranged to feed toward the tailstock. The operation performed is boring and chamfering the skirt ends of pistons.

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to drive the tailstock spindle in synchronism with the headstock spindle. This is also required when eccentric surfaces on shafts requiring tailstock support are machined. A tailstock for such applications has a spindle that is gear driven by an antibacklash gear train originating at the headstock spindle.

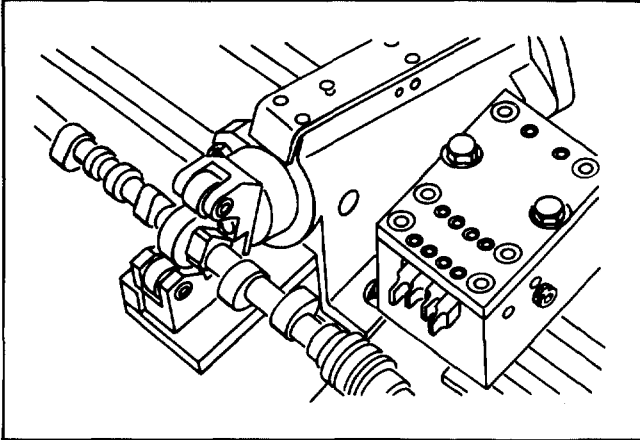


Fig. 15-3 Automatic steadyrest for supporting long cylindrical workpiece.

Center Drive

This attachment is intended for use when both ends of a shaft are to be machined. The portion of the shaft gripped by the center-drive chuck must be concentric with the centers or the shaft will have to be straightened after machining. A relieving tailstock is usually required.

Since this arrangement takes considerably longer to load than a conventional setup, careful consideration must be given to the economics of the applications. It may be more economical to use two simpler machines, each machining one end of the shaft, with both machines attended by one operator.

Steadyrests

A wide variety of two and three-roll steadyrests (see Fig. 15-3) is available to support slender workpieces against the cutting forces of front or rear tools, or both. These are generally operated automatically and, when required to clear an automatic loader, are also relieving.

Automatic Loaders

Almost any workpiece can be automatically handled (see Fig. 15-4). Some are relatively easy, while others require extensive modification to the machine and a complex handling device.

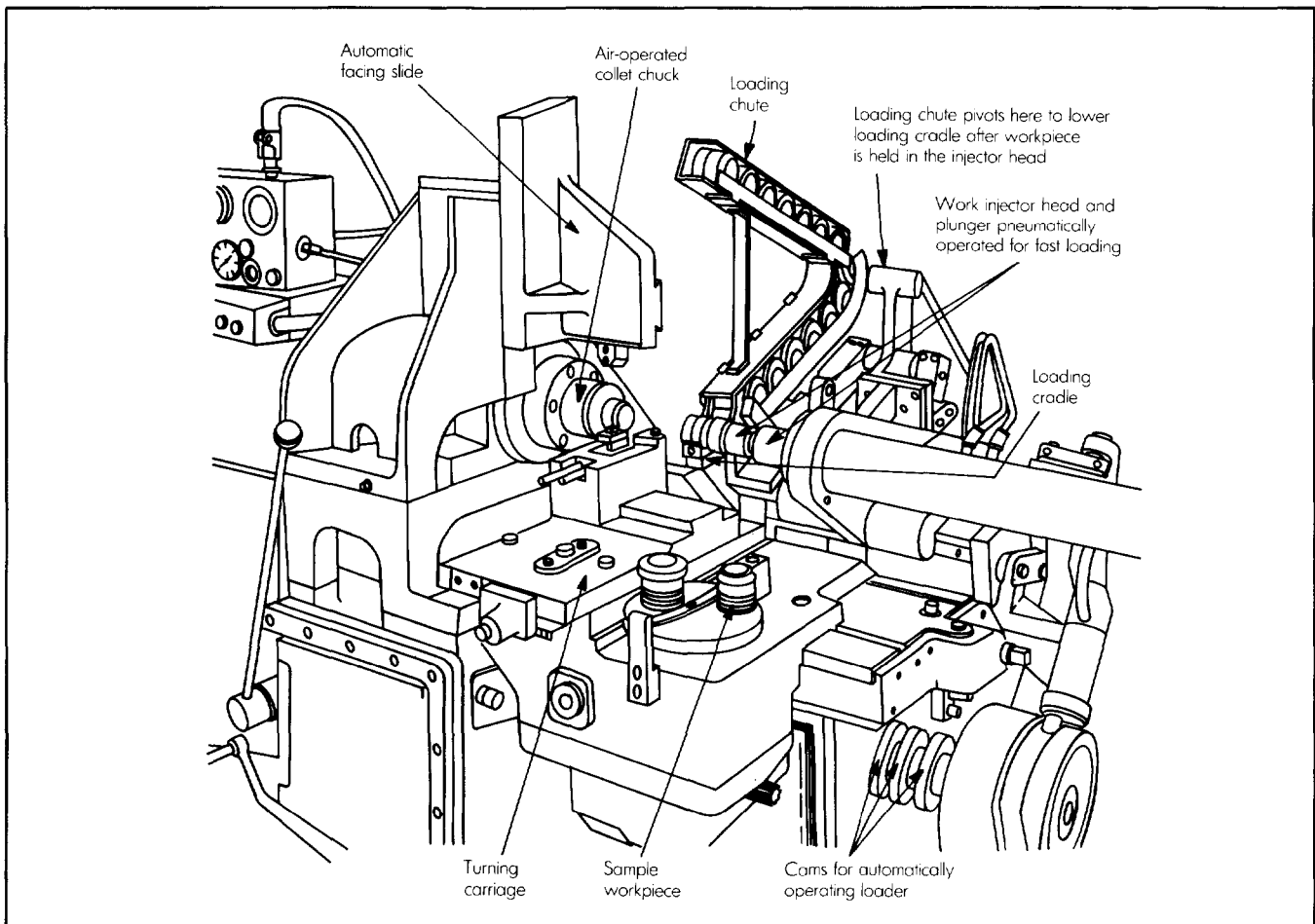


Fig. 15-4 Automatic loading device for single-spindle automatic lathe.

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When automatic loading is contemplated, consideration should be given to the complexity of the tooling and accessories. Rather than one complicated arrangement with the attendant problems of maintaining uptime, it is usually more practical to perform the operations on more than one relatively simple machine.

Consideration should also be given to possible modification of the workpiece design to improve its suitability for automatic handling.

Guards

Modern automatic lathes have the tooling area completely enclosed by guards, with access for loading by means of an interlocked door. All motions of the machine, attachments, and tooling can take place only when the door is closed, even when the machine is operated in the manual mode.

WORKHOLDING

Any type of workdriving means appropriate for the job can be used, but manual actuation is not recommended. The problem with manual chucking is that it wastes time. (It may take longer to chuck the part than it takes to machine it). Also, no assurance exists that the operator has tightened the chuck properly. When power chucks are used, their actuation can be monitored and interlocked with the spindle-start circuit.

Collets, both external and internal, can be used on machined or cold-finished surfaces. When an internal collet is long in relation to its diameter, it is usually necessary to support the outer end with a relieving tailstock. Expanding-jaw drivers can be used on as-forged or as-cast cylindrical workpieces.

Two-jaw equalizing drivers with cam-shaped jaws (see Fig. 15-5) can be used on shafts mounted between centers for manually loaded operations. These are much less expensive than a power chuck and cylinder. Face drivers are useful when the entire length of a shaft must be turned in one operation.

Slotted and lug-type drivers are used extensively for workpieces held between centers when there is a suitable projection or indentation against which the driver can exert the required torque. When possible, it is best to drive against two symmetrical surfaces to eliminate the tendency of the applied torque to push the workpiece off center. When using such a two-point drive, it is necessary that the driver nose be floating to compensate for minor variations in symmetry of the driven surfaces. Such driving surfaces are often incorporated into the design of the workpiece.

TOOLHOLDERS

Toolblocks serve to hold the cutting tools on the various attachments. The tool is clamped in a slot, and the block is clamped to the slide. Single toolblocks, containing one tool, are more flexible because the spacing between the blocks on a slide can be varied. Multiple toolblocks containing two or more tools are used when the tools must be spaced close together.

Another use for multiple toolblocks is when the machine is to be employed for a number of setups. A separate multiple toolblock can be provided for each setup. By leaving the tools in the block, all that is required to change from one tooling setup to another is to interchange blocks. When required by close tolerance requirements, micrometer or dial-indicator adjustment can be provided.

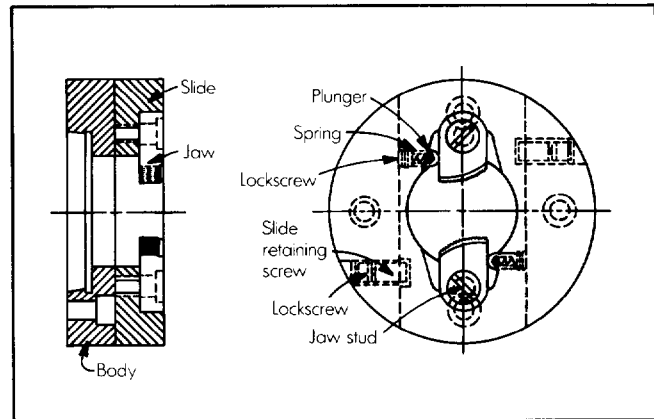


Fig. 15-5 Two-jaw equalizing driver with cam-shaped jaws.

The magazine toolblock is a variation of the multiple toolblock. Tools are mounted within a precision block (the magazine) which is mounted in a precision cavity in a block which attaches to the slide. This design is normally used with brazed tools when indexable inserts cannot be applied. Three magazines are generally provided for each block: one in use in the machine, the second ready for use, and the third in the toolroom for tool resharpener and adjustment.

Contours and tapers, when the angle between the tool path and the direction of feed of the attachment does not exceed 30° , can be generated by means of template-operated blocks. The tool is clamped in a slide having a follower which engages a stationary template.

Relieving toolblocks are available for use on squaring attachments and headstock turners which do not have tool relief built in. Their function is to eliminate tool dragout lines in cases in which the lines are objectionable. This is accomplished by rotating the tool (mounted in a cylinder within the toolblock), by moving a tool carrying slide, or by sliding the entire toolblock, whichever is most appropriate for the setup.

APPLICATIONS

Applications of single-spindle automatic lathes are so varied that it would be impractical to discuss them all in the limited space available in this volume. Instead, two operations performed on these machines in the production of rear axle shafts are illustrated in Fig. 15-6.

The machine used for the first operation has two front carriage slides and two rear squaring attachments. Air-operated retracting mechanisms are provided on two toolblocks mounted on the front carriage slide at the head end of the machine to relieve the tools during a second pass. A toolblock on the front carriage slide is template controlled. Double-path cams provide automatic longitudinal and crossfeed movements.

The automatic lathe used for the second operation has a front carriage slide (with no longitudinal feed), a rear squaring attachment, an overhead turning attachment, and an underneath chamfering attachment. A template attached to the rear squaring-attachment slide operates the underneath chamfering attachment. Toolblocks on both the rear squaring and the overhead turning attachments are equipped with tool relief mechanisms.

SINGLE-SPINDLE AUTOMATIC LATHES

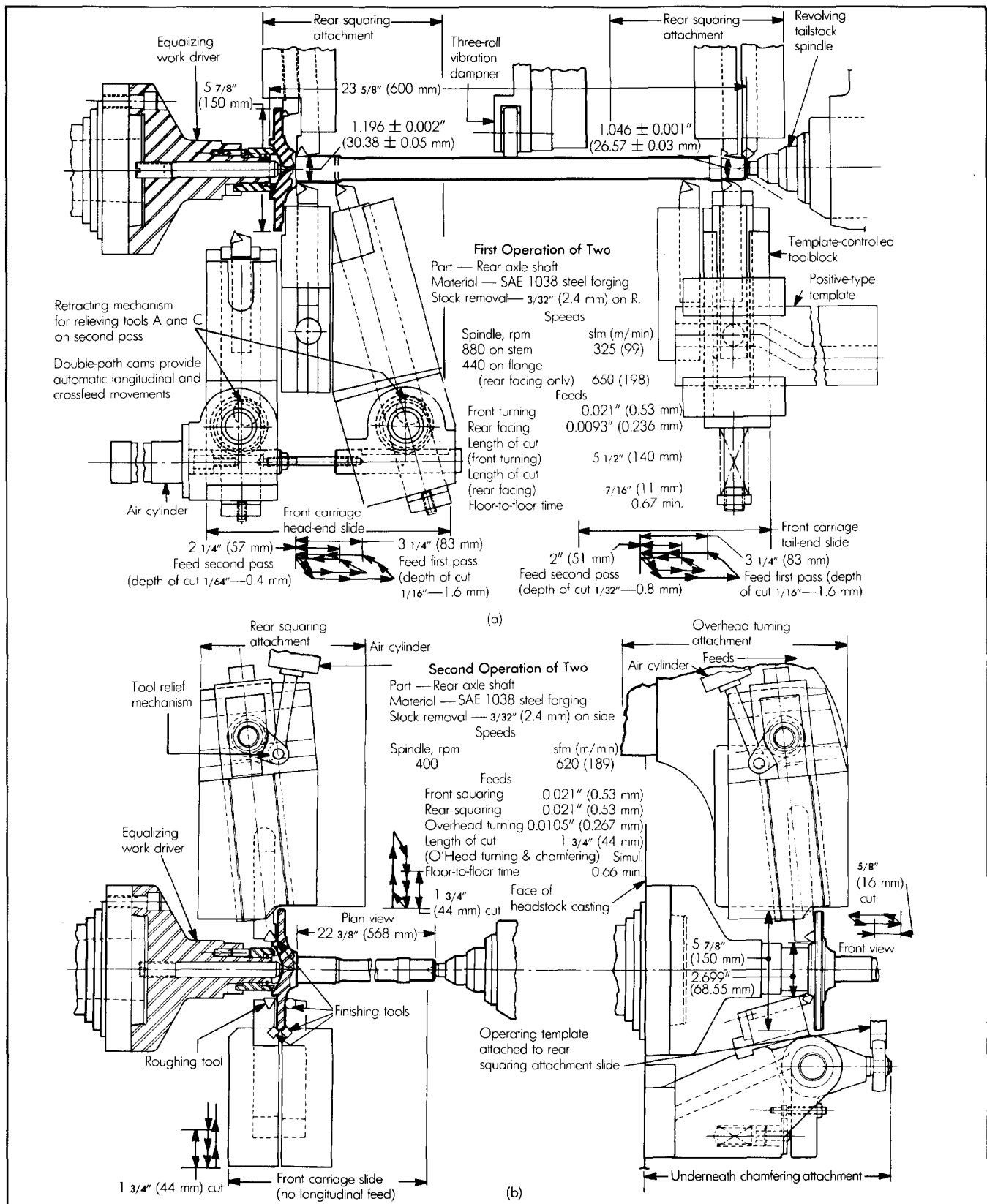


Fig. 15-6 Two operations performed on single-spindle automatic lathes in the production of rear axle shafts. (Seneca Falls Machine Co.)

SINGLE-SPINDLE AUTOMATIC SCREW MACHINES

SINGLE-SPINDLE AUTOMATIC SCREW MACHINES

The term "automatic screw machines" is not an exact, specific machine-tool classification. Use of the word "screw" originated from the initial use of these machines for producing screws. Now, these machines are employed to manufacture a wide variety of parts, but the word "screw" persists.

Automatic screw machines are designed to produce parts from bar or coil stock. With automatic operations taking place successively or simultaneously, using tools mounted on a turret and cross slides, these machines can complete workpieces at high production rates. Machines of this type have many tooling and operating principles similar to those for horizontal turret lathes (see Chapter 8, "Turning and Boring"), single-spindle automatic lathes (discussed previously in this chapter), and multiple-spindle automatic bar and chucking machines (described later in this chapter).

Two major classifications for single-spindle automatic screw machines are cam-controlled and programmable (camless) machines. Cam-controlled automatics, requiring cams and speed-change gears for specific applications, are used more extensively for the high-production requirements of a single part or family of parts. Camless automatics, programmed by toggle switches, pegboards, or NC/CNC units, provide simpler setup, faster changeover, and increased flexibility for shorter run production.

CAM-CONTROLLED AUTOMATICS

Design elements of a cam-controlled, single-spindle automatic screw machine are illustrated in Fig. 15-7. A bar of stock is held firmly in the spindle by a spring collet and rotated. Two sprockets on the spindle are driven by roller chains from driveshafts in the base. These sprockets run free and either one or the other is engaged to drive the spindle by means of a friction clutch between the sprockets. This type of drive allows direction of rotation to be reversed.

Cutting operations are performed on the bar of stock by cutting tools held in a turret and on the cross slides. The regular turret has six or eight tool positions and is automatically indexed to bring each tool into position. The cross slides are two independent slides at right angles to the spindle. Both turret and cross slides are moved to the work through levers actuated by plate cams designed to give the proper feed to each tool. The slides are withdrawn from the work by springs. Adjustable stops for the cross slides permit accurate repetition of formed diameters within close tolerances. Cutting off the completed workpiece is done by the cross slides or one of the upper slides actuated by a plate cam and lever.

The holder for the cutoff blade is constructed so that the position of the blade can be reversed to permit cutting off by either direction of spindle rotation. The basic attachments are mounted on a ledge at the front of the spindle (to the left of the front cross slide) for the performance of overlapping operations such as slotting and drilling of holes in the cutoff end of a given part. The bracket supporting the arm for transferring the workpiece from the spindle to the attachment is mounted to the right of the front cross slide.

The bar of stock is automatically fed forward to the new cutting position after each piece has been completed. It is located by being butted up against a swing stop or turret stop. Coupled driving shafts, at the rear of the machine, are driven at

constant speed through transposing gears, the positioning of which determines the direction of rotation and driveshaft speed.

Timing of idle movements of the machine such as indexing, feeding stock, and reversing the spindle is governed by clutches mounted on the driving shaft. These clutches are actuated by trip levers and trip dogs which are adjustable on the dog carriers that rotate with the camshafts.

The main driveshaft supplies power through feed change gears to the lead wormshaft (in the machine bed), which operates the two front camshafts through separate worms and adjustable wormwheels. The turret is indexed from the driveshaft through an intermediate gear and a sliding gear, then through a simple Geneva movement to index the turret.

Cam and Tool Design

The following general guidelines are given to aid in designing cams and special tools for automatic screw machines. They apply particularly to Brown & Sharpe machines:

1. Use the highest spindle speeds recommended for the workpiece material that the tools can stand.
2. Use the arrangement of circular tools best suited for the work.
3. Decide on the quickest and best method of arranging the operations before designing the cams.
4. Do not use turret tools when cross-slide tools can be used to better advantage.

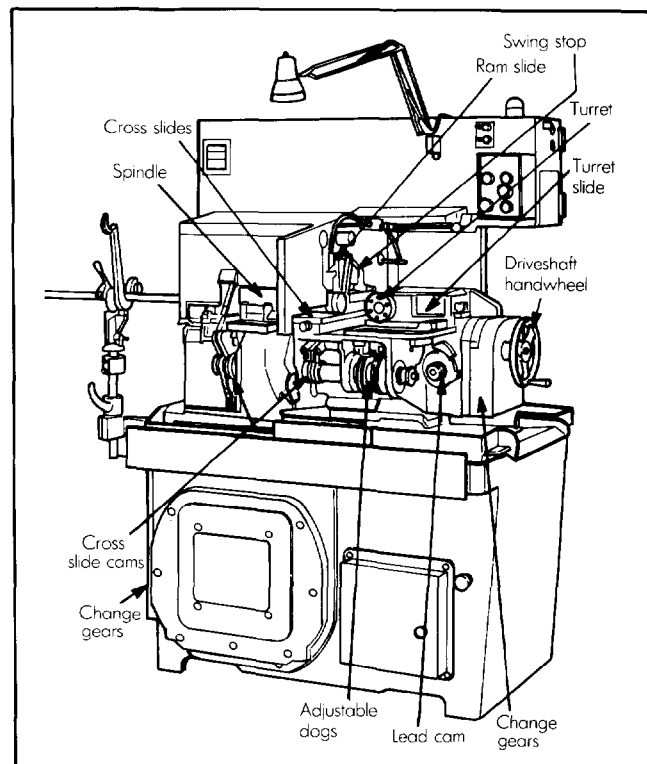


Fig. 15-7 Single-spindle automatic screw machine with cam control. (Brown & Sharpe Manufacturing Co.)

SINGLE-SPINDLE AUTOMATIC SCREW MACHINES

5. Make the shoulder on the circular cutoff tool large enough so that the hook bolt in the toolpost grips firmly.
6. Do not use too narrow a cutoff blade.
7. Allow 0.005-0.010" (0.13-0.25 mm) for the circular tools to approach the work and 0.003-0.005" (0.08-0.13 mm) for the cutoff tool to pass the center.
8. When cutting off, the feed of the cutoff tool may be decreased near the end of the cut where the piece is severed from the bar.
9. When a thread is cut to a shoulder, the workpiece should be grooved or necked to make allowance for the lead on the die. This requires an extra projection on the forming tool and also an extra amount of rise on the cam.
10. Allow sufficient clearance for tools to pass one another.
11. Always make a diagram for the cross-slide tools in position on the work.
12. Do not drill a hole to a depth of more than three to four times the diameter of the drill. For drills over 1/8" (3.2 mm) diam, steel workpieces can be drilled to a depth of about 3 1/2 times the drill diameter before withdrawal, and brass workpieces to a depth of about five times. When deep holes are drilled, it is sometimes necessary to drop back or withdraw the drill a number of times, or to introduce a new drill, depending on the material and the depth of the hole in relation to its diameter.
13. The surface speed for drilling should be in keeping with Table 15-2.
14. See that all turret tools clear the side of the machine bed and turret slide when the turret is revolved.
15. If only three turret operations are required, use the swing stop and arrange the turret for double indexing. This is generally advantageous only when machining materials such as brass or aluminum alloys, to minimize the time required for indexing during the cutoff operation.
16. Use standard tools whenever possible.
17. When designing special tools, allow as much clearance as possible. Do not design them so that they just clear each other, as a slight inaccuracy in the dimensions often causes trouble.

The principle of designing cams is to determine the number of spindle revolutions required for each operation and idle movement, overlap those operations and idle movements that can take place simultaneously, and then proportion the balance of spindle revolutions on the surface of the lead cam so that the total of these spindle revolutions equals the full circumference of the cam. Within the spaces reserved for the turret operations, lobes are developed to feed the tools on the work. The radial height, or throw, of these lobes equals the length a tool travels on the work, and the amount of cam surface occupied governs the rate of feed of the tool. The lobes are connected by drops or rises; and during these drops and rises, indexing takes place. The lead cam operates the turret tools. The cross-slide cams revolve at the same rate as the lead cam, and operations performed by cross-slide tools are laid out on these cams.

TABLE 15-2
Approximate Cutting Speeds and Feeds for Standard HSS Tools

Type of Tool	Cut		Feed Rate, ipr (mm/rev) for Material Type*								
	Width or Depth, in. (mm)	Hole Diameter, in. (mm)									
			A	B	C	D	E	F	G	H	J
Boring	0.005 (0.13)			0.0062 (0.157)	0.0055 (0.140)	0.005 (0.13)	0.005 (0.13)	0.0048 (0.122)	0.0045 (0.114)	0.0042 (0.107)	0.004 (0.10)
Box	1/32 (0.8)		0.012 (0.30)	0.0105 (0.267)	0.0093 (0.236)	0.0085 (0.216)	0.0085 (0.216)	0.0077 (0.196)	0.0068 (0.173)	0.0059 (0.150)	0.005 (0.13)
One-chip finishing	1/16 (1.6)		0.010 (0.25)	0.0085 (0.216)	0.0075 (0.190)	0.0068 (0.173)	0.0068 (0.173)	0.0061 (0.155)	0.0054 (0.137)	0.0047 (0.119)	0.004 (0.10)
V-back rest, brass	1/8 (3.2)		0.008 (0.20)	0.0075 (0.19)	0.0066 (0.168)	0.006 (0.15)	0.006 (0.15)	0.0053 (0.135)	0.0045 (0.114)	0.0038 (0.097)	0.003 (0.08)
Roller rest, steel	3/16 (4.8)		0.008 (0.20)	0.0063 (0.160)	0.0056 (0.142)	0.0051 (0.130)	0.0051 (0.130)	0.0044 (0.112)	0.0036 (0.091)	0.0028 (0.071)	0.002 (0.05)
	1/4 (6.4)		0.006 (0.15)	0.0052 (0.132)	0.0046 (0.117)	0.0042 (0.107)	0.0042 (0.107)	0.0036 (0.091)	0.0029 (0.074)	0.0022 (0.056)	0.0015 (0.038)
Finish cut, V-rest	0.005 (0.13)		0.010 (0.25)	0.010 (0.25)	0.0093 (0.236)	0.0085 (0.216)	0.0085 (0.216)	0.0079 (0.201)	0.0073 (0.185)	0.0066 (0.168)	0.006 (0.15)
Center drill		Under 1/8 (3.2)	0.003 (0.08)	0.0018 (0.046)	0.0016 (0.041)	0.0015 (0.038)	0.0013 (0.033)	0.0013 (0.033)	0.0012 (0.030)	0.0011 (0.028)	0.001 (0.03)
		Over 1/8 (3.2)	0.006 (0.15)	0.0044 (0.112)	0.0038 (0.097)	0.0035 (0.089)	0.003 (0.08)	0.0031 (0.079)	0.0027 (0.069)	0.0024 (0.061)	0.002 (0.05)

SINGLE-SPINDLE AUTOMATIC SCREW MACHINES

TABLE 15-2—Continued

Type of Tool	Cut		Feed Rate, ipr (mm/rev) for Material Type*								
	Width or Depth, in. (mm)	Hole Diameter, in. (mm)	A	B	C	D	E	F	G	H	J
Cutoff:											
Angular			0.0015 (0.038)	0.0008 (0.020)	0.0007 (0.018)	0.0006 (0.015)	0.0005 (0.013)	0.0005 (0.013)	0.0005 (0.013)	0.0004 (0.010)	0.0004 (0.010)
Circular, over 1/8" (3.2 mm) diam	3/64-1/8 (1.2-3.2)		0.0035 (0.089)	0.0018 (0.046)	0.0016 (0.041)	0.0015 (0.038)	0.0013 (0.033)	0.0013 (0.033)	0.0012 (0.030)	0.0011 (0.028)	0.001 (0.03)
Straight, under 1/8" (3.2 mm) diam	0.020- 0.040 (0.51- 1.02)		0.002 (0.05)	0.001 (0.03)	0.0009 (0.023)	0.0008 (0.020)	0.0007 (0.018)	0.0007 (0.018)	0.0006 (0.015)	0.0006 (0.015)	0.0005 (0.013)
Drills, twist		0.020 (0.51)	0.0017 (0.043)	0.0012 (0.030)	0.0011 (0.028)	0.001 (0.03)	0.0009 (0.023)	0.0009 (0.023)	0.0008 (0.020)	0.0007 (0.018)	0.0006 (0.015)
		0.040 (1.02)	0.0024 (0.061)	0.0017 (0.043)	0.0015 (0.038)	0.0014 (0.036)	0.0012 (0.030)	0.0012 (0.030)	0.0011 (0.028)	0.0009 (0.023)	0.0008 (0.020)
		1/16 (1.6)	0.0048 (0.122)	0.0025 (0.063)	0.0022 (0.056)	0.002 (0.05)	0.0017 (0.043)	0.0018 (0.046)	0.0016 (0.041)	0.0014 (0.036)	0.0012 (0.030)
		3/32 (2.4)	0.0072 (0.183)	0.0031 (0.079)	0.0027 (0.069)	0.0025 (0.063)	0.0021 (0.053)	0.0022 (0.056)	0.002 (0.05)	0.0018 (0.046)	0.0016 (0.041)
		1/8 (3.2)	0.011 (0.28)	0.0044 (0.112)	0.0038 (0.097)	0.0035 (0.089)	0.003 (0.08)	0.0031 (0.079)	0.0027 (0.069)	0.0024 (0.061)	0.002 (0.05)
		3/16 (4.8)	0.014 (0.36)	0.005 (0.13)	0.0044 (0.112)	0.004 (0.10)	0.0034 (0.086)	0.0038 (0.097)	0.0035 (0.089)	0.0032 (0.081)	0.003 (0.08)
		1/4 (6.4)	0.016 (0.41)	0.0062 (0.157)	0.0055 (0.140)	0.005 (0.13)	0.0043 (0.109)	0.0045 (0.114)	0.004 (0.10)	0.0035 (0.089)	0.003 (0.08)
		5/16 (7.9)	0.016 (0.41)	0.0069 (0.175)	0.006 (0.15)	0.0055 (0.140)	0.0047 (0.119)	0.005 (0.13)	0.0045 (0.114)	0.004 (0.10)	0.0035 (0.089)
		3/8 (9.5)	0.014 (0.36)	0.0075 (0.190)	0.0066 (0.168)	0.006 (0.15)	0.0051 (0.130)	0.0055 (0.140)	0.005 (0.13)	0.0045 (0.114)	0.004 (0.10)
		1/2 (12.7)	0.012 (0.30)	0.0075 (0.190)	0.0066 (0.168)	0.006 (0.15)	0.0051 (0.130)	0.0055 (0.140)	0.005 (0.13)	0.0045 (0.114)	0.004 (0.10)
		5/8 (15.9)	0.010 (0.25)	0.0075 (0.190)	0.0066 (0.168)	0.006 (0.15)	0.0051 (0.130)	0.0055 (0.140)	0.005 (0.13)	0.0045 (0.114)	0.004 (0.10)
	Form	1/8 & 1/4 (3.2 & 6.4)		0.002 (0.05)	0.0012 (0.030)	0.0011 (0.028)	0.001 (0.03)	0.001 (0.03)	0.0009 (0.023)	0.0008 (0.020)	0.0008 (0.020)
3/8 (9.5)			0.0018 (0.046)	0.0011 (0.028)	0.001 (0.03)	0.0009 (0.023)	0.0009 (0.023)	0.0008 (0.020)	0.0007 (0.018)	0.0007 (0.018)	0.0006 (0.015)
1/2 (12.7)			0.0015 (0.038)	0.001 (0.03)	0.0009 (0.023)	0.0008 (0.020)	0.0008 (0.020)	0.0007 (0.018)	0.0007 (0.018)	0.0006 (0.015)	0.0005 (0.013)
5/8 & 3/4 (15.9 & 19.1)			0.0012 (0.030)	0.0009 (0.023)	0.0008 (0.020)	0.0007 (0.018)	0.0007 (0.018)	0.0006 (0.015)	0.0006 (0.015)	0.0005 (0.013)	0.0004 (0.010)
1 & up (25.4)			0.001 (0.03)	0.0007 (0.018)	0.0007 (0.018)	0.0006 (0.015)	0.0006 (0.015)	0.0005 (0.013)	0.0005 (0.013)	0.0004 (0.010)	0.0004 (0.010)

(Continued)

CHAPTER 15

SINGLE-SPINDLE AUTOMATIC SCREW MACHINES

TABLE 15-2—Continued

Type of Tool	Cut		Feed Rate, ipr (mm/rev) for Material Type*								
	Width or Depth, in. (mm)	Hole Diameter, in. (mm)	A	B	C	D	E	F	G	H	J
Balance turning:											
Under 5/32" (4 mm) diam	1/32 (0.8)		0.012 (0.30)	0.012 (0.30)	0.011 (0.28)	0.010 (0.25)	0.0085 (0.216)	0.0095 (0.241)	0.009 (0.23)	0.0085 (0.216)	0.008 (0.20)
	1/16 (1.6)		0.010 (0.25)	0.010 (0.25)	0.0095 (0.241)	0.009 (0.23)	0.0077 (0.196)	0.0082 (0.208)	0.0075 (0.190)	0.0066 (0.168)	0.006 (0.15)
Over 5/32" (4 mm) diam	1/16 (1.6)		0.012 (0.30)	0.012 (0.30)	0.115 (0.292)	0.011 (0.28)	0.010 (0.25)	0.0102 (0.259)	0.0095 (0.241)	0.0087 (0.221)	0.008 (0.20)
	1/8 (3.2)		0.012 (0.30)	0.012 (0.30)	0.011 (0.28)	0.010 (0.25)	0.0085 (0.216)	0.0095 (0.241)	0.009 (0.23)	0.0085 (0.216)	0.008 (0.20)
	3/16 (4.8)		0.010 (0.25)	0.010 (0.25)	0.009 (0.23)	0.008 (0.20)	0.0068 (0.173)	0.0075 (0.190)	0.007 (0.18)	0.0065 (0.165)	0.006 (0.15)
	1/4 (6.4)		0.009 (0.23)	0.0087 (0.221)	0.0077 (0.196)	0.007 (0.18)	0.006 (0.15)	0.0063 (0.160)	0.0057 (0.145)	0.0051 (0.130)	0.0045 (0.114)
Knee	1/64 (0.4)		0.015 (0.38)	0.015 (0.38)	0.013 (0.33)	0.012 (0.30)	0.0105 (0.267)	0.0115 (0.292)	0.011 (0.28)	0.0105 (0.267)	0.010 (0.25)
	1/32 (0.8)		0.012 (0.30)	0.012 (0.30)	0.011 (0.28)	0.010 (0.25)	0.0085 (0.216)	0.0095 (0.241)	0.009 (0.23)	0.0085 (0.216)	0.008 (0.20)
Knurl			0.020 (0.51)	0.018 (0.46)	0.0165 (0.419)	0.015 (0.38)	0.0127 (0.323)	0.0137 (0.348)	0.0125 (0.317)	0.0112 (0.284)	0.010 (0.25)
Turret on			0.040 (1.02)	0.037 (0.94)	0.033 (0.84)	0.030 (0.76)	0.0255 (0.648)	0.0287 (0.729)	0.0275 (0.698)	0.0262 (0.665)	0.025 (0.63)
Turret off			0.004 (0.10)	0.0025 (0.063)	0.0022 (0.056)	0.002 (0.05)	0.002 (0.05)	0.002 (0.05)	0.002 (0.05)	0.002 (0.05)	0.002 (0.05)
Side or swing			0.006 (0.15)	0.005 (0.13)	0.0044 (0.112)	0.004 (0.10)	0.0034 (0.086)	0.0037 (0.094)	0.0035 (0.089)	0.0032 (0.081)	0.003 (0.08)
Top			0.005 (0.13)	0.0037 (0.094)	0.0033 (0.084)	0.003 (0.08)	0.0026 (0.066)	0.0027 (0.069)	0.0025 (0.063)	0.0022 (0.056)	0.002 (0.05)
			0.008 (0.20)	0.0075 (0.190)	0.0066 (0.168)	0.006 (0.15)	0.0051 (0.130)	0.0055 (0.140)	0.005 (0.13)	0.0045 (0.114)	0.004 (0.10)
Pointing and facing			0.001 (0.03)	0.001 (0.03)	0.0009 (0.023)	0.0008 (0.020)	0.0007 (0.018)	0.0007 (0.018)	0.0006 (0.013)		0.0005
			0.0025 (0.063)	0.0025 (0.063)	0.0022 (0.056)	0.002 (0.05)	0.0017 (0.043)	0.0017 (0.043)	0.0014 (0.036)	0.0011 (0.028)	0.0008 (0.020)
Reamers and bits		Under 1/8 (3.2)	0.007 (0.18)	0.007 (0.18)	0.0065 (0.165)	0.006 (0.15)	0.0051 (0.130)	0.0055 (0.140)	0.005 (0.13)	0.0045 (0.114)	0.004 (0.10)
	0.003- 0.004		0.010 (0.25)	0.010 (0.25)	0.0088 (0.224)	0.008 (0.20)	0.0068 (0.173)	0.0075 (0.190)	0.007 (0.18)	0.0065 (0.165)	0.006 (0.15)
		Over 1/8 (3.2)	0.010 (0.25)	0.010 (0.25)	0.010 (0.25)	0.010 (0.25)	0.0085 (0.216)	0.009 (0.23)	0.008 (0.20)	0.007 (0.18)	0.006 (0.15)
	0.004- 0.008							0.0095 (0.241)	0.009 (0.23)	0.0085 (0.216)	0.008 (0.20)

SINGLE-SPINDLE AUTOMATIC SCREW MACHINES

TABLE 15-2—Continued

Type of Tool	Cut		Feed Rate, ipr (mm/rev) for Material Type*								
	Width or Depth, in. (mm)	Hole Diameter, in. (mm)	A	B	C	D	E	F	G	H	J
Recessing:											
End cut			0.001 (0.03)	0.0008 (0.020)	0.0007 (0.018)	0.0006 (0.015)	0.0005 (0.013)	0.0005 (0.013)	0.0005 (0.013)	0.0004 (0.010)	0.0004 (0.010)
			0.005 (0.13)	0.0037 (0.094)	0.0033 (0.084)	0.003 (0.08)	0.0025 (0.063)	0.0027 (0.069)	0.0025 (0.063)	0.0022 (0.056)	0.002 (0.05)
Inside cut	1/16 (1.6)		0.0025 (0.063)	0.0025 (0.063)	0.0022 (0.056)	0.002 (0.05)	0.0017 (0.043)	0.0018 (0.046)	0.0017 (0.043)	0.0016 (0.041)	0.0015 (0.038)
	1/8 (3.2)		0.0008 (0.020)	0.0008 (0.020)	0.0007 (0.018)	0.0006 (0.015)	0.0005 (0.013)	0.0005 (0.013)	0.0005 (0.013)	0.0004 (0.010)	0.0004 (0.010)
Swing:											
Forming	1/8 (3.2)		0.002 (0.05)	0.0009 (0.023)	0.0008 (0.020)	0.0007 (0.018)	0.0006 (0.015)	0.0006 (0.015)	0.0006 (0.015)	0.0005 (0.013)	0.0005 (0.013)
	1/4 (6.4)		0.0012 (0.030)	0.0006 (0.015)	0.0006 (0.015)	0.0005 (0.013)	0.0004 (0.010)	0.0004 (0.010)	0.0004 (0.010)	0.0003 (0.008)	0.0003 (0.008)
	3/8 (9.5)		0.001 (0.03)	0.0005 (0.013)	0.0004 (0.010)	0.0004 (0.010)	0.0003 (0.008)	0.0003 (0.008)	0.0003 (0.008)	0.0002 (0.005)	0.0002 (0.005)
	1/2 (12.7)		0.0008 (0.020)	0.0004 (0.010)	0.0003 (0.008)	0.0003 (0.008)	0.0002 (0.005)	0.0002 (0.005)	0.0002 (0.005)	0.0002 (0.005)	0.0002 (0.005)
Turning, straight †	1/32 (0.8)		0.008 (0.20)	0.0075 (0.190)	0.0066 (0.168)	0.006 (0.15)	0.0051 (0.130)	0.0053 (0.135)	0.0047 (0.119)	0.0041 (0.104)	0.0035 (0.089)
	1/16 (1.6)		0.006 (0.15)	0.005 (0.13)	0.0044 (0.112)	0.004 (0.10)	0.0034 (0.086)	0.0038 (0.097)	0.0035 (0.089)	0.0032 (0.081)	0.003 (0.08)
	1/8 (3.2)		0.005 (0.13)	0.0037 (0.094)	0.0033 (0.084)	0.003 (0.08)	0.0025 (0.063)	0.0027 (0.069)	0.0025 (0.063)	0.0022 (0.056)	0.002 (0.05)
	3/16 (4.8)		0.004 (0.10)	0.0031 (0.079)	0.0027 (0.069)	0.0025 (0.063)	0.0021 (0.053)	0.0022 (0.056)	0.002 (0.05)	0.0017 (0.043)	0.0015 (0.038)

Note: Figures are only approximate, to be used as a basis from which proper figures for the job may be calculated. They are averages; if the work has any features out of the ordinary, take these into consideration and alter the figures accordingly. For carbide tools, feed rates are generally maintained the same, but speeds can be increased about 2 1/2 times.

* A. Free-cutting brass. Use maximum spindle speed available on machine.

B. 2011-T aluminum, 800 sfm (244 m/min).

C. 2017-T and 5052-T aluminum, 550 sfm (168 m/min).

D. 2024-T aluminum, 400 (122 m/min); copper, 300 (91.4 m/min); Naval brass and Tobin bronze, 200 sfm (61 m/min).

E. High-sulfur steel, B-1113, X-1112, and B & S 12A, 225 (68.6 m/min); C-1113, 196 (59.7 m/min); B-1112, 165 sfm (50.3 m/min).

F. Type 416 stainless steels and machined at 130 sfm (39.6 m/min).

G. Steels machined at 112 sfm (34 m/min).

H. Steels machined at 95 sfm (29 m/min).

J. All other stainless steels; tool steels, 74 (23 m/min); Monel, 60 (18.3 m/min); phosphor bronze, high-speed steel, 65 sfm (19.8 m/min).

† Feeds for swing tools when turning a taper are the same as straight turning for the greatest depth of cut.

CHAPTER 15

SINGLE-SPINDLE AUTOMATIC SCREW MACHINES

Use of approximate tables. To facilitate the designing of cams for the ordinary run of work on Brown & Sharpe automatic screw machines, Tables 15-2, 15-3, and 15-4 have been compiled. They show cutting speeds and feeds, hundredths of cam surface for feeding stock and indexing turret, and clearance between turret tools and cross-slide tools in hundredths of cam surface.

The tables are approximate only; and in some instances, cams designed using the figures from the tables contain a small amount of lost time, since the tables provide maximum allowances. Cams designed with the given data operate satisfactorily; however, faster production may be gained through closer timing on the cam surfaces.

Variation of the cutting speeds and feeds from those listed in Table 15-2 may be made, depending upon the requirements of

accuracy and finish of each job. It is generally good practice to use high speeds and low feeds for small-machine work.

Dividing cam surface into hundredths. The purpose of this step in design is to arrive at the number of hundredths of cam surface required for each operation or idle movement. Dividing to hundredths is fine enough for most purposes, and hundredths is a very easy unit of division to use in calculations. Whenever necessary, it is possible to split a hundredth into two parts to suit requirements at some particular point on the cam.

Indexing turret and feeding stock. The driving shaft at the rear of the machine carries the clutches for operating the opening and closing of the chuck, feeding the stock, and indexing the turret. As this shaft revolves at constant speed, regardless of the spindle speed, the above movements take place

TABLE 15-3
Hundredths of Cam Surface Required to Index for Throws from Full-Height 5 1/2" (140 mm) Cam

Brown & Sharpe Automatic Screw Machines Starting with Serial No. 542-00-3300					
4 to 5 1/2s		6 to 33s		36s and Over	
Drop, in. (mm)	Hundredths of Cam Surface	Drop, in. (mm)	Hundredths of Cam Surface	Drop, in. (mm)	Hundredths of Cam Surface
0 to 11/32 (8.7)	2 1/2	0 to 15/32 (11.9)	2 1/2	0 to 5/8 (15.9)	2 1/2
11/32 to 1/2 (8.7-12.7)	3	15/32 to 11/16 (11.9-17.5)	3	5/8 to 7/8 (15.9-22.2)	3
1/2 to 5/8 (12.7-15.9)	3 1/2	11/16 to 13/16 (17.5-20.6)	3 1/2	7/8 to 1 1/16 (22.2-27.0)	3 1/2
5/8 to 3/4 (15.9-19.1)	4	13/16 to 31/32 (20.6-24.6)	4	1 1/16 to 1 7/32 (27.0-31.0)	4
3/4 to 27/32 (19.1-21.4)	4 1/2	31/32 to 1 3/32 (24.6-27.8)	4 1/2	1 7/32 to 1 3/8 (31.0-34.9)	4 1/2
27/32 to 15/16 (21.4-23.8)	5	1 3/32 to 1 3/16 (27.8-30.2)	5	1 3/8 to 1 1/2 (34.9-38.1)	5
15/16 to 1 1/16 (23.8-27.0)	5 1/2	1 3/16 to 1 5/16 (30.2-33.3)	5 1/2		
1 1/16 to 1 1/8 (27.0-28.6)	6	1 5/16 to 1 3/8 (33.3-34.9)	6		
1 1/8 to 1 1/4 (28.6-31.7)	6 1/2	1 3/8 to 1 7/16 (34.9-36.5)	6 1/2		
Brown & Sharpe Automatic Screw Machines with Serial Nos. Prior to 542-00-3300					
4 to 5 3/4s*		6 to 35s			
Drop, in. (mm)	Hundredths of Cam Surface	Drop, in. (mm)	Hundredths of Cam Surface		
0 to 5/16 (7.9)	2 1/2	0 to 13/32 (10.3)	2 1/2		
5/16 to 7/16 (7.9-11.1)	3	13/32 to 19/32 (10.3-15.1)	3		
7/16 to 9/16 (11.1-14.3)	3 1/2	19/32 to 3/4 (15.1-19.1)	3 1/2		
9/16 to 21/32 (14.3-16.7)	4	3/4 to 29/32 (19.1-23.0)	4		
21/32 to 3/4 (16.7-19.1)	4 1/2	29/32 to 1 (23.0-25.4)	4 1/2		
3/4 to 27/32 (19.1-21.4)	5	1 to 1 3/32 (25.4-27.8)	5		
27/32 to 29/32 (21.4-23.0)	5 1/2				
29/32 to 31/32 (23.0-24.6)	6				
31/32 to 1 1/32 (24.6-26.2)	6 1/2				
1 1/32 to 1 3/32 (26.2-27.8)	7				
1 3/32 to 1 3/16 (27.8-30.2)	8				

Note: The hundredths of cam surface for indexing are first calculated, based on the indexing-time factor or revolutions of spindle during indexing. Before laying out cams, a check is made from this table, depending on tool throw. The larger number of hundredths of cam surface obtained from comparing these values should be used.

* If previous lobe has cutdown, subtract the following hundredths of cam surface from the figures given in the table:

Cutdown, in. (mm)	Hundredths of Cam Surface
0 to 3/16 (4.8)	0
3/16 to 5/16 (4.8-7.9)	1/2
5/16 to 1/2 (7.9-12.7)	1
1/2 to 5/8 (12.7-15.9)	1 1/2

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TABLE 15-4
Clearance in Hundredths of Cam Surface Between
Turret Tools and Cross-Slide Circular Tools

Turret Tools	Clearance									
	Front Cross-Slide Tool					Back Cross-Slide Tool				
	No. 00*	No. 0	No. 2	4	6	No. 00*	No. 0	No. 2	4	6
Balance turning tool	6	---	---	---	---	6	---	---	---	---
Balance turning tool	---	6	---	---	---	---	6	---	---	---
Balance turning tool	---	7	7	---	---	---	7	7	---	---
Balance turning tool	---	---	---	6	6	---	---	---	6	6
Box tool	8	7	7	---	---	6	7	6	---	---
Box tool	---	---	---	7	7	---	---	---	6	6
Box tool	6	6	6	---	---	7	7	7	---	---
Box tool	8	7	7	---	---	5	5	4	---	---
Box tool	8	7	7	---	---	6	6	6	---	---
Box tool	5	7	7	---	---	7	6	6	---	---
Box tool	8	---	---	---	---	6	---	---	---	---
Box tool	---	7	---	---	---	---	6	---	---	---
Box tool	---	---	7	---	---	---	---	6	---	---
Centering and face tool	8	---	---	---	---	4	---	---	---	---
Centering and face tool	---	7	---	---	---	---	3	---	---	---
Centering and face tool	---	---	7	---	---	---	---	3	---	---
Self-opening diehead	8	7	7	7	7	8	7	7	7	7
Combination right and left-hand knee tool	6	5	5	---	---	4	4	4	---	---
Knurl holder	7	6	6	---	---	7	6	6	---	---
Knurl holder	---	---	---	6	6	---	---	---	5	5
Pointing tool	7	7	7	---	---	5	6	6	---	---
Pointing tool	8	---	---	---	---	6	---	---	---	---
Pointing tool	5	---	---	---	---	7	---	---	---	---
Pointing tool	---	---	---	6	6	---	---	---	6	6
Turret tool post	---	---	---	3	3	---	---	---	---	---

* For No. 00 size machines, double the hundredths of cam surface given in the table for jobs requiring 3s or less. For a 4s job, add 5 hundredths of cam surface, and for a 5s job, add 4 hundredths.

in exactly the same length of time on all jobs. As the number of seconds to finish a piece increases, however, the lead cam revolves more slowly. A point is reached at which the time required to index the turret or feed the stock does not represent space enough on the cam circumference to permit the cam lever roll to drop to the required position to start the next operation. Therefore, although the actual length of time required for indexing the turret or feeding the stock is no greater, more circumference must be provided, and this becomes the governing factor of these movements on slower jobs.

Figure 15-8 illustrates six-hundredths of cam surface given up to indexing on a fast job. It can be seen that more space exists than is necessary for the roll to get from the top of one lobe to the start of the next, but none of this space can be eliminated. This is because six-hundredths in this particular case represents the actual length of time required for the indexing mechanism to operate.

Figure 15-9 illustrates a slower job in which cam surface governs the length of indexing time. In getting from the top of one lobe to the start of the next, the roll travels down a definite line, which is as steep as possible without allowing the roll to fall to the bottom. The lines of drop and, likewise, the lines of rise for jobs that can be done within certain ranges of seconds are established on a cam template. In Fig. 15-9, the template line of drop is used for jobs within the range of from 6 to 33 s per piece.

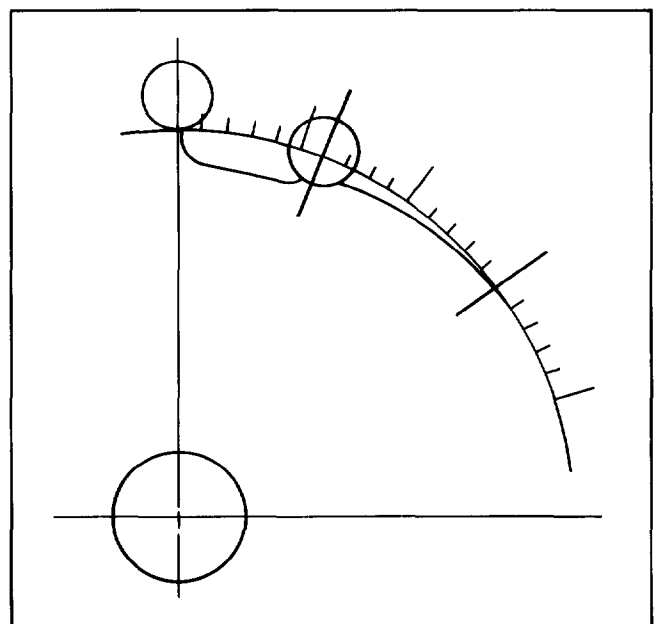


Fig. 15-8 Lead cam surface for turret indexing on a fast job.

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One hundredth of cam surface in such a case may represent far more time than is actually required for the indexing mechanism to operate.

To illustrate, a job requiring 33 s on a machine having a maximum speed of 7200 rpm will require 3957 spindle revolutions to make a piece, and one hundredth of the cam surface would represent 40 spindle revolutions. The actual length of time required for the indexing mechanism to operate on this machine is $1/4$ s, during which, at 7200 rpm, 30 revolutions take place. If a few revolutions are added to this to allow for setting the trip dogs, making it 36 revolutions, there are still 4 more revolutions than are actually required to provide for operating the indexing mechanism. Figure 15-9, however, shows that one hundredth of cam surface is necessary for the slight drop from *A* to *B*. If the roll drops approximately halfway down, from *A* to *C*, three hundredths are required and a drop to full depth, *A* to *D*, requires $6\frac{1}{2}$ hundredths of cam surface for an indexing.

Table 15-3 applies only to those jobs which are governed by cam surface. On faster jobs, the spindle revolutions within the actual length of time required are taken and, as previously stated, a few extra revolutions are added to allow for setting the trip dogs that operate the mechanism.

Figuring cams. On the cam design sheet illustrated in Table 15-5 an aluminum thumbscrew is shown that was made on Brown & Sharpe No. 00 high-speed automatic screw machine. This piece requires centering, drilling, tapping, forming, knurling, and cutting off. The steps taken in estimating the necessary cams are as follows:

1. Analyze the print of the workpiece.
2. Determine the operations to be performed and select the model and size of machine required.
3. Draw a sketch of the workpiece held in the collet, with outlines of the form and cutoff tools.
4. Decide on the type of cutting tools (HSS or carbide) and toolholders to be used.
5. List the sequence of operations to be performed, starting with feeding the stock.
6. Select a suitable spindle speed, based on machinability of the material to be cut (see Table 15-2).
7. Determine the number of revolutions required for feeding the stock and indexing the turret (see Table 15-5).
8. Determine the stroke (throw) for each operation.
9. Select the feed rate for each operation (see Table 15-2).
10. Divide the throw by the feed rate to determine the spindle revolutions required for each operation.
11. Where clearance between slide tools is required, use hundredths of cam surface instead of revolutions (see Table 15-4).
12. Total the revolutions required for all operations (including feeding and indexing) except those that are overlapped.
13. Based on the spindle speed to be used, determine the closest number of revolutions needed to provide one workpiece (see Table 15-6).
14. Based on the revolutions required to make one piece, determine the cycle time and production rate per hour (see Table 15-6).

The stock used to produce the thumbscrew shown in Table 15-5 is round 2011 aluminum alloy, fed to a stock stop. The workpiece is knurled with a turret adjustable knurl holder, the

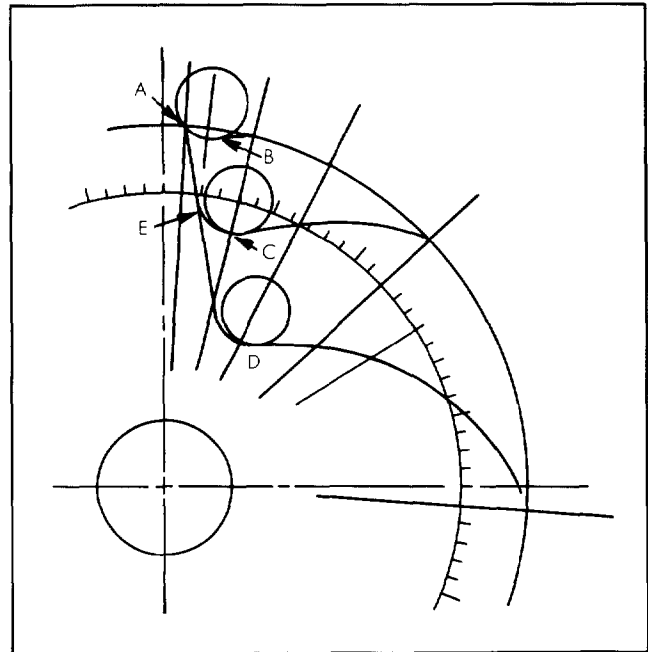


Fig. 15-9 Lead cam surface for turret indexing on a slow job.

turret is indexed, and the piece is spotted or centered for the drill. After the turret is again indexed, the tap drill pierces the piece and goes across the cutoff line. During this drilling operation, the front slide advances and forms the contour of the piece and deburrs both sides of the knurl. The back slide advances and severs the piece, roughing out the $3/8$ " (9.5 mm) diam to save knurling throw and reduce the material to be removed with the form tool, resulting in longer tool life and better finish.

Table 15-2 indicates that 2011 aluminum alloy may be machined at 800 sfm (244 m/min). This is the accepted speed for operations such as turning, knurling, forming, or cutting off. On $1/2$ " (12.7 mm) diam stock, 800 sfm gives a spindle speed of about 6100 rpm. Referring to Table 15-6 for this machine, the selected speed would be 5970 rpm as the nearest spindle speed available on the machine. Following the same procedure, it is found that the nearest available spindle speed for tapping would be 2600 rpm. This would equal 129 sfm (39 m/min) for tapping, which is well within the range of this operation.

Calculating spindle revolutions. A variety of methods are used to determine spindle revolutions required for different operations.

Knurling. Length of knurl on the workpiece (Table 15-5) plus one half the thickness of the knurling roll is the throw for knurling on the cam. Knurling on and knurling off throws are always the same. Length of the knurl, $1/8$ " (3.2 mm), plus one half the thickness of the knurl roll, 0.094" (2.39 mm), equals the knurl throw of 0.219" (5.6 mm). The feed selected from Table 15-2 is 0.018 ipr (0.46 mm/rev) for knurling on and 0.037 ipr (0.94 mm/rev) for knurling off.

Knurling on a throw of 0.219" (5.6 mm) divided by the feed 0.018 ipr (0.46 mm/rev) is 12 plus revolutions. Revolutions should always be rounded off to the next larger whole revolution; therefore, knurl on is represented by 13 revolutions. Knurl off revolution is 0.219" divided by 0.037 ipr (0.94 mm/rev), resulting in 6 revolutions to knurl off.

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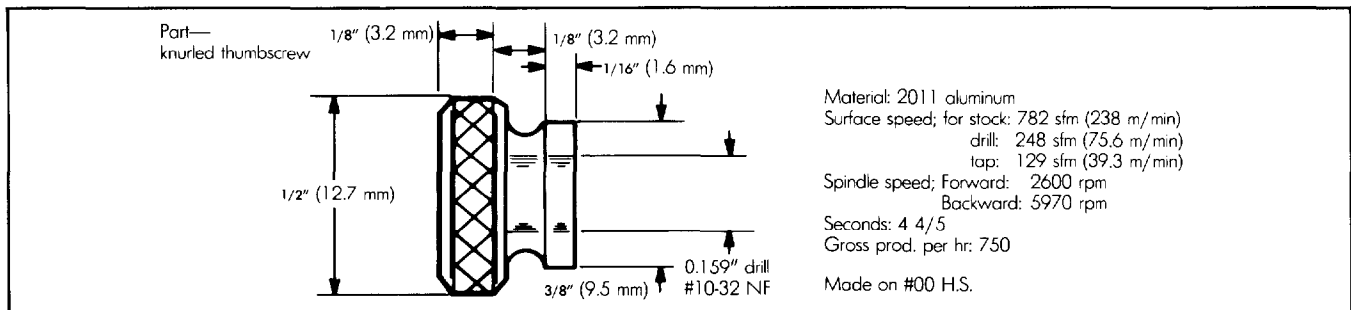


TABLE 15-5
Cam Design Worksheet for Producing Knurled Thumbscrew

Cutdown on Cam, in. (mm)	Operation	Throw, in. (mm)	Feed Rate, ipr (mm/rev)	Spindle Revolutions			Hundredths of Cam Surface		
				For Each Operation	After Deducting for Operations Overlapped	Readjusted to Equal Revolutions Available with Regular Change Gears	For Spindle Revolutions in Preceding Column	For Operations Involved	Dwell
	Feed stock to stop			30	30	31	6 1/2		
	Index turret			30	30	31	6 1/2		
	Knurl on	0.219 (5.56)	0.018 (0.46)	13	13	14	3		
	Knurl off	0.219 (5.56)	0.037 (0.94)	6	6	7	1 1/2		
	Index turret			30	30	31	6 1/2		
1/4 (6.3)	Center	0.067 (1.70)	0.0044 (0.112)	21	21	22	4 1/2		
	Index turret			30	30	31	6 1/2		
	Drill	0.413 (10.49)	0.0047 (0.119)	88	88	89	18 1/2		
	Index turret and reverse spindle			30	30	31	6 1/2		
1/8 (3.2)	Tap in	0.381 (9.68)		30	30	31	6 1/2		
	Tap out	0.448 (11.38)		13	13	14	3		
	Form, front slide	0.135 (3.43)	0.0012 (0.030)	118				24 1/2	1
	Cutoff and form, back slide	0.249 (6.32)	0.0018 (0.046)	138	138	136	28 1/2		
	Clear					10	2		
	Spindle Revolutions:								
	For 98 hundredths of cam surface				459				
	Estimated total if spindle runs at 5900 rpm continuously				468				
	Nearest actual number available on machine					478	100		

TABLE 15-6
Spindle Speeds and Revolutions per Workpiece for Laying Out Cams to be Used on Brown & Sharpe No. 00
Automatic Screw Machines (beginning with Serial No. 542-00-3300, having a driving shaft speed of 240 rpm)

High Spindle Speeds in Combination with Low Speeds																		Ratio
7200	5970	5035	4305	3715	3085	2580	2270	1915	1690	1425	1255	1050	870	750	640	540	450	
3130*	2600	2190	1875	1615		1125	990	835	735	620	545		380	325	280	235	195	2.3
2625*	2175	1835	1570	1355	1125		825	700	615	520		380	320	275	235	200	165	2.7
2305*	1910	1615	1380	1190	990	825		615	540		400	335	280	240	205	175	145	3
1945*	1615	1360	1165	1005	835	700	615			385	340	285	235	205	175	145	120	3.7
1715*	1425	1200	1025	885	735	615	540			340	300	250	210	180	155	130	105	4.2
1450	1200	1015	865	745	620	520		385	340		250	210	175	150	130	110	90	5
1270	1055	890	760	655	545		400	340	300	250		185	155	135	115	96	80	5.6
1065	885	745	635	550		385	335	285	250	210	185		130	110	95	80	67	6.7
885	735	620	530		380	320	280	235	210	175	155	130		92	79	67	55	8
765	635	535		395	325	275	240	205	180	150	135	110	92		68	58	48	9.3
650	540		390	335	280	235	205	175	155	130	115	95	79	68		49	41	11
550		385	330	285	235	200	175	145	130	110	96	80	67	58	49		34	13
	380	320	275	235	195	165	145	120	105	90	80	67	55	48	41	34		16

Revolutions at Maximum Speed to Feed Stock or Index Turret 1/4s																		
30	25	21	18	15	13	11	9	8	7	6	5	4.4	3.6	3.1	2.7	2.3	1.9	

Revolutions of Spindle at Maximum Speed to Make One Piece																		
90	75	63	54	46	39	32	28	24	21	18	16	13	11	9	8	7	6	3/4
105	87	73	63	54	45	38	33	28	25	21	18	15	13	11	9	8	6.5	7/8
120	100	84	72	62	51	43	38	32	28	24	21	18	15	13	11	9	8	1
150	124	105	90	77	64	54	47	40	35	30	26	22	18	16	13	11	9	1 1/4
180	149	126	108	93	77	65	57	48	42	36	31	26	22	19	16	14	11	1 1/2
210	174	147	126	108	90	75	66	56	49	42	37	31	25	22	19	16	13	1 3/4
240	199	168	144	124	103	86	76	64	56	48	42	35	29	25	21	18	15	2
270	224	189	161	139	116	97	85	72	63	53	47	39	33	28	24	20	17	2 1/4
300	249	210	179	155	129	108	95	80	70	59	52	44	36	31	27	23	19	2 1/2
330	274	231	197	170	141	118	104	88	77	65	58	48	40	34	29	25	21	2 3/4
360	299	252	215	186	154	129	113	96	85	71	63	53	44	38	32	27	23	3
390	323	273	233	201	167	140	123	104	92	77	68	57	47	41	35	29	24	3 1/4
420	348	294	251	217	180	151	132	112	99	83	73	61	51	44	37	32	26	3 1/2
450	373	315	269	232	193	161	142	120	106	89	78	66	54	47	40	34	28	3 3/4
480	398	336	287	248	206	172	151	128	113	95	84	70	58	50	43	36	30	4
504	418	352	301	260	216	181	159	134	118	100	88	74	61	53	45	38	32	4 1/5
540	448	378	323	279	231	194	170	144	127	107	94	79	65	56	48	41	34	4 1/2
576	478	403	344	297	247	206	182	153	135	114	100	84	70	60	51	43	36	4 4/5
600	498	420	359	310	257	215	189	160	141	119	105	88	73	63	53	45	38	5
660	547	462	395	341	283	237	208	176	155	131	115	96	80	69	59	50	41	5 1/2

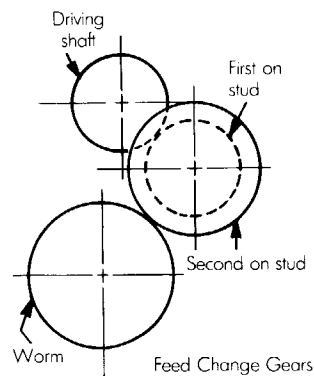


Table 15-6—Continued

719	597	503	431	371	308	258	227	191	169	143	125	105	87	75	64	54	45	6	600	80	40	25	60	5
779	647	545	466	402	334	280	246	207	183	154	136	114	94	81	69	59	49	6 1/2	553	80	40	25	65	4
839	697	587	502	433	360	301	265	223	197	166	146	123	102	88	75	63	53	7	514	50	35	40	80	4
899	746	629	538	464	386	323	284	239	211	178	157	131	109	94	80	68	56	7 1/2	480	80	50	25	60	4
959	796	671	574	495	411	344	303	255	225	190	167	140	116	100	85	72	60	8	450	100	40	20	80	4
989	821	692	592	511	424	355	312	263	232	196	173	144	120	103	88	74	62	8 1/4	436	50	55	40	60	3
1079	896	755	646	557	463	387	340	287	254	214	188	158	131	113	96	81	68	9	400	50	45	40	80	3
1124	933	787	673	580	482	403	355	299	264	223	196	164	136	117	100	84	70	9 3/8	384	80	60	40	100	3
1199	995	839	718	619	514	430	378	319	282	238	209	175	145	125	107	90	75	10	360	80	40	25	100	3
1259	1045	881	753	650	540	452	397	335	296	249	220	184	152	131	112	95	79	10 1/2	342	50	35	20	60	3
1319	1095	923	789	681	566	473	416	351	310	261	230	193	160	138	117	99	83	11	327	50	55	40	80	3
1349	1119	944	807	697	578	484	426	359	317	267	235	197	163	141	120	101	84	11 1/4	320	50	45	40	100	3
1439	1194	1007	861	743	617	516	454	383	338	285	251	210	174	150	128	108	90	12	300	50	60	40	80	3
1499	1244	1049	897	774	643	538	473	399	352	297	261	219	181	156	133	113	94	12 1/2	288	80	50	25	100	3
1559	1294	1091	933	805	668	559	492	415	366	309	272	228	189	163	139	117	98	13	276	50	65	40	80	3
1619	1343	1133	969	836	694	581	511	431	380	321	282	236	196	169	144	122	101	13 1/2	266	40	45	25	60	3
1679	1393	1175	1005	867	720	602	530	447	394	333	293	245	203	175	149	126	105	14	257	50	35	20	80	3
1799	1493	1259	1076	929	771	645	567	479	423	356	314	263	218	188	160	135	113	15	240	40	50	25	60	3
1919	1592	1343	1148	991	823	688	605	511	451	380	335	280	232	200	171	144	120	16	225	50	40	25	100	3
1979	1642	1385	1184	1022	848	710	624	527	465	392	345	289	239	206	176	149	124	16 1/2	218	50	55	20	60	3
2099	1741	1469	1256	1084	900	753	662	559	493	416	366	306	254	219	187	158	131	17 1/2	205	40	35	20	80	3
2158	1791	1510	1292	1114	925	774	681	574	507	428	376	315	261	225	192	162	135	18	200	40	45	25	80	3
2248	1866	1573	1345	1161	964	806	709	598	528	445	392	328	272	234	200	169	141	18 3/4	192	40	50	20	60	3
2398	1990	1678	1435	1238	1028	860	757	638	563	475	418	350	290	250	213	180	150	20	180	40	50	25	80	3
2494	2070	1745	1492	1288	1069	894	787	664	586	494	435	364	302	260	222	187	156	20 4/5	173	50	60	25	80	3
2638	2189	1846	1579	1362	1131	946	832	702	620	523	460	385	319	275	235	198	165	22	163	40	55	25	80	3
2698	2239	1888	1614	1393	1157	968	851	718	634	534	471	394	326	281	240	203	169	22 1/2	160	40	45	20	80	3
2878	2388	2014	1722	1486	1234	1032	908	766	676	570	502	420	348	300	256	216	180	24	150	40	60	25	80	3
2998	2488	2098	1794	1548	1285	1075	946	798	704	594	523	438	363	313	267	225	188	25	144	40	50	20	80	3
3118	2587	2182	1866	1610	1337	1118	984	830	732	618	544	455	377	325	277	234	195	26	138	40	65	25	80	3
3238	2687	2266	1937	1672	1388	1161	1021	862	761	641	565	473	392	338	288	243	203	27	133	25	45	20	60	3
3373	2798	2360	2018	1741	1446	1209	1064	898	792	668	588	492	408	352	300	253	211	28 1/8	128	40	45	20	100	3
3597	2985	2517	2153	1857	1542	1290	1135	957	845	713	627	525	435	375	320	270	225	30	120	40	60	20	80	3
3957	3284	2769	2368	2043	1697	1419	1248	1053	930	784	690	578	479	413	352	297	248	33	109	20	55	25	60	3
4317	3582	3021	2583	2229	1851	1548	1362	1149	1014	855	753	630	522	450	384	324	270	36	100	25	45	20	80	3
4497	3731	3147	2691	2322	1928	1613	1419	1197	1056	891	784	656	544	469	400	338	281	37 1/2	96	40	60	20	100	3
4797	3980	3357	2870	2477	2057	1720	1513	1277	1127	950	837	700	580	500	427	360	300	40	90	50	80	20	100	3
5396	4478	3776	3229	2786	2314	1935	1702	1436	1268	1069	941	788	653	563	480	405	338	45	80	25	45	20	100	3
5756	4776	4028	3444	2972	2468	2064	1816	1532	1352	1140	1004	840	696	600	512	432	360	48	75	25	60	20	80	3
5996	4975	4196	3588	3096	2571	2150	1892	1596	1408	1188	1046	875	725	625	533	450	375	50	72	25	50	20	100	3

Note: When threading to a shoulder, it is important that the relative position of the clutch teeth at the time of reversing be constant. To ensure this condition, "Time, s," multiplied by 40, must be a whole number. Select combinations to mesh but not interfere.

$$\text{Time, s} = 5 \times \frac{\text{1st gear on stud}}{\text{gear on driveshaft}} \times \frac{\text{gear on wormshaft}}{\text{2d gear on stud}}$$

* These combinations not to be used in opposite directions.

** Net will vary with factory conditions and the character of the work.

CHAPTER 15

SINGLE-SPINDLE AUTOMATIC SCREW MACHINES

Center drilling. Centering is performed by a short stubby drill with a 90° included-angle point and a thinned web designed to prepare the work for the drill with a concentric spot. The throw for centering is first calculated for a blind hole. The diameter of the hole or the OD of the tap, whichever is larger, is divided by two; then 0.010" (0.25 mm) is added for approach and 0.010" for a chamfer. If the workpiece has a through hole, the calculation should be for a blind hole and 0.3 of the through drill diameter is subtracted. This calculation results in a 0.067" (1.70 mm) throw, and Table 15-2 recommends a feed of 0.0044 ipr (0.112 mm/rev). The throw divided by the feed equals 16 revolutions. Centering is one of 10 operations requiring a dwell at the completion of the cut. Five revolutions are added for the dwell, and the result is 21 revolutions for centering. Other operations requiring a dwell are forming, pointing, facing, countersinking, counterboring, bottoming, recessing, trepanning, and cross-slide knurling.

Drilling. The throw for drilling is the length of the workpiece, plus the thickness of the cutoff, plus the approach. Length of the workpiece is 0.313" (7.95 mm). Thickness of the cutoff tool is determined from Table 15-7. A stock diameter of 1/2" (12.7 mm) calls for a 0.100" (2.54 mm) thick cutoff tool. Because the cutoff tool is cutting the roughed 3/8" (9.5 mm) diam on the piece, the hub furnishes reinforcement to the cutoff blade, and the thickness may be safely reduced to 0.090" (2.29 mm) to conserve material. In conjunction with this calculation, it should be kept in mind that, as stated in Table 15-7, "the least thickness used when cutting off into a tapped hole is the lead of 2 1/2 threads plus 0.010" (0.25 mm)." The lead of 2 1/2 threads would be 0.078" (1.98 mm) plus 0.010", equaling a minimum of 0.088" (2.24 mm) for the cutoff tool. In this example, the two calculations balance out. If a major difference existed between the two, the greater thickness would always be used. These sums are then added together to arrive at the total drilling throw: 0.313" (7.95 mm), for the length of piece; 0.090" (2.29 mm), for the thickness of the cutoff tool; and 0.010" (0.25 mm), for approach, equal 0.413" (10.49 mm)—the correct throw for drilling.

Tapping. At this point, the throw for tapping cannot be calculated because the spindle speed, the time in seconds to make one piece, and the hundredths of cam surface for the threading operation must be known.

To arrive at the length of time required to make a piece, the revolutions for tapping are calculated as follows: The length of thread on the workpiece is multiplied by the threads per inch; this number is rounded off, if necessary, to the next larger whole number; and three revolutions are added for approach. This equals revolutions for tapping out. For example, 0.313 (the length of thread in inches) times 32 (the number of threads per inch) equals 10. Rounding off is unnecessary in this case. Three revolutions are added for approach, resulting in 13 revolutions for tapping out on the estimate.

The revolutions to tap out, times the fast spindle speed, divided by the slow spindle speed, equals the revolutions to tap in, and this calculation equals 30, as noted on the layout (Table 15-5). The remainder of the tapping operation is completed when the time in seconds and the hundredths of cam surface have been determined.

Forming. A forming tool forms the contour and deburrs the knurl. Its advance is equal to one half the difference between the smallest diameter on the piece to which the form tool cuts and the stock size, plus 0.010" (0.25 mm) approach. For example, 0.500" (12.70 mm) minus 0.250" (6.35 mm) equals 0.250" (6.35

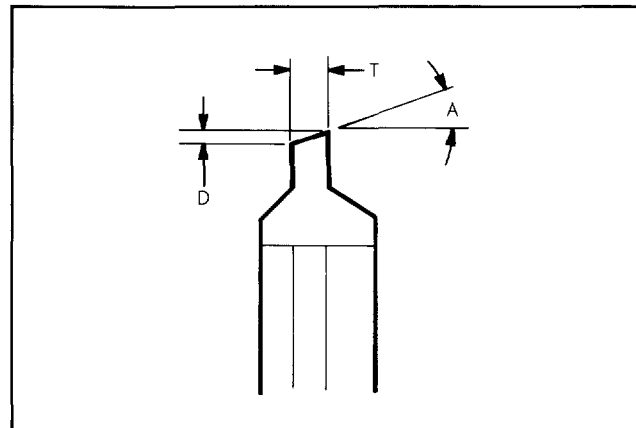


TABLE 15-7
Angles and Thickness for Circular Cutoff Tools*

Diameter of Stock, in. (mm)	Thickness T, in. (mm)	Depth of Angle D, in. (mm)	
		For Brass	For Steel
1/16 (1.6)	0.020 (0.51)	0.0085 (0.216)	0.0055 (0.140)
3/32 (2.4)	0.030 (0.76)	0.013 (0.33)	0.008 (0.20)
1/8 (3.2)	0.040 (1.02)	0.017 (0.43)	0.011 (0.28)
3/16 (4.8)	0.050 (1.27)	0.0215 (0.546)	0.0135 (0.343)
1/4 (6.4)	0.060 (1.52)	0.0255 (0.648)	0.016 (0.41)
5/16 (7.9)	0.070 (1.78)	0.030 (0.76)	0.019 (0.48)
3/8 (9.5)	0.080 (2.03)	0.034 (0.86)	0.021 (0.53)
7/16 (11.1)	0.090 (2.29)	0.038 (0.97)	0.024 (0.61)
1/2 to 9/16 (12.7 to 14.3)	0.100 (2.54)	0.042 (1.07)	0.027 (0.69)
5/8 to 3/4 (15.9 to 19.1)	0.120 (3.05)	0.051 (1.30)	0.032 (0.81)
13/16 to 1 (20.6 to 25.4)	0.140 (3.56)	0.059 (1.50)	0.038 (0.97)
1 1/16 to 1 5/16 (27 to 33.3)	0.160 (4.06)	0.068 (1.73)	0.043 (1.09)
1 3/8 to 1 7/8 (34.9 to 47.6)	0.190 (4.83)	0.081 (2.06)	0.051 (1.30)
2 to 2 1/2 (50.8 to 63.5)	0.220 (5.59)	0.093 (2.36)	0.059 (1.50)

* A is 23° when cutting brass, aluminum, copper, silver and zinc.

A is 15° when cutting steel, iron, bronze, and nickel.

Least thickness used when cutting off into tapped holes is the lead of 2 1/2 threads plus 0.010" (0.25 mm).

Least thickness used when cutting off into reamed holes smaller than 1/8" (3.2 mm) diam is 0.040" (1.02 mm).

Thickness used when cutting off tubing is 2/3 T as given above for corresponding diameters of stock.

Thickness used when angles or radii start from OD of tool is governed by varying conditions and determined accordingly.

SINGLE-SPINDLE AUTOMATIC SCREW MACHINES

mm); divided by 2, it equals 0.125" (3.17 mm); and with a 0.010" approach added, it equals 0.135" (3.43 mm) throw for forming.

Table 15-2 recommends a feed of 0.0012 ipr (0.030 mm/rev) for forming. The forming throw of 0.135" (3.43 mm) divided by 0.0012 ipr (0.030 mm/rev) equals 113 revolutions, plus five revolutions for a dwell is 118.

Cutoff. This tool must advance on the work equal to one half the amount of material to be severed. For solid stock, this would equal the radius of the stock. When the piece has a through-drilled hole, this hole is taken into account. The stock to be severed is therefore the stock size minus the diameter of the through hole; divided by 2; plus the approach 0.010" (0.25 mm), the depth of angle 0.038" (0.97 mm) (see Table 15-7), and 0.015" (0.38 mm) bypass. For a solid bar, the bypass should be 0.003-0.005" (0.08-0.13 mm).

Drawing Cams

Standardized cam sheets, printed with a circle divided into hundredths, are available from machine manufacturers and others. These sheets usually have spaces for listing the tools used, the order of operations, and all other essential information. Their use is strongly recommended.

Instructions for drawing cams, complete to the point where they can be applied in all cases, are beyond the scope of this section. The literature available from the machine manufacturers describes drawing methods in detail.

Standard Tools for Automatic Screw Machines

Some of the standard tools available for Brown & Sharpe automatic screw machines are shown in Fig. 15-10. Although the manufacturers' detailed specifications and recommendations should be considered, the following data covers the greater part of screw-machine operations.

Turning tools. The balance turning tool is the best all-around tool for straight rough turning, with plain hollow mills and adjustable hollow mills, roughing style, as second and third choice. For straight finish turning, box tools are preferable; adjustable hollow mills, finishing style, are sometimes used. The knee tool is generally used for turning scaled surfaces. On straight turning where the piece is long and very slender, a pointing tool of the box type is better than any of the above tools because the bushing ahead of the blade holds the work steady. For taper turning, the swing tool or slide tool can be used. The swing tool is also applied on some form turning where the curve is long, very shallow, and continuous, if circular form tools are not available.

Forming tools. Circular form tools on the cross slides are used as a rule for all form turning and for straight turning behind shoulders wherever they can be applied. They are also used if the length of cut is not too great in proportion to the diameter. Extra-wide circular form tools are held on the toolpost with worm adjustment. If the turning cannot be handled otherwise, the swing tool may offer a solution. Form turning may occasionally be done with a straight blade tool held in the toolpost for square tools. This arrangement is seldom used, however, as the tool has no advantages over the circular form tool and is short lived when compared with the circular type. Square tools are frequently used for short runs.

The tool that is usually best for centering the end for drilling is a center drill clamped in a floating holder, as this permits easy adjustment. If the stock stop is not used in the turret or if for any other reason the end of the bar needs to be faced off as well as

centered, a centering and facing tool should be used that combines the two operations.

To round off, deburr, or point the end of the work where it is stiff enough so that it does not spring under the operation, a pointing toolholder with a circular tool should be chosen. After this is once shaped for the job, it lasts indefinitely, as it can be ground without changing its form and can also be easily set up because of the floating adjustment of the holder. If the piece to be pointed is slender and liable to spring, a box-type pointing tool should be used that supports the work just ahead of the cut.

Drills, reamers, and counterbores. These tools should be mounted in a floating holder so that they may be easily adjusted centrally with the work. A drillholder is also used for this purpose, but it lacks the adjustable feature of the floating holder. Cutting a groove or recess inside the piece is done with the recessing tool.

Threading tools. Most threading is done with self-opening dieheads. When solid taps and dies are used, they should be held in nonreleasing tap-holders and dieholders whenever possible. The releasing type is usually required only in cases in which it is not possible to develop a thread lobe on the cam because of its slow movement and the tool must dwell somewhat before backing out.

Thread rolling is often resorted to when the thread cannot be cut by a die; it should be undertaken on brass, aluminum, and the freer machining steels. Frequently, it is also an advantage to roll short threads.

If a thread is to be rolled, a thread-roll holder for the cross slide is often employed for carrying the thread roll. The cutting-off operation immediately following the threading operation is performed with a separate toolpost. If the thread-rolling operation is heavy, the double-roll holder for the cross slide is better. Single-roll holders are satisfactory for threading brass and aluminum alloys; double-roll holders are preferable for steel. Details of thread rolling are discussed in Chapter 12, "Threading."

The self-opening diehead is used to take the place of the button die and permits both spindle pulleys to be run in the same direction. Also, it eliminates the necessity of reversing the spindle rotation to back off the die button.

Knurling tools. The adjustable knurl holder is preferred for knurling on straight work because it carries two knurls that swivel for straight or diamond knurling and gives a balanced cut. If the part to be knurled is not straight, but formed—convex, for example—then the top or side knurl holders are employed. This also applies when the knurling is behind a shoulder. The knurling swing tool applies only on formed knurling or behind-shoulder knurling when the cross-slide holders are not available.

Cutoff tools. For straight cutting off, where no deburring, rounding, or forming of the bar or the cutoff piece is required, a thin cutoff blade of the straight type is used, held in a toolpost. The circular cutoff tool is most frequently used because it can be shaped readily to part the piece properly from the bar, at the same time doing chamfering or a similar operation; once formed, it retains its shape after repeated grindings.

In cases where the cut causes considerable side pressure, tending to spring the work, as in some thread-rolling, knurling, or forming operations, a back rest should be used in the turret for support if the work permits. Swing-tool cuts on slender work also occasionally require the use of a backrest in the swing-tool shank.

CHAPTER 15

SINGLE-SPINDLE AUTOMATIC SCREW MACHINES

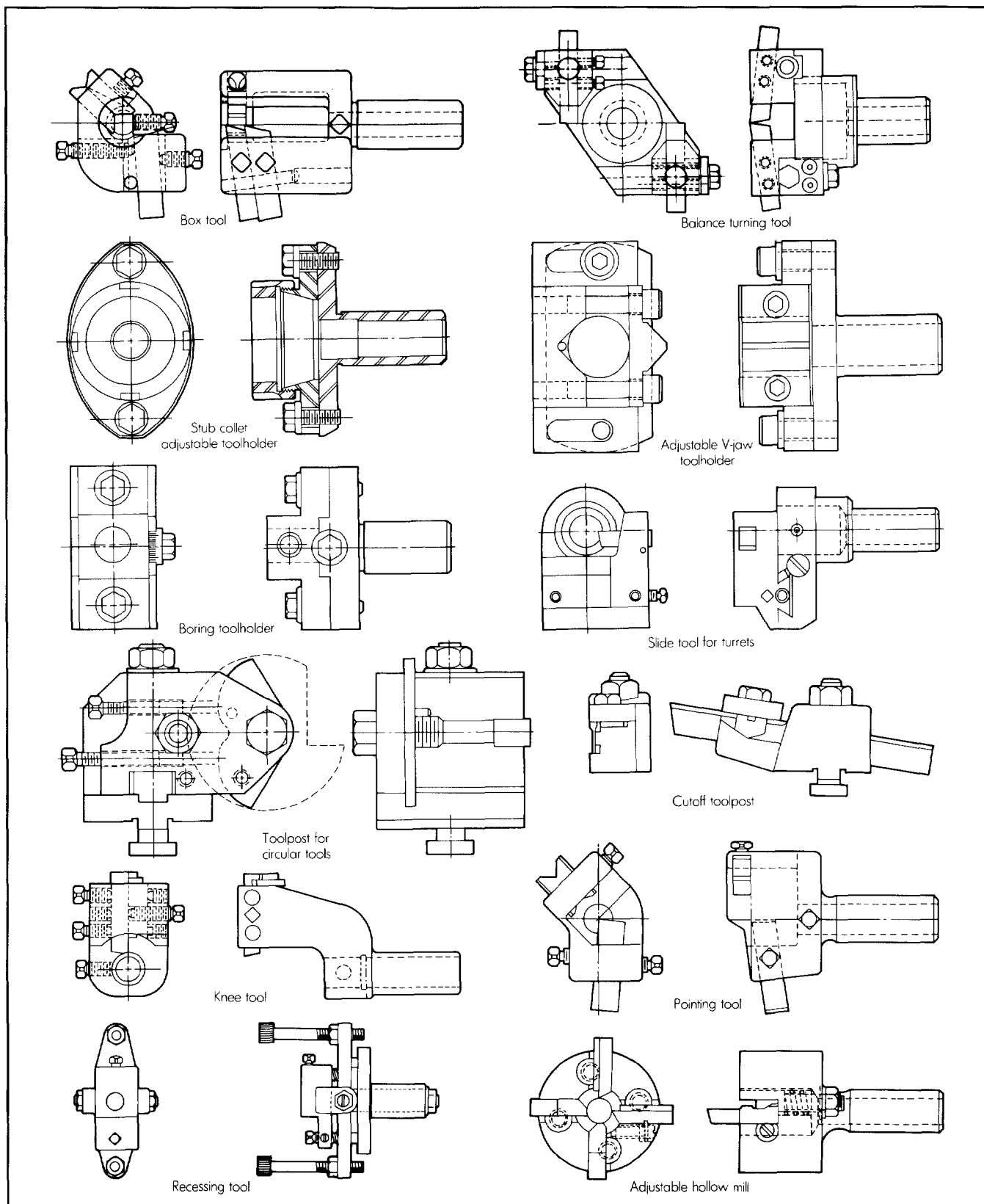


Fig. 15-10 Standard tools for automatic screw machines. (Brown & Sharpe Manufacturing Co.)

SINGLE-SPINDLE AUTOMATIC SCREW MACHINES

Boring tools. A standard boring toolholder provides means for rigidly supporting a boring bar for boring from the turret. Holders of this type are usually provided with means of adjustment and a micrometer adjustment reading directly in thousandths of an inch for accurate adjustment.

Attachments for Automatic Screw Machines

A number of standard and special attachments are available for use with these machines. The most frequently used standard attachments are the upper front slide, screw-slotting attachment, deburring attachment, turret drilling attachment, bar feed magazine, and thread-chasing attachment. In addition to these, many attachments are available that are designed to meet the particular requirements of the work to be produced. Examples of these attachments are cross milling, offset drilling, and combination cross-drill and turret milling attachments.

Magazine feeding attachments can also be applied for handling small parts and second-operation work. Second-operation magazines may be of circular type, chute type, trough type, hopper type, or other styles, as required by the work to be done.

Special milling attachments are frequently used. These may be mounted on the cross slide or held in the turret. A suitable motor-drive arrangement is provided for these special attachments. If a milling operation is required in exact relation to some other dimension of the blanks, it is possible to stop the spindle in a fixed relationship to a flat on hexagonal or square stock, drill a crosshole or mill, then index the spindle a fixed number of degrees, and repeat the cross-slide operation.

Special attachments have been designed for numerous operations such as broaching, splining, back countersinking, and assembling.

Screw-slotting attachment. The screw-slotting attachment shown in Fig. 15-11 takes screws or similar pieces as they are cut off by the machine and slots them automatically, thus doing away with an extra machine for slotting and thereby completing the piece on one machine in practically the same time required to make it without slotting. Light milling operations on the piece can be accomplished with this attachment.

A saw mounted on the adjustable slide that regulates the depth of the slot is driven directly by the motor through right-angle gearing. An arm takes the piece as it is severed from the bar and transports it to the saw where the slot is cut; the finished piece is then ejected into the chute leading to the work pan.

Movements of the arm to pick up and transport the piece and to feed it forward while the slot is being milled are controlled by standard cams, which can be adjusted on the shaft. The piece is held by means of a bushing carried in an adjustable holder mounted on the end of the screw-holder arm, a different bushing being required to conform to the shape of each different piece being made. The extreme positions of the screw-holder arm when rotated are established and maintained with reference to the machine spindle and attachment saw by setscrews and positive stops. The ejector is a piece of flat stock attached to the saw slide in such a way that it extends through a slot in the work bushing and reaches behind the piece. When the screw-holder arm withdraws after the operation is finished, the piece comes in contact with the stationary ejector and is pushed out of the bushing.

Two saws are sometimes mounted on the arbor for cutting parallel flats. When hexagonal or other odd-shaped pieces must be slotted uniformly with reference to the flats, special devices can be furnished that revolve and correctly locate the piece in

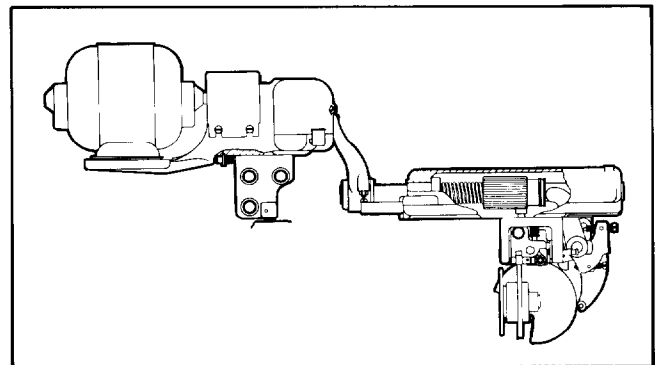


Fig. 15-11 Screw-slotting attachment for automatic screw machine.

the screw-holder arm bushing while it is being transported from the spindle to the saw.

Deburring attachment. The deburring attachment carries a single tool for removing burrs or performing light operations of counterboring or countersinking on the cutoff end of pieces of work before they leave the automatic screw machine. This attachment completely finishes the piece before it is dropped, performing the operation while the machine is producing the next piece, as do all transfer-type attachments.

Upper front slide attachment. This attachment provides an additional tool slide and, on certain classes of work, makes possible an appreciable increase in production. It is designed for forming or cutoff. Cutting off or forming can be accomplished with the spindle running in either direction. An upper rear slide is standard equipment for all Brown & Sharpe screw machines.

The attachment consists of a heavy-duty, ram-type slide mounted on the front spindle-box housing and actuated from the camshaft of the machine by a bellcrank, a link, and a rack mechanism, and a second rack and pinion in the vertical toolslide. A compression spring acting against the bellcrank lever offers resistance so that the slide moves down gradually under cam control instead of dropping down; on completion of the cut, resistance is terminated and the slide withdrawn. The slide can be used for forming.

Automatic rod magazine. This air-operated device accepts a bar of stock from the gravity-feed stock rack. The bar is advanced to a work stop by an air-operated pusher head. It is then chucked in the machine collet; a cupped section in the pusher head supports the opposite end of the bar as it rotates. A small rod located in the center of the pusher head moves the remnant forward until it is consumed.

At this point the driving shaft of the machine is automatically stopped for the short interval required to retract the pusher head, introduce a new bar, and advance it to its proper position in the chuck. The manufacturing cycle is then resumed.

Silent stock support. Objectionable noise created by stock revolving in the stock tube of an automatic screw machine is minimized by this silent stock support. The flexible metal guide tube in which the stock rotates is covered with a casing which deadens sound and prevents transfer of noise and vibration. This is of particular advantage when hexagonal or square stock is used.

Turret milling and drilling attachments. Standard turret milling and drilling attachments for performing milling and drilling operations from the turret are frequently used. These attachments are motorized and driven through a gear reduction unit so that proper speeds can be selected for machining various

SINGLE-SPINDLE AUTOMATIC SCREW MACHINES

types of metals. There are special attachments for turret milling and milling from the back cross slide.

Combination screw-slotting attachment with intermediate position for counterboring. This is a special attachment which is actually a variation of two standard attachments. The arrangement performs a counterboring or drilling operation and a slotting operation, both as secondary operations. This work is performed after the blank has been completed and the work transferred in the normal manner to a secondary position. Figure 15-12 illustrates this attachment, its operating principle being similar to the motor-driven screw-slotting attachment except for an additional intermediate position, *B*, in which the counterboring operation is performed. Arm *A* transfers the work from the cutoff position to the secondary position, identified as position *B*, where the counterboring operation is performed at point *C*. The workpiece is then retracted and transferred by arm *A* to the slotting saw at point *D*. In this position the slot is cut and the finished piece is then ejected by ejector *E* into the chute which carries the finished piece to the work pan. Special operations such as the one described are quite commonly used when a considerable number of finished parts are necessary. These special attachments are invaluable in reducing manufacturing costs and eliminating secondary handlings which often exceed the actual cost of manufacturing the blank if a secondary machine tool and an operator are required to perform that secondary operation in the customary manner. Such an attachment as this eliminates these secondary operations.

Magazine arrangement, air-operated. This is a special air-operated magazine which can be readily mounted on the turret slide of a given automatic screw machine. This type of magazine can be used for either secondary-operation work or for assembly work in which a part is assembled to a different piece being manufactured at the spindle of the machine. The air-operated magazine arrangement in Fig. 15-13 may be used for loading a part onto an inserting tool at the rear of the turret. The work is loaded into the magazine, *A*, either by hand or by a

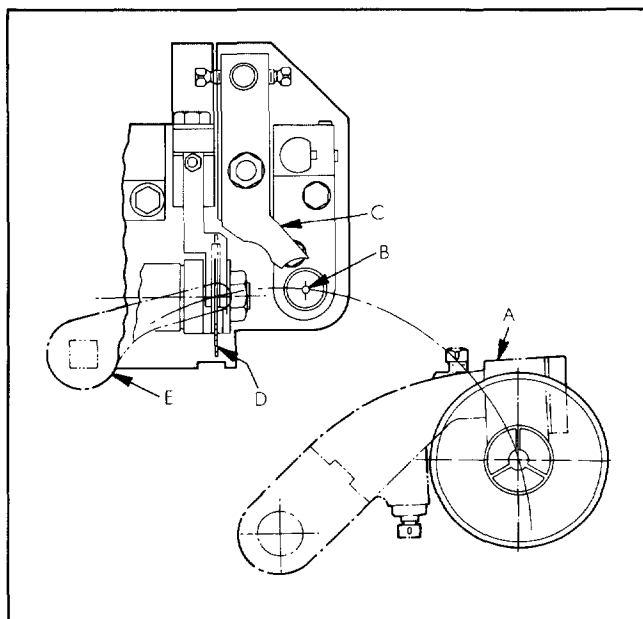


Fig. 15-12 Screw-slotting attachment with an intermediate position for counterboring.

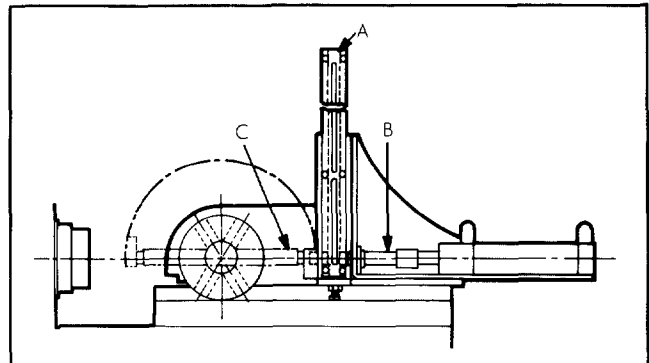


Fig. 15-13 Air-operated magazine for loading and inserting tool held in turret.

hopper arrangement. The part is then automatically loaded into an inserting tool, *C*, by an air-operated piston, *B*. The inserting tool is then indexed through normal turret motions until it is in line with the spindle. At this point the part is inserted into the workpiece being produced at the spindle nose. In this way the entire operation is an overlapping one; it consumes no additional time for loading work onto the inserting tool. Consequently, it is a very efficient arrangement for either secondary-operation work or a method of assembling two parts in the automatic screw machine.

Figure 15-14 illustrates an inserting tool used in an assembly operation in which spinning is employed to secure the assembled parts. The machine produces a given part; a bushing is assembled onto it and is retained by spinning. An air-operated magazine similar to that shown in Fig. 15-13 inserts the bushing into the inserting tool, *A*. When the loaded inserting tool is in line with the spindle, the advancing motion of the turret places the bushing, *B*, on the workpiece, *C*. Further advance of the turret allows the spinning tool, *D*, to flare the end of the workpiece. The turret is withdrawn, and the cutoff operation severs the workpiece and assembled bushing, *E*.

While many special applications can be performed in the automatic screw machine, due consideration must be given to length of run and, of course, the peculiarities and requirements of the individual part. It is, however, quite possible to perform almost any given operation and complete it on the automatic screw machine provided that it is practical, from an economical standpoint to devote the necessary engineering time and development time for any such attachment.

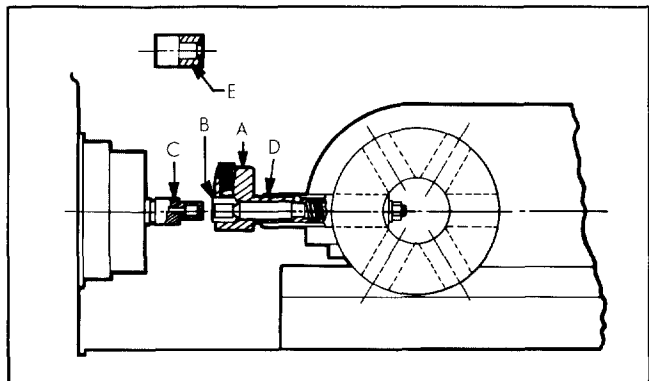


Fig. 15-14 Assembling a bushing onto a workpiece on an automatic screw machine.

SINGLE-SPINDLE AUTOMATIC SCREW MACHINES

Coil feed. Some automatics are designed to handle coiled stock. This eliminates the need for bar loading, reduces the number of stock remnants to one per coil, and in many cases provides material savings.

PROGRAMMABLE AUTOMATICS

Camless single-spindle automatics are programmed by toggle switches, pegboards, control drums, punched cards, or NC/CNC units. They are simple to set up, permit faster changeover, and provide considerable flexibility. As a result, they are being used more extensively than cam-controlled automatics for shorter run production requirements.

Toggle Switch Programming

Camless automatics made by one machine tool builder are called Programmed Turning Centers (PTC). Cycling is controlled by solid-state electronic logic with plug-in circuits and a built-in diagnostic system. Programming is done by simply flipping toggle switches on a sequence controller, with verification accomplished visually. Data can be added, deleted, or modified immediately. Automatic program loading, which permits the storage of a program in a tape cassette, is available as an option. Complete manual control for fast set up is standard.

Universal spindles on the hydraulically operated PTC machines accommodate either bar or chucking equipment. A fast-indexing, eight-tool turret with tool relief can be fed at any rate between 0.250-100 ipm (6.35-2540 mm/min) for any turret station. The turret slide, with a feed stroke of 7 1/2" (190 mm), is rapid traversed at 300 ipm (7620 mm/min) and retracted at 600 ipm (15 240 mm/min).

Positions for up to four hydraulically fed cross slides are provided on each PTC machine. A forming and cutoff slide can be mounted in any of the four positions. A single-point, longitudinal turning slide can be installed in three of the positions. An electronic single-point threading unit can be mounted in two of the four positions, and a hydraulic tracing device on one slide. Cross-slide operations may be overlapped together and can be performed with any operation or successive operations of the turret slide.

Control Drum Programming

On a camless automatic made by another machine tool builder, the entire program is placed into a main control drum. Trip dogs positioned on this drum activate hydraulic control blocks and electrical switches which control the functions of the turret and cross slides. An additional control drum that can be

preset out of the machine to further reduce setup time is offered as an option.

These drum-controlled automatics feature the ability to offset the turret. When single-point turning or boring from the turret, use of the offset eliminates withdrawal marks on the workpiece. The offset can also be used to control size. Once the turning or boring tool is clamped in its holder, all diametral size adjustments can be accomplished with the offset.

The turret slide on these drum-controlled machines carries an exchangeable turret with six or eight tool holes, and an exchangeable stop carrier for limiting the lengths of travel. Four hydraulically fed cross slides can be independently adjusted for travel and rate.

CNC Programming

Several machine tool builders offer camless single-spindle automatics with CNC units. One machine with a two-axis CNC unit features a turret mounted in a plane perpendicular to the bar stock that rotates on its axis to provide the X-axis cutting action normally achieved with cross slides. Longitudinal motion of the turret slide actuates the end-working tools. The eight-tool turret, an independent cutoff slide, and a retractable tailstock provide up to 11 tool functions. Pretooled turrets can be quickly interchanged.

Another builder offers a camless single-spindle automatic with a microcomputer control system that permits up to 94 different machining operations. A simple card data entry system is used for programming. The machines are equipped with four radial tool slides and an interchangeable eight-tool turret that accepts rotating tools in any station. A front compound cross slide can be equipped with a two-tool turret and hydraulic tracing unit. A d-c drive for optimum speed selection is also available.

With the microprocessor CNC offered on one single-spindle automatic, many part programs can be fed into the computer memory by means of previously punched tapes, by manual data input (MDI) or by means of a time-sharing terminal. Changeover from one program to another can be done in a few seconds by MDI commands. Programming is simplified by numerous subprograms that can be stored in the computer memory. These include rough and finish turning, thread chasing, and deep-hole drilling. Necessary geometric calculations for tool nose radii are carried out automatically, and the control can calculate the most economical position for turret indexing. Indexing logic of the machine (selecting the shortest route for turret indexing) permits the use of standard tool sets.

SWISS-TYPE AUTOMATIC SCREW MACHINES

The Swiss-type single-spindle automatic screw machine is not, strictly speaking, a screw machine, since it does not perform the ordinary screw jobs with the same facility as the conventional type of screw machine. Owing to the method by which the stock is fed, while rotating, by a sliding headstock through an adjustable carbide-lined guide bushing into the cutting tools, it should probably be known as a Swiss bushing-type or precision sliding-headstock automatic lathe. The Swiss-type automatic differs from the traditional automatic screw machine, which employs form tools, indexing turrets, and box tools, in that it uses single-point tools.

Machines commonly in use for instrument work have a range of 1/32 to 3/8" (0.8 to 9.5 mm) diam stock capacity and 1/32" to 2 3/4" (0.8 to 70 mm) turning lengths. Watch manufacturers employ smaller machines with a maximum stock capacity of 5/32" (4 mm) diam and a maximum length of 1 9/16" (40 mm). Other Swiss-type automatics are available with a maximum stock capacity of 1 1/4" (32 mm) diam and a maximum turning length of 9" (229 mm).

The Swiss-type automatic has distinct advantages over the conventional type of screw machine in that it is capable of producing long, slender, and complexly contoured parts with a

SWISS-TYPE AUTOMATIC SCREW MACHINES

high degree of accuracy. In the hands of a skilled operator, Swiss-type automatics have been known to repeat, over long periods of time, a total tolerance on diameters as close as 0.0002" (0.005 mm). Shoulder lengths have been held to a tolerance of 0.0005" (0.013 mm); however, a tolerance of 0.0008" (0.020 mm) is more practical.

A high quality of finish can be turned to a degree comparable to that of a ground finish using Swiss-type automatics. Therefore, the machines are invaluable when high-finish close-tolerance bearing surfaces are required on small shafts, such as those used in electric meters, watches, clocks, and other parts necessary for the instrument trade.

In addition to providing close tolerances and a high quality of finish, this class of machine is able to produce long, slender parts of extremely small diameters—down to about 0.005" (0.13 mm) diam. This is possible because the guide bushing, through which the bar to be turned must pass while rotating, can be adjusted to practically eliminate all radial movement. Best results are obtained by using centerless-ground stock as round as possible and uniform in its diameter throughout each bar length, although drawn wire to a total tolerance of 0.0003" (0.008 mm) is usually sufficient for critical applications.

Cutting tools, almost without exception, are single-point carbide and are positioned directly in front of the guide bushing. High-speed steel tools are used for some special applications. It is preferable that all tools be positioned just a few thousandths of an inch (about 0.05 mm) in front of the bushing. The bushing then relieves the turned portion, the tool load being almost entirely absorbed by the guide bushing.

Optical machines with microscopes, as well as other machines, are available for presetting tools to reduce setup times.

The Swiss-type automatic is capable of completely machining certain kinds of parts that if placed on a conventional screw machine would require secondary and tertiary machining. The Swiss-type machine, however, does not equal the productivity of a conventional screw machine on straight screw jobs. When wide tolerances are permitted and better than class 2 threads are not required, and when parts are not too long, the conventional screw machine exceeds Swiss-type machine production.

Swiss-type automatics are available with cam control or CNC units which eliminate the need for cams. Cam-controlled machines are lower in initial cost and are considered by many engineers to be the most efficient for high-volume production requirements. Machines with CNC, however, are being increasingly applied because of their short programming and setup times, which increase their flexibility.

CAM-CONTROLLED MACHINES

Movements on a typical cam-controlled Swiss-type automatic are shown diagrammatically in Fig. 15-15. A toolframe mounted vertically on the machine bed carries five toolslides that are arranged like a fan and directed toward a common center and the work area. Tools 1 and 2, mounted on a cam-actuated rocking lever, are used for turning most surfaces. Tools 3, 4, and 5, each actuated by an individual cam, are generally used for chamfering, undercutting, cutting off, spotting, boring, back and front recessing, and knurling. A stationary or rotating guide bushing is the common device used

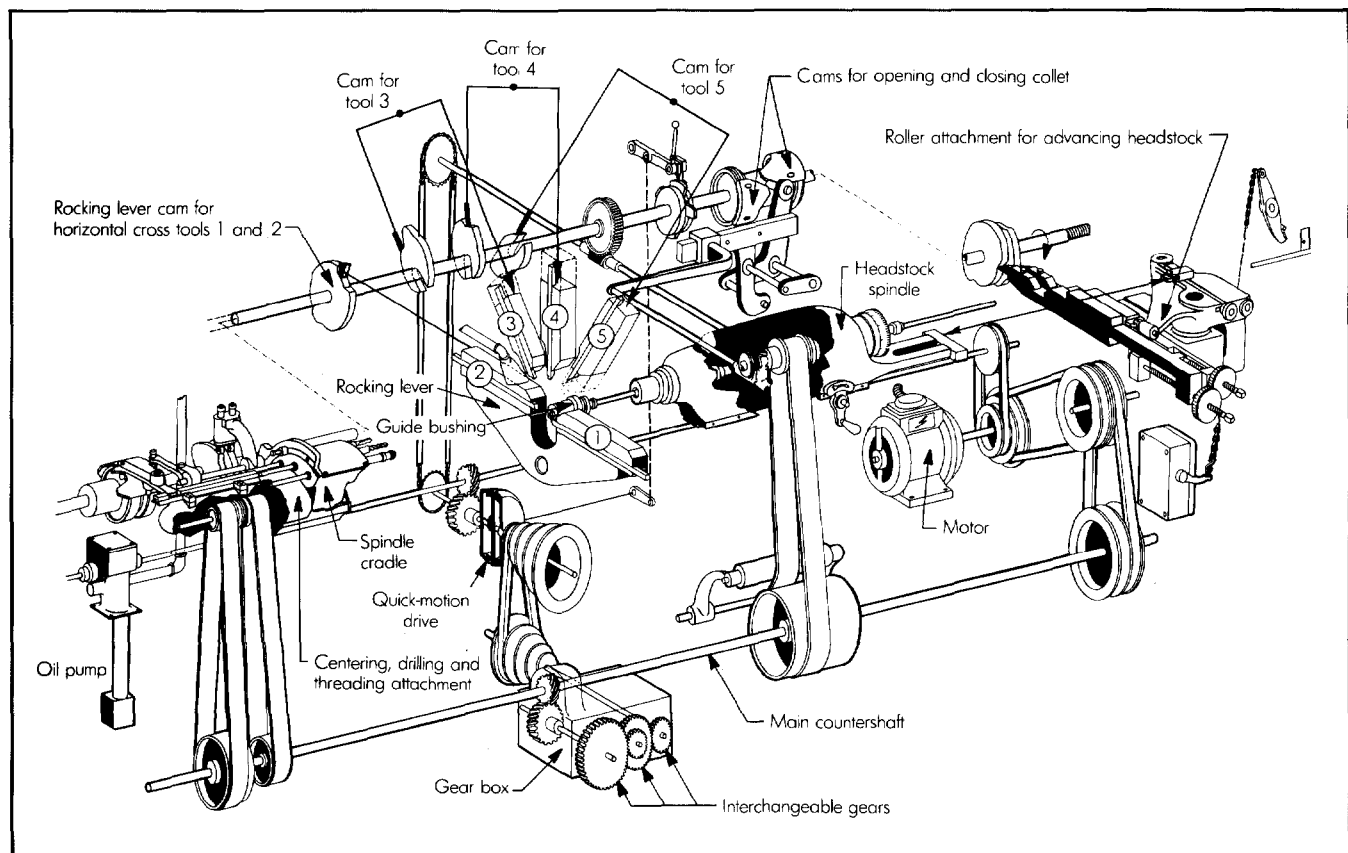


Fig. 15-15 Diagram of movements on a cam-controlled Swiss-type automatic.

SWISS-TYPE AUTOMATIC SCREW MACHINES

to support the bar stock properly at this point. Movements of the tools are only toward the center.

All actual motion or feeding for turning operations is provided by the moving headstock. The headstock, with the material-gripping device, is located behind the toolframe, with the headstock spindle perfectly aligned with the guide bushing, and slides on a bed. Tools mounted in the frame have minimum overhang from the guide bushing at all times, regardless of the length to be turned. The use of a ground bushing and centerless-ground workpiece material permits the relationship between the cutting edge of the tool and the centerline of the bar to be maintained within 0.0002" (0.005 mm), thus ensuring close tolerances on workpieces.

Straight turning of a cylindrical shape is accomplished by presenting a tool at a given diameter and feeding the headstock forward, thus feeding the stock past the tool for the length to be turned. Tapers, spheres, or any other shapes can be generated by combining movements of the tool and headstock.

Guide bushings are generally carbide lined for long life and are slit three ways, like a collet, for adjustment and proper fit for the bar stock. They are available as either push or draw-type bushings. Push types are somewhat lower in cost, but the draw types feature the tendency to open up rather than close down under heat generated by friction. This lessens the chances of freeze-up. The amount of clearance between stock and bushing is very critical. It can range anywhere from practically zero to 0.002" (0.05 mm), depending on work tolerances, type of material, depth of cut, and feed rate.

Cam Layouts

All the operations to be performed during a full 360° revolution must be laid out so that all cam movements are exactly related in degrees. Each operation should be studied carefully to determine the treatment it should receive. When diameters are to be turned, the crossfeed cams must also be taken into consideration. For instance, on a dwell for an undercut, the proper number of degrees must be allowed for the headstock cam to dwell while a cam actuates the tool that must do the undercutting. The same is true of chamfering, which is nearly always done during a dwell on the cam. This applies as well to the cutting-off operation in which the cam dwells and the cutoff tool separates the piece from the bar. After the cutoff tool completes the separation of the piece from the bar, the headstock collet is released; the headstock retracts and regrips the bar; and starting at 0°, the cycle is repeated. Flexibility is provided by equipping all toolslides with micrometer-adjusting screws for both radial and longitudinal adjustment.

The cams are usually designed to produce one part for each revolution of the camshaft. The total of the productive and unproductive degrees equal 360°. Productive degrees are the degrees necessary for actual machining operations. Unproductive degrees are the degrees required for opening and closing the collet, for unproductive movements of tools, for headstock movements, and for safety. Overlapping of tool and headstock movements is necessary to keep unproductive degrees to a minimum, thus allowing a greater number of degrees for productive rises on the cams. A 2-4° area of dwell on the cam allows the tool to dwell in position before the machining operation begins and permits the tool to dwell at the end of the machining operation for completion of the cut before being withdrawn.

Handbooks published by the machine manufacturers contain tables and charts for cam unproductive rises and falls, cam

blank dimensions, width of cutoff tools, tool clearance between bar stock and tools in neutral position, and other pertinent data required by the tool engineer when planning the operations, tools, and cams for Swiss-type automatic machines. The cams are laid out from the completed operation sheet using manufacturer's templates for scribing angular division lines between rises and falls. Other templates are available for other cams. Since the cam blanks are not calibrated, the cams are held in a fixture graduated in 360 divisions or degrees while the division lines are being scribed. One method of generating a radius is shown in Fig. 15-16. The contour being generated is indicated by *A*, and *B* is the tool which does the turning. It is assumed that 38° is the distance that equals the time required to complete the operation, as indicated by the vertical lines.

Designing and manufacturing cams for Swiss-type automatics can be complex and time consuming. With the advent of the computer, however, cams for synchronized compound movement (referred to as generating) are now quickly and easily developed. Hours of manual or graphic calculations previously necessary are no longer required. The process has been so refined that even corrections for tool nose radii can be programmed.

Attachments

Many attachments are available for Swiss-type automatics to perform various operations required for specific applications.

Single-spindle drilling attachment. This attachment is available with either a cam-activated spindle for ordinary drilling or a spring-controlled spindle for sensitive drilling.

Two and three-spindle drilling attachment. One stationary and one revolving spindle are available on the two-spindle

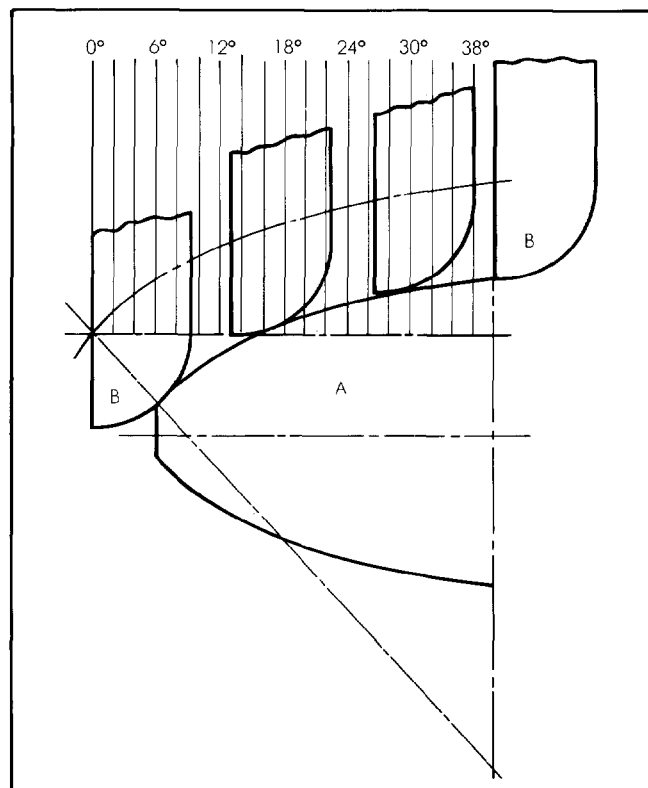


Fig. 15-16 Method for generating a radius.

SWISS-TYPE AUTOMATIC SCREW MACHINES

attachment. Either one or two revolving spindles are available on the three-spindle attachment. This attachment is normally used for centering, drilling, or reaming.

Single-spindle threading attachment. This attachment is designed to accommodate self-opening dieheads and button dies for external threads. The diehead spindle is advanced by a cam which also follows thread lead in starting dies on the workpiece.

Two-spindle threading attachment. In operation, dies on the first spindle rough the thread; the die on the second spindle finishes the thread. Normally, the attachment is used in connection with a safety device that stops the camshaft in case of faulty threading.

Two and three-spindle drilling and threading attachment. This attachment has two or three spindles for centering, drilling, threading, and tapping. Normally, one spindle is nonrotating and one or two can be either rotated or fixed. The spindles are indexed radially to position each spindle in line with the screw-machine spindle. Travel of each of the spindles is independently controlled. Right or left-hand threads can be cut with the attachment.

Back-drilling attachment. This attachment is used for chamfering, counterboring, and small drilling operations on the cutoff side of the workpiece. After it is cut off, the part is picked up by a transfer arm and is moved into the spindle position by a pick-off arm. Operation time is overlapped into the next camshaft cycle.

Slotting attachment. After being cut off, the workpiece is transferred to the slotting position by a pick-off arm. The slot can be made by a transverse movement of the saw to produce a flat bottom to the slot, or by a direct incutting of the saw which forms a concave bottom in the slot. A special two-saw slotting attachment is also available which provides a burr-free slot. The operation takes place simultaneously with machining of succeeding workpieces in the normal machine cycle.

Three-spindle attachment. This attachment, mounted on the tool bracket, permits centering, drilling, threading, or milling operations to be performed at the cutoff side of the workpiece. Cutoff workpieces are clamped and presented successively to various tool stations.

Headstock-stopping and indexing device. The headstock can be stopped with this device at any predetermined position on the camshaft cycle to enable cross drilling, sawing, or milling operations. This mechanism must be built into the machine when it is manufactured.

Multiple cams. Machines are available with space on the camshaft for as many as eight headstock cams and six rocking lever cams. With this feature, the machining of similar parts of different lengths and diameters can be accomplished without changing the cams.

Stopping ratchet. This device is used to stop the machine at the end of the bar or at any predetermined position. It is also used when thin or weak stock is fed that might be damaged by the rotating collet. The time of tripping is controlled by a graduated dial.

Single-point thread-chasing attachment. This attachment is used to produce highly precise, single and multistart threads that cannot be cut or rolled on the machine. It operates at high speeds, up to 450 passes per minute, and is synchronized with the machine spindle.

Accelerator. This device accelerates the camshaft during idle times when the tools are not in contact with the work, such as during changing of attachment spindles or during the opening and closing of the headstock collet. Production can be proportionately increased on parts requiring low feeds and speeds.

Polygon milling attachment. Some builders of automatics also offer a polygon milling attachment which allows machining two flats on the sides of a workpiece, or perfect squares, by the polygon milling/turning methods. These operations can be carried out anywhere on the workpiece, even between shoulders, at a faster rate than would be possible using spindle stop and milling attachments.

Other attachments. Among other attachments for further increasing the versatility of Swiss-type automatics are a six-tool drum turret, taper-turning attachment, revolving guide bushing for irregular contour stock, and circular form tool and knurl holders.

Operating Parameters

Single-point tools are used for practically all turning and

TABLE 15-8
Recommended Feed Rates for Turning on Swiss-Type Automatics

Workpiece Material	Workpiece Tolerance, in. (mm)				Cut-in Feeds, % of Turning Feeds
	0.0002 (0.005)	0.0005 (0.013)	0.001 (0.03)	0.002 (0.05) or more	
	Turning Feed Rate, ipr (mm/rev)*				
Brass	0.0008-0.0012 (0.020-0.030)	0.0012-0.0025 (0.030-0.063)	0.002-0.004 (0.05-0.10)	0.004-0.008 (0.10-0.20)	25-35
Aluminum	0.0008-0.0012 (0.020-0.030)	0.0012-0.002 (0.030-0.05)	0.0015-0.003 (0.038-0.08)	0.003-0.006 (0.08-0.15)	25-35
Free-machining steel	0.0004-0.0008 (0.010-0.020)	0.0008-0.0015 (0.020-0.038)	0.001-0.0025 (0.03-0.063)	0.002-0.005 (0.05-0.13)	25-35
Carbon steel	0.0003-0.0006 (0.008-0.015)	0.0006-0.0012 (0.015-0.030)	0.0008-0.002 (0.020-0.05)	0.0012-0.0025 (0.030-0.063)	25-35
Stainless steel	0.0004-0.0006 (0.010-0.015)	0.0006-0.0012 (0.015-0.030)	0.0008-0.0015 (0.020-0.038)	0.001-0.002 (0.03-0.05)	30-50

* Based on depths of cut from 1/16 to 3/8" (1.6 to 9.5 mm).

SWISS-TYPE AUTOMATIC SCREW MACHINES

TABLE 15-9
Recommended Feed Rates for Drilling on Swiss-Type Automatics

Drill Diameter, in.	Material Being Drilled						
	Brass	Copper Alloys	Aluminum	Free-Machining Steel	Carbon Steel	High-Carbon Steel	Stainless Steel
	Drilling Feed Rate, ipr (mm/rev)*						
0.020	0.0008 (0.020)	0.0004 (0.010)	0.0008 (0.020)	0.0004 (0.010)	0.0002 (0.005)	0.00015 (0.0038)	0.00025 (0.0063)
0.040	0.0014 (0.036)	0.0008 (0.020)	0.0012 (0.030)	0.0004 (0.010)	0.0004 (0.010)	0.0003 (0.008)	0.0004 (0.010)
1/16	0.002 (0.05)	0.001 (0.03)	0.0015 (0.038)	0.0012 (0.030)	0.0006 (0.015)	0.00045 (0.0114)	0.0006 (0.015)
1/8	0.0032 (0.081)	0.002 (0.05)	0.002 (0.05)	0.0018 (0.046)	0.0011 (0.028)	0.0009 (0.023)	0.001 (0.03)
3/16	0.0045 (0.114)	0.003 (0.08)	0.0028 (0.071)	0.0022 (0.056)	0.0015 (0.038)	0.0013 (0.033)	0.0014 (0.036)
1/4	0.0055 (0.140)	0.0035 (0.089)	0.0035 (0.089)	0.0026 (0.066)	0.0018 (0.046)	0.0015 (0.038)	0.0017 (0.043)
3/8	0.006 (0.15)	0.004 (0.10)	0.004 (0.10)	0.0028 (0.07)	0.002 (0.05)	0.0015 (0.038)	0.0016 (0.041)
1/2	0.006 (0.15)	0.004 (0.10)	0.004 (0.10)	0.0028 (0.07)	0.0018 (0.046)	0.0012 (0.030)	0.0014 (0.036)

* For centering operations with the cross slide, use one half the feed rate shown. When centering with the spindle, use two thirds the feed rate shown.

forming operations. For special cases, toolholders to accommodate circular form tools or boring tools are available. With such toolholders, however, extra work room must be provided, possibly resulting in losing the use of one tool slide. Carbide tools are used almost exclusively. For certain tough-to-machine materials, such as highly work-hardening types for which top rake of up to 10° is unavoidable, cast alloy or super-high-speed steel tool bits are recommended. Recommended feed rates for turning are given in Table 15-8.

Drilling operations. With the headstock spindle revolving clockwise, all drilling from end-working attachments requires left-hand cutting tools, except on CNC machines. When a job is contemplated for which tools other than standard-flute drills must be used, it should be kept in mind that left-hand cutting tools are considered specials (more expensive and not generally stock items). Whenever possible, high-speed steel drills should be used; drills from other material, such as carbide, should be used only when nothing else will provide a tool life of acceptable limits. Recommended drill feeds are given in Table 15-9.

Reaming. Single or double-flute reamers work best on Swiss-type automatics. Standard reamers usually do not perform well because the reaming speed is frequently too high and the machines work with constant speed of the headstock spindle. For sizing accurate holes in rough and hard materials, single-point boring from one of the cross slides is the best solution. This method works quite well if the depth of the hole to be bored does not exceed four times the diameter.

Threading. Threading is achieved by the differential-speed method. This means that for a right-hand thread, the tool rotates faster and overlaps the workpiece by a ratio chosen for the correct cutting speed; the tool is slowed for unthreading.

For left-hand threads, the method is reversed. Speeds are changed by shifting a double-cone clutch from high to low speed by means of the thread-depth adjustment linkage.

Self-opening dieheads for cutting or rolling of threads are limited to the larger capacity machines because of lack of space between the spindles of the threading attachment. When a thread is cut to better than class 2 in tough-to-machine materials, practically no cutting fluid reaches the cutting edge of the chasers with a fast-rotating diehead.

For very accurate threads, thread forms which cannot be cut with a diehead, threads behind a shoulder, and multiple-start threads and worms, the single-point thread-chasing attachment is recommended.

Cutting fluids. Cutting oils should be used whenever possible on Swiss-type automatics. Only in very exceptional cases, such as when exotic or nonmetallic materials are being machined, should water-soluble or chemical cutting fluids be used. The main reasons are that (1) working through a closely fitted guide bushing, the best possible lubrication is needed to prevent freeze-up and (2) closely fitted tool slides, camshafts, and spindle bearings are exposed to the cutting fluids. Certain cutting fluids invite early and frequent maintenance problems.

Tool resharpening. Freehand grinding of tools used on Swiss-type automatics is not recommended. Equipment suitable for grinding single-point cutting tools with a quick-setting tool fixture is recommended. With proper grinding wheels, a 4 μ in. (0.10 μ m) surface finish should be obtained. Such grinding prevents material build up and provides long tool life. Resharpening of tools should be done before appreciable wear occurs. Worn tools increase the pressure on the bar, which in turn can cause the material to gall or freeze in the guide bushing.

SWISS-TYPE AUTOMATIC SCREW MACHINES

To get best performance from Swiss-type automatics, good housekeeping is a must. The machines are a little more delicate than other automatics, and all manufacturers recommend that tools such as hammers or wrenches with extension handles not be used. The machines incorporate means for proper adjustments which make the use of such tools unnecessary. Micrometer screws for every possible tool setting eliminate guesswork.

CNC MACHINES

Swiss-type automatics with CNC eliminate the need for cams, minimize setup times and necessary operator skill, and are being used extensively for lower volume production requirements. Another important advantage of machines equipped with CNC is that the restriction to 360° layouts on cam-controlled machines is eliminated. This permits operations to be performed that are difficult or impossible to perform on cam-controlled machines. These operations include certain deep-hole drilling, single-point threading (both left and right-hand), taper cutting, and contouring.

Swiss-type automatics with CNC made by one machine tool builder have simultaneous two-axis control for the X-axis toolholder and the Z-axis headstock. This permits straight, taper, and circular turning, as well as threading. Five toolholders, arranged in a radial configuration on these machines, are controlled by a servodisc (see Fig. 15-17) that comes with the machines and does not have to be designed and built. Programmed signals from the CNC unit command the disc to select the predetermined toolholders, which travel the required distances by rotation of the disc.

The sliding headstock on these machines has a hydraulic chucking device that carries the bar stock longitudinally. Advancement and retraction of the headstock is controlled by a servomotor which rotates a ballscrew for travel in increments of 0.00004" (0.0010 mm). The machine spindle is driven by an a-c motor and provides infinitely variable, programmable speeds. A standard self-diagnostic function in the CNC unit permits fast troubleshooting.

Attachments similar to those described for the cam-controlled automatics are available for the CNC machines. These include cross milling and drilling attachments, rotary

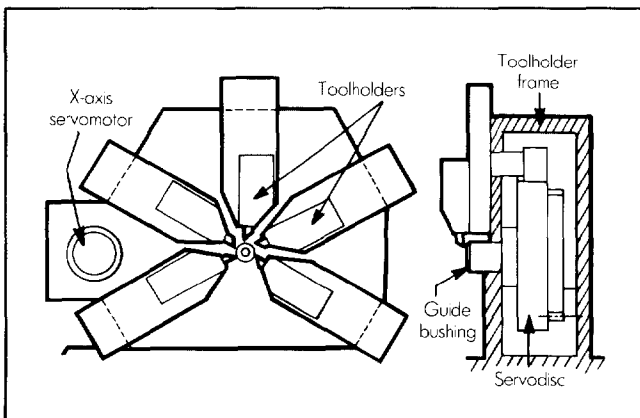


Fig. 15-17 Servodisc controls five toolholders on this CNC Swiss automatic (Hirschmann Corp.)

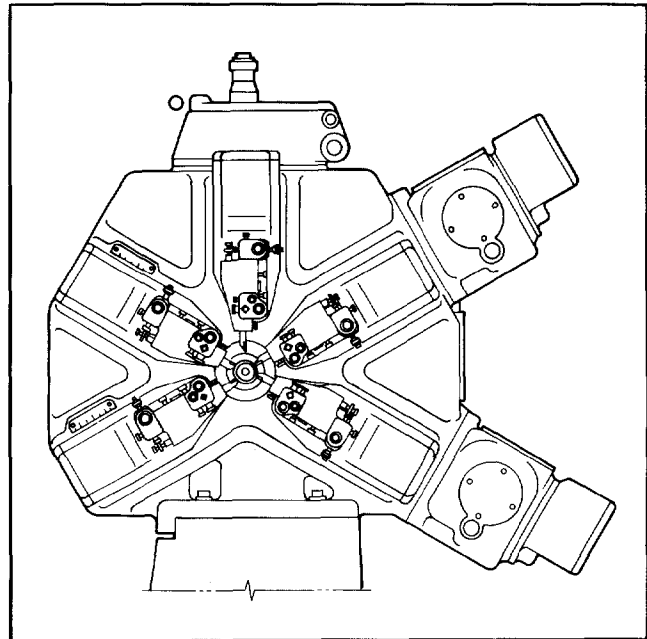


Fig. 15-18 Individual ballscrews permit precise positioning of toolslides. (Nomura, Inc.)

guide bushings, and automatic bar feeders. Also available is a sliding attachment with four dead (nonrotating) spindles that moves laterally (front to back) and provides single-spindle back-drilling capability. Each spindle is positioned by hydraulic cylinder and locator screw.

Different designs of Swiss-type automatics are offered by other machine tool builders. With one design (see Fig. 15-18), movements of the toolslides are individually controlled by ballscrews. This permits repeatability of toolslide positioning within 0.00005" (0.0013 mm).

On another machine, there are no radial slides. Tooling is mounted on two five-tool turrets, one turret being indexed while tools on the other turret are cutting. On this machine, the headstock is fixed, but the guide bushing is mounted on a slanted carriage and moves with the tools.

Another builder offers a machine with a 12 station, 30° slanted, universal turret with servocontrolled movement in the X axis. The Z-axis movement is derived from a servocontrolled sliding headstock. The headstock spindle provides for the C axis which permits (in conjunction with the turret tools) cross-machining operations. A four-position endworking attachment with lateral tool positioning is also provided.

Some CNC machines permit programming by manual data input (MDI) or punched tape. The six radial toolslides on one machine are controlled by two axes, allowing simultaneous use of two tools. Another machine allows independent movement of six radial toolslides, the headstock, and a four-spindle endworking attachment. Any five of the eight programmable axes can be operated simultaneously at varying feed rates. A dual memory in the control permits production from one memory while the second memory is being programmed for the next workpiece.

MULTIPLE-SPINDLE AUTOMATIC BAR AND CHUCKING MACHINES

MULTIPLE-SPINDLE AUTOMATIC BAR AND CHUCKING MACHINES

The principal advantage of the multiple-spindle automatic over the single-spindle machine is the reduction in time required per piece. In contrast to the single-spindle machine, on which one turret face at a time is working on one spindle, the multiple-spindle machine has each turret or end-slide tool working on its respective spindle at the same time. While on the single-spindle machine the time required to complete one piece is a total of the time needed for each turret operation plus the times necessary to index the turret; on the multiple-spindle machine, the time necessary for one cycle is the time required only for the longest single cut plus idle time.

The range of work produced by the multiple-spindle machine is comparable to that produced by lathes, single-spindle bar machines, and turret lathes. Because of its longer setup time and increased tooling cost, the multiple-spindle machine is generally less economical than the other three on short runs; however, it is more economical on long runs. Changeover time has been reduced on modern multiple-spindle automatics by features such as preset tooling, master collets and pushers which accept different stock sizes, magazine-fed bar feeders which feed stock into the reel tubes without stopping the machine, quadrant mechanisms which permit changing tooling strokes by adjustments instead of changing cams, and machine sequencing by programmable controller. Multiple-spindle machines lend themselves well to the application of special fixtures and attachments that may eliminate secondary operations on the work.

CLASSIFICATION OF MACHINES

There are five general features by which multiple-spindle automatic bar and chucking machines are classified. To identify any machine properly, all five must be used. The five classifications are as follows:

1. Method of chucking.
2. Capacity.
3. Arrangement of spindles.
4. Number of spindles.
5. Method of indexing.

Method of Chucking

The method of chucking distinguishes bar-type machines and chucking machines from each other. Bar-type machines employ collets—push, draw, or stationary types. Although the collet actuation is usually automatic, the machines may be arranged to permit manual actuation in the case of second-operation work. Chucking machines may be equipped with any type of workholding fixture within the machine capacity. Hydraulic chucking or automated mechanical chucking frequently allows the use of automatic loading and unloading devices. Manual or hydraulic chucking may be employed when the operator loads and unloads the machine.

Capacity

The capacity of a bar-type machine is the maximum diameter of stock that can be fed through the spindle, limited by the capacity of the feed fingers. It is possible to run over-capacity, round bar stock by using a roller feed mechanism, which

eliminates the need for feed fingers. Square, hexagonal, and other extruded-shape bars can also be run, providing they fit within the cross-section of the round stock.

On second-operation (chucking type) work for which the feed fingers are not used, the collet-type machine usually chucks a slightly larger diameter than the rated capacity and the portion of the work extending from the collet into the tooling zone may be larger still. The capacity of the multiple-spindle chucking machine is limited by the center distance between spindles.

Other capacities are the maximum length of stock feed and the maximum length that can be turned. The maximum length of stock feed is the longest piece of work that the bar-type machine can automatically feed out and cut off. The maximum length that can be turned is generally governed by the stroke of the endworking toolslide that must make the turning cut, withdraw, and clear the work before the machine indexes for the next cycle. Extra length can be turned, however, with the use of auxiliary spindles.

Arrangement of Spindles

On indexing-type machines, spindles are arranged radially about the endworking toolslide (see Fig. 15-19). One type of machine, with the spindles arranged vertically, is used primarily for simpler work. Each spindle on vertical-spindle machines has one end working position and two cross slides, one of which must be used for cutting off. The endworking slide can be tooled for drilling, boring, or turning; and one cross slide can be tooled for light forming or chamfering. If two pieces can be made per spindle, both cross slides are tooled for cutting off. The advantage of this machine is the added production. Each cycle of the machine produces four pieces.

Number of Spindles

The number of spindles on a multispindle machine is ordinarily four, five, six, or eight, varying with the manufacturer. An eight-spindle machine produces the average part faster than a four or six-spindle machine, within certain limitations. The advantages of a machine with the greater number of spindles are the greater variety of work that can be produced, the possibility of producing more than one piece per cycle, and a better quality of work obtainable by using roughing and finishing cuts on all surfaces to be machined.

Method of Indexing

The method of indexing on bar machines is usually one position per cycle, with work being performed on each spindle in every position. Chucking machines are similarly indexed one position per cycle with one position being an idle station for loading and unloading. With automatic loading and unloading, it is often beneficial to load and unload in separate stations when possible since this simplifies the mechanisms required.

Double indexing (indexing the spindle two positions per cycle) is often employed on six and eight-spindle chucking machines. Double-index chucking machines require two idle spindle positions equipped with chuck-operating mechanisms that serve as the load and unload positions. Position 1 is the load and unload station when the workpiece is being machined

MULTIPLE-SPINDLE AUTOMATIC BAR AND CHUCKING MACHINES

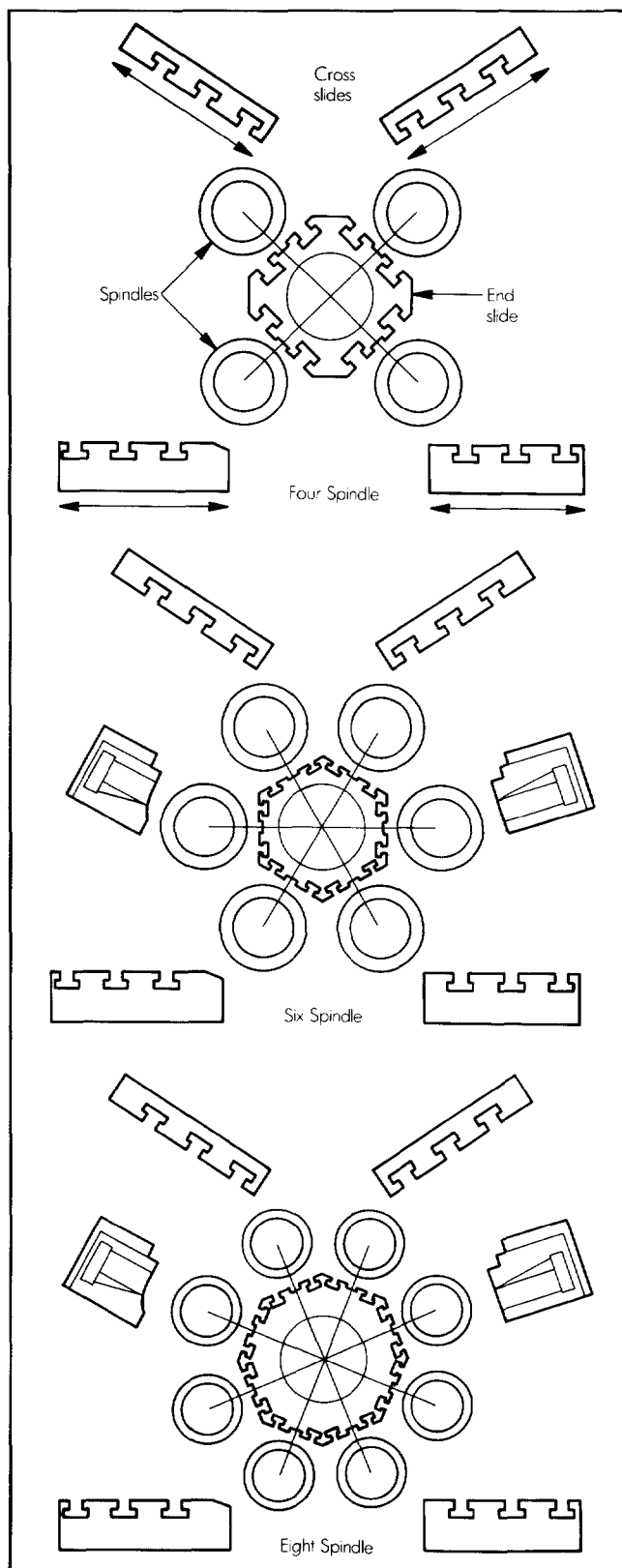


Fig. 15-19 Cross slides, end slide, and spindle arrangements for multiple-spindle machines. (National Acme Co.)

in the odd-numbered positions. The part is unloaded from position 1, inverted, and loaded into position 2 so that machining may be performed on the other end of the workpiece in the even-numbered positions. Bar machines can utilize feed-out in two positions as well as double index.

Multiple-spindle bar or chucking machines may also have the work or tool rotating, but the usual type has only the work rotating. The advantage of tool rotation is the ability to control the surface speed of the individual tool when the work has a large differential in diameters being turned.

CONSTRUCTION FEATURES OF MACHINES

Shown in Fig. 15-20 is a side view of a six-spindle bar machine, the principal operating features and general construction of which are common to all multiple-spindle bar machines. Chucking machines have much the same design, with the exception of the spindles and elimination of the stock feed mechanism.

Spindle Carrier

The spindle carrier is supported by and indexes in the frame journals of the headstock. The carrier is indexed by a modified Geneva motion consisting of the index arm, which revolves on the main drumshaft, and the index plate, which is geared to the carrier. During the working portion of the machine cycle, the spindle carrier is accurately located radially by a pin and locked rigidly in position by a plunger; the pin and plunger are withdrawn only for indexing. This method of indexing is the most common one in use, although one make of machine incorporates a worm, wormgear, and clutch arrangement in which the worm is powered at the instant the plunger is withdrawn and disengages when the carrier has completed its index.

The spindle carrier on five-spindle automatics made by one machine builder differs in that the spindles are driven by an encircling ring gear having teeth inside and out. Inside teeth mate with gears on the rear ends of all five spindles; outside teeth mate with a drive gear.

Main Toolslide

The endworking or main toolslide is mounted and moves longitudinally on an extension of the spindle carrier to provide accurate alignment of the slide with the spindles. The end toolslide is advanced and retracted by means of a cam on a drum on the main drumshaft. This drumshaft controls the timing of all the working tools. Another type of machine has independent slides for each endworking position, controlled by separate cams for each slide. This permits independent selection of feeds for each endworking tool.

On the type of slide shown in Fig. 15-21, the endworking tools, such as roller turners and knee turners, are mounted directly on the toolslide by means of T-slots or dovetails. Shank-type tools, such as drills, boring bars, or reamers, are mounted in holders that are bored in position on the machine to ensure accurate alignment of the tools with the work. On shaft-type, endworking slides, all the holders must be provided with a shank for mounting in a bored hole in the end of the slide.

On the five-spindle automatics mentioned previously, five endworking spindles are arranged for independent actuation from five cams mounted on a shaft running crosswise along the right-hand ends of the machines. Directly above the cams are five quadrant-type levers which control the strokes of the end-moving toolholding spindles. Since each spindle is actuated by a

MULTIPLE-SPINDLE AUTOMATIC BAR AND CHUCKING MACHINES

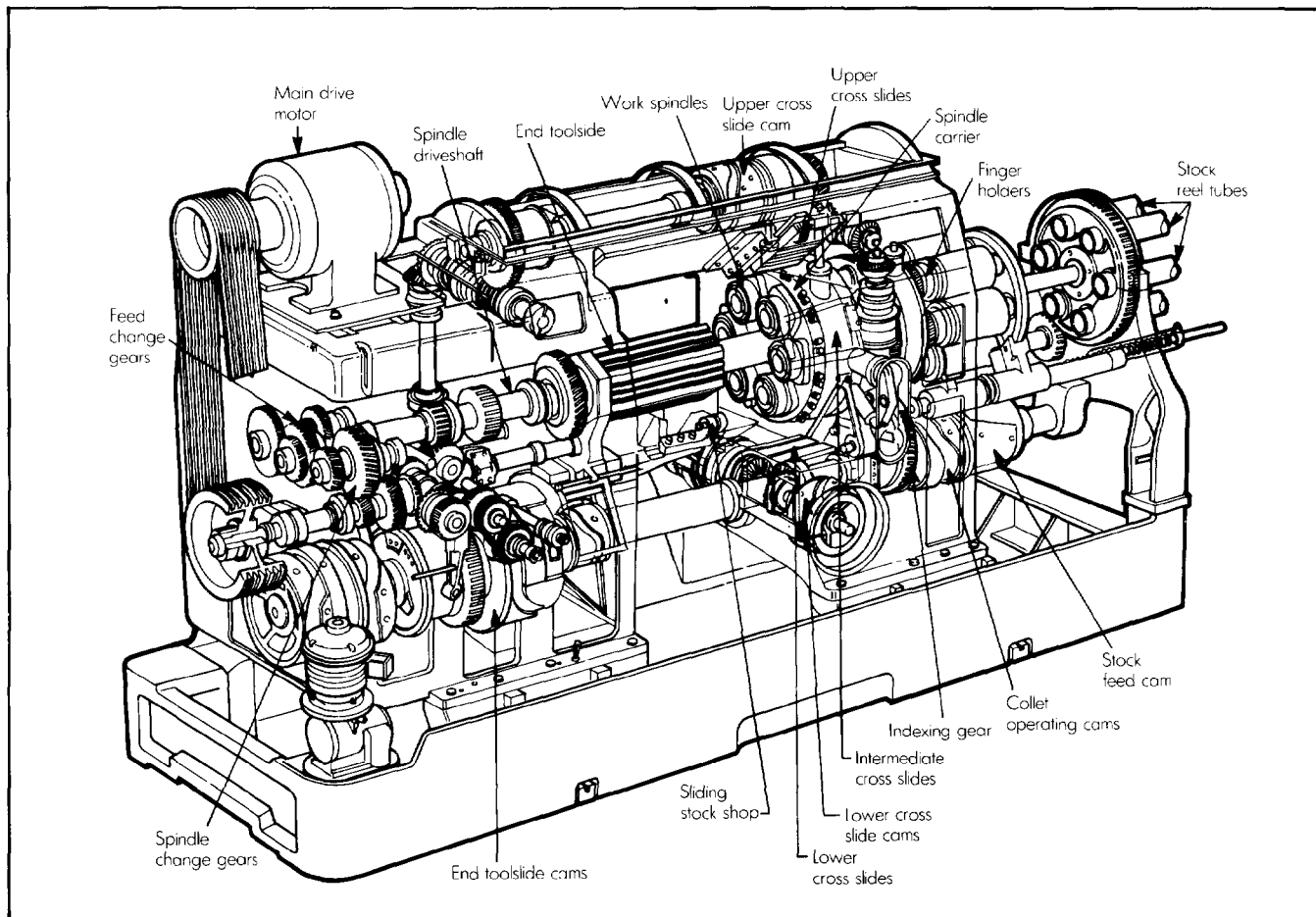


Fig. 15-20 Six-spindle automatic bar machine. (National Acme Co.)

separate cam, the stroke and feed per revolution is independent for each spindle. The quadrant system allows a variety of throws to be obtained from nominal-rise cams, thus minimizing the need for special cams.

Side Slides

The side slides, or cross slides, are mounted directly on the headstock of the machine and have a motion radial to the centerline of the work. The cross slides in the illustration are independently cammed, although in some cases two or even three slides may operate off one cam. Radial and longitudinal adjustment of the holders is provided on each slide. Independently adjustable stops on each side slide compensate for minor errors resulting from indexing and spindle spacing.

There are various ways of mounting the toolholders to the cross slides. The cross slides illustrated in Fig. 15-20 mount the toolholders on top of the slide. Figure 15-21 shows a side-mounting-type cross slide, on which the toolholders are held in place by means of a clamp, adjusted longitudinally by means of a wedge and radially by an adjusting screw that backs up the holder. In Fig. 15-22 the slides are adjusted radially by means of turnbuckles and longitudinally by means of turnbuckles or collar screws. A fourth position cross-slide attachment is available on these machines. Figure 15-23 shows the arrangement of a bar machine with a cross slide at each spindle.

Stock Feeding

Stock feeding is normally done in only one position on four, six, or eight-spindle machines. Special arrangements can be provided to feed in more than one position if required. All the stock feed operations are synchronized with the chuck opening and closing, as well as the stock-stop positioning, and are performed during the high-speed portion of the cycle.

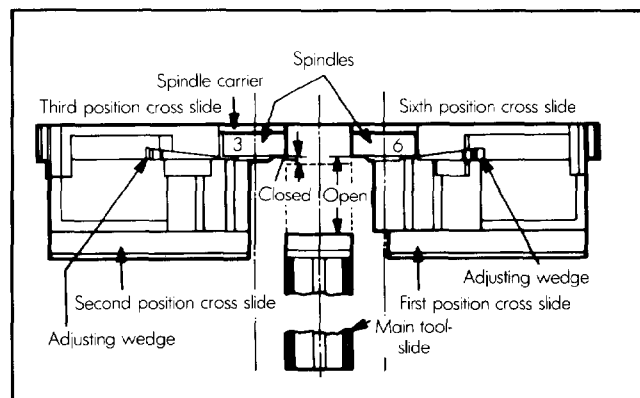


Fig. 15-21 Plan view of main toolslide, cross slides, and spindle carrier of six-spindle automatic.

MULTIPLE-SPINDLE AUTOMATIC BAR AND CHUCKING MACHINES

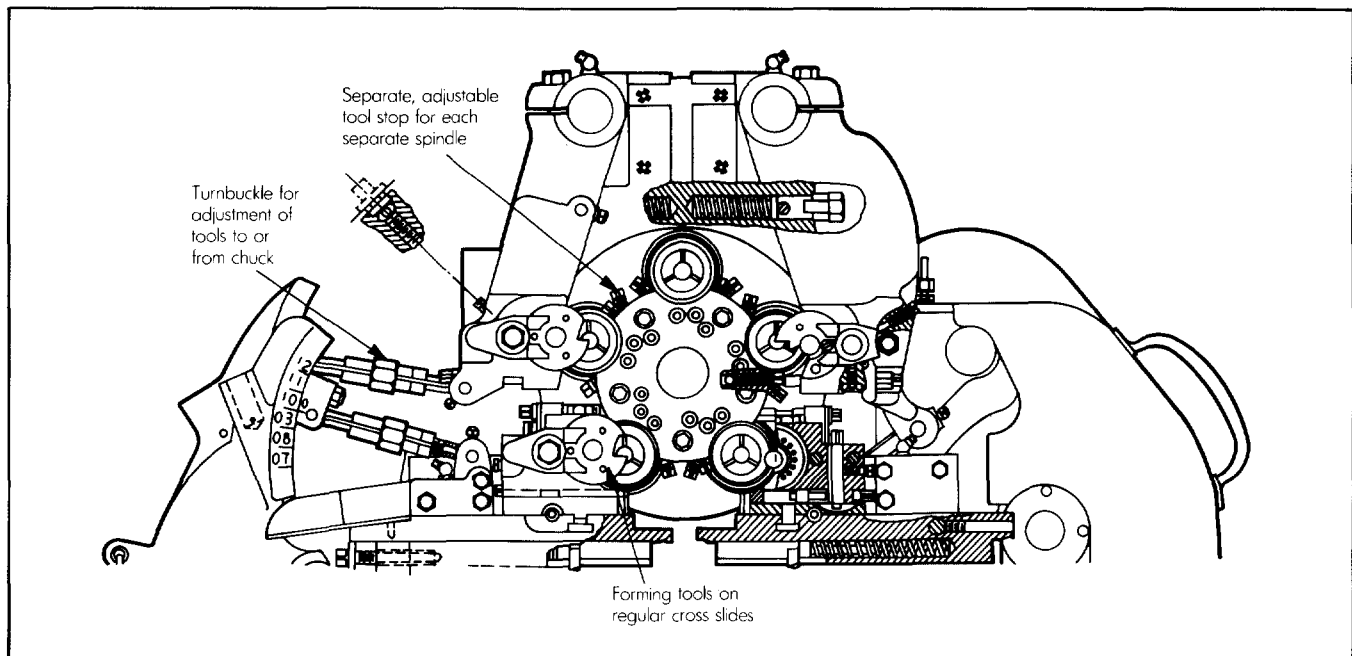


Fig. 15-22 View of headstock and cross slides showing means for radial adjustment of slides. (Davenport Machine Co.)

Each time a spindle reaches the stock feed position, the proper length of bar is fed into the machining area. A typical stock feed system is shown in Fig. 15-24. A collet opening cam moves a chucking slide forward, releasing the collet so it can open under its own spring pressure. With the bar free to move, a stock feed cam releases a stock feed slide so it can be pushed forward by a spring. The slide moves a pusher tube carrying the bar of stock forward until the bar contacts a stock stop. Another cam then retracts the chucking slide, closing the collet so it holds the bar in the forward position while the stock stop is retracted by yet another cam. At the same time, the stock feed slide is retracted to a position ready for the next cycle. Some machines are equipped with stock-depletion stops that stop the machine when a bar is not fed to the full length required.

Camming

The camming of multiple-spindle machines for various setups usually resolves itself into a selection of cams of the proper rise for the tool-operating slides; only in rare instances are the cams that control collet opening, closing, and stock stop changed, as these functions are normally performed identically on all setups. Stock feed cams are changed when it is necessary to change the length of the part being manufactured. The high and low-speed cams control the time at which the machine is shifted into high and low speed. Although they are adjustable, it is seldom necessary to reposition them even when other cams are being changed for setup. On modern machines, these cams are often eliminated or replaced by timing cams that operate limit switches. This is possible on those machines that use electromagnetic or air-actuated clutches rather than mechanical cam-actuated clutches.

For second-operation (chucking type) work, the collet opening and closing cams are occasionally changed to open the collet during the cutting cycle of the machine, so that the work may be loaded while the machine is in the slow mode. Where required, cams may be designed to provide proper timing for

special fixtures or to give variable feeds to toolslides. On chucking machines, the chucks can be opened and the spindle stopped after indexing.

The high-speed portion of the cycle time of the machine is not altered by changes in feeds and speeds since the machine is driven from the main driveshaft when shifted into high speed. The idle time of a machine is constant unless changes are made in the input shaft speed.

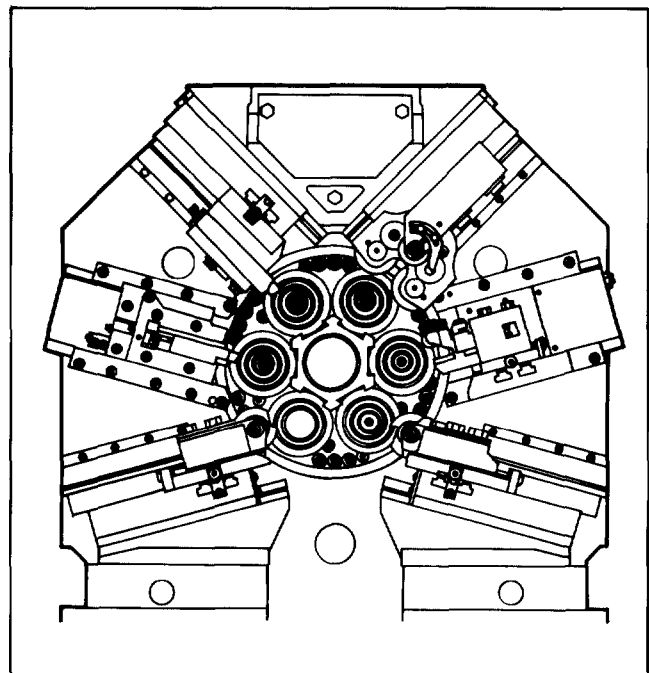


Fig. 15-23 View of a six-spindle machine with an independent cross slide at each position. (New Britain Machine Co.)

MULTIPLE-SPINDLE AUTOMATIC BAR AND CHUCKING MACHINES

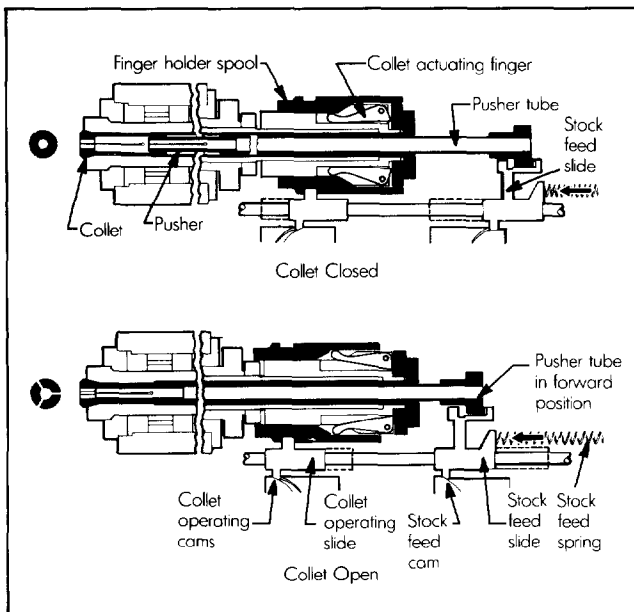


Fig. 15-24 Stock feed system for multiple-spindle automatic bar machine. (National Acme Co.)

TOOLS AND ATTACHMENTS

The actual cutting tools applied to workpieces on multiple-spindle machines are the same as those used on single-spindle automatics and turret lathes. Single-point and forming tools may be used; in fact, most setups show a combination of both. The cutting tools on one make of automatic may generally be used on any other, provided the machine capacities are the same.

Endworking Tools and Holders

On machines of the type illustrated in Fig. 15-21, where the end toolslide has horizontal mounting surfaces, the machines are provided with toolholders that accommodate drills, boring bars, counterbores, and other shank-type tools. These holders are bored in position on the toolslide, from the work spindle, to ensure accurate alignment with the spindles. The alignment of these holders is accurate enough for such work as drilling, turning, or boring, but minor errors in indexing usually make it practical to use a floating holder with a reamer.

Roller turners. These may be either base or shank type. Roller turners may be used in any position and, when used in conjunction with a forming tool from the cross slide, must have the rolls positioned so that one roll resists the normal component of the force exerted by the forming tool and the other resists the tangential force.

Roller steadyrests. These are designed with the rolls positioned as shown in Fig. 15-25 and are usually identical to the roller turner except that the tool is omitted. Roller steadyrests are used to support the work on heavy forming cuts when the length of the work is greater than one and a half diameters. Work that is to be supported by a roller steadyrest must be turned by a roller turner in a preceding position to provide an accurate diameter from which to support the work.

Knee turners. These are turning tools used primarily for roughing cuts; they may have a tangent or radial turning tool. Because of indexing errors, a knee turner does not consistently maintain the accuracy of a roller turner. When knee turners are

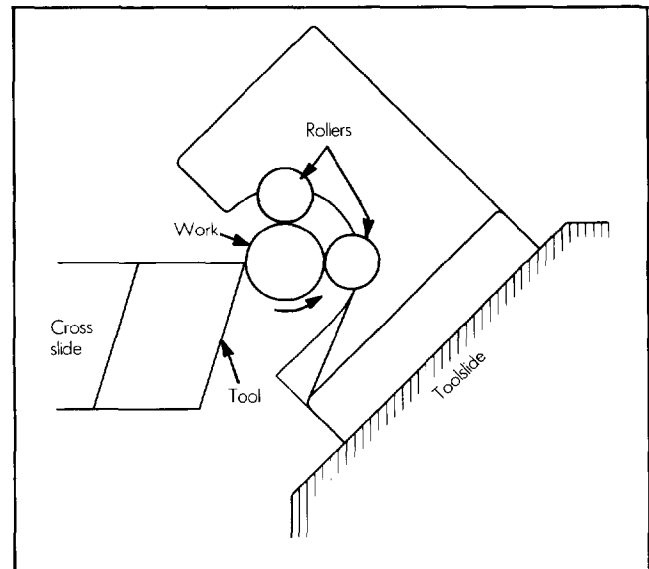


Fig. 15-25 Positioning of rollers in roller steadyrest.

designed to cut radially on the centerline of the spindle carrier, the tolerance on the diameter being turned is less affected by carrier position.

Cross-Slide Tools and Holders

Cross-slide toolholders are of several types: flat forming toolholders (designed to hold standard rectangular tool bits for facing and simple forming operations), dovetail holders, and circular form toolholders.

Shave fixtures. These tools (see Fig. 15-26) are used to improve work finish and accuracy. They are equipped with a roll which usually rotates on the diameter that is being cut. They are also equipped with a cutting tool which is set on the vertical centerline of the roll and passes under the work to the work centerline, or very slightly beyond the work centerline. The toolholder floats vertically on pins or in a dovetail in the frame of the holder. The floating toolholder compensates for index errors in the machine, and size is determined by the preset distance between the roll and the cutting tool. The shaving fixture is used primarily to size diameters, but with proper clearances, contours and shoulders may also be shaved.

Forming tools. These tools, either flat, circular, or dovetail, may be applied to multiple-spindle automatics. The flat tool is useful for cutting deep grooves. The circular tool is recommended for its long life. The dovetail tool has the advantages of better clamping on wide forms and the ease with which side clearance can be put on the tool and maintained without destroying the form. For straight-side cuts, dovetail tools can be cleared by providing a 2° angle toward or away from the surface on the holder (see Fig. 15-27). A minimum angle of 20° on the opposite side of the cut is recommended to provide automatic clearance.

The design of form tools for multiple-spindle automatics is usually simpler than that for single-spindle machines. The fact that forming slides are provided for each spindle enables the designer to split up the forming into several tools in order to gain proper clearance in each case. Figure 15-28, view *a*, shows an incorrect design. Here, all the forming is being done in one position. The tool must face on both sides of the flange on the

MULTIPLE-SPINDLE AUTOMATIC BAR AND CHUCKING MACHINES

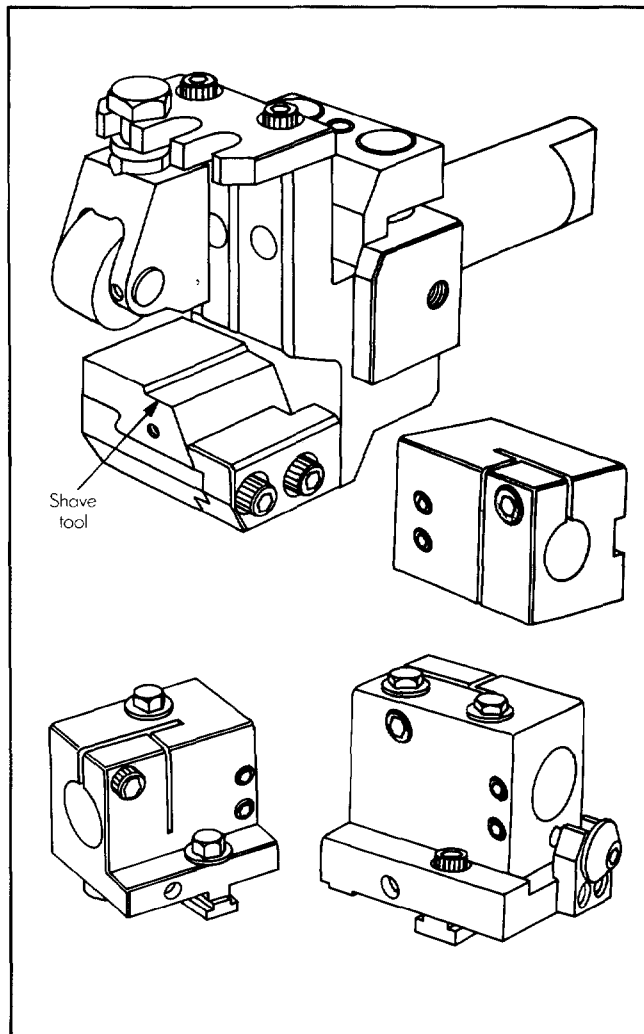


Fig. 15-26 Shave fixture with tool, roller, and adapters. (National Acme Co.)

workpiece; consequently, it must be made without side clearance. If side clearance were put on the tool, its form would be destroyed in sharpening.

Figure 15-28, view *b*, shows the correct application. The form is being made on two slides instead of one; the tool in position 1 is designed to clear the left side of the flange, while the tool in position 2 is designed to clear the right side. Neither tool will lose its form in sharpening, and the proper clearance provided will give better finish and longer tool life.

The right-hand side of the relief being formed in position 2 (Fig. 15-28, view *b*) will have less clearance than the other faces of the tool, but an angle as low as 15° will still clear with a front angle of 12° and a side clearance angle of 3° on the tool. The 15° minimum angle also applies to radii, as shown in Fig. 15-29, view *b*.

Deep straight-sided grooves, such as those shown in Fig. 15-29, view *a*, are difficult to finish with a dovetail or circular forming tool. Grooves such as these should generally be cut by separate tool bits held in a multiple toolholder. These tools should have clearance on all faces, $3\text{--}5^\circ$ on the sides and $10\text{--}15^\circ$ on the front.

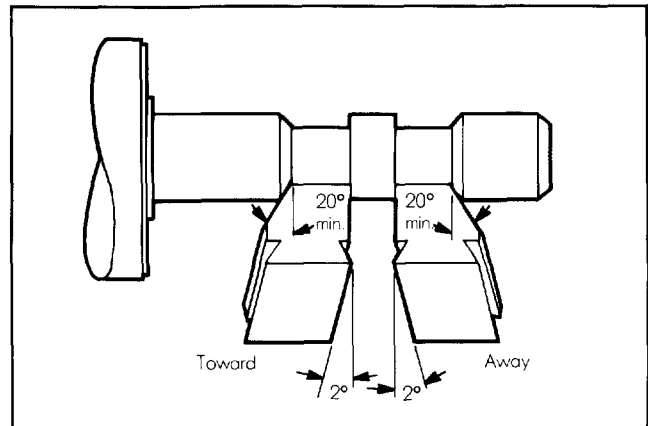


Fig. 15-27 For straight-side cuts, dovetail form tools should be provided with clearance angles. (Cone Blanchard Machine Co.)

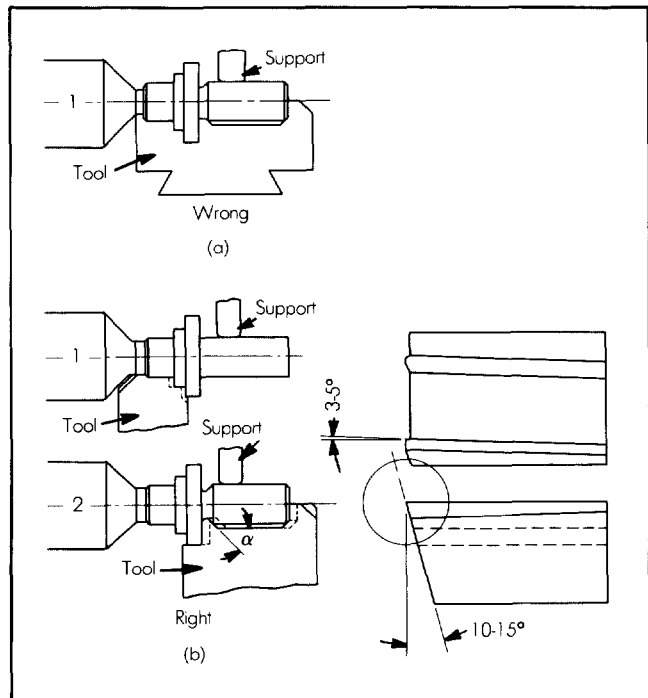


Fig. 15-28 Form tools of (a) wrong and (b) right design.

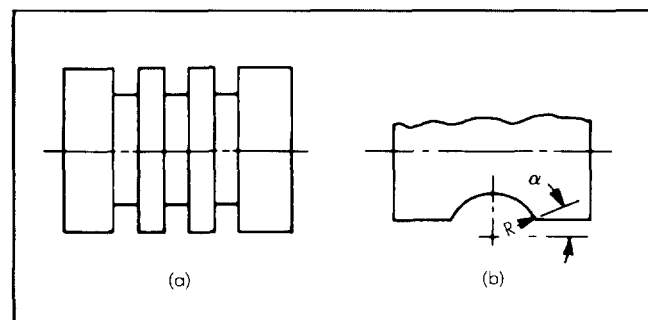


Fig. 15-29 Types of grooves which should be formed by separate tool bits.

MULTIPLE-SPINDLE AUTOMATIC BAR AND CHUCKING MACHINES

Carbide Tooling

The requirements for carbide-tool application on any lathe also apply to the automatic screw machine. Sufficient horsepower; rigidity of machine; proper alignment of spindles, carrier, and tool slides; rigidity of work and toolholders; proper speeds and feeds; ample clearances and cutting fluid supply; and proper tool angles are all important considerations for efficient economic production. Carbide tooling applied on multiple-spindle machines, however, requires considerably more study than carbide tooling applied on single-spindle machines or on turret lathes. Since the rpm's of all the spindles are the same and the feeds on all tools mounted on the end slide are the same (except on the five-spindle machines previously described), it may be impossible to arrange a setup whereby all tools have the proper cutting speed and feed. The fact that with carbide tooling, too fine a feed is just as injurious to the tool as too heavy a feed complicates the situation.

The surface speed on each tool is governed by the design of the workpiece. Wide variations in diameters to be machined on one chucking can often be achieved by the proper combination of high-speed steel and carbide cutting tools. High-speed steel may be used on the smaller diameters, and various grades of carbide on the larger, with both at or near their proper cutting speed. Special attention must be given to carbide grades, as no two tools in a multiple setup are performing under the same conditions. External and internal tools are operating under a varied range of speeds, as are facing, cutoff, and finish turning tools. Therefore, it is necessary in some cases to select more than one grade of carbide for use in one setup or tool combination. The use of inserted and clamp-on type holders makes it easier to experiment with different grades of carbide.

The power required to maintain the required spindle speeds for carbide cutting tools may be from 60-100% greater than that needed for high-speed-steel tools. The character of the workpiece material and the feed, speed, depth, and width of cut taken by a tool all govern the power requirements. Ordinary forming, shaving, turning, and drilling require 4-7 hp (3-5.2 kW) per tool. Cutoff, chamfer, and facing tools and tools of similar nature generally require 3-5 hp (2.2-3.7 kW).

Tools carrying carbide tips must have shanks made of materials capable of giving the greatest strength and rigidity, and must be mounted in holders with a minimum of overhang. All cam dwell should be eliminated to allow carbide-tipped tools to recede from working position immediately when they are through cutting. If the tool is allowed to rest in contact with the workpiece, excessive wear will result on the tools. An ample supply of cutting fluid is required to help dissipate the heat at the tool and to wash the chips away from the tool area.

Special Attachments

The design of the multiple-spindle automatic permits the use of a number of special attachments that may increase production, eliminate secondary operations, or improve machine performance. Operations such as threading, tapping, eccentric drilling, contour turning, thread chasing, thread milling, thread rolling, knurling, spiral grooving, burnishing, stenciling, stamping, broaching, polygon milling, and many others may be performed on the automatic by the use of special attachments.

Identifying part numbers, trademarks, etc., may be impressed onto the outer diameter of the work by the use of a stencil roll and holder mounted on the cross slide and advanced into the work so that the stamping tool makes one revolution in contact

with the work. Stamping may also be performed from the endworking slide by a stamp held in a spindle rotating at the same speed as the work spindle.

Independent endworking attachments. These attachments are independently cammed endworking slides, which may be installed in one or several positions to increase or decrease the travel of the tool used in that position. A common application is the use of two or three positions of the end toolslide for drilling and boring and use of the independent attachment for reaming. Since a reamer usually accepts a higher feed rate than a drill or a boring tool, the use of the attachment serves to reduce the cycle time of the machine by reducing the time of the reaming operation.

Another application of this attachment is in the cutoff position, in which it may be necessary to perform an endworking operation before cutting off. A standard machine is cammed in such a way that the cutoff tool and the end toolslide finish their cuts at the same time. The independent or auxiliary slide may be cammed in that position to advance with the end toolslide but retract before the work is parted from the bar. In the cutoff position, this slide is usually independently cammed in and out during 50% of the work cycle.

Pickup attachment. This attachment allows a variety of endworking operations to be performed on the cutoff end of the workpiece. Such operations include drilling, tapping, counter-drilling, slotting, milling, or stamping. The attachment is controlled by a cam or a combination of a cam and hydraulics or pneumatics.

Universal threading attachments. To provide the proper surface speed on the threading tools, threading attachments are arranged so that they rotate in the same direction as the work, but at a slightly lower speed when threading "on" and at a slightly higher speed when threading "off" (on right-hand threads). The effective rpm of the threading tool is the difference in rpm of the work spindle and the threading spindle. When self-opening dies or collapsing taps are used, it is unnecessary to change speed on the threading spindle. Solid taps or dies, which must thread on and off the work, use a universal threading attachment equipped with a clutch to provide two speeds.

An illustration of a two-speed threading attachment is given in Fig. 15-30. The slide, *A*, carrying the threading spindle is independently operated, with cam *B* serving to advance the slide and cam *C* to retract the slide, clearing the workpiece while the machine indexes. The threading spindle, *D*, is driven by a splined shaft or sleeve which permits it to advance while rotating. The clutches are driven by chain or gear drive from an auxiliary driveshaft installed in the machine. The universal threading attachment clutch, *E*, determines which gear (*F* or *G*) is driving the tap while the clutch is operated from cams *H* and *J* through linkage. Some machine tool builders use electric or air clutches for threading attachments.

Thread-Rolling Attachments

Thread-rolling attachments are available in both side and end-feeding types. The side-feeding type permits threading close to shoulders; since rolling can be done on the collet end of the part behind shoulders, a secondary threading operation is eliminated. The thread-rolling attachment has two opposed thread rolls which pass over the work when rolling threads. Any thread length within the width of the roll face is rolled in one pass with a few revolutions of the work spindle. The thread rolls are readily changed and adjusted to size within the capacity of

MULTIPLE-SPINDLE AUTOMATIC BAR AND CHUCKING MACHINES

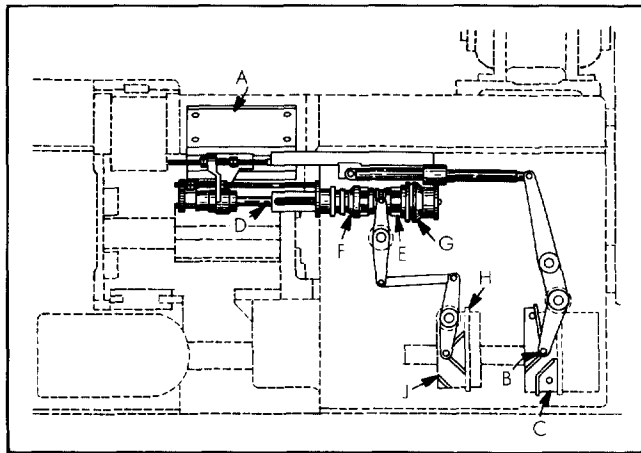


Fig. 15-30 Two-speed universal threading attachment. (National Acme Co.)

the holder. The thread rolls are connected through a gear train to ensure synchronous rotation of the rolls. Taper rolls for pipe threads are interchangeable with straight rolls within the capacity of the head.

End-feeding thread-rolling attachments employ two or three rolls and are tripped and reset similar to self-opening dieheads. Three-roll attachments generally give best results. When threads are being rolled, the thread must be completed in one pass. Because of surface concentration and hardening in a rolled thread, a second pass would damage the rolls. A shaving fixture for sizing the blank prior to thread rolling is essential. Details of the thread-rolling process are presented in Chapter 12, "Threading."

High-Speed Drilling Attachments

In cases in which the outside diameter of the work (upon which the spindle speed is based) greatly differs from the diameter of a drilled hole, it is almost impossible, with stationary drills, to obtain the proper surface speed on the drills. For such applications, a high-speed drilling attachment, which rotates the drills in the opposite direction of the work spindle to give a decrease in feed rate, per revolution, is used. Electric or air-driven motors may be used to drive the spindle, or a standard attachment gear driven from a shaft in the machine itself may be provided by the manufacturer.

Cross-Milling and Cross-Drilling Attachments

Various operations such as cross milling, cross drilling, and slotting may be performed with special attachments. The cross-milling or drilling attachment is mounted on the cross slide and independently driven, the feed of the attachment being controlled by the advance of the cross slide. When such operations are performed, the machine must also be equipped with a spindle-stopping mechanism that permits stopping the spindle rotation in the desired station. Slotting or milling from an endworking position can also be performed with the spindle stopped, and some slotting operations may be performed without stopping the work spindle by rotating the cutter spindle at the same speed and direction as the work spindle. Flats can be generated without stopping the spindle.

Pick-Off Attachment

A secondary operation may be eliminated by the use of a

pick-off attachment. This is an independently driven spindle and collet arrangement mounted in the cutoff position. When the work is indexed into the cutoff position, the attachment is advanced and locked onto the work, providing support and also driving the work at the same speed as the work spindle, thus minimizing any cutoff burr. When the operation is completed, the pick-off attachment retracts, carrying the workpiece with it. On the return stroke, the collet opens and the workpiece is ejected. The pick-off attachment then advances to receive the next workpiece.

Back Finish Slide

A back finish slide may be used in conjunction with a pick-off attachment for performing light operations on the cutoff end of a workpiece. With special camming, the pick-off attachment advances to receive a workpiece that is cut off during the first third of the machining cycle. During the second third of the cycle, the pick-off attachment retracts (with the workpiece), allowing the back finish slide to advance a counterboring tool into cutting position. The pick-off attachment then returns, carrying the workpiece to the counterboring tool. Back counterboring is performed during the final third of the cycle.

Recessing Attachments

When it is necessary to chamfer or groove the inside diameter of the work, a recessing attachment or internal necking attachment may be used. One type of recessing attachment, shown in Fig. 15-31, is bolted to the endworking toolslide; it advances with the toolslide until the forward movement of the upper slide is stopped by a checknut and draw rod. Further advance of the toolslide feeds the tool to proper depth. Depth and feed of the recessing tool are controlled by the angle in the attachment and the cam rise of the main end slide. The accuracy of the operation is controlled by the movement of the toolslide. Recess milling can also be applied.

Automation Equipment

For second-operation (chucking type) applications, there are many well-designed feed chutes, magazines, hoppers, and other parts-handling equipment that load the work into the machine spindle automatically. A workpiece should never be hand loaded or extracted from a revolving spindle, collet, or chuck.

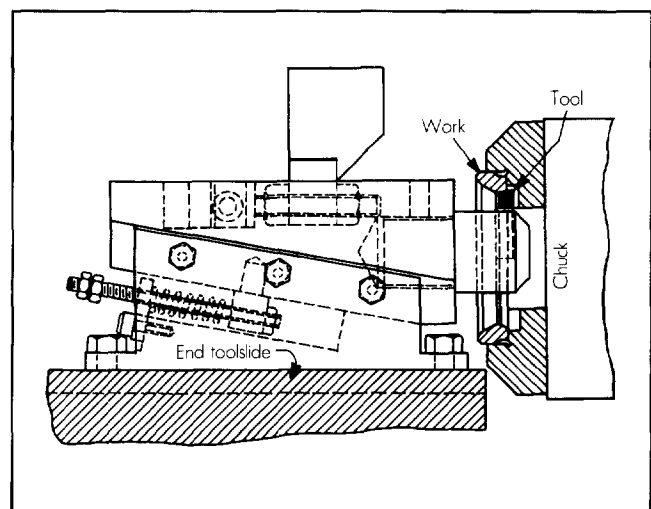


Fig. 15-31 Recessing attachment, radial style. (National Acme Co.)

MULTIPLE-SPINDLE AUTOMATIC BAR AND CHUCKING MACHINES

SPEEDS AND FEEDS

Feed rates used on multiple-spindle automatics are generally higher than those used on single-spindle automatics of the same capacity; speeds are generally the same or lower depending upon the material being machined. The feeds and speeds are about the same as those used on heavy-duty single-spindle automatic machines. Such variables as the shape of the tool, the workpiece material, the type of cutting fluid, and the condition of the machine determine to a great extent the speeds and feeds that can be maintained and also the tool life that can be expected.

Threading speeds do not ordinarily control the production time because the threaded diameter must first be turned or drilled, and the threading time is usually found to be less than the turning or drilling time. For that reason the threading speed can usually be set at that value which gives the best finish on the threads and the longest tap or chaser life.

TOLERANCES

The tolerances that can be held by multiple-spindle machines depend greatly on the type of tooling used, the condition of the machine, the material being machined, and the skill of the setup person and operator. The tolerances given here are not meant to be exact, but they may be used as a practical guide in establishing the closest tolerances that can be maintained in production.

Tools such as boring bars, knee turners, or chamfering tools, which are applied from the end toolslide and which depend on the accuracy of the machine indexing for the diameters they cut, can be expected to hold tolerances of about $\pm 0.0035"$ (0.089 mm). This may be reduced somewhat by positioning the tool so that it is radial to the centerline of the spindle carrier. With this setup, variations in the indexing of the machine affect only the location of the tool in relation to the centerline of the work, rather than there being a direct diametrical variation. Roller turners are capable of holding tolerances to $0.001"$ (0.03 mm), but tolerances of $\pm 0.002"$ (0.05 mm) are more readily attained.

Tools applied from the cross slides, where the diameters are controlled by independent positive cross-slide stops, should be given a tolerance of $\pm 0.002"$ or more. When closer tolerances are required, a shaving fixture should be substituted. A shaving fixture (see Fig. 15-27) is primarily a finishing tool that removes only about $0.008"$ (0.20 mm) of stock on the diameter and usually holds a total minimum tolerance of $0.001"$. However, on $1"$ (25 mm) diam and under, closer tolerances are possible on free-machining materials on which the blank diameters can be held more uniform.

A reamer held in a floating holder allows for some misalignment or maladjustment of the machine, and tolerances of $\pm 0.0005"$ (0.013 mm) can be held by stub screw machine or chucking reamers of $1/2"$ (12.7 mm) diam or below; for reamers up to $1"$ (25 mm) diam, tolerances can be held to $\pm 0.001"$ (0.03 mm). On sizes above $1"$ diam, tolerances are held much closer with a blade-type reamer.

The work surface finished by the parting tool must usually be refaced to provide proper finish; if it is not refaced, another operation must often be performed on that end of the work that permits facing without adding to the cost. For this reason, tolerances on overall lengths can usually be rather liberal. Wherever possible, tolerances on overall lengths should be made $\pm 0.005"$ (0.13 mm). Limits as low as $0.002"$ (0.05 mm) can be held on short work or on work that is faced; however, these

limits may necessitate a reduction in the feed rate of the cutoff tool which can increase the time required to complete the part.

Linear dimensions that are controlled by a forming tool applied from the cross slides can usually be held as close as the form tool can be made, but it should be remembered that close tolerances on the forming tool are also expensive. Since these dimensions are affected by wear and buildup on the cutting edges of the tool, repeated sharpenings may be necessary to keep the tool itself within proper limits. Linear dimensions that are held between two forming tools, on separate slides or on the same slide, may be held to $\pm 0.001"$ (0.03 mm). Again, these dimensions are dependent upon the adjustments made by the operator and close tolerances result in more downtime for adjustments.

PLANNING TOOLING SETUPS

In many multiple-spindle setups, wide variations in the type of tooling may be used with equally good results. Setups should be studied in advance and the best one should be chosen with regard to lowered tooling cost or possibly with regard to using standard tooling already on hand. In other cases, the condition of the machine may prohibit the use of certain tools; in these cases, good judgment must be used.

The actual cutting time may be determined by using the following formula:

$$T = \frac{L \times 60}{rpm \times ipr} + I \quad (1)$$

where:

T = time, s

L = length of the longest single cut, in. or mm

I = idle time of the machine (time required to withdraw the tools, index the carrier, and advance the tools back to the work), s

rpm = speed of work rotation

ipr = feed rate, ipr or mm/rev

Since the maximum speed and feed are limited by the machinability of the workpiece material, the problem of reducing the machine cycle and increasing production becomes one of reducing the length of the cut, L , by taking two cuts instead of one, by using a different tooling arrangement (substituting a forming tool from a cross-slide position rather than a turning tool from an endworking position), by reversing the workpiece to change the setup, or by omitting an operation that can be performed more economically on a subsequent operation.

Four main factors determine the type of setup used and the production obtained: (1) the size and shape of the part, (2) the material, (3) the tolerances and finish required, and (4) the quantity to be made.

The size and shape of the workpiece determine the capacity and type of machine to be used. The material determines the permissible speed and feed, the finish obtainable, and the type of tooling to be used. The tolerances and finish required also limit the speeds and feeds. Higher speeds and lower feeds may be used where close tolerances and fine finish are not required. Close tolerances and fine finish necessitate fine feeds and lowered efficiency owing to an increased setup time and downtime for tool sharpening and adjustment. The use of preset tooling reduces the need for adjustments.

The quantity to be made is important for economic reasons. The most efficient setup is that which gives the lowest cost per

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workpiece, including the cost of tooling, setup, labor, machine, and burden. Those factors which cannot be determined exactly should be estimated as closely as possible to determine the setup and machine to be used when a choice is possible.

The tooling cost, setup time, downtime for adjustments, and machine cost are usually greater for an eight-spindle machine than for a four-spindle machine. These factors must be equated against the increase in production that may be expected from an eight-spindle machine.

When a choice must be made between two machines, the proposed setups should be written up and the production calculated for each machine. From setup charts, the tools required may be obtained and the cost of tooling calculated. The time and efficiency of the setup can be estimated from past experience or from the history of similar work previously run. All these factors may then be incorporated in a chart of cost per piece versus the number of pieces. From this chart, a breakeven point may be determined at which the costs per piece are equal. Below the breakeven point, a four-spindle machine might be most economical to use; above it, an eight-spindle machine may prove the most economical.

An example of the tooling used to produce steel parts from hexagonal bar stock on a six-spindle automatic is shown in Fig. 15-32. Figure 15-33 illustrates the tooling on an eight-spindle automatic for machining parts from round, aluminum alloy bar stock.

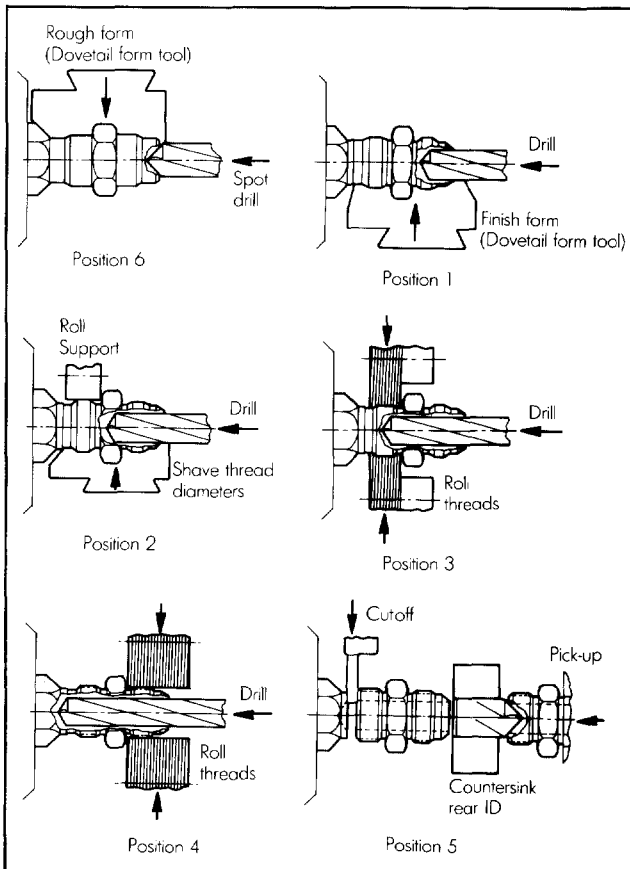


Fig. 15-32 Tooling layout for parts produced from 1 1/4" diam hexagonal bar stock (AISI 1211 cold-drawn steel) on a six-spindle automatic. A total of 13 operations are completed in a 27 second cycle. (National Acme Co.)

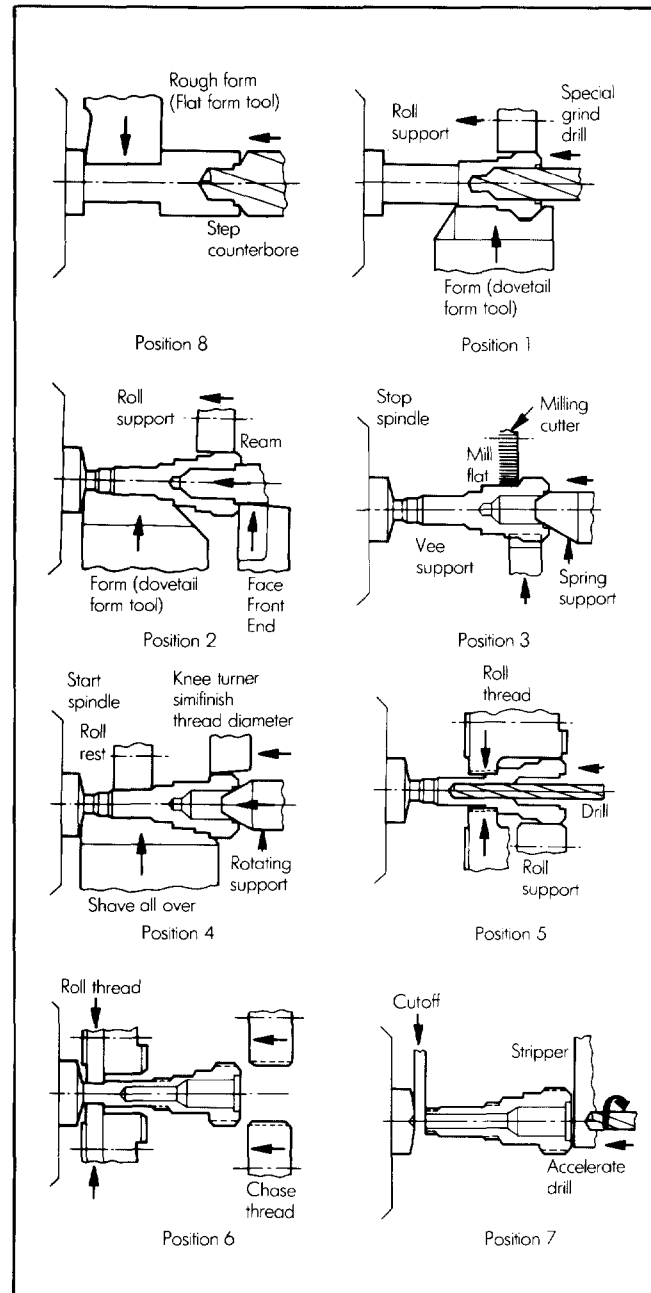


Fig. 15-33 Tooling layout for parts produced from 13/16" diam aluminum alloy bar stock on an eight-spindle automatic. There are 19 operations performed on each part in a 5.6 second cycle. (National Acme Co.)

CUTTING FLUIDS

The cutting fluid to be used for multiple-spindle automatics depends upon many variables, including the workpiece material, the types of operations to be performed, and the cutting tool design and material. Because of the number of different operations performed on these machines, selection of a cutting fluid must be a compromise to obtain the best all-round performance. Preference is usually given to the fluid which performs best on the most severe operation in any given setup.

MULTIPLE-SPINDLE AUTOMATIC BAR AND CHUCKING MACHINES

A detailed discussion of cutting fluids is presented in Chapter 4 of this volume, "Cutting Fluids and Industrial Lubricants."

TROUBLESHOOTING

Most problems encountered with multiple-spindle automatics are created by either machine malfunctions or out-of-tolerance workpieces. Priority should be given to determining the cause of the problem before anything is changed. Inspection of the workpieces produced detects out-of-tolerance parts, with tooling being the primary cause. Machine malfunctions can be detected by observing the operation and listening for unusual sounds. Keeping the machine clean and adhering to a good preventive maintenance program minimizes problems. Table 15-10 presents some typical problems and probable causes.

SAFETY

No discussion of safety can cover every possible situation that might occur, but the following general recommendations should be adhered to:

1. Read and follow all instructions in operating manuals and on warning plates before starting the machine.
2. Properly use all safety devices provided on the machine; never attempt to remove or bypass them.
3. Keep all machine covers and guards in place; never bypass the interlocks.
4. Wear safety glasses, proper fitting clothes, safety shoes, and when necessary, protective hearing devices and headgear.

TABLE 15-10
Problems and Probable Causes When Using Multiple-Spindle Automatics

Problems	Probable Causes	Problems	Probable Causes
Machine Malfunctions:		Out-of-Tolerance Workpieces (cont.):	
Excessive wear of chucking shoes	Feed stops before collet closes; collet too tight; oversize stock; improper operation of finger holders; damaged finger-holder spool; insufficient lubrication.	Parts too short (all spindles)	Incorrectly set stock stop; mis-adjusted facing or cutoff tool; stock feed cam too short or long; insufficient feed pressure.
Slow cycle time	Low-speed cam set early; high-speed cam set late; clutches slipping; brake cam set incorrectly; excessive brake tension; loose wormwheel friction plate; loose V-belt; incorrect change gears.	Parts too short (one or more spindles)	Inadequate pusher gripping force; oversize pusher; bent or oversize bar stock; stock feed cam too short; insufficient feed pressure; collet improperly adjusted; oversize collet; worn or broken collet or seat; under-size bar stock; excessive end pressure from dull tools; end tools hitting work at high speed.
Cycle too fast	Low brake tension; incorrect brake-cam location; low-speed cam set late; high-speed cam set early; incorrect change gears.	Poor concentricity (consistent error)	Misaligned tool; wrong tool; improperly set slides; poor rigidity of workpiece; incorrect tooling sequence.
Stock does not feed	Collet does not open due to dirt and/or chips; stock feed bounces due to excessive cam length.	Parts with varying concentricity	Dull or chipped tools; excessive feed; wrong tool or improper grind; tool deflection; worn slide components; worn spindle bearings; loose, worn, or eccentric collet.
Main drumshaft stops rotating	Feed clutch slipping; high-speed clutch slipping; roll clutch failure; large wormwheel slipping.	Incorrectly formed surfaces (consistent error)	Improper tool; improperly adjusted gibs; incorrectly set stop screws; insufficient stock; tool not on center-line.
Machine stops with drive motor running	Broken shear pins in pulley drive.	Incorrectly formed surfaces (variable error)	Worn cross-slide components; insufficient slide motion because of accumulated chips; loose cross-slide cams; tool above or below center; worn or chipped tools; excessive feed; varying feed rate; incorrect spool bushings; bent bar stock; dry bar stock; worn or loose toolholders; insufficient tool, stock, or work support; loose collet; loose gibs, rollers, or cams; end play in cross-slide shaft; worn spindle bearings.
Machine stalls during indexing	Machine not level; stock reel out of line.		
Spindle carrier does not lock after index	Broken locking-pin spring.		
High-speed clutch not releasing properly	Lubricating oil too heavy; lubricating oil contaminated; worn or broken clutch component.		
Out-of-Tolerance Workpieces:			
Parts too long (all spindles)	Incorrectly set stock stop; mis-adjusted facing or cutoff tool.		
Parts of varying length	Excessive end play of spindle carrier; worn spindle bearings.		

(National Acme Co.)

CENTER DRILLING AND FACING MACHINES

5. Keep hands out of machining and tooling areas when the machine is operating.
6. Keep all loose articles (gages, tools, workpieces, etc.) off the machine.
7. Keep hand tools in a toolbox, not in pockets or stuck in a belt.
8. Use care and proper tools when changing or adjusting tools.

9. Clean the machine and load stock carefully with the proper equipment and with the machine stopped.

Safety requirements for the construction, care, and use of single and multiple-spindle automatic screw, bar, and chucking machines are presented in ANSI Standard B11.13. A detailed discussion of machining safety is presented in Chapter 18 of this volume, "Safety and Noise Control."

CENTER DRILLING AND FACING MACHINES

The center drilling and facing machine is a multifunction machine now used extensively for shaft-type workpieces. The importance of center drilling is often overlooked, probably because the centers usually have no function once the workpieces are completed. Accuracy of the centers, however, has a major effect on tolerances that can be maintained in subsequent operations, such as turning, grinding, and hobbing, where the centers must be used for location. When unusually accurate center holes are required, they can be generated by grinding (see "Center Hole Grinding" in Chapter 11 of this volume, "Grinding").

CENTER DRILLING

Historically, centers were usually produced in shafts, one end at a time, on engine lathes. This is a slow process and requires a skilled machinist to produce acceptable results. In an effort to speed the process, some manufacturers use a drill press equipped with a fixture. If the shafts are long, however, this method is cumbersome and the results are often unsatisfactory. Automatic machines now available can outproduce engine lathes and drill presses, and can center more accurately.

Most workpieces which require centering are repositioned, end-for-end on centers when they are manufactured. For the features machined on both ends of the workpieces to be in proper relationship, the distance between centers must be maintained accurately. This dictates the use of a machine that drills both ends at once and that consistently and accurately repeats the end-cutting operations.

Axes of the centers must be coincident, and the centers must be round and have a reasonably good finish. Failure to achieve these conditions results in imperfect contact between the countersunk holes and the machine centers. Since heavy cuts are often taken over the tailstock center, the lack of good surface contact causes the countersunk holes to deform. This can cause chatter, inaccurate workpieces, and other problems (see "Common Errors in Center Holes" in Chapter 11 of this volume, "Grinding").

NEED FOR FACING

Most product designs require that the ends of shaft-type components be machined to provide a reasonable tolerance on overall length and smooth finish. Since facing to the tailstock center is difficult on a lathe, it is desirable to combine facing with the center drilling operation.

Plunge facing can be done with combination cutters consisting of a center drill with two or more facing blades mounted around the drill. Such tools are used in the spindles of centering machines. The diameter which can be plunge faced is primarily a function of the power available on the machine.

When the ends of the workpieces are smaller in diameter than the cutters, the entire ends are faced. When the shaft ends are larger in diameter, the cutters can be designed to spotface. Many shafts made from large-diameter bars have reduced diameters at their ends. In such cases, when stock is removed, the spotfaced surfaces cover the entire ends of the turned workpieces. When the turned surfaces are larger in diameter than the spotfaced surfaces, facing tools can be added to blend the spotfaced and faced surfaces.

Combination milling and centering machines are preferable to plunge facing and centering machines when the workpieces have ends with excessive stock, such as some forgings; when they have rough and/or out-of-square ends, such as sheared bars; or when they have large diameters for which continuous, flat, end surfaces are required.

PLUNGE FACING AND CENTERING MACHINES

These machines consist of a fixed main head and a bed, both mounted on a base. Mounted on the bed is another head that is adjustable along the length of the bed and a workholding device. Each head has a spindle mounted in a quill which feeds out of the head by mechanical, electrical, or hydraulic means.

Each spindle is rotated by its own motor-driven gear train, which includes change gears for speed changes. Standard automatic machines are available with 18-240" (457-6096 mm) length capacities and 5-25 hp (3.7-18.6 kW) motors per head. Two independent feed-cycle cams are provided: one for rapid traverse that operates at the end of the cutting cycle, and one for feed that is set by a graduated dial for proper depth of cut.

Workholding devices usually consist of a pair of self-centering vises, but special fixtures are employed for non-cylindrical and other workpieces. Figure 15-34 illustrates the tooling for plunge facing and centering both ends of rear-axle pinion shafts. The left-hand end of each shaft is completely faced while the right-hand end is spotfaced because of cutter diameter limitations. For this application, knife-edge jaws are applied to the face angles of the pinion shafts since these surfaces have the least amount of stock to be removed during subsequent turning.

A standard air-operated vise is used to hold the stem ends of steering knuckles during facing and centering, but special fixturing is required for the yoke ends. The yoke ends are located from the lower bosses of the knuckles and radially from both bosses; they are clamped endwise from the backs of the flanges. This fixturing assures uniform stock removal in subsequent turning and ensures that holes produced in the bosses are centered and in correct relation to the knuckle spindle.

CENTER DRILLING AND FACING MACHINES

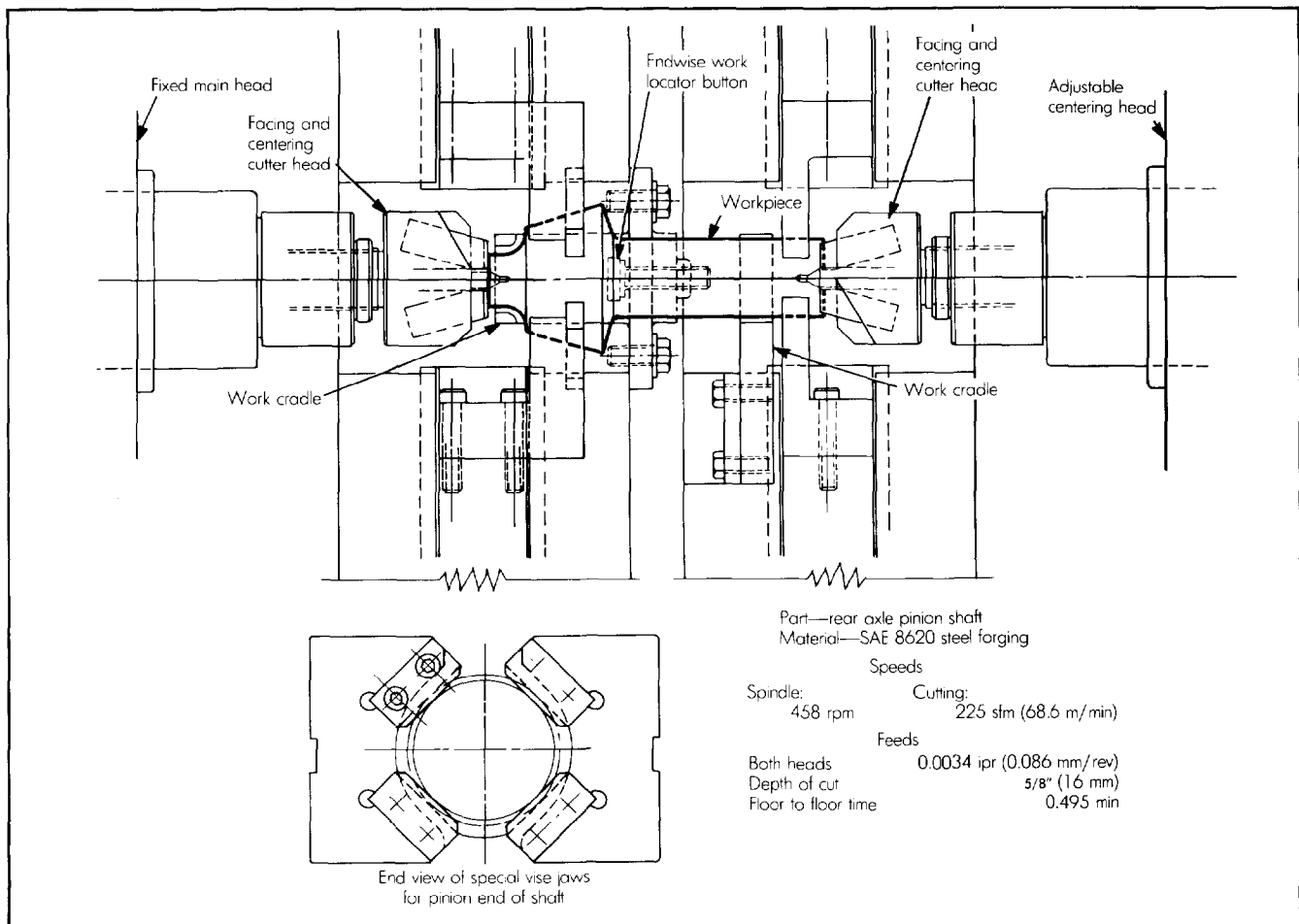


Fig. 15-34 Tooling for plunge facing and centering both ends of pinion shafts. (Seneca Falls Machine Co.)

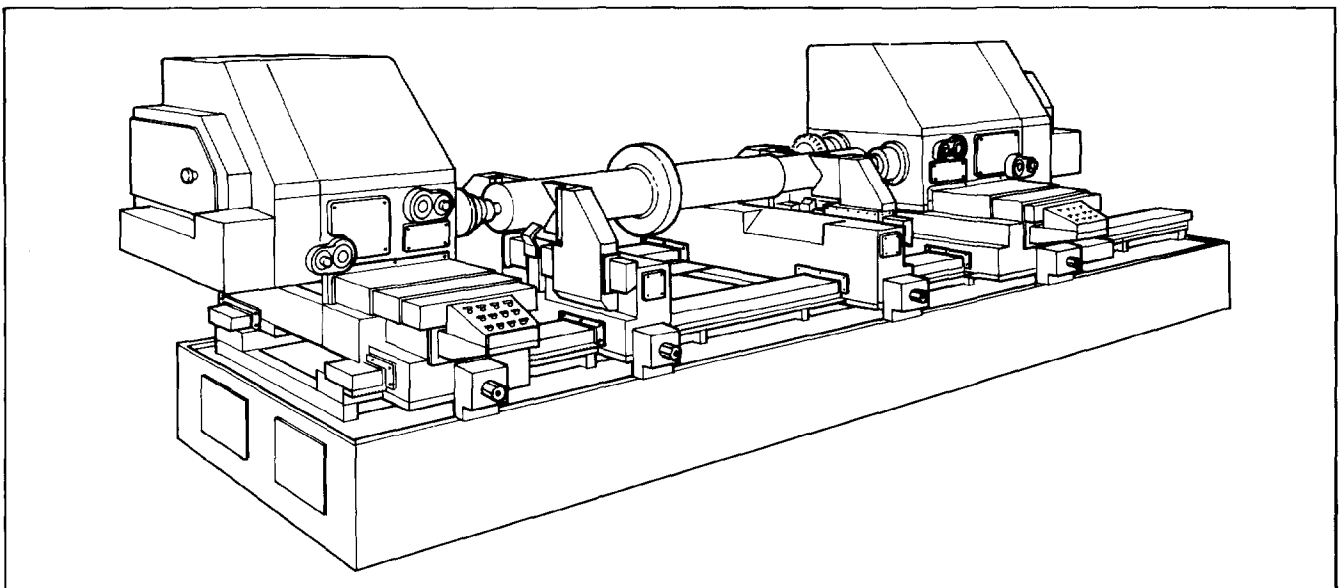


Fig. 15-35 Milling and centering machine equipped with 8" (203 mm) diam milling cutters. (Seneca Falls Machine Co.)

CENTER DRILLING AND FACING MACHINES

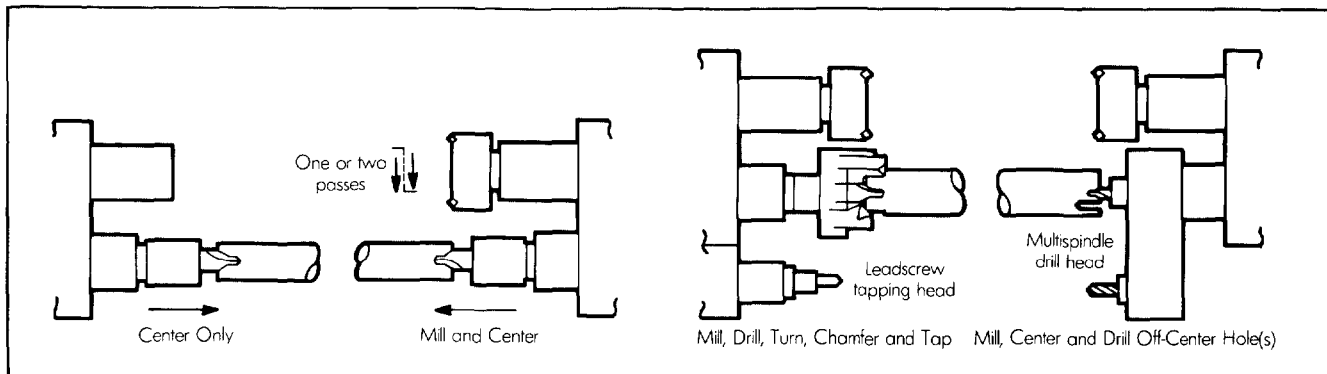


Fig. 15-36 Four of many arrangements and modes of operation on milling and centering machine. (Seneca Falls Machine Co.)

Short workpieces can often be handled with a single vise. In most cases, the front jaw of the vise is solidly affixed to the jaw slide while the rear jaw is arranged so that it pivots to accommodate small variations in diameters of the gripping areas. This design is well suited for handling cold forgings, extrusions, and bar stock.

Plunge facing and centering machines are very versatile and can be applied to a variety of other operations. These include facing, chamfering, and counterboring tubes, boring bearing seats in conveyor rolls, and various cross-drilling operations. In one application, rods are pointed at one end, faced and chamfered on the other end, and marked with the maker's name and the rod size on the faced end by means of an impression die mounted on the vise jaws. Another widely used application is facing and countersinking both sides of kingpin bosses on truck axles, one end at a time. Many high-production applications lend themselves to the use of automatic loading and unloading equipment.

MILLING AND CENTERING MACHINES

These machines consist of a base having ways on which two cross-sliding heads and a workholding means (usually two heavy-duty self-centering vises) are mounted. Both heads have two quill-mounted spindles, one for drilling and the other for milling.

The drilling quills are power fed in and out. The milling quills are manually adjustable for cutter position. They may incorporate cutter relief at the end of the face-milling strokes and/or

offer provision for cutter advance to furnish rough and finish-milling capability. Both heads are mounted on ways that are transverse to the bedways. Fixed stops position the drilling spindles central with the workpiece, while variable stops are set to return the milling cutters at the conclusion of the operation.

Standard milling and centering machines are available with milling cutter capacities to 15" (381 mm), length capacities to 240" (6096 mm), and milling-spindle drive motors of 10-40 hp (7.5-29.8 kW) per head. The machine illustrated in Fig. 15-35 is equipped with 8" (203 mm) diam milling cutters and 25 hp (18.6 kW) drive motors.

Some machines have two motors on each head, one for milling and a smaller motor for drilling. Other machines have one motor per head that drives both spindles through independent gear trains. With this design, full motor power can be applied to either spindle, with the capability of performing combination operations with the drilling spindles. The machines can also be provided with a third spindle, conventional or tapping, on one or both heads.

Milling and centering machines are very versatile. They can be furnished with a full range of capabilities for small-lot production of a variety of workpieces or just enough features for dedicated operation. One example of dedicated operation is the production of steering knuckles. The spindle ends of the knuckles are milled and faced, while the yoke ends are center drilled and spotfaced, using a standard centering-machine head. Four of the many possible arrangements and modes of operation are shown in Fig. 15-36. It can be seen that the heads on both ends of the machine need not be the same.

HORIZONTAL BORING MACHINES

Boring, the machining process for removing metal from internal cylindrical surfaces, is performed on many different machine tools. These include lathes, discussed in Chapter 8, "Turning and Boring"; some drilling machines, particularly radial drills, discussed in Chapter 9, "Drilling, Reaming and Related Processes"; automatic screw, bar, and chucking machines described previously in this chapter; and machining centers, transfer machines, and other multifunction machines discussed subsequently in this chapter.

Precision boring machines, operating parameters, and applications are discussed in Chapter 8 of this volume. This section is confined to heavy-cut boring and related operations performed

on horizontal-spindle machines. Vertical boring machines are described next in this chapter.

CHARACTERISTIC MACHINE FEATURES

Horizontal boring machines (HBM's) usually do many other operations besides boring, especially milling. As a result, they are often called horizontal boring mills or horizontal boring, milling, drilling, and tapping machines. These heavy-duty machines are employed extensively for large, complex castings, forgings, weldments, and similar workpieces. They perform different operations at various locations on the workpieces without the need for changing the basic setup, and they can

HORIZONTAL BORING MACHINES

maintain accurate relationships between the machined surfaces. These machines are not, however, high-production machines and are generally limited to low to medium size runs.

Characteristic features of HBM's include the following:

1. Horizontal spindles that rotate the cutting tools.
2. Horizontal surfaces on which workpieces are mounted.
3. Power feed of the spindle to advance cutting tools into the workpieces.
4. Power-fed relative motion between the spindle and workpiece in at least two axes perpendicular to the spindle axis.
5. Power saddle feed parallel to the spindle axis.
6. Outboard supports, on some machines, for the ends of line boring bars and arbor-mounted slotting cutters.

Horizontal boring machines are available in a wide range of capacities. The size of a machine is often identified by the diameter of its spindle, which generally varies from 3-10" (76-254 mm). Spindle rigidity is directly related to the fourth power of its diameter. As a result, considerable additional cutting power is obtainable with larger spindle diameters. Main drive motors range from 15-75 hp (11.2-56 kW) or more.

TYPES OF HBM's

Various designs of horizontal boring machines are available. Three major designs are table, planer, and floor-type machines. They are also available in traveling-bar and traveling-head types. With respect to boring only (excluding milling and other operations), they can be classified as stub boring or line boring machines. Stub boring is done with a bar supported only by the spindle. Line boring is done with a bar that extends through the workpiece and is supported at one or more points in addition to the machine spindle. Cross-feed column machines are also available, providing the column with two axes of travel: one

perpendicular to the spindle travel and the other parallel to the spindle travel.

Table-Type Machines

In table-type machines (see Fig. 15-37), the table feeds horizontally on saddle ways both parallel and at right angles to the spindle axis. On machines having a long table travel perpendicular to the spindle support, additional outboard supports on runways are often provided. The headstock moves vertically on the column, and the spindle has a horizontal feed motion. This type of machine is well suited to general-purpose work for which other machining operations are required in addition to boring.

Planer-Type Machines

These horizontal boring machines are similar to the table-type design except that they have no table-supporting saddle. The table travel is at right angles to the spindle along the base ways. Feed perpendicular to the table (parallel to the spindle) is obtained by feed motion of the spindle. Feed motion of the column along the base ways is used when exceptional rigidity is required to maintain accuracy in machining long and heavy work. A horizontal-spindle planer-type boring machine equipped with CNC and a rotary table is shown in Fig. 15-38.

Floor-Type, Traveling-Column Machines

These machines (see Fig. 15-39) use a stationary floor plate equipped with T-slots instead of a table to hold the work. They are ordinarily used to handle large workpieces of a weight, size, or shape that would make it impractical to employ a reciprocating table. Horizontal feeds perpendicular to the spindle axis are obtained by movement of the column along the base ways rather than by table movement. The headstock moves vertically on the column, and the spindle has a horizontal feed motion. On some machines of this type, the column is mounted on a saddle providing an additional motion parallel to the spindle axis.

Portable Machines

This type of machine is used when it is more convenient to move the machine to the workpiece. Such machines are used inside large vessels and/or to repair assembled components of large mechanisms in place.

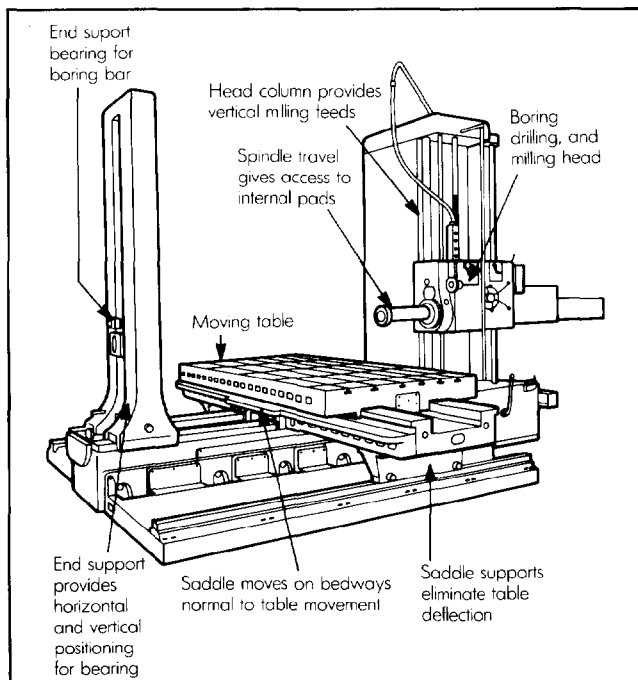


Fig. 15-37 Table-type horizontal boring, drilling, and milling machine with end support for line boring operations.

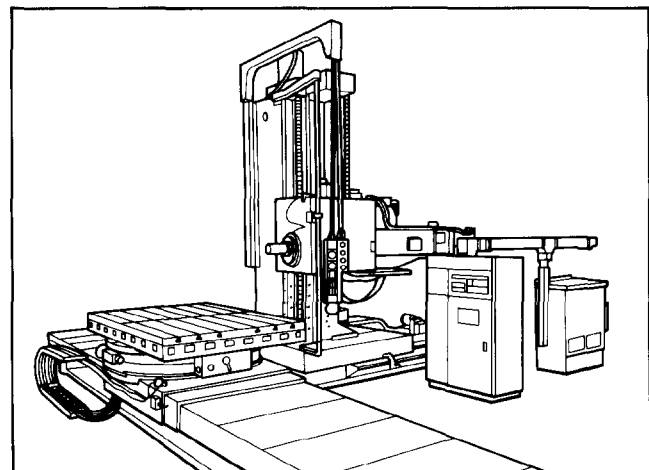


Fig. 15-38 Planer-type horizontal boring machine equipped with rotary table. (Cincinnati Gilbert Machine Tool Co.)

HORIZONTAL BORING MACHINES

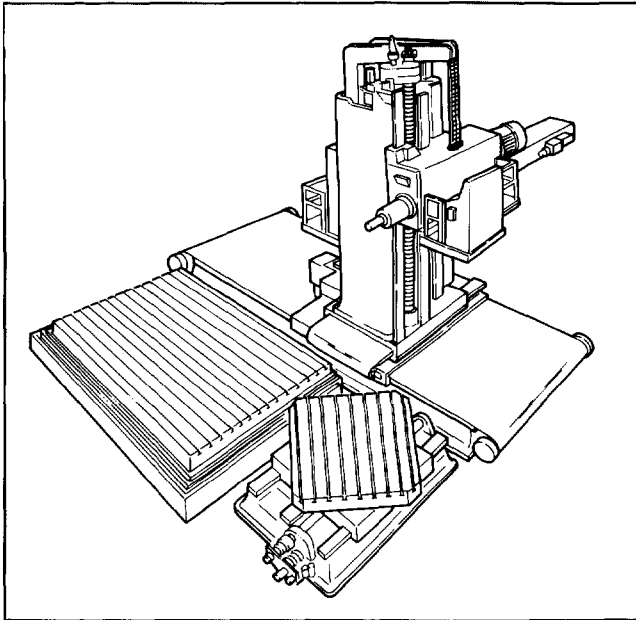


Fig. 15-39 Floor-type horizontal boring machine. (Gray Div., Warner & Swasey Co.)

Traveling-Bar Machines

Traveling-bar, heavy-duty horizontal boring machines consist essentially of a headstock containing a motor and gear reduction unit giving rotary motion to the bar or spindle. A transmission unit is also included giving feed and rapid traverse motion, in and out, to the bar. An outboard support is used to support the bar after the bar has been positioned through the bore of the workpiece. A boring head is added and clamped securely to the bar; feeding motion is then given to the bar through means in the headstock. This type of heavy-duty horizontal boring machine has one disadvantage in that it must occupy floor space almost three times its own length because of the length of the boring bar.

Traveling-Head Machines

Traveling-head machines are essentially the same as traveling-bar machines except that the boring bar contains a screw attached by a nut to the boring head and derives its feed motion from a planetary-type gearbox attached to the outboard or inboard end of the boring bar. The headstock supplies power to rotate the bar while the feed mechanism on the bar imparts feed and rapid traverse to the boring head. For loading and unloading the workpiece, the boring head may be locked securely to the outboard support. An air motor is attached to a coupling on the outboard end of the screw; and with a rolling dolly to support the boring bar, the bar is traversed to a loading position and returned to operating position after work loading is completed.

When split workpieces such as some housings and casings are machined, the lower half of the workpiece is positioned on supports under the boring bar. The bar is then lowered onto pedestal supports and the upper half of the workpiece is bolted to its lower half, with the boring bar inside the workpiece.

This machine requires floor space twice its own length and then only when loading and unloading a workpiece. Constant sag is maintained in the boring bar between two supports

because the boring head feeds over the bar. A traveling-support head may be used when long holes are to be bored to fairly close tolerances.

Toolchanging HBM's

Many builders of horizontal boring machines offer automatic toolchangers as an option. This places the machines in the class of machining centers, discussed subsequently in this chapter.

MACHINE CONTROLS

Horizontal boring machines are still built for manual operation, but most are now supplied with manual data input (MDI) or CNC for relative positioning between the cutting tool and workpiece. Digital readout units are used extensively on manually controlled machines.

MDI Controls

Manual data input controllers provide a simple and more economical alternative to CNC for small-lot production. With these controllers, the machine operator places required dimensional, feed, and speed data into the control by means of dials or switches. Once the command data is entered, the operator pushes a button and the machine automatically moves to the commanded position in the prescribed manner. The next data is then entered, the button is pushed again, and so on until the workpiece is completed.

Controllers with MDI are now available with electronic, integrated memory systems. The control/memory unit automatically records each operating sequence instructed by the machine operator. Sequence numbers are automatically assigned to each operation. Program instructions can also be entered manually, viewed, and/or edited. In most cases, in order to retain maximum operator control, feed rates and spindle speeds are not stored.

In the automatic mode, a stored program operates the controller and machine. The controller operates block by block, stopping at the completion of each block. Information for the next block is displayed, so the operator can change feed rates and spindle speeds as required. Displayed programs can be modified without changing the stored programs. The stored programs can be transferred to any compatible storage medium, such as tape cassettes, punched paper tape, or hard copy. Prerecorded program tapes can be loaded into storage.

CNC Units

Horizontal boring machines equipped with CNC can produce slopes, circles, arcs, and complex shapes. Most HBM's have four motions under CNC. On table-type machines, the spindle, head, table, and saddle are controlled; on planer-type machines, the spindle, head, table, and column are controlled; and on floor-type machines, the spindle, head, column, and on certain machines, the saddle.

Slide motions on horizontal boring machines with CNC are generally identified as follows:

- X axis Table, horizontal.
- Y axis Head, vertical.
- Z axis Spindle.
- W axis Saddle, column, or rotary table on slide.
- A axis Rotary table tilt.
- B axis Rotary table, horizontal.
- C axis Rotary table, vertical.

A comprehensive discussion of NC/CNC is presented in Chapter 5 of this volume, "Machine Controls."

HORIZONTAL BORING MACHINES

BORING BARS

A round boring bar with one cutting tool mounted at the end of the bar (see Fig. 8-116) is commonly used to perform single-diameter stub boring operations on HBM's. Many bars for line boring are designed with slots for block-type tooling or for holding several single-point tools for producing various diameters in one pass. The increasing use of indexable insert tools has brought about the extensive application of cartridge-type bars with slots for mounting insert-holding cartridges.

Bar Size

The diameter of the bar employed may or may not be larger than the spindle diameter when horizontal boring, drilling, and milling machines are used. The length of general-purpose bars needs to be sufficient to reach the end column or support at its most outward setting. It is, however, necessary to limit the amount of bar projecting beyond the support since whipping action of the unsupported end may cause chatter. Whenever possible, the boring bar should be of maximum diameter and minimum length to accomplish the boring operation involved. Intermediate supports placed in previously machined bores of the workpiece, such as the adjustable spider shown in Fig. 15-40, may be used to control bar sag. Bearing supports on the workholding fixture may also be used.

The diameter of the bar must be sufficient to prevent excessive overhang of the cutter from the bar periphery when the cutter is extended to the machining position. The limit of cutter overhang varies considerably, depending on the cross-sectional size of the cutter shank, the composition of the cutter, the chip load, and the finish required. Table 8-23 presents data that can be used as a starting point for designing single-point boring bars. Carbide-tipped cutters and indexable inserts must have exceptionally rigid mountings in order to prevent premature dulling or breaking down of the cutting edges. A boring head or support head should be considered when the maximum applicable bar diameter is insufficient to give adequate cutter support in some conventional mounting.

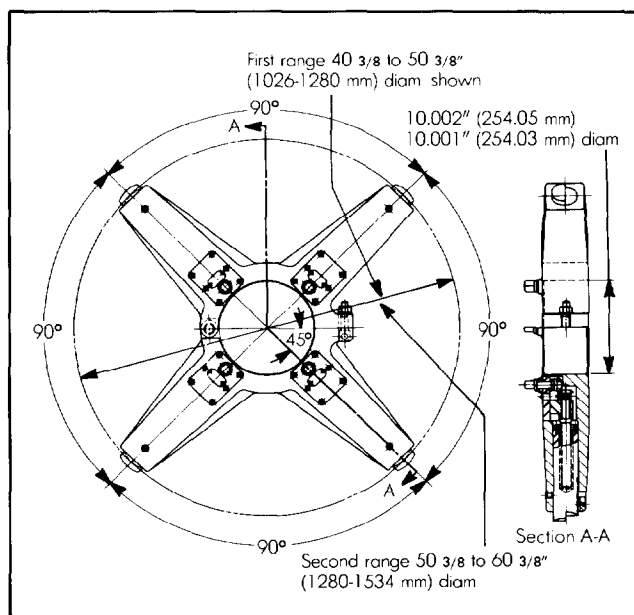


Fig. 15-40 Adjustable spider for supporting boring bar. (Davis Tool Co., Div. of Giddings & Lewis)

Bar Construction

Boring bars are available made from soft, heat-treated, or surface-hardened steels.

Soft-steel bars. These bars are often made from low-carbon steel or manganese-chromium alloy steel that is annealed to relieve internal strains. Bearing supports are usually either bronze or cast-iron bushings. Soft bars are used when points of support vary from job to job, thus avoiding concentrated wear at any one point. Their main advantages are low cost and flexibility if additional cutter slots must be machined in the bar.

Heat-treated bars. These are generally made from a medium-carbon steel alloyed with chromium and manganese. The bars are used when severe cutting loads require the added serviceability of a higher tensile strength. Heat-treated bars are not as susceptible to wear as soft bars and are within a hardness range that permits machining additional cutter slots, if required. Bearing supports are generally bronze bushings, cast-iron bushings, or antifriction bearings. Heat-treated bars are generally used in preference to soft bars because of increased wear resistance.

Carburized and hardened bars. These bars are made from low-carbon steel, generally alloyed with chromium and manganese. The hardened bar has a tough, relatively soft core that will sustain heavy cutting loads. The hard skin resulting from surface carburization and hardening is resistant to wear under production duty in which the bar supports are fixed. Nitrided bars also offer excellent service. Hardened-steel bushings, bronze bushings, or antifriction bearings are usually employed with this type of bar.

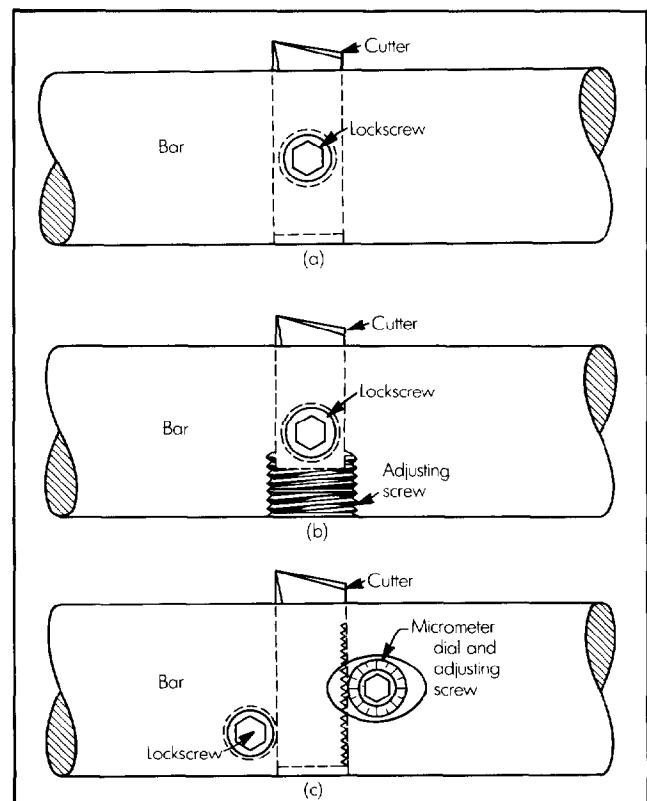


Fig. 15-41 Methods of mounting single-point tools in boring bars: (a) nonadjustable, (b) backup screw adjustment, and (c) micrometer-dial adjustment.

HORIZONTAL BORING MACHINES

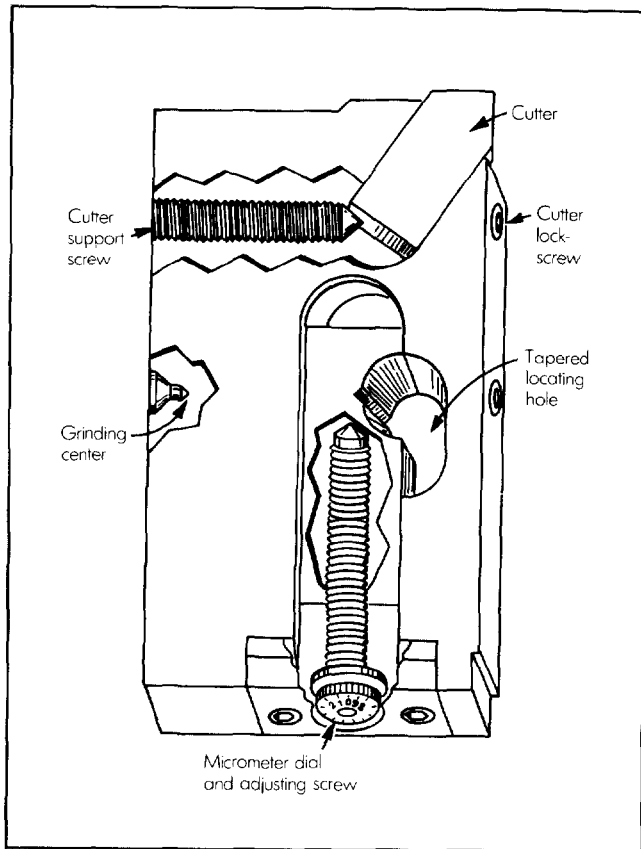


Fig. 15-42 Block-type tool for boring bar with micrometer-dial adjustment.

Cutter Mounting and Adjusting

A number of different designs are available for mounting and adjusting cutters in boring bars. Several methods of mounting single-point flycutters are illustrated in Fig. 15-41. View *a* shows a nonadjustable design, with the cutter positioned manually in the bar slot and secured by a lock screw. The design in view *b* provides an adjusting screw behind the cutter. While adjusting backup screws are still used extensively, they are increasingly being replaced by finer and more positive means such as the micrometer-dial adjusting screw illustrated in view *c*. Another micrometer-adjustable toolholder for boring operations is shown in Fig. 8-117.

Block Tooling

With block tooling (see Figs. 15-42 and 15-43), the cutters are held in blocks that are mounted in slots in the boring bars. This design provides additional support for the cutter and permits a greater working range for any given bar diameter. Several sizes of blocks may be used in a single bar to suit the bore diameter. Micrometer adjustment permits rapid and accurate settings. The design shown employs a tapered locating screw to center the block in the bar slot. Centers are provided in the block sides to permit cylindrical grinding of the cutter to a specified diameter, permitting toolroom control of bore dimensions.

Double cutters are widely used in production boring, because their cutting action (with balanced chip load between cutters) decreases machining time when compared with single-point flycutting. Chip load per revolution may be doubled with block-type tooling. Although less flexible, the method is ideally suited to repetitive production boring in which the extra cost of more efficient tooling is offset by the time saved in machining. It is also ideal for operations in which responsibility for size control and finish is to be removed from the operator and placed under toolroom control. With the exception of several commercial

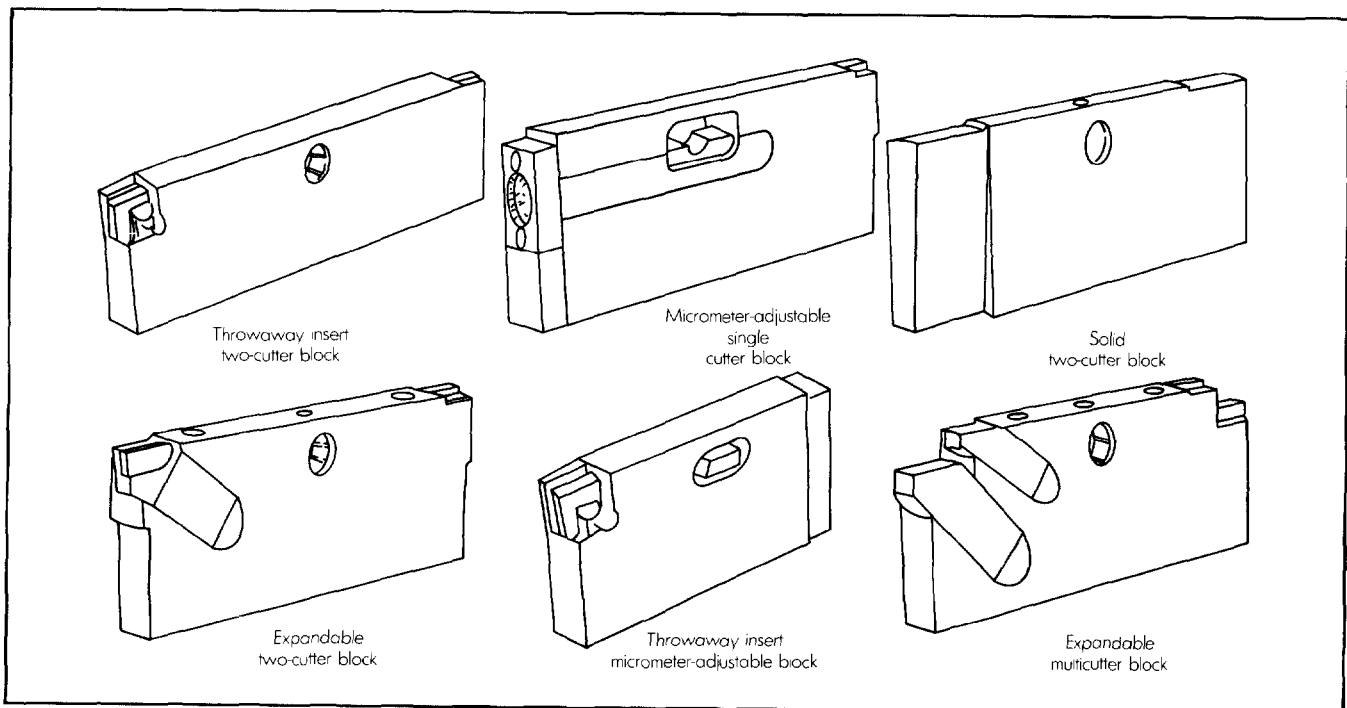


Fig. 15-43 Block-type cutters for boring. (Davis Tool Co.)

HORIZONTAL BORING MACHINES

types that simultaneously expand both cutters to an accurate setting, double cutters are harder to adjust than single-point flycutters. Unless both cutter tips are equidistant from the bar axis, a disproportionate chip load will result and vibration and deflection can occur.

Typical double-cutter arrangements are shown in Fig. 15-44. View *a* shows a double cutter with a single bit ground on each end to the diameter of the bore to be machined. It is common practice to lock the bit in the bar slot and use the bar for an arbor when grinding the tips, thus accurately establishing the cutting edges equidistant from the bar axis. The number of regrinds per bit for a given bore diameter is necessarily limited even when used for roughing work. Cutters of a similar style may be designed with the bit unlocked in the bar. The cutter is then essentially a reamer, since it is permitted to float in the bar slot and center itself during the boring operation. This type of mounting is suited only for finish cuts, where the bore surface is regular and only a small amount of stock is to be removed. When the foregoing conditions are met, the floating double cutter is preferable over the double-locked cutter. The main disadvantage is the loss of effective tip-to-tip length in regrinding. Problems encountered during regrinding can be eliminated by using double cutters with indexable inserts.

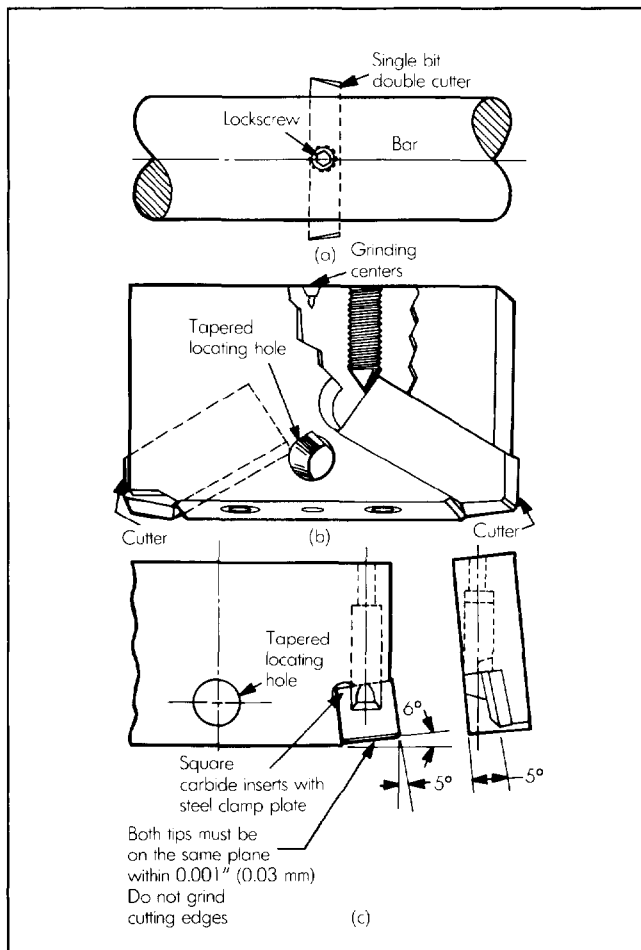


Fig. 15-44 Double cutters: (a) single tool bit, (b) expanding block type, and (c) indexable-insert block type. (Davis Tool Co., Div. of Giddings & Lewis)

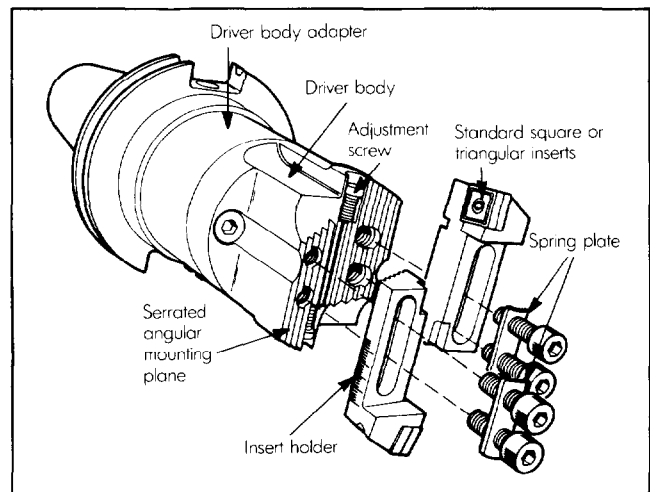


Fig. 15-45 Holder for square or triangular inserts has serrated, angular mounting surfaces for rigid clamping. (DeVlieg Machine Co.)

The expanding-block type of cutter (see Fig. 15-44, view *b*) is one of the most important boring tools for production use. The use of a block cutter and a companion boring bar places the bulk of the responsibility for bore accuracy in the toolroom. Thus, quality control becomes an integrated shop function rather than being entirely dependent on the operator's skill. Tolerances of 0.001 or 0.002" (0.03 or 0.05 mm) on large-diameter bores are controlled by this type of cutter block.

Indexable inserts are being increasingly used in preset toolblocks as shown in Fig. 15-44, view *c*. The cutting geometry is fixed; however, the toolblock may be made with either a positive or negative rake angle. This provides four cutting edges with a positive rake angle or eight edges with a negative angle. The tool may be used for roughing cuts with an accuracy of 0.004" (0.10 mm) on the diameter. Tools may also be floated for finishing cuts to tolerances as close as ± 0.0005 " (0.013 mm).

A holder for two standard, square or triangular inserts is shown in Fig. 15-45. It has serrated, angular mounting planes on the insert holder and driver body. When locked, the serrations ensure rigid cutting edges for high feed rates and heavy stock removal. Nine tools cover a boring range from 1.10-14.00" (27.9-355.6 mm). The insert holders can be set to cut the same diameter, and diameter changes are made by adjusting screws which provide lateral movement of the insert holders. Replacing one insert holder with a step-bore holder permits cutting two different diameters.

Cartridge-Type Boring Bars

Boring bars with one or more slots for mounting insert-holding cartridges (see Fig. 8-123) are being used extensively. Some standard cartridge designs for indexable inserts are shown in Table 8-24. Boring bars can be designed to carry several cartridges for multiple operations; by switching cartridges, one bar can be used for a number of different operations.

BORING HEADS

Boring heads are used to give added support to the cutter when the bore diameter exceeds the workable range of a direct bar mounting. In addition, the use of a boring head permits latitude in design for special applications not offered by a bar

HORIZONTAL BORING MACHINES

mounting. There is usually ample space to employ several cutters and thus decrease machining time.

The head may be mounted directly to the spindle by an integral shank or stub arbor, or it may be mounted on the spindle sleeve. In other designs, the head may be mounted on a line boring bar with a conventional key lock between the bar and the hub of the boring head. A dual-slide crossfeed facing

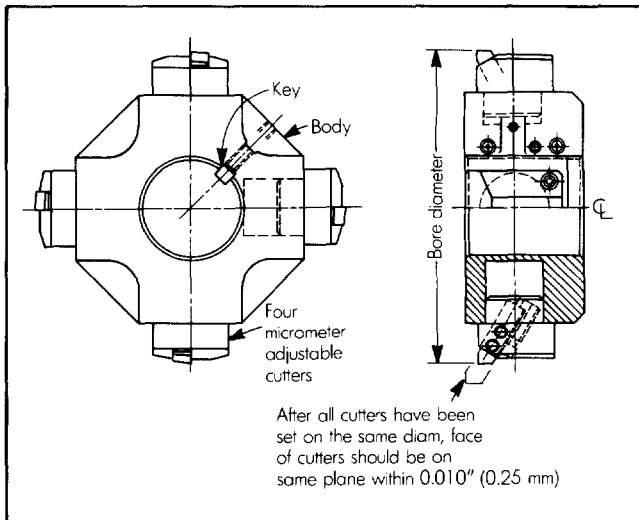


Fig. 15-46 Four-cutter rough boring head with removable toolposts. Three cutters are used for roughing and a fourth adjustable flycutter for finish boring. (Davis Tool Co., Div. of Giddings & Lewis)

head combined with a bridge-mounted boring head is illustrated in Fig. 8-127.

Commercially designed heads of the type illustrated in Fig. 15-46 are made for bores of from 6-30" (152-762 mm). They may be driven from a stub arbor or a line boring bar. These cutters are used to rough and semifinish the bore. Each head has a range of bores made possible by extending the tool bits within practical limits, or by using varying lengths of tool posts or spacers together with adjustment of the tool bits. Each tool bit has a micrometer adjustment for ease of setting it in relation to the others. The position of the tool slots in the holders provides on-center cutting for both forward and back boring. The toolholders are rotated 180° for back boring. This design permits the added machining efficiency of a multiple-cutter head in roughing operations followed by the characteristic accuracy of a micrometer-adjustable flycutter in producing the finish bore.

Figure 15-47 shows a boring head of unusual size and requirements. It is composed of a cast or welded faceplate. The forged-steel boring bar contains 12 boring heads and cutters and two generating-type toolposts with cutters. The faceplate contains 14 toolposts, each post containing either a standard tool bit or a form cutter. Adjustment within the bore range is possible to all cutters. The boring tools are arranged to cut in the same plane so that each tool bit takes an equal chip, or the cutters are staggered on both the periphery and the cutting face of the tool bits to effect a distribution of the stock between the cutters. Up to 1 1/2" (38 mm) of stock can be removed in this manner in a single pass of the cutting tool.

In boring operations it is often necessary to accomplish other

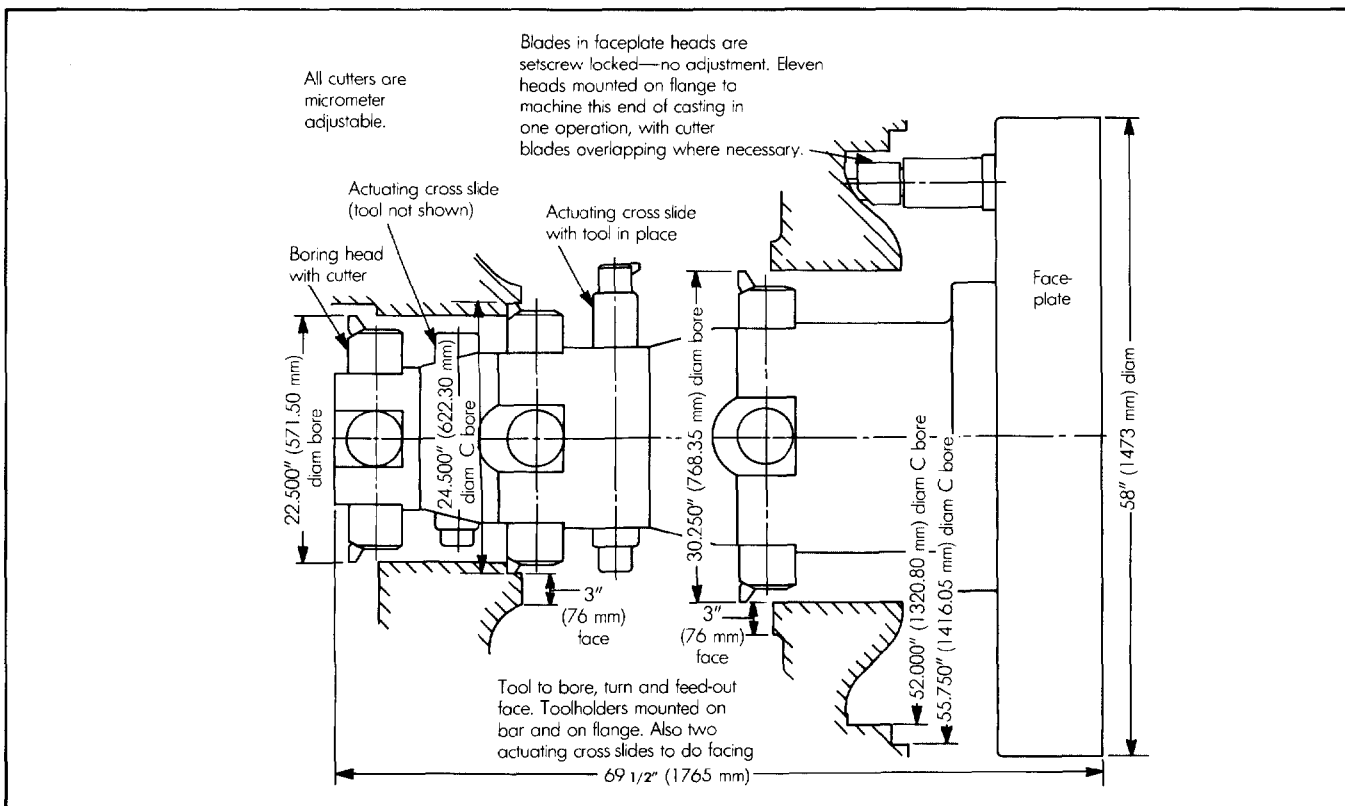


Fig. 15-47 Special tool to bore, turn, and face with toolholders mounted in bar and on flange. (Davis Tool Co., Div. of Giddings & Lewis)

HORIZONTAL BORING MACHINES

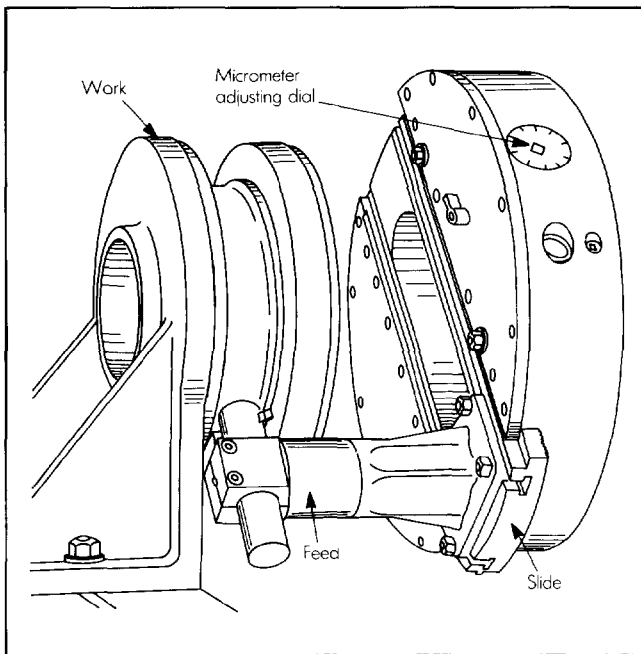


Fig. 15-48 Continuous-feed facing and boring head performing back-facing operation. (Giddings & Lewis Machine Tool Co.)

machining operations on adjacent surfaces. The continuous-feed facing and boring head (see Fig. 15-48) is equipped with a slide that is geared to the head rotation through a reactor gear, giving six separate power feeds at right angles to the spindle. This construction is used for boring, grooving, recessing, facing, turning, and threading. The various machining operations are all accomplished with such heads (also called generating or feed-out heads) in one work setting. This tool obtains its name from the action of the cross slide which feeds continuously after a clutch is engaged, as opposed to an intermittent or star-wheel type of feed. Finer finishes can thus be obtained with a minimum of shock to the tool bit. The slide is arranged to accommodate any number of special tool arrangements. A continuous-feed facing head may be used to machine internal grooves in blind bores. The tool slide is adjusted until the tool enters the smaller internal bore. It is then set to proper groove diameter by using the micrometer dial on the head. Contouring and facing heads controlled by NC are also used.

One builder offers a numerically controlled, tool-point head that permits taper and contour boring, internal and external threading, turning, grooving, recessing, facing, and other operations on four-axis, CNC, horizontal boring machines. The head, secured to the spindle sleeve of the machine, has a serrated slide on its face for changing toolblocks. An adjusting screw on each block permits accurate tool presetting of diameter and repeatable location of blocks on the slide.

Axial motion of the spindle bar positions the tool point radially (see Fig. 15-49). The cam angle of the actuating slide is such that radial movement is half the axial motion, allowing direct programming of diameter changes. Working in conjunction with the radial feed of the cutting tool, the servo W axis (table in-and-out) of the machine feeds the workpiece past the cutting tool during machining. For thread chasing, a spindle rotation feedback encoder produces the lead by interpolating spindle rotation with the W-axis feed.

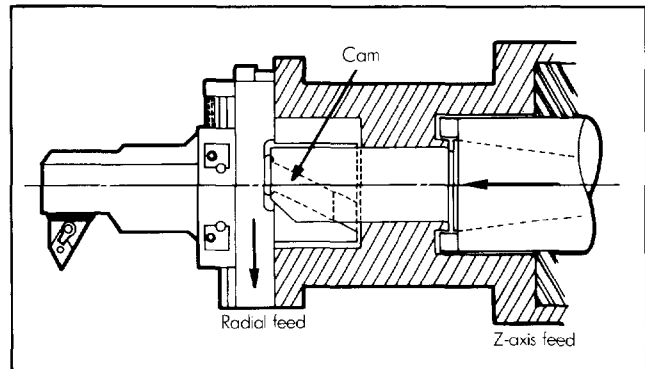


Fig. 15-49 Numerically controlled tool-point head that permits taper and contour boring, internal and external threading, and other operations on four-axis, CNC, horizontal boring machines. (DeVlieg Machine Co.)

RETRACTING AND SIZE CONTROL DEVICES

Draglines (withdrawal marks) resulting from the retraction of boring tools after cutting can be avoided by several methods. One device has a cartridge containing a cam which adjusts the tool position when it is rotated. At the completion of the cut, axial movement of the cam causes the tool to move away from the workpiece. With another method, the boring bar is mounted on a retracting head that moves the bar eccentrically or radially for clearance at the end of the cut. Hydraulic cylinders, slides, and limit switches are used on other devices to retract boring tools after cutting. A retracting cutter head is illustrated in Fig. 8-124.

Several automatic size control systems for repositioning boring tools are available. With one system (see Fig. 8-125) used on machines having hollow spindles, measuring probes gage the bores, signals are compared to required sizes, and any necessary adjustments in tool positions are made manually, semiautomatically, or automatically.

BORING TOOLS

In addition to boring tools, many other tools are used on horizontal boring machines. Turning tools, as well as precision boring tools, are discussed in Chapter 8, "Turning and Boring"; milling cutters in Chapter 10, "Milling"; and threading tools in Chapter 12, "Threading."

Tool Materials

Boring is done with single-point tools—solid, brazed tip, and most extensively, indexable inserts made from various cutting tool materials and clamped to holders. Cutting tool materials used include high-speed steels (both wrought and made from powder metallurgy processes), cast cobalt-based alloys, coated and uncoated carbides, ceramics, diamonds (single crystal and polycrystalline), and cubic boron nitride. High-speed steels and carbides are the predominant materials for boring.

Selection of a particular material for a specific boring operation depends on many variables, including workpiece material; type of operation; stock removal; machines used; operating parameters; tool cost; and production, accuracy, and finish requirements. A comprehensive discussion of the various materials is presented in Chapter 3, "Cutting Tool Materials." Details on types and selection of indexable inserts are included in Chapter 8, "Turning and Boring."

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Geometry of Boring Tools

Generally, cutting angles for boring tools, single tool bit or multiple-cutter type, carry a common geometry, governed by the diameter of the cutting tool and the material being cut. Basically, whether positive or negative angles are required, the radial or side rake angle is the only angle that varies, getting shallower as the diameter increases. The other angles may be varied with the material, but usually only after a trial cut has been taken.

Boring places an exacting requirement on the cutting angles, since changing the angles is not as simple as with, for instance, a turning tool. Emphasis placed upon correct cutting angles for boring is essential, since in most cases no other operation, such as grinding following a turning operation, is done. The chip must leave the parent metal and flow away from the surface just cut and in the direction of the center of the bore. The radial and axial rake angles do more than just provide cutting angles; they must direct the course and flow of the chip, as shown in Fig. 15-50. This is especially true of finishing tools. Chips allowed to turn toward the side of the bore can easily mar the finish in the final cut, as well as wrap themselves around the tool in heavier cuts. The axial rake angle is used to flow the chip, while the radial rake angle directs its course away from the bore surfaces.

Boring cutter geometry for brazed-type tools is as follows (see Fig. 15-51): 5° axial rake, 5° radial rake, 5° face relief, 1 1/2° peripheral relief, and 0.050 in./in. (mm/mm) of length back taper for rough cutters and 0.030 in./in. (mm/mm) for finish cutters. The referenced angles are for positive angle cutters; however, when negative angles are required, the radial rake angle becomes -3° while the axial rake angle is -5°. All angles may be changed by special requirements, and only standard geometry for average bores and materials is shown here.

As higher speeds are used and more exacting tolerances demanded, it becomes increasingly important that in regrinding, the cutter geometry be duplicated exactly time after time. The freedom of random grinding of cutters can result only in varied finishes, dulling of tools, and great inefficiency in the boring operation.

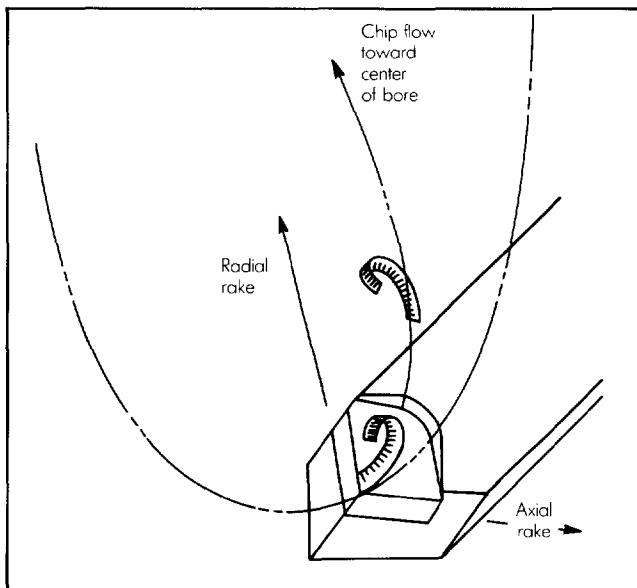


Fig. 15-50 Chip flow as the result of radial and axial rake on a boring tool.

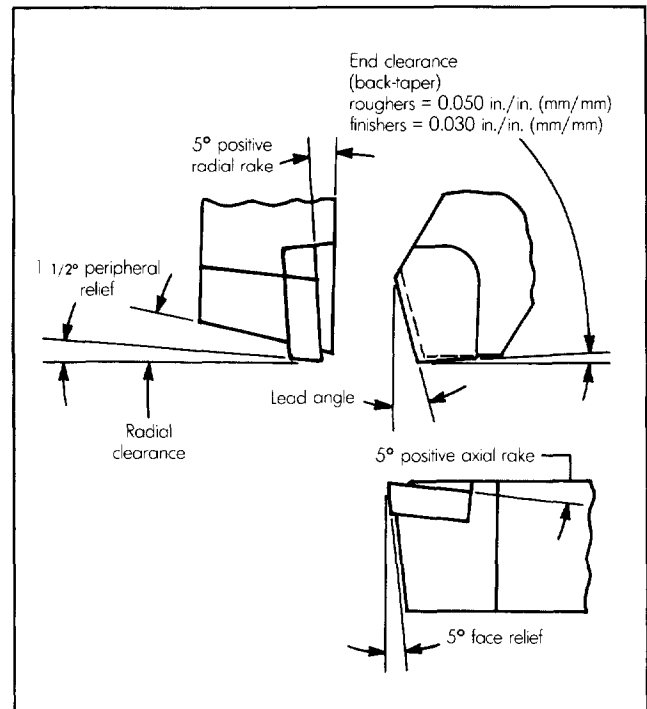


Fig. 15-51 Tool geometry for average bores and workpiece materials.

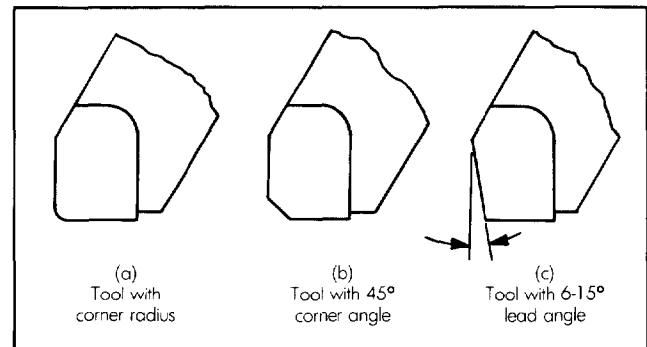


Fig. 15-52 Types of tips on standard boring tools.

In addition to cutting angles, corner angles are included in standard tipped cutters. Depending upon the size of the cutter, a fixed radius (see Fig. 15-52, view *a*) is included as standard; however, this is readily changed to a 45° corner chamfer (view *b*) in place of the radius. The corner chamfer can increase cutter stability, eliminate chatter, and give longer tool life between grinds. A tool with 6-15° lead angle is shown in view *c*. Modification of the lead angle is quite common, especially with indexable inserts, to increase cutter stability, vary the angle of cutting forces, provide clearance, and give a wider cutting face without increasing the depth of cut.

Most boring tools are now designed to accept commercially available indexable inserts because of the wide variety of geometries available.

SETUP AND OPERATION OF HBM's

Rigid setups, with adequate bar support and proper fixtures, are critical to performing successful operations on horizontal

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boring machines. The most successful boring operations are performed when there is adequate rigidity in all elements, including the machine.

Bar Support

In horizontal boring machines, the workpieces are normally stationary during machining operations, but the workpieces are sometimes moved on rotary index tables. Cutting tools are mounted on various types of boring bars that transmit motion, and power is imparted to them from the machine spindle. The method of bar support varies to suit the length of bar required to reach the surface to be machined, the accessibility of the bore, and the degree of precision or finish required.

Stub bars are supported only at the spindle end and are used to bore holes that may be positioned comparatively close to the headstock. Blind holes do not permit extension of a line bar through the work to an end support, and ordinarily a stub bar must be employed. Line bars extend through the workpiece and require some form of support external to the spindle. Generally, an end support (see Fig. 15-53, view *a*) is used for this purpose, since it may be readily brought into alignment by a simple adjustment of its bearing block.

The use of the workpiece for bar support (Fig. 15-53, view *b*) may sometimes be preferable or necessary. In certain types of blind holes with lateral holes that permit inspection of the cutter, the finished bore behind the cutter may be bushed to bar size. This procedure is also used when some form of support between the machine spindle and the end column is required and when the workpiece obstructs the use of fixture bearings at points of necessary support. Although the use of the workpiece for bar support usually consumes more machining time and in

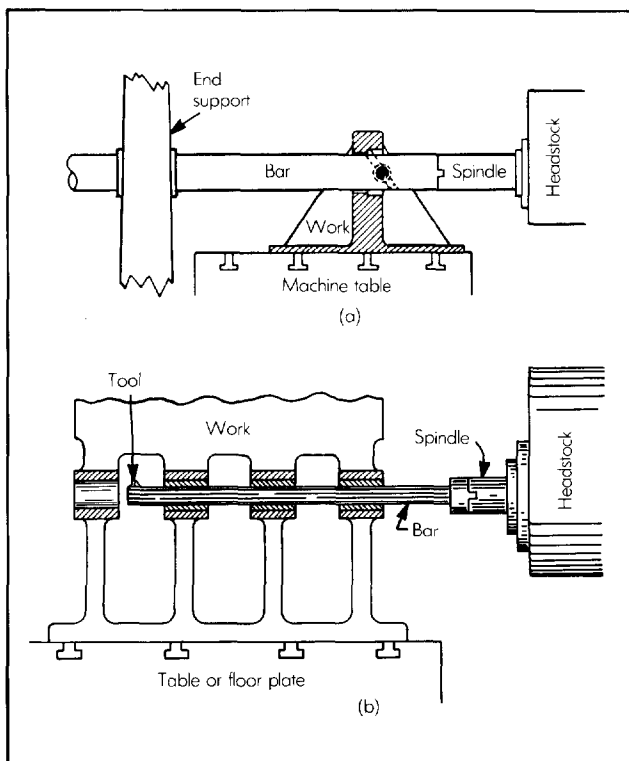


Fig. 15-53 Support of boring bar by: (a) end-support column and (b) workpiece.

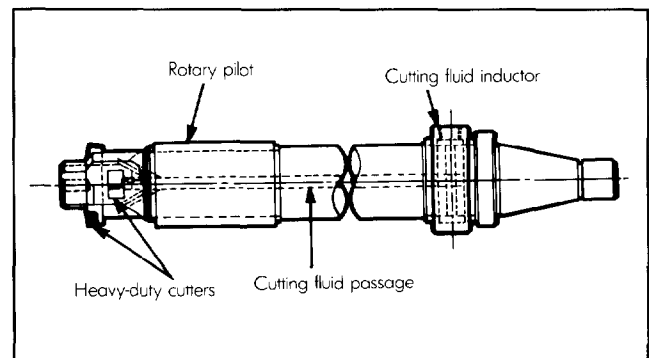


Fig. 15-54 Rotary-piloted boring bar. (Muskegon Tool Industries)

most cases is not desirable, it may be preferable over a fixture when the cost of the latter is prohibitive.

When workpiece support of the bar is not possible, a back rotary-pilot support is sometimes used, especially for deep-hole boring. A stub tool can be employed to bore the starting hole and then replaced with a piloted boring bar. A better method is to use a stationary bushing, mounted on a machine underarm support or in its own support on the machine table, to guide the piloted boring tool.

Back-piloted boring bars (see Fig. 15-54) have a rotary pilot behind the cutting tools. The bars hold at least one rough-boring cutter, followed by a finishing cutter. The pilot is designed to remain stationary in relation to the workpiece, with the bar revolving in the pilot. Proper clearance between the pilot and workpiece is essential to prevent jamming. A supply of cutting fluid through the tool is necessary for extended tool life.

Back-piloted bars for operation in blind holes are designed to permit chips to escape through the centers of the hollow bars. If the hole is large enough, this can be accomplished by providing a bronze roller pilot on which wear strips are mounted. Otherwise, wear pads are mounted directly on the bar and rotate on the ID of the bore instead of remaining stationary. High-pressure cutting fluid, forced over the bar, flushes chips back through the center of the hollow bar.

Boring Fixtures

When the need arises, boring fixtures are used to support and at the same time align the bar at the proper position preparatory to a boring operation. In general, they are used to increase the productivity of the machine when large quantities are involved. Best applications of fixtures simplify the setup and facilitate any subsequent shifting of the work on the table to a new position during the machining. Boring fixtures are of distinct advantage in producing work involving the duplication of center distances.

Most applications favor two bearing supports for every bar position in the fixture. Thus, the fixture is responsible for bar alignment and eliminates the need for close adjustments of the headstock. A floating adapter connection between bar and spindle is generally used to compensate for small differences in alignment between the axis of the fixture bearings and the spindle. The fixture bearings are usually the sleeve type, made of cast iron, hardened steel, bronze, or bearing alloy to suit the hardness of the bar and the probable length of service of the fixture. Antifriction bearings are to be preferred when center distances and first costs allow for this more expensive construction, or when high surface speeds tend to cause heat resulting from friction which may cause the bar to seize and score.

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With NC machines, many line-boring operations are being performed by saddle feeding of the workpiece. This reduces the need for line bars or fixtures.

Combined Operations

Combined machining operations are typical on horizontal boring machines. Figure 15-55 shows the application of two continuous-feed facing and boring heads set up on a line bar, one head at each end of a workpiece. The use of two heads eliminates the need to turn the work after one end is machined and gives a common center. Such a tooling arrangement is warranted when large quantities are involved, since the machining time is approximately half that required when only one head is used. This is a good example of boring, counter-boring, and facing operations being performed in one setup.

Some typical applications of special boring bars for performing combined operations are illustrated in Fig. 15-56. Production data for these applications is presented in Table 15-11.

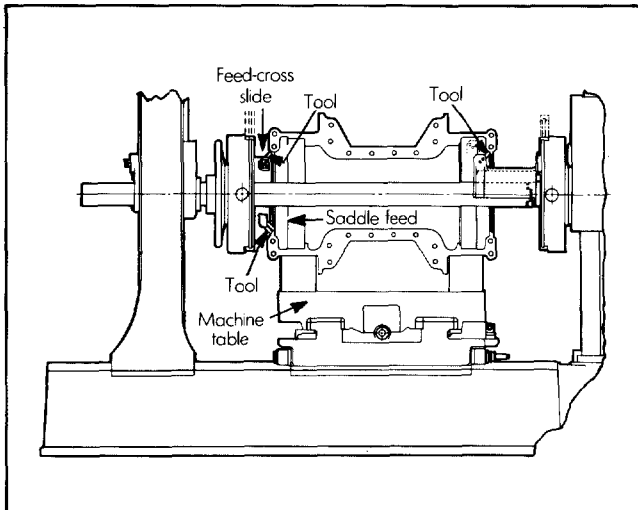


Fig. 15-55 Boring and facing both ends of axle housings using two continuous-feed heads.

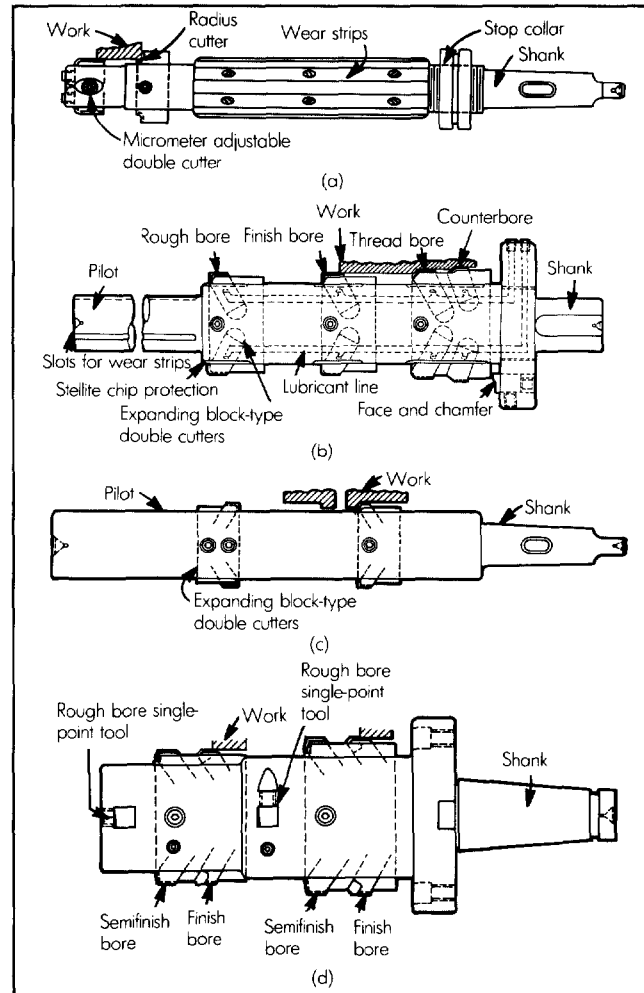


Fig. 15-56 Special boring bars for performing the following combination operations: (a) boring and forming radius; (b) boring, counter-boring, facing, and chamfering; (c) boring and back-boring; and (d) rough, semifinish, and finish boring two different diameters.

TABLE 15-11
Production Data for Special Boring Bars Shown in Fig. 15-53

Bar	Operation	Quality Control	Grouping of Operations	Bar-Wear Provision
Micrometer adjustable double cutter	(a) Boring and machining radius on connecting rods	Adjustment requires no instruments after check of trial cut. Stop collar determines depth of cut and establishes position of radius. Radius contours on cutter are self-centering when secured by locating screw.	Hole is bored and radius machined in single stroke of bar.	Replaceable hardened-steel inserts on pilot.

VERTICAL BORING MACHINES AND TURRET LATHES

TABLE 15-11—*Continued*

Bar	Operation	Quality Control	Grouping of Operations	Bar-Wear Provision
Expansion reamer with micrometer collars	(b) Boring, counterboring, facing, chamfering on forged-steel cylinder	Blocks assembled into bar with locating screws. Longitudinal bore steps established by spacings of block slots in bar. Stop collar limits the stroke and gages the depth of cuts. Face and chamfer tool ground to correct angle.	Rough and finish boring of small-diameter, machining of thread bore, and counterboring. Facing and chamfering of end. All in single stroke of bar.	Stellite facing of bar under the cutting blades. Oil groove in pilot. Lubricant channels to cutters.
Expanding block-type double cutters	(c) Facing and back boring	Block centered by locating screw. One cutter must be removed after machining in order to remove work. Block cutter mounted and dismounted without affecting cutter setting.	Combined facing and back-facing without intervening toolchanges. Forward and reverse speeds used.	
Two multiple block-type double cutters	(d) Rough and finish boring	Carbide-tipped cutters used.	Two bores of different diameters simultaneously rough and finish-bored.	

VERTICAL BORING MACHINES AND TURRET LATHES

Vertical boring machines (VBM's), such as the one shown in Fig. 15-57, and vertical turret lathes (VTL's) (Fig. 15-58) are turning machines that in many ways are similar to conventional lathes turned on end. Workpieces are mounted on a horizontal table or chuck rotating about a vertical axis. Cutting tools, which are generally nonrotating, are fed horizontally or vertically into the workpieces.

Operations performed on a VBM or VTL are similar to those done on conventional lathes. They include turning, facing, boring, grooving, generating threads, and contouring. These machines are commonly used to make round parts having short lengths in relation to their diameters and to make large, heavy, and cumbersome parts.

DIFFERENCES BETWEEN VBM'S AND VTL'S

Vertical boring machines (or mills) originally had one or two ram-type heads, while VTL's had a turret-type head. Since modern machines frequently combine the two types of heads and many ram heads now have indexable turrets, the historical distinction between the two machines has less validity than before. Also, the basic construction, tooling, workholding,

controls, and operation of the machines are essentially the same. To avoid confusion, the term "vertical turning machine" is sometimes used for both machine types.

Some machine builders and users distinguish between a VBM and VTL based on machine size and, to a lesser extent, the volume of the production run. Loosely defined, a machine is called a VTL if it handles workpiece sizes to 100" (2540 mm) diam; for workpieces above that diameter, the machine is designated a VBM. To some extent, VBM's are often characterized by one-of-a-kind and small-lot production requirements; but they can be tooled for long production runs.

ADVANTAGES OF THE MACHINES

An important advantage of VBM's and VTL's is the ease with which large or heavy workpieces can be set up and held. Gravity is the key to the relative ease of work handling with these machines. It is easier to place workpieces on the horizontal table top than it is to mount them on horizontal-spindle machines. The weight of heavy workpieces is distributed uniformly downward through the bearings and absorbed in the massive bases of the machines. This ensures accurate machining, even at relatively high cutting speeds; reduces chatter; and permits high metal-removal rates.

VERTICAL BORING MACHINES AND TURRET LATHES

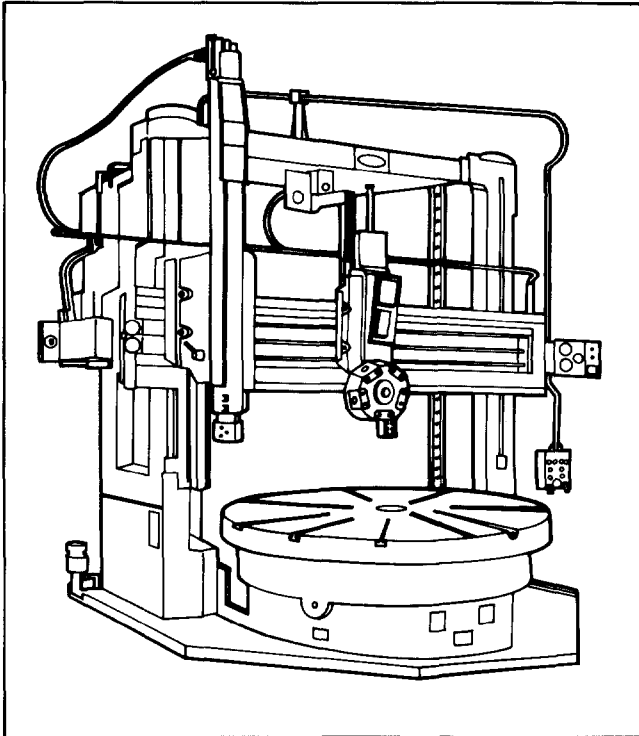


Fig. 15-57 Vertical boring machine. (Bullard Co.)

Another advantage of these machines involves applications that require indicating for quality assurance during job setup. The horizontal table presents workers with a surface on which parts may be set up, adjusted, and leveled without preliminary strapping.

Vertical boring machines and turret lathes provide increased workpiece accessibility and reduced floor-space requirements compared to horizontal-spindle lathes of similar machining capability. Through the use of counterbalances applied to the top of the worktable, they have the ability to easily balance irregular or off-center workloads and to eliminate excessive centrifugal force or radial thrust load.

MACHINE CONSTRUCTION

Typical machines consist of a base supporting a horizontal table or chuck. Attached to the base, or an integral part of it, is a single vertical column or two housings which carry an adjustable crossrail. The crossrail moves up and down along vertical ways on the column.

The crossrail carries one or two heads, each head consisting of a saddle which moves horizontally on the rail and a ram or slide which moves vertically in the saddle. A single or multiple-tool ram head or a multiple-tool turret, which carries the cutting tools, is mounted on the vertical element of each head.

On some machines, a sidehead (usually a ram head), as shown in Fig. 15-59, is mounted on the right vertical column way, with an additional rear support way. The sidehead saddle moves vertically, and the sidehead ram moves horizontally. A second sidehead is sometimes mounted on the opposite side of the machine. The sideheads provide additional cutting capability.

A cut is generated by moving the heads into position so that the nonrotating tool or tools (there can be simultaneous cutting

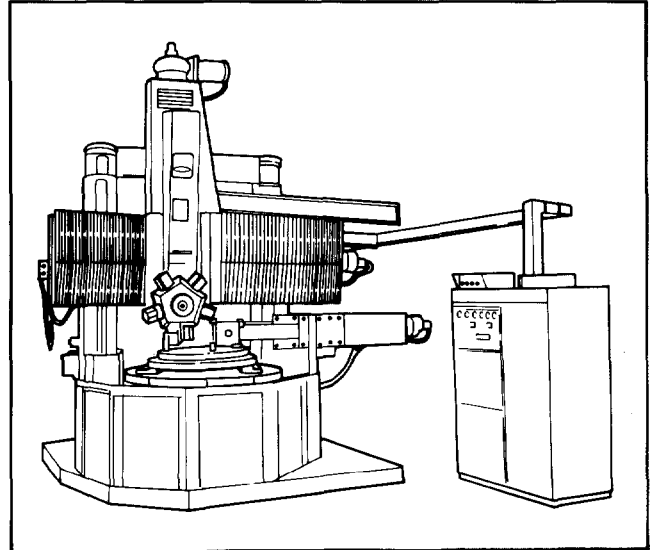


Fig. 15-58 Vertical turret lathe with CNC. (Bullard Co.)

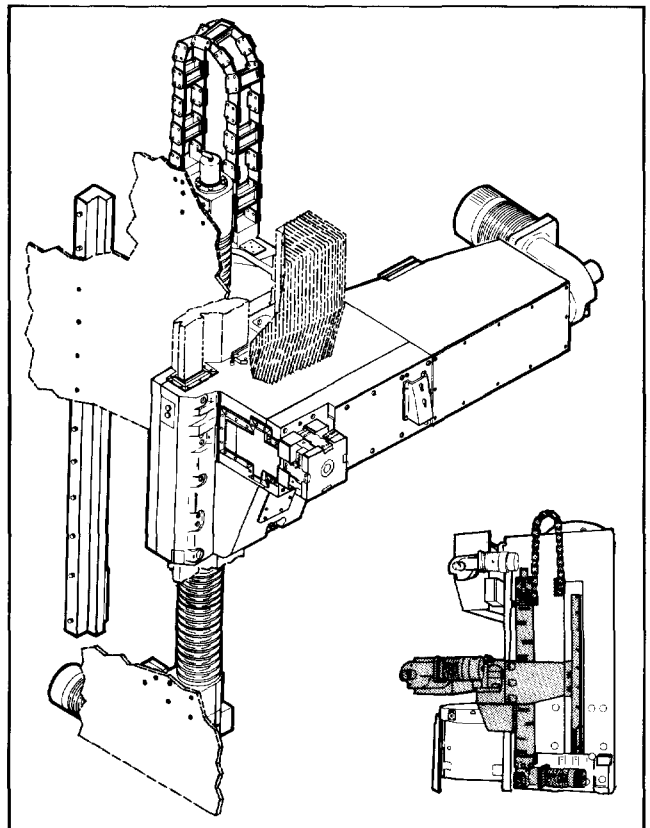


Fig. 15-59 Sidehead mounted on a VTL. (Bullard Co.)

with more than one head) contact the revolving workpiece. Tools are held in large holders, referred to as toolblocks.

To produce accurate work, the table structure and bearing system must support the work with minimum deflection and runout during machining. Construction of the table, base, and drive transmission on smaller VTL's offered by one machine

VERTICAL BORING MACHINES AND TURRET LATHES

tool builder is illustrated in Fig. 15-60. The column, rail, and head structure must also support and move the cutting tools along the horizontal and vertical axes with minimal deflection. At least one machine tool builder is supplying fabricated steel columns filled with concrete.

Fixed-Height Crossrails

A new design in vertical turret lathes with fixed-height crossrails has recently been introduced and is becoming increasingly popular for low-profile, family-of-parts work. Instead of the crossrail moving vertically along the column ways, the height is fixed at the time of machine construction. Figure 15-61 shows a VTL with a fixed horizontal rail and CNC, the rail and column being of one-piece construction. Ram or turret heads are available. The height (distance from the top of the table to the underside of the crossrail) is specified by the user. Advantages include cost savings due to the elimination of some machine ways, elimination of the crossrail raising mechanism, reduced maintenance, and improved rigidity.

Power Elements

Vertical boring machines and turret lathes incorporate a variety of power systems for different functions. Systems include d-c motors for NC/CNC machines; a-c motors for manual machines; hydraulics for power chucking, internal lubrication, and service functions such as crossrail raising and headstock shifting; air-pneumatics, normally for external lubrication; and in the case of digital readouts and NC/CNC, some electronics.

Automatic troubleshooting or fault indicating is being used increasingly for maintenance checking, including monitoring the lubrication of machine tool ways and bearings, head travel, oil pressure, feed overloads, temperature, and braking system. Most CNC units have built-in diagnostic software programs that check a variety of machine tool and control functions.

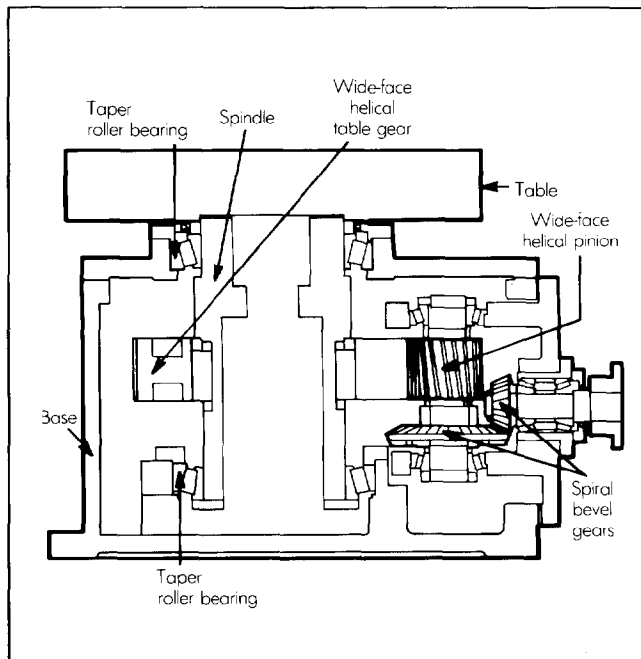


Fig. 15-60 Typical construction of table, base, and drive transmission for a small VTL. (Gray Div., Warner & Swasey Co.)

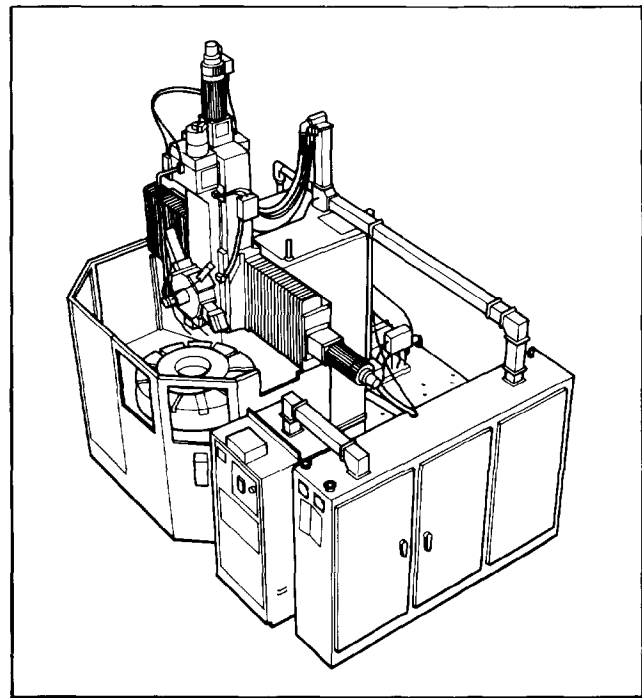


Fig. 15-61 Fixed horizontal rail is integral with column on this VTL. (Gray Div., Warner & Swasey Co.)

MACHINE CAPACITIES

Size of the workpieces to be machined is the first consideration in selecting a vertical boring machine or turret lathe. Machines are offered in a variety of standard sizes, a typical range being given in Table 15-12. The maximum weight of the workpieces to be machined determines the table load capacity. Variations in load capacity are offered by machine manufacturers.

In defining the necessary space envelope, the dimensions of supporting blocks or fixtures on the machine table and the tooling configuration must be considered. For example, if a workpiece is to be supported on blocks $3\frac{1}{2}$ " (89 mm) above the table and requires a 24" (610 mm) boring bar, the D dimension on the machine tool (see Table 15-12) must be $27\frac{1}{2}$ " (700 mm) higher than the rough workpiece in order to raise the boring bar above the workpiece.

Required speed ranges, torque capacities, and drive powers for workpieces can be derived from appropriate formulas. Reference should be made to other chapters in this volume, including:

- Chapter 8, "Turning and Boring."
- Chapter 9, "Drilling, Reaming and Related Processes."
- Chapter 10, "Milling."
- Chapter 12, "Threading."

Typical alignment tolerances are presented in Table 15-13.

CONTROLS FOR VBM'S AND VTL'S

Vertical boring machines and turret lathes can be operated in a number of modes, including manual, automatic, and numerically controlled. Manual operation is really semiautomatic, typically involving a worker using a swing-away pendant control to direct basic machine movements or a worker directing the same motions from a floor-mounted control. Handwheels

CHAPTER 15

VERTICAL BORING MACHINES AND TURRET LATHES

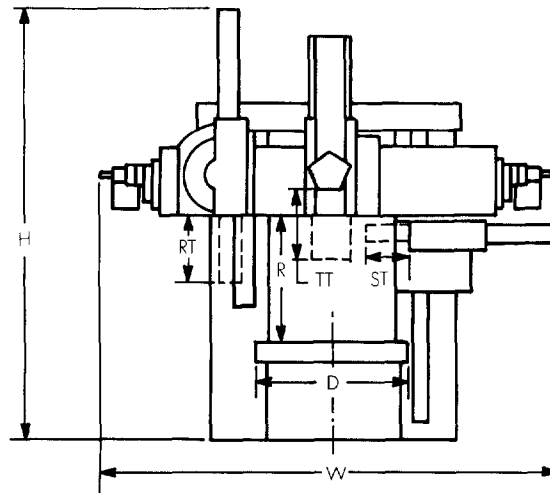


TABLE 15-12
Typical Range of Dimensions, in. (mm), for Vertical Boring Machines and Turret Lathes

Table diam, D	30 (762)	36 (914)	48 (1219)	60 (1524)	72 (1829)	84 (2134)	96 (2438)	108 (2743)	120 (3048)	144 (3658)	168 (4267)	192 (4877)
Max swing	38 (965)	44 (1118)	56 (1422)	68 (1727)	84 (2134)	96 (2438)	108 (2743)	120 (3048)	132 (3353)	156 (3962)	180 (4572)	204 (5182)
Swing with sidehead	32 (813)	38 (965)	50 (1270)	62 (1575)	78 (1981)	90 (2286)	102 (2591)	114 (2896)	126 (3200)	150 (3810)	174 (4420)	198 (5029)
Height under rail,* R	30 (762)	36 (914)	48 (1219)	60 (1524)	72 (1829)	72 (1829)	84 (2134)	84 (2134)	84 (2134)	102 (2591)	102 (2591)	102 (2591)
Ram travel,** RT	30 (762)	30 (762)	36 (914)	36 (914)	48 (1219)	48 (1219)	60 (1524)	60 (1524)	60 (1524)	72 (1829)	72 (1829)	72 (1829)
Turret travel, TT	24 (610)	24 (610)	30 (762)	30 (762)	36 (914)	36 (914)	36 (914)	36 (914)	36 (914)	36 (914)	36 (914)	36 (914)
Sidehead ram travel, ST	20 (508)	20 (508)	24 (610)	24 (610)	30 (762)	30 (762)	36 (914)	36 (914)	36 (914)	36 (914)	36 (914)	36 (914)
Overall width, W	152 (3861)	159 (4039)	172 (4369)	186 (4724)	200 (5080)	215 (5461)	230 (5842)	246 (6248)	261 (6629)	293 (7442)	325 (8255)	358 (9093)
Overall height, H	161 (4089)	167 (4242)	181 (4597)	195 (4953)	209 (5309)	224 (5690)	239 (6071)	254 (6452)	271 (6883)	303 (7696)	336 (8534)	369 (9373)
Speed range, rpm	4-330	4-315	3-280	3-250	3-220	2-190	1.5-170	1.5-140	1.0-125	1.0-90	0.8-65	0.8-50
Feed rate, ipr (mm/rev)	0.0005- 2.0 (0.013- 50.8)	0.0005- 2.0 (0.013- 50.8)	0.0005- 2.0 (0.013- 50.8)	0.0005- 2.0 (0.013- 50.8)	0.0005- 2.0 (0.013- 50.8)	0.0005- 2.0 (0.013- 50.8)	0.0005- 2.0 (0.013- 50.8)	0.0005- 2.0 (0.013- 50.8)	0.0005- 2.0 (0.013- 50.8)	0.0005- 2.0 (0.013- 50.8)	0.0005- 2.0 (0.013- 50.8)	0.0005- 2.0 (0.013- 50.8)

* Additional height to about R + 2 ft (0.6 m) may be ordered from most machine builders.

** Additional ram stroke may be ordered from most machine builders.

VERTICAL BORING MACHINES AND TURRET LATHES

can also be provided on these machines, although axis feeds generally operate under power even in a manual machine.

Automatic Controls

Machines equipped with automatic controls or cycling devices for each head can be set up for an almost infinite number of different production jobs. Most control devices permit the automatic cycle to be interrupted at any point, so the machine can be manually operated without disturbing the automatic setup. The machine can be returned to its automatic cycle at the point at which it was interrupted or at any point in the cycle desired by the operator.

Automatic controls consist of a memory device which is set up for a predetermined sequence of operations. These include machine functions such as feed and traverse rates, dwell, feed and traverse direction, speed changes, start/stop, and turret index. A function drum with locating holes filled by pins arranged in various sequences is an example of such a device.

Automatic controls also incorporate detectors for the horizontal and vertical movements of the heads. These detectors work in cooperation with the memory unit to control the exact limit of head travel and to initiate the next function required for the job.

In operation, the memory or function device is preset for the job and the detectors are set during the actual machining of the first piece (or a finished piece is used as a master gage). At the

completion of the first machining operations, heads return to their start position by the shortest path and the control mechanism automatically indexes to a zero or neutral position, ready for the next cycle.

Tracer Controls

Tracer controls are also available for vertical boring machines and turret lathes. This mode of control drives both vertical and horizontal feed motions to accurately follow a stylus tracing a template, providing a means to machine complicated shapes without using form tools or NC/CNC units.

NC/CNC Units

Point-to-point NC is a digital electronic system which directs the motions of the machine from coded signals on punched tape. It may also control various auxiliary operations, such as selecting tools, feed rates, spindle speeds, and the flow of cutting fluid.

This form of control moves the cutting tool(s) to prescribed points at preset feed rates, thus permitting orthogonal machining only. Accuracy of the motions depends on the resolution (least permissible increment) of the electronic system and the accuracy of the position feedback devices on each axis. A comprehensive discussion of NC/CNC units is presented in Chapter 5 of this volume, "Machine Controls."

Most NC units have digital switches through which commands to the control may be entered manually, instead of being inserted by tape. Point-to-point NC has been used less extensively on VBM's and VTL's than contouring, computerized numerical control (CNC), which permits greater machine flexibility and control.

CNC offers continuous-path contouring capability by providing velocity and displacement control continuously for all machine motions. As a result, tool(s) may be moved continuously along any prescribed path within the limits of the machine. CNC also handles various auxiliary operations, such as the selection of tools, feed rates, and speeds. Manual data input features permit on-site editing of programs in computer memory and the punching of new part program tapes corresponding to the changes.

These machines can also be integrated into distributed numerical control (DNC) systems in which a larger host computer stores and downloads part programs into individual machines to give them appropriate machining instructions.

OPTIONAL EQUIPMENT

Vertical boring machines and turret lathes can be fitted with various devices to improve their productivity. Work-handling systems, for example, can be mated to the machines to minimize downtime and maximize cutting time.

Machine Loading

When setup time is greater than machining time, or approaches it, then some type of off-machine loading and fixturing should be considered. This is particularly true for unique or unsymmetrical parts which require extensive fixturing time because they frequently need a lot of adjustments (datum points aligned, trueing and indicating work, etc.).

A palletizer system for workpiece loading (see Fig. 15-62) permits setup to be accomplished away from the machine tool while another part is being machined. Typically, when a machining cycle is completed, the program calls for a section of the machine's guarding to recede. The pallet on the machine is

TABLE 15-13
Typical Alignment Tolerances for Vertical Boring
Machines and Turret Lathes

Alignment	Tolerance Limit*
Table:	
flatness of top	0.001" (0.03 mm) max, concave only
levelness	0.005"/ft (0.42 mm/m) out of level
runout of OD, face, and pilot bore	0.001" (0.03 mm), TIR
Horizontal travel:	
of tool	$\pm 0.0006"/ft$ (0.050 mm/m) from true horizontal
of sidehead	0.0005"/ft (0.42 mm/m) below horizontal**
Vertical travel:	
of tool(s) and rail-head(s), side to side	$\pm 0.0005"/ft$ (0.042 mm/m) from true vertical**
of tool(s) and rail-head(s), front to back	$\pm 0.0005"/ft$ (0.042 mm/m) into cut
of tool(s) and side-head(s), side to side	$\pm 0.0005"/ft$ (0.42 mm/m) from true vertical**

* Tolerance limits may be broader for machines used only for roughing and narrower for machines used for finishing.

** To make these tolerances more realistic, particularly on large machines, the total deviation, as well as the maximum deviation in any foot (meter), is sometimes used. For example, $\pm 0.0005"$ in any ft (0.042 mm in any m), the total not to exceed $\pm 0.0005"$ (0.013 mm) + $0.00025" \times \text{stroke in ft}$ (0.0208 mm $\times$ stroke in m).

VERTICAL BORING MACHINES AND TURRET LATHES

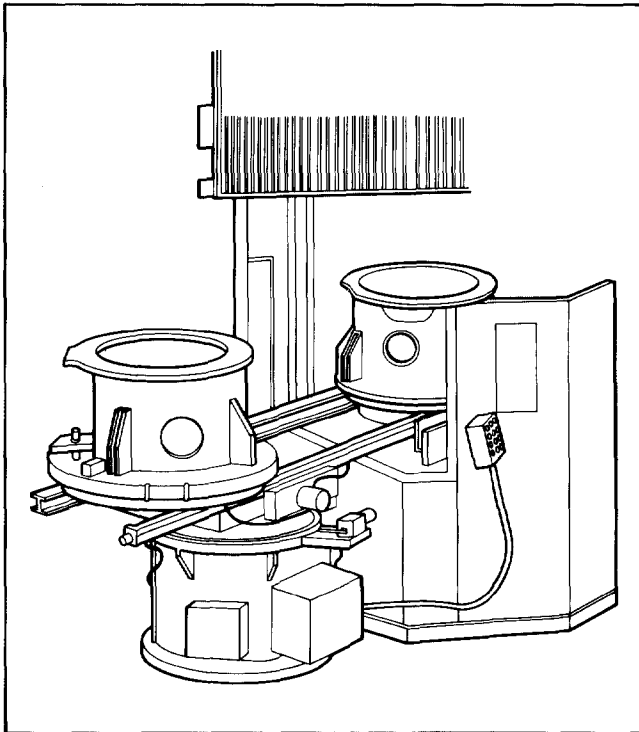


Fig. 15-62 Palletizer system for workpiece loading permits setup away from machine. (Bullard Co.)

raised and transfer arms extend to receive the finished workpiece. The pallet is lowered onto the arms, which retract to return the palletized part to an indexing mechanism. This mechanism also carries an unmachined workpiece that has been loaded on another pallet away from the machine. The indexer, now supporting both pallets, rotates to the loading position. The transfer arms position the new workpiece, and the system locates the pallet both radially and axially to ensure secure and accurate positioning. The arms then retract, and the palletized part is lowered into position for machining.

Use of Robots

Creating a manufacturing cell by installing a robotic loader/unloader with these machines is also justifiable for some applications. Such applications are primarily long, repetitive runs of similar parts. Software power and flexibility of robots, however, is increasing; and this may make shorter runs with more part changeovers, as well as the handling of different shaped workpieces, more viable.

Other Material Handling Devices

More simplified loading devices are also compatible with these machines. These devices are generally hydraulic arrangements (in place of a conventional jib or overhead crane) that rise to loading heights, swing over the table, and lower the workpiece into place.

Other material-handling configurations (like a parts conveyor) can be interfaced with the machines for semiautomated or automated production. The VBM's and VTL's have also been integrated into larger manufacturing systems which include other machine tools, material handling systems, parts washing machines, deburring units, and inspection machines.

Removing Chips

Chip removal systems are a productive option because of the high metal removal rates on these machines. Systems are available in a variety of types and sophistications, including subfloor conveyors and floor-mounted conveyors that move the chips to tote boxes.

Digital Readouts

Electronic digital readouts (DRO's) are used on these machines. They are of particular value on manually controlled machines because they enable workers to do accurate work with very little time spent checking and measuring machine position. Again, like other electronic controls, their accuracy depends on resolution and position feedback devices.

TOOLING FOR VBM'S AND VTL'S

Basic, standard classes of cutting tools are commonly used for tooling vertical boring machines and turret lathes for the average run of parts. With NC or CNC, qualified toolholders and preset inserts that are generally used with horizontal-spindle NC/CNC lathes can be used on VBM's and VTL's. Such toolholders and inserts reduce tool presetting downtime by using the tool offset capabilities of the control to make the final adjustments for tool position. A comprehensive discussion of toolholders and inserts is presented in Chapter 8, "Turning and Boring."

As the quantity of parts to be machined increases, more attention should be paid to multiple tooling setups. Tools should be laid out for optimum use of each turret face. Step, gang, form, multiple, or magazine-type tooling significantly decreases cutting time per workpiece.

Ram Head Tooling

Tooling is basically divided into two types—that for ram heads and that for turret heads. For vertical ram heads, the simplest toolblock is shown in Fig. 15-63, where the toolblock shank is locked into the ram and tools are clamped into the holder.

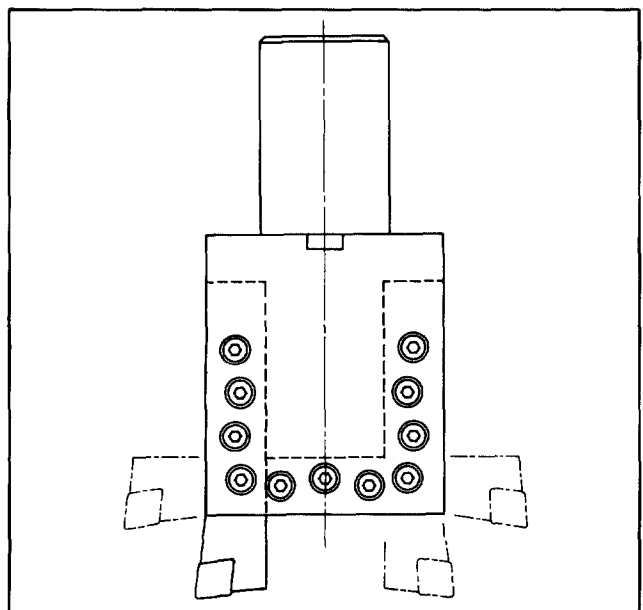


Fig. 15-63 Simple toolblock for vertical ram head.

VERTICAL BORING MACHINES AND TURRET LATHES

A ram head can reach deep below the lower edge of the crossrail, since there is no interference from other tooling, as on a turret. The relatively slim but rigid ram forging is especially suited for boring in confined spaces. It can carry one toolblock, or it may be fitted with an indexing turret that rotates on a vertical axis to present different tools to the work. Figure 15-64 shows an example of the indexing configuration; some of these can accommodate up to eight tools.

Turret Tooling

A vertical turret carries an indexing turret that rotates about an essentially horizontal axis (see Fig. 15-65). The turret is generally five-sided, although it may be four or six-sided. It can be designed to carry either one or two toolblocks per side.

There is a distinction between a toolblock and a toolholder. Toolblocks are supplied by the machine tool manufacturer to hold perishable tooling. Depending on the tooling system used, the indexable cutting insert, the tool shank (with solid tool steel, brazed high-speed steel, or brazed carbide-tip tooling) and the toolholder are all considered perishable. Toolblocks with perishable tooling mounted on a carousel are illustrated in Fig. 15-66.

For ram heads, setscrew clamping usually holds tooling in the blocks. With turret heads, a wedge-clamping dovetail mechanism that compresses metal-on-metal when locked is preferred.

Sidehead Tooling

Sideheads may each carry one tool or be fitted with a turret carrying several tools. Practically all machines that have sideheads utilize a four-position indexable turret head.

Sidehead cutting is preferred for larger diameter work because the sidehead ram is not extended too far out on its slide before it makes contact with the workpiece. This improves rigidity. The sidehead is normally used in conjunction with a

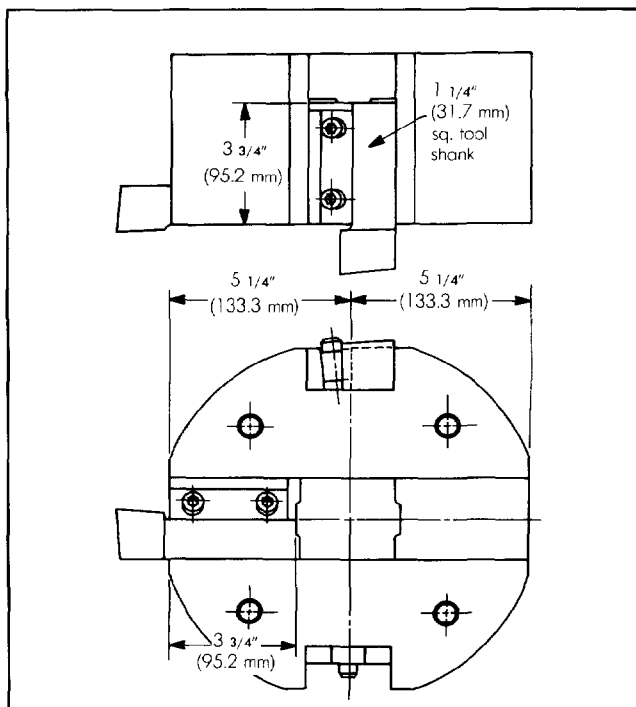


Fig. 15-64 Four-position indexable ram.

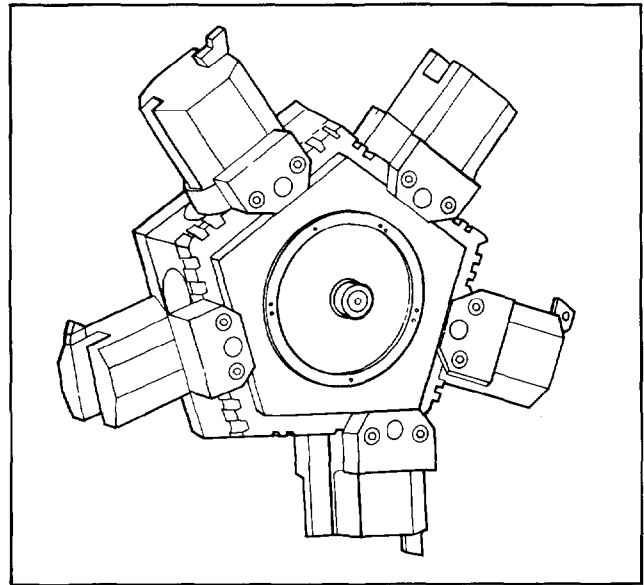


Fig. 15-65 Five-position indexable turret. (Bullard Co.)

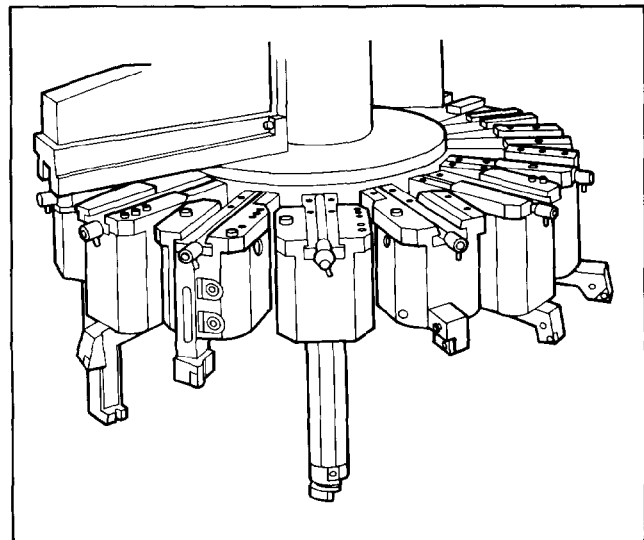


Fig. 15-66 Toolblocks mounted on a carousel. (Bullard Co.)

vertical ram during machining operations. For example, while the vertical ram is doing ID boring, the sidehead might be doing OD grooving.

If a vertical ram, vertical turret, and sidehead were operating simultaneously, a sample application might be ID boring (with the ram), OD rough-turning (with the turret), and OD finish turning with the left-hand sidehead.

Automatic Toolchanging

Many builders of VBM's offer automatic toolchangers. One design (see Fig. 15-67) consists of a 12-tool storage drum with pockets coded for tool location. The spindle nose on the machine has two hardened, ground pins for radial location. Toolblocks are retained on the ram by a hydraulic-mechanical bayonet type of clamping system.

VERTICAL BORING MACHINES AND TURRET LATHES

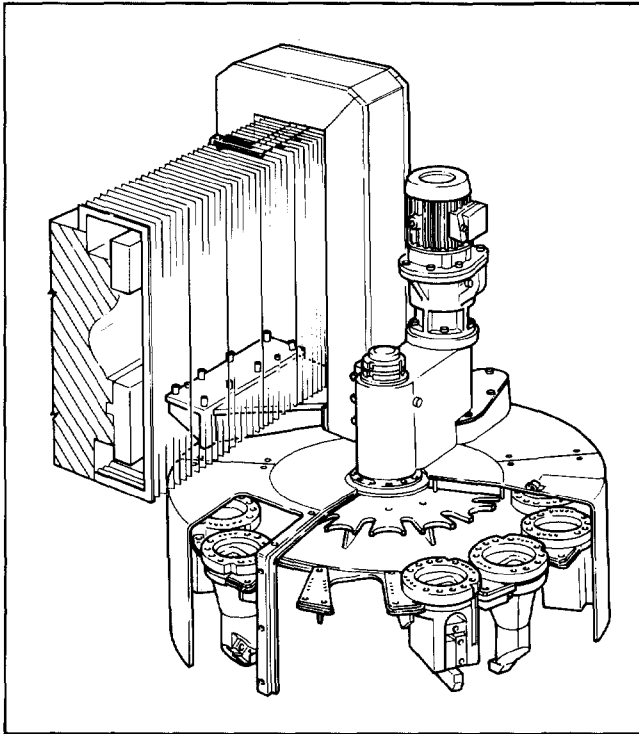


Fig. 15-67 Automatic toolchanger for CNC vertical turning and boring machine. (Monarch Sidney)

With such devices, cutting could take place with a single toolblock, carrying only one tool, to take advantage of the ram head's deep reach and relatively slim envelope. With another design, the toolblock changer draws from a library of toolblocks mounted in an adjacent carousel holding fixture (see Fig. 15-66), similar to the automatic toolchangers on machining centers, discussed later in this chapter.

When a cut is completed, the entire block is interchanged in the ram. A typical system involves a transporter mechanism, which positions the next toolblock to be called beside the ram head. At the end of the cut, the ram retracts, toolblocks are automatically exchanged, and the ram returns to the workpiece for the next cut.

Another toolblock changing technique involves ram head traverse to the carousel for direct exchange of the blocks. This design is generally more economical with smaller machines. For larger machines and workpieces above 50-60" diam (1270-1524 mm), the time lost while the ram traverses the distance to the carousel would probably make the toolblock transporter a more viable alternative. Workpiece size, general economic considerations, and the number of toolchanges per part are among the factors to be considered in making this application decision.

Benefits to be gained from the toolblock changer include no loss of maximum swing capacity from tooling constraints, general minimization of tool interference, faster tool exchange for more in-the-cut time, and tooling flexibility.

Rotating Tooling

Special attachments are available from machine manufacturers that permit rotating tooling operations, such as milling, drilling, and grinding, to be performed on workpieces. These can be temporary or permanent attachments.

WORKHOLDING DEVICES

Clamping arrangements for vertical boring machines and turret lathes include three and four-jaw chucks (both manual and power operated), three-jaw combination chucks, four-jaw independent chucks, magnetic chucks, plain tables, and independent faceplate jaws.

Chucks

Chucking is recommended for smaller and more symmetrical workpieces. Radial slots on the chuck face permit additional securing of the workpiece and allow rest supports to be inserted to raise the part if necessary.

A jaw force modulator feature compensates for the tendency of chuck top jaws to loosen at high surface speeds due to centrifugal force. Preset to hold work at a predetermined force, the device senses centrifugal force and tightens the jaws when necessary. With power-operated chucks, jaw pressure is monitored through the hydraulic system. This feature especially helps in the machining of thin-walled parts by maintaining uniform holding pressures. The device also saves setup time by holding tight for roughing and then relaxing for finish machining, without human intervention.

Magnetic chucks offer the advantage of eliminating clamping marks and workpiece distortion. However, they generally grip with less force than their mechanical counterparts, and there is a danger that the workpiece will move under heavy cutting loads.

Plain Tables

Plain tables accommodate larger parts, castings, forgings, and other workpieces that vary in configuration. Clamping parts to plain tables is accomplished by securing a fixture to hold the workpiece and then clamping the part within that fixture. It is also accomplished by using standard securing straps, adjustable rest blocks, screw-dog filler blocks, and similar workholding accessories to clamp the part directly to the table. A special fixture-locating plug is generally provided on the tables of VBM's and VTL's.

Independent Faceplate Jaws

Independent faceplate jaws are special jaws that clamp onto plain tables. Held by T-bolts, the jaws are adjusted like a workholding vise on a milling machine table.

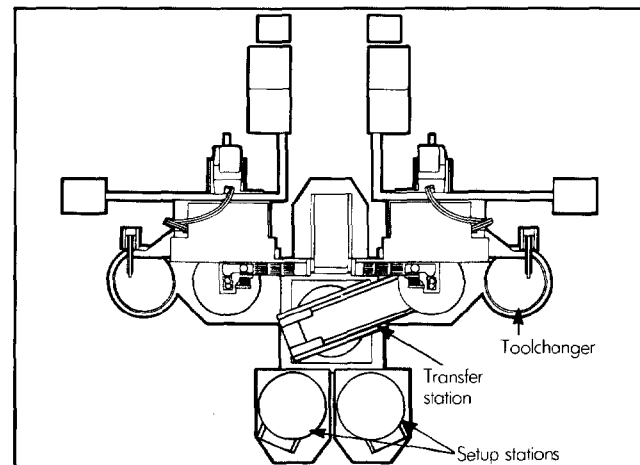


Fig. 15-68 Workchanger for two VBM's permits trueing and fixture adjustments on setup tables while machines are cutting. (Giddings & Lewis Machine Tool Co.)

VERTICAL BORING MACHINES AND TURRET LATHES

WORKCHANGING

Workchangers equipped with a rotating stand, setup station, and intermediate transfer station are available for use with one or several VBM's or other machines. A single workchanger for serving two VBM's, each having its own toolchanger, is illustrated in Fig. 15-68. Truing and fixture adjustments are done on the setup table while the machines are cutting metal. When one workpiece is finished, it is shifted to the transfer stand and the new setup is brought into position for machining. The finished piece is unloaded, and the next workpiece is set up.

APPLICATIONS

The operation sequence performed on friction pulleys, machined on a manually controlled VTL with a vertical turret head and a sidehead, is shown in Fig. 15-69. Again, as the quantity of duplicate parts increases, more attention to special tooling is justified.

Chucking must be firm enough to hold the part safely, but must not distort the part during the finishing cuts. Heads should be cutting simultaneously whenever possible.

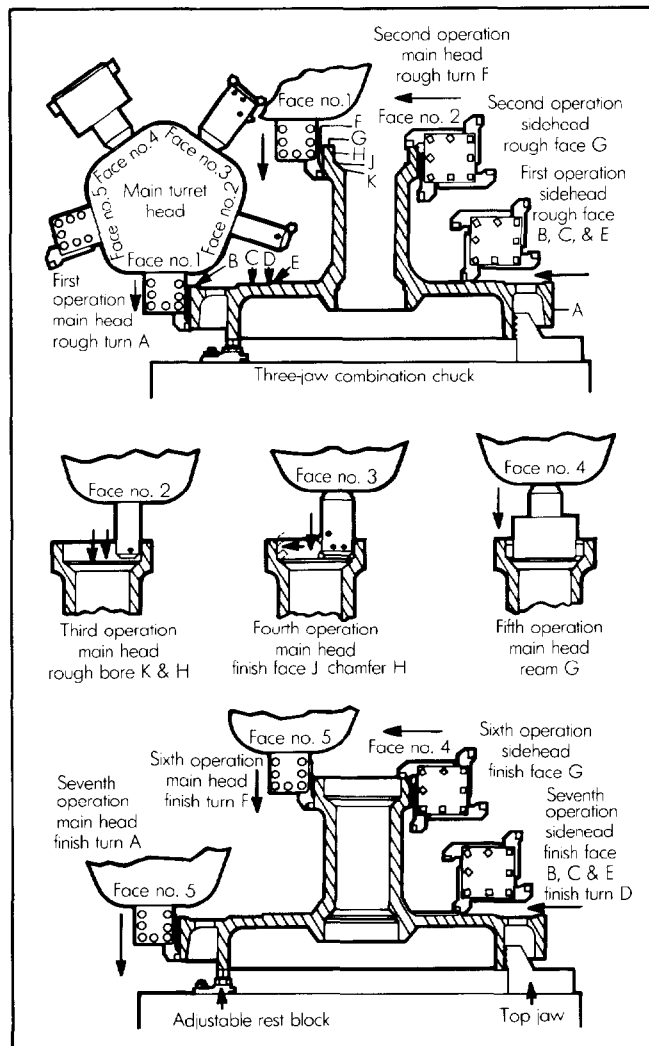


Fig. 15-69 Roughing and finishing operations performed on friction pulleys with a VTL.

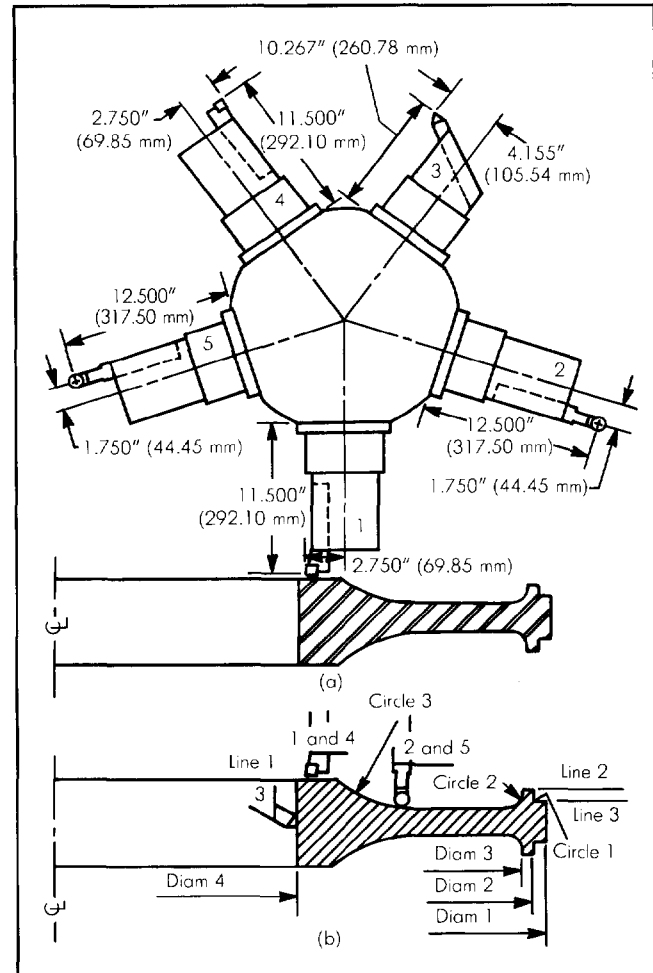


Fig. 15-70 Machining a compressor disc on an NC vertical boring machine. Geometry is defined by surfaces shown in view b.

An axial-compressor disc, machined on a VBM with NC contouring capabilities is shown in Fig. 15-70. The machine has a single vertical turret head with a five-sided turret, and tools qualified by the dimensions shown in view a. The geometry of the disc is defined to the computer by the programmer, using locating lines, diameters, and circles (see view b). The sequence of operations for one side of the disc is then programmed as follows:

Turret Face	Operation
1	Rough-face line 2 and line 3, rough-turn diameter 2, rough-turn diameter 1, and rough-face line 1
2	Rough-face circle 2, line 4, and circle 3
3	Rough-bore diameter 4
4	Finish-face line 3 and line 2, finish-turn diameter 2 and diameter 1, finish circle 1, and finish-face line 1
5	Finish circle 2, line 4, and circle 3
3	Break corner into bore diameter 4 and finish-bore diameter 4

MULTIPLE-SPINDLE VERTICAL, AUTOMATIC CHUCKING MACHINES

The program for the opposite side of the disc is the same, except for the bore and outside diameter, which are already finished. Because of the speed at which the machine positions for the successive operations, and because of its ability to cut

chamfers, radii, and other special shapes without form tools, a CNC machine represents a substantial improvement in productivity and accuracy for this type of work.

MULTIPLE-SPINDLE VERTICAL, AUTOMATIC CHUCKING MACHINES

Various types of multiple-spindle vertical, automatic chucking machines are available, similar to the one shown in Fig. 15-71. The machines embody a carrier with six or eight equally spaced, vertical columns encircling a stationary column. On the column over each spindle, except at the loading station, are combination or multiple-tool heads.

Each spindle and head comprises a station or machining unit having independent feed and speed controls for maximum flexibility and efficiency. Each station is set up to perform specific operations in sequence with the next station, so that one carrier cycle around the column produces a finished workpiece. Since all stations of the machine are working simultaneously on various operations, each spindle successively transfers a finished workpiece as it indexes through the loading station.

For continuous or long production jobs, the standard design of the machine can be varied to suit the specific application. Dual spindles and heads can be used at each station, permitting duplicate or first and second chucking operations at each station. Production is also increased on simpler jobs that can be completely machined in half the cycle by arranging two loading stations. Double indexing the spindle carrier has been used extensively where two chuckings or two sets of identical operations can be accomplished on the one machine.

Multiple-spindle vertical chucking machines have minimum floor-space requirements and are easy to relocate to suit production-line manufacturing techniques.

TOOLING

The type of head at each station is usually selected from a group of standard heads and is affixed when the machine is built. Standard power-operated chucks, top jaws, fixtures, and tooling are used extensively. For ease and speed of loading and unloading, some chucks and fixtures are equipped with power-operated work-lifting or ejector mechanisms.

Available standard heads include a plain vertical type for vertical motion only, a universal (swiveling) type for angular motion, and a double-purpose type for combination vertical and horizontal motion.

ATTACHMENTS

Attachments are available to increase production rates for specific jobs. These include drilling or tapping heads (either single or multiple), boring and precision boring heads, inside or outside spherical turning heads, elliptical facing heads, CNC heads for contouring, and many other special heads and spindle registry devices.

One or more stations can be equipped with CNC; a universal tool-carrying head; and an independent, variable-speed spindle drive, depending on requirements of the specific application. The use of CNC stations permits high-volume production of a

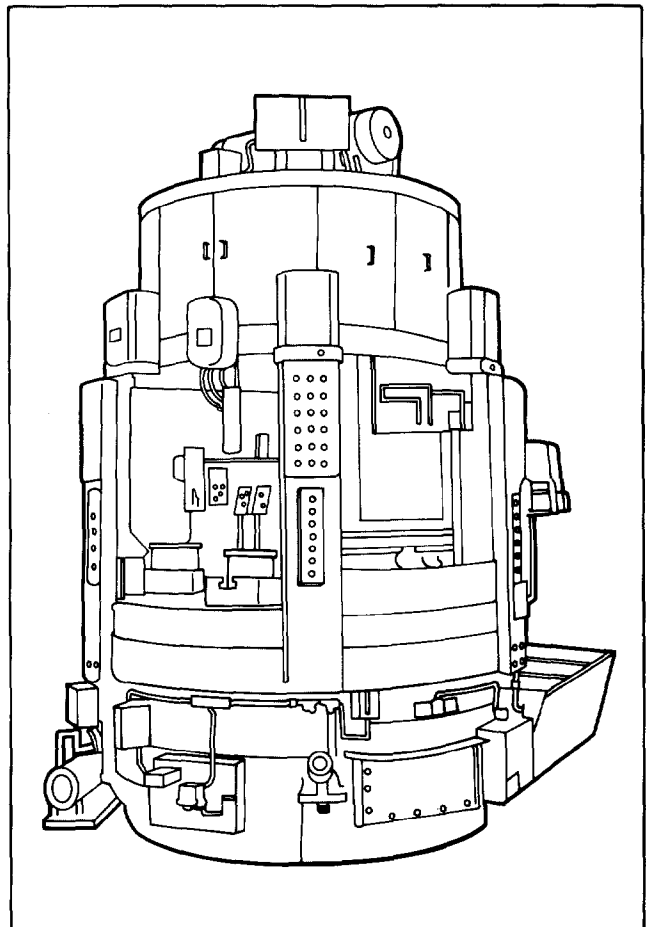


Fig. 15-71 Multiple-spindle automatic chucker. (Bullard Co.)

variety of similar workpieces in small to medium quantities because of rapid changeover capabilities.

For faster machining by the circular transfer method employed on these machines, attachments such as automatic loading and unloading devices, chip disposal units, pressurized cutting fluid systems, and automatic gaging have been developed.

APPLICATION

The tooling layout on a multiple-spindle vertical chucking machine for automatically loading, machining, and unloading automotive torque-converter housings is illustrated in Fig. 15-72. Total time per workpiece with this setup is approximately 30 s.

MULTIPLE-SPINDLE VERTICAL, AUTOMATIC CHUCKING MACHINES

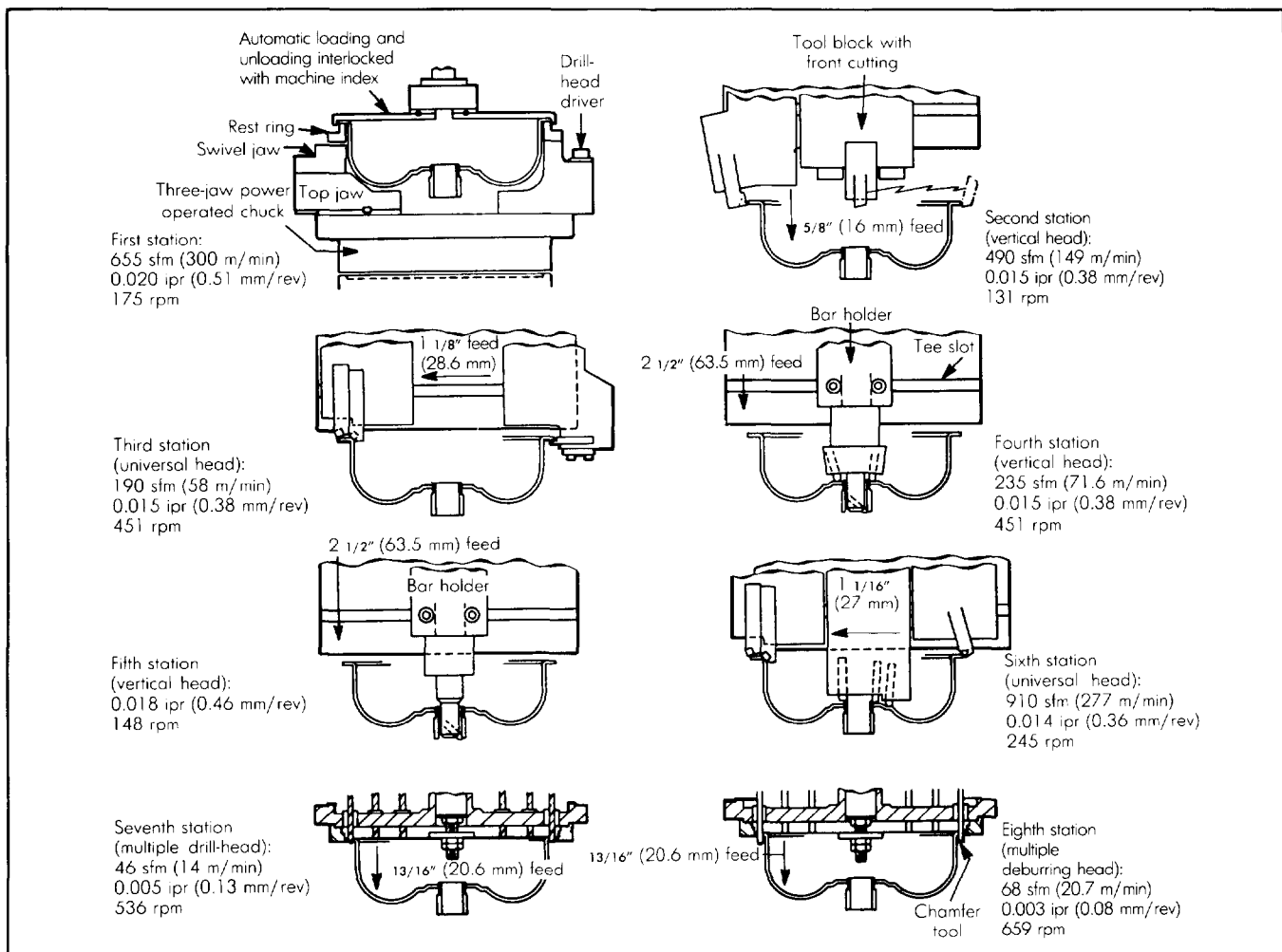


Fig. 15-72 Tool layout for producing automotive torque-converter housings on a multiple-spindle vertical chucking machine.

MACHINING CENTERS

Machining centers, a relatively new class of machine tools, have been defined as multifunction, NC or CNC machines with automatic toolchanging capabilities and rotating cutting tools. Since their introduction in the late 1950's, they have become one of the most common of all metalcutting machines.

ADVANTAGES

Increased productivity and versatility are major advantages of machining centers. The capability of performing drilling, turning, reaming, boring, milling, contouring, and threading operations on a single machine eliminates the need for a number of individual machine tools, thus reducing capital equipment and labor requirements. One relatively unskilled operator can often attend two machining centers and sometimes more. Most workpieces can be completed on a single machining center, often with one setup.

Additional savings result from reduced material handling, fixture costs, and floor space requirements. Substantial time

conventionally spent moving work from machine to machine is saved, and throughput is much faster. Also, in-process inventory, represented by skids of workpieces normally seen at several machines, is replaced by work at only one machine.

Most machining centers maintain close, consistently repetitive tolerances, resulting in higher quality parts, as well as reduced inspection costs and scrap. In particular, the relationship of machined features on the several faces of a workpiece are more easily held within tolerances. Changeover from the production of one workpiece to another can be done quickly.

Actual machining time on machining centers can be two or more times that of single-purpose, manually operated machine tools. Estimates of increases in productivity per man-hour range from 300 to 500% or more, especially on applications requiring many tools and frequent changeover.

While machining centers have a higher initial cost than many other machine tools, annual return on investment has been conservatively estimated to be about 30%. Smaller, compact

MACHINING CENTERS

models now available make these machines affordable even to small job shops. Accuracies that can be maintained and the reliability of the machines and their controls have been continuously improved.

APPLICATIONS

Machining centers have traditionally been employed primarily for automating the manufacturing of small lots of a wide variety of workpiece shapes and sizes requiring multiple operations. Now, however, they are being increasingly used for medium-lot requirements and some have been tooled for long production runs of a single workpiece.

Careful work scheduling is necessary to keep machining centers operating and thus more fully realize the profit potential of these machines. Most shops try to operate their machining centers, as well as other NC machines, at least two shifts per day to obtain a more rapid return on investment.

Another application becoming increasingly popular for machining centers is the integration of these centers with other NC machines to form flexible machining systems, discussed later in this chapter.

TYPES OF MACHINING CENTERS

Machining centers are available in a wide variety of types, configurations, capabilities, sizes, and costs. Machines with manual toolchanging are still available and being used, but most users do not consider such machines to be machining centers. Machining centers with automatic toolchangers are much more popular. Most machining centers can be categorized as horizontal or vertical-spindle types and traveling-table or column types.

Numerically controlled, turret-type machines (see "Turret Drilling Machines" in Chapter 9 of this volume, "Drilling, Reaming and Related Processes") are considered by some builders and users to be machining centers. They differ from conventional machining centers, however, in that their spindles are locked in a turret head and equipped with tools that are permanently retained throughout the cycle. The spindles are successively indexed into machining position, rather than the tools being automatically inserted and removed from a single spindle. This design limits the number of tools that can be provided on a single machine, but it is often adequate for many applications.

Headchanger machines, discussed next in this chapter, are also considered by some builders and users to be machining centers or systems. They differ, however, from conventional machining centers in that entire heads (including multispindle units), rather than spindles or tools, are transferred in proper sequence to a single work station to perform the required series of operations. The distinction between machining centers and headchanger machines is becoming less clear because multi-spindle cluster heads are now being used on machining centers.

Vertical and Horizontal-Spindle Models

The two major types of machining centers are vertical and horizontal-spindle models. Some are available with two spindles (one horizontal and the other vertical), others have more than two spindles, and another has a single spindle that can be swiveled to either a horizontal or a vertical position. One model has a full contouring head with a 150° sweep from 30° above the horizontal to 30° beyond the vertical.

Selection of a specific type of machining center depends primarily upon the application—the size, complexity, and

variety of the workpieces to be machined; production requirements; the number and types of tools needed; tolerances that have to be maintained; and other factors. Group technology, the classification of workpieces into families on the basis of commonality of size, shape, and/or part features, aids in selecting the proper type and size of machine, required tooling, and desirable options.

Vertical-spindle models. Machining centers with vertical spindles (see Fig. 15-73) provide clear work areas for easy setup and loading/unloading. They are usually preferred for plate-type workpieces if the X-axis travel is sufficient to clear the spindle from over the table. A wide variety of work positioning and indexing equipment available for processing small, multisided parts increases the versatility of these machines. Figure 15-74 illustrates a dual setup on a vertical machining center for performing operations on large diesel engine blocks and heads.

Many vertical-spindle machining centers provide X and Y-axis motions with a traveling table and saddle. Machines are also available with traveling columns for X-axis movements to handle larger workpieces, and sliding heads or rail types for Y-axis motions. Z-axis movements are provided by quill-type spindles, sliding heads, or knees under the machine tables.

Vertical machining centers of the table type, with adjustable or fixed rail construction, are a direct descendant of rail-type milling machines discussed in Chapter 10, "Milling." The addition of a right-angle head, automatically loaded and unloaded, which can be indexed in at least 90° increments, provides a universal machine with large workpiece capacity. Operations on top surfaces of the workpieces are done with the vertical spindle, and the indexing right-angle attachment is used for operations on all sides of the workpieces. Tilting right-angle heads are also available.

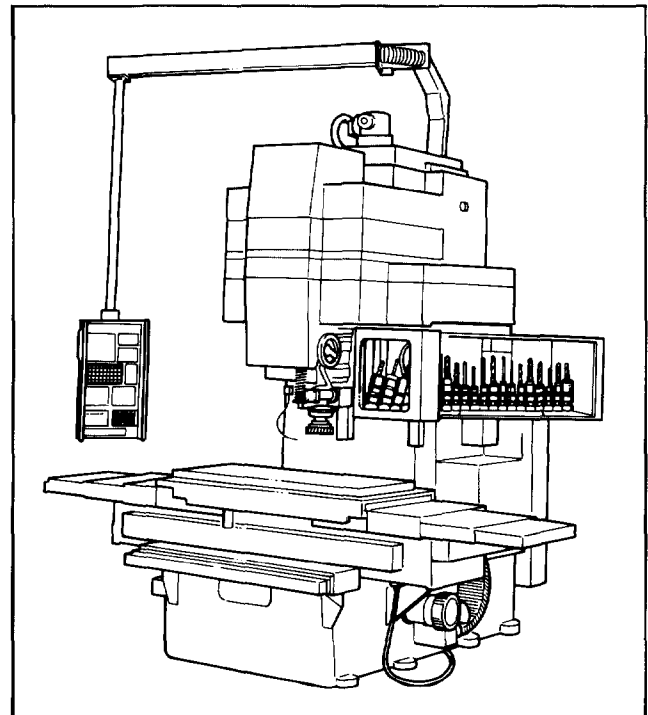


Fig. 15-73 Vertical-spindle machining center with pendant CNC. (Monarch Cortland)

MACHINING CENTERS

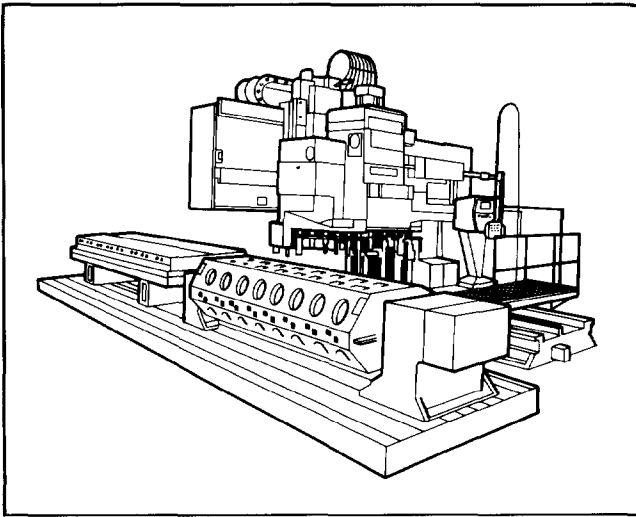


Fig. 15-74 Dual setup for diesel engine blocks and heads on a vertical-spindle machining center. (Giddings & Lewis Machine Tool Co.)

Horizontal-spindle models. Machining centers with horizontal spindles are generally more flexible than vertical-spindle models and are available in a wider range of sizes. Horizontal-spindle machining centers with numerical control of three, four, and five axes are shown in Fig. 15-75. These machines are usually preferred for large, multisided parts because they have no restrictions on workpiece height.

Horizontal-spindle bar-type machining centers (see Fig. 15-76) are direct descendants of horizontal bar-type boring mills discussed previously in this chapter. The addition of automatic toolchangers, numerical control, and pallet loading has resulted in accurate, large-capacity machining centers having four linear and one or two rotary axes.

Many horizontal-spindle machining centers provide X-axis motions with a traveling table, sometimes in combination with a saddle to furnish W-axis movements. Motions in the Y axis on some traveling-table machines are provided by a vertical column or spindle carrier mounted on a ram, both located on a rear base.

Traveling-column designs are popular for larger size machining centers. With the column traveling to the workpiece, the need for pallet changers can usually be eliminated. Dual tables are common on traveling-column machines, with the workpieces being changed on the idle table. This style of machining center, however, requires more travel in the X axis. Movements in the Y axis are provided by a spindle carrier mounted on the vertical column or by mounting the machine table on a knee. Traveling-column machining centers provide selection of X-axis travel ranges and workholding modules (see Fig. 15-77). The most popular configurations have two workholding modules (view *b*) that carry 72 or 360-position rotary index tables or full contouring tables.

Machine tool builders commonly offer a few standard versions of a particular machine type with various options. The modular machining center shown in Fig. 15-78 is available in 88 different combinations to suit specific requirements.

Five-axis machining centers, used for contouring complex workpieces, are available in several designs. One design uses a contouring rotary table as the fourth B axis and a vertical, contouring rotary table (mounted on the B-axis table) as the

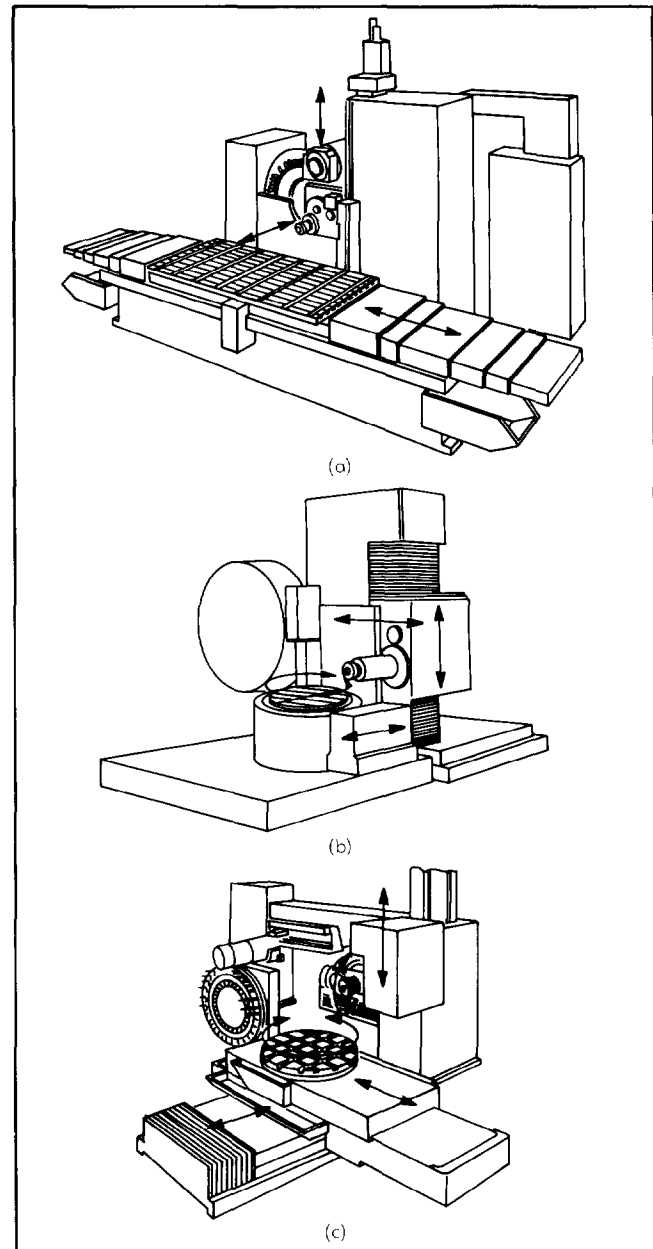


Fig. 15-75 Horizontal-spindle machining centers with numerical control of: (a) three axes, (b) four axes, and (c) five axes.

fifth A axis. When the vertical table is removed, the machine can be used for four-axis work. In another design, the contouring B axis is combined with an A axis that automatically tilts the B axis through a limited range. A third design combines the B-axis contouring rotary table with an A-axis spindle carrier designed with a programmable tilting spindle.

Machine Construction

Continuing evolutionary changes in the design and construction of machining centers and their controls are aimed at increasing productivity, quality, versatility, and reliability. Advancements have included increased rigidity and stiffness to

MACHINING CENTERS

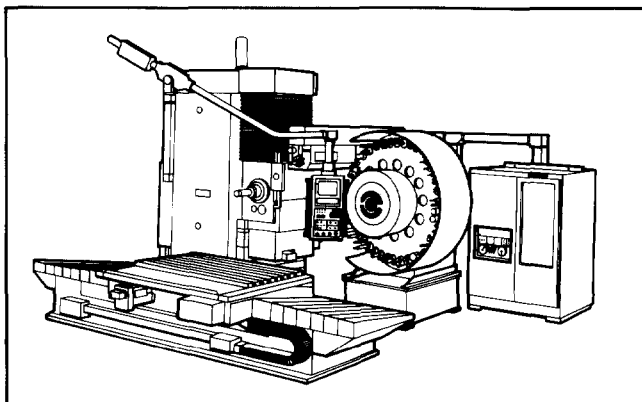


Fig. 15-76 Horizontal-spindle bar-type machining center. (DeVlieg Machine Co.)

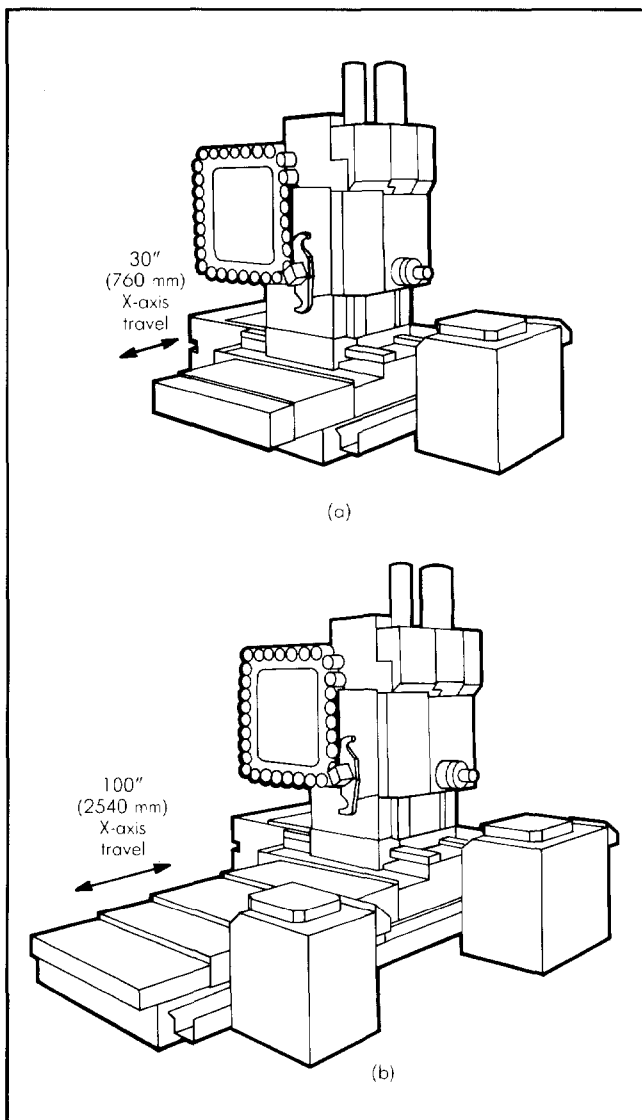


Fig. 15-77 Traveling-column machining center with: (a) one work module and (b) two work modules. (Cincinnati Milacron)

boost machining capability and improve accuracy. Some builders are using standardized modular construction with many modules common to several machines, thus minimizing costs and permitting machines to be tailored to specific application requirements.

Power and speeds. Most of the first machining centers built were in the midpower range of 10-20 hp (7.5-14.9 kW); now, however, machines are available with smaller and larger drive motors—2-75 hp (1.5-56 kW) or more. Some, especially smaller size machines, are available with single-speed or two or more speed a-c motors. Other machines are powered by solid-state, SCR-controlled, d-c motors to provide infinitely variable spindle speeds for increased versatility. There is a trend toward the increased use of variable-speed, a-c drive motors. Many drive motors are of the reversing type for tapping operations.

A common range for spindle speeds is 0-4000 rpm, with some machining centers having a maximum spindle speed of 6000 rpm. A few special machines can operate with spindle speeds to 60,000 rpm.

Spindle designs. A roller bearing spindle design offered by several builders of machining centers features automatic variable preloading for operation at different speeds (see Fig. 15-79). With this design, bearing preload is maximum from 45-1400 rpm and is automatically reduced by 30% at speeds from 1400-3500 rpm.

Several builders offer devices to control thermal expansion and contraction of the spindle carriers. With one design, the spindle is water cooled. In another design, cooling water from a thermostatically controlled refrigeration system is circulated in sealed manifolds surrounding the spindle bearings. On some machines, cooled oil from a heat exchanger is showered on the headstock and circulated through manifolds around spindle bearings. With another design, elongation or contraction of the ram assembly resulting from temperature variations is measured and depths of feed are automatically changed for compensation.

A few machining centers are equipped with special spindles to permit high-speed operation (see "High-Speed Milling" in Chapter 10 of this volume, "Milling"). One builder offers CNC machining centers equipped with special liquid-cooled, variable-frequency spindles for operation at speeds to 40,000 rpm.

Consideration should be given to the thrust forces on the spindle created by milling and boring. Bearings designed for spindle rigidity and a minimum of vibration are most beneficial.

Development work is being done with gas hydrodynamic, hydrostatic, and active magnetic bearings to increase high-speed capabilities. On one special machine, the spindle is rotated in magnetically levitated bearings for operation at speeds to 60,000 rpm.

Feed drives and rates. Feeds for the axis slides on many machining centers are driven by preloaded, precision ballscrews powered by pulse-width-modulated, or SCR, d-c servomotors. Inductosyn or other scales, resolvers, or encoders are being used for feedback systems on most machining centers to assure accurate positioning and repeatability. The accuracies guaranteed for many machines are $\pm 0.001"$ (0.03 mm) for positioning and $\pm 0.0005"$ (0.013 mm) for repeatability. Some machines, however, maintain closer tolerances, as low as $\pm 0.0002"$ (0.005 mm) for positioning and $\pm 0.0001"$ (0.003 mm) for repeatability. Consideration should be given to systems that have the ability to feed in two or more axes at the same time.

The maximum feed rate available varies with different machine builders, but generally is about 300 ipm (7620 mm/min), with a rapid traverse rate to 400 ipm (10 160 mm/min). One of the

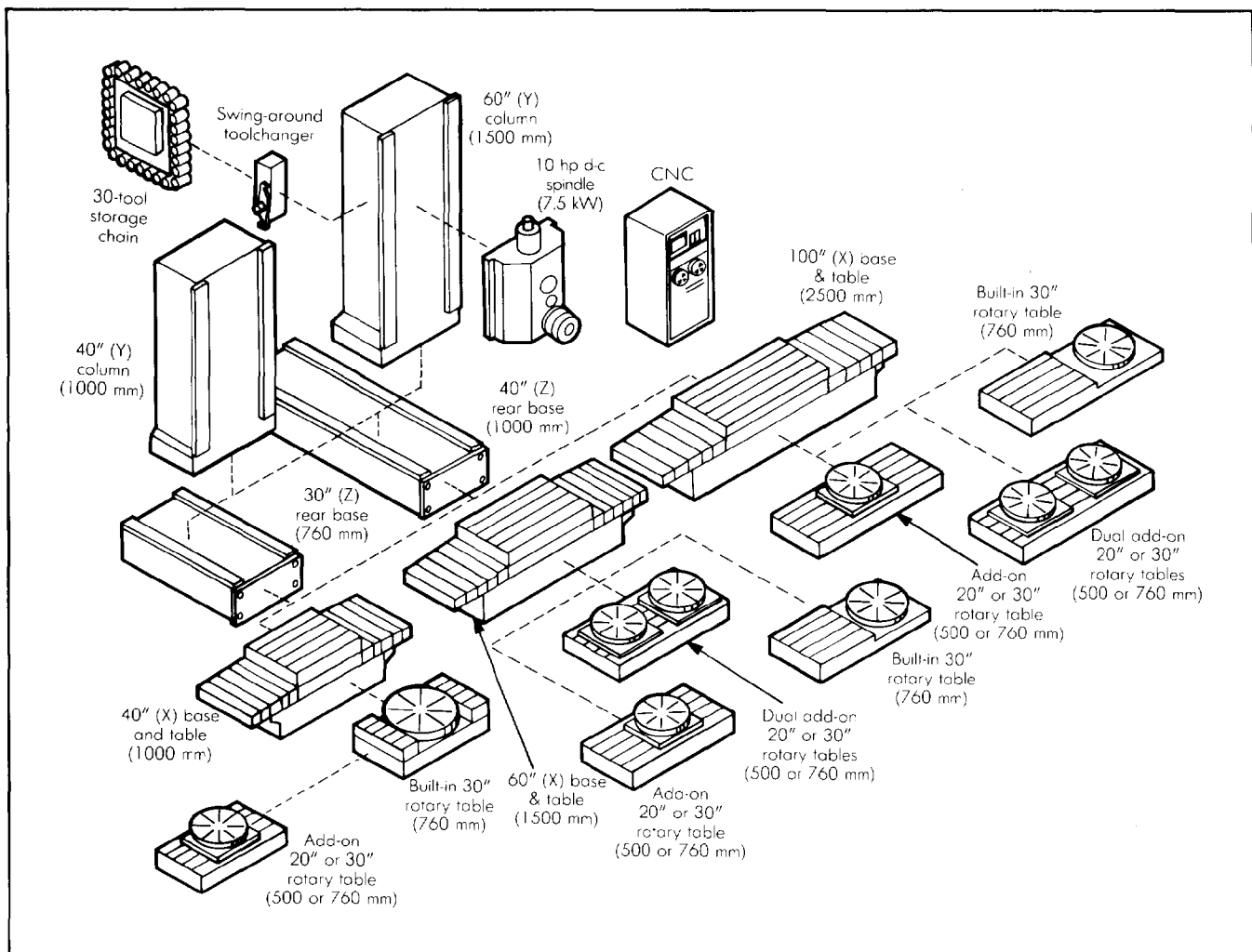


Fig. 15-78 Modular machining center available in 88 different combinations. (Cincinnati Milacron)

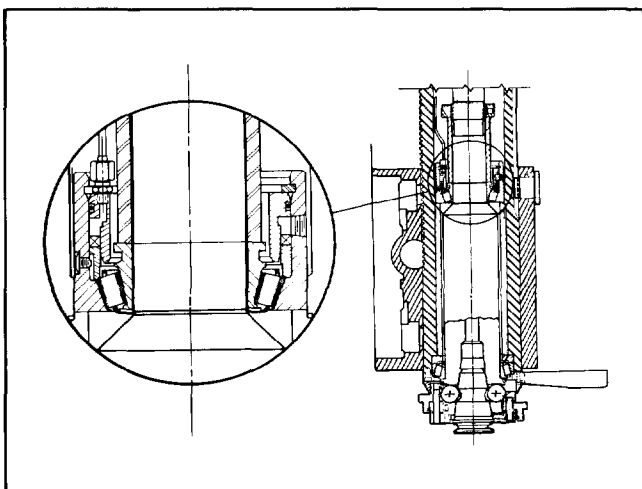


Fig. 15-79 Spindle design features automatic variable preloading for operation at different speeds. (Monarch Cortland)

special machines mentioned previously, with the spindle rotating at 60,000 rpm, has cut aluminum alloy with a 1" (25 mm) diam end mill at feed rates to 1000 ipm (25 400 mm/min).

Slide ways. Self-aligning, recirculating, caged ball bushings are being used on the axis slides of some machining centers to improve stiffness and performance. Another builder uses double-row recirculating roller packs to support the linear axes over their full travel. The roller packs wrap around all four sides of the guideways to minimize starting friction, maintain positive alignment, and ensure precise positioning. Integral roller and way assemblies of unitized design, bolted to the flat bed surfaces, are being used on some machines to reduce costs. One builder offers special machining centers equipped with air bearing slides. Nonmetallic wear surfaces (see Fig. 15-80) are also being widely used on guide edges, gib surfaces, and sliding members, with hardened ways and positive lubrication systems.

AUTOMATIC TOOLCHANGERS

A variety of toolchangers are available on machining centers offered by different builders. Most toolchangers consist essentially of a chain, drum, or dial-type magazine or matrix for

MACHINING CENTERS

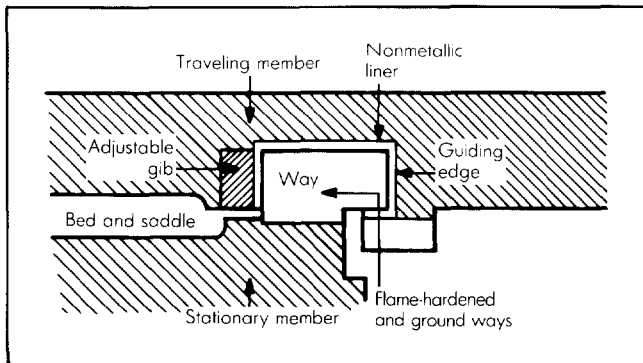


Fig. 15-80 Nonmetallic wear surfaces. (Giddings & Lewis Machine Tool Co.)

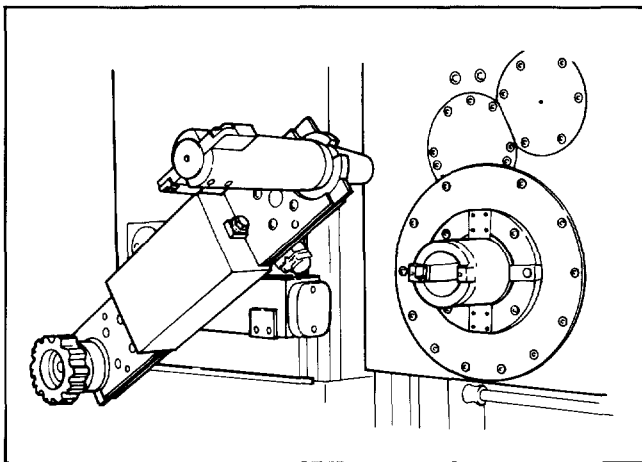


Fig. 15-81 Device for interchanging tool from storage with one in machine spindle. (Giddings & Lewis Machine Tool Co.)

idle tool storage and a device for interchanging these tools with one in the machine spindle (see Fig. 15-81). With the design shown in Fig. 15-82, tools are stored in an inverted position. The work area is clear, permitting the changing arm to be positioned close to the workpiece for rigidity. The swinging motion during toolchanging requires minimum clearance above the workpiece, resulting in minimum quill extension as the tool moves to the workpiece.

Some machines do not require an intermediate exchange mechanism such as a transfer arm. On one machining center, tools are loaded directly from a rotary drum to the spindle (and from the spindle to the drum) without an interchange device by axial motion of the quill (see Fig. 15-83). Grippers at each tool storage pocket around the drum periphery clamp and unclamp the tools at appropriate times.

Most builders offer a bidirectional rotation, random selection toolchanger system that automatically selects the shortest route to the next tool, thus reducing change time. A few machining centers, however, are available with lower cost, sequential tool selectors. Most toolchangers are an integral part of the machining centers, but some are free-standing, with a shuttle transfer system from storage to spindle.

Capacities of the different storage units vary from 3 to 120 tools or more. Some builders offer optional or expandable tool storage capacities. One vertical-spindle machining center has two tool storage magazines, each holding 15 tools and each

served by its own toolchanger arm. On some multispindle machines, the tools are changed in all spindles simultaneously. Chip-to-chip toolchanging time varies according to design of the changer, with a minimum time of about 4 seconds.

Large-diameter tools and cluster (multispindle) heads can be accommodated in the storage magazines of some machining centers if the adjacent pockets contain smaller diameter tools or are left empty. Some machines provide means for heavy tools to be mounted in cradles, away from the storage matrix, and located conveniently for engagement by the machine spindle.

At least one builder of machining centers offers high-speed units that can be automatically loaded by means of the toolchanger. Another builder offers a plug-in, cartridge-type high-speed spindle that is manually installed in the machine spindle. These units are ideal for applications requiring small end mills to operate at high spindle speeds, such as in milling nonferrous materials.

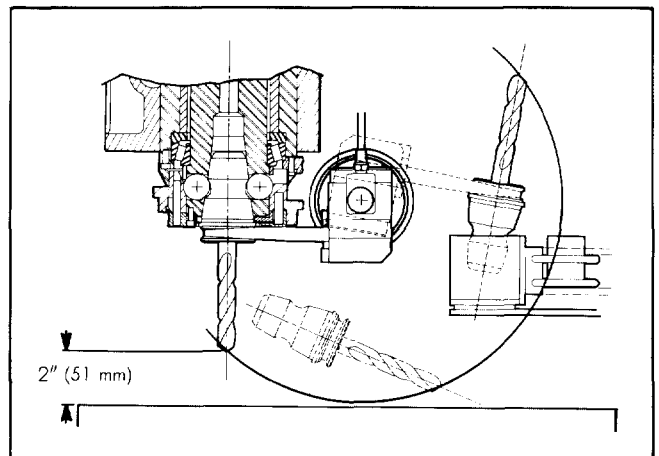


Fig. 15-82 Toolchanger with tools stored in an inverted position and swinging motion of changer arm. (Monarch Cortland)

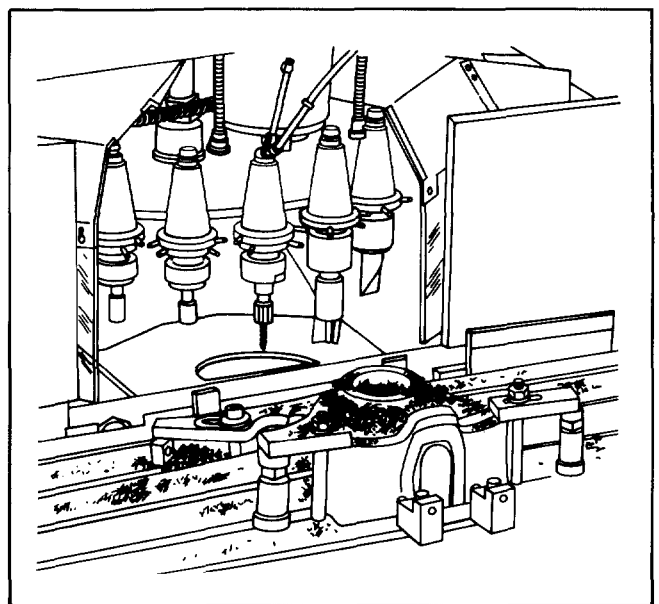


Fig. 15-83 Device for loading tools directly from rotary drum without an interchange arm. (Kearney & Trecker Corp.)

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ATTACHMENT CHANGING

Several machine tool builders offer automatic attachment changers and storage racks for use on machining centers and large milling and boring machines. The changers and racks can be used on floor-type machines or on table-type machines with the storage rack mounted on an extension of the saddle.

One attachment changer consists of a latch plate mounted to the face of a square ram. Four hydraulically actuated, collet-type clamps in the latch plate engage retention knobs on the attachment mounting surface. A proximity switch in the latch plate signals the CNC system as to the presence or absence of an attachment. Retrieving attachments from the storage rack, performing the machining operations, and returning attachments to the storage rack occur automatically.

Available attachments include right-angle milling, universal milling, contouring head, slotting, and special-purpose attachments.

CONTROLS FOR MACHINING CENTERS

A detailed discussion of NC and CNC systems used on machining centers and other machine tools is presented in Chapter 5 of this volume, "Machine Controls." Most builders now offer more compact, solid-state electronic CNC units with increased reliability built into or mounted on their machining centers for increased convenience and reduced floor space requirements.

Features generally desirable on controls for machining centers include the following:

- Sufficient memory storage for multiple part programs.
- Canned cycles and subroutines that reduce programming times.
- Program editing capability at the machine.
- Display, readout, or cathode ray tube (CRT) for position and block data.
- Linear and circular interpolation.
- Direct spindle speed and feed rate programming.
- Speed and feed overrides.

Other features (standard or optional) that can be useful include tool and fixture offsets, inch/metric switching, and cutter diameter, tool length, and backlash compensation. Manual data input (MDI) is essential for program editing at the machine, and an alphanumeric keyboard is desirable for this purpose.

Adaptive control systems to make automatic adjustments of spindle speeds and/or feed rates to compensate for changing workpiece/tool conditions are offered by some builders. Computer-based, analytic diagnostic systems are also available to quickly detect and isolate faults, problems, or malfunctions, thus reducing downtime.

TOOLING AND TOOLHOLDERS

Standard cutting tools can be used on most machining centers, but slight modifications may be required for use on some machines. High-speed steel drills and reamers and carbide cutting tools, both coated and uncoated, are used most extensively on machining centers, with ceramic and diamond tools employed to a lesser degree for certain applications. A detailed discussion of cutting tool materials is presented in Chapter 3 of this volume, "Cutting Tool Materials."

The increasing use of machining centers has led to the availability of tooling systems (packages of modular tool components) from some cutting tool manufacturers which

reduce inventory requirements and costs. Typical systems consist of a shank-end holder, an intermediate component (such as a boring bar or milling cutter body), and indexable inserts. Collet chucks, extensions, adapters for taper shank tools, and bushings of various sizes for different diameter tool shanks are available.

Tool geometries and operating parameters are essentially the same as for use on other machine tools, as discussed previously in the following chapters of this volume:

- Chapter 8, "Turning and Boring."
- Chapter 9, "Drilling, Reaming and Related Processes."
- Chapter 10, "Milling."
- Chapter 12, "Threading."

Toolholder Shanks

During the development of machining centers, many builders designed their own, often proprietary, toolholder shanks and retention knobs. For users having machining centers supplied by various builders, this required the costly stocking of many noninterchangeable holders. To reduce holder requirements, the Aerospace Industries Association (AIA) in the early 1960's developed standards; however, these standards never found wide acceptance.

A major user of machining centers (Caterpillar Tractor Co.) developed in 1973 their own standard for toolholder shanks, referred to in the industry as the CAT standard, to reduce costs. This led to the development of ANSI Standard B5.50 for V-flange tool shanks to be used on machining centers having automatic toolchangers or on manual toolchanging machines using a quick-change nut and manual or power-operated drawbar. Another standard is under consideration by ISO.

The shanks specified in both the ANSI and CAT standards, which are interchangeable, have a V-groove on the flange that is gripped by the toolchanger on the machine. The rear of the shank is threaded to accept a retention knob or a pull-back stud used to retain the holder in the machine spindle. With the retention knob removed, the holder can be used on other machines having threaded drawbars. Shanks with Nos. 30, 40, 45, 50, 55, and 60 NMTB tapers are available. Caution is necessary with respect to retention studs because they are not all interchangeable. On any particular machine, only studs designated by the machine builder should be used.

A major difference between the CAT and ANSI standard shanks is that the CAT shank has inch threads while the ANSI shank has metric threads. As a result, ANSI shanks cannot be used with existing components having inch threads. There is also a small difference between the CAT and ANSI standard shanks with respect to the depth of the flange keyways. With some machine configurations, the ANSI standard keyway is not deep enough to accept one of the spindle keys. In such cases, CAT and ANSI standard shanks can be made interchangeable by modifying the spindle key to eliminate any interference.

Many adapters are available for the standard holders to accommodate straight and taper shank tools. Collet chucks are used extensively for drilling, reaming, end milling, and similar operations. Micrometer-adjustable adapters are also available for boring bars.

Identifying Tools in Storage

Many machining centers have a station selection or pocket address design for tool selection. The tool storage magazine is programmed to index to a certain numbered position for toolchanging rather than to a certain tool. This design requires

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specific loading and reloading of the magazine with required tools in the correct locations.

Some machining centers have automatic toolchangers designed for random tool selection. With this system, each tool or holder is provided with a coding feature such as grooves or notches on the shanks, stacked rings and spacers on the holders, lugs on keys inserted into cartridges placed in the magazine, and other methods. A scanner is used with some designs to locate the coded tool it has been programmed to find as the storage magazine is indexed. Other machining centers allow the operator or part programmer to assign tools randomly to any pocket by entering the assignments into the control.

Tool Positioning

Proper alignment of the cutting edges of tools, both radially and longitudinally (with respect to locating surfaces), is essential for precision machining. Performing this function on a machining center, by making trial cuts and adjusting the tools by means of offsets, compensation systems, and/or gaging devices, can be time-consuming and costly and may cause damage to the workpiece, tools, or machine. As a result, most tools are preset before they are brought to the machining centers.

Available presetting equipment ranges from relatively inexpensive fixtures or gages with dial indicators to costly precision presetting machines. Some presetting machines are made with optical or electronic systems, as well as with microscopes, magnifiers, comparator screens, or digital readouts.

Presetting of tools, however, may not provide the necessary accuracy for close tolerance machining. For many applications, it may be necessary, or more convenient, to use the tool offsets or length/diameter compensation systems available on most controls, either standard or as an option, for final setting. Some machining centers are equipped with automatic gaging devices to check the location of cutting points and to feed back data to the machine control system for adjustment of the feed slides as required.

On machining centers made by one builder, tools are manually power-jogged during setup to touch a convenient reference on the workpiece or fixture. The memory of the machine control records the zero positions for the various tools. Another builder offers probe-initiated, zero-offset compensations for all axes. The compensations can be programmed to maintain the centerline of the workpiece index or to rezero axis reference positions.

Electronic tool gages, which can be interfaced with CNC units having tool length compensation, are offered by one builder of machining centers. When tools are placed in the gage prior to loading in the storage matrix on the machine, tool lengths are transmitted directly to the control, which coordinates with the storage locations selected for the tools. Another builder of machining centers offers a drilling and tapping control option that automatically provides feed engagement upon contact of the tool with the workpiece. This eliminates the need for preset tools and programming feed engagement of the tools above the workpiece surface.

Many machine builders offer electronic stylus-type probes which can be automatically placed in the machine spindles to qualify fixtures, calibrate the accuracies of the machines, inspect workpieces while on the machines, or perform other functions. The probe (see Fig. 15-84) contains a sensitive, three-axis, contact-sensing device coupled to the control system of the machine by means of an orbital transformer. The primary coil of the transformer is located in the probe, and the secondary

coil in the spindle-nose bearing retainer. This design eliminates the need for electrical connections and allows rotational positioning of the spindle while the probe is in operation.

Another type of probe (see Fig. 15-85) is self-contained and battery powered, and transmits the information via infrared telemetry transmission to a receiver head mounted within 25 ft (7.6 m) of the probe. It can be put into use without physical modification of the machine and permits both spindle rotation and quill extension for checking purposes. Dirt and dust do not affect data transmission, and the infrared telemetry signal ricochets off solid surfaces to be picked up by the receiver head. With the proper software support from the machine control, hole diameters, surface location, hole depth, or surface dimensions can be checked simply and easily. Even complex surfaces can be checked for profile, given the software support by the machine controls.

Coolant-Fed Tools

Machining centers are available with hollow spindles, other spindle nose arrangements, or rotary adapters to permit

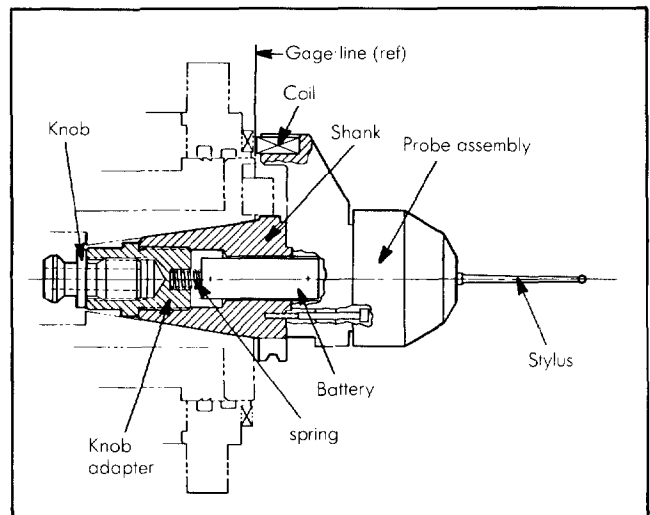


Fig. 15-84 Probed tool electronically coupled to the control system by means of an orbital transformer.

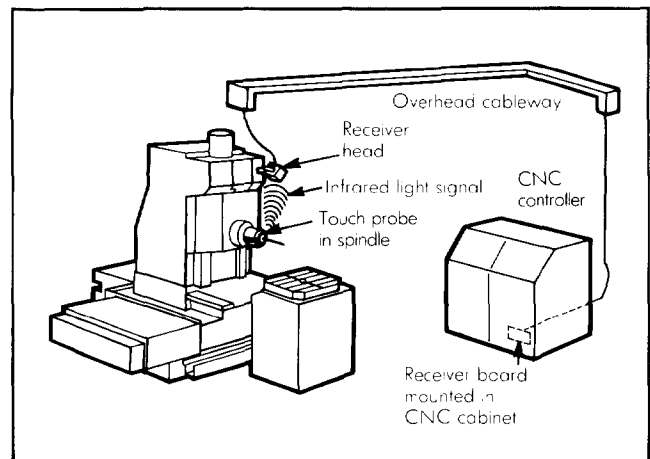


Fig. 15-85 Telemetry touch probe mounted on a horizontal-spindle CNC machining center. (Valeron Corp.)

pumping cutting fluid through the spindle. Pulsating or constant-flow cutting fluid is used with coolant-fed tooling for longer tool life or higher metal removal rates. Coolant-fed tools (drills and reamers) are discussed in Chapter 9 of this volume, "Drilling, Reaming and Related Processes," and coolant-fed taps in Chapter 12, "Threading."

WORK HANDLING

Many methods are available for holding and positioning workpieces on machining centers. Their purpose is to permit the greatest number of operations to be performed in one setup, thus increasing productivity. Workpiece transfer and handling equipment is being incorporated in some machining centers.

Plain machine tables with single-station fixtures are the simplest method, requiring no optional equipment. Small workpieces can often be set up in multiples on the tables. Multipart fixtures can be used for small workpieces. With duplicate fixtures, one fixture can be unloaded and reloaded while workpieces on the other fixture are being machined. Two-station fixtures are often used when two settings are required to machine various surfaces on the workpieces.

On vertical machining centers, tailstocks or other outboard supports are used for long slender parts. A fourth-axis indexer is also used on these machines to rotate box-like workpieces in a vertical plane to bring multiple surfaces under the tools. A column riser may be necessary for some applications to provide more distance from the spindle nose to the table top for indexing clearance. Trunnion-type indexers are also available for multisided machining with a single fixturing (as an alternative to using a horizontal-spindle machine with an indexing table).

Multiposition dial index tables, some with bidirectional rotation; pallet shuttle systems (see Fig. 15-86); and automatic pallet changers (see Fig. 15-87) are used on many machining centers. Duplicate pallets permit the operator to unload and reload (or set up the next job) while another workpiece is being machined. One builder offers two rotary tables, each with an independent drive, for its horizontal-spindle machining centers. This permits one table to remain stationary for loading, unloading, or setup, while a workpiece on the other table is being machined.

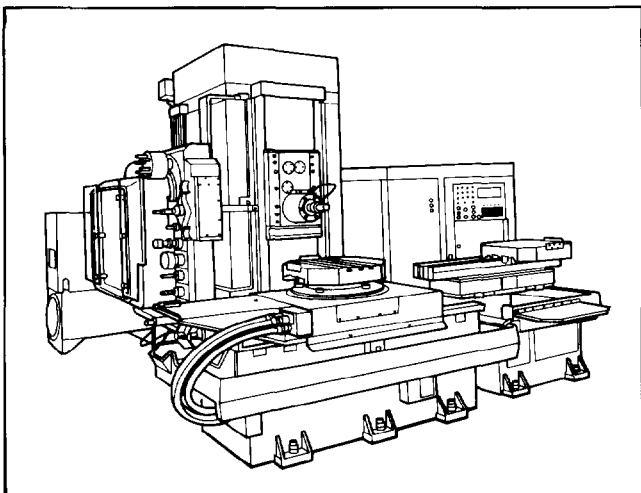
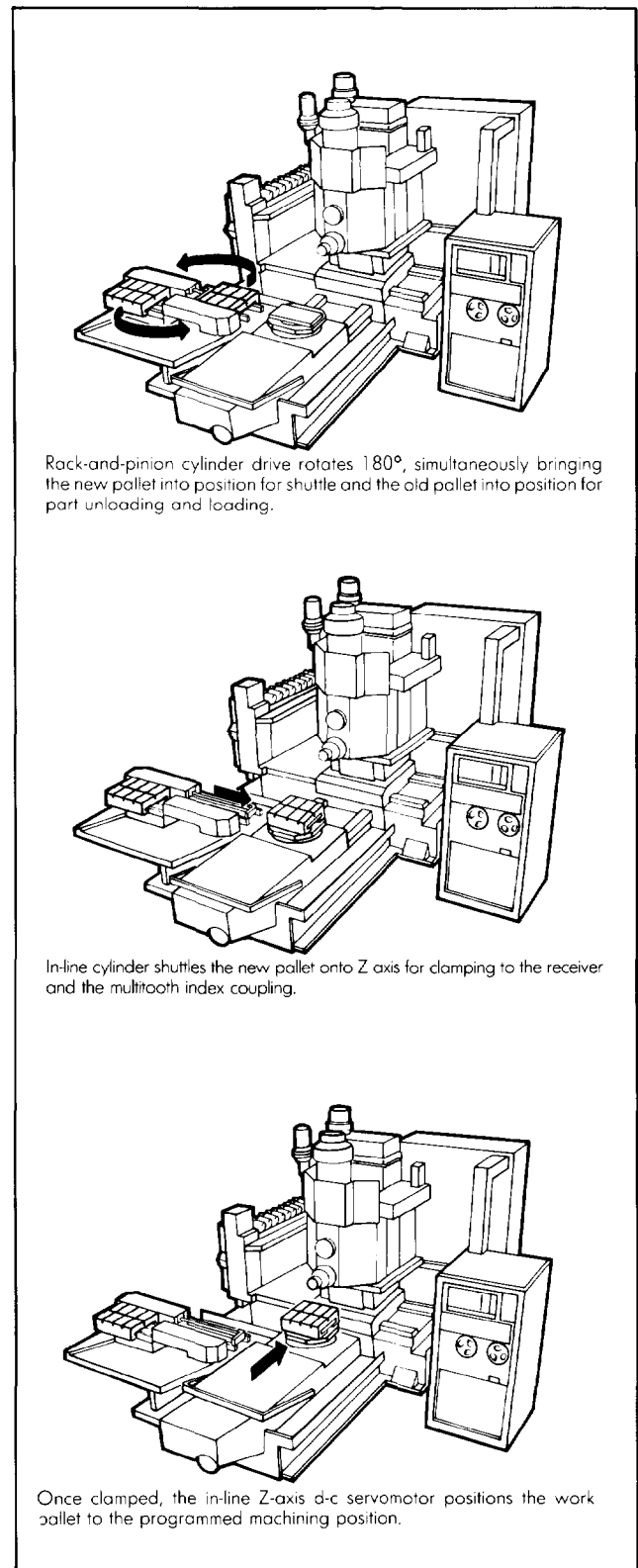


Fig. 15-86 Pallet shuttle system on a horizontal-spindle machining center. (Kearney & Trecker Corp.)



Rock-and-pinion cylinder drive rotates 180°, simultaneously bringing the new pallet into position for shuttle and the old pallet into position for part unloading and loading.

In-line cylinder shuttles the new pallet onto Z axis for clamping to the receiver and the multitooth index coupling.

Once clamped, the in-line Z-axis d-c servomotor positions the work pallet to the programmed machining position.

Fig. 15-87 Workpiece transfer is accomplished in under 26 seconds with this automatic pallet changer. (Cincinnati Milacron)

HEADCHANGING MACHINES

Traveling-column, horizontal machining centers permit using two post-type work modules at the front of the machine, with the spindle-carrying column traversing from one to the other. The posts can be equipped with rotary indexing tables or other workholding arrangements to suit specific requirements. These two basic work areas are suitable for most needs, but long parts can be bridged across the posts.

Loading and unloading of machining centers is being done with industrial robots for some applications.

Unmanned Machining Centers

So-called "unmanned machining centers" can be operated for a period of time without operator attention, but a skilled attendant or supervisor should be available at all times to monitor the operations and make adjustments if required. Installations consist of a machining center surrounded by pallets. Loading and unloading of the pallets, inspection of workpieces, maintenance of the machine, and toolchanging are normally performed during the day. Material transport systems

are discussed in the subsequent section of this chapter on flexible manufacturing systems.

During the second and third shifts, when labor costs are higher and electrical power costs are lower, the pallets automatically move to the machining center, which selects the proper program from the storage memory of the control for the specific workpiece to be machined. It is desirable to have similar operations performed on the various workpieces to keep tooling requirements within the capacity of the machine.

To minimize possible problems, the control monitors spindle speeds and torque and automatically changes feed rates to maintain programmed values. The machining centers are also equipped with automatic tool wear sensing. Tools are brought into contact with a gage on the machine that detects wear on lands or teeth. If wear exceeds the programmed limit, the tool is rejected and an alternate selected, or a warning light blinks. A gaging post on the machine detects broken tools, and the spindle can orient the tools in 1° increments to measure tool diameters.

HEADCHANGING MACHINES

Headchanging machines, like machining centers discussed in the preceding section of this chapter, are also a relatively new class of multifunction, numerically controlled machine tools. They differ from machining centers in that single or multiple-spindle heads, rather than tools, are transferred to a single work station in proper sequence to perform the required series of operations. The single work station is equipped with a spindle drive and slide feed unit; the workpiece remains in a fixed or indexable position. Additional work stations can be added on some machines if required.

Advantages of headchanging machines are similar to those of machining centers: increased productivity and versatility, reduced capital equipment and labor costs, and less material handling. Headchanging machines are generally used for larger lots of similar workpieces and for faster production requirements than are usually obtainable with machining centers. The use of modular heads and pallets on headchanging machines, however, permits quick changeover to suit various workpiece requirements. These machines are also being integrated with other NC machines in flexible machining systems, discussed later in this chapter.

On the machine shown in Fig. 15-88, standard size, cubical machining heads, with single or multiple preset tools, are stored on a multilevel carousel alongside the traveling-column machine. On command of the machine controller, the proper head is automatically transferred, positioned, and clamped on the machine spindle. Multitooth couplings ensure accurate registration of toolheads and work pallets. The shuttle pallets on the machine table permit loading and unloading one workpiece while another is being machined. Programs and tooling can be stored in this system for a variety of workpieces. Some toolheads can be dedicated to operations performed on a specific workpiece, while others can be used for one or more operations common to several workpieces.

A CNC headchanging machine made by another builder (see Fig. 15-89) is equipped with four multiple-spindle heads in an overhead indexing unit that rotates in either direction. With a workpiece loaded in the fixture, the required head is automatically indexed over the feed unit, lowered into position on

ways on the column face, and located and clamped. The drive quill in the feed unit then automatically advances and engages the driver in the multispindle head.

When machining is completed, the feed unit returns, the head is raised, the index unit brings the next head into position, and the process is repeated. The complete headchanging sequence is accomplished in 25 seconds. The machine can be equipped with T-slot mounted fixtures, indexing fixtures, or shuttle fixtures.

Programs can be loaded into the CNC unit by punched tape, magnetic tape cassette, or manual data input (MDI). With MDI, the control can be programmed by the operator when the first workpiece is being machined or during dry-run cycling. Programming normally only involves the Z axis with cutting tools preset to the required length in each head.

Headchanging machines offered by other builders are similar to rotary dial-type machines discussed later in this chapter. A major difference is that multiple-spindle heads (instead of workholding fixtures) are mounted at each index position on the main rotary dial (see Fig. 15-90). From 4 to 20 geared heads can be used depending upon workpiece size and dial diameter.

One workholding fixture, which can be equipped with a multiple-position indexing table, is mounted on a separate feed unit to move the workpiece into the tooling. A spindle drive unit is mounted inside the dial to provide power to each head as it is indexed to the machining station. Different operations can be performed in any sequential order, with a programmable controller establishing and controlling the indexing sequence of the heads as well as all functions of the feed slide and drive spindle.

Automatic machining of large tractor transmission housings is being done with two headchanging systems, one of which is illustrated schematically in Fig. 15-91. Each system has a single work station and a number of interchangeable machining heads. Switching from the production of one housing casting to another design requires changing only 13 tools on one machine and 55 on the other. For this application, many stand-alone machines, requiring a substantially greater capital investment, would have been needed to perform the same operations as the two headchanging machines.

Each machine consists of two palletized work fixtures, a

HEADCHANGING MACHINES

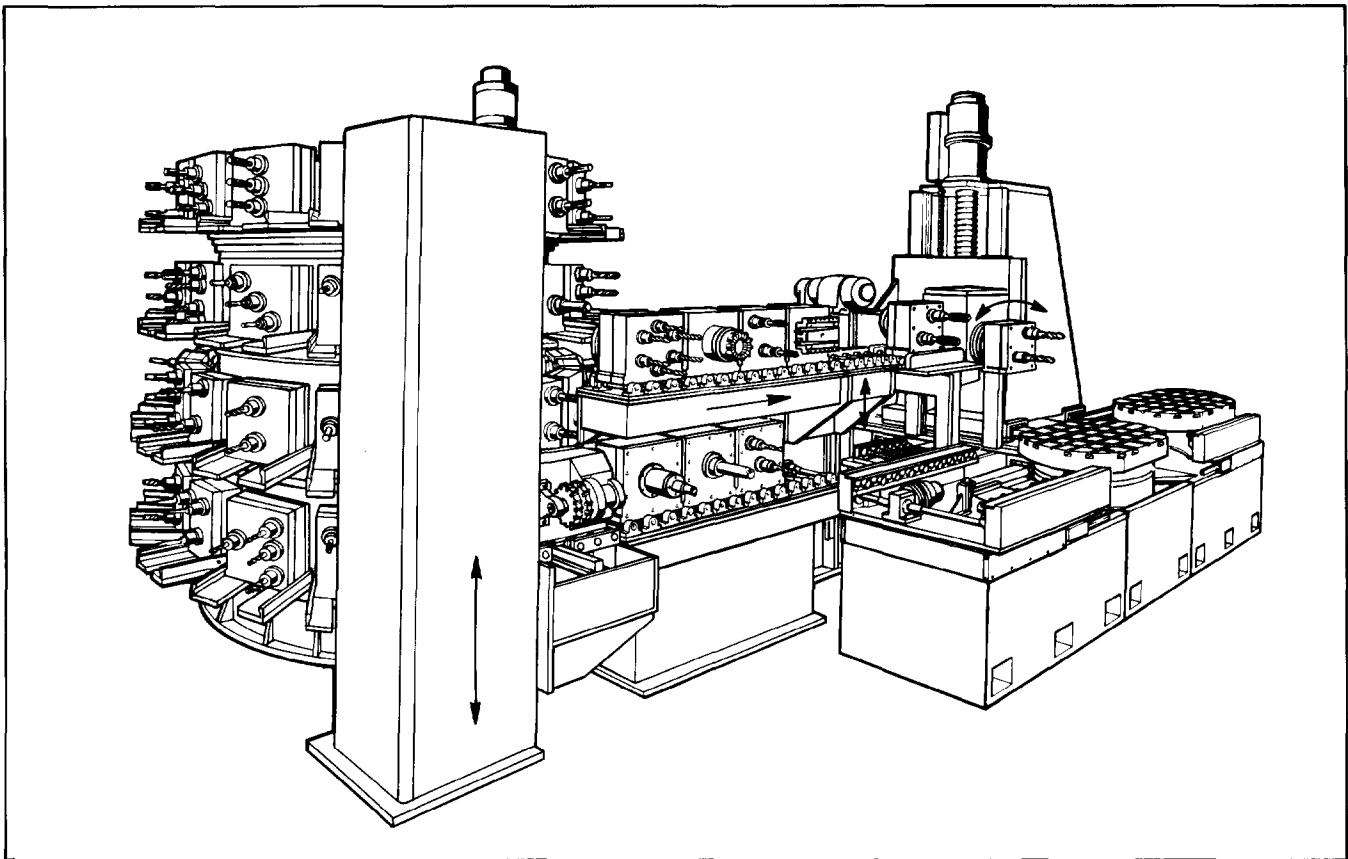


Fig. 15-88 Machining heads, stored on a multilevel carousel, are automatically transferred to spindle of traveling-column machine. (Cincinnati Milacron)

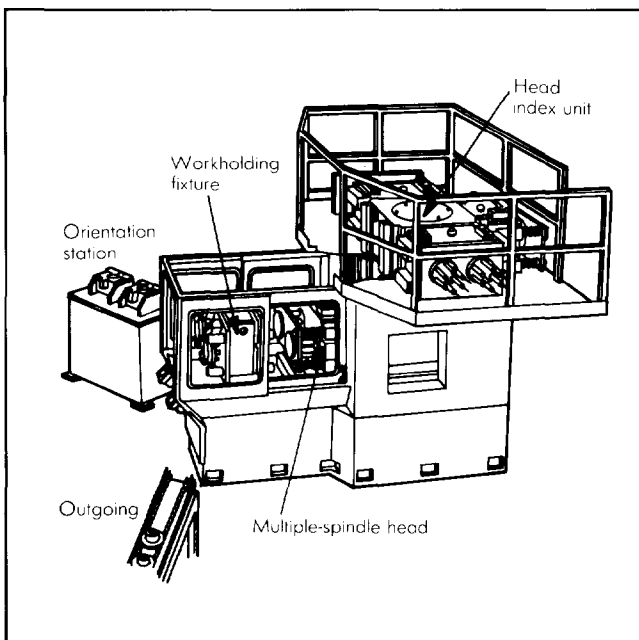


Fig. 15-89 Headchanging machine with four multiple-spindle heads in an overhead indexing unit. (Olofsson Corp.)

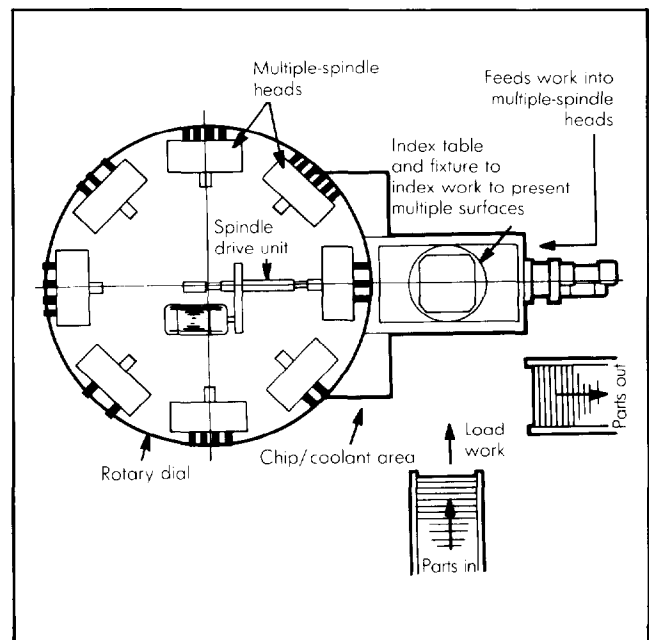


Fig. 15-90 Headchanging machine with multiple-spindle heads mounted on rotary indexing dial. (Kingsbury Machine Tool Corp.)

HEADCHANGING MACHINES

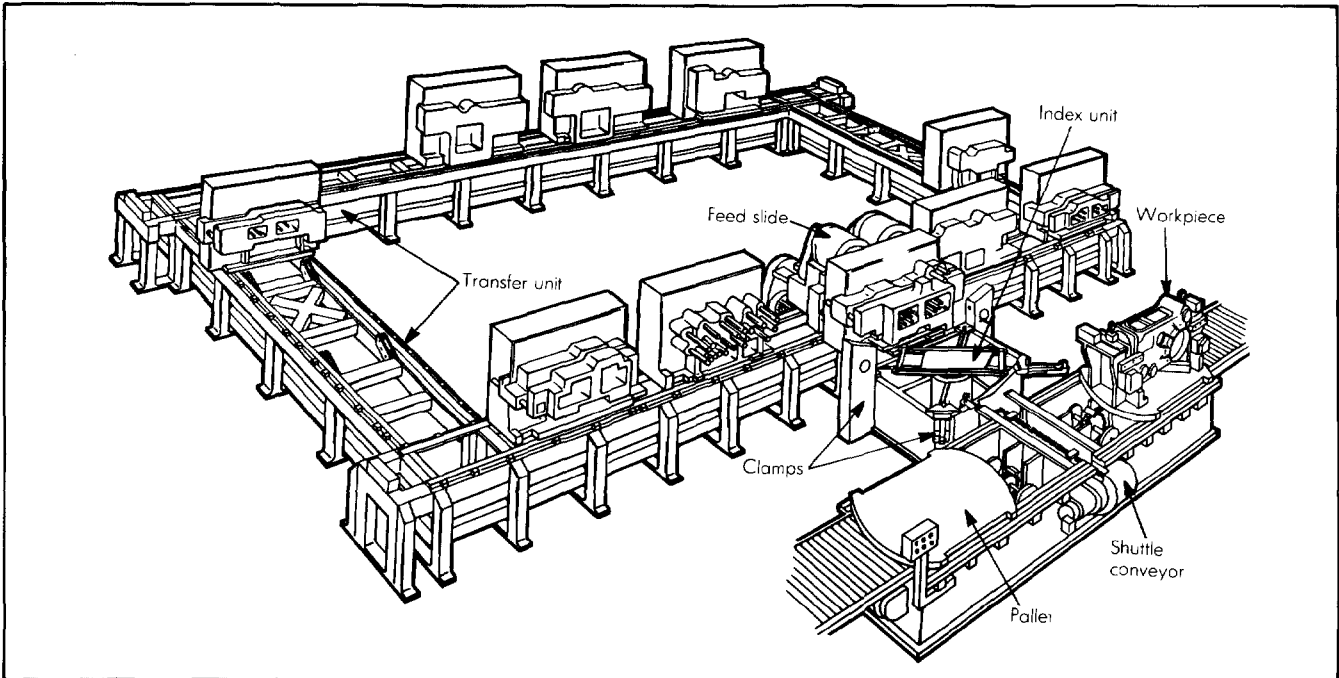


Fig. 15-91 Headchanger system has two palletized work fixtures, a load/unload pallet shuttle, a four-position index unit, a single work station, and a transfer unit for positioning multitool machining heads. (Ingersoll Milling Machine Co.)

load/unload pallet shuttle, a four-position index unit, a feed slide, and a recirculating head transfer mechanism. The feed slide has dual spindle drives—one for boring and drilling operations, and the other for tapping. Each transfer mechanism is equipped with a number of interchangeable machining heads. The heads move on skid rails, driven by hydraulically actuated transfer bars. Each head contains one driveshaft which engages the driveshaft on the feed slide when the head is in position on the slide.

While one casting is being machined, the operator loads and clamps another on the second pallet. Transfer of the pallets to and from the four-position index table is done with a chain shuttle conveyor. Four 90° movements of the index table allow each workpiece to be machined on all four sides.

As each machining head is transferred onto the slide at the work station, it engages either the drilling drive coupling or the tapping drive coupling and is clamped. Headchanging requires about 20 seconds. One motor on the spindle drive unit is for drilling, boring, and reaming operations, and the other is for tapping. The feed slide is moved by a ballscrew with two motors: a 3 hp (2.2 kW) a-c motor for rapid traverse at 300 ipm (7620 mm/min) and a 1 hp (0.7 kW) d-c motor for the required feed rates.

Control of the headchanging and other functions is accomplished with a programmable limit switch which uses a special-purpose computer. A digital encoder on the end of the slide ballscrew, connected to the computer, replaces scores of cam-operated mechanical limit switches. Each machining head automatically selects its own preprogrammed rapid-advance cycle, feed rate, dwell, and rapid-return cycle as it moves into place on the slide. The heads identify themselves by carrying dogs that engage limit switches.

With a system offered by another machine tool builder, modular and interchangeable, geared toolheads are stored and

transported on an overhead monorail, power-and-free type of conveyor. A single work station with one slide unit is provided to selectively hold and feed the heads, and a workholding fixture is mounted on a fixed base unit.

Options available with this system include rotary indexing capability for the fixture, extension of the table base to allow horizontal (X axis) movement of the fixture with respect to the main slide (Z axis), an automatic pallet changer for loading/unloading one workpiece while another is being machined, and additional storage loops for handling more heads per machine. Two or more such machines can be used together by connecting the main conveyor loops on the machines. Figure 15-92 illustrates an installation with 3 machining stations and 88 machining heads. Some of the heads are equipped with 23 spindles.

Toolhead selection is sequential, but any head not required for a specific workpiece can be quickly bypassed. Headchanging is accomplished by rotation of an overhead, reciprocating transfer bar, which causes drive dogs to engage yokes in the backing plates on the heads during transfer. Conical locator clamps hold the head backing plates to the slide unit. Total sequence time from cut to cut is about 10 seconds, with only 2 1/4 seconds needed for actual headchanging and the rest of the time required for clamping/unclamping and rapid advance and retraction.

The overhead conveyors for these machines run continuously, but most of the heads remain stationary until required. This permits maintenance, adjustments, and toolchanging to be performed while the heads are stationary, thus minimizing downtime. A CNC unit controls transfer of the heads; rapid advance, feed, and rapid retraction of the main slide; cross slide movement of the workholding fixture; and rotary indexing of the fixture. A CRT is provided on the control console for program optimization and diagnostic troubleshooting.

HEADCHANGING MACHINES

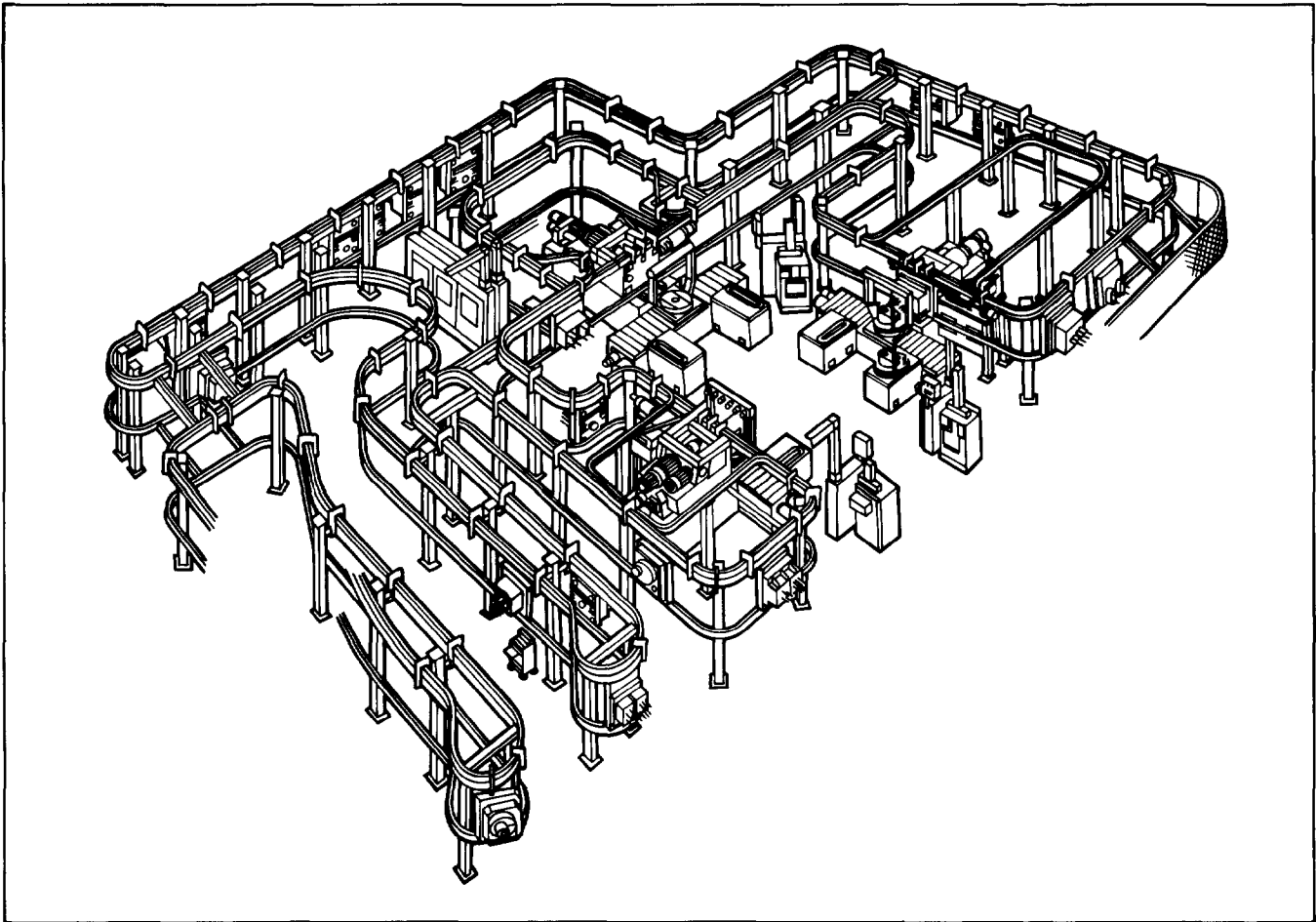


Fig. 15-92 Multiple-spindle heads are stored and transported on an overhead conveyor in this headchanging system with three machining stations. (Bendix Machine Tool Corp.)

AUTOMATED AND SPECIAL-PURPOSE MACHINES

Many of the standard machine tools already discussed in this volume are partially automated. In many cases, the addition of automatic feeding, loading/unloading, and gaging equipment can completely automate these standard machines, providing substantial production economies.

Standard machines and equipment should generally be used whenever possible because of their lower cost, quicker availability, and usually, proven performance. A possible disadvantage is that the use of such machines is usually a compromise of the ideal answer to specific automation requirements. The degree of compromise determines whether it is more economical to develop special-purpose machines and equipment that would better suit present and future automation requirements than to use standard machines.

When it is impractical, impossible, or uneconomical to use standard machines for automation, special-purpose machines and equipment must be designed and built or purchased. Special machine tools often provide production economies because of built-in automation concepts that provide maximum

efficiency in a minimum of floor space. Although they may not provide the inherent flexibility of standard machine tools, specials can have sufficient flexibility built in to produce a variety of related parts for medium or lower production if requirements are carefully planned in the design stages. If possible, continuous production should replace batch manufacturing methods. When quantities of identical parts are not sufficient for continuous production, the use of more flexible automation equipment to handle families of parts (similar in size or shape) or similar operations should be considered.

When special-purpose equipment is considered, the possibility of combining several operations normally done on a number of individual machines should be investigated. As many operations as possible should be performed while the part is still located and clamped in the special machine. Cost savings resulting from eliminating the need for moving, relocating, and reclamping the workpieces can pay part of the development costs for the special machine.

A variety of special-purpose machines have been developed

AUTOMATED AND SPECIAL-PURPOSE MACHINES

for automation, some of which are discussed in this section. These machines actually represent various degrees of automation refinement for parts having different machining and production requirements. Selection of a specific type depends on many factors, including the design of the workpiece, number and type of operations to be performed, accuracy specifications, floor space available, production requirements, and need for flexibility.

LINK LINES

A flexible and relatively inexpensive automation concept is the link line in which individual and independent, standard or special machine tools and other production equipment are connected by conveyors or other automatic materials-handling units to move workpieces from operation to operation (see Fig. 15-93 and Fig. 15-94). One operator can handle more than one

machine and still provide a certain amount of visual control of the operations, keep hoppers full, change dull tools, etc. The conveyors, hoppers, storage elevators, etc., also serve as banks for in-process parts. Each machine in the line can cycle at its own predetermined rate as long as a part is available and room exists in the subsequent bank for a finished part. In-process gaging is desirable with such setups to prevent producing too much scrap before operations can be corrected. Industrial robots are being used in some applications to transfer workpieces from machine to machine.

COMBINATION-OPERATION MACHINES

Substantial savings in floor space can be achieved in relatively low production applications by clamping the workpiece in a fixed fixture and then feeding machine heads on slides from various directions into the part, as shown in Fig. 15-95. The

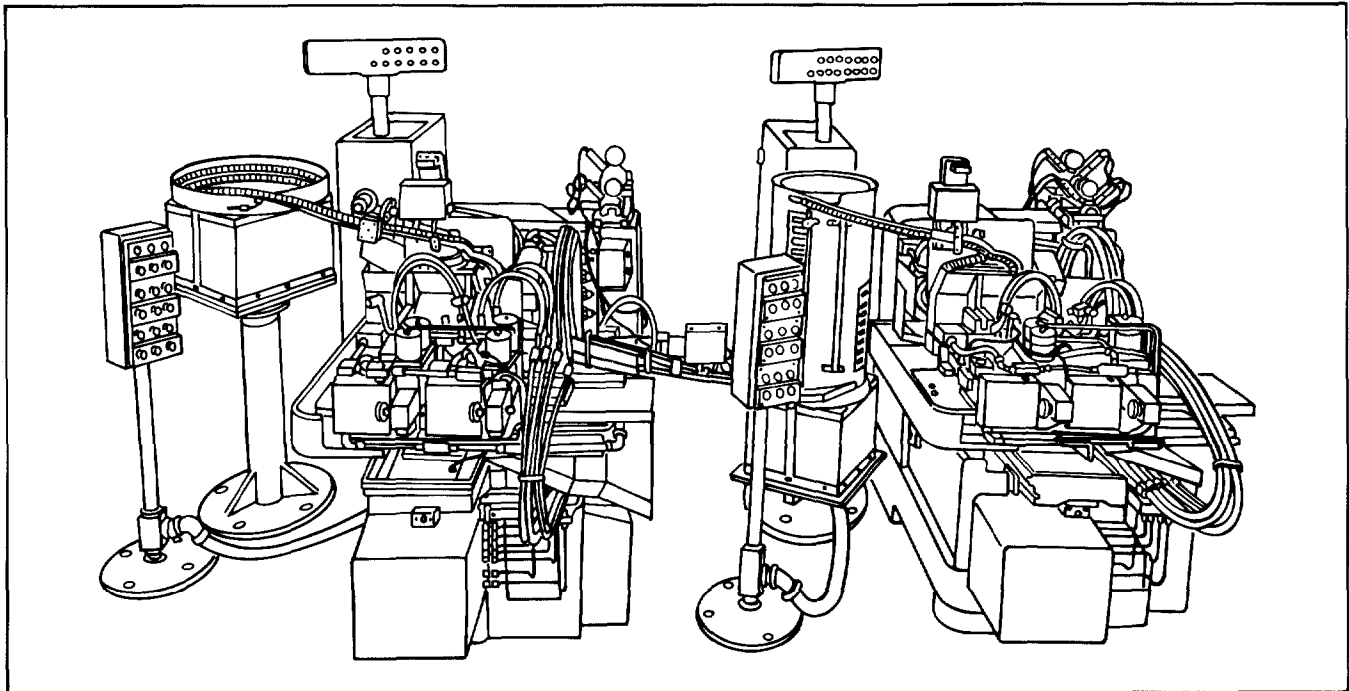


Fig. 15-93 Machine tools interconnected by material-handling and workpiece storage units.

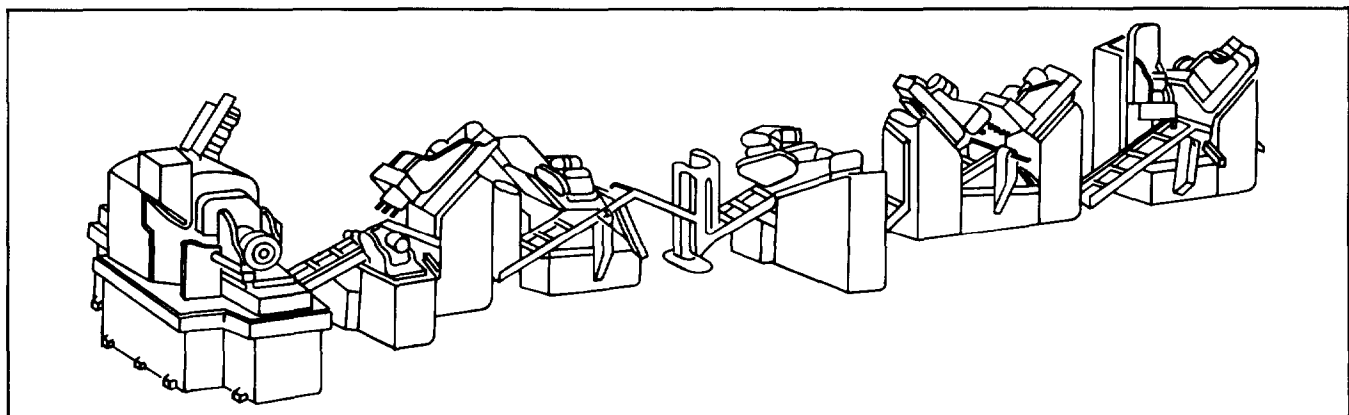


Fig. 15-94 Schematic drawing of a link line. Workpieces are transferred from machine to machine by elevating mechanisms, each including a storage magazine.

AUTOMATED AND SPECIAL-PURPOSE MACHINES

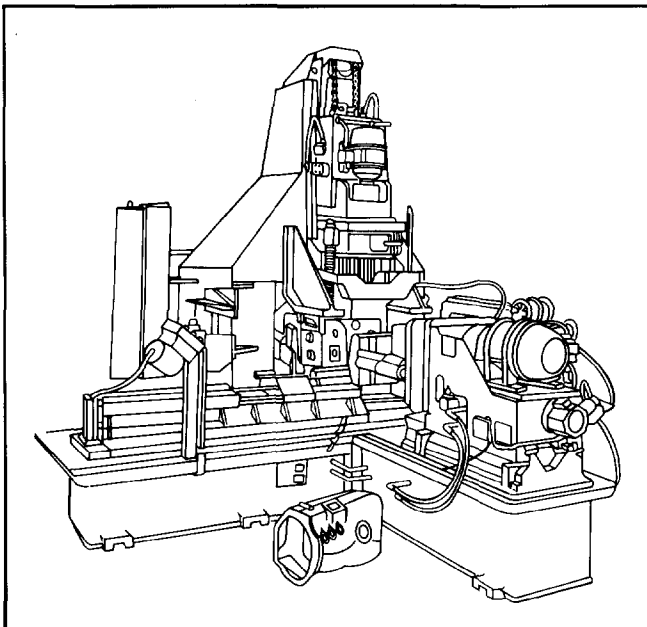


Fig. 15-95 Special combined-operation machine used for the production of tractor transmission cases. (Snyder Corp.)

machines can be two, three, or four way, depending on how many sides of the workpiece are to be machined. Such machines permit one or more of the basic metalworking operations on each part face, including milling, drilling, tapping, and spot-facing, which do not require the movement or rotation of the workpiece during the process. Automatic loading or unloading features are not usually provided on special machine tools of this type, although it is often feasible to clamp the part in the fixture outside the machining area and slide it on rails into the machining position for clamping. Flexibility in such a combined-operation machine is limited, but can be provided by using indexing or shuttle-type heads. Such machines also are capable of being readapted for new-model or part changes at the end of a production run.

DOUBLE-END MACHINES

The double-end or two-way type of machine combines two machining units to perform production operations. A part is chucked between two machining units, and both ends are machined. Such single operations as milling, drilling, chamfering, facing, centering, or boring can be performed economically on double-end machines. Examples of double-end boring machines are discussed in Chapter 8, "Turning and Boring"; duplex milling machines, in Chapter 10, "Milling"; and center drilling and facing machines, in a previous section of this chapter. Flexibility features can include interchangeable fixtures, movable or interchangeable heads, speed-changing devices, and adjustable stops. More automation can easily be applied by adding automatic feeding, loading, and unloading devices.

SHUTTLE-TYPE SPECIAL MACHINES

A higher degree of automation refinement of special machine tools is achieved with shuttle or line-index machines, such as the one shown in Fig. 15-96. On these machines, the workpiece is loaded in a fixture, indexed in a straight line to one or more

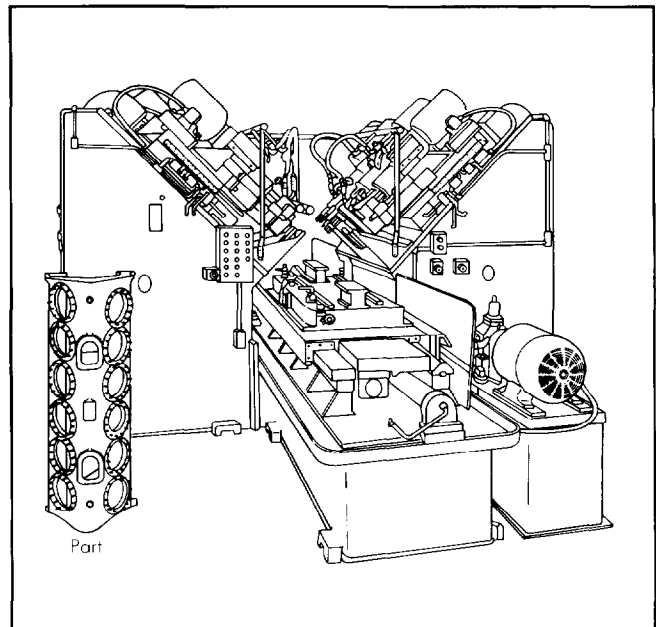


Fig. 15-96 Special line-index machine for drilling and tapping large V-12 engine blocks. (Snyder Corp.)

machining positions between single or opposed machining heads, machined, indexed to subsequent machining positions, and then indexed back to the unloading position. The number of machining stations is controlled by the number and type of operations, the required production, and the size of the part. This type of special machine tool is in the medium to low-production category but provides some of the automated features of automatic transfer machines (discussed in a subsequent section of this chapter). Heavy parts or parts of odd shape are ideal applications for shuttle or line-index machines. Some flexibility in production can be achieved by providing for head and fixture changes, but such machines should be considered mainly for the efficient production of a single part in the low to medium-production range. Numerical control is being used on some shuttle machines.

TRUNNION-TYPE SPECIAL MACHINES

The simultaneous operation at two or more machining stations is the next-highest degree of special-machine-tool automation. This is sometimes done in the higher production ranges on trunnion-type machines. In these machines (see Fig. 15-97), several fixtures are mounted on a vertical table or trunnion between opposed machining heads and indexed from one machining station to the next. All machining operations are performed simultaneously, and a finished part is produced with each index of the trunnion. It is possible to perform machining operations on five sides of each workpiece and from the periphery of the trunnion housing if desired.

The part is loaded and unloaded at one station. Some part-production flexibility can be had on trunnion-type machines by providing interchangeable heads and fixtures or fixture details for similar parts which require milling, drilling, boring, reaming, countersinking, and related operations on both ends. Maximum accuracy in trunnion-type machines demands rugged design and provision of individual bushing plates for each

AUTOMATED AND SPECIAL-PURPOSE MACHINES

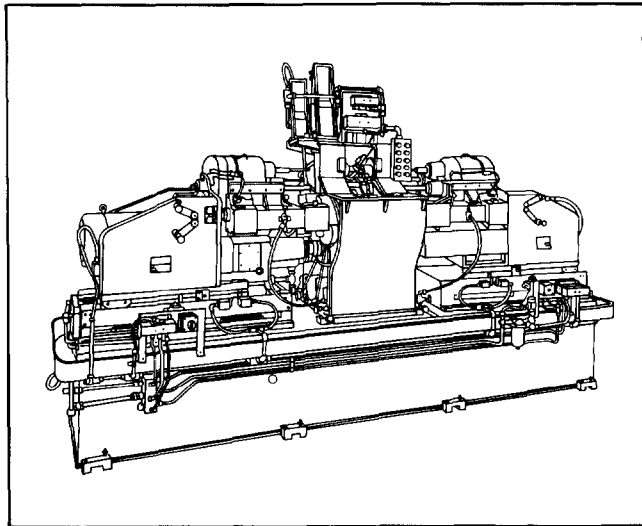


Fig. 15-97 Trunnion-type machine for drilling and milling grooves in a variety of differential spiders. (Snyder Corp.)

station, each of which picks up its own locating pins in fixture bushings. For many applications, dial-type machines have replaced trunnion-type machines.

DIAL-TYPE MACHINES

Higher production rates in a more compact floor space are achieved in automated special machines so designed that the parts are mounted in fixtures on a horizontal-index table and indexed from one station to the next in front of radial, horizontal, or vertical machining units (see Fig. 15-98). With one part in each fixture, two part faces are generally machined. Additional operations can be performed in a machine of this type by clamping two or more parts in each fixture in different positions to present more part areas for machining. One or more finished parts are produced with each machine index.

With modular construction, these dial-type (rotary-index) machines permit tailoring to specific requirements. Workpieces can be loaded and unloaded manually or automatically, and robots are being used for handling in some applications. Rotary index dials are available in various diameters to accommodate different sizes of workpieces and a number of operations. In some cases, rotating workholding fixtures are employed to allow the tools to reach different surfaces. Multiple-spindle heads are common on dial-type machines.

CENTER-COLUMN MACHINES

One limitation of the dial-type machine is that the number of vertical units limits the number of horizontal units that can be placed around the index table. The maximum number of workpiece faces and machining operations in a machine requiring minimum floor space is provided by the automated center-column special machine (see Fig. 15-99). Here, the parts are mounted in fixtures on a horizontal-index table which is indexed from station to station. The vertical machining slide units are mounted on a center column, and the radial horizontal or angular units are mounted around the periphery of the index table. The parts are loaded and unloaded at one station. All machining operations occur simultaneously, thus permitting one or more finished parts to be produced with each index. In center-column machines, more than one part can be clamped in

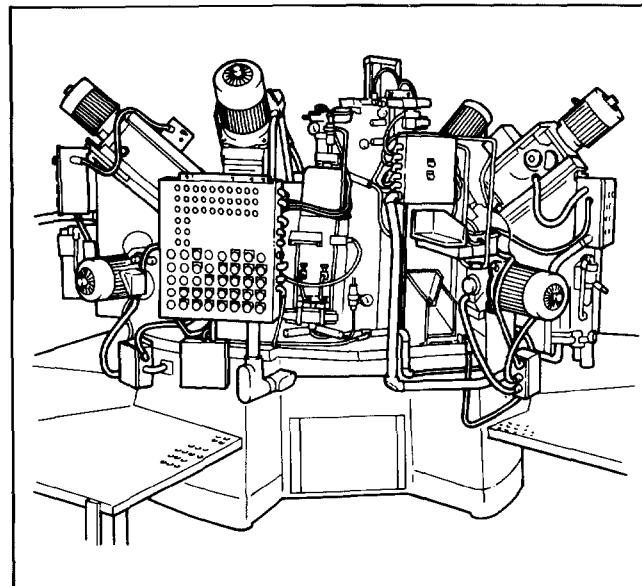


Fig. 15-98 Dial-type (rotary-index) machine with horizontal and angular-spindle heads. (Kingsbury Machine Tool Corp.)

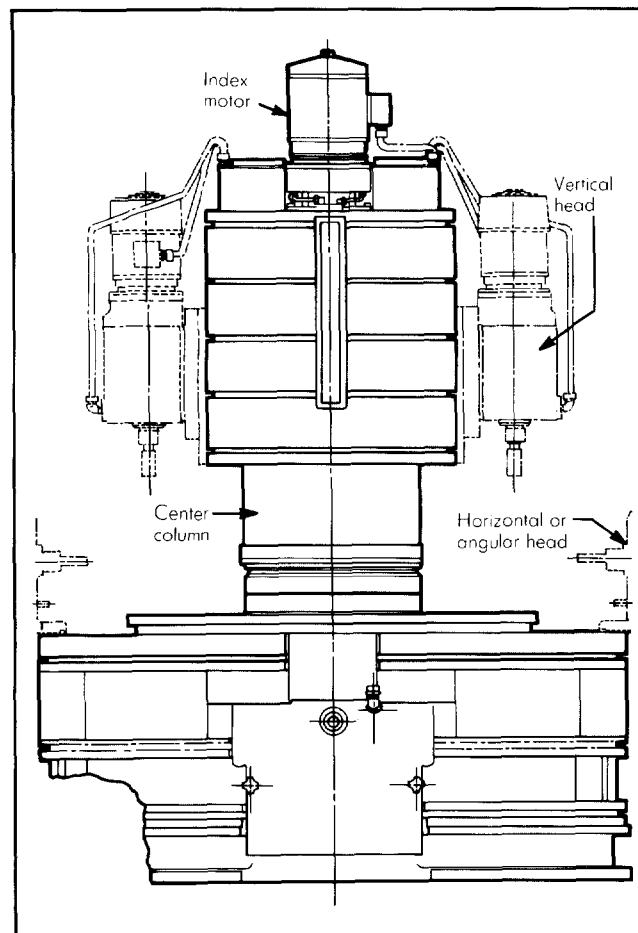


Fig. 15-99 Center column supports vertical heads on dial-type machine. (Kingsbury Machine Tool Corp.)

AUTOMATED AND SPECIAL-PURPOSE MACHINES

each fixture, either to complete the machining of a part or to produce several finished parts with each index of the machine.

MODULAR CONSTRUCTION UNITS

Almost any configuration of special-purpose machines can be made with modular units and building-block construction to perform various operations in proper sequence on different products. Various types and sizes of power feeding units, equipped with tooling devices such as milling heads and single or multiple-spindle drilling heads, can be mounted on standard bases, columns, and angular risers. The bases and columns can be arranged around a central base containing an index table (as on a dial machine), or along a shuttle-type or in-line transfer machine, and equipped with the required number of work-holding fixtures. Standards for the mounting and attaching surfaces; bolting of main bases, wing bases, feed units, adapters, and vertical and angular columns; and uniform workloading heights have been established by ANSI Standard B5.43, "Modular Machine Tool Standards" (see Fig. 15-100). A metric version is available from ASME as ANSI Standard B5.43M. Power units, bases, columns, and other modular components are available from many machine tool builders for making "do-it-yourself" machines.

Power feeding units can be either way or quill type, depending on the operation to be performed; actuation can be hydraulic, pneumatic, or electromechanical. The hole pattern to be produced, hole sizes, and tolerances that must be maintained are important considerations in selecting power feeding units.

Way-Type Power Feed Units

Way-type units usually consist of a cast-iron or welded base equipped with two hardened and ground steel ways. A cast-iron saddle, which slides on the ways and carries the tooling head (along with means for driving it), is retained by a set of keepers and is fitted to the width of the ways by means of a gib. The saddle, which either can be flat or can have a head-mounting

bracket, is generally driven hydraulically (through a cylinder) or mechanically (by means of a leadscrew).

Hydraulically driven way units can be of either the self-contained or the external-power-unit type (see Fig. 15-101). Self-contained types, in which the hydraulic equipment (including pump, reservoir, and cylinder) is carried as a part of the saddle, conserve floor space, but they are generally available only in lighter duty models. External units have an external hydraulic power unit, consisting of an electric motor, combination pump and reservoir, and filters. Valving controls the direction and feed rate of the saddle. The normal cycle for such units is rapid forward, feed, and rapid return, but additional functions such as jump, peck, and reverse feeds can be added. Limit switches and positive stops control the length of stroke, and timers and solenoids are sometimes used to vary the cycle.

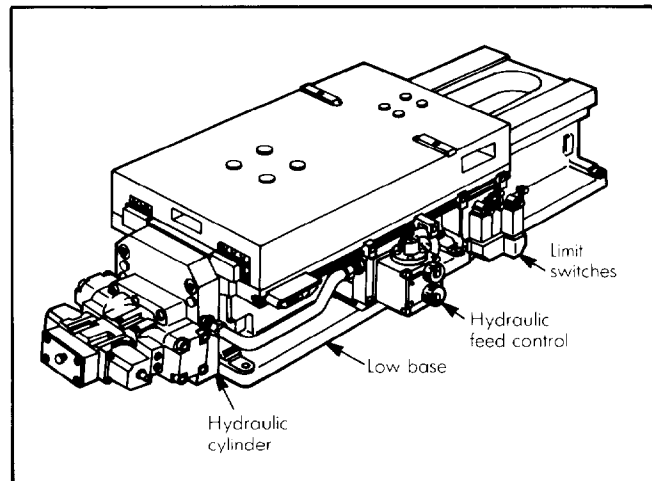


Fig. 15-101 Hydraulic way-type feed unit of the external power type. (Bendix Machine Tool Corp.)

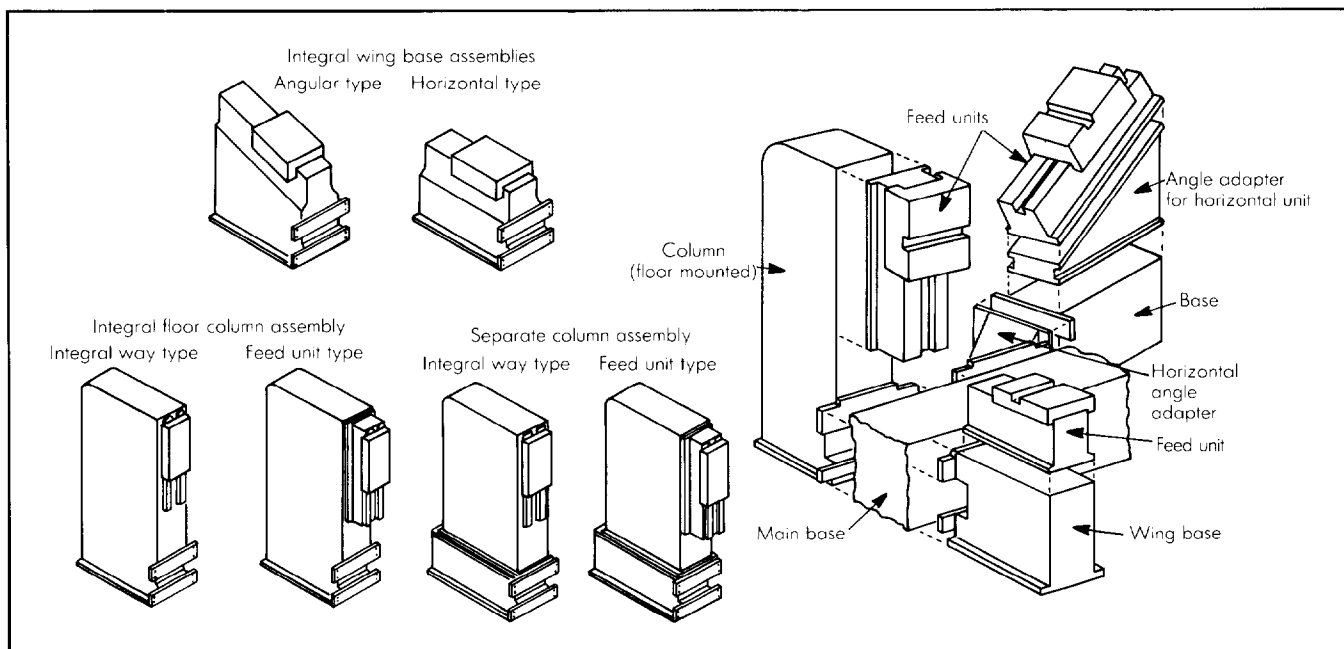


Fig. 15-100 Basic components and units, and column and wing-base assemblies. (ANSI Standard B5.43, "Modular Machine Tool Standards")

AUTOMATED AND SPECIAL-PURPOSE MACHINES

Mechanically driven way units normally have a ball nut mounted on the underside of the saddle and a mating ballscrew (of sufficient length to provide the required stroke) mounted in the way base. The screw is driven by two motors, a reducer, and a brake, all mounted on the rear of the way-unit base. One motor (for feeding) drives through the reducer, and the other (for rapid traverse) does not. When both motors are started, the saddle travels forward in rapid traverse. When a switch is tripped, the rapid-traverse motor is stopped and the brake is applied. The other motor continues to run to drive the saddle in the feed mode. When the full-depth switch is contacted, the brake is released, the rapid-traverse motor is started in reverse, the feed motor is stopped, and the saddle returns rapidly to its starting position, at which the rapid-traverse motor is stopped and the brake is applied. All the cycle variations possible with hydraulic way units can be obtained with mechanically driven units. A mechanically driven, way-type unit equipped with precision boring spindles is shown in Fig. 15-102.

Another system available, utilizing the two motors and brake concept, adapts a programmable limit switch and controls. This design compensates for brake wear and allows programming functions such as feed position and feed mode.

Mechanical feed units are now available with a single motor drive system, eliminating the need for two motors per unit, clutch/brake mechanical transmission devices, limit switches, and mechanical stops. One system makes use of a closed-loop servo drive with a-c or d-c motors, tachometer, and built-in optical encoder. The system is programmable for increased flexibility, and all slide motions can be controlled by a microprocessor.

Another single motor system uses a servo drive with a pulse-width-modulated, brushless, a-c motor for variable speed operation. Speed, distance, and sequence parameters can be changed independently.

Quill-Type Power Feed Units

Quill-type units are intended primarily for comparatively light-duty operations. They are of the self-contained type and are generally hydraulically activated, hydraulically and pneumatically actuated, or mechanically actuated. The revolving spindle is contained in a quill which moves forward and backward. Tools may be mounted directly in the spindle, in a multispindle head (mounted on the front of the quill and driven by the spindle), or in a right-angle head attachment (see Fig. 15-103). A motor, mounted on the power feed unit, drives the spindle, usually through a spline to permit the quill and spindle assembly to move axially.

In the case of hydraulically actuated quill-type power feed units, the spindle motor also drives a hydraulic pump, and the pump body serves as a reservoir. A cylinder is attached to the quill to drive it axially, and quill movement is controlled by directional and flow-control valves. Cycle variations are obtained in the same manner as previously described for way-type units.

Hydraulically-pneumatically actuated quill-type units use air for rapid-traverse feed and return. They apply air to a booster cylinder and dashpot in a closed hydraulic circuit during the feed cycle. Oil in the closed circuit can be throttled by means of a variable orifice, and more consistent control can be obtained than with just a pneumatic circuit.

Mechanically actuated quill-type units are of the cam-operated or ballscrew-actuated types. With the cam-operated type, the desired cycle is controlled by the configuration of the

operating cam. A driving motor rotates the spindle and, through gears, drives the cam. This motor runs continuously; and to initiate a cycle, a clutch is engaged to drive the cam. Thrust capacity and stroke are limited by the mechanical members of the drive train. Maximum stroke length for this type of unit is generally about 4" (102 mm).

Although cam-operated units have been widely used and will probably continue to be used because they are simple, ballscrew units are becoming increasingly popular. An important advantage of ballscrew units is their longer stroke capabilities—up to about 10" (254 mm). Ballscrew units are also available with a-c servomotors and programmable limit switches.

When a power feed unit is mounted at an angle, usually more than 15° from the horizontal, it is recommended that counterweights be used. The counterweights can be actuated mechanically, hydraulically, or pneumatically; mechanical means is generally preferred. If counterweights are not used, some type of latch or shot bolt should be employed to keep the unit from moving forward during indexing or in case of power failure.

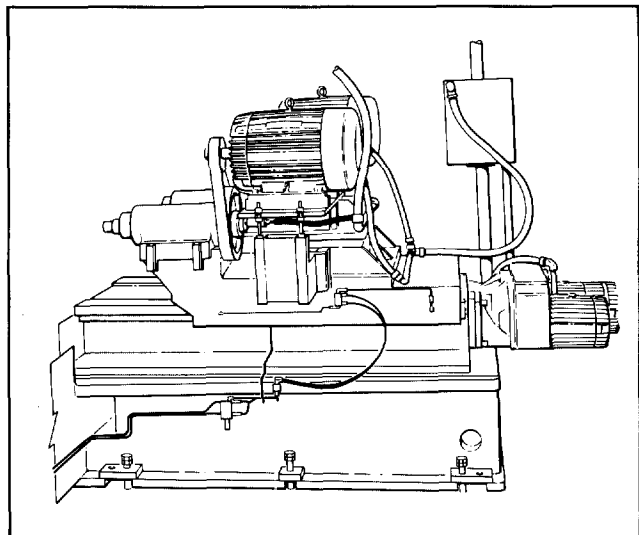


Fig. 15-102 Mechanically driven, way-type unit equipped with precision boring spindles. (Bendix Machine Tool Corp.)

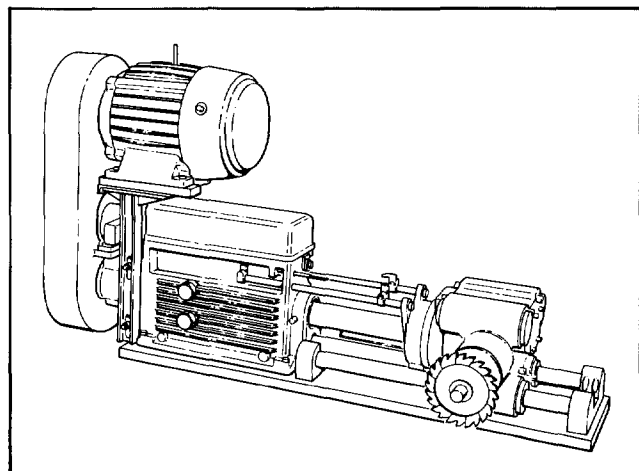


Fig. 15-103 A round-way, power feed unit equipped with right-angle milling head. (Drillunit, Inc., Bendix Corp.)

TRANSFER MACHINES

The highest degree of automation obtainable with special-purpose, multifunction machines is achieved by using transfer machines. Transfer machines are essentially a combination of individual work stations arranged in the required sequence, connected by work transfer devices, and integrated with interlocked controls. Workpieces are automatically transferred between the stations, which are equipped with horizontal, vertical, or angular units to perform machining, gaging, workpiece repositioning, assembling, washing, or other operations. The two major classes of transfer machines are rotary and in-line types.

An important advantage of transfer machines is that they permit the maximum number of operations to be performed simultaneously. There is relatively no limitation on the number of workpiece surfaces or planes that can be machined, since devices can be interposed in transfer machines at practically any point for inverting or rotating the workpiece, or orienting it, so as to complete the machining operations. Work repositioning also minimizes the need for angular machining heads and allows operations to be performed in optimum sequence. Complete processing from rough castings or forgings to finished parts is often possible.

One or more finished parts are produced on a transfer machine with each index of the transfer system that moves the parts from station to station. Production efficiencies of such machines generally range from 50% for a machine producing a variety of different parts to 85% for a machine producing one part in high production, depending upon the workpiece and how the machine is operated (material handling method, maintenance procedures, etc.).

All types of machining operations, such as drilling, tapping, reaming, boring, and milling, are economically combined on transfer machines. Lathe-type operations such as turning and facing are also being performed on in-line transfer machines, with the workpieces being rotated in selected machining stations. Turning operations are performed in lathe-type segments in which multiple toolholders are fed on slides mounted on tunnel-type bridge units. Workpieces are located on centers and rotated by chucks at each turning station. Turning stations with CNC are available for use on in-line transfer machines. The CNC units allow the machine cycles to

be easily altered to accommodate changes in workpiece design and can also be used for automatic tool adjustments.

Maximum production economy on transfer lines is often achieved by assembling parts to the workpieces during their movement through the machine. Such items as bushings, seals, welch plugs, and heat tubes can be assembled and then machined or tested during the transfer machining sequence. Automatic nut torquing following the application of part subassemblies can also be carried out. More detailed information on automatic assembly with transfer and other special machines is presented in Volume IV of this Handbook series.

Gundrilling or reaming on transfer machines is an ideal application provided that proper machining units are employed and good bushing practices are followed. Contour boring and turning of spherical seats and other surfaces can be done with tracer-controlled single-point inserts, thus eliminating the need for costly special form tools. In-process gaging of reamed or bored holes and automatic tool setting are done on transfer machines to maintain close tolerances.

Less conventional operations sometimes performed on transfer machines include grinding, induction heating of ring gears for shrink-fit pressing on flywheels, induction hardening of valve seats, deep rolling to apply compressive preloads, and burnishing.

Transfer machines have long been used in the automotive industry for producing identical components at high production rates with a minimum of manual part handling. In addition to decreasing labor requirements, such machines ensure consistently uniform, high-quality parts at lower cost. They are no longer confined just to rough machining and now often eliminate the need for subsequent operations such as grinding and honing.

More recently, there has been an increasing demand for transfer machines to handle lower volumes of similar or even different parts in smaller lot sizes, with means for quick changeover between production runs. Built-in flexibility, the ability to rearrange and interchange machining units, and the provision of idle stations increases the cost of any transfer machine, but such features are economically feasible when product redesigns are common. Many such machines are now being used in nonautomotive applications for lower production requirements.

Special features now available to reduce the time required for part changeover include standardized dimensions, modular construction, interchangeable fixtures mounted on master pallets that remain on the machine, interchangeable fixture components, the ability to lock out certain stations for different parts by means of selector switches, and programmable controllers. Product design is also important, and common transfer and clamping surfaces should be provided on different parts whenever possible.

ROTARY TRANSFER MACHINES

Rotary transfer machines (see Fig. 15-104) are a relatively new development. They combine many of the desirable features of dial-type machines (discussed previously in this chapter) with those of in-line, pallet-type transfer machines (described next), while eliminating some of the disadvantages of each. While rotary transfer machines are similar in appearance to dial-type

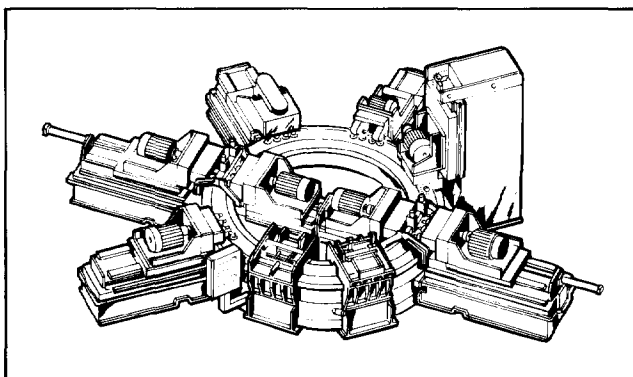


Fig. 15-104 Rotary transfer machine on which workholding pallets are transferred in a circular path. (Greenlee Manufacturing Systems Div., Ex-Cell-O Corp.)

TRANSFER MACHINES

machines, there are major differences between the two. For example, rotary transfer machines have no dial or table and no center column.

On rotary transfer machines, workpieces are located and clamped in floating, pallet-type fixtures that are indexed in a circular path. This eliminates the need for pallet-return conveyor systems (required on palletized, in-line transfer machines) and substantially reduces floor space and installation requirements. The centers of the machines are open, permitting horizontal, vertical, and angular machining units to be mounted inside as well as outside the pallet-carrying rails. The number and positions of the machining units can be easily changed to suit production requirements.

Pallets are accurately located independently at each station with pins and wedges. They are clamped to a fixed bed, rather than to a movable table, as is the case in dial-type machines, thus providing increased rigidity. Indexing fixtures or fixtures that hold multiple workpieces are mounted on the pallets when required. Programmable controllers are used on most rotary transfer machines and many of the other machines discussed in this chapter to direct and monitor all machine functions.

While rotary transfer machines are lower in cost and require less floor space than in-line, pallet-type transfer machines, they are generally limited to smaller workpieces and fewer stations.

IN-LINE TRANSFER MACHINES

With in-line, sometimes called straight-line, transfer machines, workpieces always move in a straight line. These machines are generally suitable for operations involving larger workpieces and for those in which more work stations are required.

Major types of in-line transfer machines are sliding or free transfer, walking-beam (lift-and-carry) transfer, and palletized transfer. The type of transfer used for moving workpieces from station to station is usually dictated by the shape, size, and rigidity of the workpieces, as well as their locating surfaces or points.

Sliding and Walking-Beam Transfer Methods

When the shape of the workpieces is suitable, the most economical method of moving them from station to station is via a synchronous free-transfer machine using a transfer or shuttle bar, without any fixture or workholding means during transfer. With synchronous (intermittent) motion, all workpieces are transferred at the same time.

A method of transfer sometimes used when workpieces have flat surfaces is sliding of parts from station to station on skid rails by means of a transfer-bar mechanism (see Fig. 15-105). Other typical methods of transfer used are shown schematically in Fig. 15-105. One of these is the walking-beam (lift-and-carry or rise-and-fall) system, which picks the part up at one station, carries it to the next station, and lowers it into position without damaging the work surfaces. This method is frequently used for parts that do not have sliding surfaces or that are unsuitable for sliding. Advantages of the walking-beam system, compared to the sliding method, include better control, eliminating the possibility of workpiece damage because of sliding, and the ability to use fixed pins for workpiece location. For heavy parts such as railroad-car axles, an overhead lift-and-carry transfer system (not shown) is sometimes used. Such systems have arms that lower to grip all workpieces, raise, traverse, lower, unclamp, and retract. Smaller parts such as automotive-engine camshafts to be turned are carried between the lathe-type stations in a free-transfer lift-and-carry system.

When workpieces can be trapped on both ends, a rotating-finger slide-type bar is often used. As the shuttle bar rotates, each workpiece is trapped at its station by means of the finger. Each part is then pushed into the next station, where it is accurately located by jacking against finished surfaces or over locating pins and then is securely clamped. As machining operations are performed, the shuttle bar is simultaneously rotated, disengaging the fingers from the workpieces, and returned to its starting position, ready for the next cycle. A third type of transfer bar is a disappearing-finger (pawl) design, which is simple and inexpensive.

For long operations (such as boring) that cannot be divided between two or more stations, double indexing can be used. With one system, two workpieces are collected and transferred through two stations and are left there while other workpieces pass through two cycles. This necessitates use of a separate transfer bar that is actuated during alternate movements of the main bar. Double indexing is also done with the same bar used for regular transfer. The combined times for double indexing and machining must be no longer than the allowed cycle time.

Palletized Transfer

When workpieces are of a shape that is difficult if not impossible to handle in free-transfer systems, if they are not provided with suitable locating holes or surfaces, or if the nature of the operations does not permit other transfer means, workpieces are often placed in individual pallets. The pallets are holding fixtures in which the workpieces are located and securely clamped throughout all operations. Rotating transfer bars are sometimes used to traverse pallets to successive stations. Palletized transfer machines are available with walking-beam (lift-and-carry) systems. Pallets can also be linked together and pushed or pulled; for small parts, a continuous chain is sometimes used. A schematic drawing of a synchronized pallet-type, bar transfer system, is shown in Fig. 15-105. At each station the pallets are accurately located and securely clamped. At the end of the machine, empty pallets are returned to the loading station through a wash and blowoff station by a power conveyor.

Palletized lines are of either rectangular or square, closed-loop configuration. Figure 15-106 shows a palletized transfer line connected to a free-transfer, lift-and-carry line for producing rear-axle housings. The housings are transferred axially (end to end) in the palletized machine, and then rotated 90° in a horizontal plane for transfer through the lift-and-carry machine in a transverse position. Workpieces must be unloaded from the pallets before they enter the free-transfer line. Provision of rapid changeover features such as swivel machining units permits this system to handle 10 different housings, which are grouped into three families.

Palletized transfer machines are generally more expensive than free-transfer types because of the increased cost of the pallets, the automatic pallet clamping and unclamping mechanisms, the pallet-return conveyor, and the washer that is needed to clear the pallets of chips. However, such machines are effective when parts cannot be freely transferred. They are also particularly effective when a variety of workpieces with common machining operation requirements are to be processed over one transfer line.

Transfer-Bar Operations

Transfer-bar systems can be operated hydraulically or mechanically. Hydraulic systems include cylinders and separate

TRANSFER MACHINES

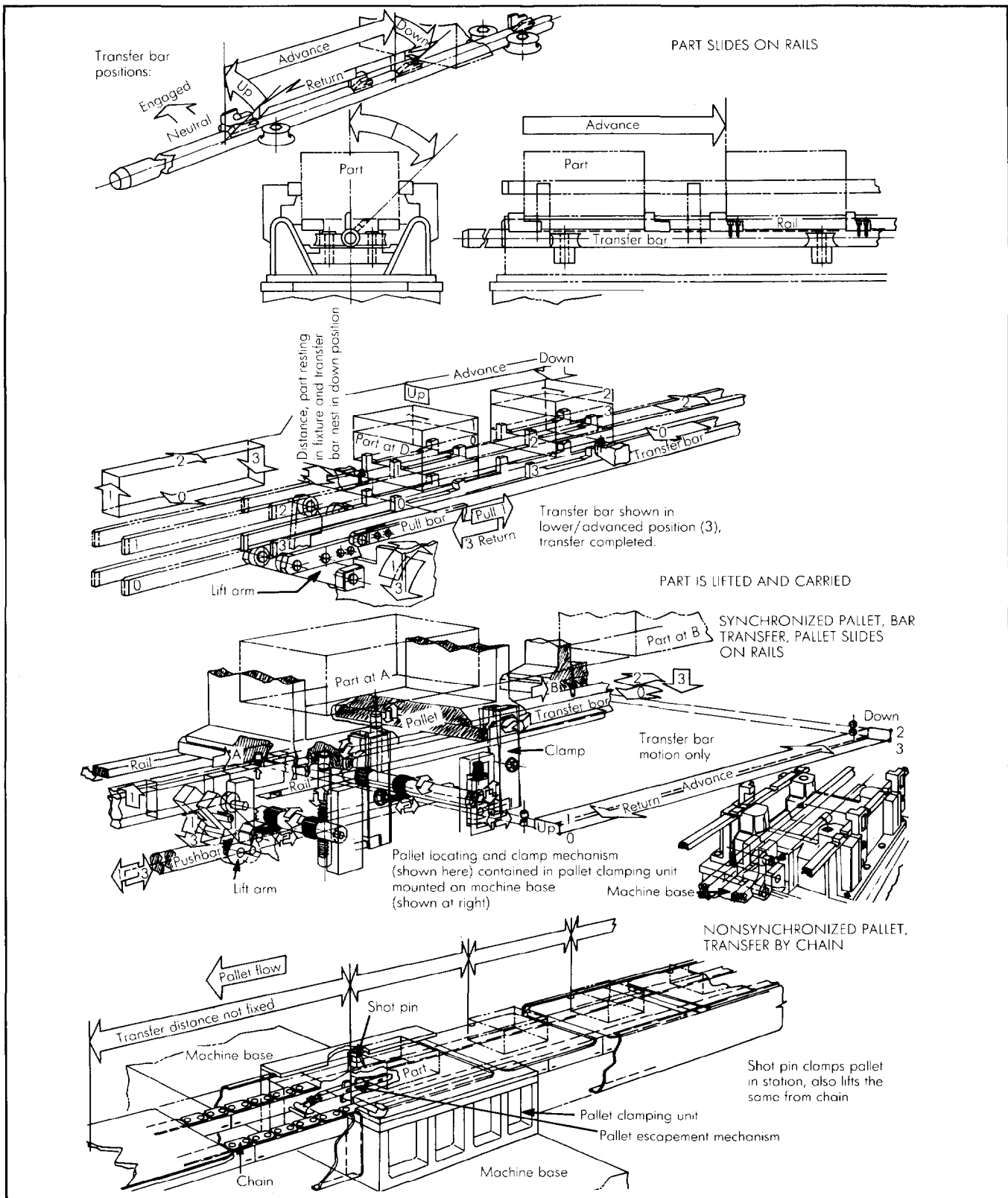


Fig. 15-105 Typical transfer methods. (The Cross Co.)

TRANSFER MACHINES

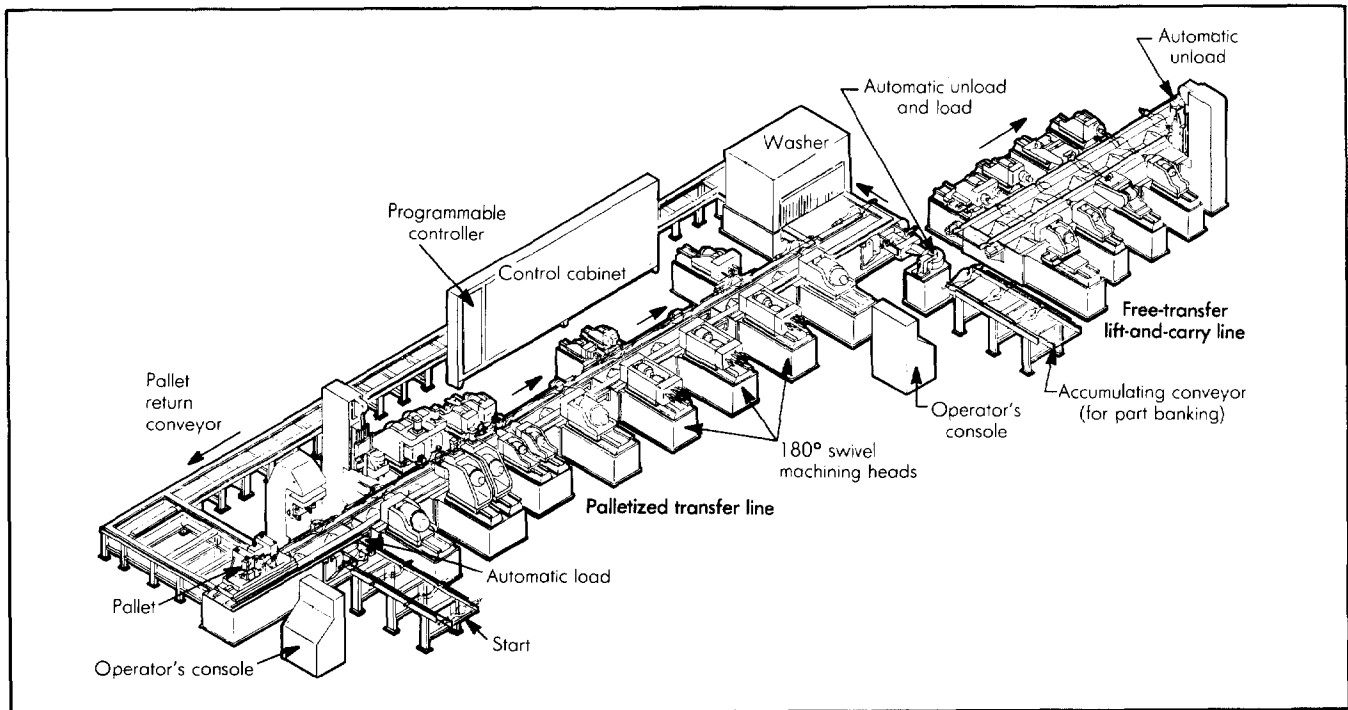


Fig. 15-106 System for machining 10 different rear-axle housings combines a palletized transfer line and a free-transfer, lift-and-carry line. (Snyder Corp.)

pumps and reservoir tanks. Mechanical systems generally use a reversing-brake motor, with a worm and crank arm that provides a harmonic-drive arrangement. Such mechanical systems are often preferred because they provide optimum acceleration and deceleration characteristics that permit rapid and smooth part transfer, avoid possible hydraulic leaks, and have lower noise levels.

Components of a mechanical transfer drive offered by one machine tool builder are illustrated in Fig. 15-107. This unit provides high-speed transfer by driving a crank arm from a heavy-duty, double-enveloping worm and gear set. The crank arm imparts motion to the main transfer arm through a slider block which provides transfer repeatability in the range of 0.001-0.002" (0.03-0.05 mm). Harmonic motion of the drive, coupled with the natural acceleration period of the electric motor, provides smooth acceleration and deceleration while avoiding high velocities. A creep motor is provided for manual operations, and a breakaway arm and several other safety devices are provided to avoid damage if the transfer bar encounters an obstruction. Transfer distances are changed by varying the length of the crank arm, and speeds are changed by varying belt or gear ratios.

With a unit offered by another builder, transfer is accomplished by cycloidal motion using a motor-driven cluster of gears and pivot-arm linkage to provide smooth acceleration and deceleration. During acceleration and deceleration, the drive gear travels in the opposite direction of rack travel. Maximum rack speed is attained while the rotating drive gear moves in the same direction as the rack. Acceleration and deceleration rates, index distances and times, and dwell times can be varied by changing gear sizes, linkage lengths, motor speed and power, and other parameters. Fast transfer is attained with accurate positioning of the transfer rack.

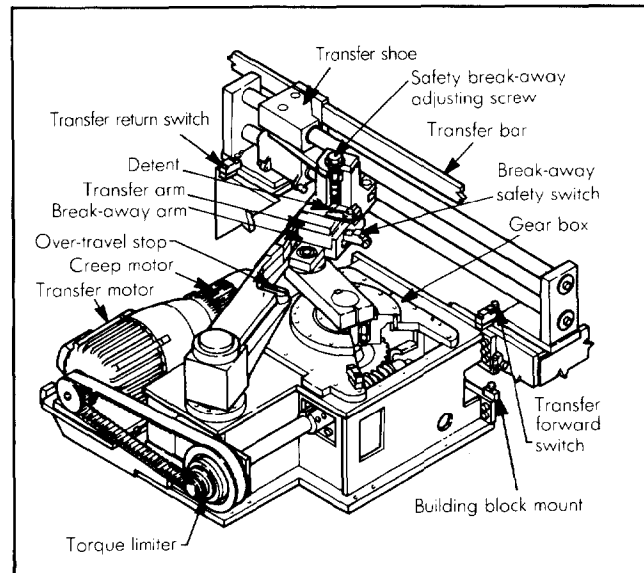


Fig. 15-107 Components of a mechanical transfer drive unit. (Greenlee Manufacturing Systems Div., Ex-Cell-O Corp.)

Workpiece turnover and orienting devices are often used between groups of work stations on synchronous free-transfer lines to permit new surfaces to be presented to the horizontal, vertical, or angular machining units. These can be simple devices that use the transfer motion to rotate a workpiece on-the-fly. For more complex workpieces or motions, they are generally hydraulically operated and often require a considerable amount of design ingenuity. Without workpiece-orienting

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mechanisms, the utility of transfer machines would be hampered and floor-space requirements would be increased.

Nonsynchronous Transfer

Synchronous, index-type transfer lines, such as those previously discussed, operate at constant speed because of their fixed cycle. As a result, the production rate is limited by the cycle time of their slowest station and the operator cannot vary the production rate. When the length of time required to perform different operations varies greatly, as may be the case with certain assembly and testing and some machining operations, nonsynchronous transfer or accumulative-type systems with free-floating pallets are widely used. A major advantage of nonsynchronous transfer machines is increased versatility because the workpieces move independently.

On most nonsynchronous transfer machines, pallets are freely supported and are moved from station to station by a continuously running endless chain (see Fig. 15-105). Each self-contained station is independent. Pallets are accumulated ahead of each station and are supplied to the station on demand. When one or more stations are down for any reason, others can continue to operate from the float of parts, thus minimizing production interruptions. Manual or automatic stations can be added or removed and spaced at random to accommodate product-design changes or to increase or decrease the automation of the system. For operations requiring longer cycles, parts can be indexed into identical stations. Also, parts can be transferred through several short-cycle stations while a long-cycle operation is being performed on another part.

MODULAR CONSTRUCTION UNITS

Standard modular bases, columns, and adapters, discussed in the preceding section of this chapter on special-purpose machines (see Fig. 15-100), are used with building-block

construction in making transfer machines. Standards for the mounting and attaching surfaces; bolting of main bases, wing bases, feed units, adapters, and vertical and angular columns; and uniform workloading heights are presented in ANSI Standard B5.43, "Modular Machine Tool Standards." A metric version has been published as ANSI Standard B5.43M.

MACHINING UNITS

Various types and sizes of tooling, powered feeding units are mounted on the standard bases, columns, and adapters of transfer machines. Way and quill-type feeding units, powered hydraulically, pneumatically, or electromechanically, are discussed in the preceding section of this chapter devoted to special-purpose machines (see Fig. 15-101, 15-102, and 15-103). There is a trend toward the increased use of mechanically powered feeding units on transfer machines, but hydraulic units are sometimes preferred for certain operations, such as positioning and controlled-depth operation. Both mechanical and hydraulic units are used on some transfer machines.

A mechanical-feed machining unit supplied by one builder of transfer machines is shown in Fig. 15-108. This unit has an electrically driven ballscrew and provides a smooth, positive feed at a constant rate. Such mechanical units are generally preferred when it is essential to maintain a definite chip per tooth on the cutting tools, maintain accurate time cycles, and provide fast cycling. They also have a lower noise level, eliminate the possibility of hydraulic leaks, and often provide longer tool life. Mechanical units can provide dwell functions and usually have built-in torque limiting safety devices.

Mechanical feed units are now available with a single-motor drive system, as discussed in the preceding section of this chapter on special-purpose machine tools. These units use a servo drive with an a-c or d-c motor for variable-speed operation. An advantage of these programmable units is the

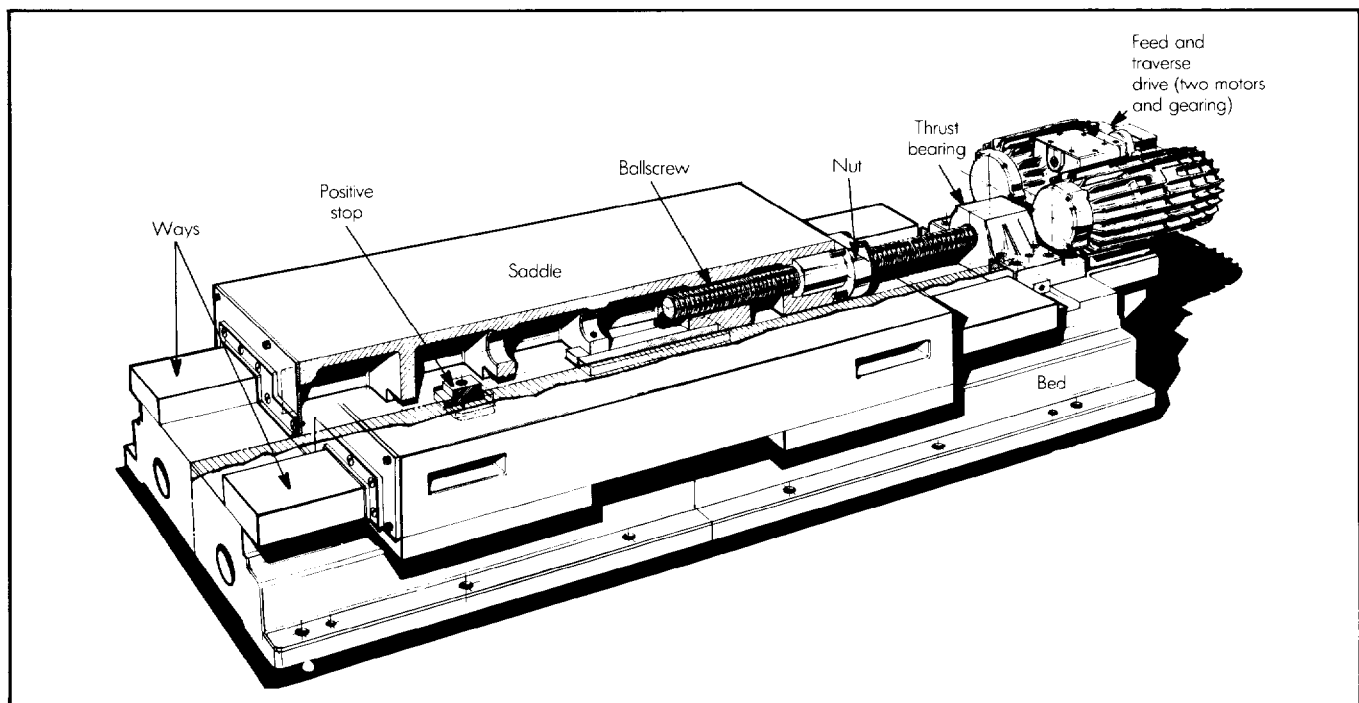


Fig. 15-108 Mechanical unit provides a smooth and positive feed at a constant rate. (The Cross Co.)

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elimination of the need for two motors per unit, a clutch/brake mechanism, limit switches, and a mechanical stop.

A microprocessor-controlled, programmable, servo drive system offered by one builder is illustrated in Fig. 15-109. It uses a brushless a-c synchronous motor and a position-monitoring encoder. In this design, the center line of the ballscrew is aligned with the top of the slide ways to reduce the height of the unit.

In transfer machines (and other industrial equipment), the use of a-c servomotors and microprocessor technology provides increased flexibility. Indeed, the character of the transfer-line concept is changing as a result of such new technologies. For example, some new transfer lines have been built without hydraulic power units—drives for slides and clamping systems are provided by microprocessor-controlled a-c servomotors. Increasingly, electronic intelligence at individual stations of transfer equipment may lead the way toward the integration of programmable stations—machining centers integrated with various dedicated work stations within a single transfer machine. Some experts expect this approach to become a viable solution to upper midvolume manufacturing problems that feature too high a production volume for manufacturing techniques (such as stand-alone NC-equipment or FMS manufacturing) and too low a production volume for traditional transfer line technologies.

While standardization is important from the standpoint of increased versatility, buyers of transfer machines should not overemphasize the value of standardized machining units. Often the key to meeting a specified production rate may lie in the ability to combine two or more machining operations into a single nonstandard head. Special heads can frequently reduce cycle time, increase production capability, and reduce the length and cost of the line.

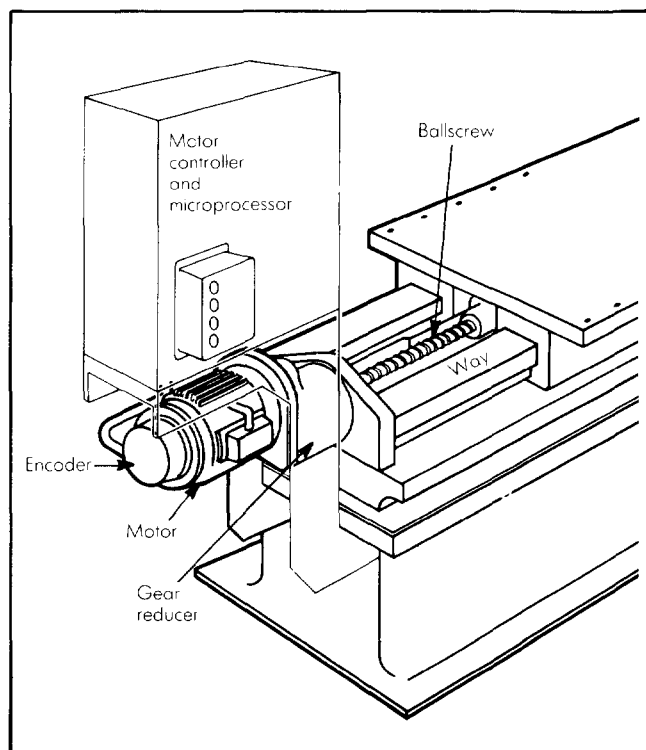


Fig. 15-109 Microprocessor-controlled servo drive system for mechanical feed unit. (The Ingersoll Milling Machine Co.)

Too much tooling at any one station, however, should be avoided. While adding stations to simplify the operations performed at each will increase the length and cost of a machine, return on investment may be rapid because of reduced maintenance and increased efficiency. Also, more suitable cutting speeds and feed rates can be used for individual operations than would be possible for combined operations at single stations. Close-center spindles should also be avoided whenever possible. More open construction permits better head design, simpler gear trains, and larger bearings.

Swivel machining units having rotating-tool potheads at both ends (see Fig. 15-110) are used to reduce changeover time. These units swivel 180° in a horizontal plane to permit two different hole patterns, as well as different-sized holes if required, to be drilled in dissimilar parts at one work station. Air pressure is used to lift the unit for easy swiveling. Rotating heads and horizontal and vertical shuttle heads are used for the same purpose. In addition to reducing changeover time, such units also reduce the overall length of transfer lines by eliminating the need for additional work stations. Another means of speeding changeover is the use of indexing turret heads.

Way-type machining units, each equipped with a dual-spindle, master drivehead, are also used to reduce changeover time. Each master drivehead is powered by two motors and has two change gearboxes to alter the speed of either spindle. One or both motors on each head can be used as required. Two-directional motors with magnetic brakes are employed if tapping is to be performed. One or two interchangeable tooling potheads can be mounted on each master head, depending on requirements, and each has its own gear drive for the individual spindles. The potheads are pretooled, but in some cases it may be necessary to change only tools instead of heads. The easily changed potheads are located by dowels and splines in the master heads, and clamped in position by bolts. Use of the interchangeable potheads permits varying the size, number, and location of spindles for different hole patterns.

Preset and quick-change tools, mounted on conveniently located control boards that automatically signal required toolchanges, are helpful in reducing downtime and speeding changeover. Turret toolholders are also being used on transfer machines. Each turret holds several tools, and a new tool is automatically indexed into position after the old tool has cut a

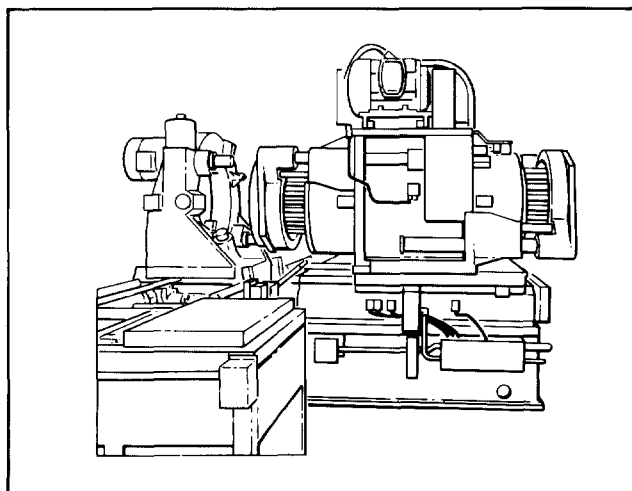


Fig. 15-110 Swivel machining unit has rotating-tool potheads at both ends to produce different hole patterns in two workpieces.

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certain number of parts. The entire turret can be replaced with one having sharpened and preset tools.

CONTROL OF TRANSFER MACHINES

Electrical interlocks are provided on transfer machines to show that a workpiece has been loaded at the first station and another part unloaded from the last station before transfer takes place. At each station, electrical interlocks also assure that workpieces or pallets are properly located and securely clamped before the machining units perform their operations. All machining, inspecting, ejecting, repositioning, and orienting units, as well as the lubrication and cutting fluid systems, are also electrically interlocked to show their operating status and ensure proper cycling. Pressure switches and solenoid-operated valves are often provided to prevent damage or stop the machine in case of hydraulic, air, or electrical power failure. In addition to full controls on a conveniently located operator's console, pushbuttons with selector switches are generally provided at each operating unit so that the units can be operated independently during setup or changeover.

On some versatile transfer machines, electrical interlocking assures proper setup when different parts are being produced. The operator simply selects the part to be produced by means of a switch on the console; the machine cannot be cycled until the required heads and slides for that particular part are in their required positions. In some cases certain heads are automatically made inoperative when specific parts are being produced.

Some means, such as pilot lights on the control console, are provided to quickly locate improperly operating units or other functions, thus minimizing downtime. A disconnect switch or circuit breaker should be provided. Limit switches must be kept away or sealed from the cutting fluid, hydraulic fluid, and other wet areas.

Conventional electromechanical relay sequence-control panels, long the standard on transfer and other machines, are being superseded by programmable controllers and microprocessors. Reasons for this change include increased versatility (easy reprogramming), greater reliability, floor-space savings, fast setups, diagnostic capability for fast troubleshooting, reduced downtime and maintenance, and easy interfacing with computers.

Interfacing of transfer-machine controls for future connection to computers is now common practice. Computers are being used to control some transfer machines. Functions performed by the computer include making necessary logic determinations, signaling for each action in the operating sequence, and supplying data for management information systems (production counts, downtime, comparing actual and planned cycle times, etc.) In general, however, computers have been found more valuable for monitoring transfer machines, including a rapid means of diagnostic troubleshooting. Diagnostic systems are resulting in increased productivity from transfer machines.

GAGING ON TRANSFER MACHINES

Originally, when extremely close tolerances were required, transfer machines performed only roughing and semifinishing operations. Today, many precise parts are finished completely, and as a result, many in-process and final gaging operations are performed. Details on automatic gaging are presented in Volume IV of this Handbook series.

It is important that any conditions that might damage tooling on transfer machines be detected immediately. In the case of tapped holes, probing operations are carried out before and

after tapping. This assures that the holes are drilled properly before tapping and that no broken taps remain in the holes. When such conditions are detected, the machine shuts down automatically and lights on the control panel indicate the station at which trouble has occurred. Probe units can also be used to assure that forgings or castings are within acceptable tolerances at the loading stations. Several designs of broken-tool detectors are being used on transfer machines. One system uses a magnetic field created by an electrically charged coil, with any broken tool causing oscillations in the circuit. Another system uses photoelectric cells to detect broken tools. Air-operated probes that check the tools provide a reliable system.

Precision-bored holes are also frequently gaged on transfer machines. These gaging operations can have so-called dimensional adaptive controls that automatically reset the tools in preceding boring stations by means of feedback signals to correct undersize or oversize conditions and compensate for tool wear. With one in-process gaging system, measuring probes gage the bore and send signals to an amplifier at which the existing size is compared to required size; a stepping motor resets the boring tool as required. Another pneumatic-hydraulic system uses an air gage that provides a back pressure corresponding to the actual diameter of the bored hole. When deviation in size exceeds a preset limit, a controller changes the position of the tool. Air testing of castings for leaks is another operation often performed on transfer machines. Some machines automatically eject castings from the line if they fail to pass the leak test.

The decision as to the amount of gaging to provide on a transfer machine is generally a matter of economy and judgment, but there are other factors that should be considered. Too much gaging may prove to be uneconomical. However, when the gaging or probing devices assure a minimum number of unsalvageable rejects due to broken or worn tools, the equipment is well worth its extra cost.

MAINTAINING TRANSFER MACHINE EFFICIENCY

It is important that toolchanging schedules be established and that sharp tools be available at all times on transfer lines. Tool control boards are one method of instituting proper toolchanging schedules. A new trend on machines equipped with controllers is to preprogram toolchanging schedules and to use computer monitoring to assure that the schedules are followed.

Since there is a continuing trend toward the use of transfer machines designed to produce a variety of parts in lower production volumes, it is important that toolchanges be made with maximum facility. Segmented transfer lines that provide space or idle stations between work stations permit good tool accessibility and easy maintenance. Even on nonsegmented lines, sufficient distance should be provided between successive stations to permit good accessibility for servicing and toolchanging and to permit occasional visual inspections. Future work stations are also often desirable to accommodate possible product design changes.

Another approach to maintaining high efficiency of transfer machines in the high-production, single-workpiece category (especially long machines with numerous stations) is to build the machine in sections and provide means for banking parts between the sections. Then, by establishing a stock of qualified parts between successive stations, it is possible to keep some sections in production while others are down for maintenance,

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toolchanging, or other reasons. This arrangement avoids a complete interruption of production.

Efficient chip-disposal means is an important consideration. High-pressure, flume-type, chip-disposal systems below the machines are being widely used instead of drag conveyors because of reduced maintenance requirements. Automatic

lubrication of the machines is also desirable, and filtering equipment for the cutting fluid should be provided on recirculating systems, especially when the machines are to be operated continuously. A good preventative maintenance program is also essential to maintain operating efficiency.

FLEXIBLE MANUFACTURING SYSTEMS

A flexible manufacturing system or flexible machining system (FMS) is an automated production system for the manufacture of families of workpieces at midvolume output rates. The acronym FMS is often used generically to describe a wide range of systems that are generally similar in concept. As shown in Fig. 15-111, a typical FMS consists of a number of machine tools tied together by a workpiece handling system and controlled by a central computer.

Although the acronym FMS is considered to be somewhat generic, many other terms and acronyms are used to describe this general class of manufacturing equipment—Computer Integrated Manufacturing System (CIMS), Computer Managed Parts Manufacturing (CMPM), Variable Mission Manufacturing (VMM), for example. In countries other than the United States, terms such as Flexible Automation, Flexible Manufacturing System Complex (FMC), and Computer Integrated and Automated Manufacturing System (CIAM) are used.

Machine tools employed in an FMS usually are CNC machining centers or headchangers, but may also be other production equipment such as CNC lathes, automated testing or assembly stations, or even forming or finishing equipment. The uniqueness of the FMS concept of manufacturing is characterized by the ability to bring together in an integrated fashion, work stations, automated material handling, and computer control.

An FMS is capable of producing similar workpieces (one or more families of parts) randomly and simultaneously. Some systems require batching of workpiece families, while other systems accept workpieces from various families of parts in random order. Workpieces are transported to and from member machine tools via automated fixture carts or conveyors, although robots may be employed in special applications (see “Programmable Robots” in Chapter 16 of this volume, “Machine Loading and Unloading”).

FMS ELEMENTS

As mentioned previously, there are three major building blocks of an FMS—work stations, material handling or material transport, and control systems. Often, the form each element takes can vary significantly among FMS's, depending upon such things as system configurations, processing requirements, economics, operating environment, level of system configuration, etc.

Work Stations

The work stations of an FMS are employed to execute the many manufacturing processes required for the production of parts. To date, the stations employed most often for metal-cutting operations have been three, four, or five-axis machining centers. Except for a few modifications, such machining centers are standard. Modifications that are often required include

provisions in the machine control for accepting DNC-mode downloading of NC part programs from the central computer (normal FMS operation does not require the use of a tape reader; see “Fundamentals of Direct Numerical Control” in Chapter 5 of this volume, “Machine Controls”); the addition of a special shuttle mechanism for accepting fixture carts from the workpiece handling system; and special modifications for cutting fluid handling and chip removal. In some cases, machining centers have been specially modified for rough milling or drilling operations; thus, the particular machining center is transformed into a “roughing station” for general use in the production of a family of workpieces (more on this later).

Head storage machines are also heavily employed in FMS networks for multiple spindle drilling, tapping, boring, facing, grooving, milling, etc. Multiple spindle head indexing machines with up to 24 heads that are stored on rotary indexing platens have been used in FMS installations. Conventional head changing machines are used frequently.

In some cases, manual loading/unloading, small assembly jobs, or inspection operations are performed on the fixture cart or are performed on small tables adjacent to the work handling system of the FMS.

Coordinate inspection, stock allowance checks, and workpiece and fixture cleaning are additional operations that have been incorporated in existing FMS installations. Future systems may include stations for such operations as grinding, hobbing, forming, heat treatment, or even painting.

In general, the most desirable characteristic of a work station for an FMS installation is flexibility. Such flexibility in work station design should be characterized by the ability to handle a wide variety of workpiece configurations with an appropriate variety of tooling. Additionally, load balance is enhanced when like or similar operations can be performed at more than one station in FMS. In this way, changes in production mix and/or interruptions of production can be handled effectively.

The tradeoff between flexibility and efficiency is an important consideration in work station design. The most productive FMS work station is one that strikes an appropriate balance between flexibility and process specialization given the specific requirements of the family or families of parts to be manufactured. Usually, efficiency of an FMS is enhanced when one or more stations are dedicated to the efficient execution of a specific type of process, such as rough machining. Production efficiency is increased when such an operation is applicable to a large percentage of the parts to be processed. Efficiency can also be enhanced by including stations which employ multiple spindle heads or other equipment that is designed specifically for the family of workpieces to be produced. This approach can be particularly effective when special features are common to many workpieces of the family or families of parts to be processed.

FLEXIBLE MANUFACTURING SYSTEMS

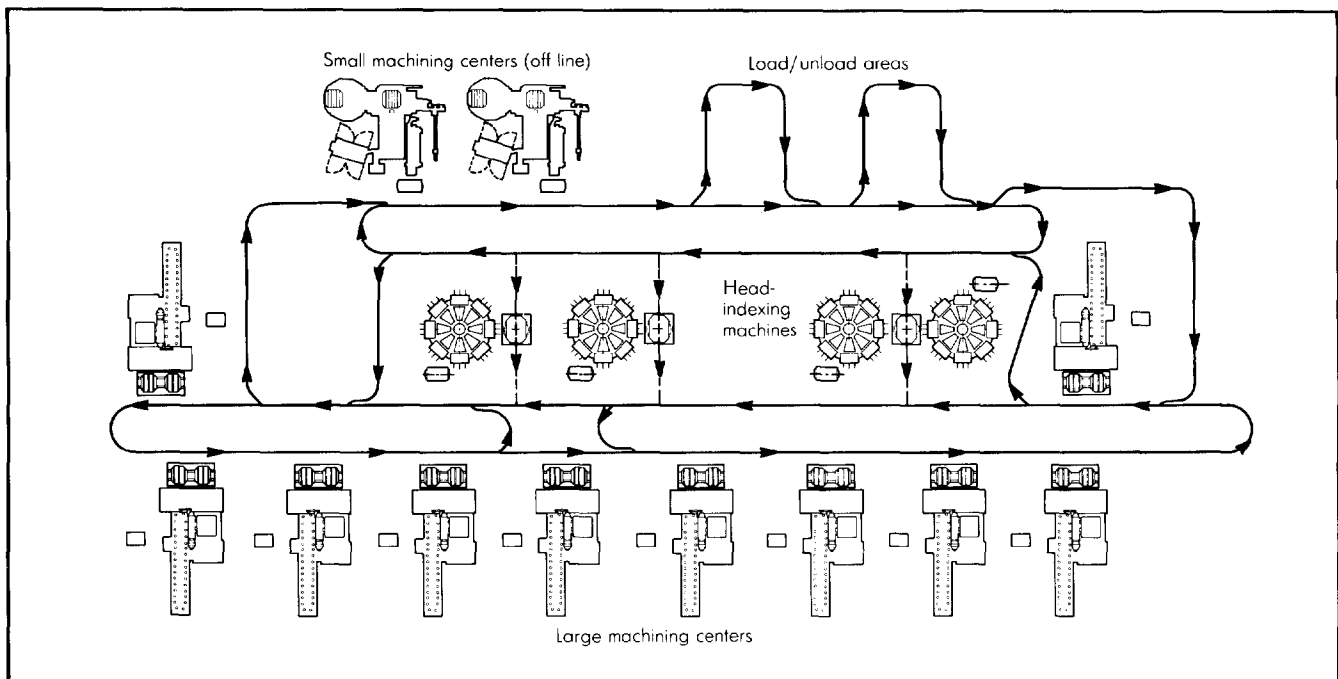


Fig. 15-111 Plan view of typical Flexible Machining System (FMS). Large machining centers and head-indexing machines are linked via automated fixture cart transportation system under computer control. NC part programs are downloaded to CNC machining centers from memory of the central computer. (Kearney & Trecker Corp.)

Enhancements like adaptive control (see “Adaptive Control” in Chapter 5 of this volume, “Machine Controls”), horsepower upgrading, or other special changes to general-purpose machines like machining centers can also improve process efficiency in an FMS.

The downtime of member machine tools of an FMS has less overall effect on system efficiency than does the downtime of stations of a transfer machine. Random employment of machine tools in an FMS minimizes the adverse effects of downtime of individual machine tools. Although this is true, overall FMS performance is still tied closely to the integrity of individual machine tools in the system. Positioning accuracy, repeatability, stiffness, horsepower, and other machine capabilities and characteristics must be considered carefully according to the requirements of the full range of workpieces to be produced.

Typically, the cost of individual work stations make up the most significant portion of the relatively high capital costs of an FMS. Overall capital costs can be minimized through the use of standard, off-the-shelf machine tools such as machining centers and by standardization of work stations, where possible. Because the goal of an FMS is to increase productivity and manufacturing flexibility through the minimization of human intervention, work stations should be designed to operate at minimum levels of attention. In work station design, it is important to strike the appropriate compromise between the latest state-of-the-art automation and reliability.

Material Transport System

Various types of material transport systems are in current use or have been proposed for use in future FMS installations. Of the types in the following list, the tow-line, powered cart, and roller conveyor types of transportation systems are the most

commonly employed today. Robotic systems are increasing in use. Systems which employ robots as the transportation media are sometimes referred to as flexible transfer lines or robotic work cells (see “Programmable Robots” in Chapter 16 of this volume, “Machine Loading and Unloading”).

- **Tow-line systems**—Workpieces are transported by individual cart-like carriers that are towed by chains under the floor. Such fixture carts are guided by slots in the floor.
- **Powered cart systems**—Following rails or electronically defined pathways (in-floor wiring), powered cart transportation systems are self-propelled either with an on-board energy source or with power pick-up.
- **Roller conveyor systems**—Fixture pallets are propelled along floor-mounted, powered roller conveyors.
- **Air-film conveyor systems**—Fixture pallets float on films of air along conveyor-like pathways, driven by linear motors.
- **Overhead conveyor systems**—Workpieces are held in fixtures suspended from the ceiling, following specific pathways.
- **Stacker crane systems**—Stacker cranes serve as workpiece transportation devices, interfacing with work stations and storage matrixes.
- **Robot systems**—Programmable robots move workpieces to and from work stations.

The function of the material transport system of an FMS is to move workpieces to and from member work stations. Under control by the central computer, the movement of workpieces through the system is usually automatic. The material transport system of an FMS interfaces with work

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stations and serves as a banking medium for temporary storage of workpieces. In addition, short operations such as manual loading and unloading of workpieces, cleaning, deburring, etc., may be performed at designated positions along the material transport system.

In general, the main objective of a material transport system of an FMS is to help achieve maximum work station utilization through efficient workpiece movement. Capacity, speed, and random delivery capabilities must be considered in the design of such systems. Extremely important is the ability of the transport system to effectively handle congestion in the system caused by work station downtime, system surges, or other irregularities.

Flexibility in transport system design is also important. Potential changes in production mix or other operating characteristics of the FMS must be considered in the design phase of the transport system to ensure efficient operation as changes occur.

Reliability is also important as the transport system is the central unit upon which all work stations depend. The most productive transportation systems are simple, durable, and easy to repair. Provisions should be designed into the system to bypass any section that is inoperative due to system failure until another modular transport section can be installed in the failed section. Manual operation should be a built-in capability in case of failure of automatic control.

Many other considerations must be given to the material transport system of an FMS. For example, maintenance of workpiece integrity is of prime concern. The transport system must be designed to ensure that the workpiece is not damaged in any way or that location of the workpiece in the fixture cart is altered as a result of movement through the FMS. Shocks and bumps should be avoided.

Expandability is one of the most significant advantages of the FMS concept and must be considered in the design phases of the system. With careful planning, modular growth at various levels of automation can significantly enhance the effectiveness of an FMS.

Shuttle mechanisms, integral components of an FMS transportation system, are employed to interface the individual work stations with the main transportation network. Shuttles remove workpieces from the main transportation system, store workpieces until the work station is ready to accept it, move workpieces into the station, remove workpieces from the station, store the workpiece until the transportation system is ready to accept it, and move workpieces into the main transportation network.

Shuttle mechanisms can take many different forms, depending upon the type of FMS. In-line shuttles with two-position banking before and two-position banking after the work station have been used extensively by one FMS manufacturer. Rotating and side-ways slicing shuttle devices have also been used effectively. Such devices feature two banking positions which are shared for both before and after work station functions.

Control Systems

Flexible manufacturing systems typically feature hierarchical control. The first level of control is the intelligence built in at the CNC units of the machine tools themselves. The second level of control is provided by the central computer which operates in a DNC mode, downloading NC part programs to member machine tools (see "Fundamentals of Direct Numerical Control" in Chapter 5 of this volume, "Machine Controls"). Also supplied by the central computer is the third level of

control which directs the flow of workpieces through the system, maintains production scheduling information, and produces management reports. The following is a summary of the various functions of an FMS control system:

- Control of workpiece and fixture location.
- Material transportation system control.
- Work station control.
- Records maintenance.
- NC part program control and maintenance.
- Tool control and tool life control and maintenance.
- Generation of performance reports.
- Visual display of status.
- Communication with systems operator(s).
- Provide information for production planning.

The control system is comprised of both software and hardware elements. Sometimes, two minicomputers are used simultaneously to provide required control; in such cases, one computer is employed for DNC data transmission and related tasks, and the second computer is employed for overall control of the system. Additional computers are sometimes employed as backup.

Usually, minicomputers, associated memory, power supply, and interface boards make up the heart of an FMS control system. Mass data storage is usually in the form of disc or drum. Communication terminals in various forms are provided for human intervention; CRT terminals may also be available for NC part program editing. A line printer is usually part of the control system for efficient generation of reports and listing of NC part programs.

Communications hardware is an important component of any FMS control system. Such hardware, which may include digital multiplexing, is employed to transmit and receive signals from the material transport system and member work stations. Peripherals, including punched tape reader and tape punch (for program generation and loading) and magnetic tape drives (for quick system backup and update), may also be part of the control system.

Work stations usually are equipped with data input/output devices for human interaction with the control system. Interface modules may be required for data input to NC machines via DNC. Software for the control system usually includes modules written by the computer manufacturer, including real time operating systems. It also includes modules written by the FMS supplier, some of which will be standard and some tailored to the requirements of the particular FMS.

FMS OPERATION

The operations of a typical FMS are relatively simple. Typically, an FMS is programmed to operate according to predefined objectives; for example, the optimization of material flow or the maximizing of station utilization. The central computer selects a specific workpiece to be machined according to production schedules stored in computer memory. An appropriate fixture cart is sent via the workpiece handling system to the load/unload station. The load/unload station operator receives instructions (via teletype or CRT) from the computer as to which workpiece to position in the fixture cart. When the operator has loaded the workpiece, he signals the computer to move the fixture cart to the first operation.

Stored in the central computer is an ordered listing of processing steps for each workpiece. This listing is used by the

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computer to select an appropriate station (machine tool) for the first processing step. Upon command by the computer, the fixture cart is directed to an appropriate station to begin processing. An optimum route through the system is selected as calculated by the control system. At the first processing station, the workpiece may be required to wait; when the station is clear, the workpiece is shuttled into it to begin processing. When the first operation is complete, the workpiece is automatically moved to the next appropriate station as defined by the ordered list of processing steps stored in computer memory. Thus, workpieces simultaneously travel through the system in random order stopping only at selected stations. When processing is complete, the workpieces are sent to the load/unload station for removal by the operator. At this stage, the workpiece may be complete or may require further processing using a different fixture cart; in the latter case, an appropriate fixture cart is automatically sent to the load/unload station for loading by the operator, and a new sequence of processing steps through the FMS is initiated by the computer.

Loading and unloading of workpieces in fixture carts is the only manual function required in the operation of an FMS (except of course, normal tool setup, monitoring, and maintenance); every other function is completely automatic in most cases.

FMS DEVELOPMENT

Although it is difficult to pinpoint the first FMS to be developed, because definitions are somewhat clouded, it appears that the first FMS's were developed in the late 1960's.¹ No less clouded today are estimates of the number of operating FMS's. One report suggests that between 25 and 100 FMS installations can be counted worldwide.² The same report lists Caterpillar Tractor Co. as the largest domestic FMS user with 39 installations, although some experts claim some installations at Caterpillar are multimachine complexes that may not qualify under certain definitions of FMS. Another source reports that as many as 300 FMS's are currently operating in various countries.³

The confusion surrounding the census of FMS installations notwithstanding, the obvious trend worldwide is toward increased employment of FMS technology. In efforts to further automate production facilities, potential FMS users have shown great interest in FMS technology evidenced by increasing attendance at various seminars and conferences conducted in the United States, Japan, Germany, France, and other countries. Increasing interest in FMS technology is also confirmed by a dramatic increase in recent years in the number of machine tool builders offering FMS products or similar hardware. One source reports that over 15 major machine tool builders in the United States alone are offering FMS technology.⁴

Further evidence of increasing interest in FMS technology worldwide is provided by a report which explains a seven-year research program initiated by the Japanese. The \$62 million (1978 dollars) project, aimed at exploring flexible manufacturing systems (and building a plant to house a system), is being conducted by three Japanese research institutes and about 20 Japanese manufacturers. The FMS project is to entail the integration of numerous processes into the framework of an FMS, including working with powder metal, bar, and plate and using such operations as forging, cutting, assembly, and inspection in addition to the integration of laser cutting, welding, and heat treating.⁵

FMS ADVANTAGES AND JUSTIFICATION

For many years, so-called midvolume, midvariety manufacturing processes have exhibited rather unique problems not the least of which has been the rationalization of the tradeoff between flexibility in manufacturing and efficiency. Transfer machines have long provided the established and most productive method for machining high-volume, low-variety workpieces. Low-volume, high-variety workpieces traditionally have been produced in a cost effective manner using stand-alone, single-purpose machine tools or NC or CNC machining centers. The special problems of midvolume manufacturing, until the advent of FMS concepts, have not been solvable with the technologies employed for strictly high or low-volume output.

This lack of appropriate technologies for midvolume manufacturing over the years has spurred an array of special problems. In the past, lead times and in-process inventories in midvolume manufacturing were often excessive. This was caused primarily by the large amount of handling of the workpieces during their respective manufacturing processes. Batch processing of midvolume parts loaded machine tools fully for lengthy periods of time, causing other lower priority jobs to wait in-process for available machine tools. The large number of stand-alone machine tools required to handle midvolume manufacturing requirements utilized a disproportionate amount of floor space in relation to the machine's productivity, in many cases. These and other problems associated with midvolume manufacturing have been intensified by the fact that mass production accounts for at most 25% of the total value of metalworking production in all industrialized nations; the remaining 75% is nonmass produced, with at least half of these workpieces produced in batches of less than 50 parts.⁶

The FMS concept is viewed by many experts as at least a partial solution to the problems of batch or midvolume manufacturing, as shown in Table 15-14.⁷ One source suggests that the FMS concept is particularly well suited to workpieces produced in volumes of about 1000 to 100,000 units per year.⁸ Other sources indicate that aggregate production should range between 15,000 and 35,000 units per year. Yearly production volumes for individual parts may range between 100 and 8000 units. A graphical representation of production flexibility versus productive capacity for FMS, as well as other machines and machining systems, is presented in Fig. 15-112.

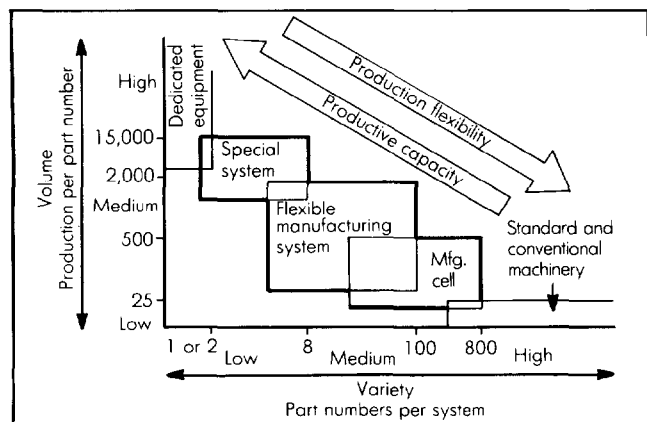


Fig. 15-112 Production flexibility vs. productive capacity for FMS, as well as other machines and machining systems. (Kearney & Trecker Corp.)

FLEXIBLE MANUFACTURING SYSTEMS

TABLE 15-14
Comparison of Machine Tool Systems for Production at Various Volumes

	Piece Production	Batch Production	Mass Production
Annual volume per year*	1 to 10,000	5000 to 200,000	over 100,000
No. of part pieces per lot*	1 to 100	100 to 50,000	over 50,000
Primary motivation	Ability	Flexibility	Volume
Manufacturing cost per part at full utilization	Highest	Lower	Lowest
Cutting tools	Standard	Some special	Custom
Automatic part handling	Seldom	Some cases	Always
Flexibility to change to a completely different part	Yes	Possible	Impossible
Flexibility to change to a similar but somewhat different part	Yes	Yes, if previously planned	Very limited
Ability to change materials	Yes	Limited	Extremely limited
Ability to implement gradually	Yes	Possible	Difficult
Machine tools best suited to the job	Tool shop: several machine tools or NC machining centers	Job shop: NC machining centers, cell of machines, FMS networks	Transfer lines
Typical applications	Aircraft, tool and die shop, maintenance shop, repair shop, specialty machinery for industrial-process equipment (centrifuges, filters, etc.)	Agricultural machinery, off-road vehicles, mining machinery, trucks, furniture, truck diesel engines, associated subcontract shops, aerospace propulsion	Automotive factory, automotive part supplier, metal fasteners, appliances

Source: *Iron Age*, September 28, 1981, p. 85.

* Typical case; numbers vary with size, complexity, and cost of workpieces.

The FMS concept is most applicable to family-of-parts processing; a range of midvolume workpieces such as axle housings, air compressor housings, or engine blocks are typical examples. Workpieces which are part of a family of parts that feature a significant number of processing options are good candidates for FMS manufacturing (see "FMS Applications" at the end of this section).

Most existing FMS installations are employed to manufacture prismatic parts that require operations such as drilling, milling, tapping, boring, or grooving. Typical workpiece weights range from 80-1000 lb (36-453 kg). Table 15-15 is a comparison sheet for analyzing the relative advantages and disadvantages of various manufacturing techniques for low and midvolume manufacturing.

Labor Costs

The direct labor component of the total cost of manufacturing a workpiece is said to be decreased through the use of FMS technology because of the high degree of automation employed. Indirect labor (maintenance, etc.) may be increased due to the higher level of hardware complexity employed, however.

Equipment Utilization

Many claims have been made concerning the ability of FMS's to increase machine utilization. Proponents of the concept

suggest that the pacing effect of computer control and optimization effects provided by computer algorithms spur increased machine tool utilization. It is also stated that utilization is improved by the flexibility of FMS's because downtime of individual work stations usually does not shut down the entire production process. Utilization rates of up to 80-90% are cited.⁹ However, some studies show considerably less average machine tool utilization with FMS equipment. One study of FMS performance explored system utilization (the ratio of machine hours actually used to theoretical capacity) and found actual operating utilization to be only 50-60%.¹⁰

Manufacturing Flexibility

An FMS installation is capable of accommodating changes in part volumes and/or product mix, design changes, etc., with fewer problems than conventional equipment. Because FMS equipment is flexible with respect to part design, the useful life of the equipment is considered to be longer than specially tooled conventional equipment; thus, increased flexibility can eliminate the need for some future capital outlays for new equipment.

Because an FMS can process a wide variety of workpieces at random, downtime associated with traditional changeover techniques is eliminated. Computer control allows more flexibility in part routing to minimize production time.

FLEXIBLE MANUFACTURING SYSTEMS

TABLE 15-15
Worksheet for Comparing Relative Advantages and Disadvantages of Various
Machining Systems for Low and Mid-Volume Manufacturing

OBJECTIVES Assign relative weights, based on your requirements	ALTERNATIVES										
	Relative Weight	Standard Machinery With Special Tooling		Special Dedicated Machinery		Transfer Line		NC— Stand Alone		Flexible Machining System	
		Rating	Perf. Index	Rating	Perf. Index	Rating	Perf. Index	Rating	Perf. Index	Rating	Perf. Index
Minimize direct labor	250	2	500					5	1250	8	2000
Minimize tooling and fixture investment											
React to market changes	80	3	240					8	640	6	480
Maximize equipment utilization	60	3	180					5	300	7	420
Minimize setup	150	2	300					6	900	7	1050
Minimize indirect labor											
React to engineering changes	60	3	180					10	600	8	480
Minimize leadtime											
Minimize lot size											
Minimize work-in-process inventory	100	3	300					5	500	8	800
Minimize factory expense											
Minimize production control											
Minimize industrial engineering requirements											
Minimize accounting and finance requirements											
Minimize marketing leadtime for forecasting											
Minimize capital investment	300	8	2400					4	1200	3	900
Maximize flexibility											
Maximize inventory turn											
Maximize ability to match capacity with requirement											
	1000		4100						5390		6430

Source: Kearney & Trecker Corp.

This worksheet can be used to compare alternative solutions to a manufacturing problem. In this specific case, the problem was to machine nine different parts for aircraft engines. Total annual production of the nine parts is 24,000. In this case, seven objectives were relevant. Each objective was assigned a value for Relative Weight; values total 1000. Under the three alternatives evaluated, each objective was rated on a scale from 1 to 10 with 10 meaning that the objective was met fully and 1 meaning that it was not met at all. In each case, the rating is multiplied by the objective's Relative Weight to get a Performance Index. The total of the Performance Index numbers suggests the best of the alternatives. All values are, of course, arbitrary. Selected objectives and numbers will vary depending on the individual project. In this case, the installation consists of 11 Milwaukee-Matic Modu-Lines, 3 head indexers, and 2 Milwaukee-Matic 800s, all serviced by a towline material handling system, as shown in the drawing.

Inventory

In many cases, processing of workpieces through the shop is considerably faster with FMS than with conventional equipment. For this reason, in-process inventory can be greatly reduced. When using transfer line production methods, in cases in which more than one workpiece is produced on the line, setup time and costs may dictate that workpieces be run in rather large batches, thus increasing inventory costs.

Management Control

Computer control of FMS installations affords greater production control than that possible with conventional, stand-alone machine tools. Accuracy of short-term decision making can be increased through generation of timely management reports, and changes in production schedules, etc., are more easily handled.

FLEXIBLE MANUFACTURING SYSTEMS

TABLE 15-16
Stages in Planning an FMS Installation

Stage* 1	Stage 2	Stage 3	Stage** 4	Stage† 5
Define the “cadence” of your machine shop: • You produce a variety of parts in mid-volume—neither continuous production nor prototype and one-of-a-kinds. • People in your plant can handle computers, NC, and machining problems. • Your products, and therefore the component parts, will be made in relatively short runs, repeated during the year. • Your inventory turns are low. • Several (or many) of the machined components are of roughly the same size, with similar geometries requiring similar processing and machining operations. • Setup time is high. • Machining cycles are long. • Tolerances are close for multisetup processing. • Floor space requirements are reduced. • Other: _____	Establish “families” of parts among your products or components: Classical families are: 1. By assembly: grouping parts together that would be required to make up a single assembly, such as all the major casting housings of a tractor assembly, or an engine assembly. The system would be designed to allow the user to order these castings against an assembly schedule, rather than in batch order quantity. 2. By type: categorizing parts by type that would go into the system by a production volume range, such as transmissions or torque converters. This family represents the relieving of low to mid-volume part numbers from higher volume production lines, eliminating the line changeover generated by the lower volume parts. 3. By size and similar operations: In this family a group technology study could be applied to selected workpieces, categorizing them by production and volume range and by machining operations. For instance, all parts below a determined volume rate requiring milling, drilling, boring, and tapping might become the basis for a system.	• Determine your current (anticipated) annual requirement for each of the parts in a family. • Determine the total annual requirements for the total number of parts in the family.	• Define the annual requirements for these parts over the next five years. Over the next 10 years. • Define changes in those parts through redesign or other changes during the next five years. Next 10 years. • Define new products that might fit the “family” as you can best perceive them for the next 5 and 10 years. Changing customer wants means changes for you. • Analyze how the product mix might change during those periods. • Evaluate your need for, and use of, automatic flexibility.	• Analyze in depth the capabilities of your personnel (or of the personnel you may need to hire) to run an FMS at optimum utilization and effectiveness. • Determine whether your present labor agreements or contracts will permit you to properly manage and staff the FMS department. If not, you will need to consult with the workers or with the union regarding special agreements that will permit utilization of best skills and that will result in worker continuity. • Make certain that you have a person competent to become Project Manager of the FMS system, from the time the order is placed through installation and run-in. Then make certain that you have supervisors qualified to run the line in production—one per shift. If these capabilities are missing from your staff, know that your company is willing to acquire such capabilities.

Source: Reprinted by permission; *Production*, August 1981, p. 5-76.

* These conditions would typify (but not exclusively define) plants that are users of or prime candidates for FMS.

** An analysis of these kinds of factors will be essential to your justification procedures; it also is vital if your machine suppliers are to do a thorough job of engineering the proper system for your needs.

† These first five steps can assure you that you either are, or are not, a candidate for FMS. If you are, the information you have developed will be invaluable in implementing the rest of the program.

‡ Adequate preparation during preparatory stages will make this a routine evaluation.

FLEXIBLE MANUFACTURING SYSTEMS

TABLE 15-16—Continued

Stage† 6	Stage 7	Stage 8	Stage 9	Stage 10	Stage 11	Stage 12
• Work with system suppliers to determine alternative system solutions to your problems. • Pick the best possible (and economical) solution which will meet all of your requirements. • Ask for proposals from two or three builders. (You may have to pay for some engineering.)	• Cost justify the investment with normal plant or company procedures. Systems can cost from \$1 million (very small) to \$20 million or more. Include a consideration of gains not always quantified, such as: reduced work-in-process and finished products inventory, reduction of scrap, shorter leadtimes, higher utilization rates, reduced setup times, closer tolerances, optimum balance of components delivered to assembly, ability to accommodate design changes and future products (vs. dedicated methods). Marketing benefits would include shorter product leadtimes, ability to accommodate design changes and reduced product cost. FMS major disadvantage may be the time and the cost of total process planning and implementation (including staffing) that are needed to make it work properly. Further, it may be difficult or impossible to retain the level of skills you need, due to the shortage of qualified NC and computer-control skills for upgrading and maintaining programs. It should also be noted that where the skills exist, supplier training will provide the necessary specific knowledge, usually without additional cost. Be certain to consider cost avoidance, comparing the FMS cost vs. the cost of achieving the same output, efficiencies and benefits via either dedicated special machines or stand-alone standard machines. With its high utilization rates, FMS often will be the least costly method.	ORDER THE SYSTEM	Project Manager • Set up programs to explain the FMS to plant employees, selling them on the need for the new system. Explain just what it will mean in terms of their jobs and in terms of the company's economic health. Follow through to assure union support when it is a factor. • Work with all other departments, including marketing, product design, purchasing, quality control, plant engineering, personnel and finance. • Meet with suppliers to explain requirements for delivery schedules, maintenance of proper stock allowance and of tolerances (including machinability variations), etc., and of all quality characteristics.	Project Manager • Work with all necessary departments to develop production scheduling and process routines for each part to be machined on the FMS. • Establish tool maintenance and replacement facilities and procedures for the FMS. (Consider having the FMS capability separate from the rest of the plant's tooling department.) • Select FMS operators, technicians and supervisors, and schedule them for training at the control/system suppliers' plants. • Clear the appropriate area(s), and undertake the construction stages that precede installation. • At an appropriate time, check out FMS machines, tooling, controls, programs, etc., at builder plant. Acquaint and train operators and demonstrate system to other persons who will work with it.	INSTALLATION	Post Audit • It is essential that your original plans include a detailed specification of what the system is to do. It also is recommended by every builder contacted that a post audit be conducted so that everyone involved knows how and when performance (success?) will be measured.

FLEXIBLE MANUFACTURING SYSTEMS

Incremental Phased Installation

Most flexible manufacturing systems are designed to utilize a phased-in equipment installation approach. With this approach, machine tools are purchased and installed as production needs dictate. Should the market increase, additional machines can be implemented into the system to meet increased production requirements. Should the market not develop to its maximum projected level, the user has only purchased equipment needed, thus saving on capital investment.

PLANNING FMS INSTALLATIONS

Table 15-16 traces the various stages of planning, specifying, purchasing, and installing a new FMS. Both FMS builders and

users suggest that successful application is assured only through extensive planning from the outset. Some of the stages presented in Table 15-16 are complex; some may be routine. The emphasis any one stage receives depends upon the people and the situation at the specific plant performing the analysis. However, experience has shown that it is best not to bypass any of the cited stages entirely.

FMS APPLICATIONS

Figures 15-113 through Fig. 15-119 illustrate and briefly describe several FMS installations that are in current use in various plants and systems that are proposed for production.

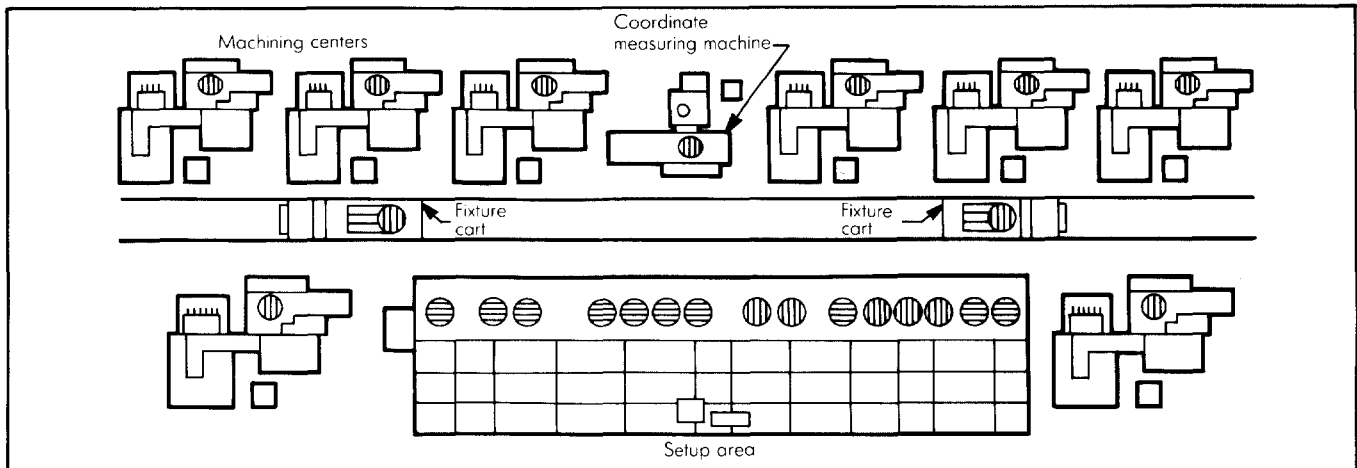


Fig. 15-113 Plan view of Flexible Machining System (FMS)—White-Sundstrand Omniline—featuring eight machining centers and coordinate measuring machine. Operations: roughing, finishing, finish boring, and tapping of tractor parts—main frame, clutch housing, spacer covers, and bolster. (Source: *American Machinist*, March 1980, p. 169.)

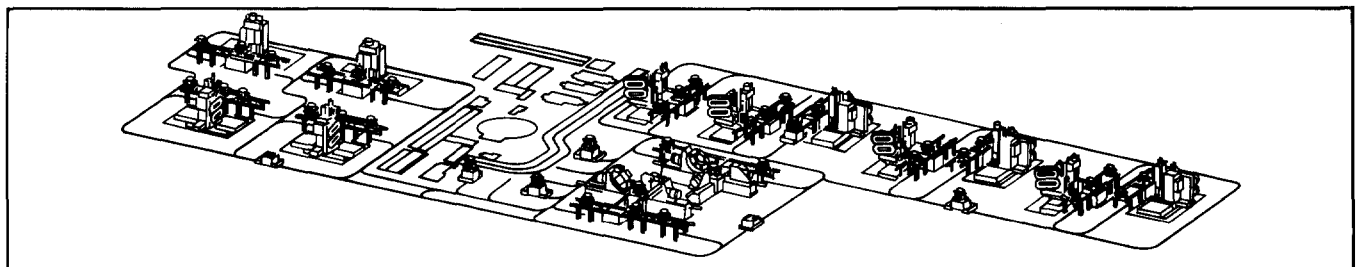


Fig. 15-114 Plan view of 13-station Flexible Machining System (FMS) featuring pallet-carrying carts that follow wires buried in the plant floor. Designed for the manufacturing of 10 different aircraft cylinder heads. (Cincinnati Milacron)

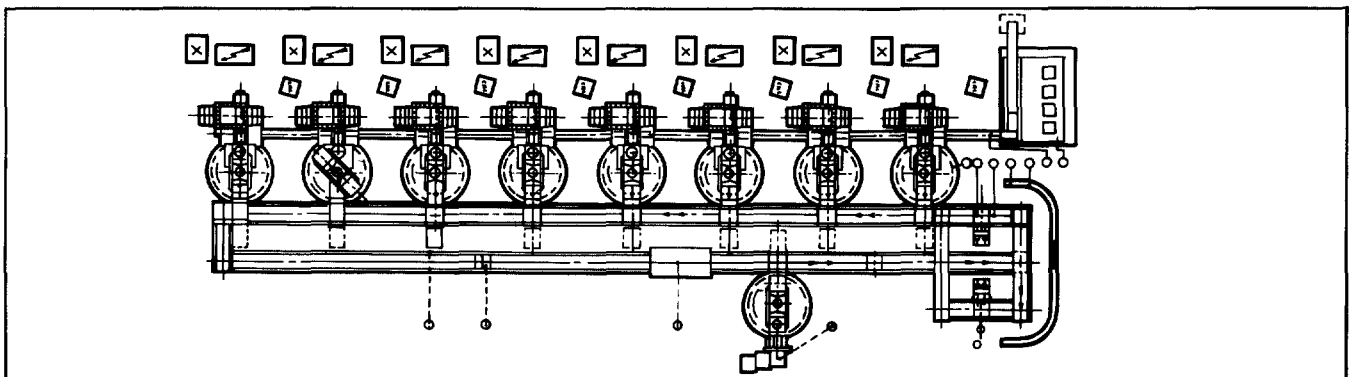


Fig. 15-115 Plan view of Flexible Machining System (FMS) that employs roller conveyors for fixture cart transportation. (Source: *Journal of Manufacturing Systems*, vol. 1, no. 1, 1982.)

FLEXIBLE MANUFACTURING SYSTEMS

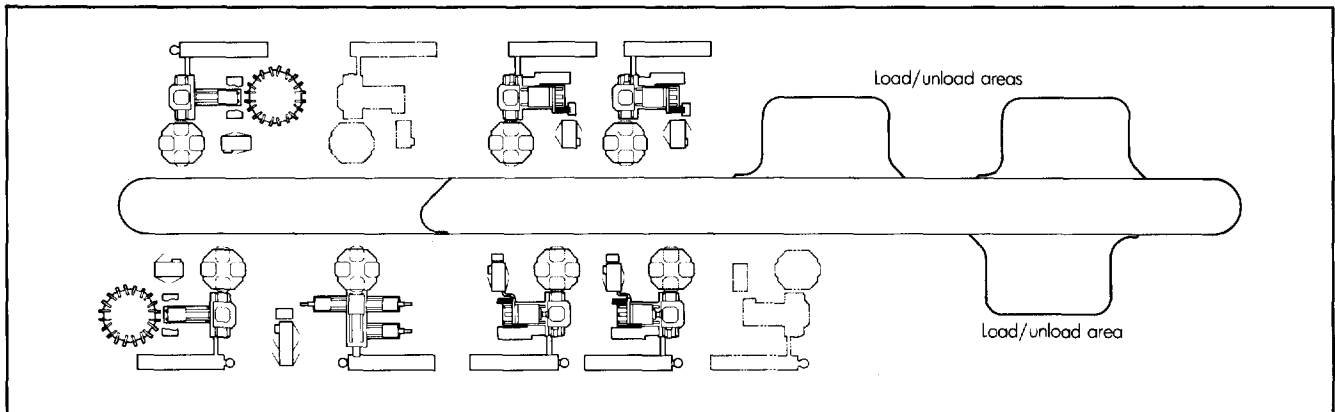


Fig. 15-116 Plan view of Multistation, Towline Material Handling System, Computer-Controlled Flexible Manufacturing System featuring two system component phases. Phase 1: Four Milwaukee-matic 800's; two horizontal head changers; and a special finish-boring station. Phase 2: Two Milwaukee-matic 800's. Overall system size: 200 ft (60.96 m) x 58 ft (17.68 m). (Kearney & Trecker Corp.)

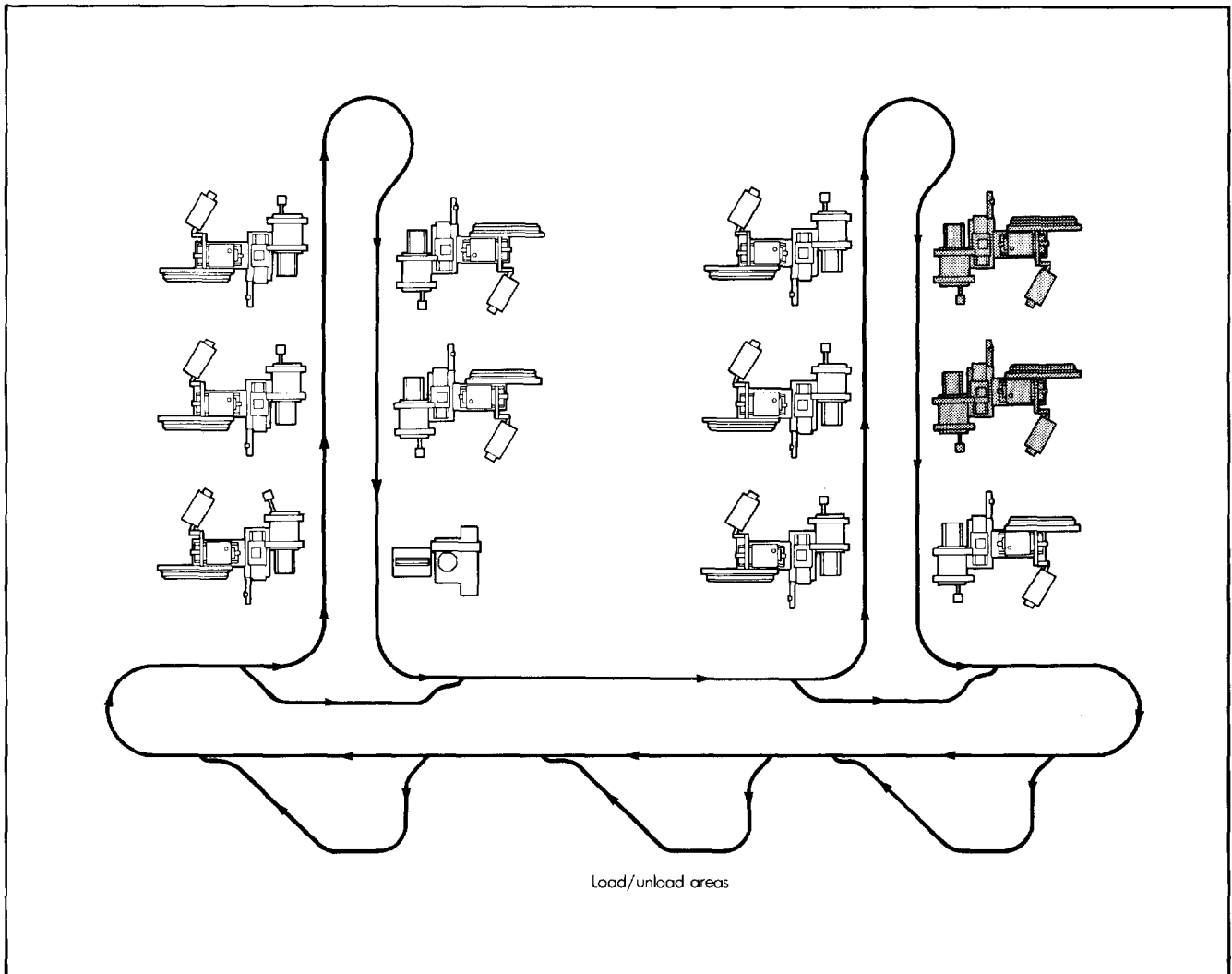


Fig. 15-117 Plan view of Multistation, Towline Material Handling System, Computer-Controlled Flexible Manufacturing System with on-line inspection and featuring two system component phases. Phase 1: Nine Milwaukee-matic 600's; one cordax inspection station; a Towline Material Handling System; and a central computer. Phase 2: Two Milwaukee-matic 600's. Overall system size: 122 ft (37.19 m) x 92 ft (28.04 m). (Kearney & Trecker Corp.)

FLEXIBLE MANUFACTURING SYSTEMS

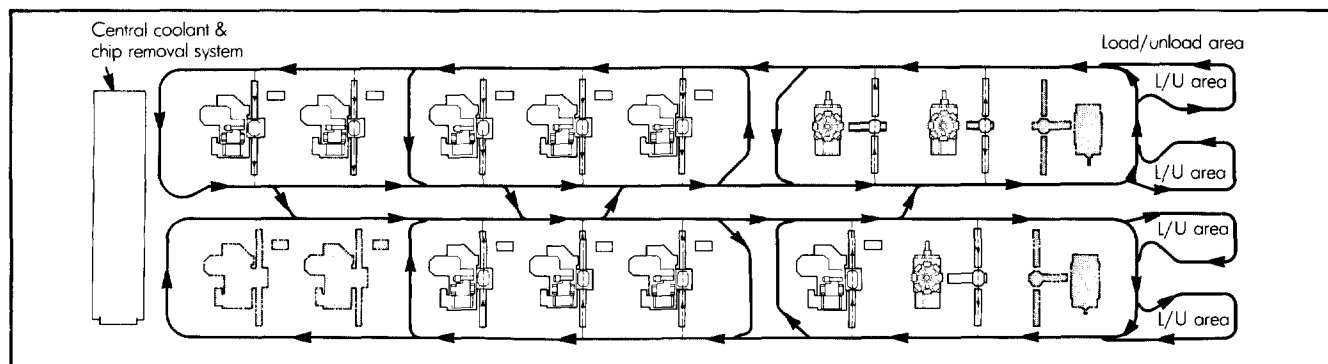


Fig. 15-118 Plan view of Multistation, Towline Material Handling System, Computer-Controlled Flexible Manufacturing System featuring nine Milwaukee-matic Modu-lines; three simplex head indexers; a Towline Material Handling System; and computer control. Overall system size: 320 ft (97.54 m) x 120 ft (36.58 m). (Kearney & Trecker Corp.)

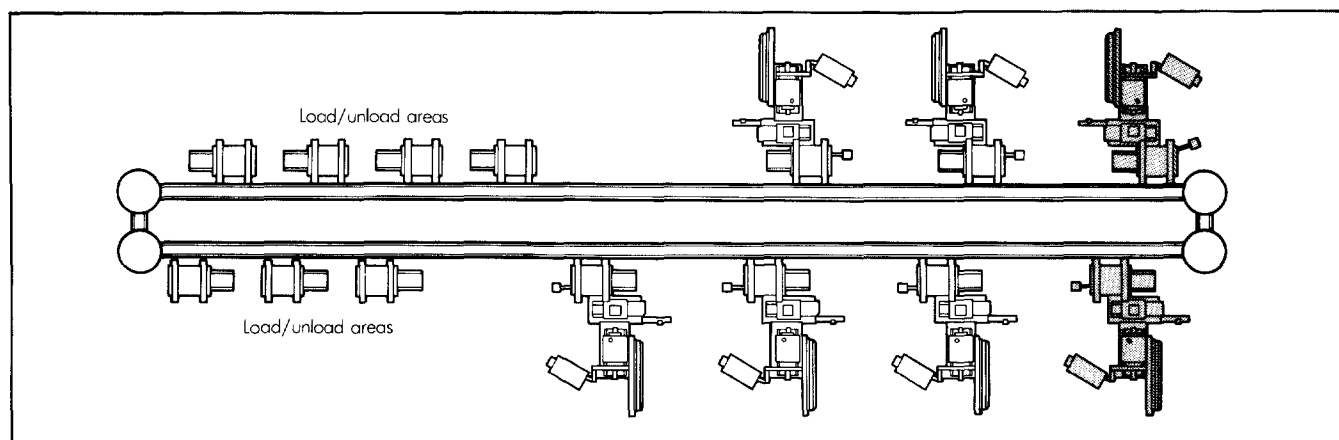


Fig. 15-119 Plan view of Multistation, Cartrac Material Handling System, Computer-Controlled Flexible Manufacturing System featuring two system component phases. Phase 1: Two Milwaukee-matic 600's; a Cartrac Material Handling System; and computer control. Phase 2: Five Milwaukee-matic 600's. Overall system size: 150 ft (45.72 m) x 80 ft (24.38 m). (Kearney & Trecker Corp.)

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