

Cutting Tool Applications

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Chapter 10

Boring Operations & Machines

10.1 Introduction

Boring, also called Internal Turning, is used to increase the inside diameter of a hole. The original hole is made with a drill, or it may be a cored hole in a casting. Boring achieves three things:

Sizing: Boring brings the hole to the proper size and finish. A drill or reamer can only be used if the desired size is 'standard' or if special tools are ground. The boring tool can work to any diameter and it will give the required finish by adjusting speed, feed and nose radius. Precision holes can be bored using micro adjustable boring bars (Fig. 10.1)

Straightness: Boring will straighten the original drilled or cast hole. Drills, especially the longer ones, may wander off-center and cut at a slight angle because of eccentric forces on the drill, occasional hard spots in the material, or uneven sharpening of the drill (see Fig. 8.10). Cored holes in castings are almost never completely straight. The boring tool being moved straight along the ways with the carriage feed will correct these errors.

Concentricity: Boring will make the hole concentric with the outside diameter within the limits of the accuracy of the chuck or holding device. For best concentricity, the turning of the outside diameter and the boring of the inside diameter is done in one set-up, that is, without moving the work between operations. The basics discussed in Chapters 4 and 5, the Turning Chapters, also apply to boring. However, with boring there are a number of limitations that must be taken into account in order to reach a high stock removal rate combined with satisfactory accuracy, surface finish and tool life. Therefore, in this chapter the limitations that distinguish internal turning from external turning will be discussed in greater detail. A typical boring operation is shown in Figure 10.2.



FIGURE 10.1: Adjustable boring bar for precision holes.
(Courtesy: National Acme Co. Div. DeVlieg-Bullard, Inc.)

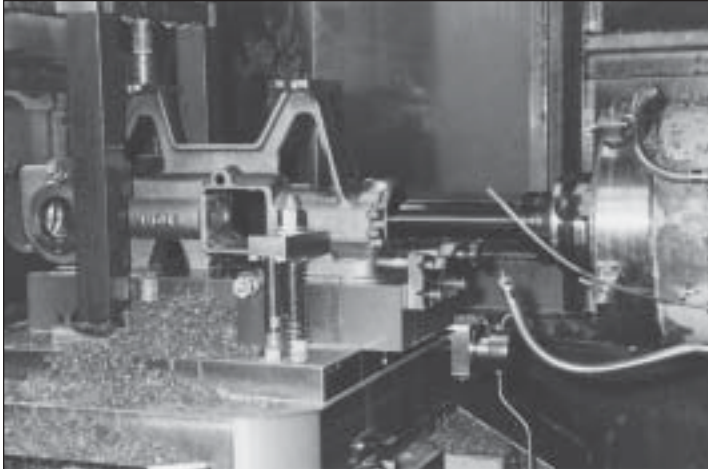


FIGURE 10.2: Typical horizontal boring operation. (Courtesy Sandvik Coromant Co.)

10.2 Boring Operations

Most of the turning operations that occur with external turning are also to be found in boring. With external turning, the length of the workpiece does not affect the tool overhang and the size of the tool holder can be chosen so that it withstands the forces and stresses that arise during the operation. However, with internal turning, or boring, the choice of tool is very much restricted by the work piece's hole diameter and length.

A general rule, which applies to all machining, is to minimize the tool overhang in order to obtain the best possible stability and thereby accuracy. With boring the depth of the hole determines the overhang. The stability is increased when a larger tool diameter is used, but even then the possibilities are limited since the space allowed by the diameter of the hole in the workpiece must be taken into consideration for chip evacuation and radial movements.

The limitations with regards to stability in boring mean that extra care must be taken with production planning and preparation. By understanding how cutting forces are affected by the tool geometry and the cutting data chosen, and also understanding how various types of boring bars and tool clamping will affect the stability, deflection and vibration can be kept to a minimum.

10.3 Cutting Forces

On engagement, the tangential force and the radial cutting force will attempt to push the tool away from the

workpiece, which results in the deflections.

The tangential force will try to force the tool downwards and away from the centerline. Due to the curving of the internal hole diameter the clearance

angle will also be reduced. Therefore with small diameter holes it is particularly important that the clearance angle of the insert be sufficient in order to avoid contact between the tool and the wall of the hole.

The radial deflection will reduce the cutting depth. In addition to the diametrical accuracy being affected, the chip thickness will change with the varying size of the cutting forces. This causes vibration, which is transferred from the cutting edge to the tool holder. The stability of the tool and clamping will be the factor that determines the magnitude of the vibration and whether it is amplified or dampened.

Insert Geometry: The geometry of the insert has a decisive influence on the cutting process. A positive insert has a positive rake angle. The insert's edge angle and clearance angle together will equal less than 90 degrees. A positive rake angle means a lower tangential cutting force. However, a positive rake angle is obtained at the cost of the clearance angle or the edge angle. If the clearance angle is small there is a risk of abrasion between the tool and workpiece and the friction can give rise to vibration. In those

cases where the rake angle is large and the edge angle is small, a sharper cutting edge is

obtained. The sharp cutting edge penetrates the material more easily but it is also more easily changed or damaged by edge or other uneven wear.

Edge wear means that the geometry of the insert is changed, resulting in a reduction in the clearance angle. Therefore, with finish machining it is the required surface finish of the workpiece that determines when the insert must be changed. Generally, the edge wear should be between .004 and .012 inches for finishing and between .012 and .040 inches for rough machining.

Lead Angle: The lead angle affects the axial and radial directions of the cutting forces. A small lead angle produces a large axial cutting force component while a large lead angle results in a larger cutting force in the radial direction. The axial cutting force has a minimal negative effect on the operation since the force is directed along the boring bar. To avoid vibrations, it is consequently advantageous to choose a small lead angle but, since the lead angle also affects other factors such as the chip thickness and the direction of the chip flow, a compromise often has to be made.

The main disadvantage of a small lead angle is that the cutting forces are distributed over a shorter section of the cutting edge than with a large lead angle. Furthermore, the cutting edge is exposed to abrupt loading and unloading when the edge enters and leaves the workpiece. Since boring is done in most cases, in a pre-machined hole and is designated as light machining, small lead angles generally do not cause a problem. Lead angles of 15 degrees or less are normally recommended. However, at a lead angle of 15 degrees the radial cutting force will be virtually double that of the cutting force with a 0 degree lead angle. A

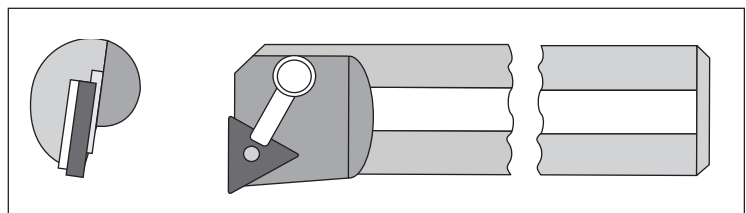


FIGURE 10.3: Typical indexable insert boring bar with 0 deg lead angle.

typical indexable insert boring bar with a 0 degree lead angle is shown in Figure 10.3.

Nose Radius: The nose radius of the insert also affects the distribution of cutting forces. The greater the nose radius, the greater the radial and tangential cutting forces, and the emergence of vibration. However, this is not the case with radial cutting forces. The deflection of the tool in a radial direction is instead affected by the relationship between the cutting depth and the size of the nose radius. If the cutting depth is smaller than the nose radius, the radial cutting forces will increase with increased cutting depth. If the cutting depth is equal to or greater than the size of the nose radius, the radial deflection will be determined by the lead angle. Therefore, it's a good idea to choose a nose radius which is somewhat smaller than the cutting depth. In this way the radial cutting forces can be kept to a minimum, while utilizing the advantages of the largest possible nose radius, leading to a stronger cutting edge, better surface finish and more even pressure on the cutting edge.

10.4 Chip Breaking and Evacuation

Obtaining relatively short, spiral shaped chips is the goal in internal turning. These are easy to evacuate and do not place such large stresses on the cutting edge when chip breaking occurs. Hard breaking of the chips, i.e. when short chips are obtained, demands power and can increase vibration in the boring bar. However, this is preferred over having long chips, which can make chip evacuation more difficult. Chip breaking is affected by a number of factors such as the insert geometry, nose radius, lead angle, cutting depth, feed and cutting speed. Generally, reduced feed and/or increased cutting speed results in longer chips. The shape of the chip breaker affects the radius of the chip, where any built-up edge or crater wear can also act as chip breaker. The direction in which the chips flow and the way that they turn in the spiral, is affected by the lead angle or the combination of cutting depth and nose radius.

The parameters that affect chip control also affect the direction and size of the cutting force. Therefore, it is necessary to choose a grade and

insert geometry that, together with the selected machining parameters, fulfill the requirements for good chip control. At the same time, the machine, boring bar and tool clamping must provide sufficient stability in order to resist the cutting forces that arise.

During boring operations the chip flow can be critical, particularly when deep holes are being machined. The centrifugal force presses the chips outwards. With boring, this means that the chips remain in the workpiece. The remaining chips could get pressed into the machined surface or get jammed and damage the tool. Therefore, as with internal turning, tools with an internal cutting fluid supply are recommended. The chips will then be flushed out of the hole effectively. Compressed air can be used instead of cutting fluid and with trough holes; the chips can be blown through the spindle and collected in a container.

10.5 Boring Rigidity

Part geometries can have external turning operations as well as internal operations. Internal single point turning is referred to as boring, and can be utilized for either a roughing or finishing operation. Single point boring tools consist of a round shaft with one insert pocket designed to reach into a part hole or cavity to remove internal stock in one or several machine passes. Figure 10.4 shows various sizes and styles of boring bars.

The key to productivity in boring operations is the tool's rigidity. Boring bars are often required to

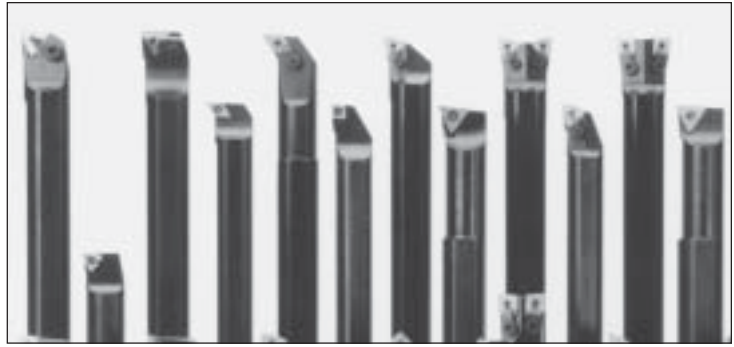


FIGURE 10.4: Various sizes and styles of boring bars. (Courtesy Dorian Tool)



FIGURE 10.5: Boring bars are often required to reach long distances into parts to remove stock. (Courtesy Sandvik Coromant Co.)

reach long distances into parts to remove stock (see Fig. 10.5). Hence, the rigidity of the machining operation is compromised because the diameter of the tool is restricted by the hole size and the need for added clearance to evacuate chips. The practical overhang limits for steel boring bars is four times their shank diameter. When the tool overhang exceeds this limit, the metal removal rate of the boring operation is compromised significantly due to lack of rigidity and the increased possibility of vibration.

Boring Bar Deflection: The size of the boring bar's deflection is dependent on the bar material, the diameter, the overhang and size of the radial and tangential cutting forces. Boring bar deflection can be calculated, but such calculations are beyond the scope of this book.

Increasing the diameter of the tool to create an increased moment of inertia can counteract this deflection. Choosing a boring bar made of a material that has a higher coefficient of elasticity can also counteract deflection. Since steel has a lower coefficient of elasticity than cemented carbide. Cemented carbide boring bars are better for large overhangs.

Compensating for Deflection: Even with the best tool clamping,

some vibration tendency will occur in boring. Radial deflection affects the machined diameter. Tangential deflection means that the insert tip is moved in a downward direction away from the centerline. In both cases the size and direction of the cutting forces are affected by changes in the relationship between the chip thicknesses and insert geometry.

If the exact size of the deflection of the insert tip is known in advance, then the problem can be avoided. By positioning the insert tip distance above the centerline, the insert under the effect of the tangential force, will take up the correct position during machining. In the same way, setting the machine at a cutting depth that is greater than the desired cutting depth compensates for the radial deflection. When cutting begins, the radial cutting force reduces the cutting depth.

Even if the approximate deflection can be calculated, the practical outcome will be somewhat different because the clamping is never absolutely rigid and because it is impossible to calculate the cutting force exactly.

Boring Bar Clamping: The slightest amount of mobility in the fixed end of the boring bar will lead to deflection of the tool. The best stability is obtained with a holder that completely encases the bar. This type of holder is available in two styles: a rigid (Fig. 10.6a) or flange mounted bar, or a divided block (Fig. 10.6b) that clamps when tightened. With a rigidly mounted bar, the bar is either preshrunk into the holder and/or welded in. With flange mounting, a flange with a through hole is normally used. The flange is usually glued onto the

shank of the bar at a distance that gives the required overhang. The bar is then fed into the holder and clamped by means of a screw connection or by being held in the turret.

Less efficient are those tool-clamping methods where the screw clamps onto the bar. This form generally results in vibration and is not recommended. Above all, this method must not be used for the clamping of cemented carbide bars. Cemented carbide is more brittle than steel and cracks will occur as a result of vibration, which in turn may result in breakage.

10.6 Boring Bars

Boring bars are made in a wide variety of styles as shown in Figure 10.4. Single-point boring bars (Fig. 10.7) are easily ground but difficult to adjust when they are used in turret and automatic lathes and machining centers, unless they are held in an adjustable holder (Fig. 10.8).

More expensive boring bars are provided with easily adjustable inserts. These bars are made in standard sizes, with a range of 1/4 to 1/2 inch on the diameter. A fine adjustment is included in increments of 0.001 inch or in some cases 0.0001 inch. They are standard up to about 6 inches in diameter. A boring bar with adjustments is shown in Figure 10.9. A different style of adjustable boring bar with two indexable inserts is shown in Figure 10.10.

Standard boring bars with interchangeable heads to permit various internal operations such as turning, profiling, grooving, and threading are shown in Figure 10.11.

Many times it may be economical to order special bars with two or more preset diameters, set at the proper distance apart. These spe-



FIGURE 10.7: Single-point boring bar. (Courtesy Morse Cutting Tools)



FIGURE 10.8: Adjustable boring head for single-point boring tools. (Courtesy Kennametal Inc.)

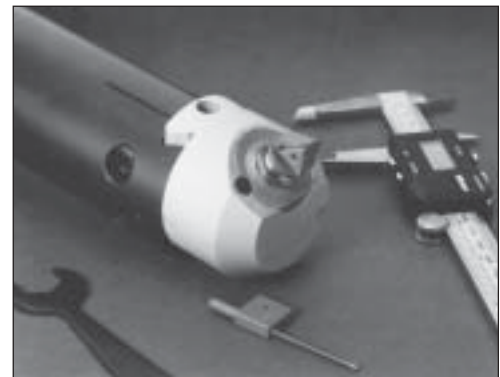


FIGURE 10.9: Adjustable boring bar with fine-tuning adjustment. (Courtesy Valenite Inc.)

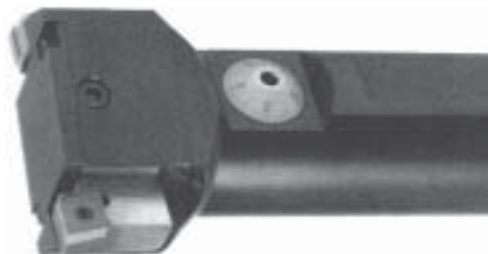


FIGURE 10.10: Adjustable boring bar with two indexable inserts. (Courtesy Kennametal Inc.)



FIGURE 10.11: Standard boring bar with interchangeable heads for various internal operations such as turning, profiling, grooving, and threading. (Courtesy Valenite Inc.)

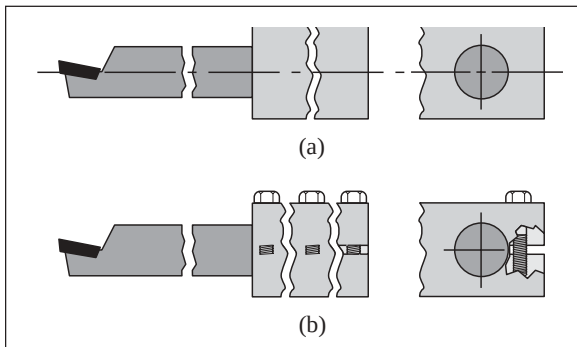


FIGURE 10.6: Two proper boring bar clamping methods.



FIGURE 10.12: Special multi-operation boring bar. (Courtesy: National Acme Co. Div. Devlieg-Bullard, Inc.)

cial bars cost more and are generally only used when large quantities make their use economical. Sometimes this may be the only way to hold the required tolerances and concentricity. Such a special boring bar is shown in Figure 10.12.



FIGURE 10.13: A twin-cutter adjustable boring head with indexable Trigon inserts. (Courtesy Komet of America, Inc.)



FIGURE 10.14: Various indexable replaceable cartridges used in special boring heads. (Courtesy Valenite Inc.)

Other special boring bars, sometimes called boring heads, are designed with replaceable cartridges. A twin cutter adjustable boring tool is shown in Figure 10.13. Various replaceable cartridges for special boring heads are shown in Figure 10.14.

Boring Bar Types: Boring bars are available in steel, solid carbide, and carbide-reinforced steel. The capacity to resist deflection increases as the coefficient of elasticity increases. Since the elasticity coefficient of carbide is three times larger than that of steel, carbide bars are preferred for large overhangs. The disadvantage of carbide is its poor ability to withstand tensile stresses. For carbide-reinforced bars, the carbide sleeves are pre-stressed to prevent tensile stresses.

Boring bars can be equipped with ducts for internal cooling, which is preferred for internal turning. An internal coolant supply provides efficient cooling of the cutting edge, plus better chip breaking and chip evacuation. In this way a longer tool life is obtained and quality problems, which often arise due to chip jamming, are avoided.

Boring Bar Choice: When planning production, it is very important to minimize cutting forces and to create conditions where the greatest possible stability is achieved so that the tool can withstand the stresses that always arise. The length and diameter of the boring bar will be of great significance to the stability of the tool. Since the appearance of the workpiece is the decisive factor when selecting the minimum overhang and maximum tool diameter that can be used, it is important to choose the tool, tool clamping and cutting data which minimize, as much as possible, the cutting forces which arise during the operation. The following recommendations should be followed in order to obtain the best possible stability:

- Choose the largest possible bar diameter, but at the same time ensure that there is enough room for chip evacuation.

- Choose the smallest possible overhang but, at the same time, ensure that the length of the bar allows the recommended clamping lengths to be achieved.

- A 0 degree lead angle should be used. The lead angle should, under no circumstances be more than 15 degrees.

- The indexable inserts should be positive rake that results in lower cutting forces.

- The carbide grade should be tougher than for external turning in order to withstand the stresses to which the insert is exposed when chip jamming and vibration occur.

- Choose a nose radius that is smaller than the cutting depth.

Modern boring bars are designed to take into account the demands that must apply because the operation is performed internally and the dimensions of the tool are determined by the hole depth and the hole diameter. With a positive rake insert geometry, less material deformation and low cutting forces are obtained. The tool should offer good stability to resist the cutting forces that arise and also to reduce deflection and vibration as much as possible. Due to space requirements, satisfactory chip control and good accessibility are also properties of greater importance than with external turning.

10.7 Boring Machines

Boring operations can be performed on other than boring machines, such as lathes, milling machines, and machin-

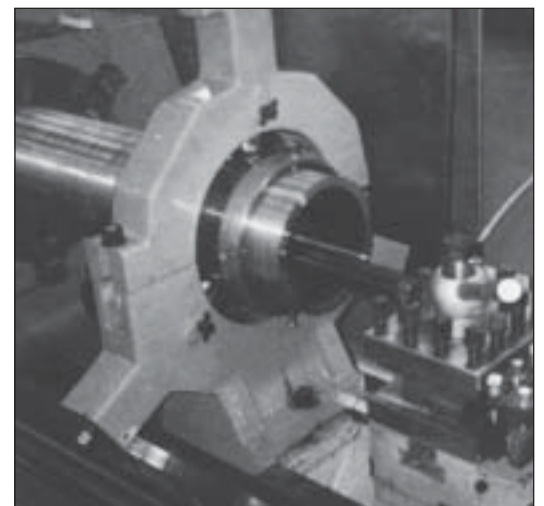


FIGURE 10.15: A typical boring operation performed on a lathe; a steady rest is being used to provide support for the part being machined. (Courtesy Sandvik Coromant Co.)

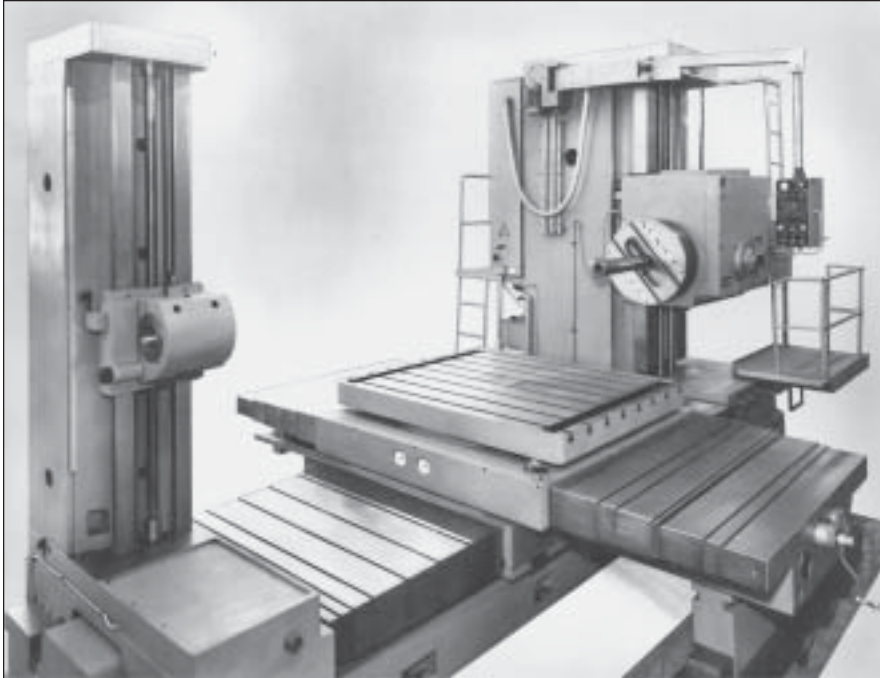


FIGURE 10.16: Table-type horizontal boring machine (HBM) (Courtesy Summit Machine Tool Manufacturing Corp.)

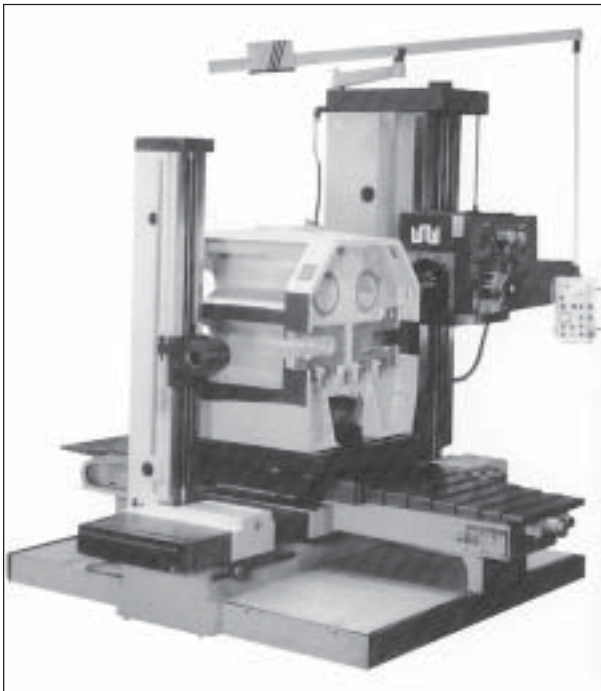


FIGURE 10.17: Large part being machined on a table-type horizontal boring machine. (Courtesy WMW Machinery Co., Inc.)

ing centers. A typical boring operation performed on a lathe is shown in Figure 10.15. A steady rest is being used to provide support for the part being machined.

Boring machines, like most other machine tools, can be classified as horizontal or vertical:

10.7.1 Horizontal Boring Machines (HBM)

The HBM is made to handle medium to very large-sized parts, but these parts are usually somewhat rectangular in shape, though they may be asymmetrical or irregular. The available cutting tools only limit the size of cut, the rigidity of the spindle, and the available horsepower. There are two types of Horizontal Boring Machines:

Table-type Horizontal Boring Machines (HBM)

The table-type HBM shown in Figure 10.16 is built on the same principles as the horizontal-spindle milling machines.

The base and column are fastened together, and the column does not move. The tables are heavy, ribbed castings which may hold loads up to 20,000 pounds. Figure 10.17 shows a large part being machined on a table-type horizontal boring machine.

Size of HBM: The basic size of

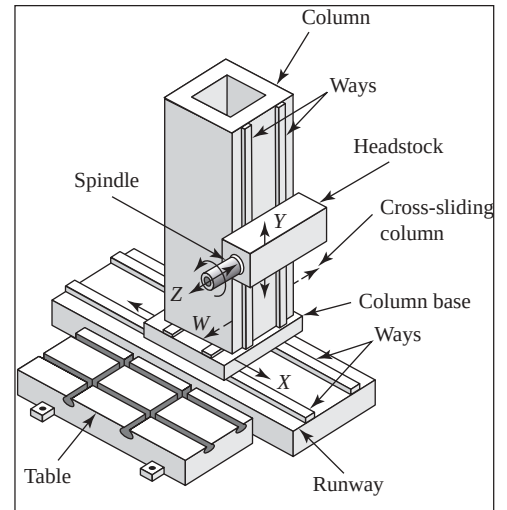


FIGURE 10.18: Principal parts of a floor-type horizontal boring machine (HBM).

an HBM is the diameter of the spindle. Table-type machines usually have spindles from 3 to 6 inches diameter. The larger sizes will transmit more power and, equally important, the spindle will not sag or deflect as much when using a heavy cutting tool while extended. The size is further specified by the size of the table. Although each machine has a 'standard' size table, special sizes may be ordered. The principal parts of the horizontal boring machine are shown in Figure 10.18.

Work Holding: Work holding is with clamps, bolts, or fixtures, the same as with other machines. Rotary tables allow machining of all four faces of a rectangular part or various angle cuts on any shape of part. Rotary tables up to 72 inches square or round are used for large work. If large, rather flat work is to be machined, an angle plate is used. The workpiece is bolted or clamped onto the angle plate so that the 'flat' face is toward the spindle. Figure 10.19 shows a five-axis ram-style machining center. Parts can be clamped to the table and numerically (NC or CNC) positioned to perform a boring operation.

Cutting Tools: Cutting tools are held in the rotating spindle by a tapered hole and a drawbar. To speed up the process of tool changing, either or both of two things are done:

- The drawbar (which pulls the tapered tool holder tightly into the spindle

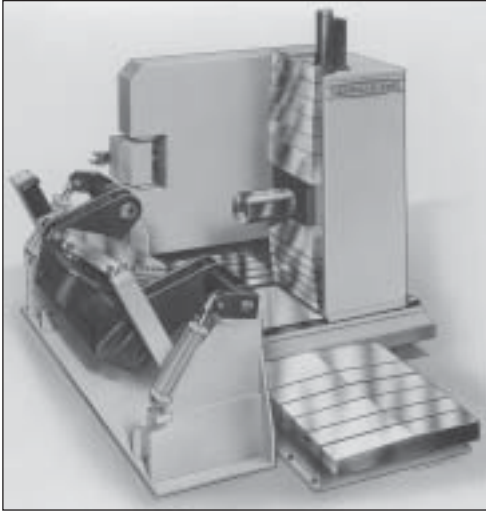


FIGURE 10.19: Five-axis ram-style machining center. (Courtesy Giddings and Lewis, LLC)

hole) can be power operated. Thus, the holder is pulled tight or ejected very quickly.

- Quick-change tooling is used. A basic holder is secured in the spindle. It has a taper into which tools may be secured by a quarter to half turn of the locking collar. Thus, the operator can change preset tools in 10 to 30 seconds.

Tool holders and quick-change tool holders in particular will be discussed in the milling chapters.

Speeds and Feeds: Speeds and feeds cover a wide range because of the wide variety of cutters that may be used on the HBM. Speeds from 15 to 1500 RPM and feed rates from

0.1 to 40 IPM are commonly used.

Floor Type Horizontal Boring Machine (HBM)

The floor type HBM (Fig. 10.18) is used for especially tall or long workpieces. The 'standard' 72-inch runway can be made almost any length required for special jobs. Lengths of 20 feet are in use today. The height of the column, which is usually 60 to 72 inches, can be made to order up to twice this height if the work requires it. Figure 10.20 shows a large floor-type horizontal boring machine.

HBM Table: The table is separate from the boring machine though it is, of course, fastened to the floor. It may be bolted to the runway.

The entire column and column base move left and right (the X axis) along special ways on the runway (Fig. 10.18). The runway must be carefully aligned and leveled when it is first installed, and then checked at intervals as the machine is used.

HBM Headstock: The headstock can be moved accurately up and down the column (the Y axis). The 6 to 10 inch diameter spindle rotates to do the machining. It is moved in and out (the Z axis) up to 48 inches for boring cut, drilling, setting the depth of milling cuts, etc. As in the table-type HBM, the spindle diameter and table size specify the machine size.

Cutting Tools: Cutting tools are the same as those used on the table-type machine. Work holding is also the same, and angle plates are frequently used.

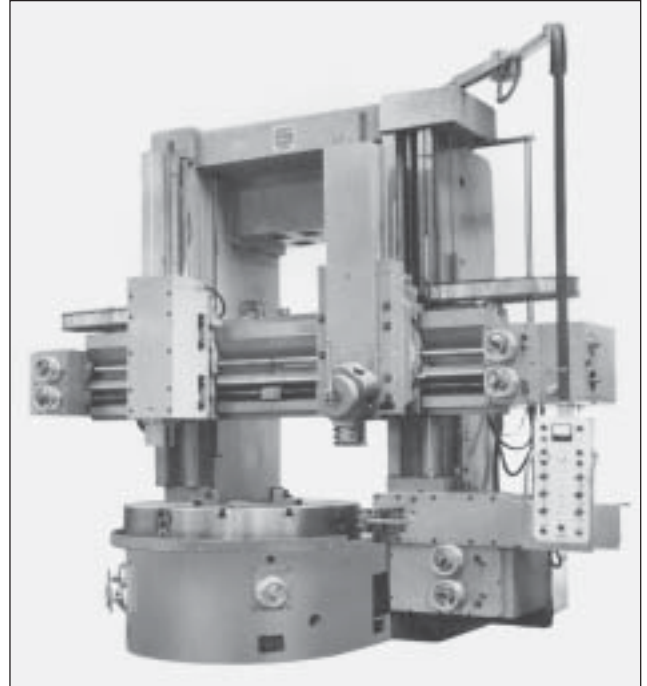


FIGURE 10.21: Vertical boring machine (VBM). (Courtesy Summit Machine Tool Manufacturing Corp.)

10.7.2 Vertical Boring Machines (VBM)

A general description of a vertical boring machine would be that it is a lathe turned on end with the headstock resting on the floor. This machine is needed because even the largest engine lathes cannot handle work much over 24 inches in diameter. A vertical boring machine is shown in Figure 10.21.

Today's VBMs are often listed as turning and boring machines. If facing is added to that name, it pretty well describes the principal uses of this machine. Just like any lathe, these machines can make only round cuts plus facing and contouring cuts.

Figure 10.22 shows the general construction and the motions available on the VBM. The construction is the same as that of the double-housing planer, except that a round table has been substituted for the long reciprocating table, and the toolholders are different since the VBM does not need clapper boxes.

The size of a vertical boring machine is the diameter of the revolving worktable. The double-housing VBM is most often made with table diameters from 48 inches to 144 inches. Larger machines

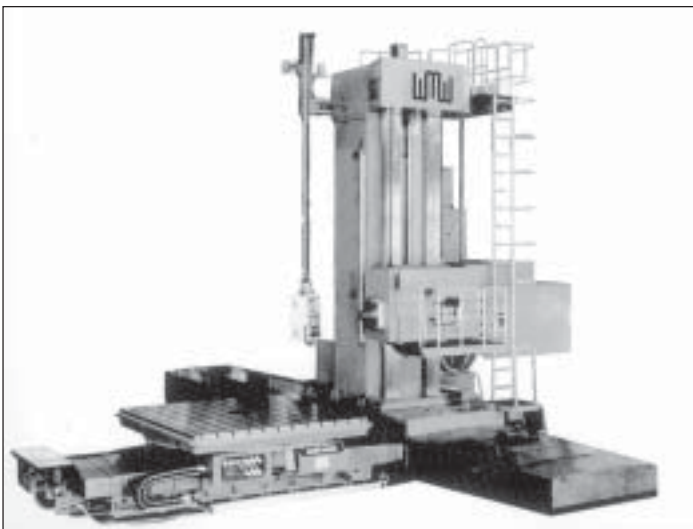


FIGURE 10.20: Large floor-type horizontal boring machine. (Courtesy WMW Machinery Co., Inc.)

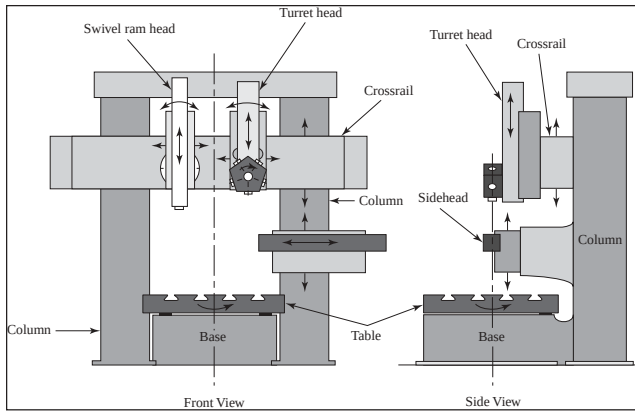


FIGURE 10.22: General construction, components and motions of a vertical boring machine (VBM).

have been made for special work. A rather large VBM is shown in Figure 10.23.

10.7.3 Jig Borers

Jig borers are vertical boring machines with high precision bearings. They are available in various sizes and used mainly in tool rooms for machining jigs and fixtures. More versatile numerically controlled machines are now replacing many jig borers.

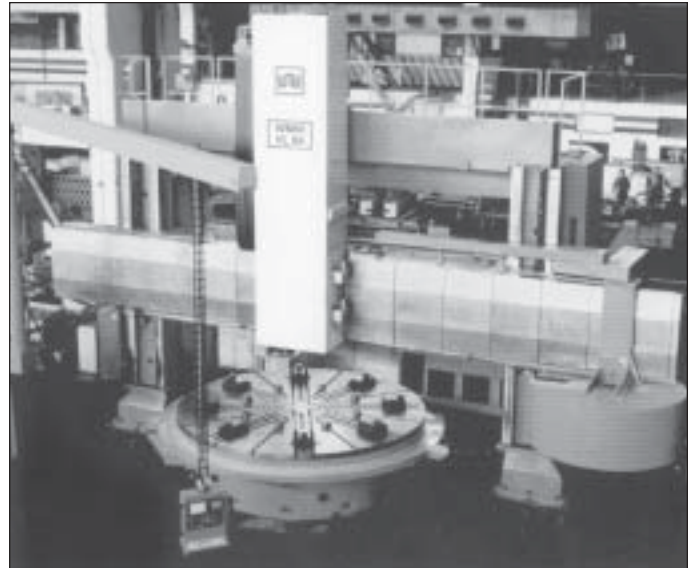


FIGURE 10.23: Large Vertical Boring Machine (Courtesy: WMW Machinery Co., Inc.)