# 1B Integrated Design Project

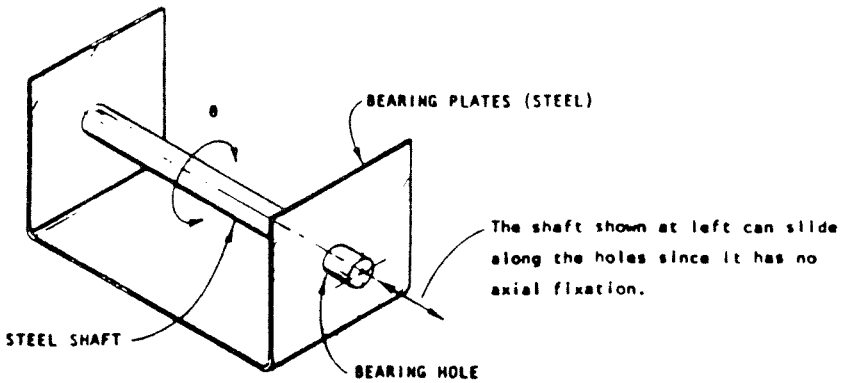
# Practical Guidelines for Mechanical Design and Manufacture

# M.1 Machine Elements

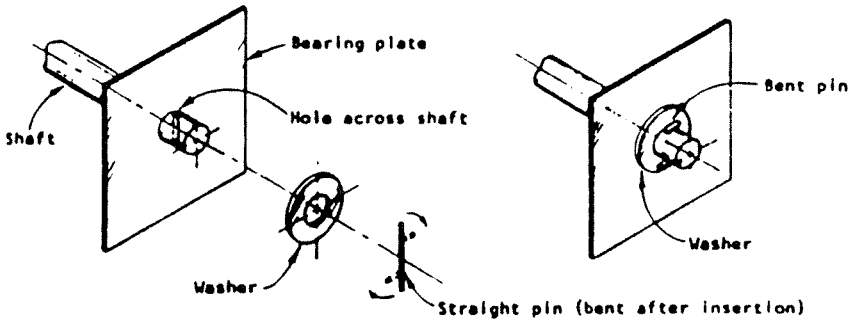
## M.1.1 Pivots and bearings

### Pivots

Whenever possible, pivoted or turning joints must be used instead of sliding joints. **Linear sliding joints are notorious sources of trouble.**
To minimize frictional forces, pivoted joints should be made of hard materials, preferably steel, and pivoting elements should be of small diameter.



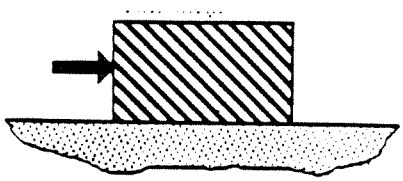

This form of bearing has very small surface of contact and cannot be lubricated. Shaft load must also be light to minimize wear.

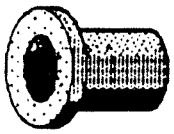



AXIAL FIXATION OF SHAFT BY SIMPLE PIN AND WASHER.
A hole is drilled at each end of the shaft, a washer is inserted, and a pin or wire is put through the hole and bent around the shaft as shown. The same must be done at the opposite end of the shaft.

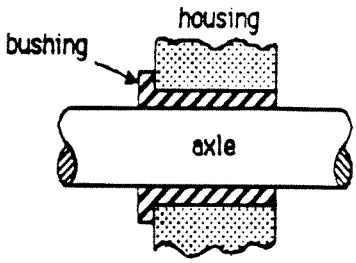
# Sliding contact

Sliding bearings are those in which two or more elements in the bearing assembly slide over one another. The properties of the bearing are determined by the coefficient of friction of the two materials upon one another and the loads transferred to the bearing. These properties can be aided by the use of lubricants, generally oil or grease. The lubrication does not totally eliminate contact between the surfaces, and this is the distinguishing factor between sliding- contact and non-contact bearings.





Bushing



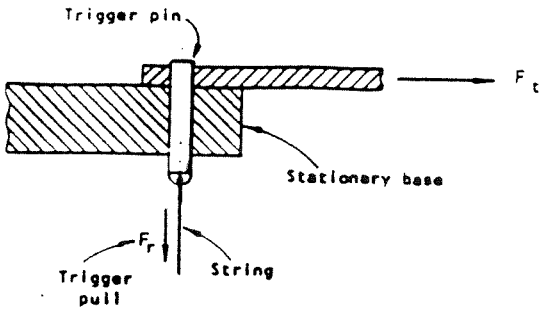

Bushed bearing

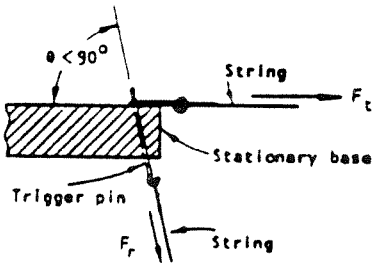
A bushed bearing (also called a plain, sleeve, or journal bearing) is a type of sliding-contact bearing that is commonly used for rotating shafts. The shaft rotates in the bushing which is usually made of a low-friction material such as Teflon.

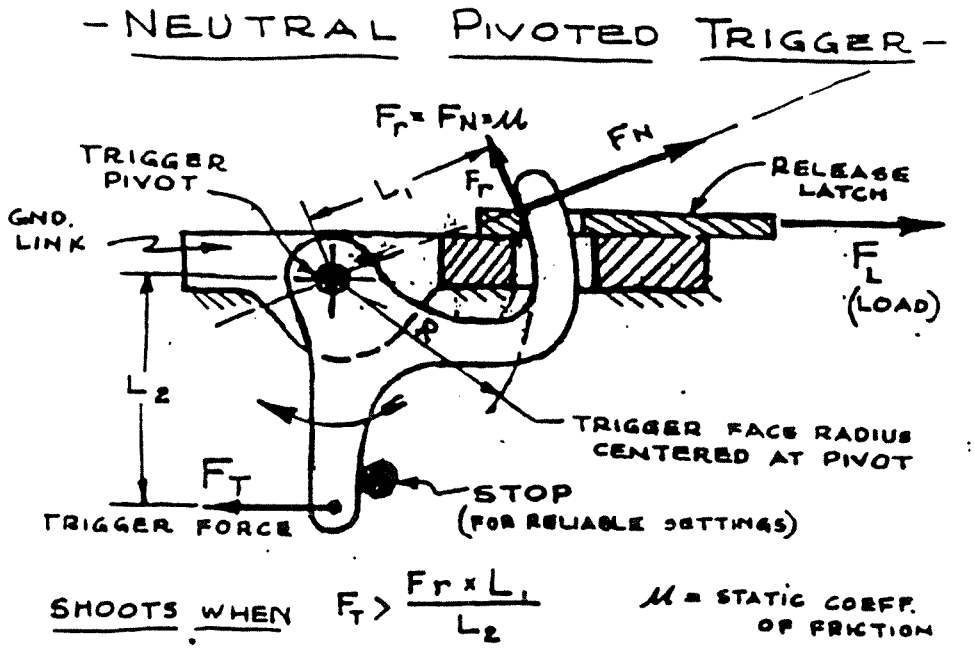
### M.1.2 Trigger mechanisms

A common mistake made by designers is to seek very sensitive trigger systems. Those are usually called *hair triggers*, and tend to fire at the wrong time!

#### M.1.2.1 Different types of triggers

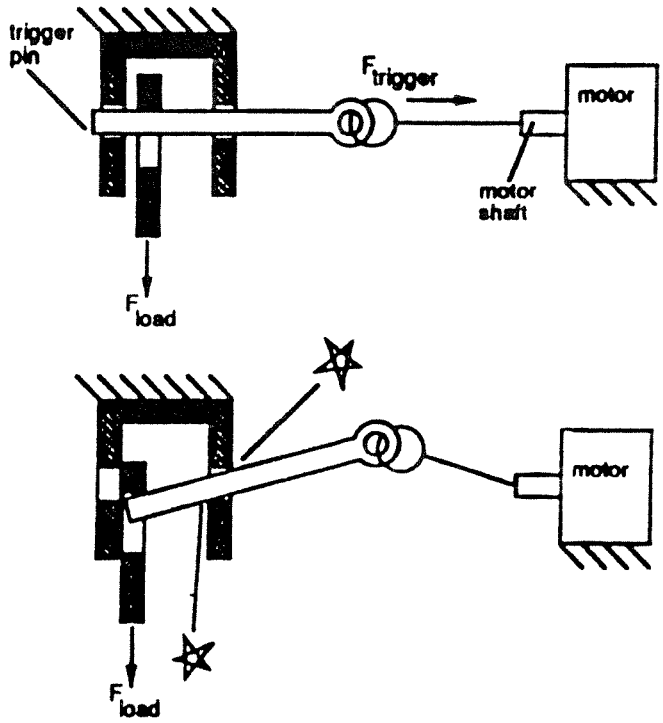


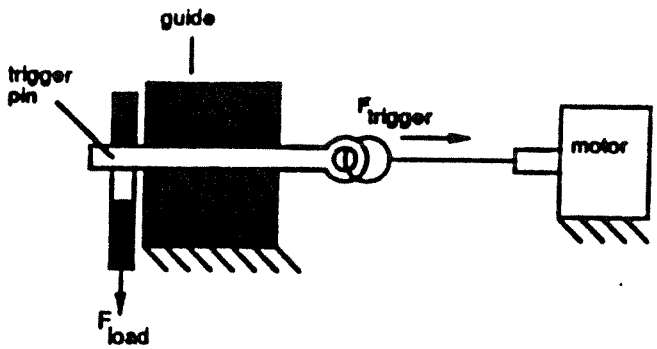




NOTE - The trigger force $F_T$ may result from the pull from a string attached to the shaft of a small motor, or from any other convenient mechanical action at a desired time, i.e. striking something.

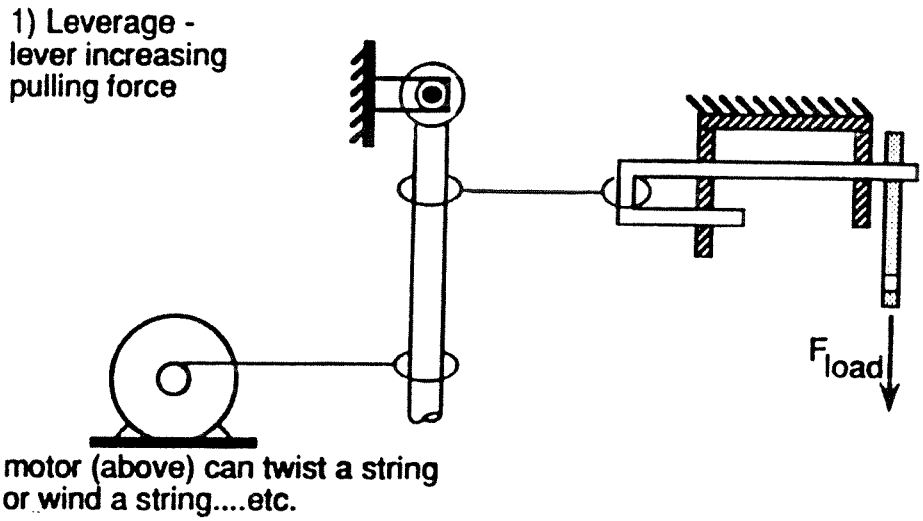
Trigger that fails:

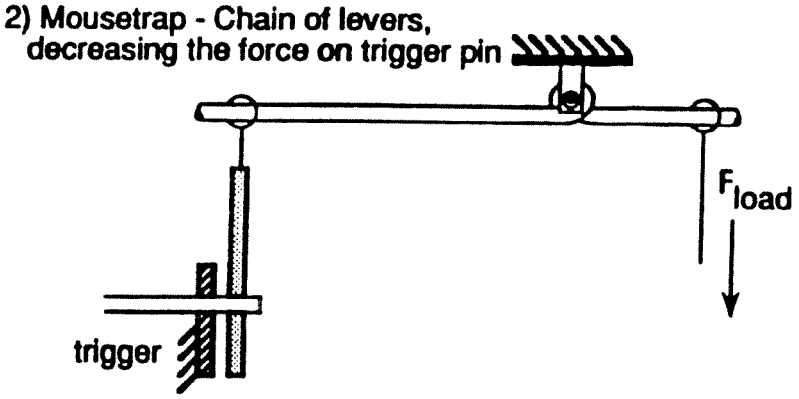



Trigger that works:

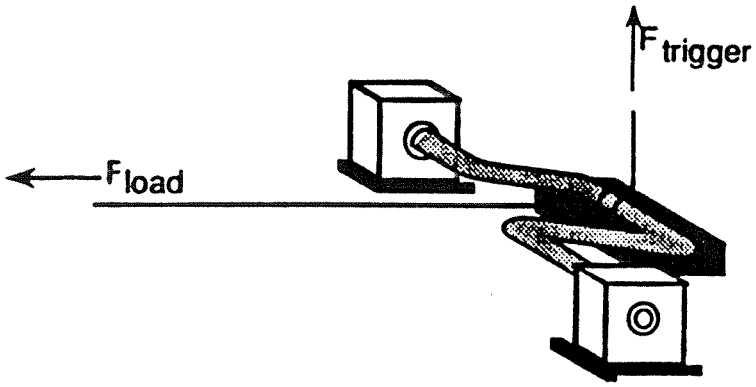


Triggering a large force from a small one

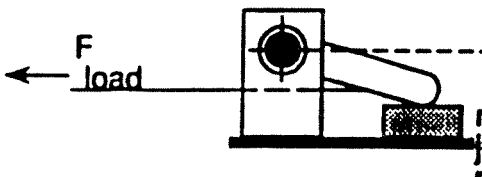


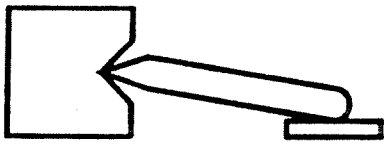
Over-dead-centre crank



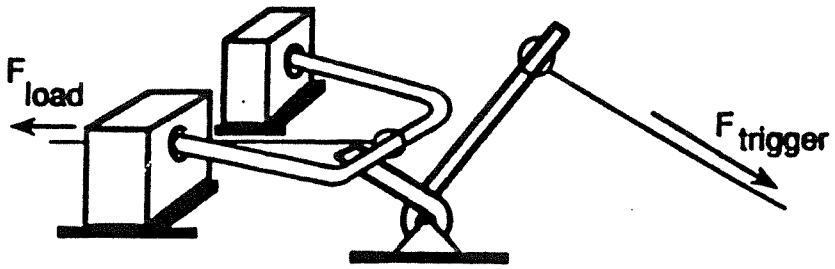

Section:




OR



(when crank is lifted
through dead center,
it flips on around,
no longer resisting load)



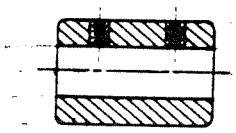
## M.1.3 Couplings

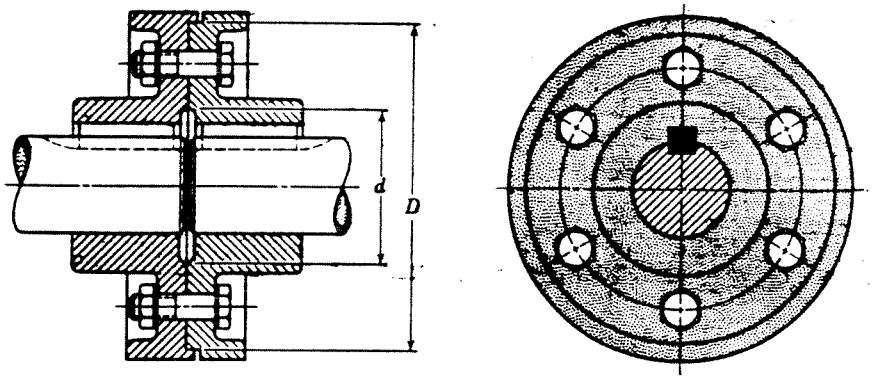
Couplings may be required to join shafts at angles, to compensate for misalignment between shafts, to prevent the transmission of overload power, or to alter the vibration and shock characteristics of the drive.

### M.1.3.1 Rigid couplings

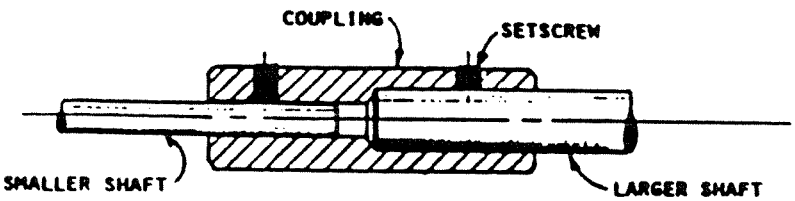
Rigid couplings do not accommodate for misalignment.

For shafts of same diameter:



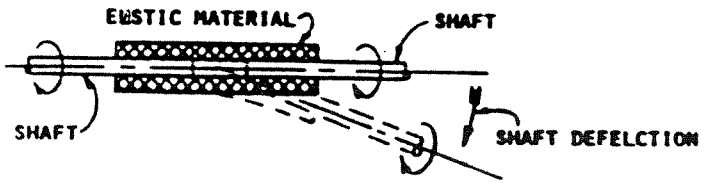



For shafts of different diameter:



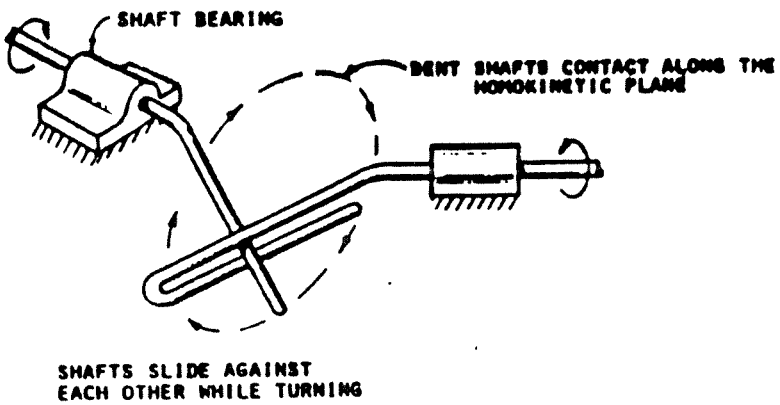
### M.1.3.2 Flexible couplings

Flexible couplings will operate satisfactorily under some type of misalignment. And because of their torsional flexibility or resilience, they assist in lessening the effects of shock loads or vibrations which may be present.



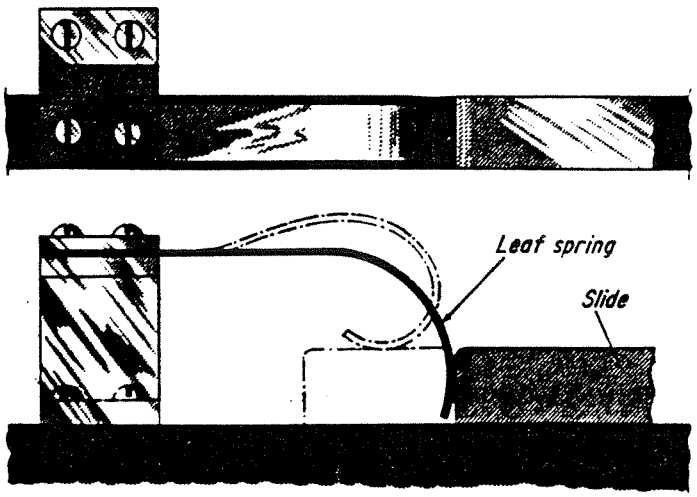

The attachment of shafts to the tube of elastic material (rubber) could be made by using cyanoacrylate (loctite).

### M.1.3.3 Simple universal joint

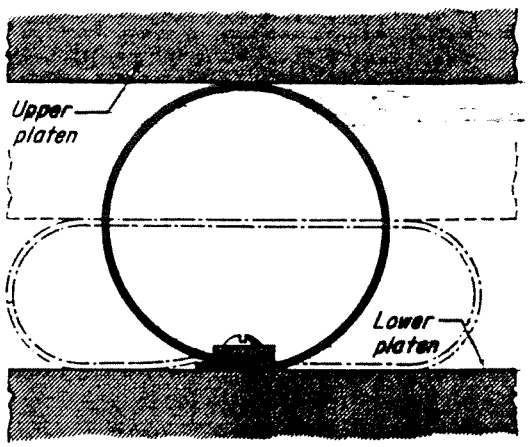


## M.1.4 Springs

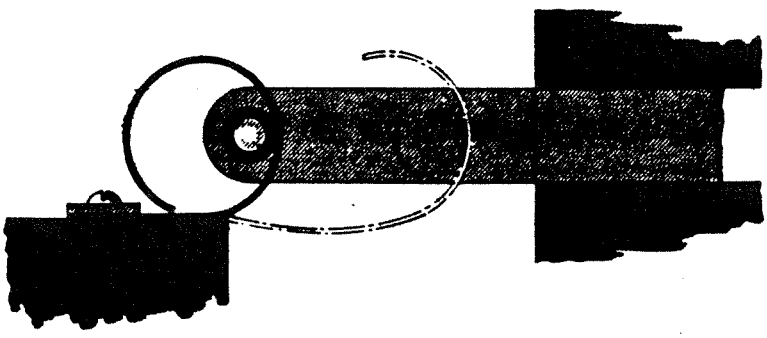
### M.1.4.1 Constant force springs in mechanisms




**SPRING-LOADED SLIDE** will always return to its original position unless it is pushed until the spring kicks out.

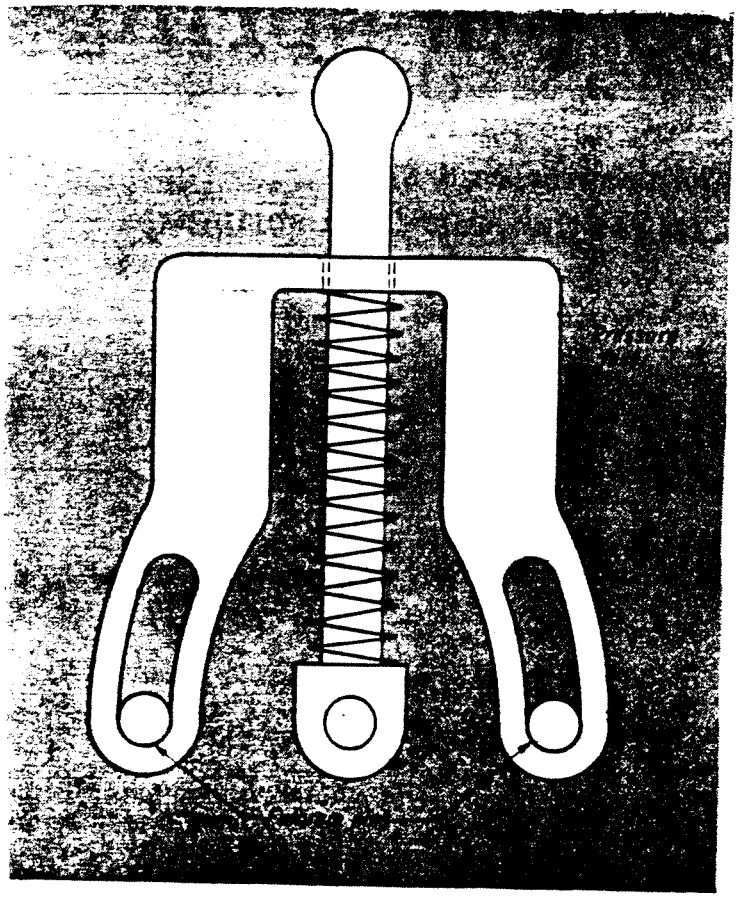



**INCREASING SUPPORT AREA** as the load increases on both upper and lower platens is provided by a circular spring.

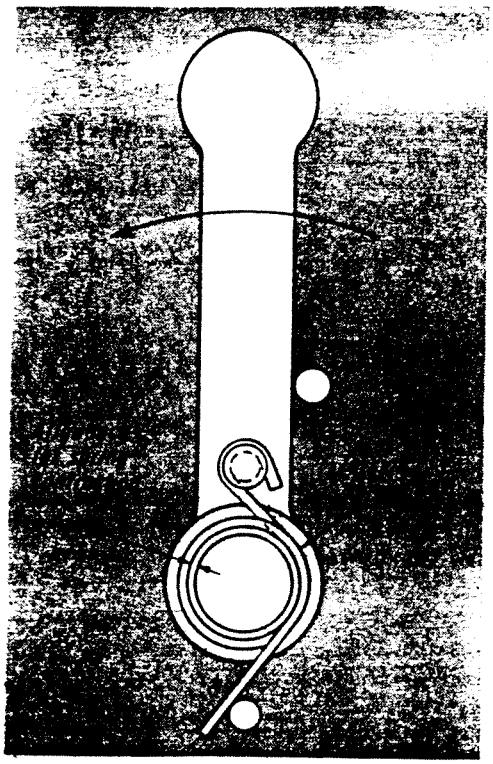


**CONSTANT TENSION** in the spring, and thus force required to activate slide, is (almost) provided by this single coil.

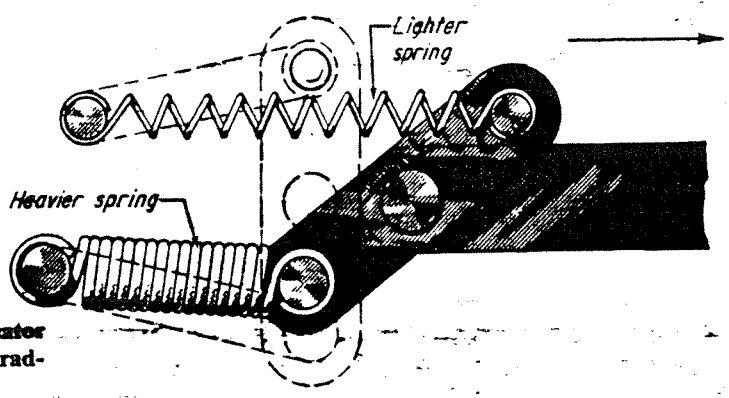
## M.1.4.2 Helical and torsion springs in mechanisms



**DOUBLE PRESSURE-LEVER** returns handle to center from either direction by compressing spring. Lever pivots on one pin and comes to stop against the other pin.



**TORSION SPRING** must have coil diameter larger than shaft diameter to allow for spring contraction during windup.

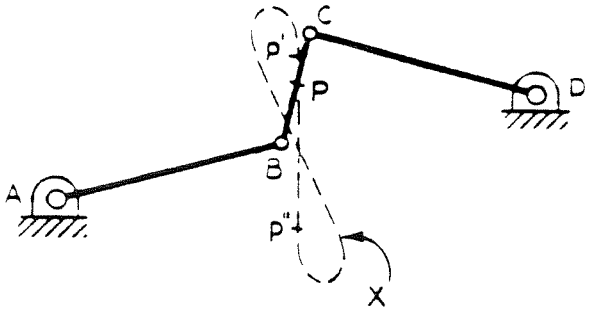



**DIFFERENTIAL-RATE** linkage lets actuator stroke be under light tension at start, then gradually heavier tension.

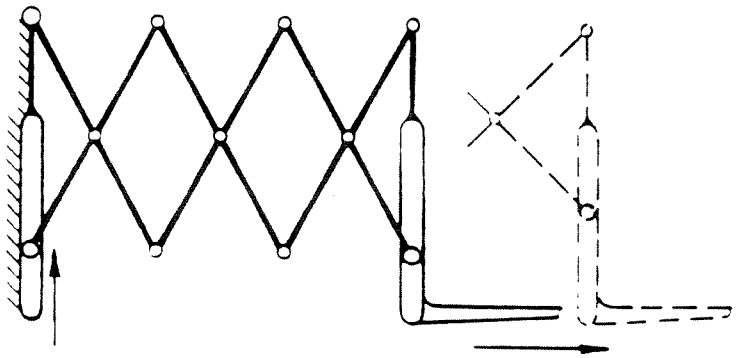
### M.1.5 Linkages

Please refer to the 1A mechanics notes on kinematics for the details on how to work out the velocities and accelerations of the linkages.

#### M.1.5.1 Some basic four-bar linkages

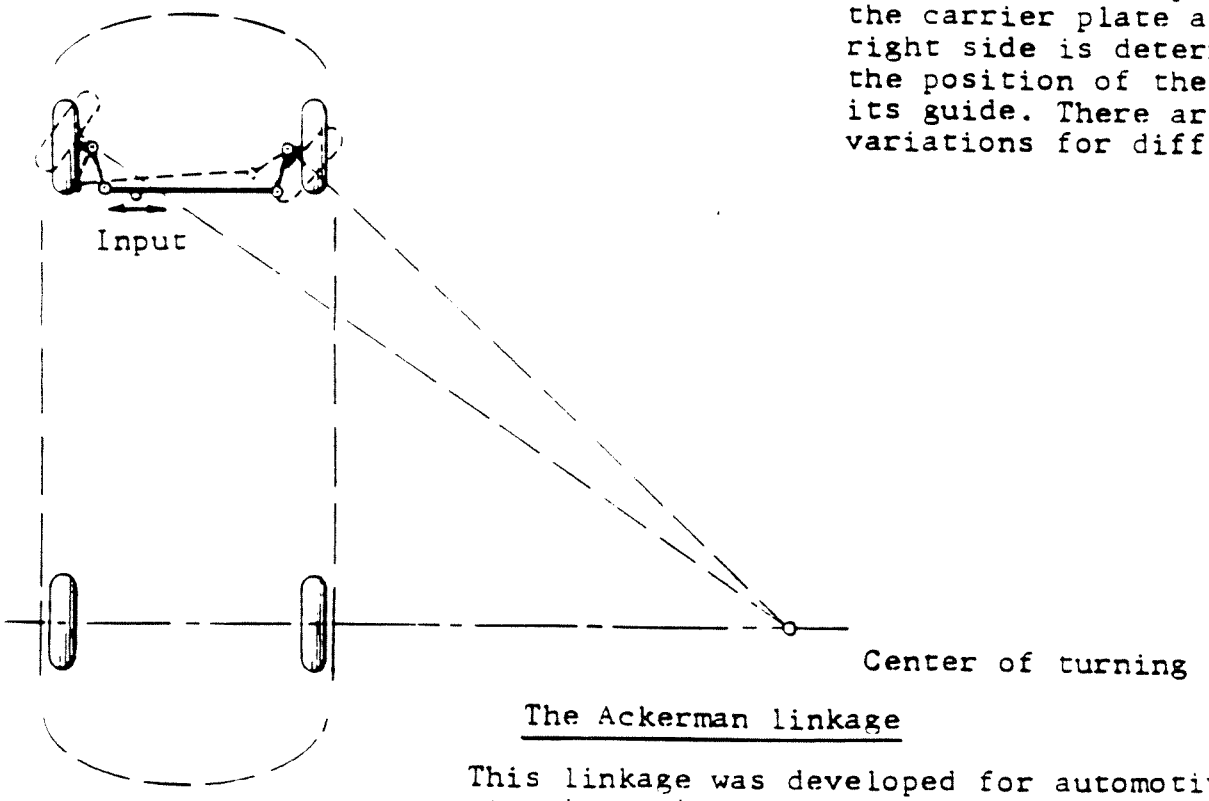



James Watt's approximate straight-line linkage. Point P between joints B & C moves in straight line between points P' & P". Links AB and CD are the same length.




The Lazy Tongs linkage.

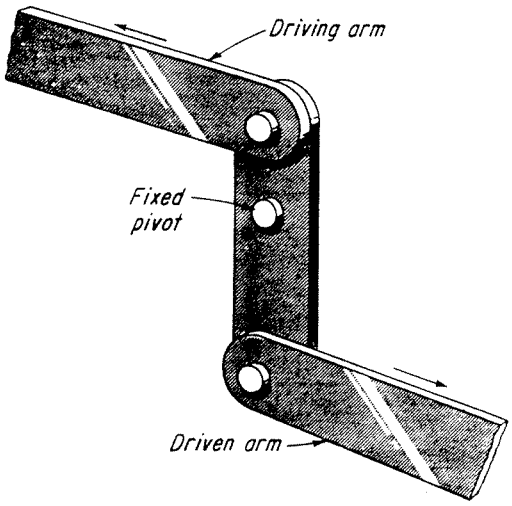
This is a variation of the slider-crank as can be seen at each end. The position of the carrier plate at the right side is determined by the position of the slide on its guide. There are many variations for different uses.



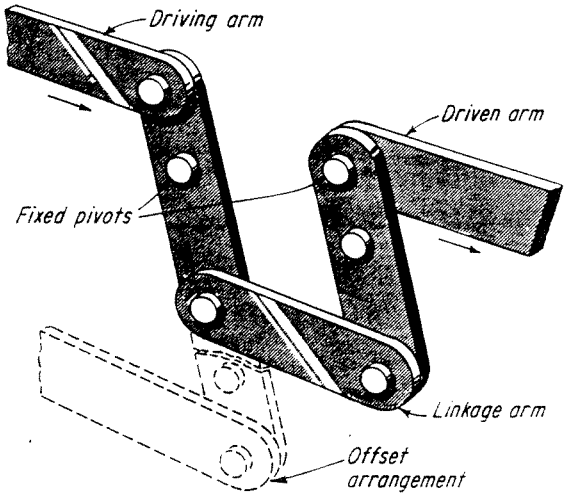

The Ackerman linkage

This linkage was developed for automotive steering. As can be seen it is also a form of a four-bar linkage. When the input joint is moved to left or right the axes of the front wheels are made to intersect along the centerline of the rear wheels.

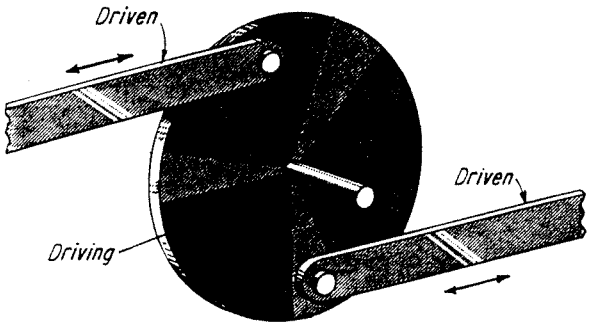
## M.1.5.2 Push-pull linkages



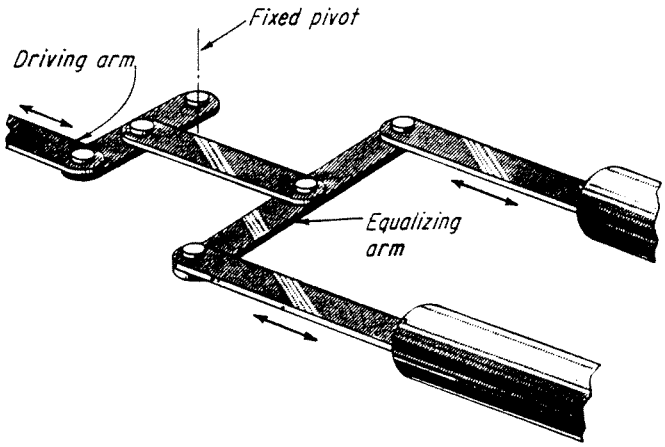

**FIXED PIVOTS** on arm lengths are located to control ratio of input and output movements of this push-pull-actuated linkage. Mechanism can be either flat bars or round rods of adequate thickness to prevent bowing under compression.



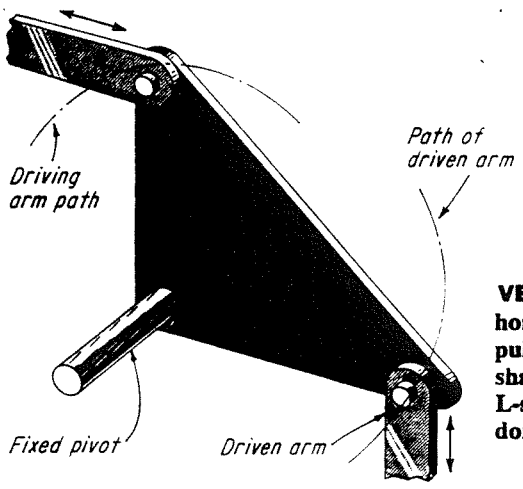

**PUSH-PULL LINKAGE** for same direction of motion can be obtained by adding linkage arm to previous design. In both cases, if arms are bars it might be best to make them forked rather than merely flatted at their linkage ends.




**ROTARY-ACTUATED LINKAGE** gives opposite direction of motion and can be obtained by using 3-bar linkage with pivot point of middle link located at midpoint of arm length. Disk should be adequately strengthened for heavy loads.




**EQUALIZING LINKAGE** here has an equalizing arm that balances the input force to two output arms. This arrangement is most suitable for air or hydraulic systems where equal force is to be exerted on the pistons of separate cylinders.




**VERTICAL OUTPUT MOVEMENT** from horizontal input is gained with this push-pull linkage. Although the triangular-shaped plate could be substituted by an L-shaped arm, the plate gives greater freedom of driving- and driven-arm location.

## M.2 Manufacturing

The materials available for this project are: aluminium, steel, plastic and wood. General machining guidelines for selected manufacturing processes are given in the next sections. But first, a reminder on safety procedures.

### M.2.1 Safety

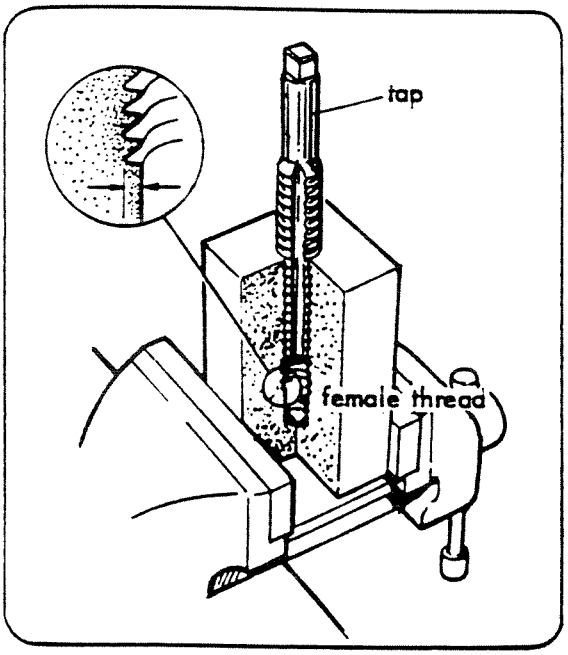
# THE WORKSHOP IS AN EYE PROTECTION AREA. PLEASE WEAR YOUR SAFETY GOGGLES.

## Before operating any machine please ensure:

1. You are not wearing loose clothing
2. Long hair is tied back
3. The workpiece is securely clamped
4. **If in doubt, check with the workshop staff before commencing work**

Note: Compressed air is potentially dangerous: please use the air line and pneumatic control lines with care.

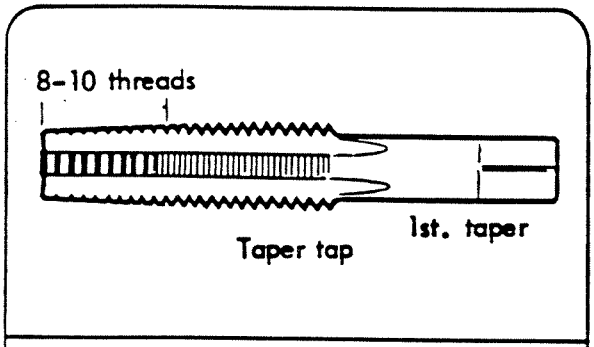
## M.2.2 Tapping and screwing



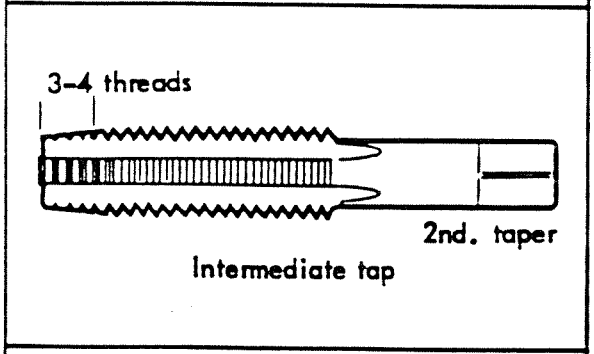

**Taps**
A tap cuts an internal (female) thread, either left or right hand.

**Set of Taps**
Taps are usually made in sets of three: a taper tap, an intermediate tap, and a plug tap.

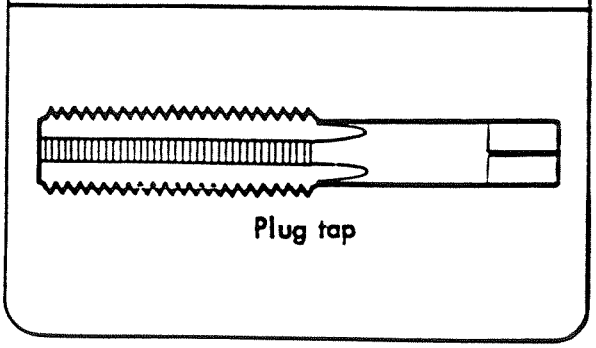
Safety
Beware of cutting edges when handling.



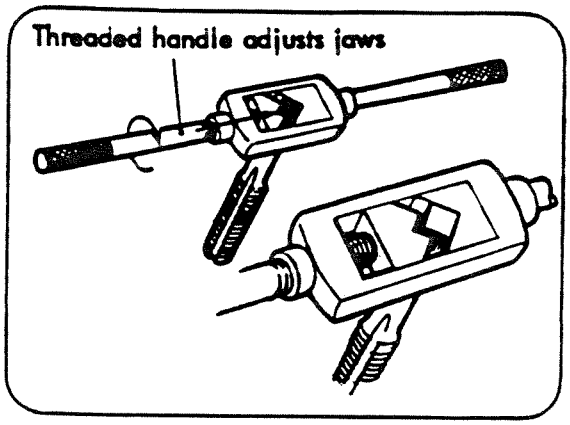

**The Taper Tap**
The taper tap is tapered off for 8 to 10 threads, and is used first, cutting to the full thread gradually.



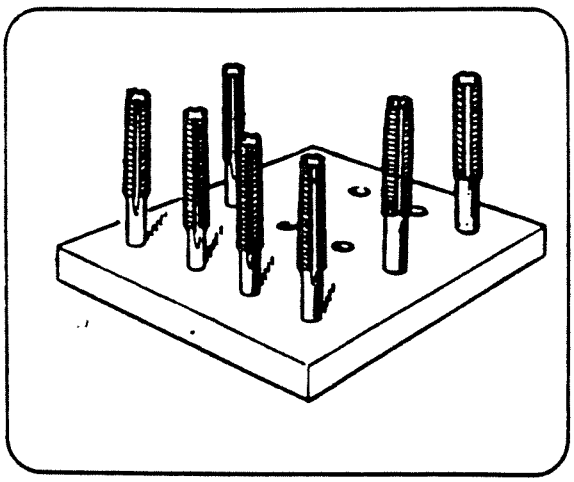

**The Intermediate Tap**
The intermediate tap usually has three or four threads chamfered. The second tap can finish a through hole.



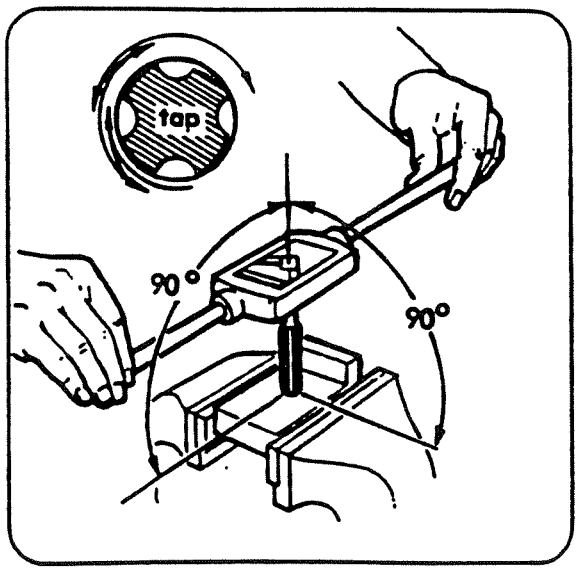

**The Plug Tap**
The plug tap has a full-sized untapered thread to the end, and is the main finishing tap. In the case of a blind hole, a plug tap must be used.



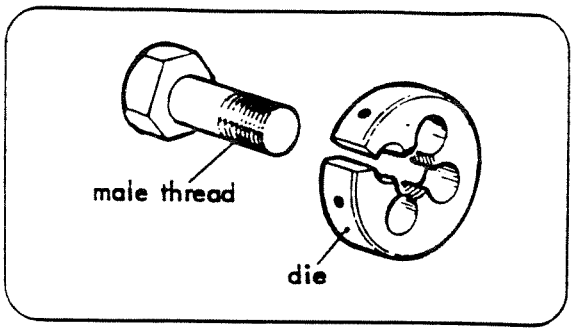

**The Wrench**
The appropriate size wrench should always be used for a given tap, to ensure that the jaws fit correctly.



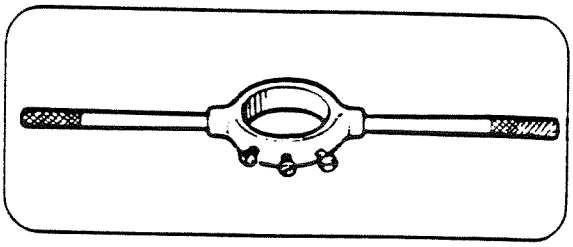
**Care of Taps**
Care must be taken not to damage the cutting edges. A chipped tap must never be used. When not in use, taps should be kept clean, and stored in a rack.




**Using Taps**
A hole must be drilled to the tapping size for the thread. The workpiece must be securely supported. When starting the cutting, the tap must be at $90^{o}$ in all planes to the work. Excessive force must not be used, as this will result in breaking the tap. Cutting fluid should be used. The threads must be cleared as often as is necessary to prevent flute clogging.

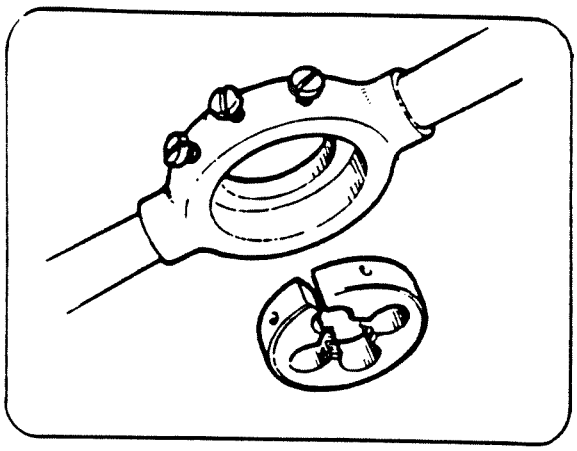



**Dies**
A die cuts an external (male) thread, which may be right or left hand. A die is made of high quality tool steel, suitably heat treated.

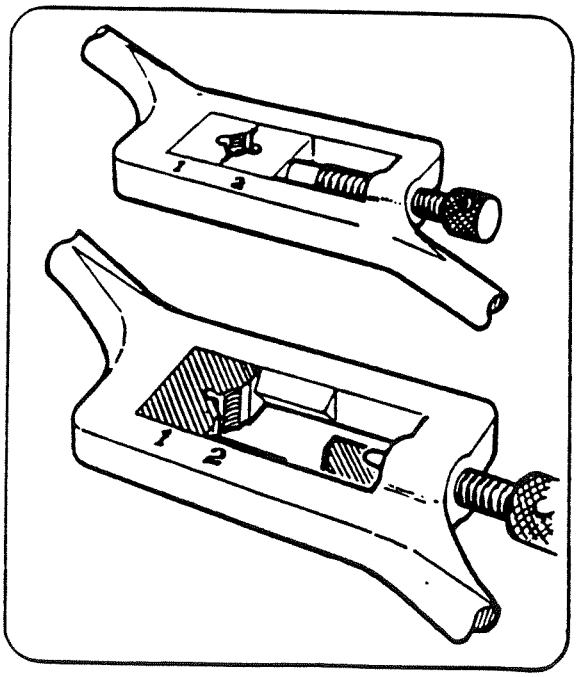


**The Stock**
A die is held in, and turned by, a stock.

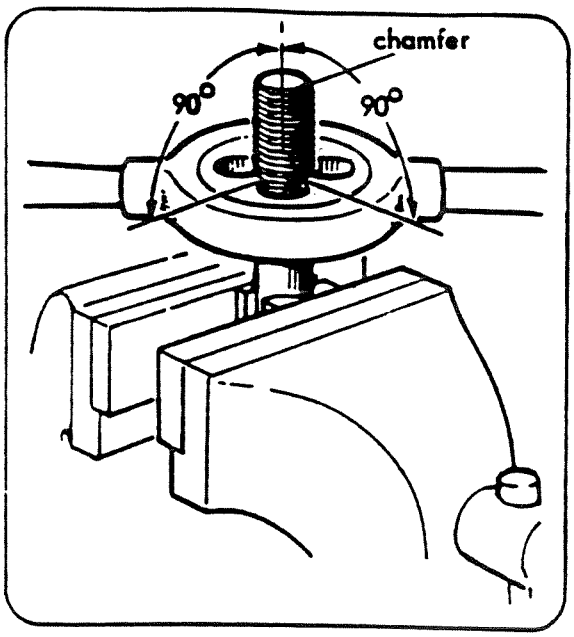
**Types of Dies**
There are button dies, half dies, and solid die nuts.



**The Button Die**
The button (or split) die allows a limited amount of adjustment in the depth it will cut, by means of screws in the stock which spring it open or shut. It should be fully open for the first cut, and then gradually reduced to finished size. It must be checked against an existing thread or die nut of correct size.




**Half Dies**
Half dies have the advantage of taking smaller cuts to reach correct size, so the amount of material taken off can be controlled. Half dies are in matched pairs, and should always be used together.




**Using Dies**

The work should be chamfered for ease of starting. The workpiece must be securely supported, and vertical in the vice. Great care must be taken to start the thread true to the axis of the bar. Lubricant should be used. The threads must be cleared as often as is necessary.

# Drill Size Tables

## ISO Metric Coarse Pitch Threads

| Nominal diameter mm | Pitch mm | Minor diameter (basic) mm | Tapping drill Size mm |
|---|---|---|---|
| 1 | ·25 | ·729 | ·75 |
| 2 | ·40 | 1·567 | 1·60 |
| 3 | ·50 | 2·459 | 2·50 |
| 4 | ·70 | 3·242 | 3·30 |
| 5 | ·80 | 4·134 | 4·20 |
| 6 | 1·00 | 4·917 | 5·00 |
| 7 | 1·00 | 5·917 | 6·00 |
| 8 | 1·25 | 6·647 | 6·80 |
| 9 | 1·25 | 7·647 | 7·80 |
| 10 | 1·50 | 8·376 | 8·50 |
| 11 | 1·50 | 9·376 | 9·50 |
| 12 | 1·75 | 10·106 | 10·20 |
| 14 | 2·00 | 11·835 | 12·00 |
| 16 | 2·00 | 13·835 | 14·00 |
| 18 | 2·50 | 15·294 | 15·50 |
| 20 | 2·50 | 17·294 | 17·50 |
| 22 | 2·50 | 19·294 | 19·50 |
| 24 | 3·00 | 20·752 | 21·00 |
| 27 | 3·00 | 23·752 | 24·00 |
| 30 | 3·50 | 26·211 | 26·50 |
| 33 | 3·50 | 29·211 | 29·50 |
| 36 | 4·00 | 31·670 | 32·00 |
| 39 | 4·00 | 34·670 | 35·00 |
| 42 | 4·50 | 37·129 | 37·50 |
| 45 | 4·50 | 40·129 | 40·50 |

## ISO Metric Fine Pitch Threads

| Nominal diameter mm | Pitch mm | Minor diameter (basic) mm | Tapping drill Size mm |
|---|---|---|---|
| 3 | ·35 | 2·621 | 2·65 |
| 4 | ·50 | 3·459 | 3·50 |
| 5 | ·50 | 4·459 | 4·50 |
| 6 | ·75 | 5·188 | 5·20 |
| 7 | ·75 | 6·188 | 6·20 |
| 8 | ·75 | 7·188 | 7·20 |
| 9 | ·75 | 8·188 | 8·20 |
| 10 | ·75 | 9·188 | 9·20 |
| 11 | ·75 | 10·188 | 10·20 |
| 8 | 1 | 6·918 | 7 |
| 9 | 1 | 7·918 | 8 |

## British Association Threads (B.A.)

| Designating no. | Nominal diameter in. | Threads per inch | Minor diameter (basic) | Tapping drill | |
|---|---|---|---|---|---|
| | | | | Size | Decimal equivalent |
| 0 | ·2362 | 25·4 | ·1890 | 5·00 mm | ·1968 |
| 1 | ·2087 | 28·2 | ·1661 | 4·40 mm | ·1732 |
| 2 | ·1850 | 31·3 | ·1468 | 4·00 mm | ·1575 |
| 3 | ·1614 | 34·8 | ·1268 | 3·30 mm | ·1299 |
| 4 | ·1417 | 38·5 | ·1106 | 2·95 mm | ·1161 |
| 5 | ·1260 | 43·1 | ·0980 | 2·60 mm | ·1024 |
| 6 | ·1102 | 47·9 | ·0850 | 2·25 mm | ·0886 |
| 7 | ·0984 | 52·9 | ·0756 | 2·00 mm | ·0787 |
| 8 | ·0866 | 59·1 | ·0661 | 1·75 mm | ·0689 |
| 9 | ·0748 | 65·1 | ·0563 | 1·50 mm | ·0590 |
| 10 | ·0669 | 72·6 | ·0504 | 1·35 mm | ·0532 |
| 11 | ·0591 | 81·9 | ·0445 | 1·20 mm | ·0472 |
| 12 | ·0512 | 90·9 | ·0378 | 1·00 mm | ·0394 |

## M.2.3 Cutting rigid plastics

Safety

The safety precautions for machining plastic materials are the same as those required for machining metals.

Good ventilation is essential due to the unpleasant and often harmful fumes given off when some plastic materials are heated.

### General

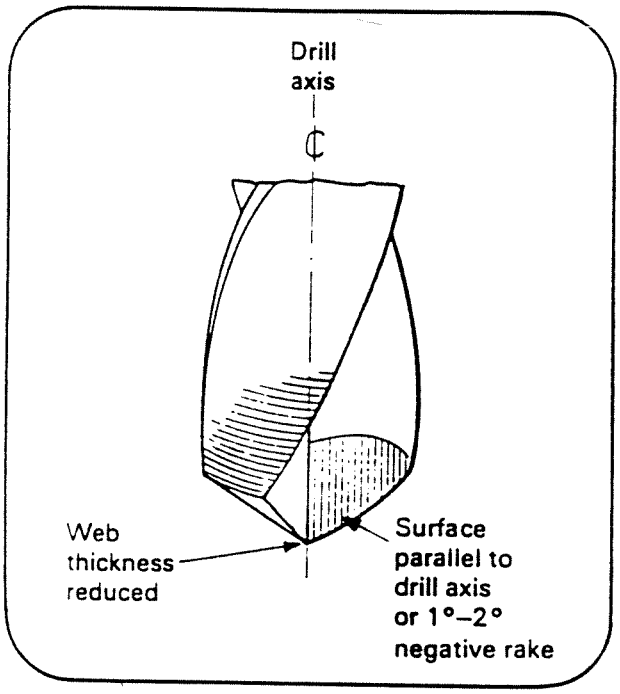
Use metal working tools and machines for all machining operations and:

(a) keep cutting edges very sharp

(b) keep tool cool, particularly when cutting thermoplastics using compressed air blast or continuous flow of cutting fluid or water

(c) use fast speed and fine feed. If chattering occurs reduce the speed

(d) use high speed steel (HSS) or tungsten carbide tipped tools.




### Drilling

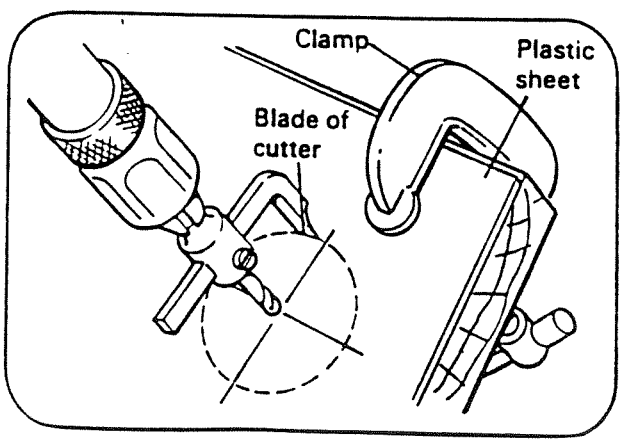
For drilling plastics use standard twist drills having wide flutes and quick spiral.

Grind a zero or 1°–2° negative rake on the cutting face and reduce the web thickness.

Clear the drill frequently.

Keep the drill cool.

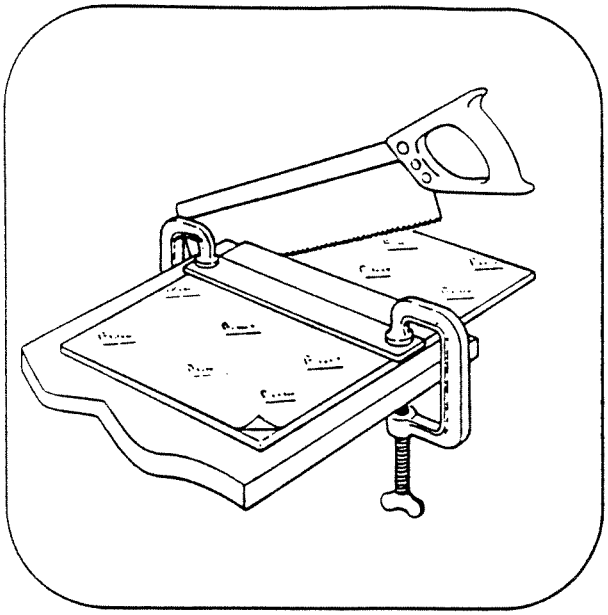
Use a pilot drill, maximum 10 mm diameter, for large holes and progressively use larger drills, or alternatively a boring bar.




*Note:* Ensure that the work is firmly clamped during drilling operations. Insert suitable packing under clamp jaws to protect finish of plastic sheet.

### Threading

Use normal taps and dies which must be sharp to avoid tearing or chipping.

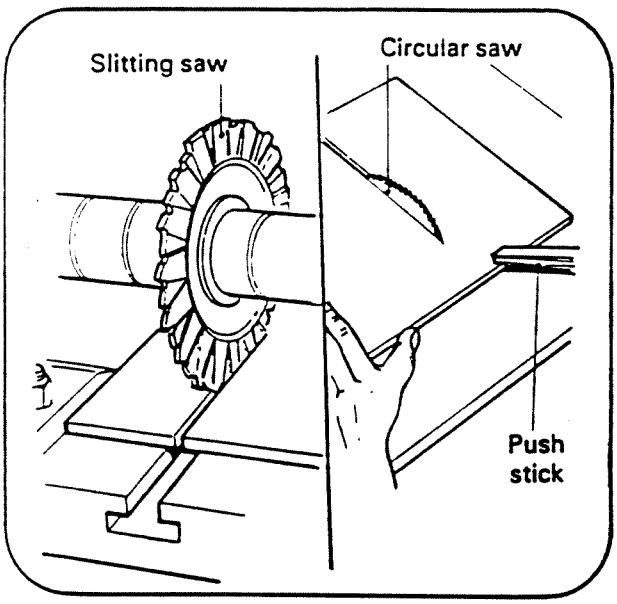


## Hand sawing

1. Clamp plastic sheet firmly to bench.

2. Cut along cutting line with a fine toothed saw using smooth even strokes.

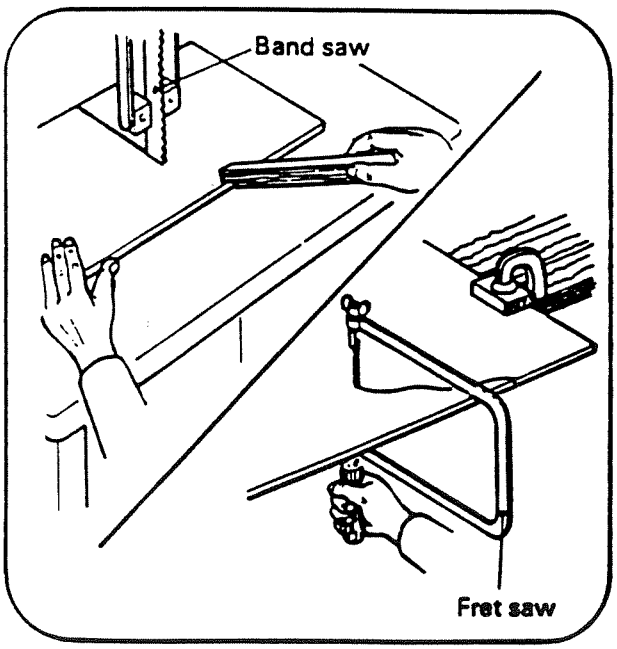
*Note:* Take care to avoid splintering the material by too vigorous use of the saw.




## Machine sawing

Circular hollow ground saws can produce a smooth cut with teeth up to 10 mm pitch and zero or very small rake at speeds of 3000 rpm with 200–250 mm diameter blades.

> Safety
> Use a push stick when cutting on a circular saw and band saw.




Band saws with a metal cutting blade having very little set will produce a rough cut.

Intricate shapes can be cut using a jigsaw or fretsaw. Saw blades with 5–6 teeth per cm are usually satisfactory.

*Note:* Avoid the build up of excessive heat during cutting and feed the material slowly and steadily.

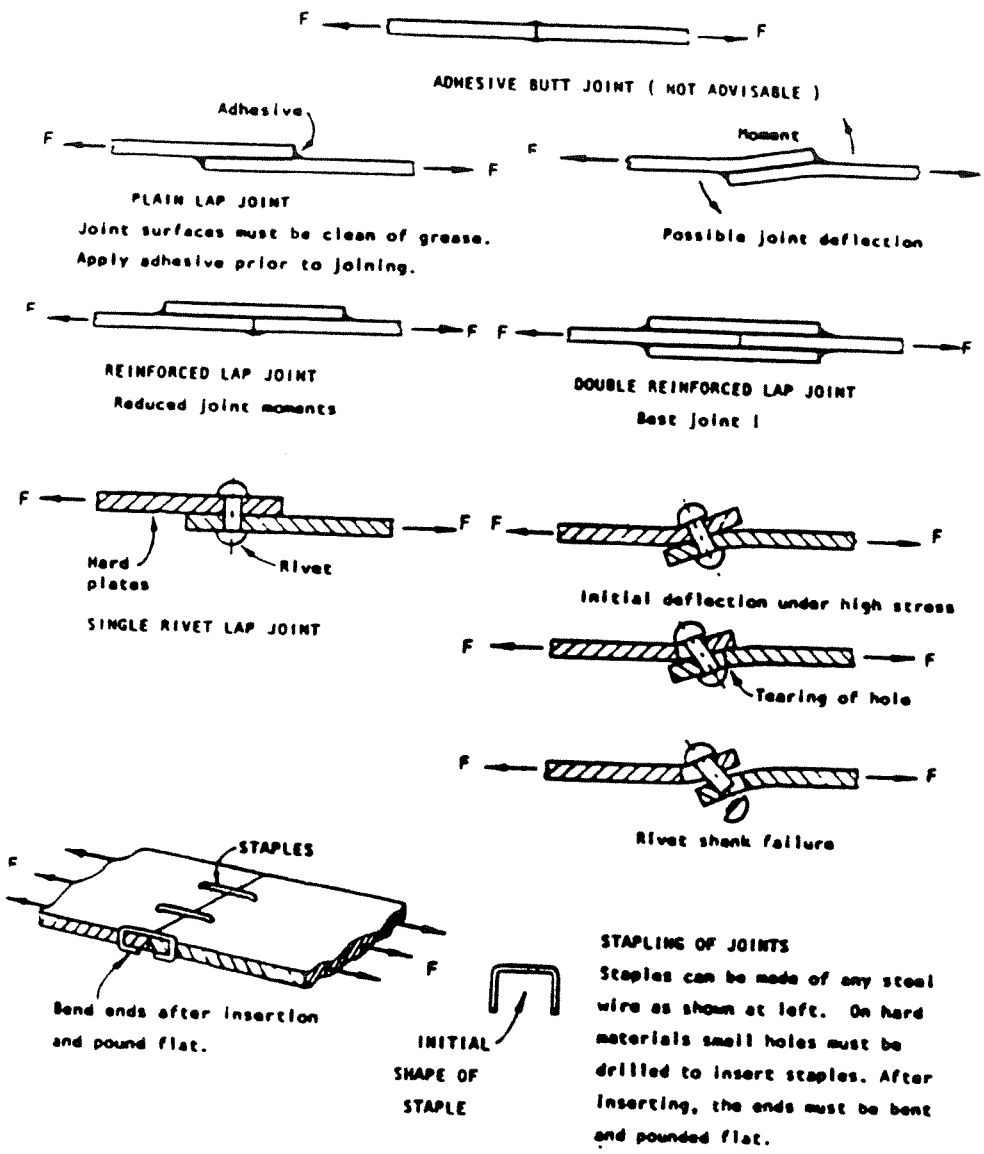
## M.2.4 Machining rigid plastics

Most plastics are very free cutting, but are very tough and high speed tool steels will lose their cutting efficiency fairly quickly it is therefore important to mantain the cutting edge in good condition. High speeds and feeds give the best results, both as to finish and to tool life. A high speed and coarse feed will throw the chips away and will prevent the rubbing action which dulls the tool. The table below give a general guide to cutting, feed and depth of cut for general machining of plastics:

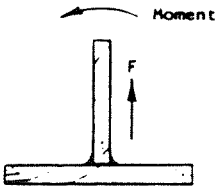
| Material | Turning | | | Drilling | | Sawing (band saw) | | Coolants |
|---|---|---|---|---|---|---|---|---|
| | Speed m/min | Feed mm/rev | Depth mm | Large revs per min | Small | Speed m per min | Feed | |
| Phenolic amino | 100–250 | 0·12/0·25 | 0·12/0·8 | 300–1000 | 1000+ | 2000 700 | 1–5 0·5–2 | Air, water, soap solution, oil water. |
| Laminated thermosets | 100–250 | 0·25 0·8 | 0·25 –2 | 300/750 | 5000+ | 5000 2000 | 2–7 | Air, water, soap solution, soluble oil. |
| PVC cellulose acetate | 100/350 | 0·12 0·5 | 0·012 –2·0 | 500/1000 | 4000/6000 | 1200/2500 | 0·5–8 | Air or water and soluble oil for cellulose acetate. |
| Polystyrene | 100/350 | 0·1/0·25 | 0·12/1·0 | 100/500 | 1000/2000 | 1000 | 0·5–3 | Air, water, soap solution, soluble oil. |
| Acrylics | 150/350 | 0·12 0·25 | 0·12 0·25 | 250/750 | 2000/5000 | 1500/3500 | 0·5–7 | Air, water, soap solution, soluble oil. |
| Nylon | 150/350 | 0·12 0·25 | 0·80 2·0 | 300/750 | 2000/3000 | 1000 | 0·5–3 | Nylons will absorb water when heated. Cutting oil or air should be used or a controlled supply of water. |
| PTFE, PCTFE Polythene | 20/00 | 0·25 –2·0 | 0·5 –2·0 | 250/500 | 1000 | 700/1000 | 0·5–7 | Water or soap solution. |

## M.3 Joining and Fastening

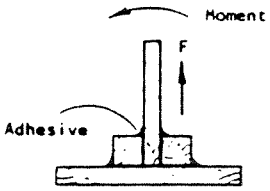
### M.3.1 Adhesives, single rivet and stapled joints



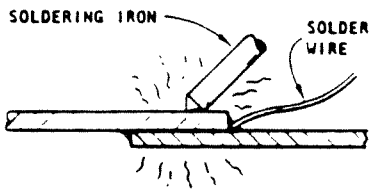
## M.3.2 T-joints and soldered joints




PLAIN ADHESIVE "T" JOINT
(Strongly discouraged )




REINFORCED ADHESIVE "T" JOINT
(Highly advisable)



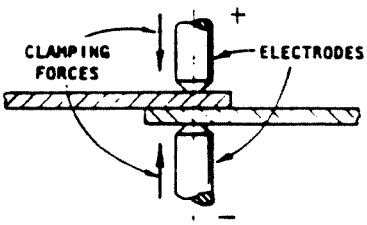

Failure of soldered joints are very similar to those of adhesive joints. Design criterion is surface shear area.

SOLDERING (LEAD-TIN)

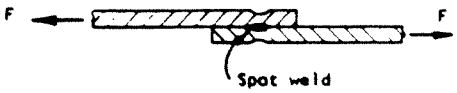
Soldering is good for medium-stress joints in metals.

DIRECTIONS:

1- Brush clean joint surfaces
2- Apply flux
3- Heat joint with iron
4- Apply solder wire
5- Continue heating until solder flows all over joint.




SPOT WELDING

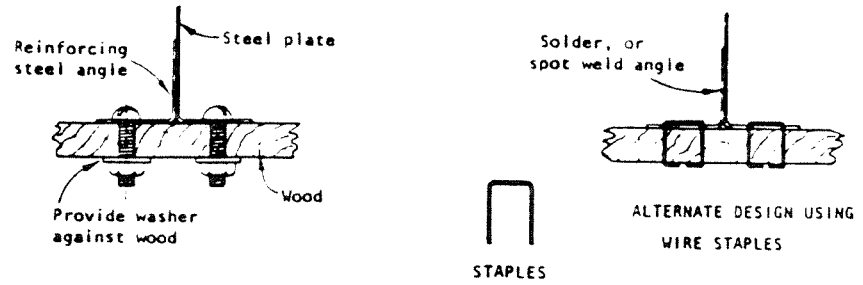



Spot welding is one of the best means of joining metal sheets. It functions like a rivet and it is a lot cheaper.

## M.3.3 Metal to wood joints

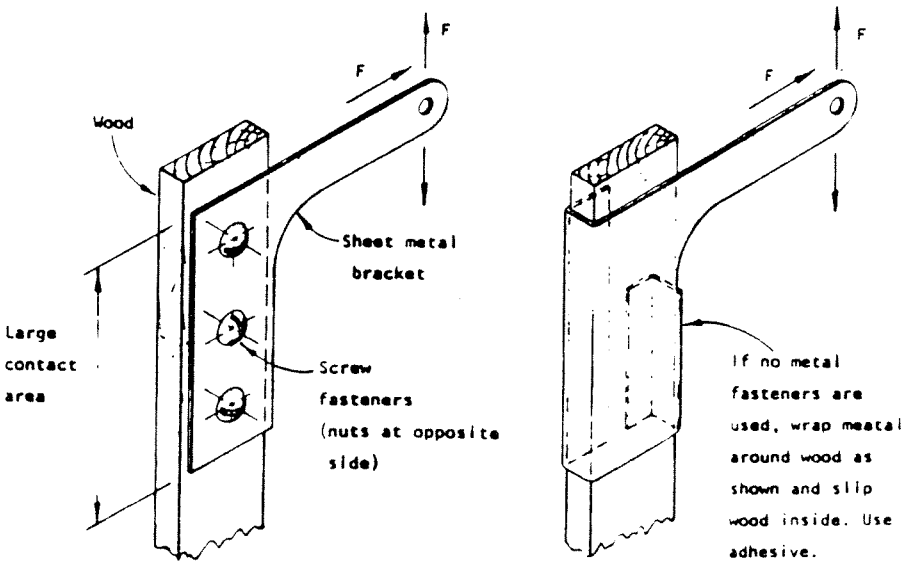
These joints are inherently tricky.

Metals, being stronger and harder than wood, must be joined to softer materials by providing large surfaces of contact for the transmission of stresses.



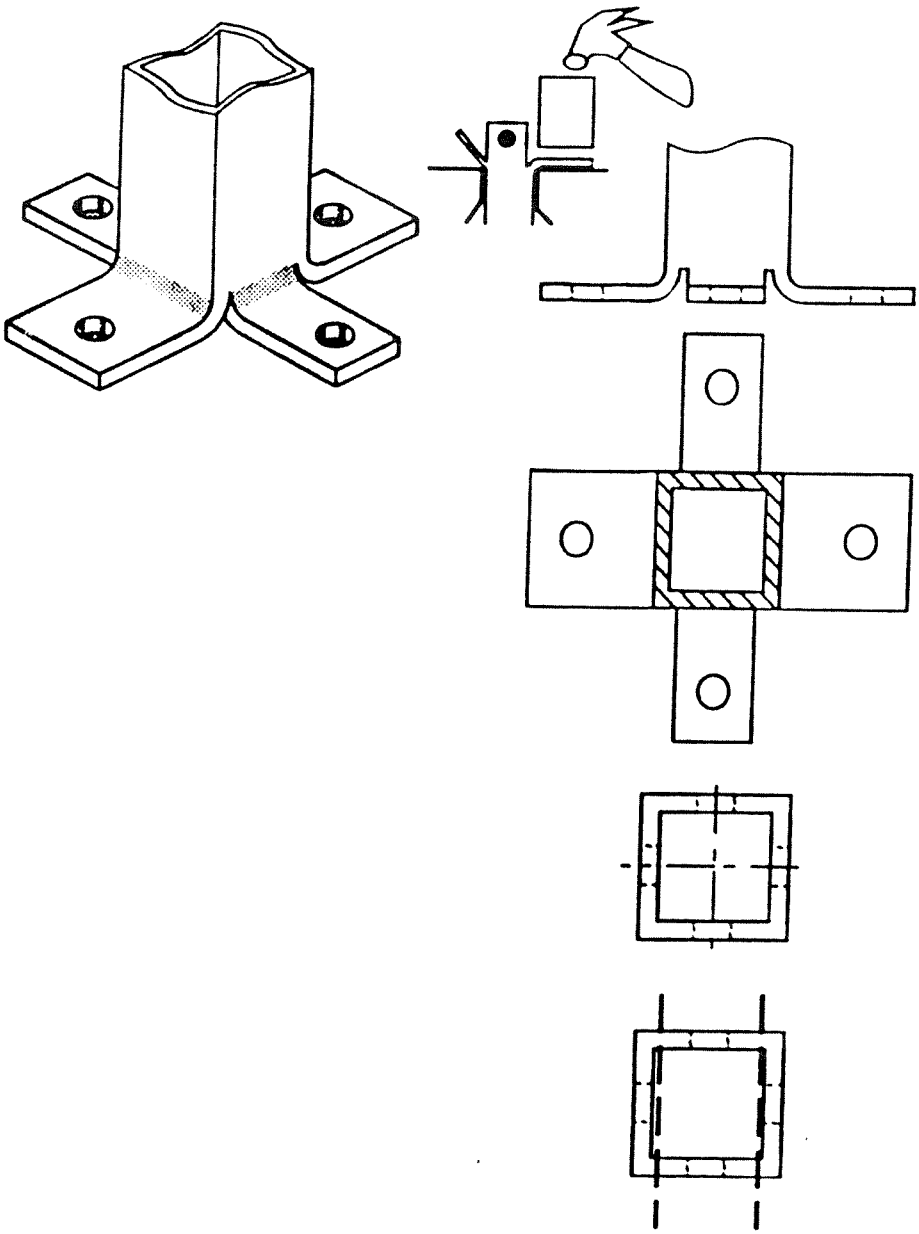

METAL TO WOOD "T" JOINTS

If adhesive is used to fasten metals to wood, the surface of the metals must be very clean from grease and coarse sanded to make it rough. Such joints should only be made to work in shear. Peeling forces will break them easily. Whenever possible steel fasteners should be used as shown above.

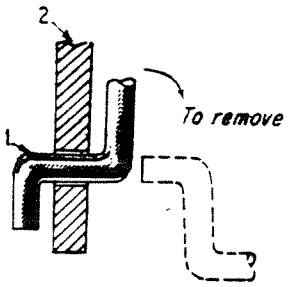


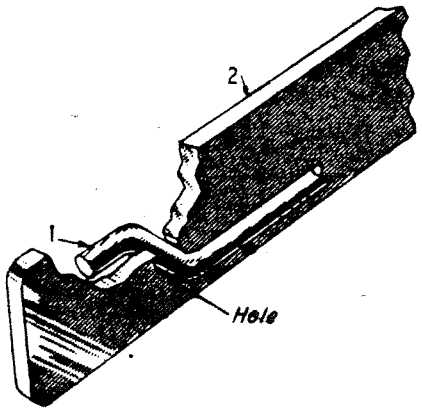
### M.3.4 Example of joint: Column base

Provides a sturdy attachment that resists tilting moments in all directions.

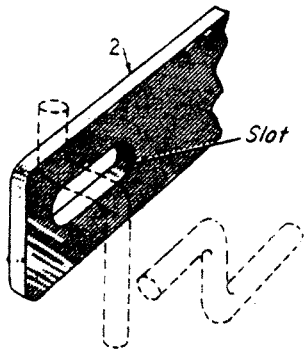


## M.3.5 Examples of quick-disconnect fasteners



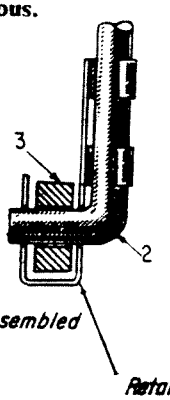



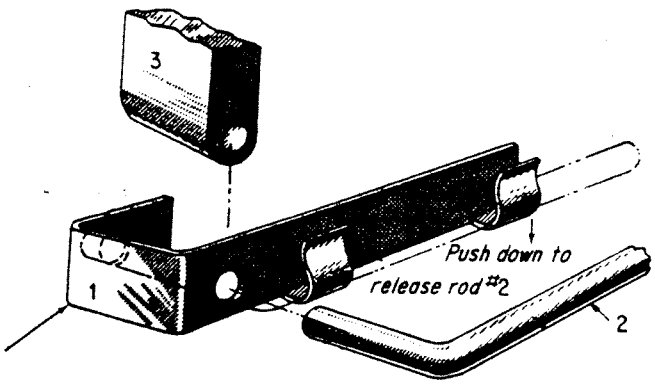

(A)




(B)

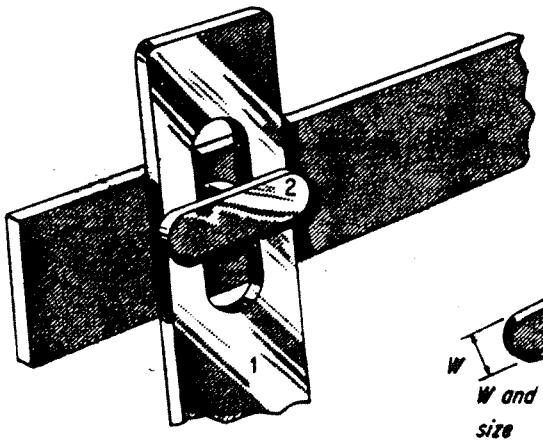
**FORMED ROD** in hole or slot allows disassembly only when the rod is free to be manipulated out of the arm. Slot design has play, which may or may not be advantageous.




**RETAINER CLIP** and formed rod are ideal when production quantities are high enough to warrant tooling costs necessary for clip. But the clip is relatively easy to make.

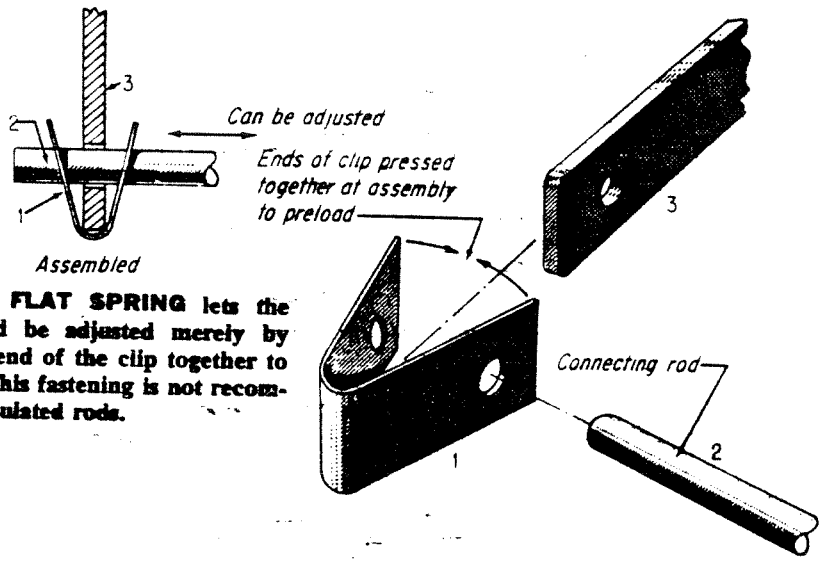

Assembly





W and D same size

**ELONGATED FASTENER HEAD** and slot can be disconnected only when head and slot are aligned. Phase the linkage to avoid alignment of slot and head; otherwise it may work free.




**PRELOADED FLAT SPRING** lets the connecting rod be adjusted merely by squeezing the end of the clip together to remove grip. This fastening is not recommended for insulated rods.