Fasteners (pp. 1455-1701)

In design, there is a need to fasten two different parts to each other. There are many ways to do this, each of which has its pros and cons.

Fasteners can be classified in the categories:

- **Nails, Spikes, and Wood Screws (not covered in this course)**
- **Rivets**
- **Bolts and Machine Screws (including nuts)**
- **Pins and Studs**
- **Retaining Rings**
- **Welds (pp. 1362-1407)**

Fasteners have many qualities which can be used to determine when to use them:

- **cost of fastener**
- **cost of machining**
- **precision**
- **ease of unfastening**
- **obtrusiveness**
- **strength of fastening**

Fastening Methods Chart

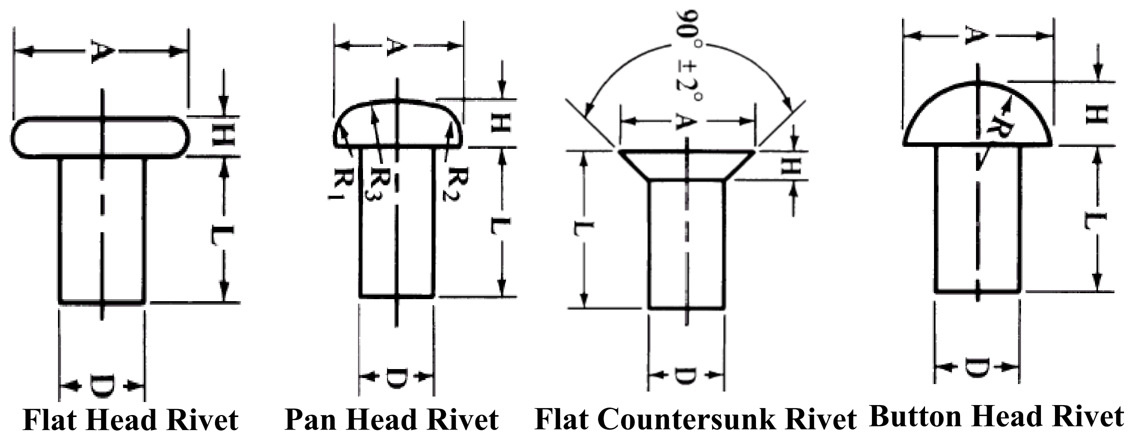
Fastener Type	cost of fastener	cost of machining	precision	ease of unfastening	obtrusive-ness	strength of fastening
Rivets	very low	low	low	medium	low-medium	low-high
Bolts and Machine Screws	medium	medium	high	very easy	low-medium	medium-high
Pins and Studs	low	low	high	very easy	medium	medium-high
Retaining Rings	medium	high	medium	easy	high	low-medium
Welds	very low	low	medium	very hard	high	very high

Riveted Joint

Factors to consider are:

- **spacing of rivets**
- **type and size of rivet**
- **type and size of hole**
- **rivet material.**

For a hard-core design of a riveted joint, the spacing of rivets, the size of rivets, and the rivet material determines the strength of the joint. Formulas and rules of thumb are available in Machinery's Handbook or standard mechanical design texts.



Standard Types of Rivets, from 26th Edition of Machinery's Handbook

The load is shared among the rivets in a joint. However, the material which is being joined is weakened by the number and size of the rivets. Each rivet represents a stress concentration (ie hole in a plate).

These factors must be balanced. As rivets are added, the strength of the fastened material goes down. Once the point where the rivet fails first is passed, the material will fail first and adding rivets reduces the strength in the joint.

Once the point where the material fails first is passed, the only solution to increase the strength of the joint is to thicken the fastened material, which may not be an available solution.

Failure of Rivets

Rivets may fail either by shearing or by popping the head off the rivet (a normal stress failure).

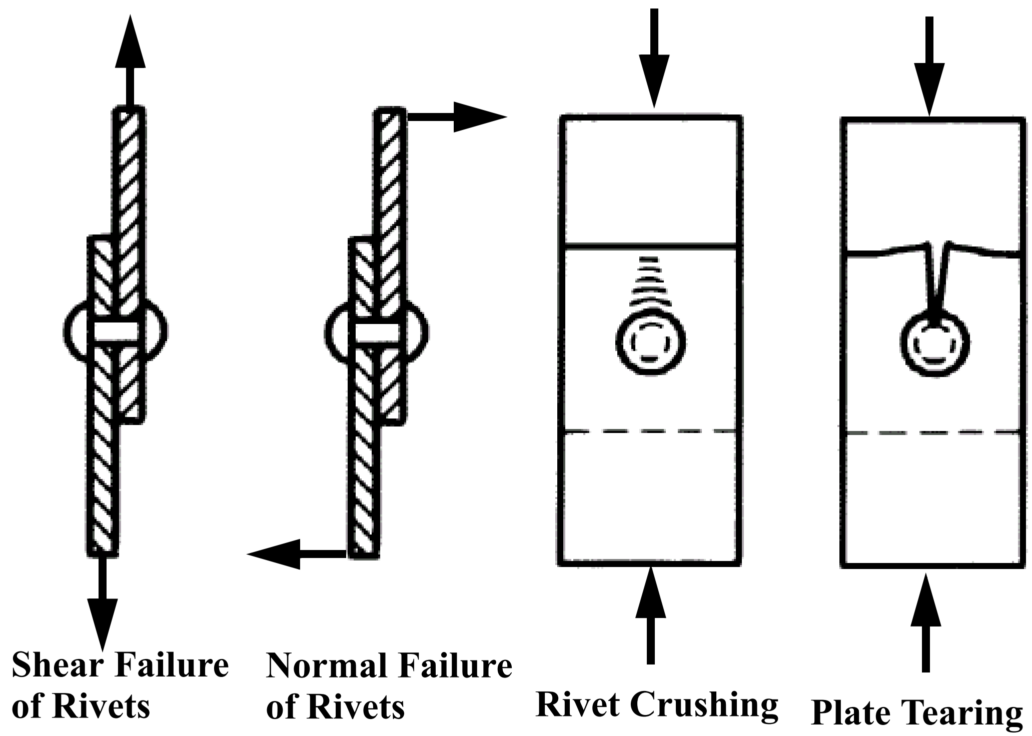
The type of failure (and its solution) depends on the loading of the joint.

The rivets may also be crushed.

Failure will result either from inadequate design preparation or (more generally) from unknown or unexpected loading.

The type of failure can be examined and the unknown loads can be back calculated.

A clever designer can juggle his available parameters and either rearrange or reinforce the rivets so as to avoid future failure.



Rivet Failure, from 26th Ed. Machinery's Handbook

Machine Screws

From 26th Edition of Machinery's Handbook:

"A bolt is an externally threaded fastener designed for insertion through holes in assembled parts, and is normally intended to be tightened or released by torquing a nut.

A screw is an externally threaded fastener capable of being inserted into holes in assembled parts, of mating with a preformed internal thread or forming its own thread and of being tightened or released by torquing the head.

An externally threaded fastener which is prevented from being turned during assembly, and which can be tightened or released only by torquing a nut is a bolt. (Example: round head bolts, track bolts, plow bolts.)

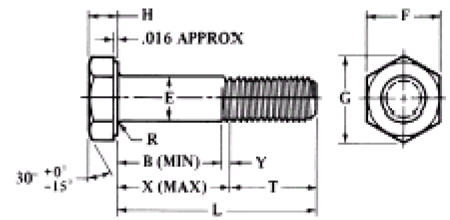
An externally threaded fastener that has a thread form which prohibits assembly with a nut having a straight thread of multiple pitch length is a screw. (Example: wood screws, tapping screws.)

An externally threaded fastener that must be assembled with a nut to perform its intended service is a bolt. (Example: heavy hex structural bolt.)

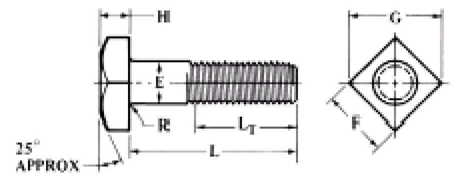
An externally threaded fastener that must be torqued by its head into a tapped or other preformed hole to perform its intended service is a screw. (Example: square head set screw.)

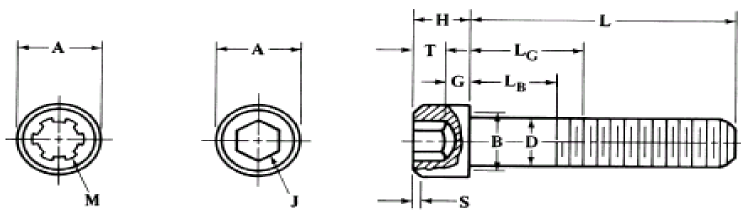
Machine screws come in a variety of types and include American Standard and Metric.

Hex Head

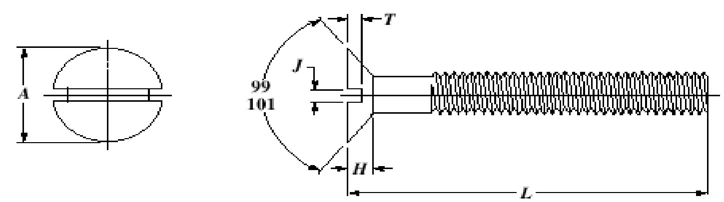


Square Head





Socket Head Cap Screw (Torx and Allen Drive)



Flat Countersunk Screw with Slot Drive

Selection of Screws with Different Head Styles From 26th Ed. Machinery's Handbook

Attributes of Screws

The different attributes of machine screws include:

- **thread (course or fine, American or metric, threads per inch)**
- **length (bolt length and threaded length)**
- **head type (hex, square, rounded, flat, oval, button, fillister, none [for set screws])**
- **material and grade (strength of screw)**
- **drive type (Allen, Phillips, slotted, Torx)**

Fine threads are in all ways desirable. The main difficulty in using fine threads is the increased probability for cross-threading during assembly. High school students should not use fine threads!

Lengths of fasteners are generally quantized in rough size quanta. For instance, 0.5”, 0.75”, 1”. If a custom size is needed, either a standard fastener can be ground down or a custom fastener manufacturer will make you some (for a price). In general, try to design so that you can use standard fastener lengths. Some accommodation can be made by varying the depth of the hole.

For most applications, hex heads are desirable. Hex head screws can be driven either by its drive section or by a nut driver. Some hex head screws do not have a drive section and are intended to be drive by a nut driver.

Button head screws have a lower profile than standard cap screws. There are very useful when obtrusiveness of the head must be minimize. Generally, design around the standard cap screw. If interference becomes a problem, you can drop back on your friend, the button head screw. (E.g. Buford’s wheels)

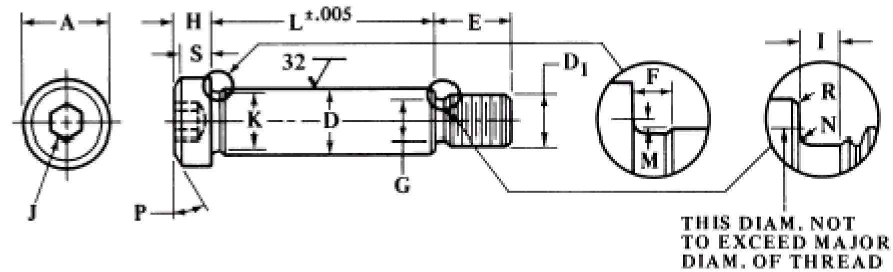
Flat head screws are designed for counter-sinking. The counter-sink allows these screws to self-align parts.

Shoulder Bolts

A shoulder bolt is a special kind of bolt.

It has an unthreaded length which is precisely machine, both as to length and diameter.

When a shoulder bolt is fastened, the shoulder jams against the nut or tapped material and maintains a precise spacing.

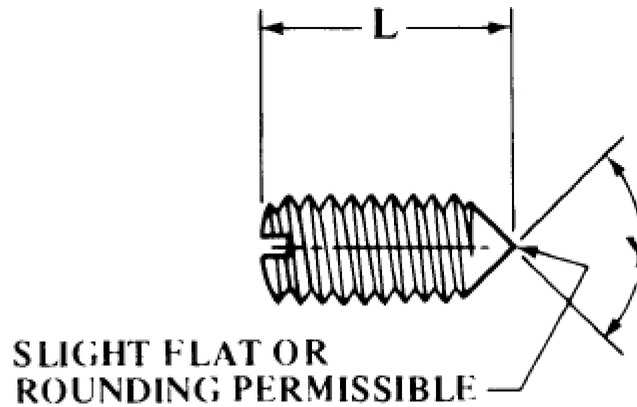


The unthreaded length can be used as a bearing surface.

Shoulder bolts, due to their tolerances and many details, are much more expensive than conventional machine screws.

Set Screws

Set screws are head-less fastners which are used to attach parts to shafts.



There are many applications for set screws. However, they cannot hold large loads and should only be used for lightly loaded applications.

A place to use a set screw: holding a potentiometer shaft to a coupler.

A place to use a set screw: holding a key in place in a key way (set screw on top of key).

A place to avoid a set screw: the primary coupling for a high torque drive system.

When using a set screw, good practice would require that the shaft either have a flat or a dimple.

Many times, two set screws (and flats) at 90° would be used for a loaded shaft.

When using a dimple with a set screw, the dimensions on the screw hole and the dimple must be accurately controlled.

American Standard Threads

In America, the most common type of thread in use is the American Standard thread.

The two thread grades are the UNified Course (UNC) and the UNified Fine (UNF).

Many tables in Machinery's Handbook relate to important thread dimensions for these fasteners.

Size of Screw		No. of Threads per Inch	Tap Drills		Clearance Hole Drills			
					Close Fit		Free Fit	
No. or Diam.	Decimal Equiv.		Drill Size	Decimal Equiv.	Drill Size	Decimal Equiv.	Drill Size	Decimal Equiv.
0	.060	80	3/64	.0469	52	.0635	50	.0700
1	.073	64 72	53 53	.0595 .0595	48	.0760	46	.0810
2	.086	56 64	50 50	.0700 .0700	43	.0890	41	.0960
3	.099	48 56	47 45	.0785 .0820	37	.1040	35	.1100
4	.112	36[a] 40 48	44 43 42	.0860 .0890 .0935	32	.1160	30	.1285
5	.125	40 44	38 37	.1015 1040	30	.1285	29	.1360
6	.138	32 40	36 33	.1065 .1130	27	.1440	25	.1495
8	.164	32 36	29 29	.1360 .1360	18	.1695	16	.1770
10	.190	24 32	25 21	.1495 1590	9	.1960	7	.2010
12	.216	24 28	16 14	.1770 .1820	2	.2210	1	.2280
14	.242	20[a] 24[a]	10 7	.1935 .2010	D	.2460	F	.2570
1/4	.250	20 28	7 3	.2010 .2130	F	.2570	H	.2660
5/16	.3125	18 24	F I	.2570 .2720	P	.3230	Q	.3320
3/8	.375	16 24	5/16 Q	.3125 .3320	W	.3860	X	.3970
7/16	.4375	14 20	U 25/64	.3680 .3906	29/64	.4531	15/32	.4687
1/2	.500	13 20	27/64 29/64	.4219 .4531	33/64	.5156	17/32	.5312

[a] These screws are not in the American Standard but are from the former A.S.M.E. Standard.

Metric Threads

Metric fasteners are specified by their thread size and pitch: `MTXP`, where M indicates a metric thread, T is the thread size (e.g. 6 meaning 6 mm) and P is the pitch (e.g. 0.75 meaning there is 0.75mm between threads).

Hence, a M4x0.75 is a metric screw with a 4 mm body diameter and 0.75 mm between threads.

Nominal Size of Tap	Pitch	Recommended Tap Drill Size
1.6 mm	0.35 mm	1.45 mm
1.8 mm	0.35 mm	1.65 mm
2.0 mm	0.40 mm	1.8 mm
2.2 mm.	0.45 mm	2.0 mm
2.5 mm	0.45 mm	2.3 mm
3.0 mm	0.50 mm	2.8 mm[a]
3.5 mm	0.60 mm	3.2 mm
4.0 mm	0.70 mm	3.7 mm
4.5 mm	0.75 mm	4.2 mm[a]
5.0 mm	0.80 mm	4.6 mm
6.0 mm	1.00 mm	5.6 mm[a]
7.0 mm	1.00 mm	6.5 mm
8.0 mm	1.25 mm	7.4 mm
10.0 mm	1.50 mm	9.3 mm

Tapping and Fastening

Screws can be fastened either by using a nut or by tapping a hole.

Washers and lock washers can be used to prevent the screw from unfastening.

Lock nuts (which have a plastic insert which self-taps when a screw is first inserted) can also be used to prevent unfastening. Note, do not reuse lock nuts!

Locking compounds, such as Loctite, can be applied to the threads to prevent unfastening.

When tapping, a hole is drilled. There are standards charts to determine both the body drill (for clearance holes) and the tap drill for a particular thread.

Note: Pro/Engineer and Autocad Inventor allow you to select a standard hole and by default indicate the necessary drill size.

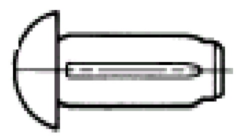
Otherwise, this information is usually printed on the Drill Index (a selection of precisely sized drill bits) or in Machinery's Handbook or Pocket Reference.

Pins and Studs

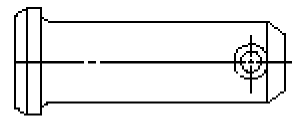
Types of pins:

- **Dowel Pins**
- **Tapered Pins**
- **Cotter Pins**
- **Clevis Pins**
- **Spring Pins**
- **Drive Studs**

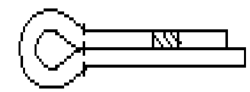
Pins can be used either for alignment or retention. They provide better alignment capabilities than screws or rivets.



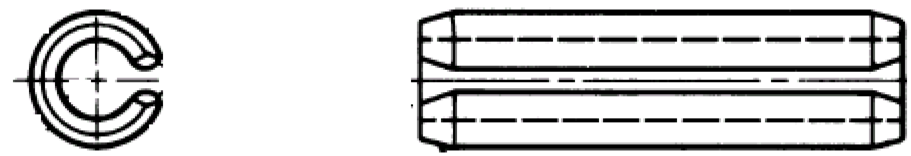
Grooved Drive Stud



Clevis Pin



Cotter Pin



Spring Pin

Retention is accomplished when the pin is introduced into an undersized hole. This results in a press fit between the two parts.

Spring pins are particularly desirable for this use. A spring pin is a roll of spring steel. When introduced into the hole, it compresses. Once it has stabilized, it springs back and exerts a spring loaded normal force on the hole walls.

Cotter pins and clevis pins slip through a slightly oversized hole and are held in place either by deforming the tabs on the cotter pin or using wire wound through the clevis pin hole.

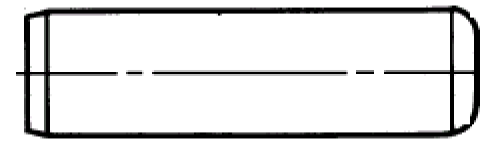
Dowel Pins and Taper Pins

Dowel pins can be used either for retention or alignment.

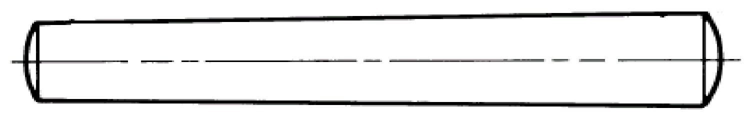
For retention, they are inferior to spring pins. For alignment, they are superb.

They are subject primarily to shear strain and the strength of the pin would be determined according to this consideration. The strength of the pin is determined by material, material treatment (e.g. case hardening), and diameter.

In aligment applications, the size of the pin should be chosen approximately the same as the size of the fastener used to retain the parts.



American Straight Dowel Pin



Tapered Dowel Pin

In soft parts, the hole should be reamed 0.001" smaller than the dowel pin.

The mating part hole should be about 0.001" larger than the dowel pin.

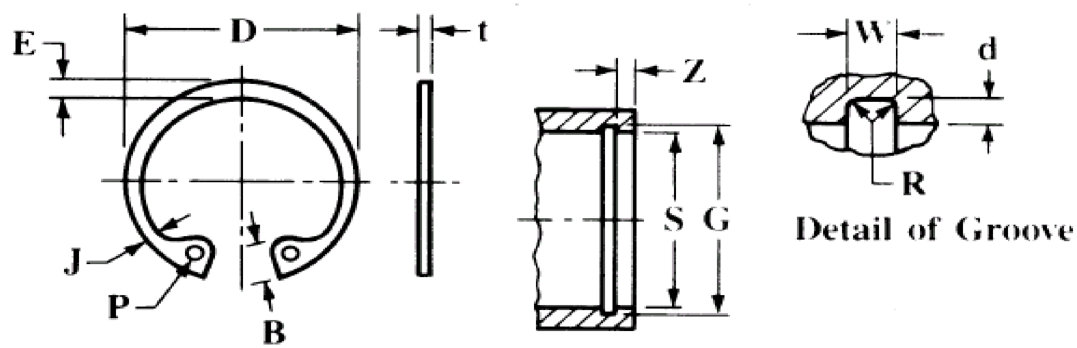
For parts that will be assembled and disassembled frequently, the tapered dowel pin is preferred. Otherwise, the straight pin would be appropriate.

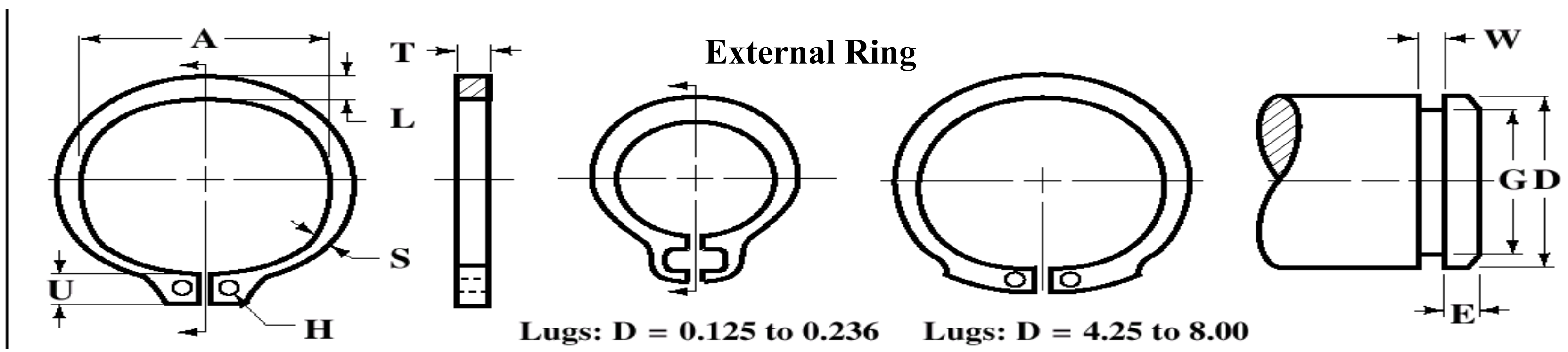
Retaining Rings

A retaining ring acts as an artificial shoulder either on a shaft (external ring) or in a housing (internal ring).

An internal ring is compressed into its groove.

Internal Ring





An external ring is expanded around its groove.k

Although there are standards, generally the groove dimensions should be obtained from the ring manufacturer.

Shaft Coupling

A special case of fasteners is the shaft coupling. A shaft coupling involves connecting a piece which is to rotate onto a shaft. The piece may be a drive gear, a lever arm, a cam, etc.

The easiest method for shaft coupling (and the most unreliable, of course) is to use a set screw. Set screws are effective in low loading conditions only.

At the expense of additional manufacturing time, a key way can be cut into the shaft and broached into the mating piece. A key (such as a square key or a Woodruff key) fits into the mating grooves and provides the power transfer. It is a good idea to put a set screw on top of the key to hold it in place.

The mating piece can be press fit onto the shaft. Sometimes the shaft is knurled to accommocate the press fit. This is suitable only in lightly loaded situations, as the press fit can slip. Pressing is not a good choice if the item has to be removed frequently.

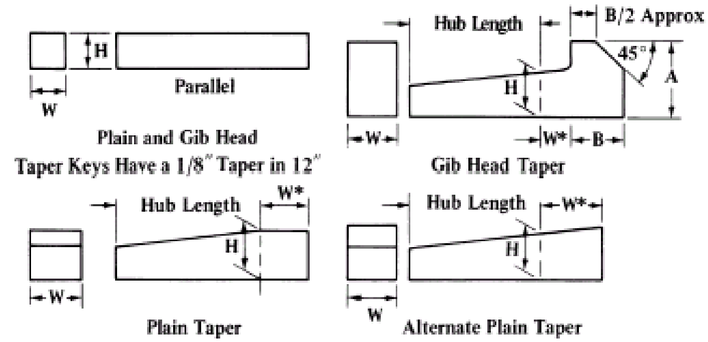
Spline shafts are perhaps the best method for shaft coupling. They require more manufacturing time and therefore may be more expensive. As an example, the window motor on the Hook of Heck and on the Wedge of Doom III gear box use a gear as a spline.

Square and hex shaft may be used to provide coupling. The external square or hex is machined onto the shaft. The mating piece has a square or hex hole. A cotter pin may also be used to ensure that the shafts do not slide out of contact with each other. Mini-me's drive axles used the square fastening method.

Pinning the two pieces together is another alternative. The Phoenix's drive system output shafts are pinned.

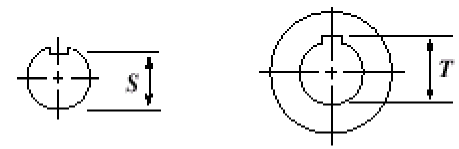
Square and Woodruff Keys

Types of keys include parallel (which we use exclusively), tapered, gib head taper, and alternate taper.

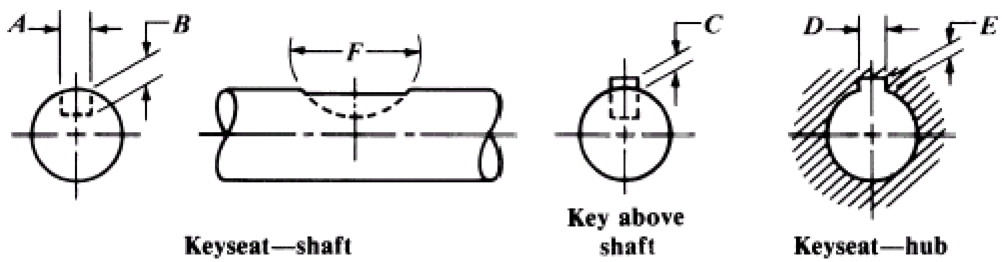


A table indicating recommended key size versus shaft diameter is presented on the 26th Edition of Machinery's Handbook on pg. 2343.

It is recommended that the key way on the shaft be cut no more than .01" over-sized. Some over-size is necessary to allow the key to be placed easily into the shaft. I typically use about .002-.005".



Woodruff keys have a half-moon shape. The key seat in the shaft is cut using a Woodruff key cutter and has a semicircular section. The key way in the mating piece has a standard key form.



We have used both square and Woodruff keys in projects at UALR. I prefer the square key. I suspect that the Woodruff key induces smaller stresses in the shaft.

Machining Key Seats

A square key way is machined into a shaft by milling. Usually, a bit the size of the key is used and a polishing pass (.002-.005” larger than the key) is taken to clean up the back side of the key way. Special key way cutters are available.

A Woodruff key cutter (each standard type of Woodruff key has its own cutter) is used to cut a Woodruff key way. This cutter is brought into contact with the shaft and cuts through to the specified depth.

The key seat in the mating part is made by broaching.

A set of broaches is a special set of saws which, when pressed through a piece of material, gradually cut away a square half-hole.

One advantage of keys as a shaft coupler is that failure can be designed into the key. In other words, the shearing stress required to fail the key can be calculated. As long as this failure occurs before failure in the key set or the shaft or any other part, then the key protects the rest of the system from failure.

An example of this design feature occurs in the lawn mower drive shaft. If a blade hits a stump, then the key is designed to fail before the mounting bolts, the blades, or the drive shaft itself.

A $.25 key can protect a $1000 system.

Press Fit

A press fit involves pushing a larger diameter piece into a smaller diameter hole. Consult with a machinist for press fit values.

However, a rule of thumb is to specify the diameter mismatch by about .001" (light press fit) to .003" (heavy press fit).

If a very heavy press fit is desired, either the hole can be heated, causing expansion or the shaft can be cooled, causing contraction.

As an example, the big measurement ring on the rocket motor was press fit onto the rocket motor body. This press fit is about .005" and was desireable to create a sealing surface without welding.

The rocket body was dipped in liquid nitrogen and cooled down to about -270° Celcius. Once it returned to room temperature, the two parts were as one. Since both parts are steel, this heavy of a press fit will eventually result in a friction welding effect. I.e. over time, the two pieces will physically join.

The down-side to a press fit is that both parts must be precisely machined, the fit is "permanent," and only friction is holding the two parts together. On Johnny #5's gear boxes, a press fit was used to hold the output shaft into its drive wheel. When the gear boxes were stalled, the press fit started to spin. Once it had been broken, the part was useless. My advice was heeded after this, to make the part out of a solid piece, despite the extra machining time.

Pinning

Pinning involves drilling/reaming a hole into both the shaft and the mating piece.

A dowel pin is press fit into the two holes.

This kind of press fit is a good thing, as the forces to remove the press fit are very small. The drive forces are perpendicular to the pin.

To remove the pin, a pin driver or punch is used. Therefore, drive through <u>both sides</u> of the mating piece. Otherwise, the pin will be in for good.

Pins may fail in shear. As with keys, this provides a means of protecting more expensive parts in the system. As an example, the shear pin in the lathe lead screw drive system is designed to fail if the cross feed is crashed against a stop. It is a 2 minute job to fix this type of failure (punch out the old pin, drive in the new pin.) The other place for failure would occur in the lead screw, a disastrously expensive fix!

Shaft Couplers

A final method for joining a shaft to a mating element is to use a shaft coupler.

Shaft couplers come in a variety of forms. The basic concept is to surround the shaft with a material which can be made to grab the shaft. In other words, some mechanical advantage (such as a screw) is used to create a large normal force around the circumference of the shaft. This normal force creates a friction force, which is tangent to the circumference. The friction force keeps the shaft and shaft coupler in a no slip condition.

Examples of shaft couplers can be found in the Small Parts catalog. One of my favorites is the Trantorque. This coupler is designed to have a shaft pass through it and a hub pass around it. When a nut is tightened, an inner surface grips the shaft and an outer surface grips the hub.

Other features to the shaft coupler include the ability to account for misalignment. In the extreme, the shaft coupler would include a universal joint, which can account for three dimensional misalignment between mating shafts.

Rather than show many possible examples of shaft couplers, I would advise that the interested student go to different parts sellers, such as Small Parts, Stock Drive Products, PIC Design, or McMaster Carr and see what actual couplers are available.

Square and Hexagonal Shafts and Broaching

Another method of coupling a shaft to a part is to use either square shaft or hexagonal shaft. The only problem is that the accompanying hole must be either square or hexagonal.

There are a couple of processes by which a square or hexagonal hole can be made.

The easy way (if the hole goes all the way through the part) is to make a round hole and then <u>broach</u> it.

A broach is a cutting tool which removes an increasingly large amount of material as it is pushed through the part.

A press (in many cases an arbor press) is used to push the broach through the hole.

Square and hexagonal shafting is available almost as commonly as round stock.