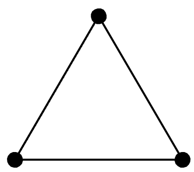
# Jig and Fixture Design

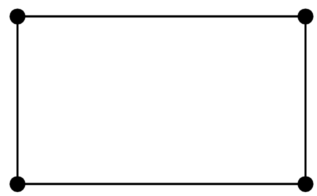
## General Information

All six degrees of freedom, along X, Y, and Z axis, both laterally and rotationally, need be constrained for a part to be fully located.

Two basic locating principles are 3-2-1 locating and 4-2-1 locating. The first, 3-2-1 locating, is the minimum requirement for location. It provides equilibrium but not necessarily stability. The second, 4-2-1 provides both equilibrium and stability.



3-2-1 locating principle



4-2-1 locating principle

Consideration should be given to five major requirements in addition to locating and stopping. Wear resistance, ease of replacement, visibility, accessibility for cleaning and use, and protection against chips and dirt, are all serious considerations in tooling design.

Rule-of-Thumb regarding tolerances, the tolerance for the fixture should be roughly 40% of the tolerance of the finished part. Example: if the width tolerance on two pieces joined with a weld is ± 0.20, the tolerance on the fixture width to hold those pieces should be ± 0.20 X 0.40 or ± 0.08.

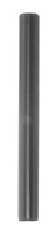
## Common Point Locating Devices

*Buttons*

Buttons are used as supports or as stops. Buttons can be threaded or press fit for location purposes. Press fit are preferred for greater accuracy and resistance to movement from vibration. A through hole or breathe hole is necessary to permit ease of installation and removal. If a breathe or through hole is not possible, drilling the hole deeper and reaming only to the desired depth of the pin is also permissible. A class LN 3 to FN 2 fit (Hendriksen 46.) is preferable. Commonly flat buttons are used for machined surfaces; crowned buttons are used for unmachined surfaces

*Pins*

A pin is any cylindrical component contacted on its side. Buttons may be used for pins but not vice versa. Pins are used primarily for nesting and for use as side stops. Round pins may be used on concave and machined surfaces. On plane machined surfaces a flat is used on one side of the pin. For higher precision the flats are machined after installation. Pins typically use the same press fit as buttons for installation. A caution using pins as side stops, use only with light loads to avoid a large bending moment.



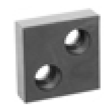
Using relief space around both pins and buttons can help with chips and dirt around the locators.

Another use of a pin as a locator is a dowel coupled with a straight drill bushing. The hardened pin may be inserted into a hardened drill bushing for a precise and wear resistant locating device.

Circular locators, especially large ones, should be provided with some type of relief to minimize jamming when loading and unloading parts. A triangular relief is simple and provides adequate bearing area if there are 3 lands of 30° each, spaced 120° apart.

*Pads*

Pads are flat components, used as base locators where buttons do not provide sufficient area. Pads are secured by screws with well sunk heads and located by means of dowels, usually two unless other locational means are available.

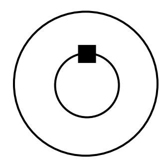


**Radial Locators**

Three types of radial locators are commonly used, keys and keyseats, dual cylinder, and indexing.

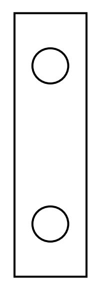
*Keys and Keyseats*

Keys and keyseats need very close tolerances to be used with accuracy and consideration should be given to their hardness as they will be inserted and removed as long as the fixture is in use.



*Dual Cylinder*

Dual cylinder locating is another means of radial location. The use of a diamond pin or expanding pins increases the ease of use. Caution should be taken with using a split bushing type expanding pin as they can be over tightened and damaged. Pre-positioning and successive entering also aid in the use of dual cylinder locating. Pre-positioning can be accomplished with a long lead on the pin or a chamfer. Successive entering is simply allowing only one pin to enter at a time; one example is changing the lengths of the pins.



*Indexing*

Indexing can be accomplished by rotating or sliding the fixture to a predetermined angle or distance.

**Centralizers**

Centralizers center the part. Locating is with respect to one surface, centralizers locate at least two surfaces and one plane or as many as three planes. Several types of centralizers include self-centering chucks, V-blocks, and conical locators.

**Loading and Unloading**

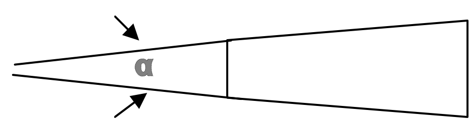
There are several things during the loading and unloading of the fixture to consider. Asymmetry of the part can cause improper loading when not addressed and many things can cause difficulty unloading after processing. When loading the fixture consideration should be given to the symmetry of the part. If the part is symmetric along all axes there is no incorrect way to load the part. This is usually not the case. Many different approaches are used to foolproof the loading and unloading. Using notches, contours, pins, and blocking are all ways to prevent incorrect loading. Burrs, warping, heavy parts, and those which have parts added while in the fixture can all present unloading problems. Ejectors can help with some of these issues as can movable pieces within the fixture.

**Clamping**

Types of clamps commonly used are: screws, straps, wedges, cams, toggles, and rack and pinion. These can be operated manually, hydraulically, or pneumatically.

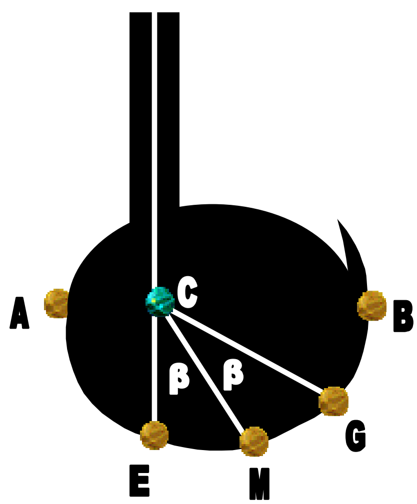
*Wedges*

Wedges work on the principle of friction. Tapers for self locking wedges are typically between 1:20 ($\alpha$ = 2°52') and 1:15 ($\alpha$ = 5°44') up to a wedge angle of 7° (Hendriksen 106). If the wedge is exposed to vibration a better rule-of-thumb is not to exceed a taper of 1:15 ($\alpha$ = 3°47') (Hendriksen 106).




*Cams*

Cams are another type of wedge wrapped around a cylinder. There are several points around the cam which are of interest. The low point (A) and the high point (B, dead center) are the limits of the cam mechanism. Point C is the pivot and $\beta$ is the angle created between the pivot and points E, M, and G. This is the working range of the cam, typically 70° to 80°, $\beta$ = 35° to 40°. Care must be taken to prevent G from getting too close to B to prevent snap through in the case of overload, especially as the cam wears (Hendriksen 109).



*Toggle Clamps*

Toggle clamps use a linkage to exert a force on the part many times the force applied. Toggle clamps are widely useful and several exist to rotate completely out of the way for loading and unloading. Contact must be made shortly before dead center for the clamp to work effectively. At dead center the clamp only works if all parts are dimensionally exact, after dead center the clamp slips through and is useless. After contact is made pressure increases and elastically deforms the toggle.

*Straps*

Strap clamps are mechanically the same as beams. Simple beam bending calculations can be used to determine applicable forces and deflections. Strap clamps are usually slotted to allow for movement for loading and unloading of the fixture.

*Clamping Screws*

A screw acting as a clamping device is essentially a wedge wrapped around a cylinder. The torque applied creates the clamping force. A simplified equation for calculating clamping pressure based on torque is **T = 0.2*D*P**, representative of average shop conditions. T is Torque, D is nominal screw diameter (UNC), and P is clamping pressure (Hendriksen 107). Clamping screws can be tightened with a wrench or by hand. When a heavy load need be clamped a socket head screw is more commonly used. The wrench cannot slip when properly inserted and they are usually made from high strength steel of tensile strength about 185,000 psi. When the load is lighter or there is a possibility of over-tightening a hand actuated device to tighten the screw is preferable (Hendriksen 116). Hand knobs, wing nuts, and knurled heads are all common hand actuated devices. Jack screws are a specific type of screw used when parts vary significantly such as with a casting. There are jack screws available with a set end pressure to eliminate over-tightening. Once the jack is set and the check nut tightened the jack acts as a rigid body to clamp the part.

**<u>Equalizers</u>**

Equalizers are used for the following purposes:

1. To distribute an otherwise concentrated clamping force more evenly over the surface of a part
2. To align clamping forces with locators
3. To clamp on rough surfaces
4. To clamp on surfaces (rough or machined) of different heights
5. To clamp simultaneously on a horizontal and a vertical surface
6. To spread the clamping forces (and their matching locator reactions) evenly over a wider area to avoid distortion of a thin-walled and elastic workpiece
7. To center a part
8. To clamp simultaneously on more than one part (multiple clamping)

(Hendriksen 137)

The basic principle of the equalizer is the “floating principle”. A component is left floating. This component “is statically determinate and adjusts its position freely until force equilibrium is reached” (Hendriksen 136). The function is to distribute force equally or proportionately and eliminate redundancy. Rockers, double movement clamps, floating screws, rollers, and hydraulic pressure are all examples of equalizing mechanisms.

**Some Standard Tooling Part Suppliers**

Reid Supply Company
Fastenal
Carr Lane Mfg Co
McMaster Carr
Jergens Inc.
Fixtureworks
MSC/J & L
HYTEC
VEKTEK Inc.

**Manual Forces**

Some rule-of-thumb numbers to use when calculating manual forces applied to tooling equipment are useful. For levers up to 8 inches in length, 2.8 lbf/in lever length is the average applied force in one hand operations. Force applied repeatedly by one hand should not exceed 30 to 40 lbf. Typical practice is to use 30 lbf for calculating operating force and 90 lbf as an occasional maximum force for calculating dimensions. These are all limiting values not necessarily operating values (Hendriksen 107-108). When reviewing tooling, take into consideration the size and geometry of the specific instruments involved.

**Fixture Body Design**

*T-slot Table Fixtures*

Fixtures for use on a T-slot table should be equipped with slots as opposed to holes to eliminate the need to remove the nuts before removing the fixture. A key is used to locate the fixture on a T-slot table. A strong rule to follow when using keys is “a fixture must align against only one side of the T-slot” (Hendriksen 171)

*Consideration for Operator*

The minimum finger clearance recommended is 5/8” and more if more grip is required. All projecting points, corners, and edges should be rounded, blunted, or covered to prevent hazard to the operator. Thought should be given to the weight of the fixture if it is to be lifted, rotated, or otherwise manually manipulated.

## Construction Methods

Three construction methods for fixture bodies are built-up (fastened), cast, or welded. Listed in order or least to greatest in rigidity they are: built-up, welded, and cast. Listed in order of a clean profile they are: cast, welded, built-up.

*Built-up Fixture Body*

Built-up fixtures are fastened with assembly screws, but usually require the use of dowel pins to increase locating accuracy. Two pins located as far from each other as permissible and at a diagonal is best practice. Dowel pin sizing for built-up fixtures is generally one size smaller than the assembly screw used. For presswork the dowel is sized the same as the assembly screw due to the shock and vibration. The recommended length of engagement into the second member is 1½ to 2 times the dowel diameter. The use of unhardened pins is acceptable where no shear is assumed on the pins. Hardened pins are used wherever shear stress is assumed on the pin or a closer tolerance is needed (Hendriksen 174). The recommended length of engagement for assembly screws is:

| | |
|---|---|
| In Steel | 1½ X D |
| In Cast Iron | 2 X D |
| In Aluminum | 2½ X D |
| In Fiber & Plastic | 3 X D & up |

(Hendriksen 174).

Preferred material thickness for built-up fixtures with respect to assembly screws is 2 X O.D. of screw.

*Cast Fixture Body*

Some general rules can be applied when dimensioning the thickness of cast parts. Wall thickness of beam height H and thickness t:

Single web beams

$t = 0.2\sqrt{H}$ (inch) $\quad$ $t = \sqrt{H}$ (mm)

Double web beams

$t = 0.16\sqrt{H}$ (inch) $\quad$ $t = 0.8\sqrt{H}$ (mm)

Length L, between cross members

$t = \frac{1}{4} + \frac{1}{15}\sqrt{L}$ (inch) $\quad$ $t = 6 + \frac{1}{3}\sqrt{L}$ (mm)

Internal corners $\quad$ $r = 0.5 * t$ to $r = 1.0 * t$

External corners $\quad$ $r = 0.18 * t$ to $r = 0.2 * t$

(Hendriksen 178)

All rule-of-thumb calculations refer to lower limits. When using a larger value consideration should also be given to cooling rates to avoid hot spots.

*Welded Fixture Body*

Many different shapes and sizes of material may be used in a welded fixture body. Square, rectangular, round, angle, I-beam, Z- beam and plate are commonly available and widely used in welded fixtures. Straight plates, strips, and bars are cheaply made and easy to weld. These can be made into gussets and straps which are simple, inexpensive components to increase the rigidity in welded fixtures. Bent sections are usually unnecessary and increase the cost of the fixture. When determining the correct fillet size to specify, the thinner section should be used for calculations. After welding, annealing or normalizing may be necessary. Consider the material properties of the base metal and the effects of welding. (Hendriksen 181-182)

## Jig and Fixture Drawings

The layout drawing for the final fixture is shown complete with the part located for manipulation. If the fixture is for cutting or milling, direction is usually indicated on the drawing. Fixtures used to locate multiple parts in different orientations should show each part and its orientation in the fixture. Tooling number assignment usually differs from product number assignment. The entire fixture may receive only one or a few numbers instead of every component. Sections are also used more frequently to detail the assembly of the fixture. To improve contrast and readability of fixture drawings the part(s) are outlined in red phantom lines, the drawing is done in pencil or grey, and the dimensions, dimension lines, arrowheads, and extension (witness) lines are drawn in India ink or dark black lines. Detail drawings of fixture parts show critical dimensions, overall dimensions, and others that define machining operations.

## Standards Steels

| Class | Types of Steel |
|---|---|
| 10xx | Plain carbon steel |
| 11xx | Free cutting (carbon) steel |
| 13xx | Manganese steels |
| 2xxx | Nickel steels |
| 3xxx | Nickel-chromium steels |
| 4xxx | Molybdenum steels |
| 5xxx | Chromium steels |
| 6xxx | Chromium-vanadium steels |
| 7xxx | Tungsten steels |
| 8xxx | Nickel-chromium-molybdenum steels |
| 9xxx | Silicon-manganese steels |

(Hendriksen 20)

| Tool Steels | Carbon content and alloy |
|---|---|
| W1 | 0.60-1.40 / NA |
| W2 | 0.60-1.40 / NA |
| O1 | 0.90 / W, Cr |
| O2 | 0.90 / Mn |
| O6 | 1.45 / Mn, Si, Mo |
| SAE 52100 | 0.95-1.10 / Cr |

(Hendriksen 21)

Miscellaneous parts that do not carry any heavy load are typically made of low carbon (18–33) and may be case hardened. Highly stressed parts are made from alloy steels with medium carbon content (40-45) with or without heat treatment depending on the stress level during operation. For excessively heavy duty oil hardened tool steel O6 is used. Straps in clamping are typically made from low carbon (20-30) steel and the tips case hardened.

Tool steel is usually hot rolled and annealed when purchased. This must be machined to remove the decarburized surface. Minimum machining allowances are given in the appendix. Low carbon steel parts to be case hardened must be fully carburized to a depth of 1/16$^{th}$ inch. (Hendriksen 22)

## Appendix

### Representative Average Operating Time for Clamping Devices

Time is for clamping only and does not include release time

| **Type of Clamp Operated** | **Time Minutes** |
|---|---|
| Socket head screw | 0.22 |
| Hexagonal nut or set-screw | 0.16 |
| Screw Jack | 0.16 |
| Bar knob, bar screw | 0.16 |
| Spoke nut | 0.12 |
| Hand wheel | 0.11 |
| Backup screw (on strap) | 0.10 |
| Star-shape or other form of hand knob | 0.09 |
| Hand-operated cam | 0.07 |
| C-washer | 0.06 |
| Sliding strap and other quick-acting clamps | 0.02 to 0.04 |
| L- and T-pins (for locating through a hole) | |
| ½ - inch diameter, and up | 0.09 |
| Less than ½ - inch diameter | 0.05 |

(Hendriksen 115)

### Minimum Machining Allowance for Tool Steel

| **Diameter** | | **Minimum machining allowance on Diameter (inch)** | **Minimum machining allowance on Diameter (mm)** |
|---|---|---|---|
| (Inches) | (mm) | | |
| ½ or less | 13 or less | 1/16 | 1 ½ |
| Over ½ to 1 ¼ | 13 to 32 | 1/18 | 3 |
| Over 1 ¼ to 2 ½ | 32 to 63 | ¼ | 6 |
| Over 2 ½ to 5 | 63 to 127 | 3/8 | 10 |
| 5 and over | 127 and over | ½ | 13 |

(Hendriksen 22)

## Bibliography

Hendriksen, Erik K.. Jig and Fixture Design Manual. New York: Industrial Press Inc., 1973.