UNIT-V
JIGS AND FIXTURES

Locating and clamping are the critical functions of any work holder. As such, the fundamental principles of locating and clamping, as well as the numerous standard components available for these operations, must be thoroughly understood.

BASIC PRINCIPLES OF LOCATING

To perform properly, work holders must accurately and consistently position the workpiece relative to the cutting tool, part after part. To accomplish this, the locators must ensure that the workpiece is properly referenced and the process is repeatable.

Referencing and Repeatability

"Referencing" is a dual process of positioning the workpiece relative to the work holder, and the work holder relative to the cutting tool. Referencing the work holder to the cutting tool is performed by the guiding or setting devices. With drill jigs, referencing is accomplished using drill bushings. With fixtures, referencing is accomplished using fixture keys, feeler gages, and/or probes. Referencing the workpiece to the work holder, on the other hand, is done with locators.

If a part is incorrectly placed in a work holder, proper location of the workpiece is not achieved and the part will be machined incorrectly. Likewise, if a cutter is improperly positioned relative to the fixture, the machined detail is also improperly located. So, in the design of a work holder, referencing of both the workpiece and the cutter must be considered and simultaneously maintained.

"Repeatability" is the ability of the work holder to consistently produce parts within tolerance limits, and is directly related to the referencing capability of the tool. The location of the workpiece relative to the tool and of the tool to the cutter must be consistent. If the jig or fixture is to maintain desired repeatability, the work holder must be designed to accommodate the workpiece's locating surfaces.

The ideal locating point on a workpiece is a machined surface. Machined surfaces permit location from a consistent reference point. Cast, forged, sheared, or sawed surfaces can vary greatly from part to part, and will affect the accuracy of the location.

The Mechanics of Locating

A workpiece free in space can move in an infinite number of directions. For analysis, this motion can be broken down into twelve directional movements, or "degrees of freedom." All twelve degrees of freedom must be restricted to ensure proper referencing of a workpiece.

As shown in Figure 3-1, the twelve degrees of freedom all relate to the central axes of the workpiece. Notice the six axial degrees of freedom and six radial degrees of freedom. The axial degrees of freedom permit straight-line movement in both directions along the three principal axes, shown as x, y, and z. The radial degrees of freedom permit rotational movement, in both clockwise and counterclockwise radial directions, around the same three axes.

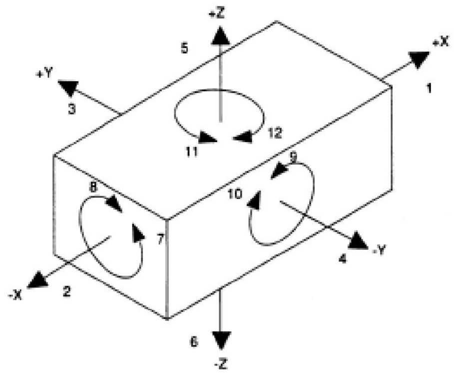

Figure 3-1. The twelve degrees of freedom.

The devices that restrict a workpiece's movement are the locators. The locators, therefore, must be strong enough to maintain the position of the workpiece and to resist the cutting forces. This fact also points out a crucial element in work holder design: locators, not clamps, must hold the workpiece against the cutting forces.

Locators provide a positive stop for the workpiece. Placed against the stop, the workpiece cannot move. Clamps, on the other hand, rely only upon friction between the clamp and the clamped surface to hold the workpiece. Sufficient force could move the workpiece. Clamps are only intended to hold the workpiece against the locators.

Forms of Location

There are three general forms of location: plane, concentric, and radial. Plane locators locate a workpiece from any surface. The surface may be flat, curved, or have an irregular contour. In most applications, plane-locating devices locate a part by its external surfaces, Figure 3-2a. Concentric locators, for the most part, locate a workpiece from a central axis. This axis may or may not be in the center of the workpiece. The most-common type of concentric location is a locating pin placed in a hole. Some workpieces, however, might have a cylindrical projection that requires a locating hole in the fixture, as shown in Figure 3-2b. The third type of location is radial. Radial locators restrict the movement of a workpiece around a concentric locator, Figure 3-2c. In many cases, locating is performed by a combination of the three location methods.

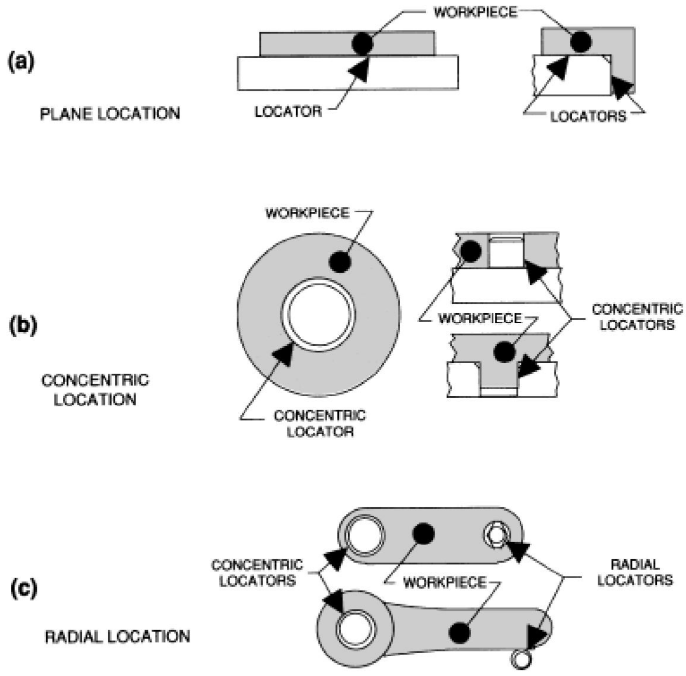

Figure 3-2. The three forms of location: plane, concentric, and radial.

Locating from External Surfaces

Flat surfaces are common workpiece features used for location. Locating from a flat surface is a form ofplane location. Supports are the principal devices used for this location. The three major forms of supports are solid, adjustable, and equalizing, Figure 3-3.

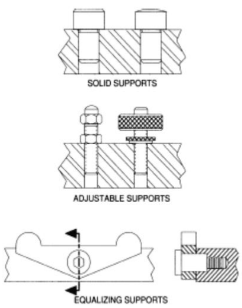

Figure 3-3. Solid, adjustable, and equalizing supports locate a workpiece from a flat surface.

Solid supports are fixed-height locators. They precisely locate a surface in one axis. Though solid supports may be machined directly into a tool body, a more-economical method is using installed supports, such as rest buttons.

Adjustable supports are variable-height locators. Like solid supports, they will also precisely locate a surface in one axis. These supports are used where workpiece variations require adjustable support to suit different heights. These supports are used mainly for cast or forged workpieces that have uneven orirregular mounting surfaces.

Equalizing supports are a form of adjustable support used when a compensating support is required. Although these supports can be fixed in position, in most cases equalizing supports float to accommodate workpiece variations. As one side of the equalizing support is depressed, the other side raises the same amount to maintain part contact. In most cases adjustable and equalizing supports are used along with solid supports.

Locating a workpiece from its external edges is the most-common locating method. The bottom, or primary, locating surface is positioned on three supports, based on the geometry principle that three points are needed to fully define a plane. Two adjacent edges, usually perpendicular to each other, arethen used to complete the location.

The most-common way to locate a workpiece from its external profile is the 3-2-1, or six-point, locational method. With this method, six individual locators reference and restrict the workpiece.

As shown in Figure 3-4, three locators, or supports, are placed under the workpiece. The three locators are usually positioned on the primary locating surface. This restricts axial movement downward, along the -z axis (#6) and radially about the x (#7 and #8) and y (#9 and #10) axes. Together, the three locators restrict five degrees of freedom.

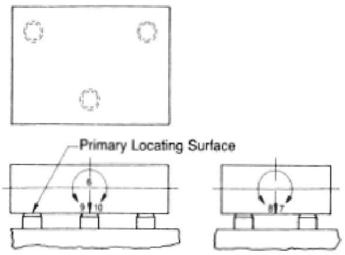

Figure 3-4. Three supports on the primary locating surface restrict five degrees of freedom.

The next two locators are normally placed on the secondary locating surface, as shown in Figure 3-5. They restrict an additional three degrees of freedom by arresting the axial movement along the +y axis(#3) and the radial movement about the z (#11 and #12) axis.

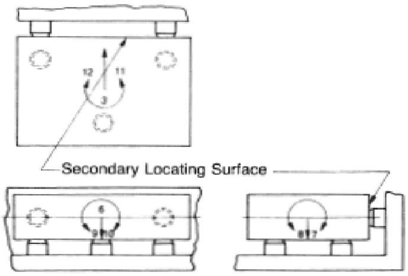

Figure 3-5. Adding two locators on a side restricts eight degrees of freedom.

The final locator, shown in Figure 3-6, is positioned at the end of the part. It restricts the axial movement in one direction along the -x axis. Together, these six locators restrict a total of nine degrees of freedom. The remaining three degrees of freedom (#1, #4, and #5) will be restricted by the clamps.

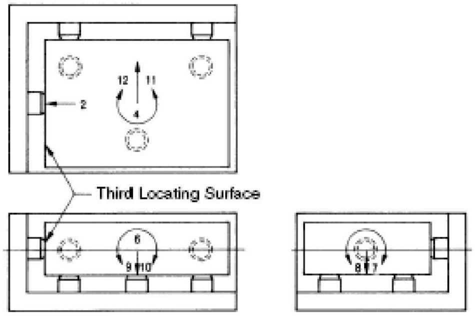

Figure 5-6. Adding a final locator to another side restricts nine degrees of freedom, completing the 3-2-1 location.

Although cylindrical rest buttons are the most-common way of locating a workpiece from its external profile, there are also other devices used for this purpose. These devices include flat-sided locators, veelocators, nest locators and adjustable locators.

Locating from Internal Surfaces

Locating a workpiece from an internal diameter is the most-efficient form of location. The primary features used for this form of location are individual holes or hole patterns. Depending on the placement of the locators, either concentric, radial, or both-concentric-and-radial location are accomplished whenlocating an internal diameter. Plane location is also provided by the plate used to mount the locators.

The two forms of locators used for internal location are locating pins and locating plugs. The only difference between these locators is their size: locating pins are used for smaller holes and locating plugs are used for larger holes.

As shown in Figure 5-7, the plate under the workpiece restricts one degree of freedom. It prevents any axial movement downward, along the -z (#6) axis. The center pin, acting in conjunction with the plate as a concentric locator, prevents any axial or radial movement along or about the x (#1, #2, #7, and #8)and y (#3, #4, #9, and #10) axes. Together, these two locators restrict nine degrees of freedom. The final locator, the pin in the outer hole, is the radial locator that restricts two degrees of freedom by arresting the radial movement around the z (#11 and #12) axis. Together, the locators restrict eleven degrees of freedom. The last degree of freedom, in the +z direction, will be restricted with a clamp.

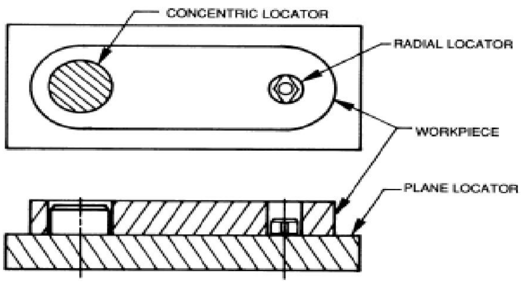

Figure 5-7. Two locating pins mounted on a plate restrict eleven-out-of-twelve degrees of freedom.Analyzing Machining Forces

The most-important factors to consider in fixture layout are the direction and magnitude of machiningforces exerted during the operation. In Figure 5-8, the milling forces generated on a workpiece when properly clamped in a vise tend to push the workpiece down and toward the solid jaw. The clamping action of the movable jaw holds the workpiece against the solid jaw and maintains the position of the part during the cut.

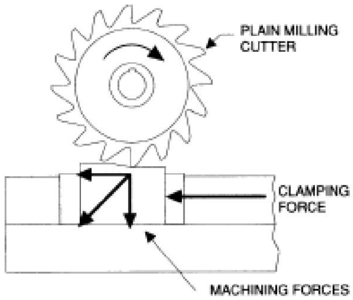

Figure 5-8. Cutting forces in a milling operation should be directed into the solid jaw and base of the vise.

Another example of cutting forces on a workpiece can be seen in the drilling operation in Figure 5-9. The primary machining forces tend to push the workpiece down onto the workholder supports. An additional machining force acting radially around the drill axis also forces the workpiece into the locators. The clamps that hold this workpiece are intended only to hold the workpiece against the locators and to maintain its position during the machining cycle. The only real force exerted on the clamps occurs when the drill breaks through the opposite side of the workpiece, the climbing action of the part on the drill. The machining forces acting on a correctly designed workholder actually help holdthe workpiece.

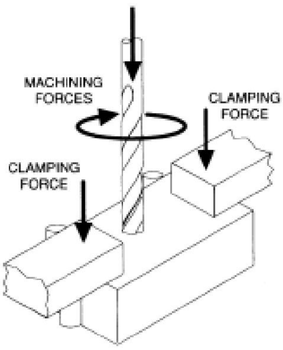

Figure 5-9. The primary cutting forces in a drilling operation are directed both downward and radiallyabout the axis of the drill.

An important step in most fixture designs is looking at the planned machining operations to estimate cutting forces on the workpiece, both magnitude and direction. The "estimate" can be a rough guess based on experience, or a calculation based on machining data. One simple formula for forcemagnitude, shown in Figure 5-10, is based on the physical relationship:

$$\text{Force} = \frac{\text{Power}}{\text{Velocity}}$$

Please note: "heaviest-cut horsepower" is not total machine horsepower; rather it is the maximum horsepower actually used during the machining cycle. Typical machine efficiency is roughly 75% (.75). The number 33,000 is a units-conversion factor.

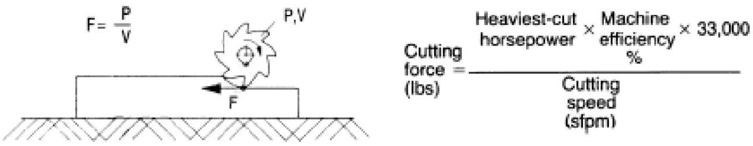

Figure 5-10. A simple formula to estimate the magnitude of cutting forces on the workpiece.

The above formula only calculates force magnitude, not direction. Cutting force can have x-, y-, and/or z-axis components. Force direction (and magnitude) can vary drastically from the beginning, to the middle, to the end of the cut. Figure 5-11 shows a typical calculation. Intuitively, force direction is virtually all horizontal in this example (negligible z-axis component). Direction varies between the x and y axes as the cut progresses.

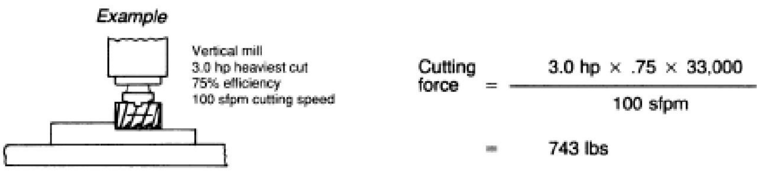

Figure 5-11. Example of a cutting force calculation.