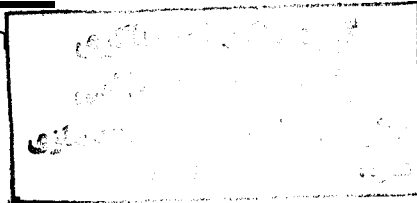# Jigs and Fixtures
Design Manual

Second Edition

Jigs and Fixtures
Design Manual

Second Edition

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Foreword and Edited by:
Robert O. Parmley, P.E.

This book is dedicated to
my beloved mother

Kesar

and

the ingenious engineers of India

Contents

Foreword
to the Reprint
of the Second Edition

Rarely does one encounter a well described and clearly illustrated technical book on a basic subject. Therefore, when one is discovered, its contents should be preserved. Joshi's *Jigs and Fixtures Design Manual* is such a work.

Originally published in India, this current edition has been minimally Americanized. However, the metric measurement format has been allowed to stand as originally published so the basic continuity will remain in tact. In that same vain, the British and Indian tables and material listing were left undisturbed. Therefore, the western reader should be cautioned to substitute, where applicable, relevant standards, i.e. ANSI, SAE, ASTM, etc. It is assumed that the readers will have the technical savvy to obtain current material and component standards for their respective projects.

As alluded to previously, it is the basic design fundamentals that represents the core value of this current edition, entitled *Jigs and Fixtures Design Manual.* The well executed illustrations greatly enhance the overall presentation and bridge the gap between the text and final product.

It is a well established fact that use of jigs and fixtures help to reduce manufacturing costs of large production runs, as well as reducing errors. However, the key to success is properly designing the jigs and fixtures. This manual plainly describes the important aspects of elementary design and provides some basic exercises in the last chapter to round out the presentation.

— Robert O. Parmley, P.E., CMfgE, CSI

Editor-in-Chief of: *Standard Handbook of Fastening & Joining, 3/e &*
Illustrated Sourcebook of Mechanical Components

Preface
to the Second Edition

The overwhelming response to my first technical treatise Jigs and Fixtures by students, academicians and practicing professionals spurred me to write three more books on tool design.

I was pleasantly surprised to hear from Production Engineering professors that my treatise has become more popular than old and contemporary classics on the subject.

As a consultant servicing small and medium scale industries, I witnessed ingenuity rarely manifested in big industry with ample resources. Jobbing shops have to manufacture satisfactory samples before procuring an order. They cannot afford to invest a big sum in a jig or a fixture without a commensurate order for recovery of the investment. The inventive methods they use to manufacture the few samples also test the methods of location and clamping to be used in the sophisticated fixtures later. The ingenuity of the small and medium scale engineering industry inspired me to write an additional chapter on shop set-ups. None of the previous or present books on jigs and fixtures includes any information on shop set-ups.

Other additions include more standard clamps, ingenious methods of clamping (Fig. 3.10b), adjustable jigs for similar workpieces, more welding fixtures, and summaries at the end of chapters on clamping, drill jigs, and milling fixtures.

Production engineers have to estimate the cost of jig/fixture. I have given thumb rules used by jobbing tool rooms for quick estimation in the additional chapter on estimation.

A query on working of diamond pins motivated me to study the geometry of the application in depth and derive the formula for computing

the diamond pin diameter to suit the engagement land and the variation in the centre distance. Inclusion of this original derivation also makes the second edition of Jigs and Fixtures unique.

I hope that with these valuable and original additions, the second edition would prove even more popular than the first, which has seen a dozen reprints in its 12 years life.

I am thankful to the readers: students, professors and practicing professionals for the response which has been far beyond my expectations.
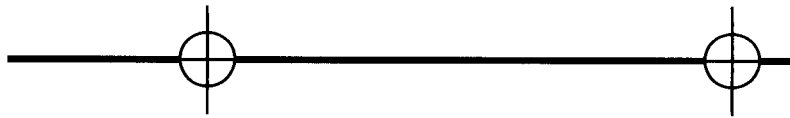
Preface
to the First Edition

After working for 25 years as a tool designer and an industrial engineer, I taught jigs and fixtures to production engineering students for some years. This book is a product of the experiences gained in that tenure.

Being an experienced professional, I noticed some shortcomings in the existing books available to the students. I have attempted to make up those deficiencies in this book.

I have included a large number of drawings of workpieces from which the necessary jigs and fixtures can be independently designed. The book meets most of the syllabi requirements of students of production engineering. It would also serve as a useful reference manual for practicing engineers.

I had been involved with English literature for 20 years before I ventured into technical writing. I have strived to impart the brevity, clarity and order so essential in literature to this work. It is for the readers to judge how far I have succeeded in my endeavor.

Acknowledgements

— Prakash Hiralal Joshi

Introduction

Mass production aims at high productivity to reduce unit cost and interchangeability to facilitate easy assembly. This necessitates production devices to increase the rate of manufacture and inspection devices to speed-up inspection procedure.

Production Devices

Production devices are generally workholders with/without tool guiding/setting arrangement. These are called jigs and fixtures.

Jigs are provided with tool guiding elements such as drill bushes. These direct the tool to the correct position on the workpiece. Jigs are rarely clamped on the machine table because it is necessary to move the jig on the table to align the various bushings in the jig with the machine spindle.

Fixtures hold the workpiece securely in the correct position with respect to the machine/cutter during operation. There is sometimes a provision of the fixture for 'setting' the tool with respect to the workpiece/fixture, but the tool is not guided as in a jig. Fixtures are often clamped to the machine table.

Elements of Jigs and Fixtures

Generally all the jigs and fixtures consist of :

1. **Locating Elements**   These position the workpiece accurately with respect to the tool guiding or setting elements in the fixture.

2. **Clamping Elements**   These hold the workpiece securely in the located position during operation.

3. **Tool Guiding and Setting Elements**   These aid guiding or setting of the tools in correct position with respect to the workpiece. Drill bushings guide the drills accurately to the workpiece. Milling fixtures use setting pieces for correct positioning of milling cutters with respect to the workpiece.

Advantages of Jigs and Fixtures

1. **Productivity**   Jigs and fixtures eliminate individual marking, positioning and frequent checking. This reduces operation time and increases productivity.

2. **Interchangeability**   Jigs and fixtures facilitate uniform quality in manufacture. There is no need for selective assembly. Any parts of the machine fit properly in assembly, and all similar components are interchangeable.

3. **Skill Reduction**   Jigs and fixtures simplify locating and clamping of the workpieces. Tool guiding elements ensure correct positioning of the tools with respect to the workpieces. There is no need for skillful setting of the work piece of tool. Any average person can be trained to use jigs and fixtures the replacement of a skilled workman with unskilled labor can effect substantial saving in labor cost.

4. **Cost Reduction**   Higher production, reduction in scrap, easy assembly and savings in labor costs result in substantial reduction in the cost of workpieces produced with jigs and fixtures.

Inspection Devices

Inspection devices facilitate interchangeability. It calls for uniformity which must be limited, taking into account the machine's capability. Certain variations in the size of shaft (or hole) should be allowed for economic reasons.

Limits and Fits

The largest and the smallest dimension of the shaft (or hole) are called the high and low limit, respectively. The difference between these limits, i.e. the permissible variation, is called tolerance. If tolerance is allowed only on one side of the nominal dimension it is called unilateral. For example, $20.00^{+0.02}_{-0.00}$ has got unilateral tolerance. If tolerance is allowed on both sides of the nominal dimension (e.g. $20.00^{+0.01}_{-0.01}$) it is called bilateral.

Classification of Fits

Tolerance and its direction depends upon the functional requirements of the assembled parts. The following four classes of fits cover most of the functional requisites of engineering assemblies.

1. ***Running Fit*** *(Figure 1.1a)* This provides for easy rotation as well as axial movement of shaft (male part) in hole(female part). It is used for bearing diameters of rotating shafts. Locators in production devices are made running fit with workpiece for quick loading and unloading.

2. ***Push Fit*** This fit requires light hand pressure or tapping for assembly of the mating parts. It is used mainly for precise assembly of replaceable locators in jigs and fixtures.

3. ***Press Fit*** *(Figure 1.1a)* The mating parts are assembled by hammering or with a press. There is a positive interference between the hole and the shaft. This prevents rotary as well as axial movement between the assembled parts. Hence, press fit is used widely for assembly of drill bushings (outside diameter) and locators which are rarely replaced).
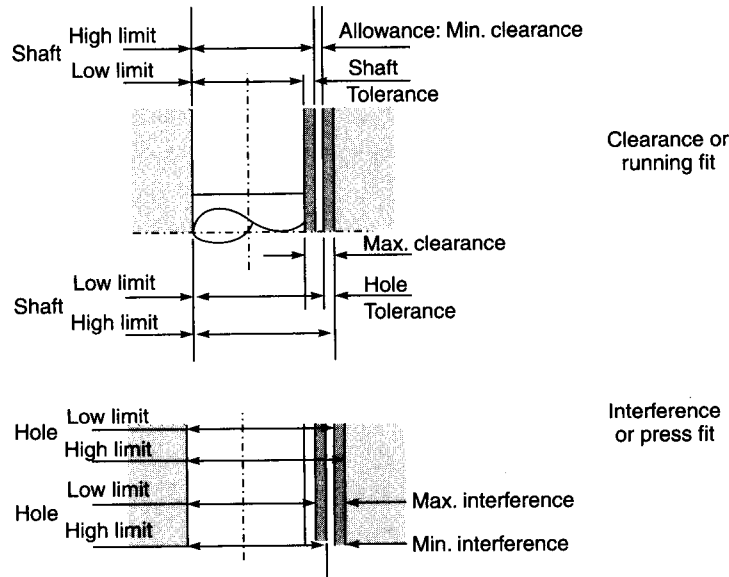
Figure **1.1a**
Limits and Fits

4. *Force Fit*   This is used for permanent assemblies such as
wheels and hubs on shaft force fit parts require heavy pres-
sure for assembly.

The clearance or interference provided for obtaining the various
fits is called allowance. In shaft basis of fits the diameter of the
shaft is kept constant while that of the hole is varied. In hole
basis, the hole size is kept constant and the shaft size is varied to
obtain the various fits. As most of the holes are made by fixed
diameter tools (drills, reamers, etc.) the hole basis is used widely
in modern industry to keep the investment in cutting tools low.

The International Standards Organization has standardized 27
types of fits and 18 grades of tolerances, which have been adopt-
ed by many countries. The tolerance depends upon the mating
diameter sizes. The distribution of the tolerance is specified by al-
phabets. Holes are specified by capital letters A,B,C,D, etc.
whereas shafts arespecified by small letters a,b,c,d, etc. The

alphabets are suffixed by digits 1,2,3,4,5...16 showing the grade of accuracy. Digit 1 signifies the highest accuracy and digit 16 the least *(Figure 1.1b)*.
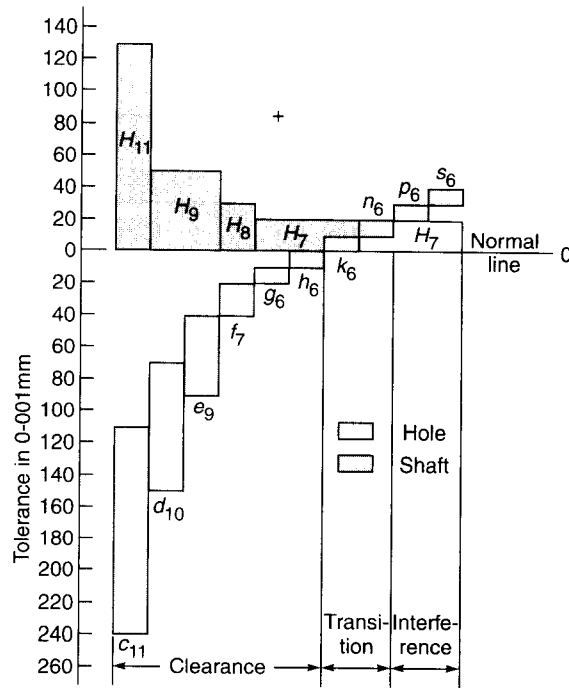
Figure **1.1b**
Limits and Fits

In tool making accuracy grades 7 to 11 have been found most convenient. Generally unilateral H type tolerance distribution is preferred. Most of the accurate holes are made to $H7$ limits which can be obtained by careful reaming. For mass production, the less accurate $H8$ holes are used. Simple drilling produces a hole within $H11$ tolerance. Figure 14.1 shows the limits for the grades of holes used widely. A 20ϕ hole falling in range 18 to 30 mm has got the following tolerances for the various grades:

$20\emptyset\ H7\text{---}20^{+0.021}_{+0}$

$20\emptyset\ H8\text{---}20^{+0.033}_{+0}$

$20\emptyset\ H11\text{---}20^{+0.13}_{+0}$

Shaft sizes are varied to obtain the required fits with the desired degree of precision. The following combinations are widely used in tool making.

	High Precision Hole/Shaft	Accurate Hole/Shaft
1. Running Fit	H7/f6	H8/f7
2. Push Fit	H7/h6	H8/h7
3. Press Fit	H7/p6	H8/p7
4. Force Fit	H7/s6	H8/s7

For example, for a $20\emptyset\ H7$ hole, the shaft should be:

$20\emptyset f6$, i.e. $20.00^{-.016}_{-.034}$ for precision running

$20\emptyset h6$, i.e. $20.00^{0}_{-.017}$ for push fit

$20\emptyset p6$, i.e. $20.00^{+.022}_{+.035}$ for press fit

$20\emptyset s6$, i.e. $20.00^{+.035}_{+.048}$ for force fit

Thus, by controlling the hole and shaft sizes within certain tolerances we can obtain the desired fit with interchangeability in various assemblies.

The workpiece are inspected at every stage to ensure that the dimensions are within the tolerance. The checking is speeded up by using inspection devices such as gauges and fixtures. These simplify inspection so that unskilled/semiskilled labour can be used to keep down the inspection costs.

Materials used
in Jigs and Fixtures ─────────

Jigs and fixtures are made from a variety of materials, some of which can be hardened to resist wear. It is sometimes necessary to use nonferrous metals like phospher bronze to reduce wear of the mating parts, or nylons or fibre to prevent damage to the workpiece. Given below are the materials often used in jigs, fixtures, press tools, collets, etc.

1. *High Speed Steels (HSS)* These contain 18% (or 22%) tungsten for toughness and cutting strength, 4.3% chromium for better hardenability and wear resistance and 1% vandadium for retention of hardness at high temperature (red hardness) and impact resistance. HSS can be air or oil hardened to RC 64–65 and are suitable for cutting tools such as drills, reamers and cutters.

2. *Die Steels* These are also called high carbon (1.5–2.3%) high chromium (12%) (HCHC) cold working steels and are used for cutting press tools and thread forming rolls. Hot die steels with lesser carbon (0.35%) and chromium (5%) but alloyed with molybdenum (1%) and vanadium (0.3–1%) for retention of hardness at high temperature are used for high temperature work like forging, casting and extrusion.

3. *Carbon Steels* These contain 0.85–1.18% carbon and can be oil hardened to RC62–63. These can be used for tools for cutting softer materials like woodwork, agriculture, etc. and also for hand tools such as files, chisels and razors. The parts of jigs and fixtures like bushings and locators, which are subjected to heavy wear can also be made from carbon steels and hardened.

4. *Collet Steels (Spring Steels)* These contain about 1% carbon and 0.5% Manganese. Spring steels are usually tempered to RC 47 hardness.

5. *Oil Hardening Non-Shrinking Tool Steels (OHNS)*
These contain 0.9–1.1% carbon, 0.5–2% tungsten and
0.45–1% carbon. these are used for fine parts such as taps,
hand reamers, milling cutters, engraving tools, and intri-
cate press tools which cannot be ground after hardening
(RC 62).

6. *Case Hardening Steels*   These can be carburised and case
hardened to provide 0.6–1.5 thick, hard (RC 59–63) exte-
rior. 17 Mn1Cr95 steel with 1% manganese and 0.95%
chromium is widely used. 15 Ni2Cr1Mo15 steel with addi-
tional nickel (2%) reduces thermal expansion up to 100°C.
Case hardening steels are suitable for parts which require
only local hardness on small wearing surfaces where cost-
lier, difficult to machine full hardening tool steels are not
warranted.

7. *High Tensile Steels*   These can be classified into medium
carbon steels with 0.45%–0.65% carbon (En8–9) and alloy
steels like 40 Ni2Cr1M028 (En24). The tensile strength
can be increased up to 125 kg/mm2 (RC 40) by tempering.

Medium carbon steels are used widely for fasteners and
structural work while alloy steels are used for high stress
applications like press rams.

8. *Mild Steel*   It is the cheapest and most widely used mate-
rial in jigs and fixtures. It contains less than 0.3% carbon.
It is economical to make parts which are not subjected to
much wear and are not highly stressed from mild steel.

9. *Cast Iron*   It contains 2–2.5% carbon. As it can withstand
vibrations well, it is used widely in milling fixtures. Self-
lubricating properties make cast iron suitable for machine
slides and guide-ways. The ingenious shaping of a casting
and the pattern can save a lot of machining time.
Although, the strength of cast iron is only half the strength
of mild steel, a wide variety of grades have been developed.
Nodular cast iron is as strong as mild steel, while meehan-
ite castings have heat resistant, wear resistant, and corro-
sion resistant grades.

10. *Steel Castings*   These combine the strength of steel and shapabilty of a casting.

11. *Nylon and Fibre*   These are usually used as soft lining for clamps to prevent denting or damage to the workpiece under high clamping force. Nylon or fibre pads are screwed or stuck to mild steel clamps.

12. *Phospher Bronze*   It is widely used for replaceable nuts in screw operated feeding and clamping systems. Generally screw making process is time consuming and costly. So, their wear is minimized by using softer, shorter phospher bronze mating nuts. These can be replaced periodically.

Phospher bronze is also used in applications calling for corrosion resistance, like boiler valves.

Presentation of Workpiece ———

A jig or fixture drawing shows the workpiece in position with the jig/fixture. However, the workpiece should be easily discernible from the jig/fixture. To accomplish this, the workpiece is drawn in a chaindotted line, preferably in color (red, green or blue) which can be easily distinguished from the black linework of the jig/fixture drawing.

The workpiece drawn in a jig/fixture drawing is considered transparent. As a result, locators, studs or other parts of the fixture passing through the workpiece are drawn in full lines instead of dotted (*Figure 1.2*). Similarly, the parts of the fixture placed behind the workpiece are drawn full instead of dotted. As the workpiece in transparent, it would not obstruct or block the view of any part of the jig or fixture.

The workpiece is drawn mainly to facilitate drawing of the jig/fixture. In fact, the designer first draws the workpiece in colored chaindotted line and then draws the jig/fixture around it. He can thus position the locators, clamps and bushings quickly and correctly with respect to the workpiece. Tool room, methods
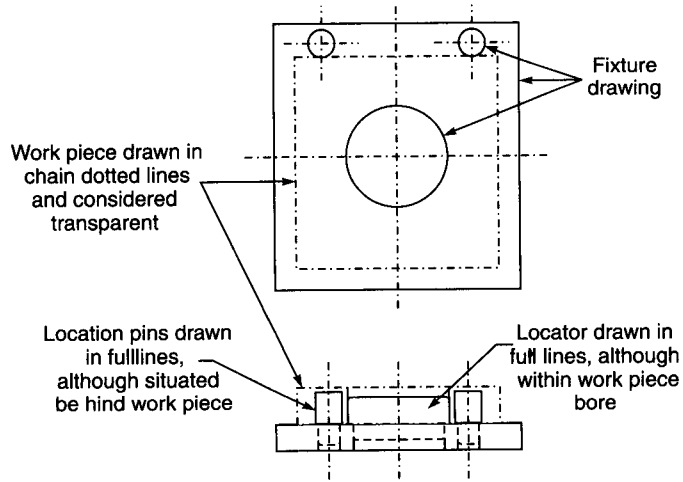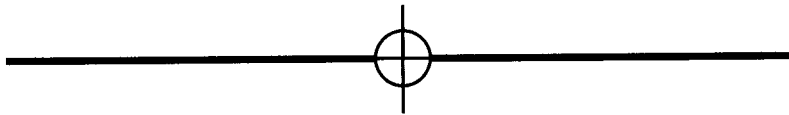
Work piece drawn in
chain dotted lines
and considered
transparent

Fixture
drawing

Location pins drawn
in fulllines,
although situated
be hind work piece

Locator drawn in
full lines, although
within work piece
bore

Figure **1.2**
Presentation of workpiece

and manufacturing engineers studying a jig/fixture drawing, can
distinguish the workpiece from the chaindotted linework and see
how it is placed in the jig/fixture. Thus delineation of workpiece
facilitates drawing of jig/fixture. It also helps the manufacturer
and user of the jig/fixture to understand disposition of the work-
piece with respect to jig/fixture.

Location

Principles

Workpiece Requisites

The location has to meet dimensional requirements of the workpiece stated on the component drawing. For example, in the workpiece illustrated in *Figure 2.1*, the drawing clearly states that hole C should be at distance D from face A. Consequently, we must use face A as a datum for locating the workpiece while drilling hole C. This would ensure that hole C is at distance D from face A. If we use face
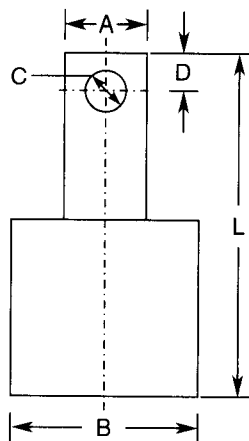

Figure **2.1**
Location and workpiece dimensions

B as a stopper, the variation in length L would cause inaccuracies in the position of hole C. If length L is oversize by 1 mm, hole C will be at $(D + 1)$ mm from face A. If length L is undersize the hole would shift towards face A and would be nearer than distance D from face A.

If we locate on face A the hole would always be at distance D from face A irrespective of the variation in length L.

Accuracy

Location should be done on the most accurate surface of the workpiece. A machined surface is preferable to an unmachined one. When more than one machined surfaces are available, locate from the most accurate surface. For example, the center of the turned part in *Figure 2.2* can be located from outside diameters 110 or 80 or from central 40ø bore. 80ø has the minimum tolerance of 0.05, so the workpiece can be located most accurately from outside diameter 80ø. Location from 40ø bore would be less accurate than location from 80ø but more precise than location from outside diameter 110ø which has a much wider tolerance of 1mm (±0.5 mm).
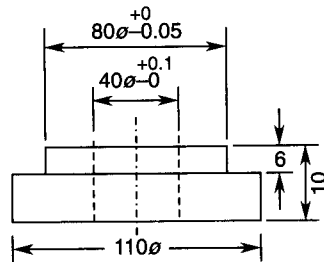

Figure **2.2**
Accuracy of location surfaces

Constraints

Location should prevent linear and rotary motion of the workpiece along and around the three major axes X,Y and Z.

The plate shown in *Figure 2.3* can move along the three axes X,Y and Z and can also rotate around these axes. The location system should prevent all these motions positively.
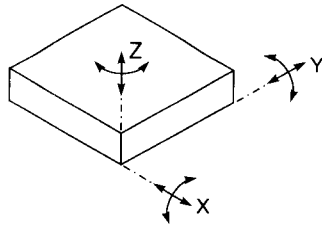

Figure **2.3**
Six degrees of freedom

Motion Economy

Location system should facilitate easy and quick loading of the workpiece in the fixture. It should effect motion economy. For example, there are two ways of drilling holes B and C in the turned component illustrated in *Figure 2.4a*. We can drill either of the holes B and C first by locating on the machined bore A and then, locate on the drilled hole to drill the other hole.

If we drill hole C first and use it for location we would have to use two locators at right angles to each other and the workpiece need to be loaded on the locator for bore A first.

It would be necessary to use another removable locator for hole C (*Figure 2.4b*). Otherwise it would not be possible to load or unload the workpiece on the locator in bore A. Also, location on hole C would involve two motions—first, loading on locator A then inserting a removable pin in hole C which must be removed before the workpiece can be slid off axially from locator in bore A for unloading.

On the other hand, if we drill hole B first and use it for location while drilling hole C, it is possible to load the workpiece on both the locators in hole A and B in one motion as both the locators would be parallel (*Figure 2.4c*). Thus, parallel locators are preferable to those placed at right angles.
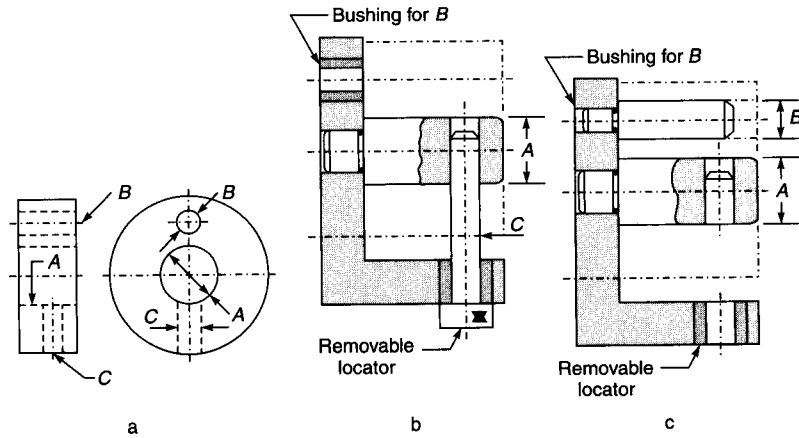
Figure **2.4**
Motion economy in location

Redundant Locators

Redundant locators should be avoided. In case of the workpiece depicted in *Figure 2.5*, we can only locate effectively on surface A or B. For, although both the surfaces had been machined during previous operations, the distance between them would vary according to the process capability. If a fixed surface similar to A is provided to locate the surface at B also, it would act as a redundant location since the job can be located from either A or B only. If the distance between surfaces A and B of the workpiece is more, there would be clearance between the locator and surface B. When clamped, the
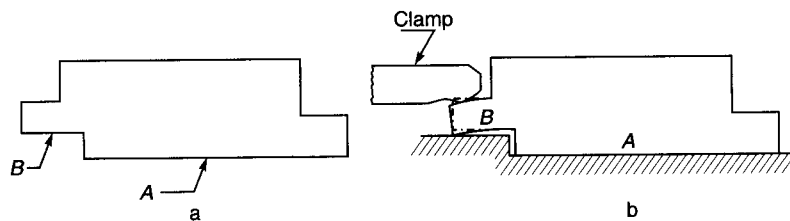

Figure **2.5**
Redundant location

workpiece would bend as shown in *Figure 2.5b*. When the clamp is released, the distorted part would spring back to its original position causing dimensional as well as form (flatness) errors. If the step in the component is less than the height of the locator, the component would not seat properly either on surface A or B (*Figure 2.6*). The clamping force would distort the workpiece. This would cause errors as the distorted part would spring back to its original position when the workpiece is unclamped.
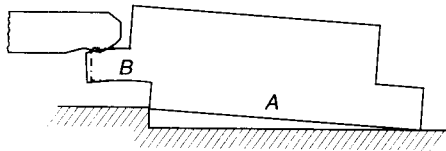
Figure **2.6**
Workpiece distortion due to redundant location

Under such circumstances, the redundant location at surface B should be replaced by an adjustable support illustrated in *Figure 2.7*.
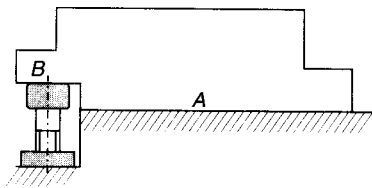
Figure **2.7**
Adjustable support

Foolproofing

The location system should positively prevent wrong loading of the workpiece in a fixture by foolproofing. The workpiece shown in Figure 2.8 is to be located from holes A and C. As holes B and C are equidistant from A and their size is also the same, there is a risk of

the workpiece being loaded wrongly as shown by the chain dotted line. This wrong loading can be prevented by providing a foolproofing pin which would obstruct the path of the workpiece if it is loaded wrongly. It would be impossible to load the workpiece wrongly due to the foolproofing pin.

Foolproofing pin

B-12ø

80

A-20ø

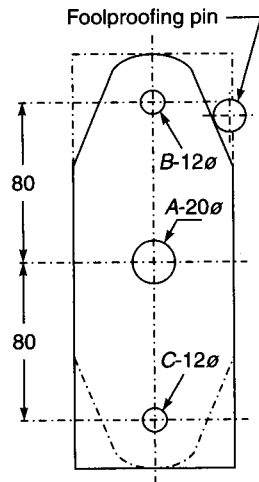80

C-12ø

Figure **2.8**
Foolproofing

Locating Methods

A workpiece can be located from:

1. *Plane surface*

2. *Profile*

3. *Cylindrical surface*

Location from Plane Surface

A plane surface can be located with three points on the surface. A rough unmachined surface can be located with three location pads having point contact. This can be done by providing three location

pins having spherical surfaces at the locating points as shown in *Figure 2.9*. The pins should be spaced as widely as possible for more accurate location. The height of the collar of the pins should be equal so that the located surface is parallel to the baseplate resting on the machine table. Although the three pins can define a plane, they cannot provide adequate support to the workpiece during machining operation such as milling. Additional adjustable supports are necessary to prevent distortion and vibrations in the workpiece during clamping and machining. The number of adjustable supports would depend upon the shape, strength and size of the workpiece.
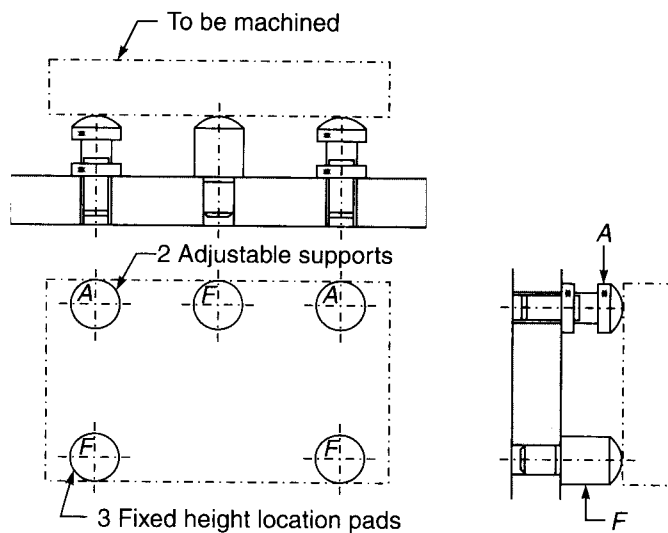

Figure **2.9**
Adjustable support for rectangular workpieces

Figure 2.10 illustrates a threaded adjustable support with the locking nut. Care should be taken that the adjustable supports do not dislocate the workpiece from the locating (resting) pins. This can be done by limiting the force used for adjusting the support. The screw illustrated in *Figure 2.10* is adjusted by rotating the knurled collar by using one's fingers so that the adjusting force would not dislocate (lift) the workpiece from the fixed locating pads (*Figure 2.9*).
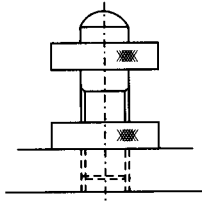
Figure **2.10**
Adjustable support

Surfaces which are reasonably plane (flat) such as hot or cold rolled plates can be located by fixed locating pads and adjustable supports.

For locating very rough, uneven surfaces, it is necessary to use adjustable locating pads. Casting and forging can be located by adjustable screw pads as illustrated in *Figure 2.11*.
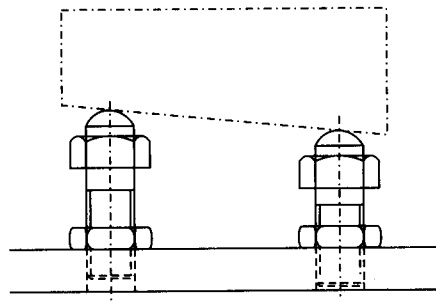
Figure **2.11**
Adjustable locators

During the first operation, it is often necessary to level the surface to be machined with a marking block by adjusting the locating pads. Even in the case shown in *Figure 2.11*, there should only be three locators, and the workpiece should be supported at other points by adjustable supports having knurled collar. A hexagonal head screw rotated by a spanner can easily act as a screw jack and dislocate the workpiece from the locating pads. Sometimes, it is difficult to reach a support which is in recess or is distant from the operator. Under such circumstances, it is necessary to provide an elaborate adjustable support as shown in *Figure 2.12*.
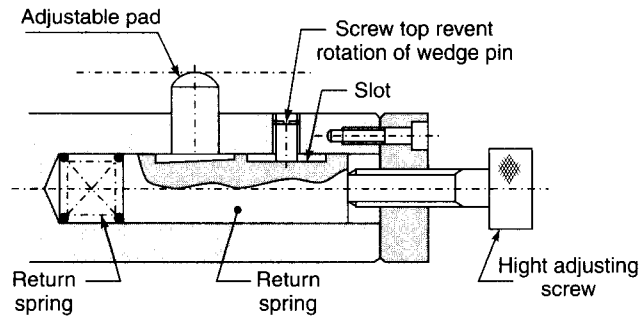
Adjustable pad
Screw top revent
rotation of wedge pin
Slot
Return spring
Return spring
Hight adjusting screw

Figure **2.12**
Adjustable support at inaccessible place

The inclined surface on the wedge pin raises the pad when the wedge pin is pushed forward by the height adjusting screw. When the adjusting screw is withdrawn the return spring pushes the wedge pin towards the right and the pad slides down by gravity.

Figure 2.13 shows another arrangement in which the pad is spring-loaded so that it adjusts itself against the workpiece surface with limited spring force. The pad is locked in position by the clamping screw. The retaining screw prevents the pad from being pushed out of the housing by the spring.
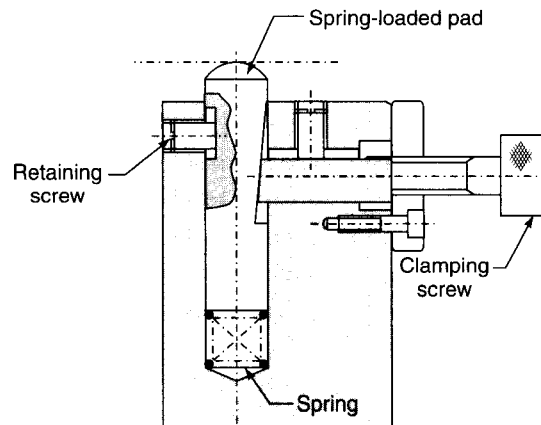
Spring-loaded pad
Retaining screw
Clamping screw
Spring

Figure **2.13**
Spring-loaded pad

Square or rectangular workpieces can be located better by replacing one of the locating pads by an equalising rocker as shown in *Figure 2.14*.
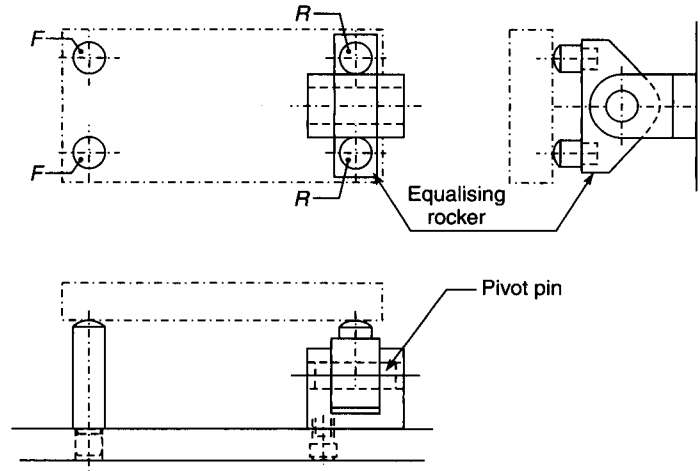

Figure **2.14**
Equalising rocker location

The rocker provides support at two points R. It pivots itself to suit the surface to be located. It provides contact at four points without contradicting the three-point location of the plane. The pivot pin of the rocker acts as a single point complementing the other two points F in defining the plane.

A machined surface can be located better by pads having a flat surface. For large components, the pads can be screwed to the body of the fixture as shown in *Figure 2.15*. This saves machining time as only seats for the pads need to be machined instead of the entire body of the large fixture. Moreover, the locating pads can be levelled easily by grinding them individually after removing them from the fixture body. Errors in the machine of pad seats can be easily corrected by providing compensation in the pads.

For small workpieces, no location pads are necessary. The fixture body itself can be machined suitably to provide the locating surfaces. Ample recess should be provided in the corners so that burr on the
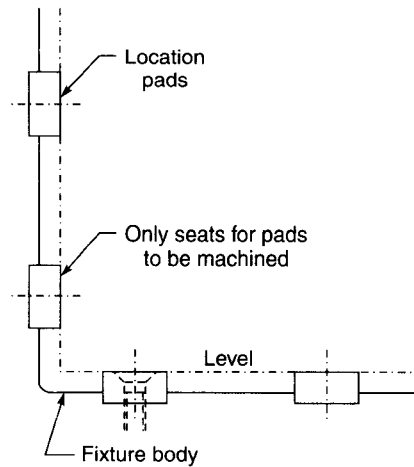
Location pads

Only seats for pads
to be machined

Level

Fixture body

Figure **2.15**
Location pads for large fixtures

workpiece corners, or dirt or swarf do not obstruct proper location
through positive contact of the workpiece with the locating surface
(*Figure 2.16*).

Location pads in large fixtures automatically provide similar recess.
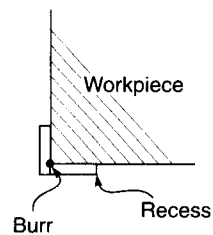
Workpiece

Recess

Burr

Figure **2.16**
Recess for burr and dirt

Six-point Location   *Figure 2.17* illustrates six point location of a
cubical workpiece. The workpiece is clamped against pads 1, 2, and
3. This prevents its linear movement along Y axis and rotation about
axes X and Z. Pads 4 and 5 prevent linear motion along Z axis and

rotation about Y axis. Pad 6 prevents linear motion along X axis. Thus, linear motion along the three axes as well as rotation around them is prevented.
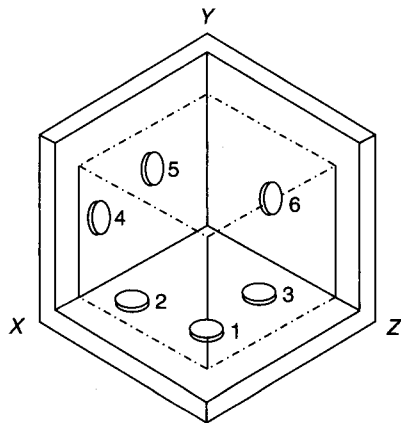

Figure **2.17**
Six-point location

Location from Profile

For simple components where appearance is important, a sighting plate can be provided. It is slightly bigger than the workpiece. The workpiece can be positioned on the sighting plate in such a way that there is equal margin on all the sides as shown in *Figure 2.18*.

Figure **2.18**
Sighting location

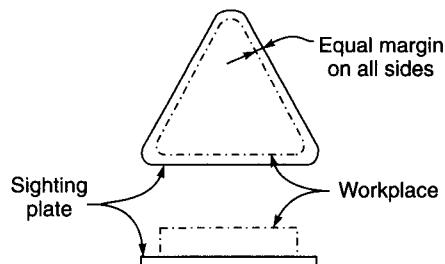The profile of a workpiece can also be located by confining the profile with cylindrical locating pins (*Figure 2.19*).
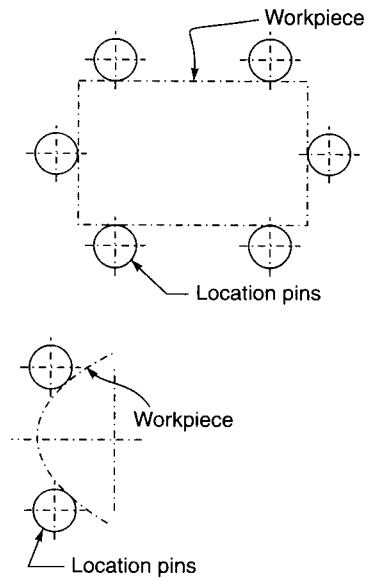
Figure **2.19**
Profile location by pins

When there is considerable variation in workpiece dimensions from batch to batch, an eccentric locator can be used (*Figure 2.20*). The eccentricity of the locator can be varied by rotating it to suit the
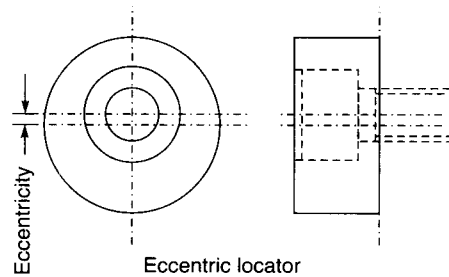
Figure **2.20**
Eccentric locator

workpieces in the batch. The workpiece shown in *Figure 2.21* has got a milled flat on the collar. Dim F of the flat would be almost be the same for all the workpieces milled in a single batch. So, the eccentricity of the locator can be set to suit one of the workpieces from the milled batch and the eccentric locator would locate accurately all the workpieces in the batch.
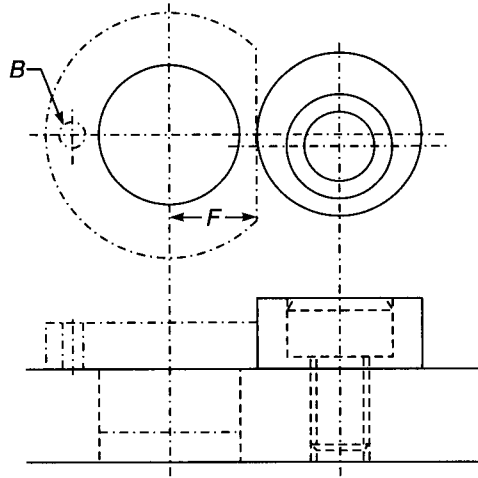
Figure **2.21**
Application of eccentric locator

The profile of a workpiece can be located by providing a pocket or nest around the profile of the workpiece (*Figure 2.22*). The inside profile of the nest matches with the outside of the workpiece. The height of the nest should be lesser than the workpiece to permit grip over the workpiece for unloading. For thin sheet metal workpieces, finger slots or ejection arrangement should be provided for unloading the workpiece. Alternatively, a partial nest can be used.

Sheet metal blanks from the same die or die cast components from the same mould are almost identical. Such workpieces with little variation can be located precisely by a close fitting nest.
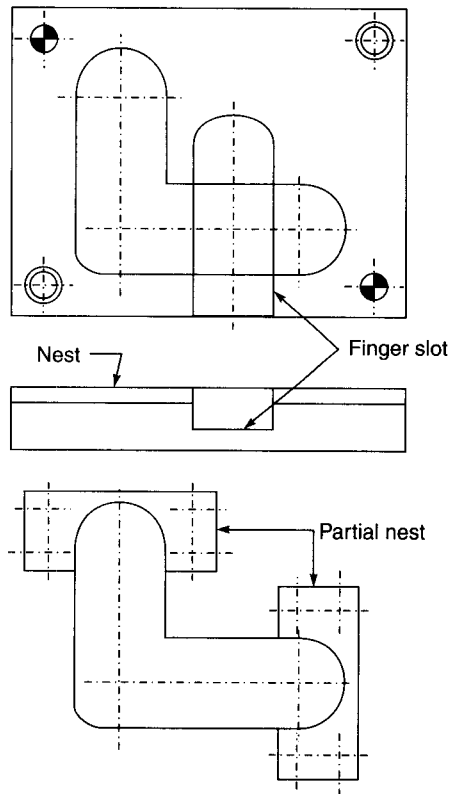
Figure **2.22**
Location nests

Location from Cylinder

Location from a cylinder is the most common and convenient form of location. For, when a cylinder is located on its axis and base, it can only rotate about its axis. All other motions are constrained. If the cylinder shown in *Figure 2.23* is located on a spigot having axis Y–Y, it can neither more linearly not rotate around axes X–X or Z–Z. Clamping from top prevents linear motion along axis Y–Y. The seating surface for the locator should be recessed to provide space for dirt or workpiece burr. This ensures proper seating of the workpiece on the locating face. There should be ample chamfer or radius at the

Figure **2.23**
Cylindrical location

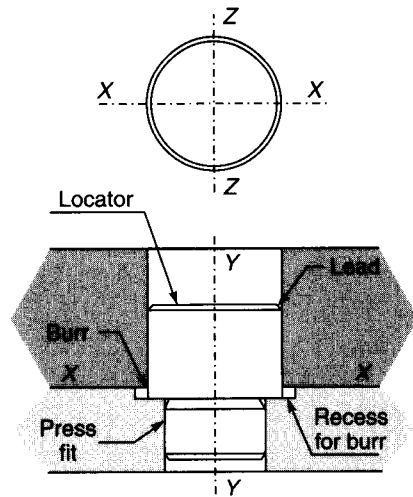entry point so that the components can be loaded quickly. The chamfer is called lead. It centralises the workpiece quickly with the locator. The locator itself is located in the fixture by a concentric diameter generally made press fit in the fixture body.

Locating posts are often used for anchoring clamping studs (*Figure 2.24*). The posts used for clamping should be secured by a retainer nut or a grub screw to prevent it from coming out of the fixture body when the clamp is tightened.

The length of the locator should be short to prevent *jamming* of the workpiece. The workpiece is likely to be tilted to the axis of the location post during quick loading. A long lead aligns the axis of the workpiece with the locating post. If the locator is long and the lead short, the workpiece would get jammed on the post shown in *Figure 2.25*. However, the locator is also subjected to various forces developed during operation. The locator provides support to the workpiece during operation. Hence, it is necessary to use long location posts when the workpiece is fragile. Under such circumstances, there should be ample lead at the entry point and the locator should be relieved, i.e. made undersize in the central portion.

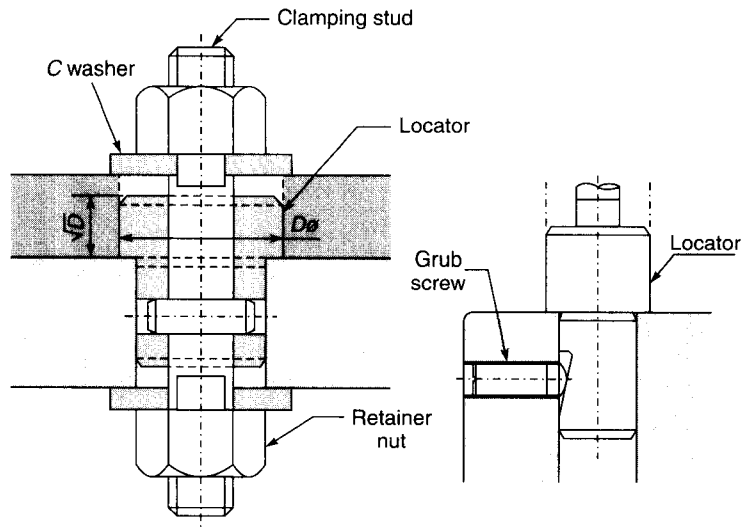Figure **2.24**
Locators subjected to axial pull
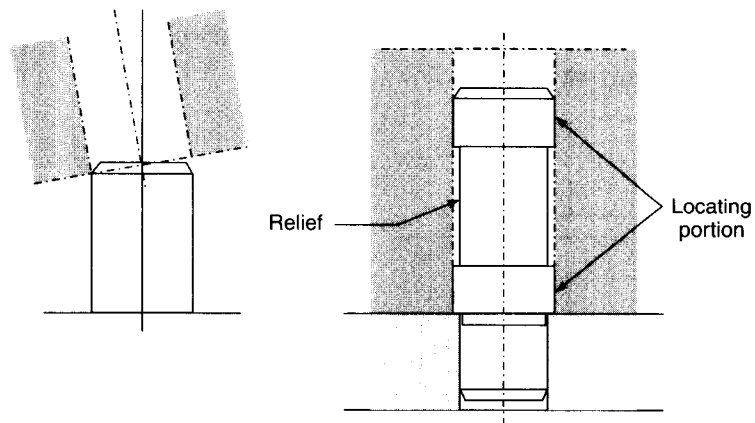
Figure **2.25**
Prevention of jamming

The jamming of the workpiece on the locating post can also be pre-vented by a provision for a special lead at the entry point as shown in *Figure 2.26*.

μ = Co-efficient of friction

$l = \mu d$

$l_1 = \sqrt{2d(D-d)}$
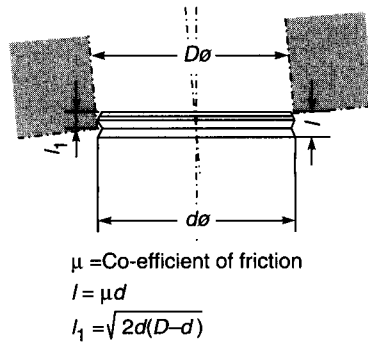
Figure **2.26**
Jamming prevention lead

In this type of lead, the workpiece would not jam on the locator even if it is considerably tilted towards the axis of the locator at the time of loading.

For locating a cylinder on the outside diameter, it is necessary to use a bushing, which is called location pot. They should have generous lead at the entry point, and the central portion should be relieved, in case of long pots (*Figure 2.27*).

Figure **2.27**
Female locators

A single cylindrical locator cannot prevent rotation of the workpiece around the axis of the locator. For this, it is necessary to provide a second locator. For example, it is necessary to use two dowel pins to ensure that the piece is completely constrained.

If we want to fix plate B on base A we must use at least two dowel pins P and Q as shown in *Figure 2.28*. If we use only one 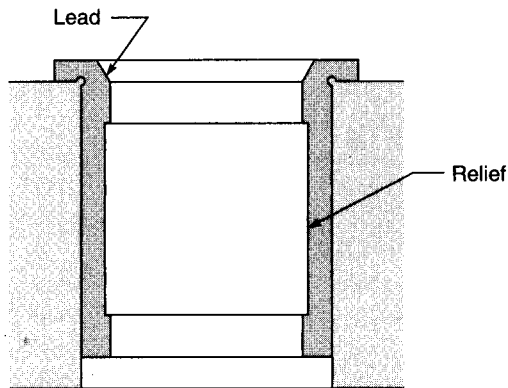dowel pin P, plate B can pivot around P. The provision for dowel Q would prevent plate B from pivoting around P. The dowels P and Q should be placed as far as possible.
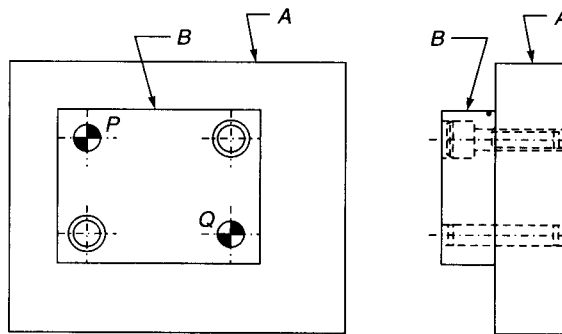
Figure **2.28**
Use of dowels

The dowels are used for permanent assembly of two parts. The holes in base A should be located from plate B so that there is no question of variation of centre distance between dowel holes P and Q.

When we have to use two holes in a workpiece for location, we must take into account the variation in the centre distance of the two holes due to the wear of the guide bushes for cutting tools.

This variation can be taken care of by making one of the two location pins diamond shaped as shown in *Figure 2.29*.

Out of the two holes, the important and accurate one should be used for principal cylindrical location with a full pin. The diamond shaped pin should be used to constrain pivoting of the workpiece

Principal locator

$C \pm V$

Diamond pin

C = Center distance
V = Valuation in center distance

D = Work piece bore min.
d = Diamond pin dia. max.

$$d = 2\sqrt{\frac{D^2}{4} - V^2 - VW}$$

Figure **2.29a**
Diamond pin application
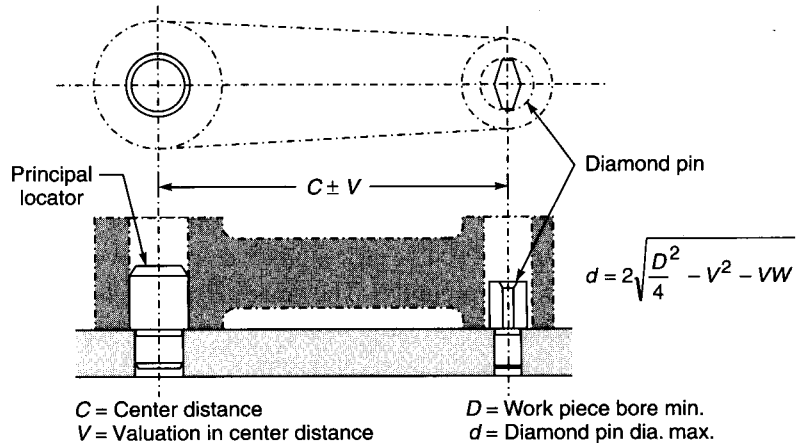
around the principal locator. The principal locator should be longer than the diamond pin so that the workpiece can be located and pivoted around it before engaging with the diamond pin (*Figure 2.29a*). This simplifies and speeds up loading of the workpiece.

Diamond pin can also be used for accommodating the variation in the distance of a hole from a plane surface (*Figure 2.29b*).

Figure 2.29c illustrates the principle of a diamond pin. The locating surface of a diamond pin is usually less than 8% of a full cylindrical pin. This provides more clearance at location points. Clearance V at corner Q is much more than radial clearance $(D-D/2)$ between the workpiece hole and the diamond pin. Referring to *Figure 2.29c* in triangle PRS:

$$PS^2 = PR^2 + RS^2$$

$$= (PQ + QR)^2 + (QS^2 - QR^2)$$

$$\therefore \quad \left(\frac{D}{2}\right)^2 = \left(V + \frac{W}{2}\right)^2 + \left(\frac{d}{2}\right)^2 - \left(\frac{W}{2}\right)^2$$

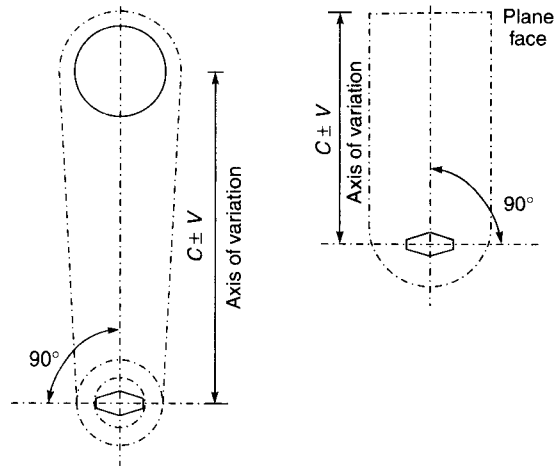$$\frac{D^2}{4} = V^2 + VW + \frac{W^2}{4} + \frac{d^2}{4} - \frac{W^2}{4}$$

Figure **2.29b**
Positioning diamond pin correctly

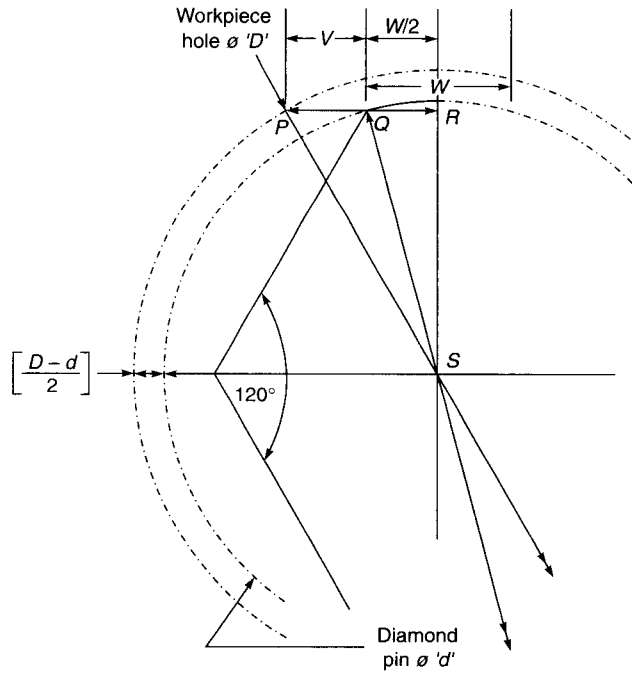Figure **2.29c**
Principle of diamond pin

$$\therefore \qquad d = 2 \sqrt{\frac{D^2}{4} - VW - V^2} \qquad\qquad \text{... Eqn. 2.1}$$

Example 2.1 Calculate the diameter of a diamond pin placed at 45 ± 0.15 distance from a plane surface if the locating hole in the workpiece D is 55.55/55.596 and engagement width W of the pin is 2 (*Figure 2.29 b*).

Solution: Minimum ø of workpiece hole = D

$$D = 55.55$$

$$\text{Variation} = V = 0.15$$

$$W = 2$$

$\therefore$ Diamond p in ø = d

$$d = 2 \sqrt{\frac{55.55^2}{4} - 0.15 \times 2 - 0.15^2}$$

$$= 2 \sqrt{771.45 - 0.3 - 0.0255}$$

$$= 2 \sqrt{771.1275} = 55.538$$

Radial clearance $(D-d)/2$ is only 0.006. But the clearance at location corner 'Q' is 0.15, i.e. 25 times the radial clearance. The pin should be made further undersize to provide precision running fit (H7/f6) with the workpiece.

$$\text{Diamond pin ø} = d = 55.538 \text{f6}$$

$$= 55.538 \, ^{-0.03}_{-0.049}$$

Width W of the diamond pin is usually kept one-eighth of the workpiece hole ø D (*Figure 2.30*). It can, however, be varied suitably to accommodate variation V in centre distance C in the workpiece and the desired fit between the diamond pin and the hole.

Example 2.2 Determine permissible variation V in centre distance 45 in example 2.1, if width W is increased to 7. While pin d remains same, i.e. 55.538f6.
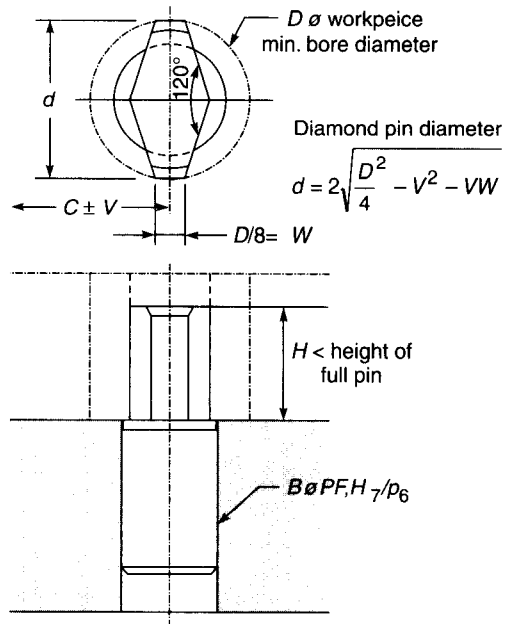
$D\,\varnothing$ workpeice min. bore diameter

Diamond pin diameter

$$d = 2\sqrt{\dfrac{D^2}{4} - V^2 - VW}$$

$D/8 = W$

$H <$ height of full pin

$B\varnothing\,PF,H\,_7/p_6$

Figure **2.30**
Diamond pin design

$$d = 2\sqrt{\dfrac{D^4}{4} - VW - V^2}$$

$$\therefore \qquad 55.538 = 2\sqrt{771.45 - 7V - V^2}$$

or $\quad V^2 + 7V - 0.33264 = 0$

$$V = \pm\,0.0472$$

Angular accuracy required in location is the ultimate criterion for the radial clearance permissible between the diamond pin and the workpiece hole.

Example 2.3 Determine the angular accuracy of location if a diamond pin with 4 mm land is used for locating axis of $2\varnothing\ 32\ H7$ holes and centre distances between the holes (*Figure 2.29a*) is 200 ± 0.2.

Solution $\quad D = 32; \quad W = 4; \quad V = 0.2$

$$\therefore \quad d = 2\sqrt{\frac{D^2}{4} - VW - V^2}$$

$$= 2\sqrt{\frac{32^2}{4} - 0.2 \times 4 - 0.2^2}$$

$$= 31.947$$

$$\therefore$$

$$\text{Pin } \varnothing = 31.947 \, f6 = 31.947 \, {}^{-0.025}_{-0.05}$$

$$\text{Angular Accuracy} = \tan^{-1}\left[\frac{D-d}{2C}\right]$$

$$= \tan^{-1}\left[\frac{32 - 31.897}{2 \times 200}\right]$$

$$= 0.01475° = 0°0',53.11''$$

Location land W of diamond pin should be square to the axis along which variation V occurs. When a diamond pin is used to locate the axis of two cylindrical holes (*Figure 2.29a*), the land should be square to the axis joining the centers of the holes. While locating a plane surface and a hole (*Figure 2.29b*), the centre line of land W should be parallel to the plane surface.

Conical Location Conical locators are used mainly to locate rough unmachined cylinders in castings and forgings. Cored holes and bosses are centralized by conical locators (*Figure 2.31*). Conical locators generally have axial adjustment with a screw which is also used to clamp the located workpiece in position. When a casting has a single boss which is to be drilled, a bushing is made integral with the locator to facilitate drilling of the workpiece in the located position.

Vee Location Vee locators are used extensively to locate cylindrical surfaces from outside. Fixed V blocks are used for approximate location. These are generally fixed by screws to the fixture body and dowelled to prevent shifting during operation (*Figure 2.32*).

For more accurate location, it is necessary to make V locator adjustable along the axis of V. The position of V block is adjusted by a screw to take care of the variation in the size of the workpiece (*Figure 2.34*).
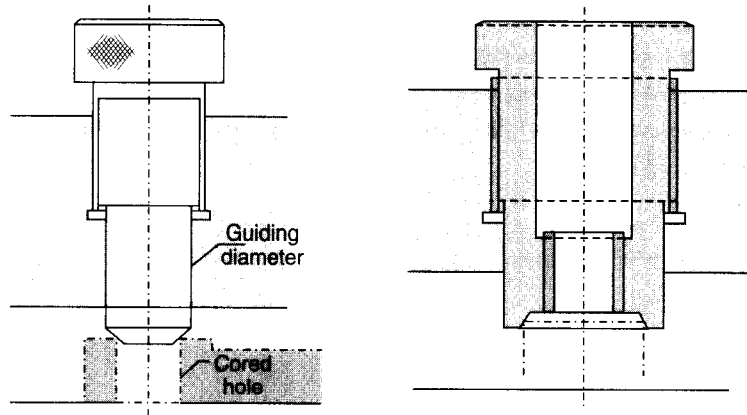
Guiding
diameter

Cored
hole

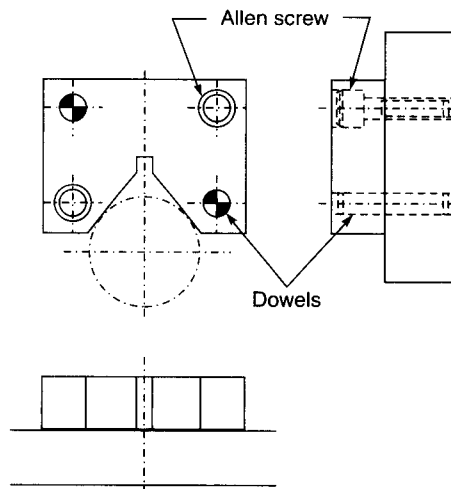Figure **2.31**
Conical locators

Allen screw

Dowels

Figure **2.32**
Fixed V locator

An adjustable V locator should be guided by a guide plate to constrain its movement along the axis of V. The guides must be dowelled to prevent shifting during operation. The side of the V face is sometimes inclined slightly to provide downward clamping force (*Figure 2.33*).
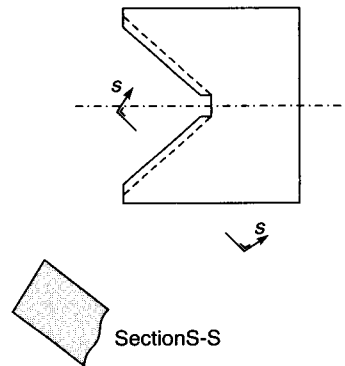

SectionS-S

Figure **2.33**
Inclined V

A Vee locator can be adjusted quickly by using a cam for adjustment (*Figure 2.35*).

It is necessary to provide a return spring for bringing back the V location to its original position when a cam is used.

When the V plate has to be withdrawn quickly for a considerable distance a swinging eyebolt is used. A slotted thrust plate must be provided as a seating face for the V adjusting nut. (*Figure 2.36*).

When a cylindrical workpiece is located by the V block the position of its centre would depend on its diameter. However, the centre would always lie on the centre line of V. So, for drilling central holes in round bars, the V block should be placed in such a way that its centre line is vertical. Even if the size of the workpiece varies, the drilled hole would always be at its center (*Figure 2.37*).
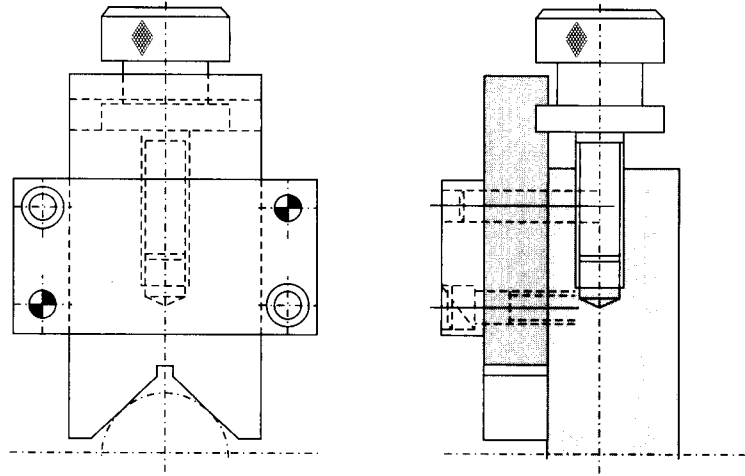
Figure **2.34**
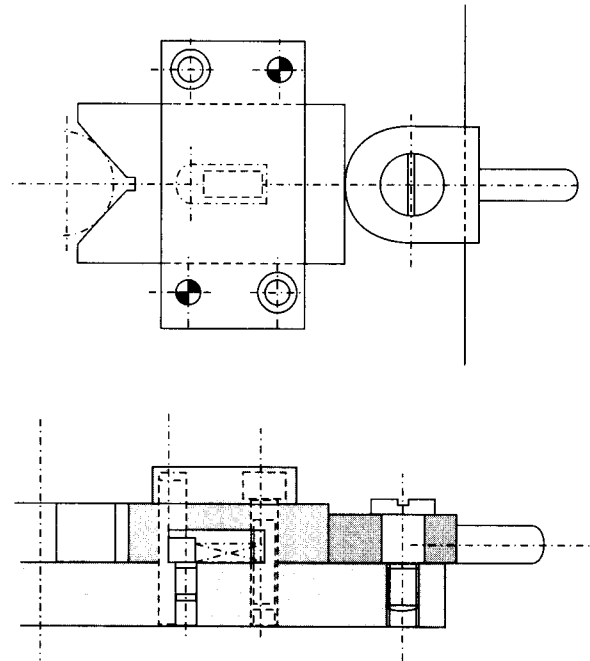*Screw adjusted V locator*

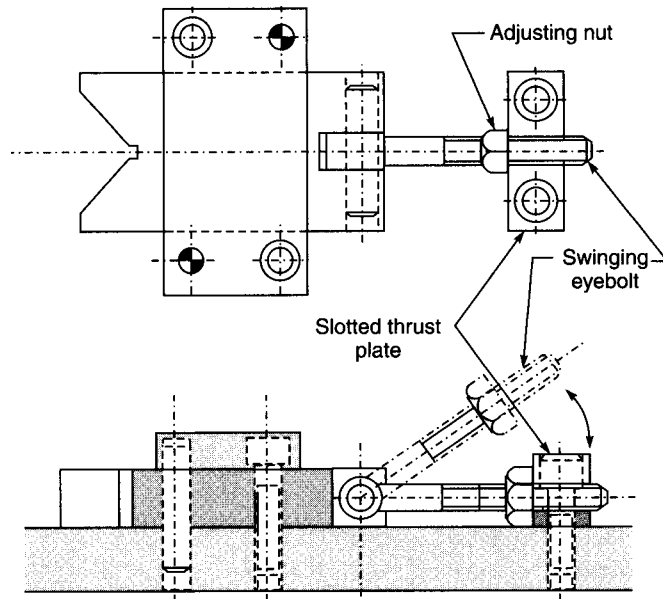Figure **2.35**
Cam-operated V locator
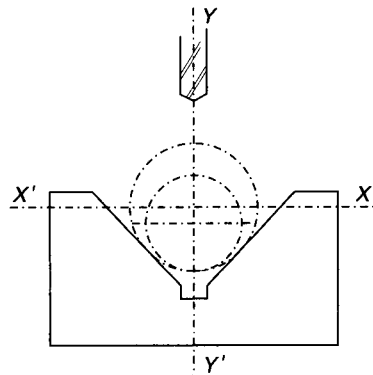
Figure **2.36**
Quick action V locator

Figure **2.37**
Correct position of V

On the other hand, if the V block axis is horizontal, the variation in the diameter of the workpiece would lead to errors. As shown in *Figure 2.38*, the hole in undersize bar would be eccentric by length

A, whereas in case of an oversized bar, the hole would be offset by length B.
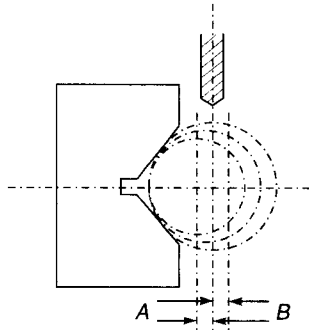
Figure **2.38**
Correct position of V

Summary

Principles of Location

1. Location must be related to the dimensional requirements stated on the component/workpiece drawing.

2. It is preferable to use a more accurately machined surface than a less accurate surface for location.

3. The workpiece should be prevented from moving along and rotating around the X,Y and Z axes.

4. Location system should facilitate easy and quick loading and unloading of the workpiece and aim at motion economy.

5. Redundant locators must be avoided.

6. Location system should positively prevent wrong loading of the workpiece by foolproofing.

Locating Methods

Plane Surfaces

1. A reasonably flat surface can be located by three pins of equal height having spherical surfaces at the location points.

2. A rough, uneven or tapered plane surface should be located by three adjustable location pins having spherical ends.

3. Additional adjustable supports are necessary to prevent vibrations or distortion of the workpiece during machining operation. The force for adjusting the supports should be kept minimum so that the workpiece does not get dislocated or lifted from the location pins.

4. A machined surface can be located by pads having flat surface.

5. There should be ample clearance for burr or dirt to ensure proper seating of the workpiece surfaces.

6. A cube can be prevented from linear movement and rotation around axes X,Y and Z by six location pads.

Profile

1. A profile can be located approximately by aligning it with a slightly bigger sighting plate.

2. Locating pins can also be used to locate a profile or cylindrical workpieces.

3. Variations in workpiece sizes from batch to batch can be taken care of by using eccentric locators whose eccentricity can be set to suit the batch.

4. Workpieces with little variation can be located precisely with nesting plates with suitable provision for unloading or ejection.

Cylinder

1. Spigots used for locating bores should have ample lead for easy entry and their length should be short to prevent jamming of the workpiece.

2. Long locators for fragile workpieces should be relieved at the centre.

3. Location posts which are also used for clamping should be retained by a nut or a grub screw.

4. When two location pins are used, the less important one should be made diamond-shaped. The important full pin should be longer than the diamond pin in order to facilitate easy loading of the workpiece.

5. Rough cored holes and bosses are located by conical locators which often have integral clamping arrangement and drill bush.

6. Fixed V blocks are used to locate approximately the outside surface of a cylinder.

7. For precise location, an adjustable guided V block is necessary. The V block can be adjusted by a screw or a cam. It can be withdrawn quickly by using a swinging eyebolt.

8. V blocks should be positioned in such a way that the variation in the workpiece would not affect the location for the operation. For drilling central holes, the center line of V should be vertical.
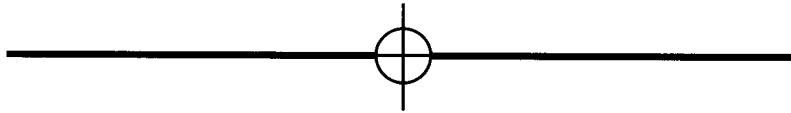
Clamping

Clamping elements hold the workpiece firmly engaged with the locating elements during operation. The clamping system should be strong enough to withstand forces developed during operation. At the same time, the clamping force should not dent or damage the workpiece. Speed of operation, operator fatigue and strategic positioning are other important considerations for contriving a clamping system.

Principles of Clamping

Position

Clamping should be positioned to direct the clamping force on a strong, supported part of the workpiece. Clamping on unsupported part bends slender workpieces as is shown in *Figure 3.1*. This affects
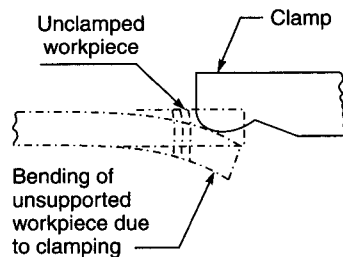

Figure **3.1**
Distortion of unsupported workpiece

the accuracy of the operation. A vertical hole drilled in the bent workpiece would become angular when the unclamped workpiece springs back to its original shape as is shown by the chairdotted lines in *Figure 3.1*.

The clamping system should not obstruct the path of loading and unloading of the workpiece. The clamps in the path of loading should be retractable (*Figure 3.9*) or swinging type (*Figure 3.10*) so that the clamps can be withdrawn or swung clear of the path of loading and unloading of the workpiece.

Clamps should not obstruct the path of the cutting tool. They should not get drilled, milled or welded during operation.

Strength

The clamping system should be capable of holding the workpiece security against the forces developed during operation. The clamping force should not dent or damage the workpiece with excessive pressure. For clamping weak or fragile workpieces, the clamping force should be distributed over a wider area of the workpiece. While clamping soft workpieces, clamps should be fitted with pads of softer materials, such as nylon or fibre to prevent damage and denting of the workpiece.

Productivity

Clamping time should be minimized by using hand knobs, tommy bars, knurled screws, handwheels and handles (*Figure 3.2*), so that the clamp can be tightened or loosened manually without using spanners, as a spanner further adds motions of picking, aligning, and laying it down.

Operator Fatigue

Operator fatigue should be taken into account. If a considerable number of clamps are to be tightened and loosened repeatedly, it is better to use pneumatic or hydraulic clamping which, in addition to
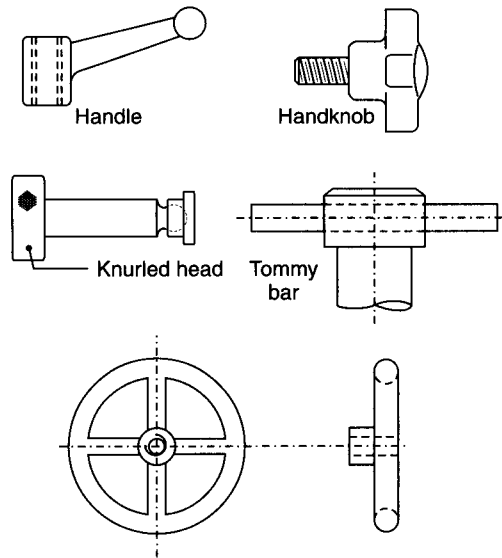
Figure **3.2**
Hand operated clamping devices

reducing operator fatigue, also saves clamping time. Power clamping facilitates tightening or loosening of many clamps simultaneously.

Workpiece Variation

The clamping points should be provided with ample radius to make the clamp operable even if there is variation in the workpiece. Heel pin pressure surface should also be made spherical to permit some tilting of the clamp (*Figure 3.3a*).

Misalignment between the clamp surface and the clamping nut due to tilting of the clamp can be countered by use of spherical washers between the clamp and the nut. As washers are used in pairs, the two washers have matching male and female spherical seats. The spherical bearing allows the washers to tilt with respect to each other. The lower female washer tilts with the clamp while the upper male washer below the nut remains square to the nut. The spherical seat transmits the clamping pressure from the nut to the clamp. (*Figure 3.3b*) shows a clamp with a cylindrical washer.
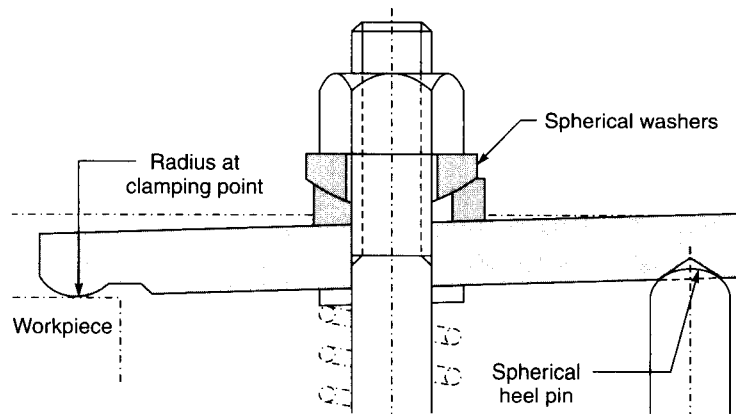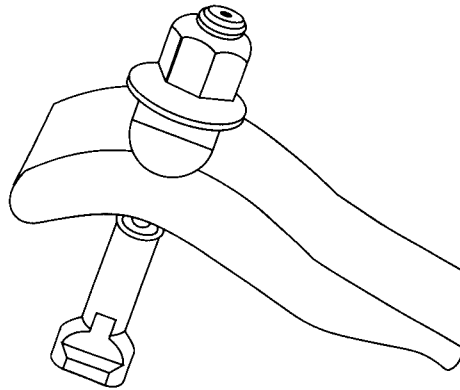
Figure **3.3a**
Clamping variable workpieces

Figure **3.3b**
Universal clamp with cylindrical washer

In multiple clamping, a pivoted equalizer is used for clamping two unequal workpieces simultaneously. The equalizer clamp pivots around the pin to suit the workpieces (*Figure 3.4*). The equalizer principle can be extended to facilitate clamping of many even number of workpieces simultaneously by a single clamp (*Figure 3.5*).
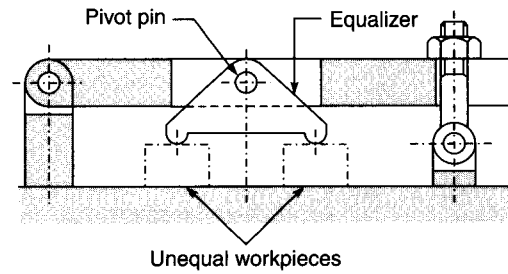
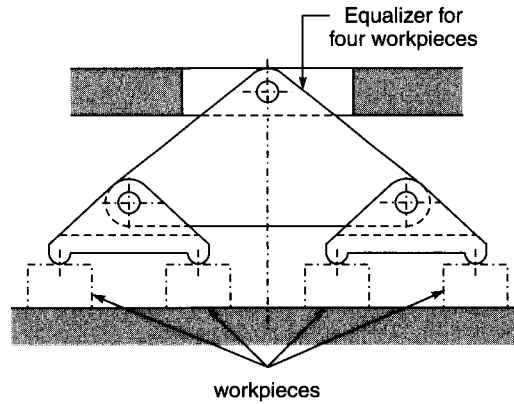Figure **3.4**
Equalizer for two workpieces

Figure **3.5**
Equalizer for four workpieces

Types of Clamps

Clamps can be broadly classified into screw clamps, strap clamps, pivoted clamps, hinged clamps, swinging clamps, quick action clamps, multiple clamps, power clamps and non-conventional clamps.

Screw Clamps

Screw clamps are threaded devices with knurled collar, hand knob, tommy bar, or spanner flats for rotating and tightening the screw (*Figure 3.6*).
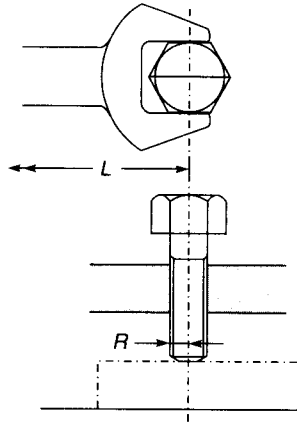
Figure **3.6**
Screw clamp

The Clamping area of a screw clamp can be increased by a provision for a pad (*Figure 3.7a*). The clamping pad is free to rotate on the pivot. This eliminates friction between the workpiece and the pad. The clamping pad remains stationery on the workpiece while the screw rotates and rubs on the conical seat of the pad.

A swivel-type clamping pad provides a spherical joint between the clamping pad and the clamping screw (*Figure 3.7a*). This allows the clamping pad to swivel around the clamping screw. The swivelling pad adjusts itself to suit the inaccuracies in the clamping face of the workpiece. The cross pin pulls the pad backwards when the screw is retracted. *Figure 3.7b* shows another type of floating pad.

The force developed by the screw can be calculated with the following formula:

$$F_S = \frac{F_h L}{R \, Tan \, (\alpha + \varnothing)}$$

Figure **3.7a**
Floating pad

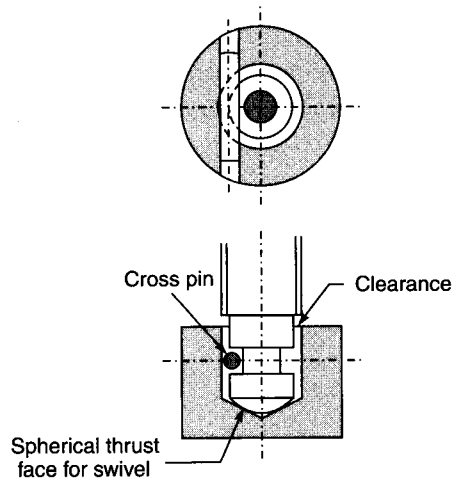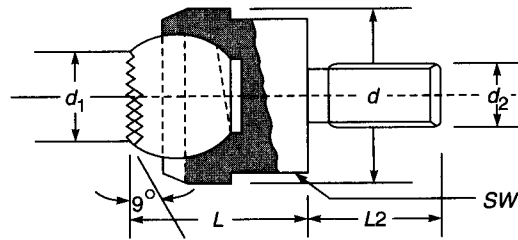Figure **3.7b**
Another type of floating pad

F_S = Force developed by screw

F_h = Pull or push applied to spanner

R = Pitch radius of screw thread

α = Helix angle of thread

ϕ = Friction angle of thread

L = Length of spanner or lever

A 12 mm hexagonal headed bolt with 100 mm long wrench and a 10 kg manual pull can develop 700 kg clamping force along the axis of the screw.

Strap or Plate Clamps

These are made of rectangular plates and act like levers. In its simplest form the clamp is tightened by rotating a hexagonal nut on a clamping screw (*Figure 3.8*). One end of the clamp presses against the workpiece and the other on the heel pin, thus, loading the clamp like a simply supported beam. The clamping face of the clamp is curved and the pressure face of the heel pin is made spherical to take care of any variations in the workpiece.
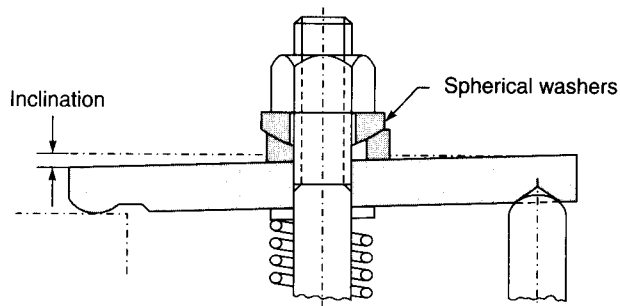

Figure **3.8**
Simple plate clamp

The provision for spherical washers between the clamp and the hexagonal nut provides a spherical joint which permits the clamp to tilt with respect to the screw and the nut. Thus, the clamp operates satisfactorily, even if there is considerable variation in the workpiece height.

Generally, strap clamps are provided with a washer and a spring below the clamp. The spring lifts the clamp as the nut is loosened. The workpiece becomes free of even the gravitational load due to clamp weight. The spring holds the clamp in a raised position during loading and unloading of the workpiece.

Retractable Strap Clamps When clamps fall in the path of loading and unloading, they are made slotted to permit linear withdrawal (*Figure 3.9a*). The clamp is retracted to the position shown by the chaindotted line during loading and unloading of the workpiece. *Figure 3.9b* shows a U clamp which can be removed altogether.
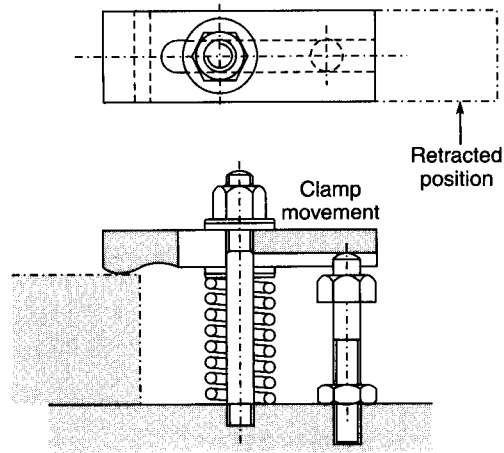
Figure **3.9a**
Slotted strap clamp
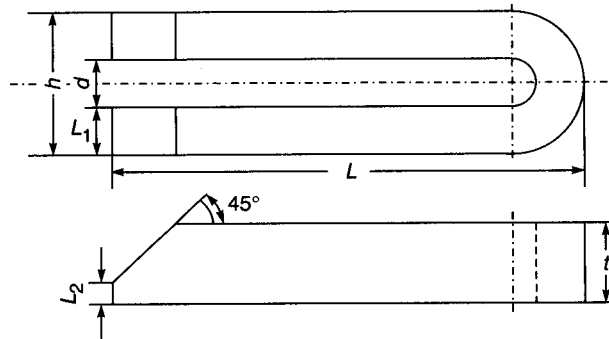
Figure **3.9b**
U clamp with open slot

Swinging Strap Clamps In another design, the clamp is rotated by
90° to clear the passage for loading/unloading the workpiece (*Figure
3.10a*). The clamp is swung to the position shown by the chaindot-
ted line during loading and unloading of the workpiece.

Figure 3.10b shows a 45° swinging diagonal clamp developed by the
author for clamping a jig for terminal box holes in the workpiece. As
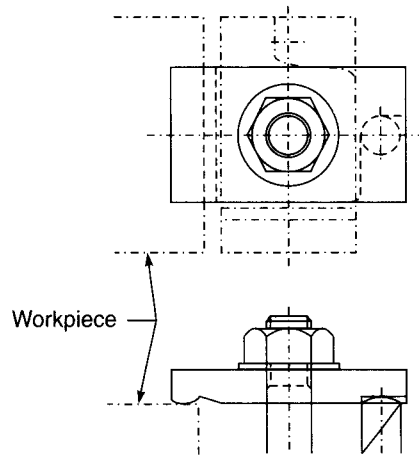it is shaped to suit the square opening in the terminal box, the ends

Figure **3.10a**
Swinging strap clamp

of the clamp are chamfered to enable loading and unloading of the clamp. The auxiliary view of the diagonal loading/unloading position of the clamp is in chaindotted lines.

The clamp is swung by 45° to bring the chamfered ends below the terminal box in the clamping position. The stop pins fitted in the jig plate facilitate bringing the clamp blindly in the clamping and loading/unloading positions. The clamping bolt is welded to the clamp to simplify swinging of the clamp along with the bolt. The clamp is kept in the diagonal position while loading/unloading the jig. The clamp is lowered or raised through the opening in the terminal box. Clamping is effected by sandwiching the terminal box rim between the jig plate and the clamp.

After drilling is finished, the clamp is swung to the chaindotted diagonal position to permit withdrawal through the terminal box opening.

Edge Clamps Strap clamps are used extensively for clamping workpieces on the edges during facing operations. *Figure 3.11* shows a simple edge clamp. The tightening of the hexagonal nut wedges the clamp between the workpiece and the angular heel surface. This clamps the workpiece. *Figure 3.12a* shows another edge clamp.

Figure **3.10b**
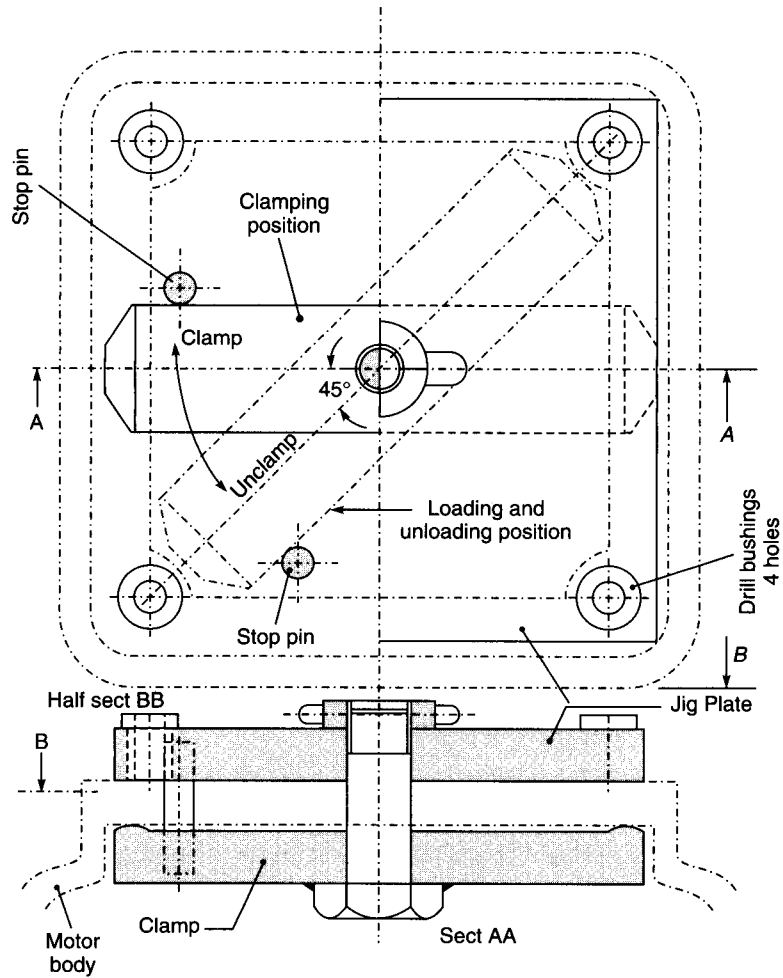*Special swing clamp for drill jig for terminal box holes in electrical motor body*

It slides down the inclined heel as the hexagonal nut is tightened.
This pushes the jaw against the workpiece to clamp its edge. *Figure*
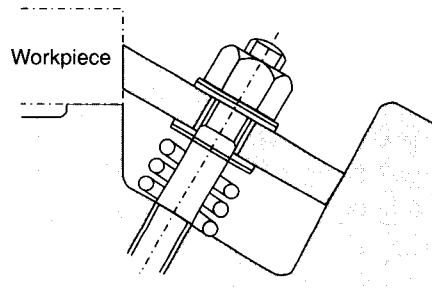*3.12b* shows a pivoted edge clamp.
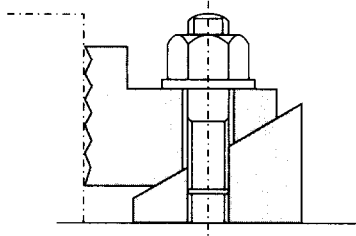
Figure **3.11**
Edge strap clamp

Figure **3.12a**
Edge jaw clamp
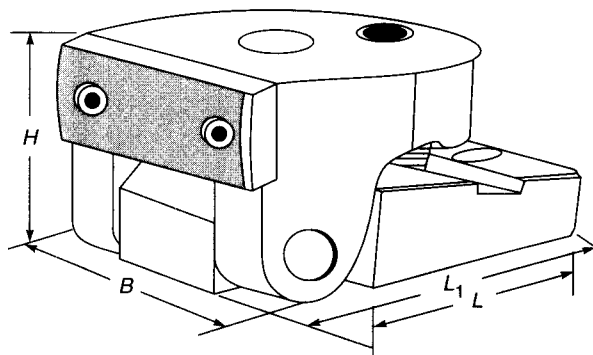
Figure **3.12b**
Hinged jaw clamp

Special Strap Clamps The clamp shape can be changed to suit the workpiece and the operation. In milling fixtures, clamps are often slotted at the center to permit passage of the cutter (*Figure 3.13a*). Circular and symmetrical workpieces can be clamped well with a spider clamp having three clamping points (*Figure 3.13b*). As the clamp acts as a sort of rigid washer, no heel pin is necessary.
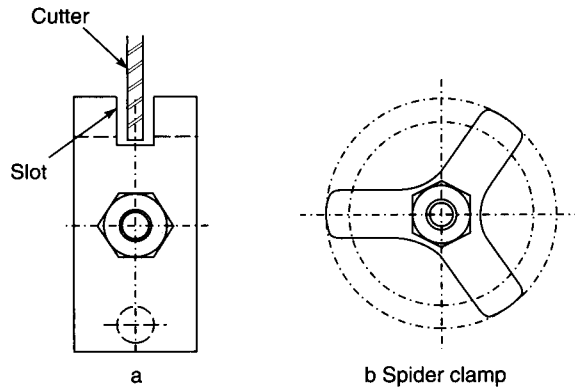
Figure **3.13**
Tool slot in clamp

Pivoted Clamps Clamps are often pivoted at the center to simplify their operation. *Figure 3.14* shows a pivoted strap clamp. It is tightened and loosened by the knurled head screw. The clamp pivots around the central pin during operation.

Figure **3.14**
Pivoted strap clamp

Figure 3.15 shows a couple of pivoted edge clamps. The point of operation should be noted, i.e. the screw has been shifted from the

center to the end opposite the clamping point. This makes the clamp screw more accessible to the operator.
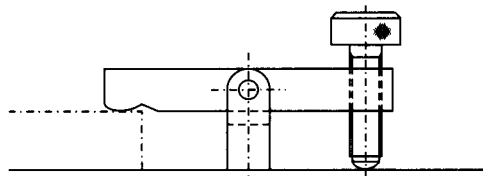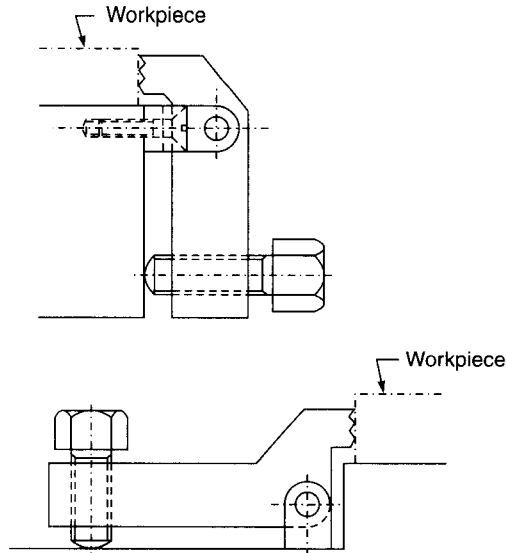

Figure **3.15**
Edge clamps

Pivot action can be used for two-way clamping of the workpiece (*Figure 3.16*). The tightening of the knurled screw first pushes the workpiece till it touches the locator. Further tightening of the screw pivots the clamp anti-clockwise till the curved face of the clamp touches downward on the workpiece. Still further tightening of the screw clamps the workpiece vertically and horizontally with the curved surface and the end of the knurled head screw. Thus, a two way-pivoted clamp pushes the workpiece against two locators before it clamps the workpiece simultaneously in two directions.

Hinged Clamps Hinged clamps provide rapid clearance of the loading and unloading passage. It is generally clamped with a swinging eyebolt. The clamp has an open slot through which the eyebolt can be swung into position as shown in *Figure 3.17b*. The tightening of the hexagonal nut clamps the workpiece. For loading and unloading

Figure **3.16**
Pivoted two-way clamp

a

b

Figure **3.17**
Hinged clamp

the workpiece the hexagonal nut is loosened half-a-turn and the eyebolt is swung out of the open slot to free the hinged plate as shown in *Figure 3.17a*. The hinged plate is swung aside during loading and unloading.
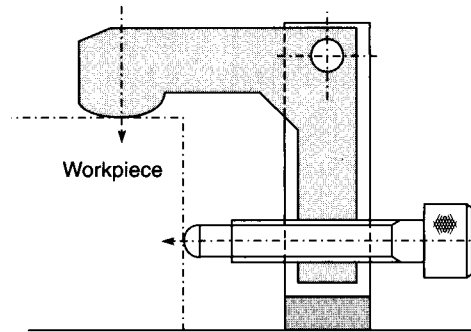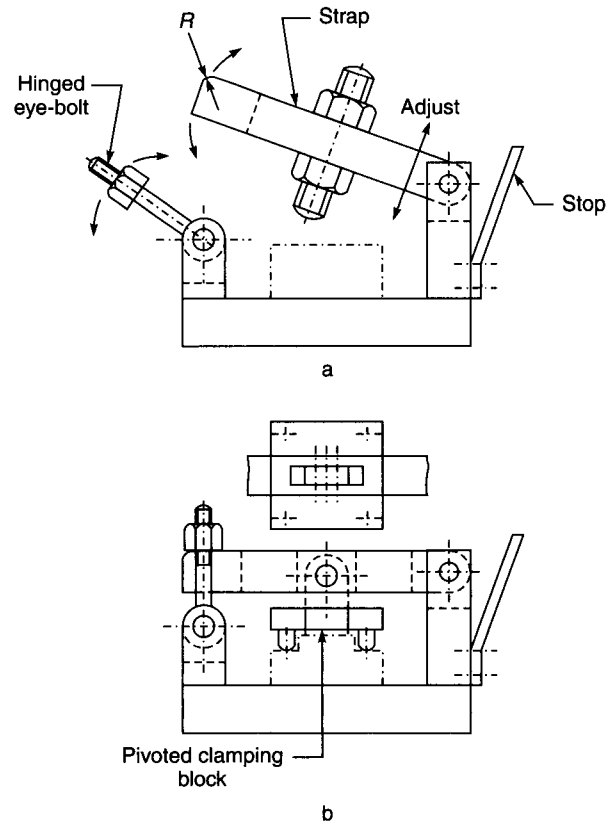
A hinged clamp can also be used for two-way clamping (*Figure 3.18*). The workpiece is pushed against the location pins by the pivoted edge clamp which also houses the swinging eyebolt. The tightening of the knurled nut against the hinge clamp first pushes the workpiece against the location pins. After that, further tightening of the knurled nut pushes the clamping pad towards the workpiece which is clamped simultaneously in two directions by the edge clamp and the pad in the hinge. The knurled nut is loosened only by half-a-turn before swinging the eyebolt and the hinge plate aside for loading and unloading the workpiece.
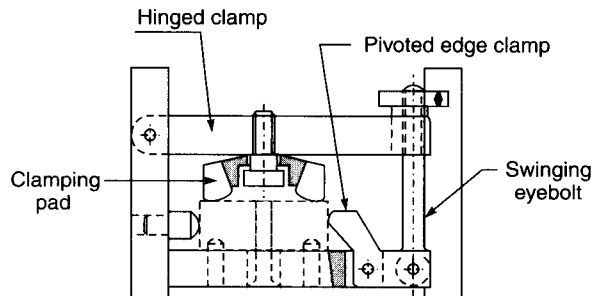
Figure **3.18**
Hinged two-way clamp

Swinging Clamps Like hinged clamps, swing clamps must be swung to the working position. However, in swinging clamps, the axis of rotation is square to the clamping plate face. Consequently, the swing clamps rotate in the planes of their plates. *Figure 3.19* depicts a simple swinging clamp which is pivoted about the shoulder screw. The workpiece is clamped by the knurled head screw as shown in full lines. For loading and unloading the workpiece, the clamp is swung aside as shown by the chaindotted line.

Turning fixtures use compact and sturdy swinging hook bolt clamps (*Figures 3.20* and *14.6*). The clamp is shaped like a short cantilever

Figure **3.19**
Swinging strap clamp

Clamping
position

Swing aside for
loading/unloading
workpiece

Clamp

Housing

Spring

Figure **3.20**
Swinging hook clamp

with a turned outside diameter which slides in a housing. The hous-
ing is milled with two steps which are at right angles to each other.
These act as stoppers for the working and unloading position of the
clamp. A spring raises the clamp clear above the workpiece as the

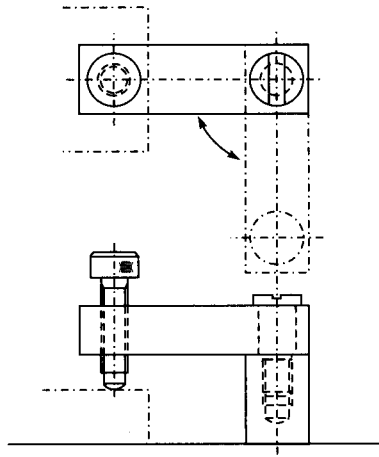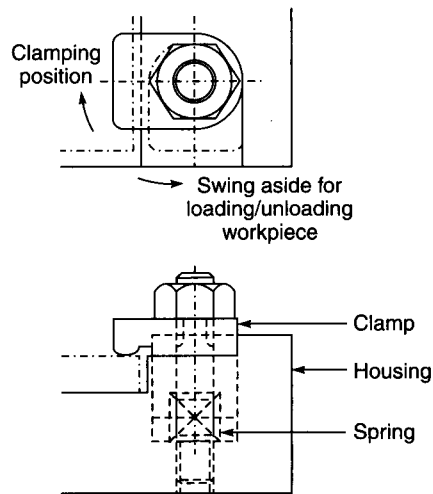clamp is loosened. For securing the workpiece, the clamp is turned through right angle to touch the stopper face in the housing. It holds the clamp in position as it is tightened by the hexagonal nut. The length of the clamping lever should not be more than one-half to three-fourth of the turned portion slided in the housing.

Figure 3.21 a shows a swinging latch with an open slot at one end. The latch is swung around pivot *P* at the other end. Shoulder screw *S* enters the open slot during operation. The workpiece is clamped by a knurled head screw. Collars of shoulder screws *P* and *S* provide reaction backing during clamping. For unloading and replenishment of the workpiece, the clamping screw is loosened slightly and the latch is swung aside to the position shown by the chaindotted line.
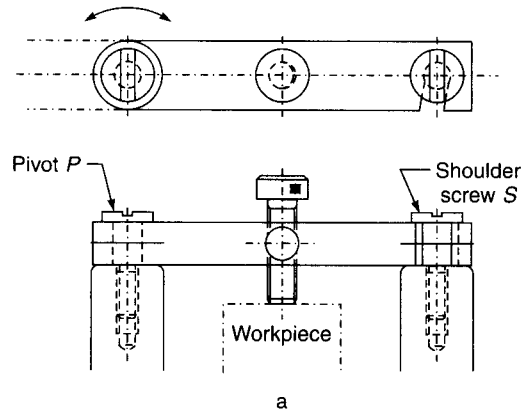
Figure **3.21a**
Swinging latch

Figure 3.21b shows three other types of latches and their methods of operation. The chaindotted lines show the latches in clear loading and unloading position, whereas the full lines show the latches in the clamping position.

Shoulder screws are often used as pivots for thrust pads in jigs and fixtures. The shoulder diameter must be bigger than the thread diameter so that the shoulder face acts as a stop when the screw is tightened. The thickness of the pivoted part should be less than the shoulder length to provide clearance for trouble-free operation of the pivoted joint.

b
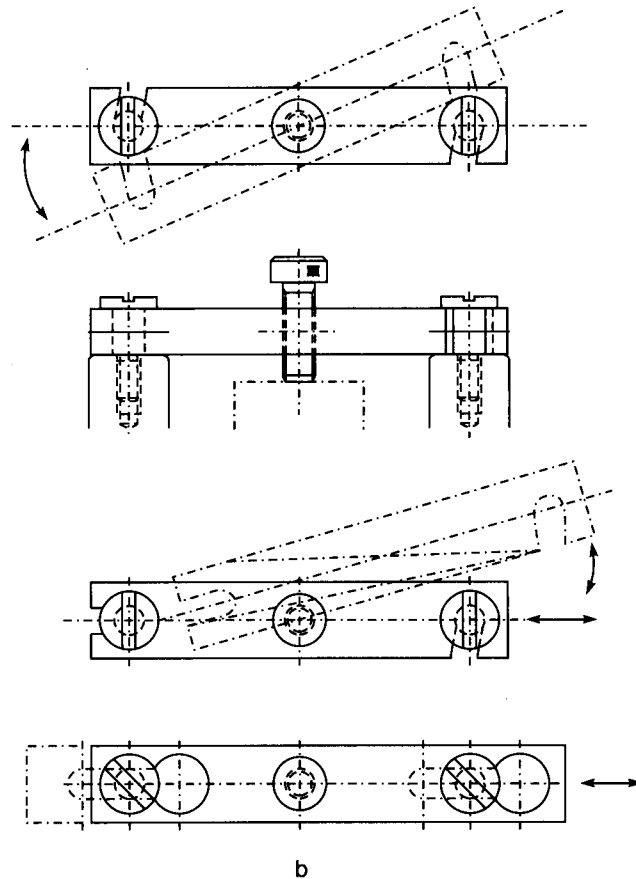
Figure **3.21b**
Various types of latches

C Washer The C washer is a strap clamp with an open slot (*Figure 3.22*) and is simple and quick in operation. The slot permits removal of C washer after a slight loosening of the hexagonal nut. The distance across corners of the hexagonal nut should be less than the bore of the workpiece to permit passage of the nut through the bore during loading and unloading. The loss of washer can be prevented by chaining it to the fixture or pivoting it around a shoulder screw. The pivot shoulder screw makes the C washer captive.

C Washer   Captive C washer
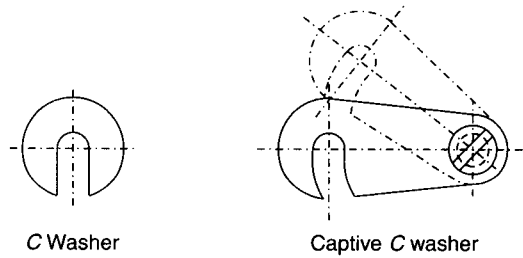
Figure **3.22**
C *Washers*

Quick Action Clamps

The advent of mass production has resulted in the development of several ingenious quick action clamping gadgets. Some of these are described below.

Cams They are popular as quick action clamps. Cams tend to shift their mating faces. There is a risk of the cam clamp getting loose due to vibrations. The co-efficient of friction between the cam and the mating surface must be taken into account while determining the eccentricity of the cam.

Eccentric cams are the easiest to manufacture. Eccentric pivoting of a cylinder converts it to a cam (*Figure 3.23*). The eccentricity of the
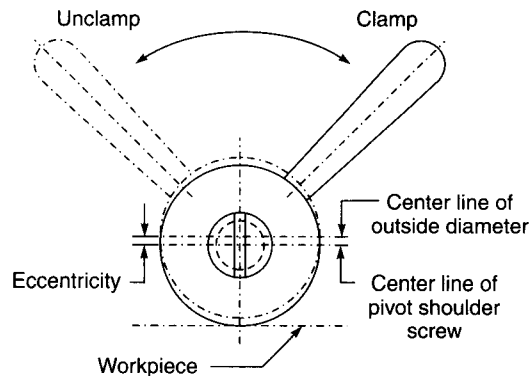
Figure **3.23**
Eccentric cam clamp

cam should be more than 1.5 times the variation in the workpiece. The outside diameter of the eccentric depend upon the co-efficient of friction between the eccentric and the mating surface. If the co-efficient of friction is more than 0.1, the outside diameter should be more than 20 times the eccentricity to prevent loosening due to vibrations.

The eccentric cam can replace the hexagonal nut in a strap clamp (*Figure 3.24*) or a heel pin in a strap clamp (*Figure 3.25a*). A female cylindrical surface can be used as a hook clamp (*Figure 3.26*). *Figure 3.25b* shows a cam operated edge clamp.
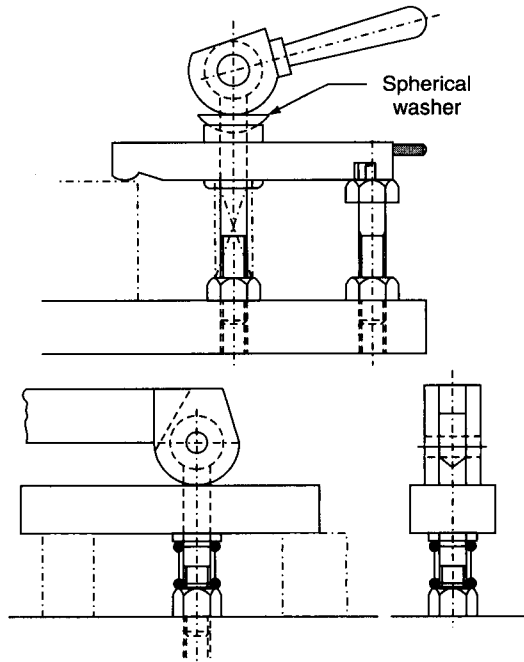
Figure **3.24**
Replacing nut by cam

An eccentric shaft has been used for sandwich-type clamping in *Figure 3.27*. The rotation of the eccentric shaft with a pinned handle raises and lowers the jig plate fixed to the two connecting rods. The jig plate is clamped against the workpiece face during drilling. For loading and unloading the workpiece, the jig plate is raised by rotating the handle in the opposite direction.
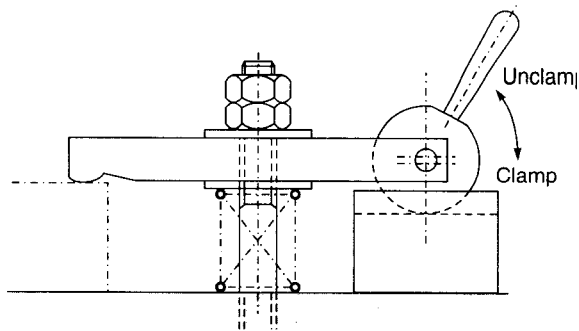
Figure **3.25a**
Replacing heel by cam
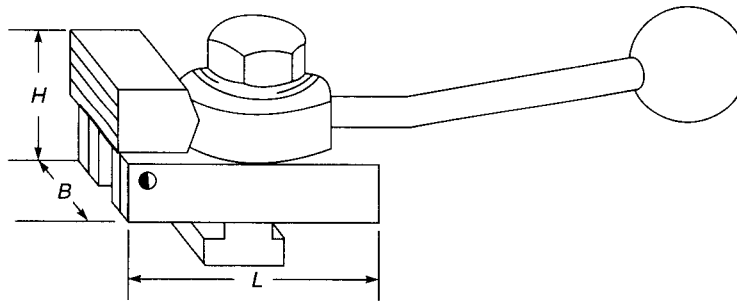
Figure **3.25b**
Cam operated edge clamp

Bayonet Clamp This is a cylindrical cam with a part thread serving as a cam (*Figure 3.28*). The motion of the bayonet is guided by the spherical-ended screw mating in the groove in the bayonet. A part of the bayonet groove is straight. The bayonet can be pulled back straight axially through the straight slot to provide ample clearance during loading and loading of the workpiece. For clamping the workpiece, the bayonet is first pushed forward through the straight groove to close the distance between the workpiece and the bayonet face. At the end of its straight portion, the bayonet is turned clockwise. The inclined groove in the bayonet acts like a part of a thread. The spherical-end screw pushes the rotating bayonet towards the

Unclamp

Clamp

Pivot pin

Pin

Cam face

Figure **3.26**

Hook cam clamp

Jig plate

Connecting rod

Handle

Axis of pivot

Eccentricity

Figure **3.27**

Eccentric shaft clamping

workpiece to clamp it. To prevent the clamp from loosening due to vibrations the thread or helix angle of the inclined groove should be between 1° to 7°.

Helixangle 1° to 7° ⌐   ⌐ Bayonet

Workpiece

Straight axial slot
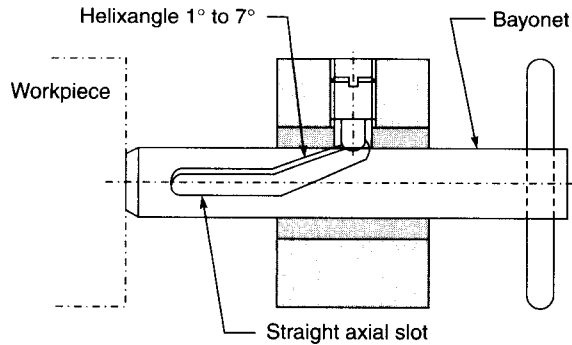
Figure **3.28**
Bayonet clamp

Toggle Clamps These are quick action clamps which can be withdrawn by a considerable distance for loading and unloading of the workpiece. *Figure 3.29* shows two types of toggle clamps. The C frame clamp can b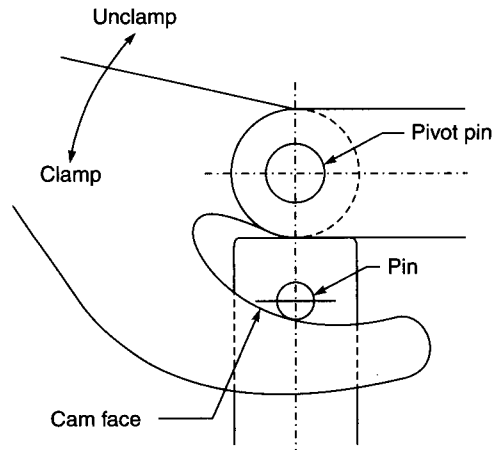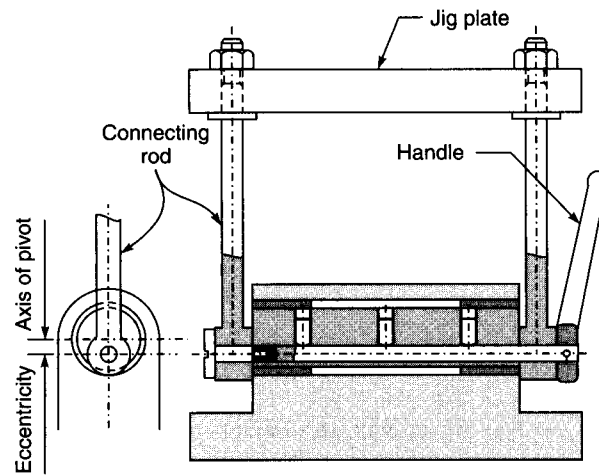e swung to the chaindotted position during loading and unloading. The pusher-type toggle clamp withdraws backwards during unclamping. Toggle clamps are vulnerable to workpiece variations. Most of the toggle clamps are, therefore, provided with adjustable clamping screws.

Quarter-Turn Screw (*Figure 3.30*) It is also called thumb screw and is used to clamp and unclamp hinged jig plates and latches within a quarter-turn. In the unclamped position, the head of the thumb screw can pass through the slot provided in the jig/latch plate. The plate can be swung clear of the thumb screw head to the required position. For clamping the jig/latch plate, the thumb screw is turned through 90° so that its head is at right angles to the slot in the plate. In this position, the thumb screw clamps the plate in the working position. For proper clamping, the mating faces of the thumb screw head must be filed to suit the thickness of the plate.

Quarter-turn screws are suitable for light loads only. For heavy loads, it is better to use a swinging eyebolt and knob–combination (*Figures 3.17* and *5.17*).

Workpiece

C–frame type toggle clamp

Workpiece

Pusher type toggle clamp
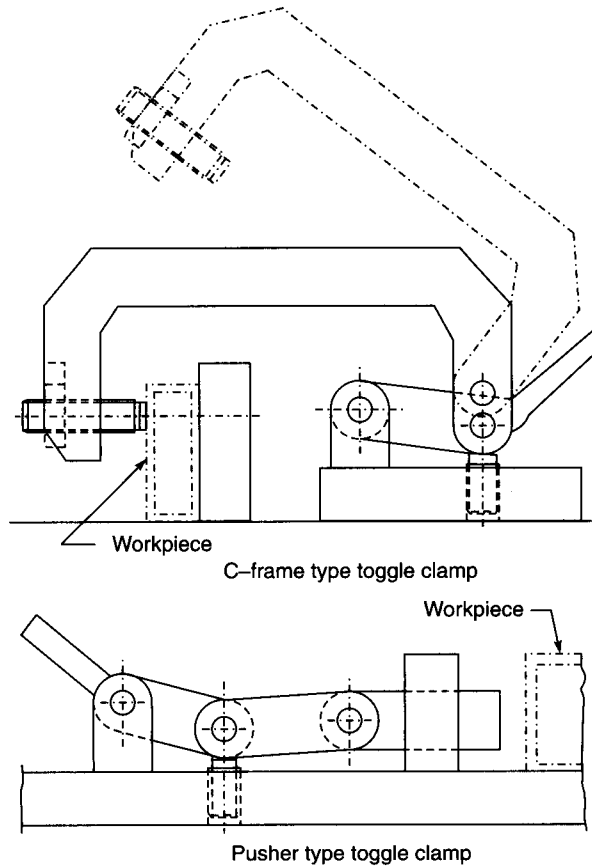
Figure **3.29**
Toggle clamps

Multiple Clamping

Double Clamping Two workpieces with limited variation can be clamped by a single strap clamp (*Figure 3.31*). Swivelable spherical washers between the nut and the clamp allow the clamp to tilt slightly to suit the variation in the two workpieces.
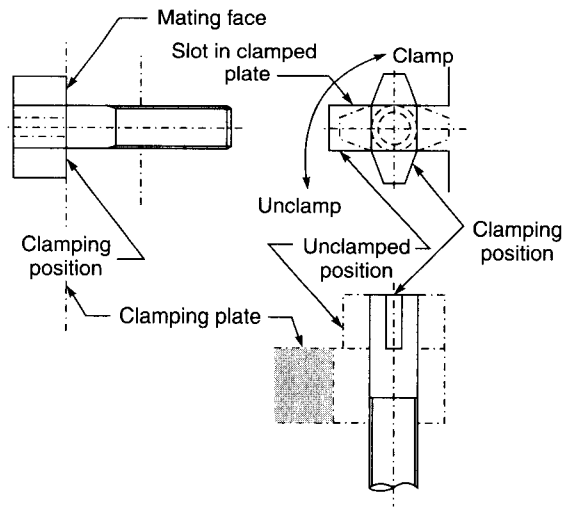
Figure **3.30**
Quarter-turn screw
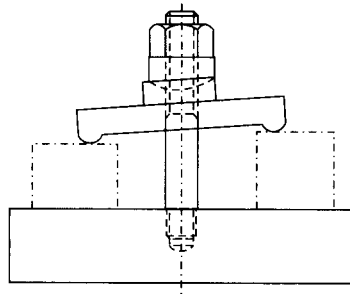
Figure **3.31**
Double clamping

Equalizer This method of compensating variation in two workpiece pivots the clamp around a pin (*Figure 3.4*). The equalizer clamp pivots to suit the variation in the workpieces. The equalizer principle can be extended to clamp more than two workpieces. *Figure 3.5* shows an equalizer arrangement for clamping four workpieces simultaneously with a single clamp.

Naturally only an even number of workpieces can be clamped by an equalizer.

Stacking Often, workpieces can be stacked together and the entire stack can be secured by a single clamp (*Figure 3.32*). Alternatively, workpiece can be sandwiched between locators and the multilayered sandwich can be secured by a single clamp. In the string milling fixtures shown in *Figure 6.12*, round workpieces are sandwiched between V locators. All the workpieces are clamped simulateously by the hexagonal head bolt at one end of the fixture.
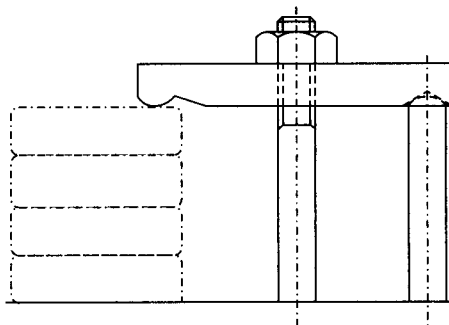
Figure **3.32**
*Stack clamping*

Power Clamping A number of clamps can be operated simultaneously by power clamping. Power clamping can be broadly divided into the following categories:

   1. Fluid power clamping
       (a) Pneumatic clamping
       (b) Hydraulic clamping
   2. Vacuum clamping
   3. Magnetic clamping
   4. Electrostatic clamping

   1. *Fluid Power Clamping* Fluid power clamps are generally actuated by cylinders. *Figure 3.33* shows a clamping fixture
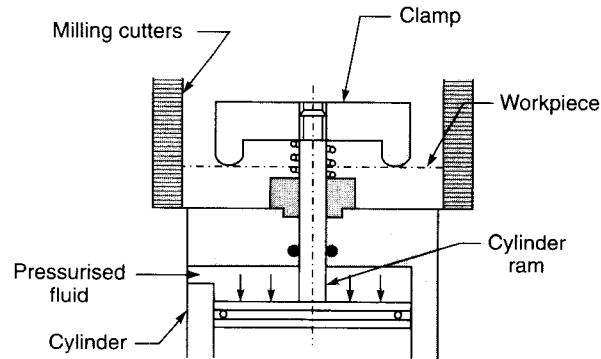
Figure **3.33**
Fluid power clamping

with the clamping nut attached to the cylinder ram. The feeding of pressurized fluid through the port pulls the ram downwards and presses the clamp against the workpiece. For unclamping, the port is connected to an unpressurized discharge line. The force of the spring under the clamp pushes the clamp and ram upwards. In addition to unclamping the workpiece, the rising piston also drives the fluid out of the cylinder through the port.

For connecting the port alternately to pressure and discharge lines for clamping and unclamping, it is necessary to use a three-way direction control valve. Lever, pedal or electrical operation of the direction-control valve clamps or unclamps the workpiece.

The operation of a single-direction control valve can actuate a number of clamps through a number of cylinders. The valve simultaneously connects all the cylinders to pressure or discharge line. *Figure 3.34* shows a fixture with four clamps and cylinders which can be actuated by a single valve.

Moreover, the clamping pressures of all the clamps would be equal. The clamping pressure can be varied by regulating the pressure of the fluid. Higher pressure can be used for heavy roughing cut. The pressure can be reduced considerably during light finishing cut.
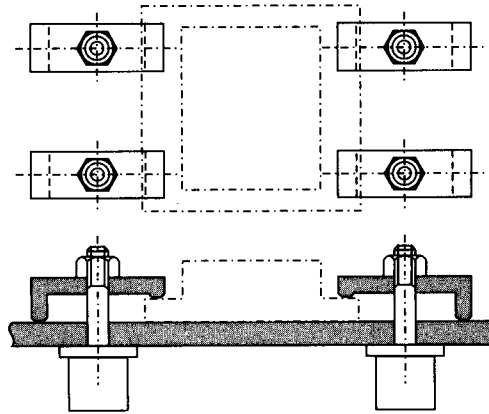
Figure **3.34**
Multiple clamping by fluid power

There is a risk of sudden pressure drop in the event of a power failure. This can be countered by provision of a non-return valve in the pressure supply line. If the power fails, the non-return valve automatically closes the passage between the pressure line and the cylinder. This entraps pressurized fluid between the cylinder piston and the non-return valve. It prevents unclamping due to depressurisation of the supply source.

Some designers prefer to use positive rack and pinion non-return mechanism between the clamp and the cylinder (*Figure 3.35*). The fluid power cylinder is used only to move
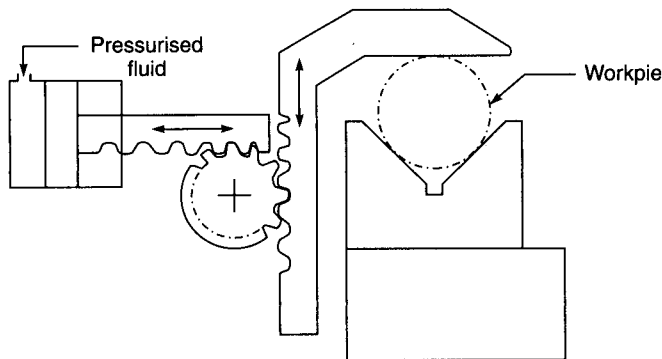
Figure **3.35**
Rack and pinion actuated fluid power clamping

the clamp into the position. The clamp would stay in position even if the cylinder is depressurised, due to a power failure.

Figure 3.36 shows a variety of cylinder mounting styles.

Figure **3.36**

Cylinder mounting styles

(a) **Pneumatic Clamping** In pneumatic clamping compressed air is used as the fluid for power transmission and application. The air is pressurized to 5 to 6 atmospheres (5 to 6 kg/cm2) to energize it. Depressurised exhaust is discharged directly into the atmosphere through direction-control valve. Generally, a large centralized compressor supplies pressurized air to the entire shop—all the pneumatic drives and fixtures in the work place.
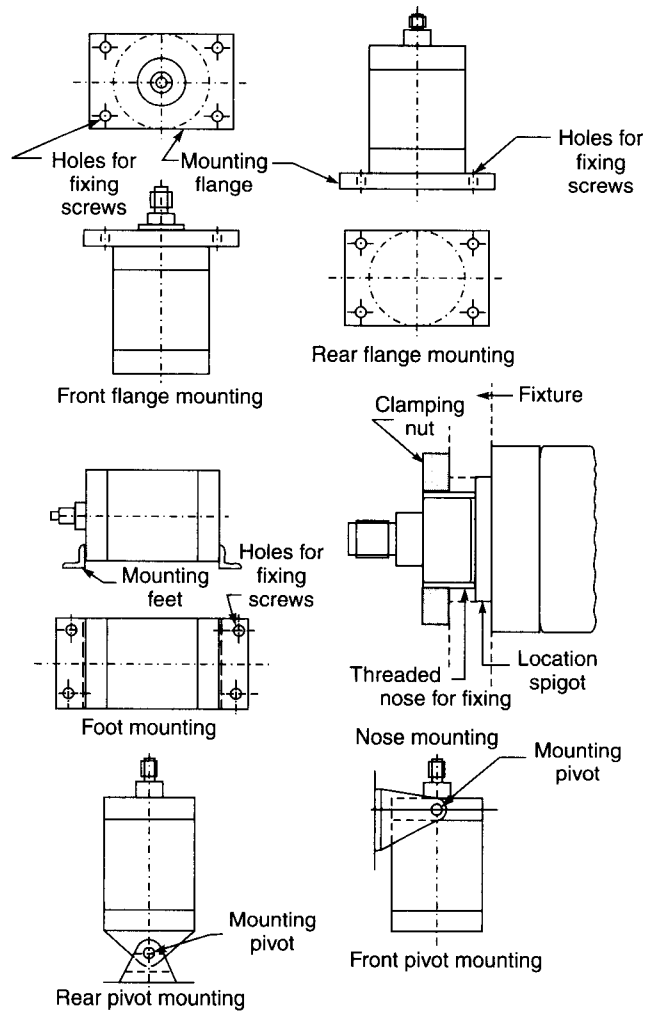
Although very rapid in operation, air-operated devices are vulnerable to variations in the load they move. If the load resistance increases, the speed of the pneumatic device drops and vice versa. Consequently, pneumatic devices are unsuitable for applications in which speed variations are unacceptable. Moreover, due to ageing, joints of old distribution pipes start leaking. This causes a drop in the pressure and wastage of energy. In humid climates, moisture in the air causes rusting of pneumatic cylinders and valves. This can be minimized by filtering out the moisture in the air before it enters the pneumatic fixture. It is necessary to use a lubricator also because it impregnates the air with oil mist which is carried into the cylinders and valves to lubricate them. If it is necessary to vary the system pressure, a pressure regulator is also used.

(b) **Hydraulic Clamping** Unlike air, hydraulic oils are almost incompressible. Consequently, variation in load does not cause much speed variation in hydraulic systems. It can be minimized further to almost negligible by using pressure compensated flow control valve. The operating pressure of a hydraulic system ranges from 7 to 250 atmospheres. High pressure permits use of small compact cylinders to develop high force. However, hydraulic cylinders are slow in operation in comparison with pneumatic actuators. Oil is recirculated in the system through a reservoir. Generally, every machine or fixture would have its own individual hydraulic reservoir and power unit. Large centralized power units are rarely used. The hydraulic operation of a mechanism generally requires substantial investment for hydraulic power pack and cylinders.

2. *Vacuum Clamping* This is particularly convenient for securing thin flat sheets which are vulnerable to distortion under heavy clamping force. Vacuum clamping provides light clamping. The holding face is provided with 0.025 mm deep grooves which serve as vacuum ducts. The clamping face is circumscribed by a rubber seal groove all around. The seal in the groove segregates the clamping vacuum area from the space outside the seal. The vacuum pressure is usually limited to 1 kg/cm². *Figure 3.37* shows a vacuum-holding fixture, distribution grooves and rubber seal.
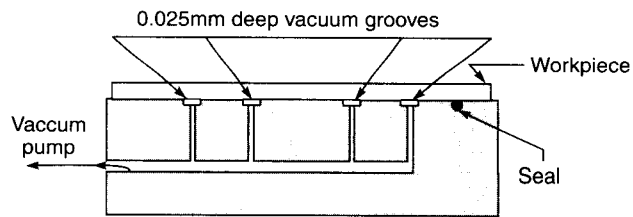
Figure **3.37**
Vacuum clamping

3. *Magnetic Clamping* Magnetic clamping force can be developed by permanent magnets and electromagnets.

(a) *Permanent magnets* They are mounted on a sliding member which can be moved under a non magnetic material on a table to block magnetic flux. This releases the workpiece. For clamping the workpiece, permanent magnets are moved under the magnetic part of the table. This allows the magnetic flux to pass through the workpiece and hold it magnetically. The permanent magnets are slid in the clamping and unclamping positions by a lever.

Generally, the magnetic table area is divided into alternative strips of magnetic and nonmagnetic material. The non magnetic strips block the path of a part of the magnetic flux and force the flux to pass through the workpiece to clamp it magnetically (*Figure 3.38*). Thus, the nonmagnetic strips act as flux dams or barriers. In permanent magnet tables, the mag-

nets are slid below the nonmagnetic strips to completely block the magnetic flux during unclamping.

Work

Non-magnetic flux dam

a

Work

b

Locator

Keeper plate
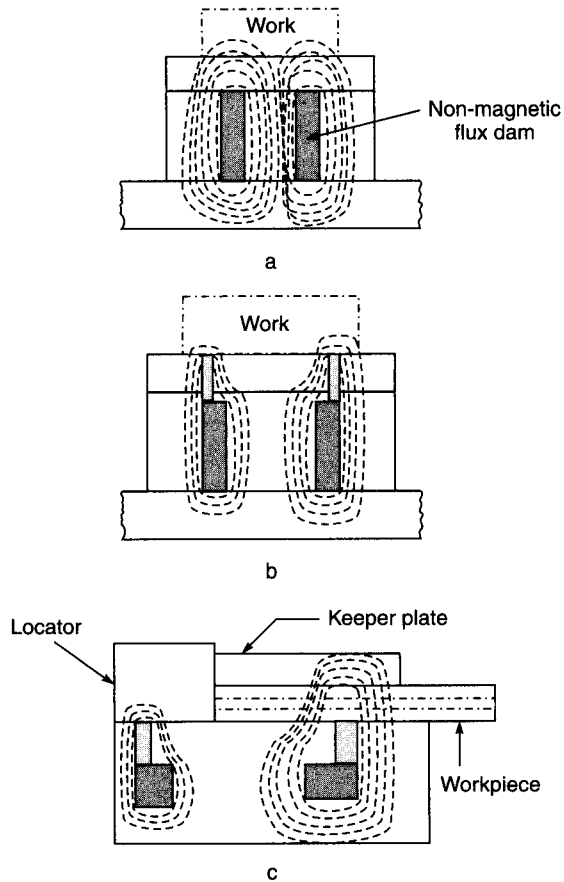
Workpiece

c

Figure **3.38**
Magnetic clamping

(b) *Electromagnetic Clamping* Electromagnetic tables use sole-noid coils as temporary magnets. When DC current is passed through the solenoid coil, it acts like a magnet. The coils and the table is demagnetized on switching off the current and the

workpiece is released. The magnetic clamping force can be varied by varying the current passing through the solenoid coil.

Magnetic clamping leaves some residual magnetism in the workpieces. This can be removed by demagnetizing the workpiece.

4. *Electrostatic Clamping* In this method, the workpiece is charged with static electricity with polarity opposite to the polarity on the chuck face. The opposite attracting polarities of the workpiece and the chuck face develop the clamping force. The workpiece and the chuck are separated by insulating dielectric fluid. The clamping force can be varied by varying the static electrical charge. Even non-conducting materials can be coated with a thin metallic layer and secured by electrostatic clamping. The workpieces must be clean and dry for good electrostatic clamping.

Nonconventional Clamping

Adhesive Clamping Flat-surfaced workpieces subjected to light loads can be stuck to workholders by a thin film of compatible adhesive. However, adhesives require some curing time for hardening. Furthermore, after completion of the operation, the workpiece has to be cleaned and the adhesive removed which is a time-consuming operation. Consequently, adhesive clamping is used only when no other alternatives are available. Even then it can be used only for light loads.

Fusion Clamping In this, the workpieces are jacketed by a cast of low melting point bismuth alloy which is melted and poured around the workpiece. On cooling and solidification, the alloy secures the workpiece firmly. Complicated shape can be secured well by this method.

The alloy casting can be cut into two valves and machined to attach them to chuck or vice jaws. The jaws can be used for repeated clamping of the workpieces. Fusion clamping is, sometimes, the only method of clamping possible in odd-shaped difficult workpieces.

Compensating
Differential Clamps ━━━━━━━

Differential clamps adjust their position themselves to suit the work-piece (*Figure 3.39*). As a result, the clamps do not subject the work-piece to bending or any other distortion. They clamp the workpiece without shifting its position. The lever jaws are closed or opened by
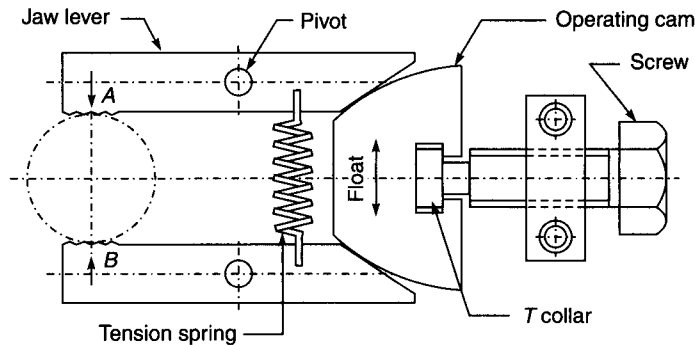

Figure **3.39**
Differential clamp

turning a screw which engages in T slot in the operating cam. The slot in the cam is much wider than the T collar of the operating screw. This wide clearance allows the cam to slide towards any of the lever jaws. If jaw A touches the workpiece first the cam slides in the oppo-site direction towards jaw B till B also touches the workpiece. With both the jaws touching the workpiece, further tightening of the operating screw forces the jaws against the workpiece and clamps it firmly. Differential clamps are very convenient for securing a work-piece without shifting or distorting it.

Figure 3.40 shows a gripper used for clamping parallel plates. The swivelling clamping pads position automatically to suit the object to be gripped as the clamping screw is turned.
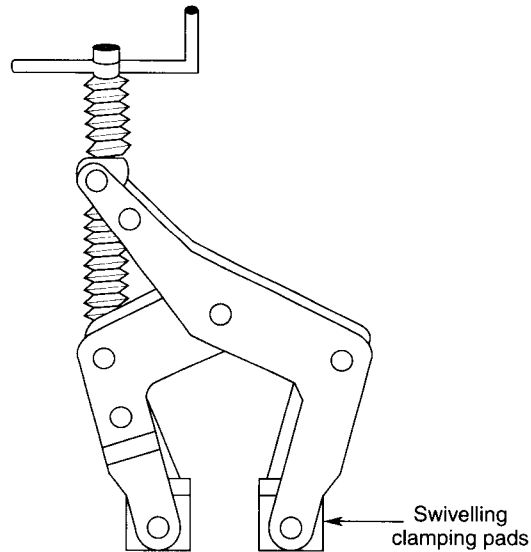
Figure **3.40**
Differential clamp

Swivelling
clamping pads

Summary

Principles of Clamping

1. Position clamp on a strong supported part of the workpiece, clear of the workpiece loading/unloading and cutting tool paths.

2. Clamp strength should be adequate to withstand operational forces without damaging the workpiece.

3. Quick operation without spanner (knobs, levers). Pneumatic/hydraulic operation for simultaneous actuation of numerous clamps.

4. Compensation for variation in the workpiece through radii at clamping point and on the heel pin, use of spherical washers, and equalisers (in multiple clamping).

Clamps Types

1. Screw clamps with/without floating pad.

2. Plate clamps: slotted, swinging, edge clamps, pivoted two-way clamps, hinged clamps, hook clamps, latches, C washers.

3. Quick action clamps: Cam clamps, bayonet clamps, quarter-turn screw, toggle clamps.

4. Multiple clamping: double clamping, stacking workpieces, power clamping with pneumatic/hydraulic actuation, magnetic clamping.

5. Non conventional clamping using adhesives, fusion.
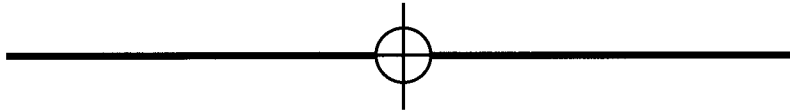
Indexing Devices

I ndexing is a process of quick, accurate location of a workpiece or fixture in a number of specific positions. Indexing involves periodic linear or rotary movement of the indexed part to the next position. An indexing plunger locates the indexed part precisely in each position.

Indexing

Linear Indexing

When a number of holes with the same size and pitch are to be drilled in a workpiece (*Figure 4.1*), the cost of the jig can be reduced greatly by resorting to linear indexing. *Figure 4.2* depicts an indexing jig for a workpiece. The indexing pin is first inserted into hole A and used as a stopper for drilling the first hole through the drill bushing. After drilling, the pin is removed from hole A and the workpiece
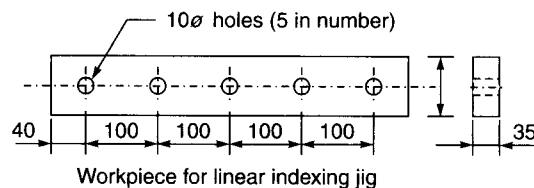
Workpiece for linear indexing jig

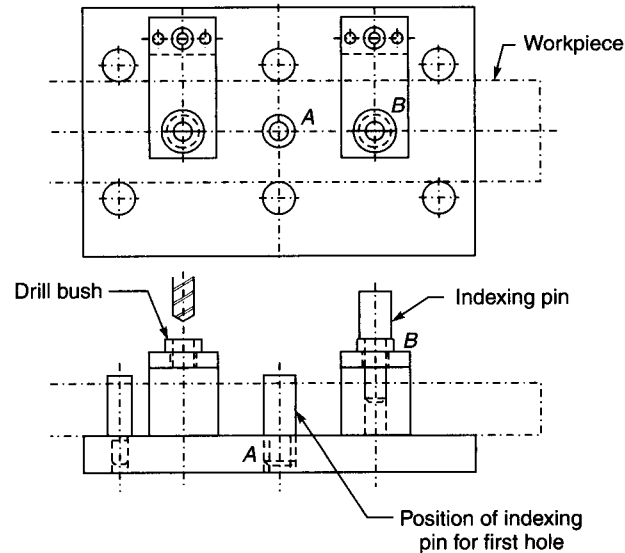Figure **4.1**

Workpiece for linear indexing drill jig

Figure **4.2**
Linear indexing drill jig

is moved towards the right till the center line of the drilled hole coincides with the center line of bushing B. The indexing pin is inserted into the drilled hole in the workpiece through bushing B. The workpiece is, thus, indexed linearly to drill the next hole at 100 mm distance (pitch) from the hole drilled earlier. After drilling the second hole, the indexing pin is removed from the workpiece and the workpiece is moved further to the right till the hole drilled later coincides with the axis of the indexing pin in bushing B. The indexing pin is inserted through the workpiece drilled hole later to hold it in position for drilling the next hole. The procedure can be repeated to drill any number of holes at the given 100 mm pitch in similar workpieces. Thus, if there are 20 holes in the workpiece, we can eliminate 18 drill bushings by using linear indexing arrangement.

A similar arrangement can be used for milling slots with equal size and pitch in a workpiece as shown in *Figure 4.3*. In both instances, the indexing plunger is located on the previously machined part of the workpiece. The part must be unclamped for indexing and reclamped before the operation commences.
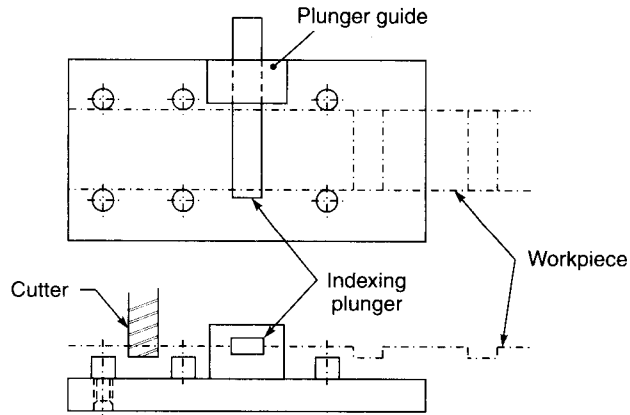
Figure **4.3**
Linear indexing milling fixture

Rotary Indexing

Rotary indexing facilitates accurate positioning of a part around its axis. It can be used conveniently for drilling equi-spaced holes in round workpieces (*Figure 4.4*).

After drilling the first hole through bushing A the workpiece is unclamped and rotated clockwise to align the drilled hole with the axis of the indexing pin. The indexing pin is inserted in the drilled hole to index the workpiece for drilling the next hole. The workpiece is clamped again before drilling the next hole. Thus, rotary indexing can be used to drill any number of equi-spaced holes with only two guide bushings.

Indexing Plate

For more precise indexing, the workpiece is located and clamped on an accurate indexing plate which moves alongwith the workpiece (*Figure 4.5*). The indexing plate is provided with hardened bushings or slots to minimize wear caused by repeated operation of indexing arrangement in mass manufacture.
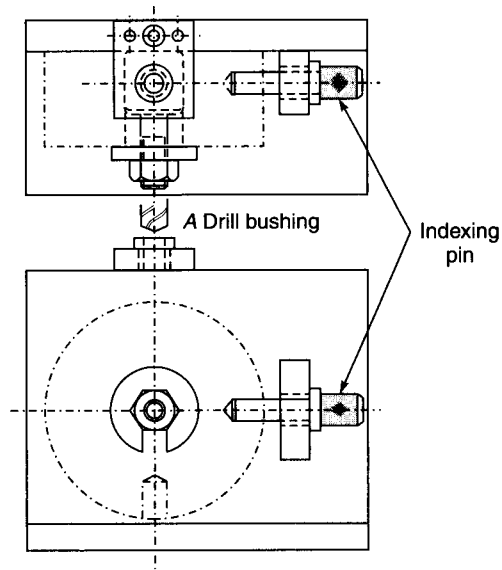
A Drill bushing

Indexing pin

Figure **4.4**
Rotary indexing drill jig

The indexing plate can be rotated about the central pivot and clamped in position with a hand knob. The pivoted indexing lever engages in accurately machined slots of hardened indexing plate to position the workpiece precisely.

The slots can be shaped angularly to prevent inaccuracies resulting from wear. Similarly, a round bushing and indexing pin can be tapered to counter the effect of wear (*Figure 4.6*).

Instead of an indexing pin and bushing, we can use a ball and conical dimple arrangement for indexing (*Figure 4.7*). The ball is pushed against the conical dimple by a spring. When the indexing plate is rotated with some force, the ball is pressed downwards against the spring and remains there till its center aligns with the next conical dimple in the indexing plate. As soon as the dimple aligns with the ball, the spring pushes the ball into the dimple and the indexing plate is indexed. For indexing the next position, the indexing plate must again be rotated with some force to drive the ball out of the dimple against the spring. After indexing, the indexing plate must
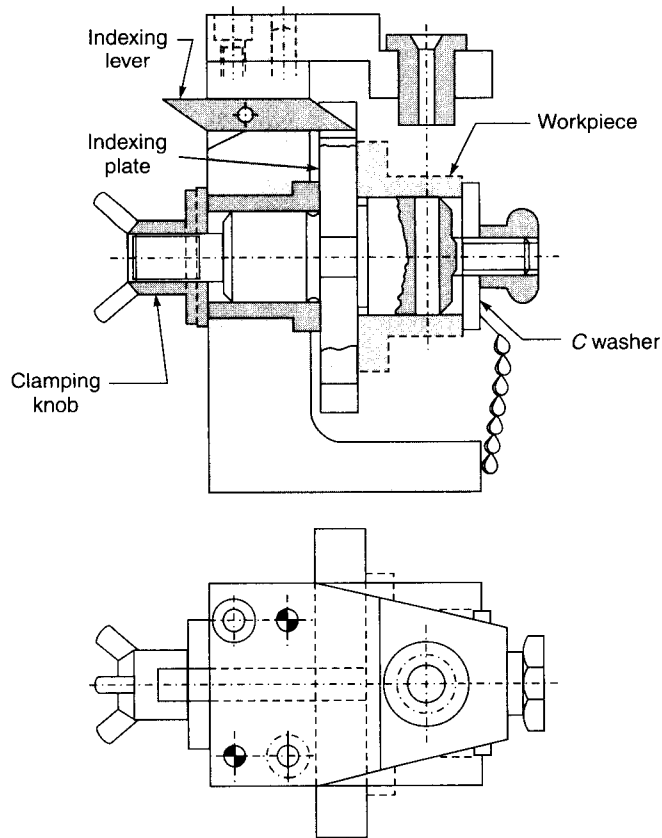
Figure **4.5**
Drill jig with indexing plate

be clamped in position for the operation. It must be unclamped during indexing.

Rotary Indexing Tables

In rotary tables rack and pinion are often used for withdrawal of the indexing pin (*Figure* 4.8). A pinion engages with the gear teeth of a rack in the indexing pin. The spring below the indexing pin pushes the indexing pin into the bushing in the indexing plate.
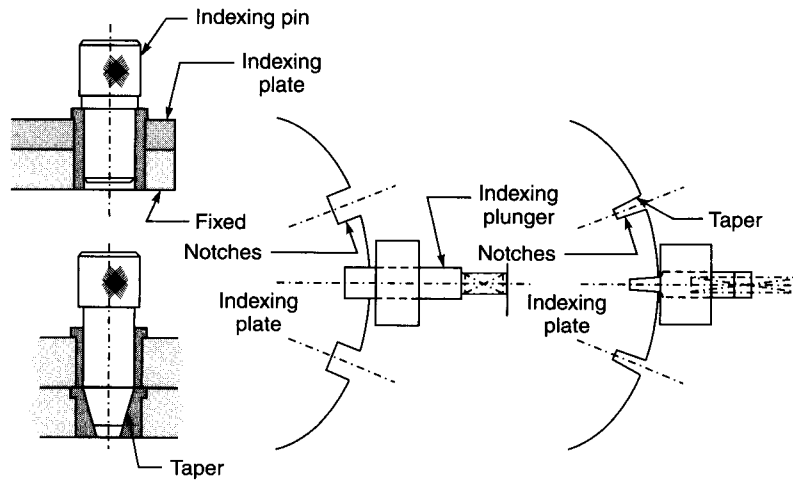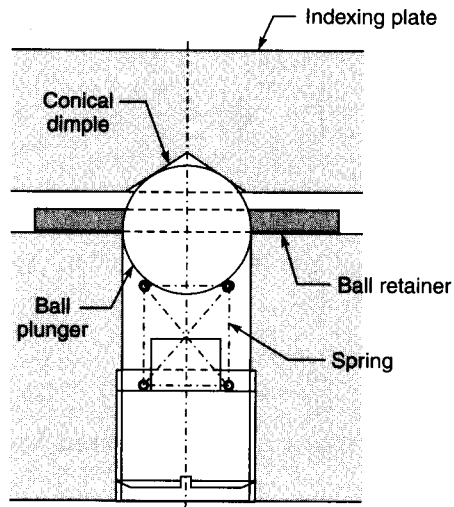
Figure **4.6**
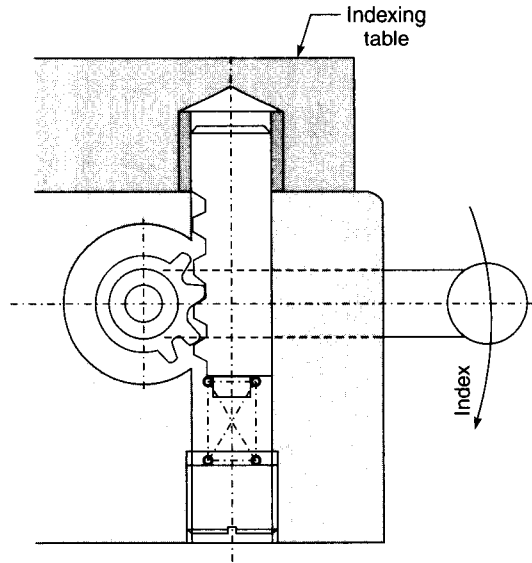*Indexing plungers*

Figure **4.7**
Indexing by a ball

Figure **4.8**
Indexing in rotary tables

For indexing, the handle attached to the pinion is turned clockwise. This rotates the pinion clockwise and the gear teeth push the indexing pin downwards to withdraw it from the bushing in the indexing plate. The indexing table can now be rotated for indexing. After rotation, the handle can be released. When the center to the next bushing in the indexing table aligns with the center of the indexing pin, the spring automatically pushes the indexing pin into the bushing and the table is indexed.

Figure 4.9 shows a standard indexing table with 12 indexing positions. *Figure 4.10* shows another standard indexing (dividing) fixture with a built-in-collet clamping arrangement for round parts. This fixture can be used conveniently for milling flats, squares and hexagons on round workpiece of various sizes. For different diameters of round workpieces, different collets are required. If the collet clamping arrangement is replaced by a self-centering chuck (Chapter 7), it can clamp a wide range of round workpieces eliminating the need for a number of collets of different diameters.
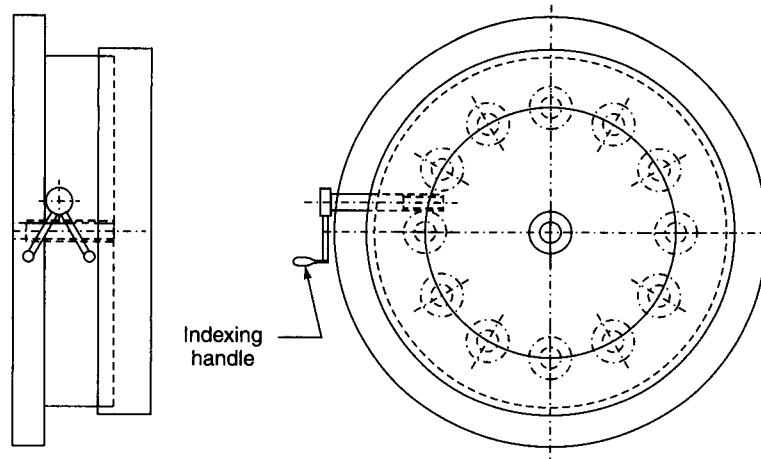
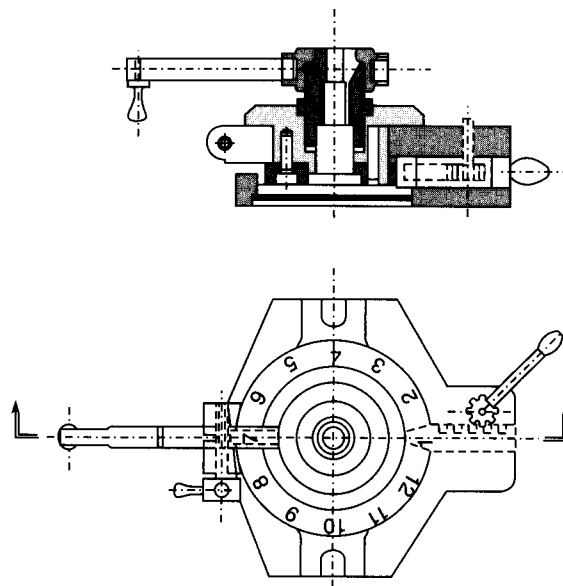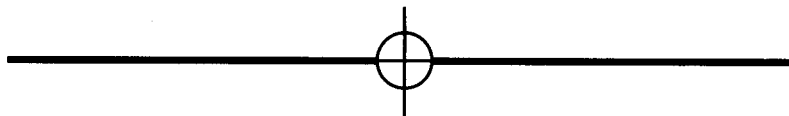Indexing
handle

Figure **4.9**
Standard indexing table

Figure **4.10**
Standard dividing fixture

Drill Jigs

Locating and clamping elements in drill jigs are subjected to high torque in the direction perpendicular to the axis of the cutting tool. The jig and the workpiece are also subjected to thrust in the direction of the feed of the tool.

The following are the requirements of a good drill jig:

1. Quick and accurate location of the workpiece.

2. Easy loading and unloading of the workpiece and prevention of wrong loading.

3. Prevention of bending or movement of the workpiece during drilling.

4. Ample chip clearance with facilities for metal filings removal and cleaning.

5. Light weight to minimise operator fatigue, due to repeated handling.

6. Prevention of loss of loose parts by chaining them to the jig body.

7. Clearance for overshoot of the drill.

Drill Bushings

Drill jigs use bushings to guide drills, reamers and other cutting tools to the workpiece. Bushings are made of water hardening carbon steel with 0.85–1% carbon and 0.5–0.9% manganese, and is hardened to R_C 60–64 to minimise wear due to contact with hard, rotating tools.

Bushings are generally finished by grinding the inside and outside diameters within 0.001 mm concentricity. The inside diameter is ground precision running fit (*F7*) with the drill/reamer which needs to be guided whereas the outside diameter is made press fit (*p6*), precision location fit (*h6*) or precision running fit (*f6*) depending upon the function and application of the bushing.

Press Fit Bushings

Press fit bushings are the most common type of bushings and are pressed interference fit in the bushing plates also referred to as jig plates. These bushings are used in batch production where the bushings often outlast the life of the jig.

Headed bushings (*Figure 5.1*) are preferable to headless bushings because the collar provides positive stop against the jig plate. Moreover, it is found that the chances of the bushing getting loose in the jig plate and sliding axially with the drill are lesser in the collared bushings. However, when the spacing of the bushings is close or the top surface of the jig plate is required to be free from the projecting collars, headless bushings are used (*Figure 5.2*).

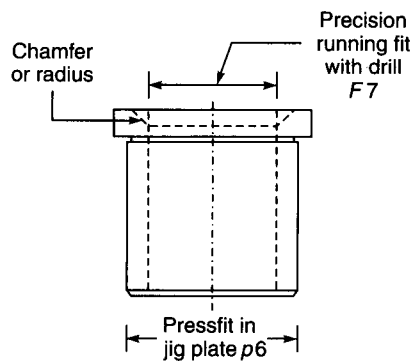Press fit bushings are also used as liners for renewable and slip bushings.

Figure **5.1**
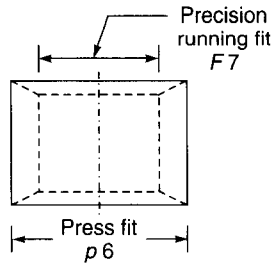*Headed collared press fit bushing*

Precision
running fit
F 7

Press fit
p 6

Figure **5.2**
Headless press fit bushing

Renewable Bushings

For continuous or large batch production , the inside diameter of
the bushing is subjected to severe wear due to continuous contact
with hard cutting tool. The guide bushings require periodic replace-
ment. The replacement is simplified by making the outside diame-
ter precision location fit (*h*6). The bushings can then be assembled
manually without any press. The use of liner in the jig plate pro-
vides hardened wear resistant mating surface to the renewable
bushing (*Figure 5.3*). The renewable bushing must be prevented
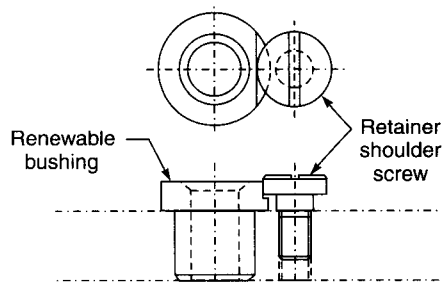
Renewable
bushing

Retainer
shoulder
screw

Figure **5.3**
Renewable bushing

from rotating and moving axially with the cutting tool. This is
accomplished by provision of a flat on the collar. The flat arrests
with the collar of the retainer shoulder screw to prevent rotation.

The bushing flange below the collar of the shoulder screw prevents the bushing from getting lifted with the cutting tool.

Slip Bushings

When a hole in the workpiece requires two operations such as drilling and reaming, it is necessary to use two different guide bushings for the different tools. The hole is first drilled using a bushing having a bore suitable for the drill. After drilling, the drill bushing is removed and a reaming bushing is used to guide the reamer. In mass production, the changeover of these bushings should be effected quickly. This is accomplished by provision of slip bushings. There are a number of different types of slip bushings in use. In the most common type, the bushing is provided with a flat on the head similar to the renewable bushing and a circular cutout in the flange to facilitate quick assembly and removal (_Figure 5.4_).
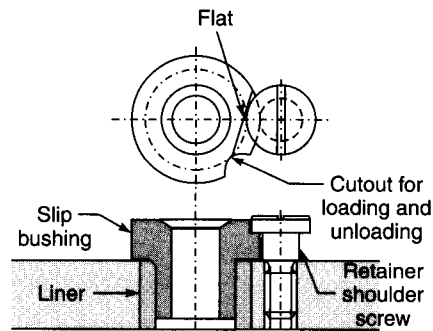
Figure **5.4**
Slip bushing

For loading or unloading of the slip bushing, the cutout in the flange is aligned with the collar of the retainer shoulder screw. The bushing can be moved freely axially in this position. For assembly, the slip bushing is aligned with the shoulder screw and inserted into a liner. When the bushing collar touches the jig plate, the slip bushing is rotated clockwise to arrest the flat on the bushing flange against the collar of the retainer shoulder screw. This prevents rota-

tion of the bushing during drilling. The bushing flange below the collar of the shoulder screw prevents the slip bushing from rising up with the cutting tool. For removal, the slip bushing is rotated anti-clockwise to align the bushing cutout with the shoulder screw collar. Then the bushing can be lifted axially out of the liner. In a variation of the slip bushing, the straight flat is replaced by a circular step (*Figure 5.5*).
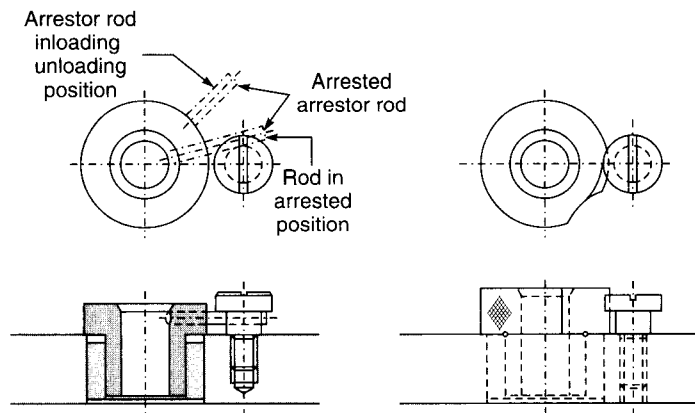

Figure **5.5**
Other types of slip bushings

In another design, the head of the slip bushing is fitted with a rod as shown in *Figure 5.5*. For assembly, the rod is turned to arrest it against the shoulder of the retaining screw to prevent rotation. In this position, the collar of the shoulder screw prevents the rod and the bushing from being lifted with the cutting tool. For removal, the bushing is rotated anti-clockwise to turn the rod clear of the collar of the shoulder screw. Then, it can be removed axially from the liner.

Threaded Bushings

The bushings used for clamping the workpiece are threaded on the outside. There should be another plain guiding diameter for accurate location of the bushing (*Figure 5.6*). The collar of the liner bushing is usually placed on the opposite side to take the axial thrust of the

screw. The liner bushing should be prevented from rotation by a grub screw or a flat on the collar (*Figure 5.6*). The flat mates with a machined step on the jig plate.

Figure **5.6**
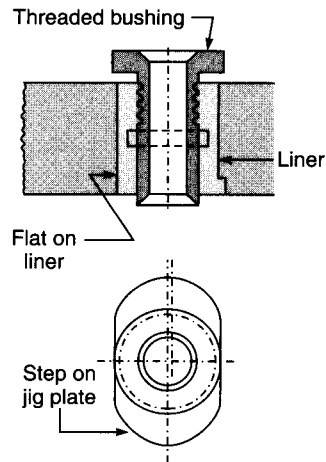*Threaded bushing*

Alternatively, an unthreaded bushing can be clamped with a spring-loaded lever (*Figure 5.7*). The pressure of the spring holds the bushing pressed against the workpiece boss. For unclamping, the lever is pressed down to compress the spring. This raises the pivoted bushing up, thus, releasing the hold on the workpiece.
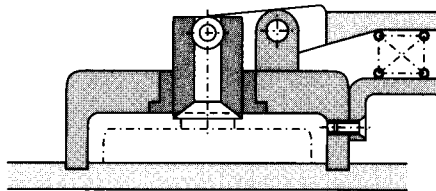

Figure **5.7**
Spring-loaded clamping of threaded bushing

Special Bushings

Some workpieces or operations require unusual types of bushings. In many instances, these involve simple modifications in the standard bushings.

A twist drill tends to slide down inclines and curves (*Figure 5.8*). This causes bending and breakage of the drill. The problem can be countered by altering the shape of the drill bushing to provide better support and resistance against bending. This generally involves matching the end of the bushing with the profile of the workpiece (*Figure 5.9*).
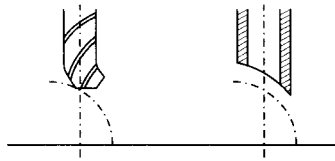
Figure **5.8**
Drill bushing for curved surface

Figure **5.9**
Drill bushing for incline surface

Sometimes, the center of the drilled holes are placed so close that it is just impossible to provide any drill bushings in the jig plate (*Figure 5.10*). The bushings shown by the chaindotted lines in *Figure 5.10* obstruct each other. Consequently, there would be little wall material between the two holes for the bushings. Under such circumstances, a combined plate- type of bushing is used (*Figure 5.11*).

The plate bushing is made of tool steel. A number of bushings can be combined into a single plate bushing. The plate bushing is screwed and dowelled to the jig plate.
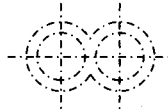
Figure **5.10**
Problems due to close center distance in drilling holes

Figure **5.11**
Plate bushing

Various Types of Jigs

Depending upon their construction and method of operation, drill jigs can be broadly classified as follows:

1. Plate jigs and channel jigs with workpiece pots

2. Angle plate jigs

3. Turn-over jigs

4. Leaf or latch jigs

5. Box jigs

6. Trunnion-type indexing jigs

7. Sandwich and pump jigs

8. Jigs for multi-spindle machines

Plate-type Jigs

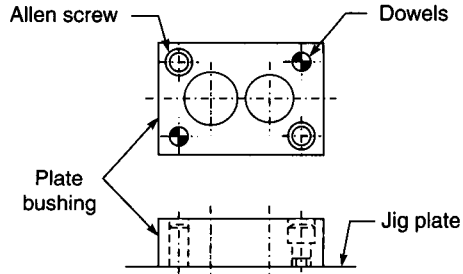Plate-type jigs mainly consist of a single bushing plate with a provision for location and the clamping of workpiece. *Figure 5.12* shows a plate-type of jig for the shown workpiece. The workpiece profile is located by six location pins and clamped by two knurled screws against the location pins. Sometimes, it is economical to make the jigs channel shaped in order to simplify location and clamping
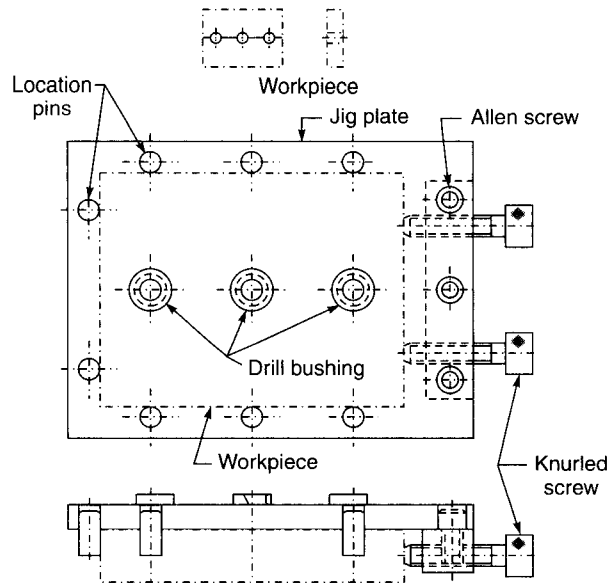
Figure **5.12**
Plate drill jig

(*Figure 5.13*). It can then be called a channel jig. In any drill jig, the workpiece should be supported adequately against bending due to the downward thrust of the drill. Furthermore, there should be enough clearance below the workpiece for overshoot of the drill after passing through the workpiece. This can be achieved by providing a resting pot for the workpiece (*Figure 5.14*). The pot is machined with bigger slots or holes for passage of the drill and disposal of chips. These slots must be aligned with the drill bushings in the jig (bushing) plate. This is accomplished by providing a location

Figure **5.13**
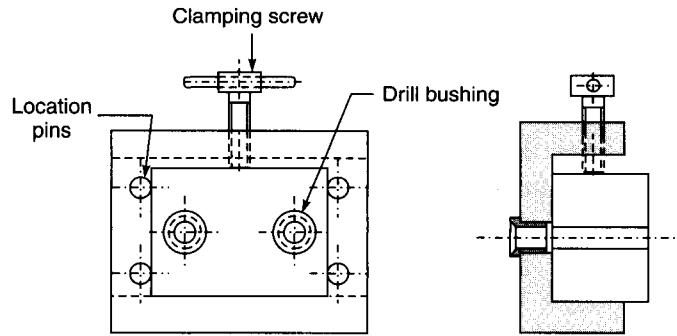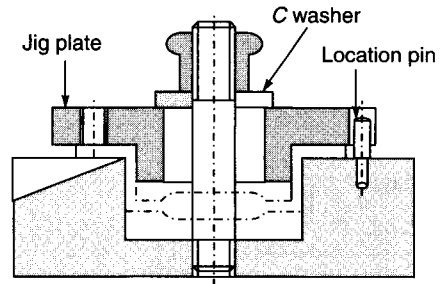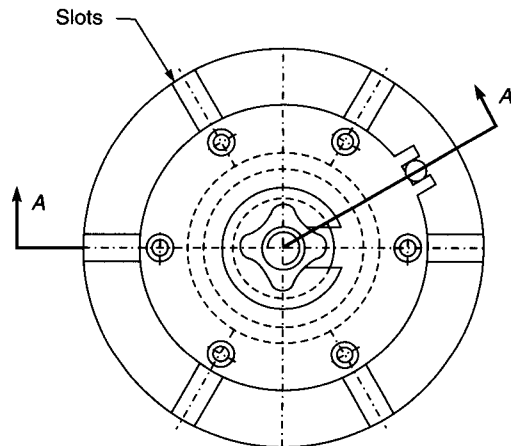*Channel drill jig*

Figure **5.14**
Pot drill jig

pin in the pot and a corresponding slot in the jig plate. As shown in the figure, the pot is also used for anchoring the clamping stud. Moreover, the base of the pot also provides a square resting surface for drilling. The plate jig locates the workpiece with a spigot which engages into the machined bore of the workpiece. The C washer facilitates quick sandwich clamping of the workpiece between the pot and the plate jig.

Angle Plate Jigs

In angle plate jigs, locators are generally fixed to the vertical wall of the angular body (*Figure 5.15*). The workpiece is located by a central locator and a diamond pin for angular position. A C washer is used for quick clamping of the workpiece. The central locator must have a groove for passage of the drill after breaking through the workpiece.
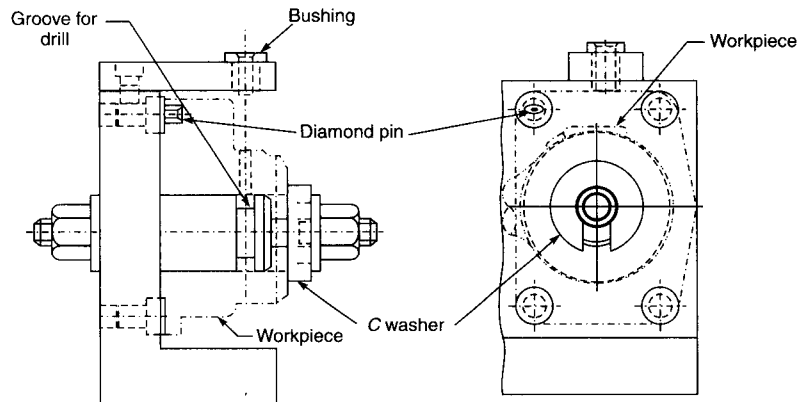
Figure **5.15**
Angle plate jig

Turn-over or Table-type Jigs

Workpieces having no suitable resting surface for drilling can be drilled conveniently with turn-over jigs. Turn-over jigs are plate jigs with jig feet. The feet provide square resting surface to the jig dur-

ing drilling. The resting diameter of the jig feet should be bigger than the T slots of machine table to prevent the feet from falling into the slots.

Figure 5.16 depicts a turn-over jig for drilling 13 mm holes in the depicted workpiece. It is located on a 100 ø machined bore for concentricity and three location pins for angular position. A C washer and a handknob provide quick clamping. The height of the feet must be longer than the clamping stud to provide proper resting face during drilling.

Figure **5.16**
TurnOover or table jig

All turn-over jigs must be turned over for the loading and unloading the workpiece. After loading the workpiece, the jig must be tu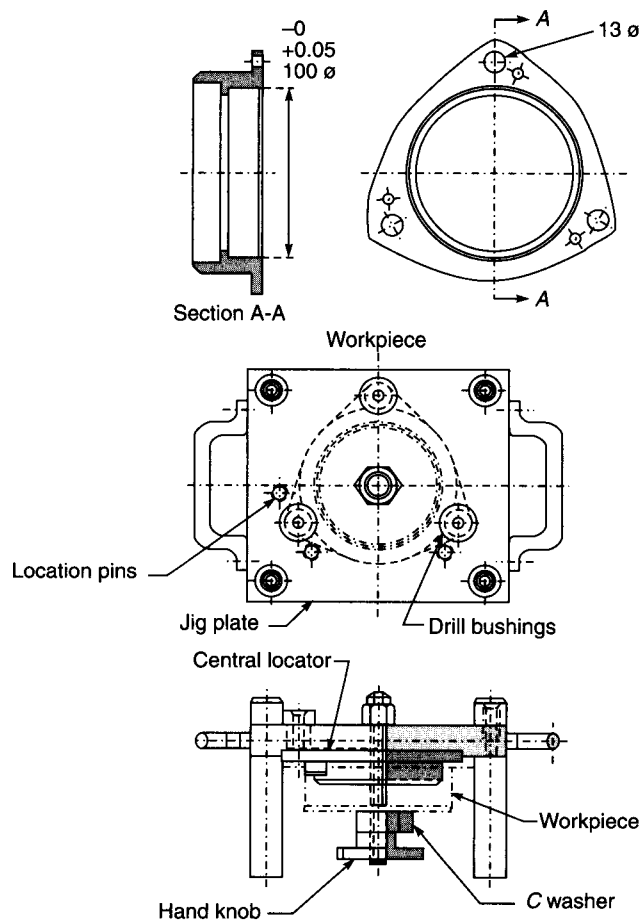rned over again to rest on the jig feet for drilling as shown in the figure. Turn-over jigs are very convenient for drilling flanged workpieces which must be drilled from the flange end.

Leaf of Latch Jigs

These generally have a hinged jig (bushing) plate (*Figure 5.17*). The jig plate can be swung aside as shown by the chaindotted lines to provide clear path for loading and unloading the workpiece from the top. The jig plate must have positive resting face to ensure that the axes of bushings are vertical during drilling. The jig plate must be clamped against the resting face by an eyebolt. The open slot in the jig plate and swinging eyebolt facilitate quick clamping and unclamping of the jig plate. The handknob needs to be loosened by only half-a-turn and the eyebolt swung to the position as shown by the chaindotted line, in order to permit swinging of the jig plate aside for loading and unloading of the workpiece from top.
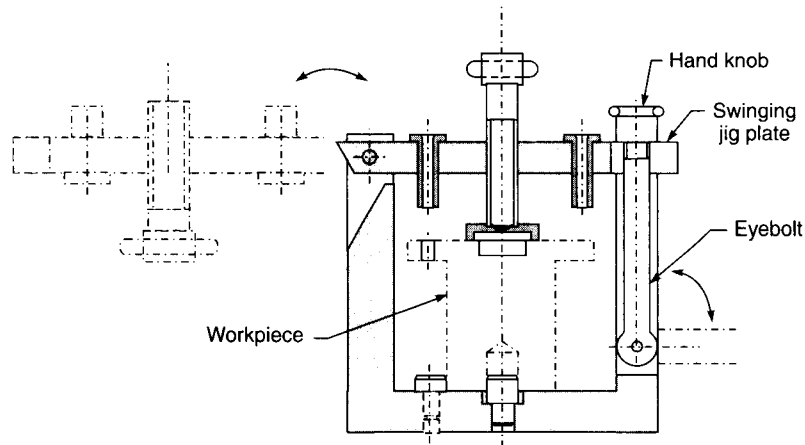
Hand knob

Swinging jig plate

Eyebolt

Workpiece

Figure **5.17**
Leaf or latch jig

Leaf-type jigs are particularly suitable for workpieces having location surfaces and holes to be drilled on opposite sides. As shown in the figure, the jig plate is often used to house the clamping screw.

Box Jigs

Workpieces having holes on a number of sides can be drilled economically with box jigs. The jig body is generally shaped like a box with one side open for loading and unloading the workpiece. The open side is provided with a hinged latch which often houses bushings and clamping screws. The jig is fitted with bushings on various sides and suitable jig feet on the opposite sides.

Figure 5.18 shows a box jig for the workpiece shown in the diagram. The workpiece rests on the machined base of the jig plate. It is located by four profile location pins and an adjustable V block which
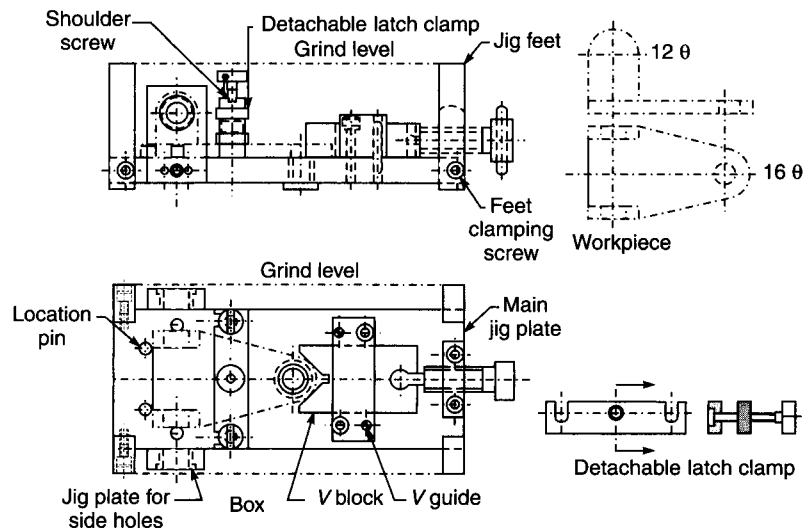

Figure **5.18**
Box jig

centralises the boss and pushes the workpiece against the location pins. The workpiece is clamped by a detachable latch clamp with open slots for two shoulder screws which provide anchorage to the latch during clamping. Jig plate for 12 diameter side holes are fixed to the main jig plate with Allen screw and dowels.

Jig feet are made rectangular to facilitate resting of the jig on (*Figure 5.18*) two square faces. The feet are provided with location slots to accommodate thickness of the main jig plate. The location slot along with the feet clamping screw hold the feet parallel and square to the main jig plate. One side of the rectangular feet provides a square resting surface during drilling of 12 diameter side holes. The ends of the jig feet provide resting surface for drilling a 16 diameter hole in the flange of the workpiece.

Thus, the box jig permits drilling of holes in three sides of the workpiece with a single location and clamping operation. This saves time and increases production. Moreover, box jigs have built-in accuracy. The precision positional relationships between jig bushings in the different planes are passed on to the workpiece. For example, the box jig illustrated in *Figure 5.18* provides positive relationship between the 16 diameter flange hole and 12 diameter side holes. This would be rather difficult to achieve if the 16 diameter flange hole and the 12ø side holes are drilled separately instead of with a single box jig.

Trunnion Jigs

When large, heavy workpieces are to be drilled from a number of sides, the jig is constructed like a box with jig bushings on various sides. Due to the large size and weight of the workpiece and the jig, it is impossible to tumble the jig manually for drilling the holes on the various sides.

To ease this operation, the jig body is provided with pivots at both ends. The pivots are supported with ball bearings in the supporting
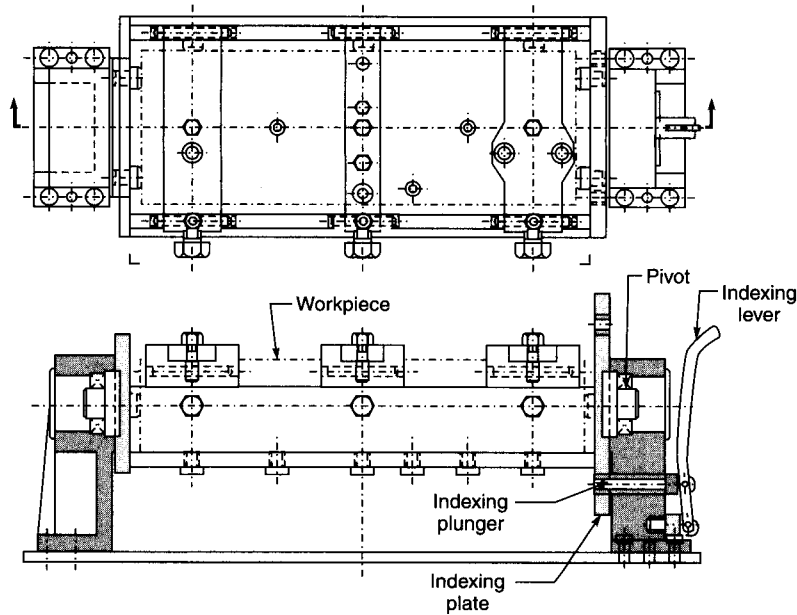
Figure **5.19**
Trunnion jig

brackets at both ends (*Figure 5.19*). This reduces friction and consequently, the force required to turn the jig around the pivots. On one side of the jig is attached an indexing plate with location bushings for indexing. When the indexing plunger is engaged with one of the indexing bushings, the workpiece and jig is held in position for drilling holes on one side. For drilling holes on the other side, the indexing plunger is withdrawn from the bushing and the jig is rotated to drill holes on the other side. When the indexing plunger enters the indexing bushing in the indexing plate, we can be sure that the drill jig is held accurately for drilling holes on one side.

Thus, trunnion facilitates moving and positioning of heavy workpieces and jigs for drilling holes on various sides. The heavy jig and trunnion remain stationary during drilling. The drill machine spindle must be moved to align with the drill bushings in the jig. Consequently, trunnion-type jigs can be used only on moveable spindle machines such as a radial drilling machine.

Sandwich and Pump Jigs

These are plate jigs with guide pillars for alignment of jig plate with the base plate (*Figure 5.20*). The workpiece is located on the base plate by pins. The base is aligned with the jig plate by guide pillars which locate by engagement with guide bushings in the jig plate. Thus, guide pillars position the drill bushings correctly with respect to the workpiece located on the base plate.
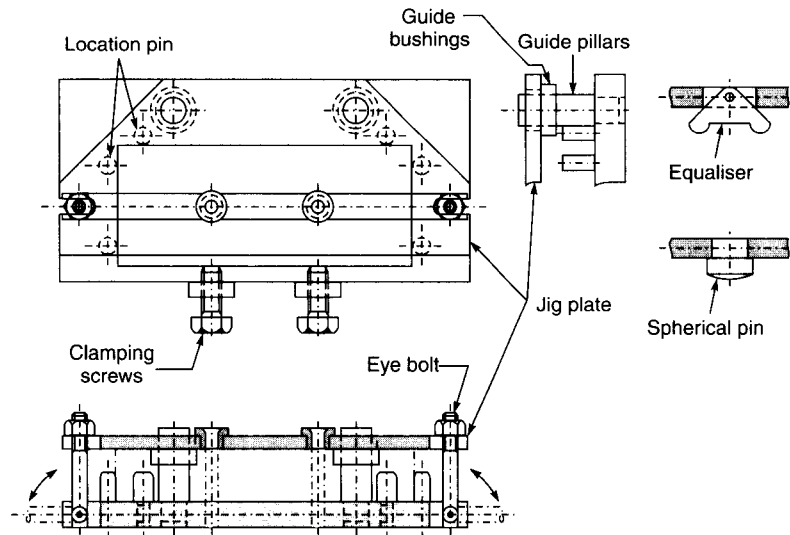

Figure **5.20**
Sandwich jig

Sandwich Jig In sandwich jig, the workpiece is clamped like a sandwich between the base plate and the jig plate. The clamping can be accomplished by two swinging eyebolts and corresponding open clamping slots in the jig plate. The tightening of the hexagonal nuts in the position shown clamps the jig against the workpiece and the base plate.

For unclamping, the hexagonal nuts need to be loosened by only half-a-turn to permit eyebolts swung aside through the open slots in the jig plate (*Figure 5.20*).

The jig plate can now be removed from the pillars and kept aside while the drilled workpiece is removed and a new one is loaded and located on the base plate. After that, the pillar guide bushings in jig plate are aligned with the pillars on the base and the jig plate is slid down on guide pillars to touch the workpiece. The swinging eyebolts are swung vertical through the slots in the jig plate to the position shown. The operator has only to tighten the hexagonal nuts by half-a-turn to sandwich clamp the workpiece between the jig plate and the base plate. Sandwich type of jigs are particularly suitable for workpieces which have parallel machined surface square to the axis of drilling. If the workpiece has got only one machined surface, it should be rested on the base plate. The jig plate should be fitted with a spherical-ended pad or an equaliser clamp to facilitate clamping on the unmachined top surface of the workpiece.

Pump Jigs These are smaller versions of sandwich jigs. Instead of removing the jig plate completely from guide pillars, it is merely raised above to provide passage for loading and unloading of the workpiece (*Figure 5.21*). The guide pillars attached to the jig plate have rack gear teeth on one side. The pinion gear meshing with the
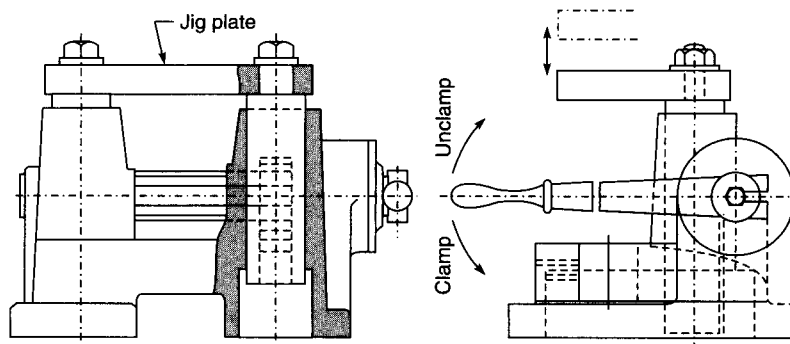
Figure **5.21**
Pump jig

rack can be rotated by a handle to raise or lower the rack pillars and the jig plate attached to them. The jig plate is lowered to touch and clamp the workpiece. After drilling, the jig plate is raised to permit replacement of the drilled workpiece with a new one. Pump jigs are very convenient for drilling workpieces having parallel surfaces such as rolled plates and flats.

Workpieces having only one machined surface can be clamped by fixing a spherical pin in the jig plate (*Figure 5.20*). As they are rather heavy, pump jigs cannot be slid easily on the machine table. Consequently, pump jigs are suitable for drilling only a single hole on a fixed spindle drilling machine. The jig is generally clamped on the machine table. If a radial drilling machine is available, pump jigs can be used for drilling more than one hole as the moving spindle can be brought to each drill bushing. Standardised pump jigs are readily available in the market. These reduce the manufacturing time for a jig substantially. Moreover, one pump jig can be used for a number of workpieces by providing detachable jig plates and base plates for different workpieces.

Jigs for Multi-spindle Machines

Figure 5.22 shows a drill jig for a multi-spindle drill head. The design is similar to the sandwich jig in some respects. The base plate is clamped firmly on the machine table. The base is provided with location and clamping arrangement for the workpiece. The jig plate is suspended on the drill head with four columns having resting nuts. The jig plate is held against the nuts by springs which also provide force for sandwich clamping of the workpiece (*Figure 5.22*). For loading and unloading the workpiece, the multi-spindle drill head and the suspended jig plate are raised to provide clear passage for the workpiece. For drilling, the drill head is brought down. The suspended jig plate touches and clamps the workpiece before drilling commences. Thus, in addition to guiding the drills through bushings, the jig plate also automatically clamps and unclamps the workpiece. It functions somewhat like a spring-loaded top stripper plate in a press tool.
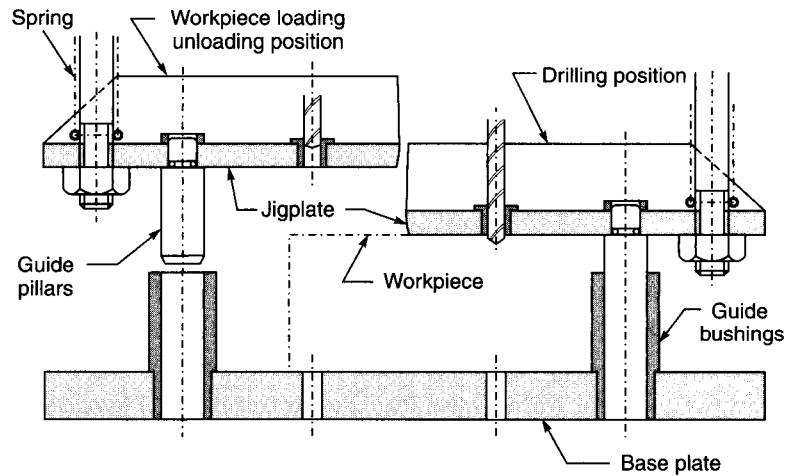
Figure **5.22**
Jig for multispindle drilling machine

The jig plate also carries two location pillars which engage in the guide bushings in the base plate to align both the plates precisely with each other and the workpiece.

Adjustable Jigs

Workpieces made from the same size of rolled steel angles, channels, squares, flats and round bars can often be drilled in a single adjustable jig. The differences in positions and or sizes of the holes can be taken care of by making the locators and jig plates adjustable. The variation in sizes of holes can be accommodated by using renewable bushings of required basis.

Figure 5.23 shows three workpieces which can be drilled in the common adjustable jig shown in *Figure 5.24*.

All the workpieces are made from 30 Sq. (outside) tube with a wall of 1.6 mm thickness. The section is located by pins for centrality of the holes along width 30. Another pin locates the workpieces for longitudinal position of the holes from the left hand end. Section P-P shows the clamping arrangement while section Q-Q shows the
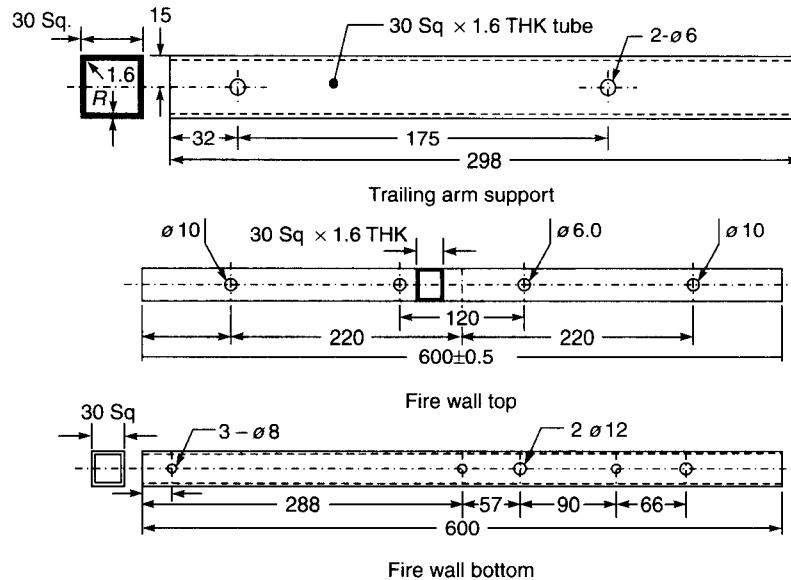
Figure **5.23**
Workpieces for adjustable jig

adjustable jig plate. It has got a key-way location fit with the key fitted on the jig base. The jig plate is clamped to the base by two Allen screws. Note the stepped flat welded below the channel. It provides seating surface for the nuts mating with the Allen screws. The step engages with one of the flats of the nuts and prevents their rotation when the Allen screws are tightened. It is convenient to provide a removable location pin for quick, precise setting of the jig plate in the required position.

Removable renewable bushings take care of the variation in the sizes of the holes. A slot in the base provides drill overshoot clearance while drilling through holes.

Figure 5.25 shows an adjustable jig for central holes in round bars. The V block can accomodate a range of round bars. The adjustable screw location enables changing of the position of the hole from the end face of the workpiece bar. Such jigs are used widely for drilling split-pin holes in shafts.
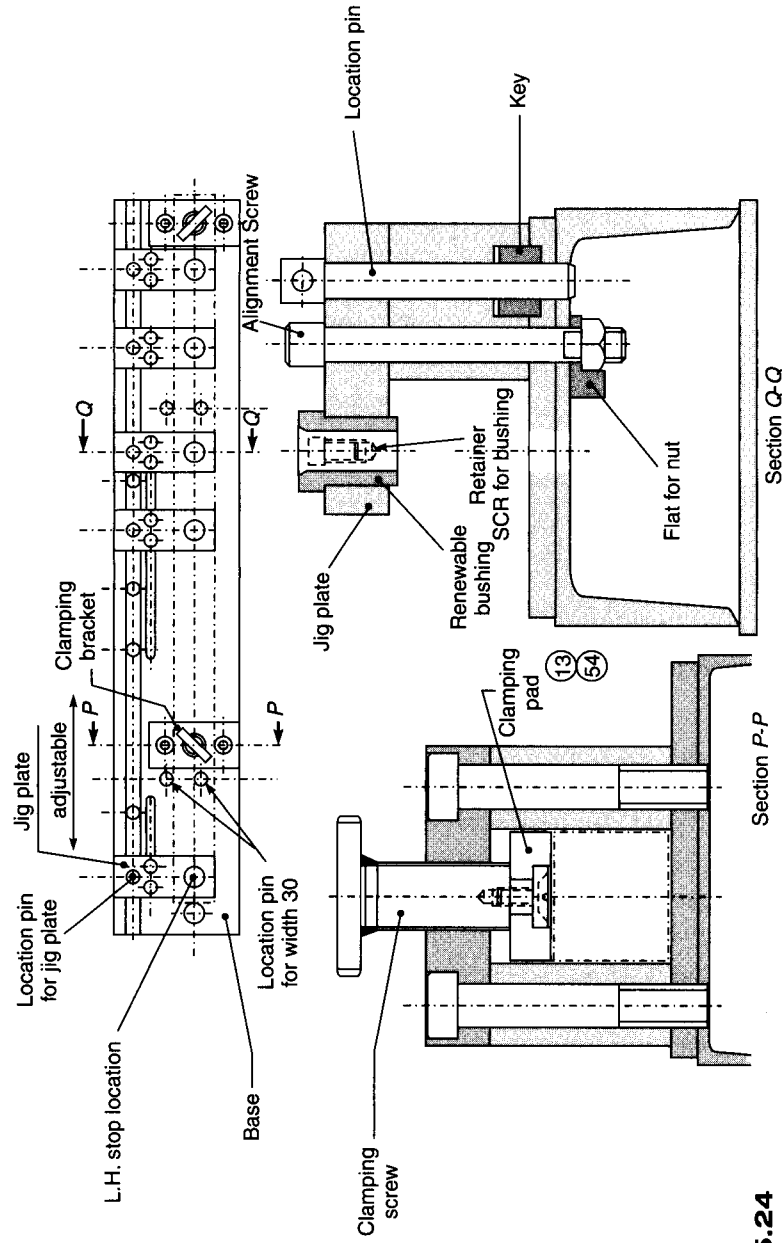
Figure **5.24**
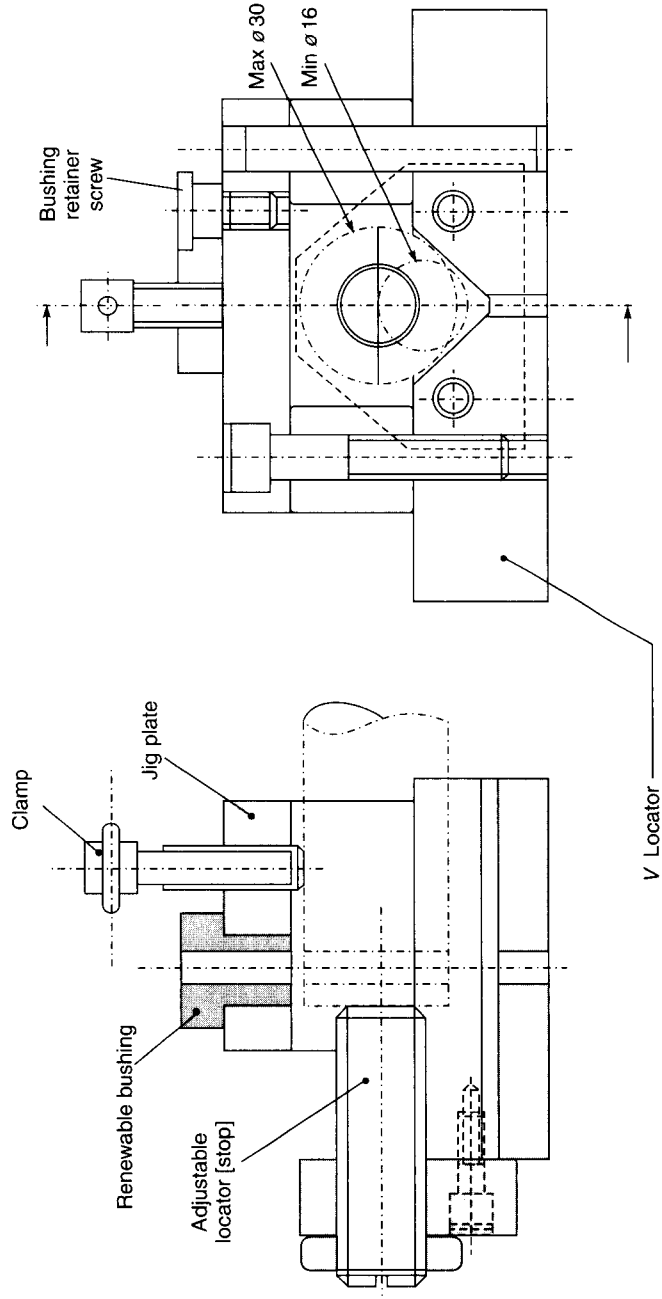*Adjustable jig for square tubes*

Bushing retainer screw

Max ⌀ 30

Min ⌀ 16

Clamp

Jig plate

Renewable bushing

Adjustable locator [stop]

V Locator

Figure **5.25**

Adjustable jig for holes up to 8.5ø in 16-30ø bars

Summary

1. A good jig facilitates precise location and easy foolproof loading/unloading of the workpiece. It also prevents bending of the workpiece. It has ample chip space and is light in weight.

2. Drill bushings have G7/F7 hole to guide the drill. They are made of steel hardened to R_C 62/65.

Types of Bushings

1. Press fit bushings for short runs.

2. Renewable bushings for high wear applications.

3. Slip bushings for multiple operations: drilling, reaming, counter-boring.

4. Threaded or spring-loaded bushings to combine clamping with guiding.

5. Special bushings with end shaped suitably to prevent drill deflection.

6. Plate bushings combining two or more bushings for very closely spaced holes.

Types of Jigs

1. Plate jigs for workpieces having parallel machined faces on sides to be drilled and used for resting.

2. Angle plate jigs for holes square to the machined bores.

3. Turn-over or table jigs for workpieces having the machined surface on the same side as the holes (and also square to the holes).

4. Leaf or latch jigs for workpieces having the machined surface on the side opposite to the holes (and square to the holes).

5. Box jigs for drilling holes from a number of sides in light workpieces.

6. Trunnion jigs for drilling holes from a number of sides in heavy workpieces.

7. Sandwich and pump jigs for workpieces having parallel machined surfaces on the side to be drilled and the side to be rested.

8. Jigs for multi-spindle machines with jig plate fixed to the machine spindle and aligned by guide pillars with the workpiece holding the fixture clamped on the machine table.

9. Adjustable jigs with adjustable locators and jig plates for workpieces having similar shape but different hole positions. Renewable bushings to vary hole size.
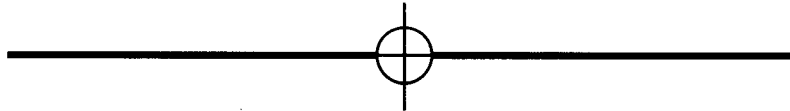
Milling Fixtures

The direction and intensity of forces in milling depend considerably upon the type of milling machine, cutter, and direction of feed.

Types of Milling Machines

Vertical Milling Machine

In this, the axis of the rotating cutter is vertical. This causes inevitable milling torque in the horizontal plane. Milling fixture elements should be able to withstand this torque and thrust of the milling cutter.

Horizontal Milling Machine

These drive cutters around a horizontal axis. Depending upon the direction of feed, the workpiece is lifted up or pressed down against the table. Horizontal machines often use a gang of many cutters. This increases the total cut and the resultant cutter thrust. Consequently, milling fixtures for horizontal machines should be able to bear torque in the vertical plane and thrust in the horizontal direction.

Type of Cutter ━━━━━━━━━━

Bigger cutters such as face milling cutters develop higher cutting torque and thrust than smaller cutters like end mills and slitting saws. The helix angle of the cutting teeth develops axial thrust which is passed onto the drawbolt and arbor nut. If two similar cutters are used simultaneously, they should be mounted in such a way that the helix angles of the two cutters are in opposite directions. Their axial thrusts should oppose and neutralize each other.

Direction of Feed ━━━━━━━━━

Up Milling (Conventional)   The directions of feed and cutting oppose each other (*Figure* 6.6). The cutter tends to lift the workpiece and fixture from the table. This calls for heavy downward clamping. The thrust resulting from the cutting force should be directed to a solid, fixed part of the fixture instead of the clamp or other movable parts.

Down Milling   The feed direction is the same as the direction of cutting force. The cutter tends to press the fixture and workpiece down on the table. This subjects the machine to vibrations and so old, worn-out machines with excessive clearance between slides and lead screws are unsuitable for down milling.

Essentials of Milling Fixtures ━━━━━━

1. *Strength*   Milling fixtures should be heavy and robust to withstand heavy forces and severe vibrations developed in milling. Cast iron is a suitable material for milling fixtures. It can withstand vibrations well.

2. *Thrust*   Heavy thrust caused in milling should be transmitted to strong solid structures. The thrust should not be directed towards a clamp or a movable part. If a vice is used, it is better to direct the thrust towards the fixed jaw instead of the movable jaw.

3. Cutter Setting Suitable cutter setting pieces should be provided for easy and accurate tool setting. It is customary to keep 0.40 to 0.5 mm gap between the cutter and setting piece. This gap facilitates cutter setting with the help of a feeler gauge (*Figure 6.1*).
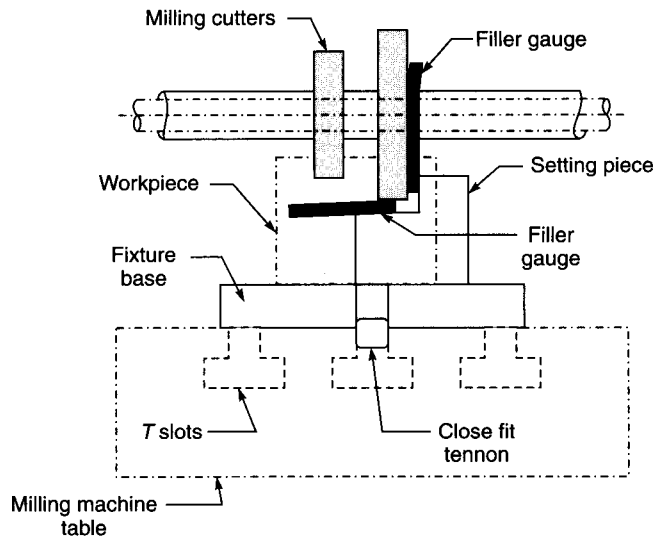
Figure **6.1**
Cutter setting piece

4. Machine Location Tennons Milling fixtures are generally fixed with locating tennons (tongues). These are fixed in slots machined on the resting face of the base (*Figure 6.2*). Tennons are made close sliding fit in machine *T* slots. Tennons align the milling fixture with the longitudinal stroke of the machine.

5. Rigid Clamping The fixtures must be clamped firmly to the machine table in order to prevent sliding due to cutter thrust

and vibrations. This is accomplished by a provision for U slots in the fixtures (*Figure 6.2*). These facilitate direct clamping with T bolts, instead of external clamps. A minimum of two clamping slots are provided. In case of heavy cut and thrust, the number of clamping slots are increased to four or six.
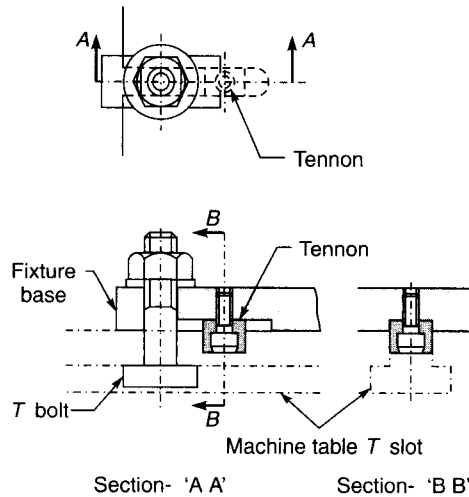

Figure **6.2**
Machine location and clamping arrangement for milling fixtures

6. *Motion Economy* Clamping time can be reduced by securing more than one workpiece with a single clamp (*Figure 6.11*). In large scale continuous production, pneumatic or hydraulic power clamping should be considered. Generally, clamping time can be overlapped with machining time by using more than one fixture (*Figures 6.7, 6.8 and 6.9*).

7. *Metal Filings Disposal* Unlike drilling, milling chips are discontinuous. In case, metal filings gets accumulated in closed pockets, big chip removal gates should be provided for cleaning the fixture.

Special Vice Jaws

For simple workpieces in small batches, a machine vice can be used conveniently. Many machine vice jaws have vertical and horizontal V grooves which facilitate holding of round workpieces in vertical or horizontal position. Many odd-shaped workpieces can be held in a vice by using suitable special jaws. The capacity of a vice can be increased by using extension jaws (*Figure 6.3a*). Vice jaws can also be affixed with locators. *Figures 6.3b* shows a fixed jaw with an angular slot and rest pin to provide nesting location and vertical stop to the workpiece. The other movable jaw is plain surfaced as it is used only for clamping. Some workpieces require locators on both the jaws as shown in *Figure 6.3c*. In such cases both the jaws should be positively aligned with each other. This can be accomplished by providing guide pins and bushings. Some machine vices have location
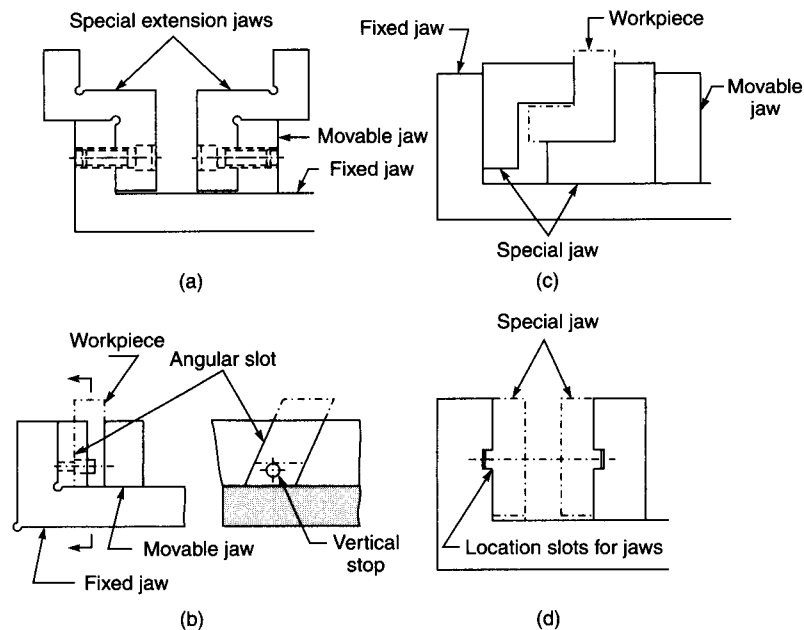
Figure **6.3**
Special vice jaws

slots for precision positioning of jaws. The jaws are provided with close-fitting location tongues (tennons) as shown in *Figure 6.3d* .

Milling operations can be broadly classified as:

1. Facing

2. Slotting

Facing Fixtures

Milling machines are used extensively for facing seating and mating flat surfaces. Milling is often the first operation performed on the workpiece. *Figure 6.4* shows a simple face-milling fixture.
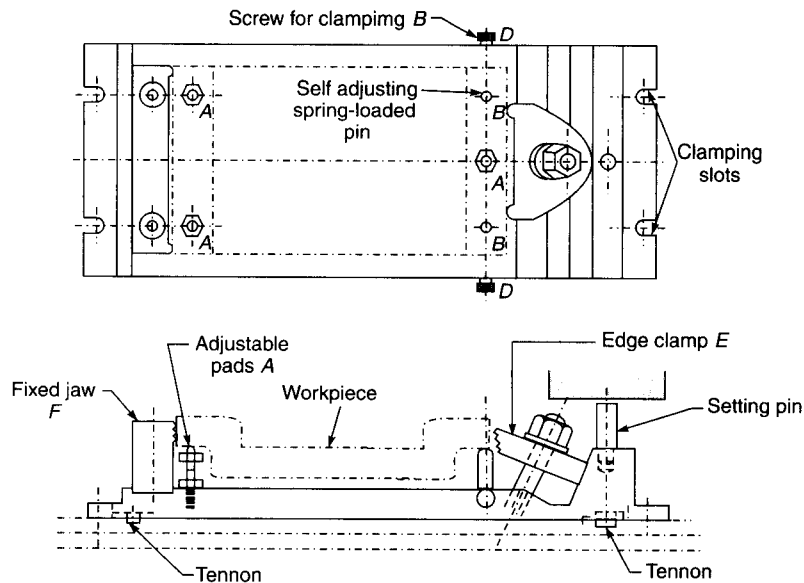

Figure **6.4**
Face milling fixture

The workpiece is supported by three adjustable spherical-ended pads A which are adjusted to suit the variation in casting and locked in position by check nuts. Two-self adjusting supports B are pushed upwards by light springs which ensure that supports B are positively in contact with the workpiece. Supports B can be locked in this position by clamping screws D. The tightening of edge clamp E pushes the casting against fixed jaw F which is keyed in the fixture body to provide solid support to the workpiece against the heavy thrust developed during operation. The cutter should be fed to the workpiece in such a way that the milling thrust is directed towards the solid support of the fixed jaw. Setting piece S is placed in the path of the cutter so that it can be set before it commences facing operation. Generally, locating tennons are not necessary in plain face milling operations. An approximate location effected through clamping slots is adequate enough. The position and size of the clamping slots should match with the spacing of T slot on the machine table. Four clamping slots are provided to counter the heavy forces developed during operation. Generally, two clamping slots are sufficient for lesser cutting load.

Figure 6.5 illustrates a fixture for simultaneous facing of two sides of a boss. This method of milling is called straddle milling. The workpiece is located on the machined bore and face of the bigger boss of the workpiece. It is clamped against the face of the resting pad by a bolt. The hexagonal nut and C washer hold the workpiece against the collar of the locator.

The two milling cutters face both sides of the boss simultaneously. The milling thrust is directed toward the rest pad which passes it on to the solid fixture body. The fixture is located in machine table T slots by two tennons. Four U shaped slots in the fixture base simplify clamping on the machine table. The machined side faces of the casting below the rest pad are used for cutter setting. The cutters are positioned at 0.5 mm from the faces of the casting with a feeler gauge.

Straddle milling is widely used for milling precisely the parallel opposite faces of a workpiece.

Figure 6.6 depicts a gang milling fixture for milling one slot and a number faces in the workpiece shown. A gang of three side and face cutters is used to mill seven faces on the workpiece.
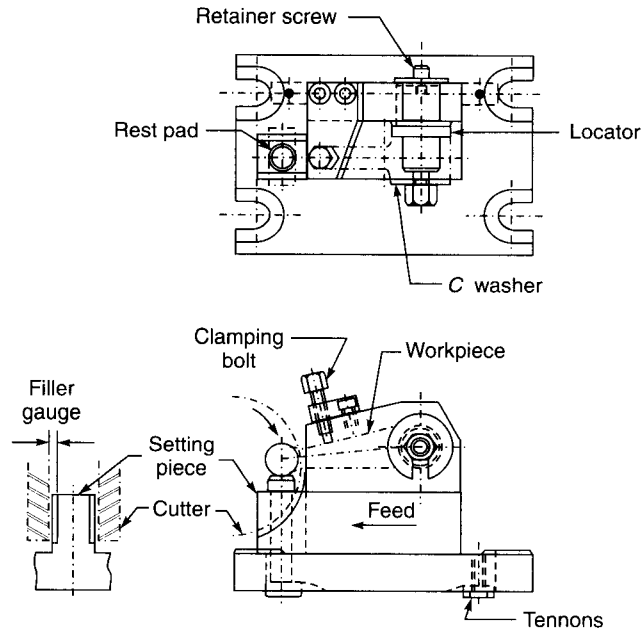
Retainer screw

Rest pad

Locator

C washer

Figure **6.5**
Straddle milling fixture

Clamping bolt

Workpiece

Filler gauge

Setting piece

Cutter

Feed

Tennons

Workpiece

Feed

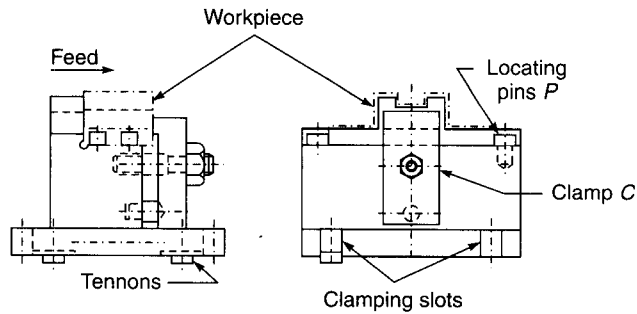Locating pins *P*

Clamp *C*

Tennons

Clamping slots

Figure **6.6**
Gang milling fixture

The workpiece is located by four pins *P* and it is clamped against a solid section of the body against which the milling thrust is directed. Clamp C has got a downward angle at the clamping point. In

addition to holding the workpiece against the vertical face, the angular clamping face also exerts downward pressure on the workpiece, while pressing it against the horizontal face.

Most of the clamps used in horizontal milling exert some downward force on the workpiece to prevent it from getting lifted during conventional upmilling feed (*Figure 6.4*).

The profiled portion of the body also serves as a cutter setting piece. It is made 0.5 mm undersize to facilitate use of feeler gauge for cutter setting.

The fixture is provided with two locating tennons at the base to align it with table *T* slots. Four *U* shaped clamping slots facilitate strong clamping to withstand the heavy thrust due to the three cutters.

A large part of industrial milling consists of milling a single mounting and reference face of the workpiece. Such plain facing work can be speeded up by overlapping the workpiece loading and clamping time over the machining time. While one workpiece is being machined, the previously machined piece is unclamped and unloaded; and the next piece to be machined is loaded and clamped. The new piece is ready for machining before the preceding piece is completely machined. This can be accomplished by the following methods.

1. Index milling

2. Rotary milling

3. Reciprocal milling

1. Index Milling It uses a multi-station indexing table on which a number of fixtures are mounted. In a two-station fixture shown in *Figure 6.7*, while workpiece *A* is milled at the machining station, the previously machined workpiece is removed and replaced by a fresh piece at the loading and unloading station. When machining of *A* is over, the indexing device is rotated and indexed to bring the new workpiece *B* to the machining station. The machined workpiece a can be replaced by a fresh workpiece while piece *B* is being machined.
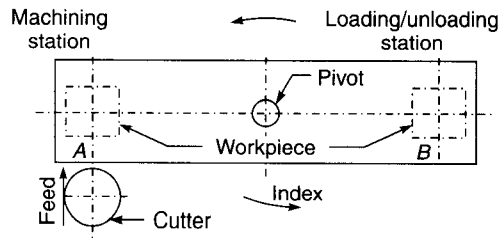
Figure **6.7**
Index milling

2. Rotary Milling In this, a number of workpieces are mounted on a rotary fixture which is rotated to feed the workpiece stream to the milling cutter. At the opposite end of the rotary table the machined workpieces are replaced by fresh ones even while the rotary fixture is moving (*Figure* 6.8).
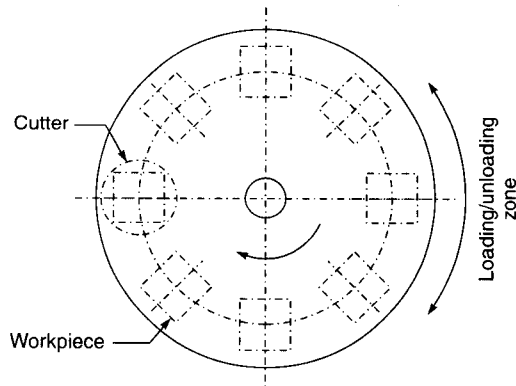

Figure **6.8**
Rotary milling

3. Reciprocal or **Pendulum Milling** (*Figure* 6.9) In this, two fixtures are mounted at the two ends of the machine table. The machined workpiece at one end is replaced by a fresh one while the work-piece at the other end is being machined. After completion of machining, the machine table is traversed to feed the workpiece at the other end of the table. While this is being ma-

chined, the preceding machined workpiece at the idle end is replaced by a fresh one. Thus, the table is reciprocated like a pendulum to machine alternately the workpiece at both the ends of the table.
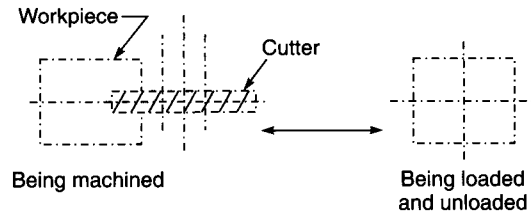
Figure **6.9**
Pendulum or reciprocal milling

Slotting Fixtures

In slotting fixtures, the workpiece should be clamped as close to the portion being machined as possible. *Figure 6.10* shows a slot milling fixture for a lever. The lever is located on two previously machined holes. The bigger locator as well as the angle plate are slotted to permit passage of the slotting cutter. The slot can be used for setting the cutter. The workpiece is clamped against the angle plate by a swinging strap clamp. The clamp is loosened and turned anti-clockwise to the chaindotted position to clear the path of loading and unloading the workpiece. The base is slotted for locating tennons which align the fixture with the machine traverse.

Figure 6.11 depicts a key-way milling fixture for shafts. The shafts are located and supported by V blocks. A single clamp secures two shafts simultaneously. Both the shafts are milled simultaneously for key-ways by a gang of two cutters which can be set with the help of the setting piece. A stopper locates shaft axially and takes the milling thrust. The fixture is aligned with the machine table by two tennons and clamped through U slots.

Round parts can be slotted economically on a standard string milling fixture as shown in *Figure 6.12*. The workpieces are held

Clamping slot

Spring

Clamp

Workpiece

Diamond
pin
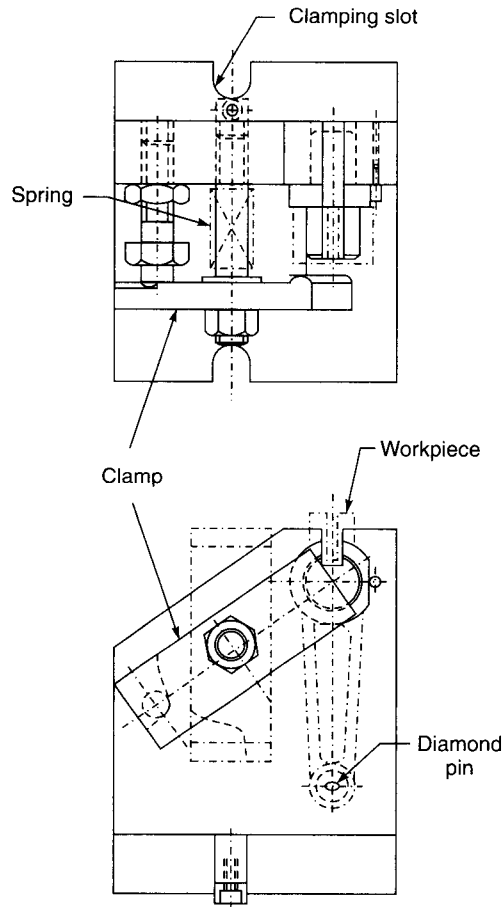
Figure **6.10**
Slotting Fixture

between V blocks which slide freely in a guide slot in the body. The top guide plate prevents V blocks from getting lifted up during milling. The V blocks can grip a wide range of round diameters. Axial location can be provided by a rest plate which acts as a vertical stopper for the workpieces. This plate can be changed for different workpieces.

Large chip removal gates must be provided for removal of the chips falling into the box-like structure of the fixture body. The cutter
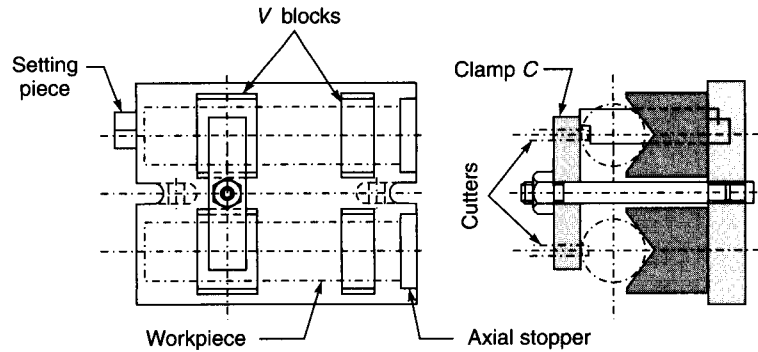
Figure **6.11**
Key-way milling fixture
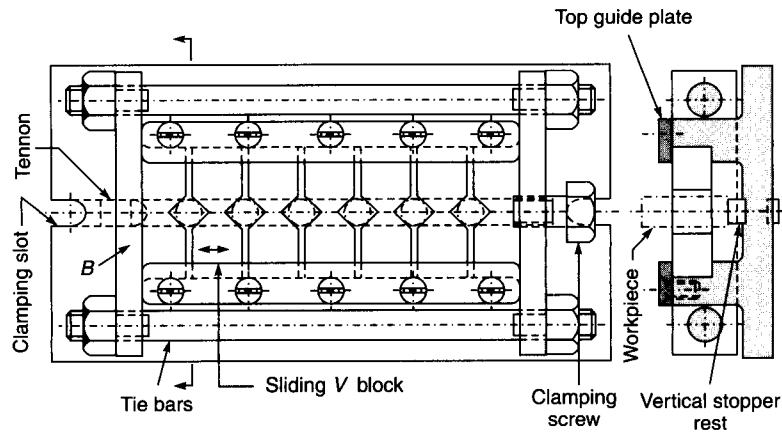
Figure **6.12**
Standard string milling fixture for round parts

thrust should be directed towards fixed plate B. A number of work-pieces are clamped simultaneously by a single hexagonal-headed bolt which holds the workpieces like a multi-layered sandwich of alternate V blocks and workpieces. Two tennons at the bottom align the fixture with the machine travel and the U slots serve as integral clamps.

String milling can be used conveniently for many workpieces requiring only a short machine stroke for operation. It utilizes a large part

of the machine stroke. Numerous workpieces are machined in a single traverse. The number of workpieces which can be milled in a single stroke depends upon the accuracy of the machine slide movement along the traverse and permissible centrality tolerances on the workpiece.

Summary

Milling Machines

1. Vertical (spindle) milling machines generate torque in the horizontal plane and thrust in the feed direction.

2. Horizontal (spindle) milling machines tend to lift or press the downwards workpiece and generate thrust in the direction of the feed.

Cutter Types

1. Bigger the cutter, more the torque and thrust. Helix angle of the cutting teeth leads to axial thrust.

Feed Direction

1. Up milling feed in direction opposite to the cutting force. Tends to lift the workpiece and fixture.

2. Down milling feed in direction of the cutting force. Tends to press the workpiece and fixture downwards. Severe vibrations.

Essentials of Milling Fixture

1. Strength to withstand heavy forces.

2. Thrust should be directed towards a strong, solid structure.

3. Cutter setting piece should be provided.

4. Milling fixtures should be aligned with locating tennons.

5. Rigid clamping.

6. Motion economy through multiple/power clamping.

7. Gates for chip removal.

Special Vice Jaws

They enable usage of a standard vice with replaceable jaws for milling.

Facing Fixtures

No part of the fixture should be in the path of the cutter.

1. Straddle milling uses two cutters for milling two parallel faces of a workpiece simultaneously.

2. Gang milling uses a number of cutters to mill many faces of a workpiece simultaneously.

3. In index milling, a machined workpiece is unloaded and a fresh one is loaded on the idle station of the indexing table while another workpiece is being milled at the other station.

4. In rotary milling, a table mounted with a number of work-pieces rotates continuously. The milled workpieces are un-loaded and fresh ones are loaded on the table in the part away from the cutter.

5. Pendulum or reciprocal milling uses two fixtures at opposite ends of the machine. The loading and unloading of the work-piece at one end of table is done while the workpiece at the other end is being milled.

Slotting Fixtures

They often use clamps with a slot for the cutter to accomplish clamp-ing of the workpiece as close as possible to the part being milled.

1. Key-way milling fixtures for horizontal machines often use double clamping and a gang of two cutters to mill two shafts simultaneously.

2. String milling fixtures place a number of similar round work-pieces in one line for milling them in a single traverse of the cutter.

Turning Fixtures

Turning fixture mainly consists of workpiece locating and clamping elements. These fixtures are used for facing, boring and turning operations. For all these operations, the workpiece must be positioned correctly with respect to the rotating machine spindle. For boring and turning, the axis of the bore or the outside diameter to be machined must be aligned with the machine spindle axis.

Generally, turning machine spindles have accurately machined spigots for location and threads for clamping of locators and work holders (*Figure 7.1*).
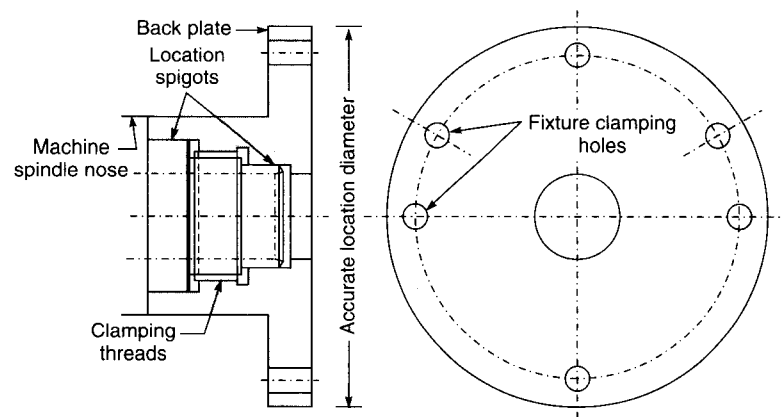
Figure **7.1**
Back plate for turning fixtures

Most of the machines are provided with a back plate which is permanently mounted on to the machine spindle. The back plate is used to locate and clamp turning fixtures, chucks and other workholders on the machine. The outside diameter of the back plate is generally machined precisely to the sixth grade of tolerance. It is used as a locating spigot for aligning axis of rotation of the fixtures with the machine spindle. The back plate is provided with three or more equi-spaced holes for clamping turning fixtures. Generally, the fixtures are provided with clamping studs which are inserted in the clamping holes in the back plate and secured by hexagonal nuts (*Figure 7.2*). Even the standard chucks and commercial workholders are fixed to the back plate in a similar manner.
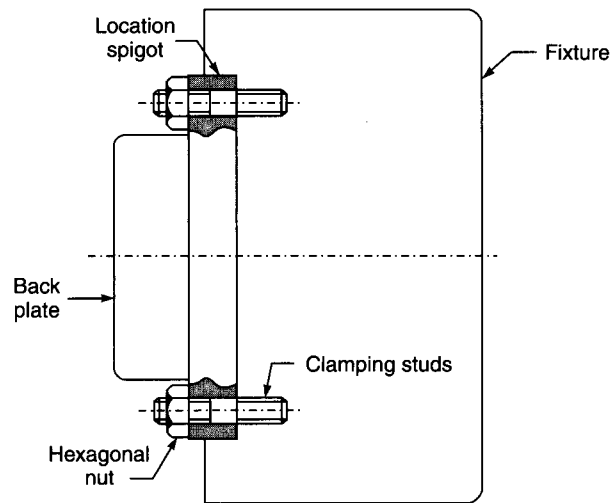
Figure **7.2**
Location and clamping of turning fixtures

The majority of workpieces processed on turning machines (lathes, turrets and etc.) are circular in shape. Most of these can be held and located (centralized) satisfactorily in the standard commercial chucks and collets. Many rectangular and other odd shapes can be clamped satisfactorily on the standard face plates. As a matter of fact, most of the turning fixtures are special face plates designed to

facilitate quick loading, locating and clamping of workpieces in mass production.

Standard Chucks

Self-centering Three-jaw Chucks

In this, all the jaws move simultaneously and are operated by rotating a screw with a chuck key. The standard jaws always remain concentric with the axis of the chuck during movement. This centralizes the workpiece. *Figure 7.3* illustrates a typical three jaw- scroll chuck. Self-centering chucks are also available in two or four jaw varieties.
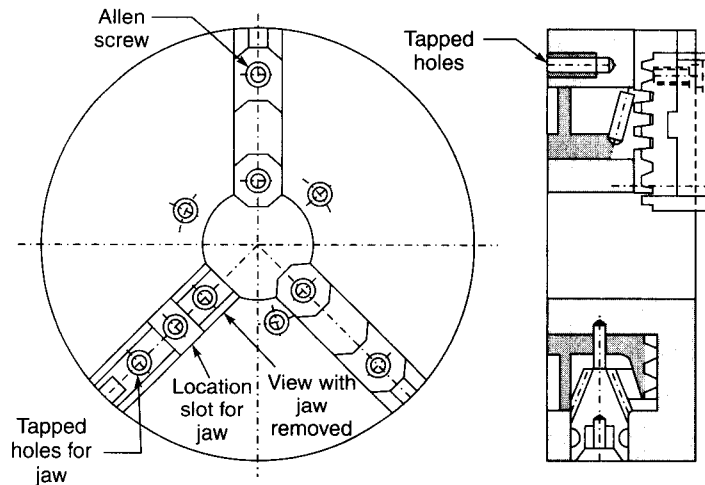
Figure **7.3**
Three-jaw self centering scroll chuck

independent Four-jaw Chucks

In this type, each one of the four chuck jaws can be moved independent of the other jaws. This helps in making the jaws deliberately non-concentric to centralize an offset bore in a rectangular work-

piece (*Figure* 7.4). Independent jaw chucks are also used for most accurate centralizing of round workpieces. They are also available in two-jaws variety.
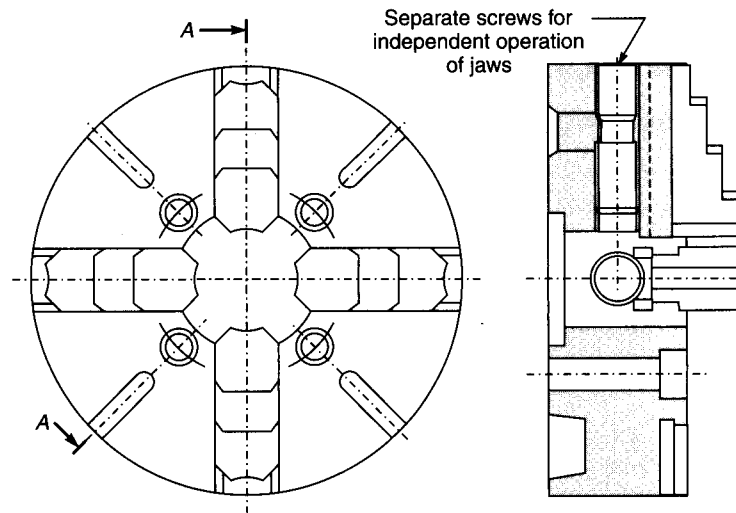
Figure **7.4**
Independent four-jaw chuck

Combination Chucks

These combine the advantages of the independent jaw and self-centering chucks.

Each jaw can be moved towards or away from the center of the chuck by a separate adjusting screw. This facilitates location of odd shaped workpiece (*Figure 7.5*). After adjustment, all the jaws can be moved simultaneously by the master socket for quick clamping and unclamping of the workpiece.

Power-operated Chucks

In this, the use of compressed air or pressurized hydraulic oil for moving the jaws reduces operator fatigue and facilitates fine control of clamping pressure. Moreover, the clamping force can be varied during rough and finish machining. For example, a workpiece is

One jaw offset
to suit workpiece
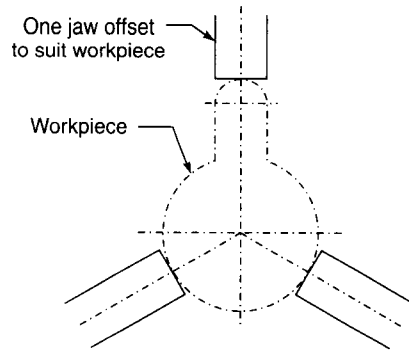
Workpiece

Figure **7.5**
Combination chuck

clamped with 4 kg/cm^2 air pressure during roughing heavy cut. During light cut finishing, the air pressure is reduced to 1 kg/cm^2. This releases the workpiece from the temporary distortion caused by high clamping force used in roughing. Finishing under low force clamping prevents inaccuracies due to distortion of the workpiece.

Special Jaws

A wide variety of odd-shaped workpieces can be located and clamped satisfactorily by modifying the shape of the standard jaws. *Figure 7.6* depicts typical standard jaws.

For frail and thin-walled parts the length and area of the clamping face of the jaw is increased considerably to distribute clamping pressure over a wider area. This reduces distortion and damage of the workpiece (*Figure 7.7*).

Soft Jaws

They are used for highly concentric second operation machining. These jaws are not hardened. They are machined to size after assembly on the chuck just before commencing manufacture.

Before starting production of every batch, a light cut is taken on the soft jaws to ensure high degree of concentricity during second operation machining of the workpiece.

Locating slot

Locating tongue
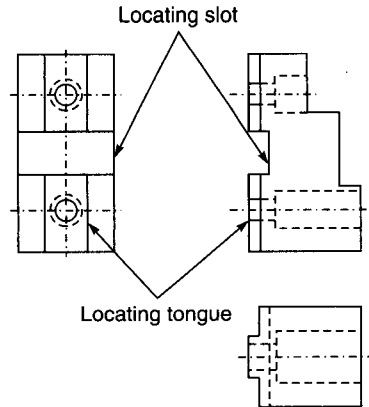
Figure **7.6**
Standard jaws
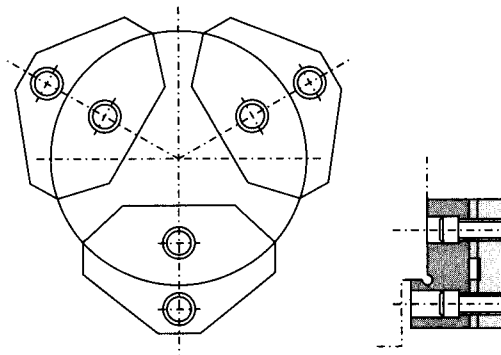
Figure **7.7**
Special jaws to increase clamping area

The shape of the jaw clamping face can be modified to suit the workpiece profile (*Figure 7.8*). This helps in quick location and clamping of odd-shaped workpiece on the standard chuck. A combination chuck is more convenient for use of such jaws. For, the different jaws can be positioned independently by individual adjusting screws. After setting the jaws to suit the workpiece all the jaws can be operated simultaneously by the master socket for quick clamping and unclamping.
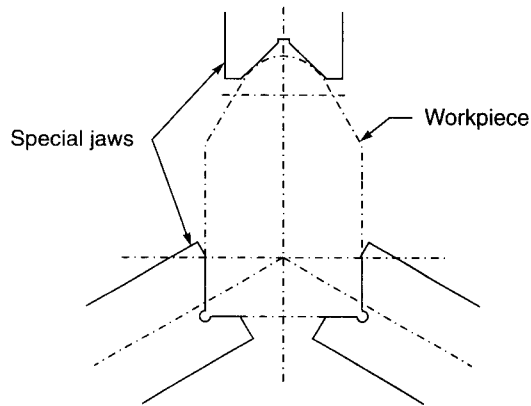
Figure **7.8**
Special jaws for odd-shaped workpiece

Face Plate

The standard face plate can be used conveniently for machining simple, short height components. The addition of locators and clamps on the face plate facilitates quick location and clamping of the workpiece (*Figure 7.9*). Face plate fixtures are particularly suitable for facing a number of workpieces simultaneously on the lathe (*Figure 7.10*).

Spring Collets

Cold, rolled round bars can be centralized accurately and clamped/unclamped quickly by using hardened collets. However, these can be operated only within a limited range of about 0.15mm. Consequently, different collets must be used for different sizes of bars and the variation in the bar size should be less than 0.15 mm.

The compactness of collets permits the cutting tool to be taken very close to the griping point. The stock is held almost all around the
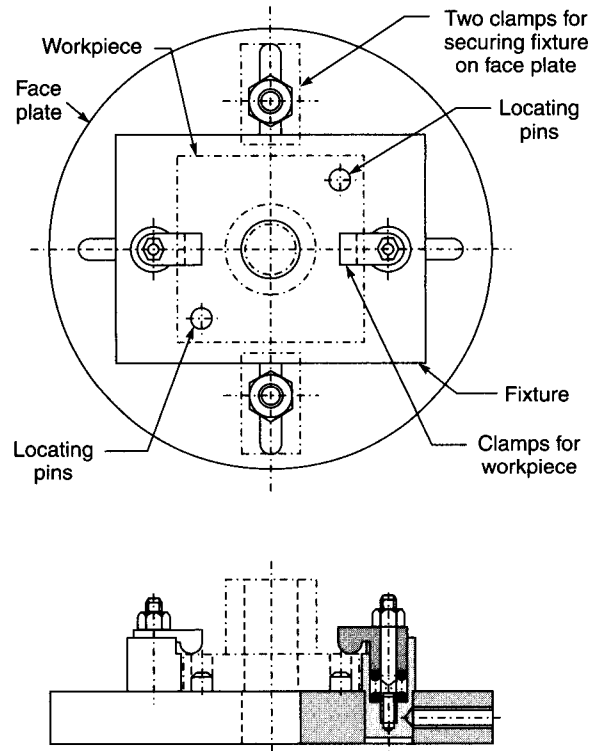
Figure **7.9**
Face plate fixture

periphery. This distributes the clamping pressure over a wide surface of the bar and prevents distortion and clamping dents.

Most of the collets have got a clamping cone which bears against the conical bore on the spindle nut. For gripping the bar, the collet is pressed against the conical surface in the nut. This is mostly done manually by a handle which moves a draw tube in the machine spindle. In some machines, the tube is moved by a pneumatic cylinder.

Collets can be broadly classified into three types:

     1. Push-out collets

     2. Pull-in collets

     3. Dead length collets

To be faced

Workpiece

Workpiece

Machine location spigot

Clamp

Facing

Tool
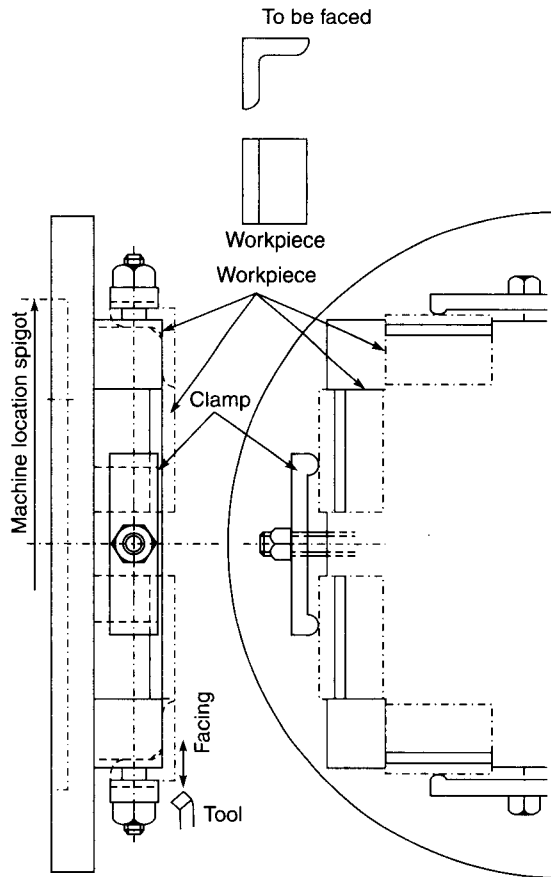
Figure **7.10**
Angles facing fixtures

Push-out Collets

For clamping the bar, the push tube pushes the collect against the
conical seat of the spindle nut as shown in *Figure 7.11*. This bends
the gripping portion of the collet inwards to clamp the bar. Push-out
type collets tend to push the stock outwards. This is good for the first
operation in which the bar is pushed against the stopper. For chang-
ing the collet, it is necessary to remove the nut from the spindle.
Collets are made of spring steel and are hardened and tempered. The
gripping portion is slotted to permit bending to facilitate clamping.

Thin wall — — Gripping portion

Bending — point

Slots

Conical seat

Machine — spindle

Conical seat

Push tube — Spindle nut — Gripping portion
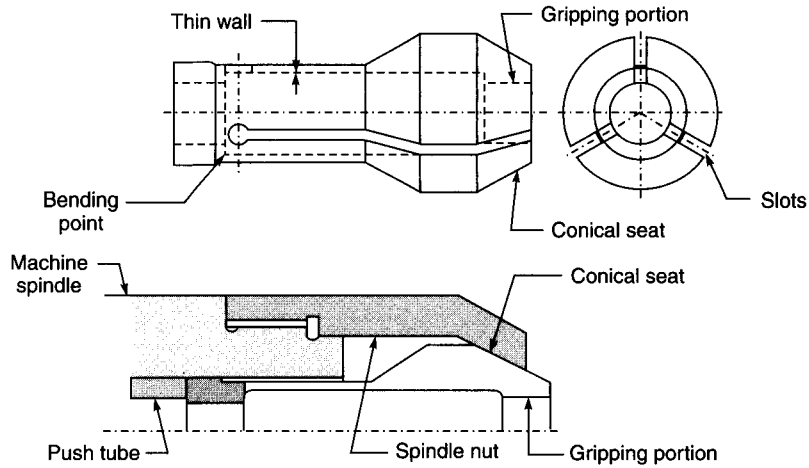
Figure **7.11**
Push-out collet

The wall at the bending point is thinned to reduce the force required for bending during gripping.

Pull-in Collets

Pull-in collets (*Figure 7.12*) are threaded at the rear end. A draw tube is screwed into the collet. For gripping the bar, the draw tube pulls the collet against the conical seat of the nut. This bends the gripping portion of the collet inwards to clamp the bar.

Pull-in collet tends to move the stock towards the machine spindle during gripping. This type of collet can be changed over without removing the spindle nut.

Dead Length Collets

A dead length collet (*Figure 7.13*) has two conical seats. The tapered portion on the machine spindle side bears with the cone on the pressure sleeve whereas the angular seat on the opposite side matches with the angle on the nut. The tightening of nut squeezes
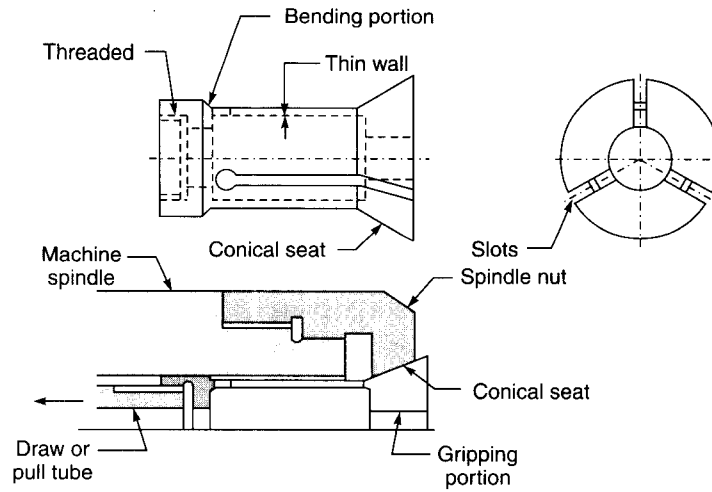
Figure **7.12**
Pull-in collet
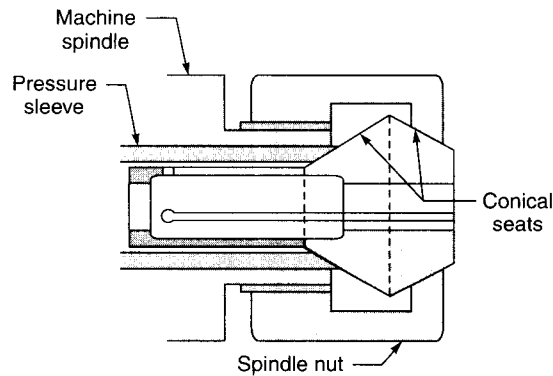
Figure **7.13**
Dead length collet

the collet between the two conical seats to clamp the stock. Consequently, dead length collets do not move the stock inwards or outwards like pull-in or push-out collets.

This type of collet is also less economical as the manufacture of the two conical mating surfaces increases machining cost. Moreover,

the collet must be tightened or loosened manually by rotating the nut. This takes a little more time than handle or air operated push-out and pull-in collets.

Cylindrical Liners

Collets of bigger size can be used for gripping smaller stock by using cylindrical split-bushing type liners (See *Figure 7.14*). As the liners do not have any conical seats, they cost less than conical collets. Liners serve mainly as packing between the collet and the stock. The wall of the liner must be thinned at the bending point.

Split-bushing

Wall thinned at
bending point
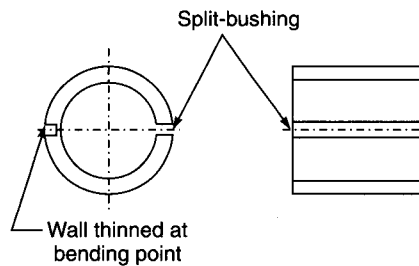
Figure **7.14**
Split-bush liner

Mandrels

Mandrels are internal locators used for concentric machining of the outside diameter of the workpieces with finished bores. Mandrels can be classified as below:

  1. Tapered mandrels

  2. Axial clamping mandrels

  3. Expanding mandrels

  4. Threaded mandrels

Tapered Mandrels

These are tapered bars with center at the ends for aligning with the machine axis and a flat for fixing the drive carrier (*Figure 7.15*). The taper generally ranges from 0.4 to 0.5 mm per meter. This limits the variation in the bore of the workpieces and so, for wide difference in the bores, different mandrels must be used. The taper facilitates friction drive for the workpiece, which is generally pressed on the mandrel with an arbor press. For repeated use, the mandrels should be hardened and the centers protected by counterbores to prevent damage due to an accidental fall. Tapered mandrels are rarely used in mass production as they require longer workpiece loading and unloading time.
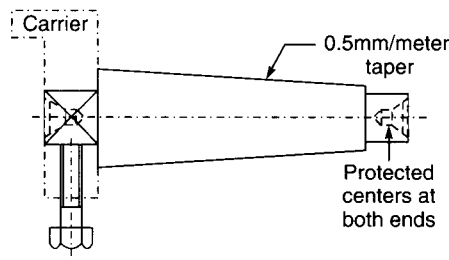
Figure **7.15**
Tapered mandrel

Axial Clamping Mandrels

These are used extensively for grinding outside diameter of bushings. The locating diameter must be close push fit with the minimum size of the workpiece bore. Consequently, the maximum bore size workpiece would be loose on the mandrel by the amount equal to the workpiece tolerance. Thus, the possible concentricity between the inside and outside diameter of the workpiece would be equal to the tolerance on the bore of the workpiece. For example, if the bore of a workpiece is between 50.00 mm and 50.04 mm the diameter of the mandrel should be push fit with 50.00 mm bore to permit usage of the mandrel for all workpieces. A workpiece having 50.04 mm bore

would, naturally, be loose by 0.04 m on the mandrel, and its concentricity can vary from 0.00 to 0.04 mm with respect to the bore. The workpiece is clamped axially with a C washer and a hexagonal nut which permit quick loading and unloading (*Figure 7.16*). The drive pin serve as an integral drive carrier. The mandrel is provided with protected centers and is hardened to minimize wear on the locating diameter.
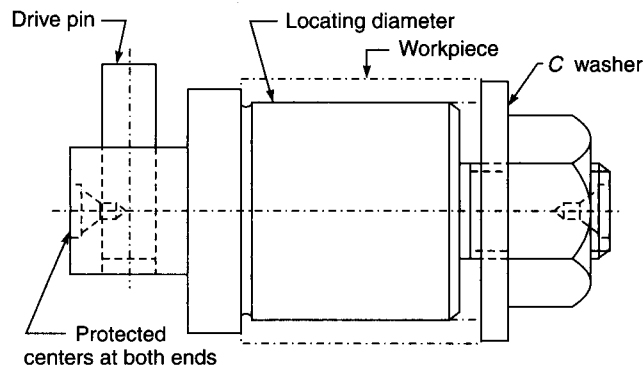
Figure **7.16**
Axial clamping mandrel

Expanding Mandrels

For a high degree of concentricity, expanding mandrels should be used. These permit adjustment of the locating diameter to suit the variation in the bore size of the workpiece. In fact, expanding mandrels clamp the workpiece on the bore as a collet grips the stock on the outside diameter. Consequently, there is no clearance between the mandrel and the workpiece which explains the high degree of concentricity.

The mandrel is split into three or four pieces as shown in *Figure 7.17*, and are held against the expanding cone by a retainer spring. The clockwise rotation of the cone pushes the mandrel pieces outwards against the workpiece to locate and clamp it. The rotation of the cone in the opposite direction reduces the distance between the mandrel pieces which are pressed inwards by the retainer spring.
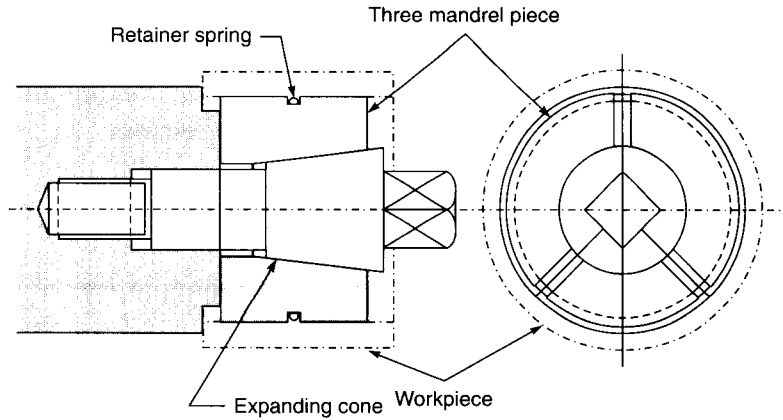
Figure **7.17**
Expanding mandrel

This contracts the mandrel to provide clearance between the mandrel and the workpiece for easy loading and unloading.

Threaded Mandrels

For workpieces with internal threads, the locating mandrel should have a clamping collar which has internal threads in the direction opposite to the thread in the workpiece (*Figure 7.18*). These facili-
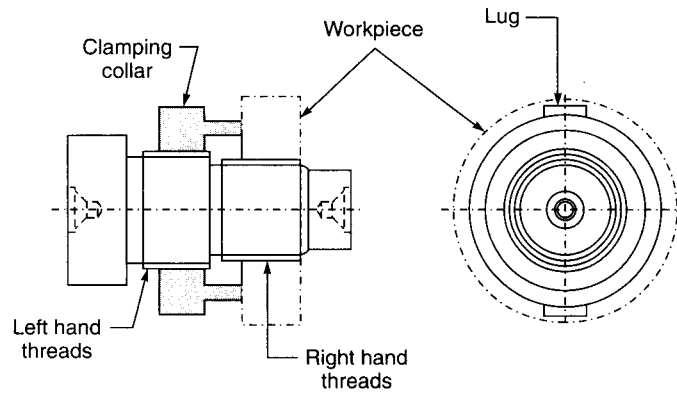
Figure **7.18**
Mandrel for threaded workpiece

tate tightening of the workpiece and the clamping collar against each other, and prevents the collar from unscrewing during turning operation. For unclamping the workpiece, lug on the clamping collar is knocked in an anti-clockwise direction by a hammer.

Turning Fixtures

Some workpieces require special turning fixtures for quick location and clamping. These are generally special face plates. Their swing should be lesser than that of the machine. The overhang of turning fixtures should be the bare minimum necessary for the operation. The fixtures should be balanced in position with the workpiece. The clamping arrangement should be capable of withstanding the various forces developed during operation—cutting force tangential to the cutting circle, axial and radial forces due to feed of the tool and bending forces due to pressure of tool on the workpiece.

Figure 7.19 shows a typical turning fixture. The workpiece rests on angle plate face A and its boss is centralized with the machine axis
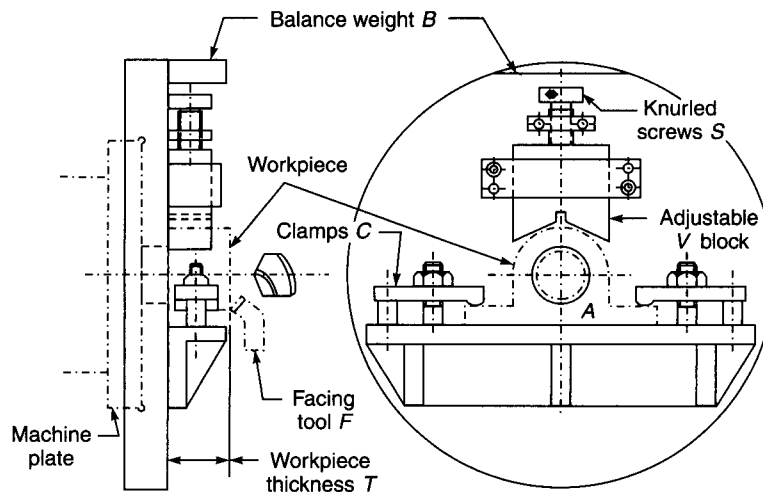
Figure **7.19**
Boring and facing fixture

by a sliding V block which can be operated with knurled scores S. The workpiece is clamped in this position by two clamps C. The height of the angle plate, sliding V and other parts is kept less than workpiece thickness T to prevent obstruction to facing tool F. The workpiece is bored through and one side of its boss is faced on this fixture. The eccentric masses due to the workpiece, angle plate and clamps are counterbalanced by balance weight B.

Figure 7.20 shows a second operation turning fixture for pump mounting bracket. The workpiece is located on earlier machined spigot S, and clamped against the fixture face by two swinging hook bolt clamps H. The clamps are loosened and swung anti-clockwise to the position shown by the chaindotted lines to clear the path of the workpiece during loading and unloading. No balance weights are necessary because of the even and symmetrical distribution of mass around the center line of the fixture.
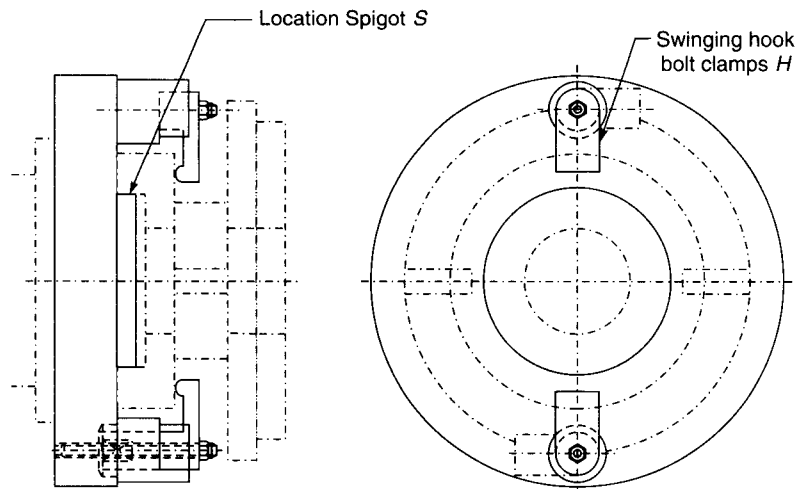
Figure **7.20**
Second operation turning fixture

Summary ━━━━━━━━━━━━━━━━━━━━━

Turning fixtures are mounted precision location fit (G7/h6) on the machine spindle. A back plate with internal threads and spigot for the machine spindle, and a external precision (h6) spigot (flange) and clamping holes for the fixtures are used as an adapter.

Standard Chucks

1. Self-centering three-jaw scroll chucks for cylindrical workpieces.

2. Independent four jaw chucks for odd-shaped jobs.

3. Combination chucks with radially adjustable, changeable, jaws.

4. Special jaws with suitable shapes for odd-shaped or soft/fragile workpieces.

Collets for bars

1. Push-out collets tend to the push the workpiece outwards for the first operation.

2. Pull-in collets tend to pull in the workpiece for the second operation.

3. Dead length collects with double cones are free from pull/push or the bars.

4. Split bush collets for small batch manufacture.

Mandrels

1. Tapered (0.5/m) mandrel with location centers and flats/square for drive carriers for machining bushes outsides.

2. Axially clamped mandrel with C washer and nut gives lesser concentricity than the tapered mandrel.

3. Expanding mandrel for precise location of the workpiece with the variation in the bore size.

4. T headed mandrel with opposite hand threads on the clamping collar.

Boring and Facing Fixtures

They should align the bore to be machined with the axis of the machine spindle. Facing fixtures should have the locator and clamps/studs clear of the tool path, Balance weights for reducing vibrations.

Grinding Fixtures

Surface Grinding

Surface grinding is used widely in industry to finish lengths and thicknesses of the workpieces within precise tolerances. The standard magnetic tables furnished with surface grinding machines can be used satisfactorily for workpieces having resting surface parallel to the surface to be ground. Solid plates can be ground under magnetic clamping alone and no other fixtures are necessary. However, light workpieces having lesser resting area tend to tilt and fly off the magnetic table due to the high speed of the grinding wheel and the high feed used in grinders with reciprocating or rotating tables. As lesser magnetic clamping force is not sufficient to secure the workpiece during the grinding operation, it is necessary to provide additional supports by nesting the workpiece. This can be done by placing solid plates around the workpiece as shown in *Figure 8.1*. With more weight and resting area, the nest plates are held firmly by the magnetic force of the table. The nest plates siege the workpiece from outside and arrest its movement in the horizontal plane, thus, preventing it from flying off or tilting due to high speed and feed inherent in the grinding operation.

In mass production, the capacities of the machines should be utilized to the maximum possible extent. Consequently, the maximum possible area of the magnetic table should be utilized to grind as many workpieces as possible in a single batch. To achieve this, the jig and tool design office should furnish a layout of the workpieces on the
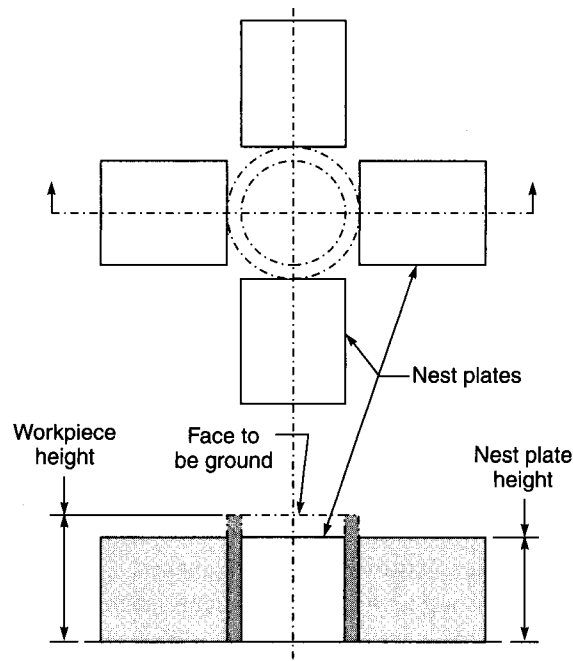
Figure **8.1**
Nesting

magnetic table. For round spacers the work-pieces are arranged in rows with common supporting nest plates around. The thickness of the nest plates should be lesser than the finish height of the work-piece to prevent obstruction of the grinding wheel (*Figure 8.2*).

For odd-shaped workpieces with little variation in size, an epoxy resin nest can be used (*Figure 8.3*). The nest prevents, the tilting and sliding of the workpieces during grinding operation.

For workpieces unsuitable for magnetic clamping, special fixtures must be designed. Surface grinding fixtures are generally similar to face milling fixtures in design. However, generally face milling is the first operation whereas grinding is done at a much later stage when a number of machined portions of the workpiece are available for location and clamping.
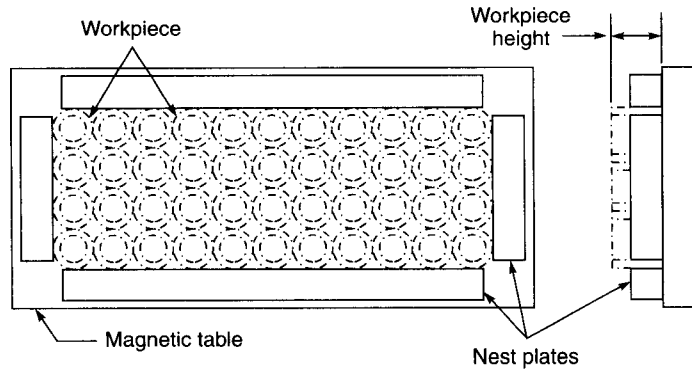
Figure **8.2**
Surface grinding layout
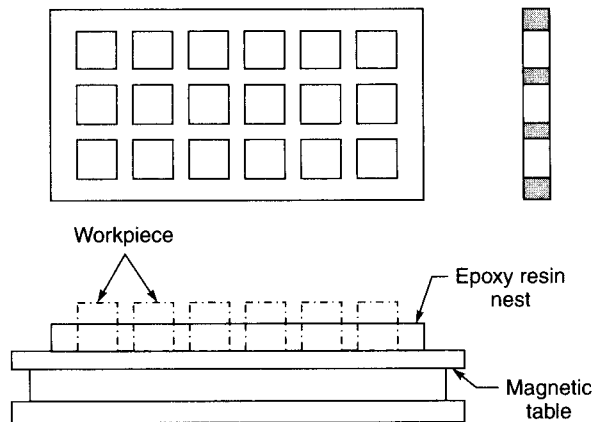
Figure **8.3**
Epoxy resin nest

Cylindrical Grinding

Fixtures for cylindrical grinding are similar to fixtures used for turning
and boring. A variety of mandrels can be used for grinding the outside
diameters of the bushes concentric with the inside diameter. Fixtures
used for internal grinding are similar to face plate fixtures used for bor-

ing workpieces on turning machines. The design features for location and clamping of the workpiece are similar to those of turning fixtures. Only the arrangement for securing fixtures to the machine spindle should be made suitable for the spindle of the grinding machine.
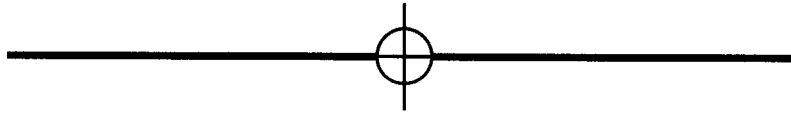
Broaching Fixtures

Broaching is a fast and accurate method of metal cutting. The built-in precision of the broach is reproduced in the workpieces by broaching fixtures which position the workpiece and guide the broach accurately. Consequently, most of the broaching fixtures serve the following functions:

1. Location of the workpiece in the correct position with respect to the machine.

2. Guiding of the broach to suit the dimensional requisites of the workpiece.

Both vertical as well as horizontal broaching machine tables have a round location hole in the table for locating broaching fixtures. The fixtures are provided with a close fitting male spigot which mates with the hole in the table to position the fixture correctly with respect to the machine.

The fixture also positions the workpiece and the broach precisely with respect to each other.

Broaching processes can be broadly classified into the following categories:

1. Internal broaching is used mainly for key-ways, splines, square and hexagonal holes and slots.

2. External broaching is used for outside profiles of connecting rod mating faces, etc.

Key-way Broaching

It is used extensively for cutting internal key-ways in pulleys, gears, sprockets, etc. The broaching process is much faster than other methods such as machining on the slotting machine.

Figure 9.1b depicts a simple broaching fixture for cutting key-way in the workpiece shown in *Figure 9.1a*.

The fixture in *Figure 9.1b* locates the workpiece on its bore for concentricity. A diamond pin in the hole in the flange positions the workpiece correctly to ensure the required angular relationship between 11 ø holes and the key-way to be broached.

The broach is guided in the slot provided in the fixture. The depth of the slot depends upon the maximum height of the broach and the key-way depth in the workpiece. For example, if the maximum height of 8 mm key-way broach is 14 mm, the depth of the guide slot for the broach in the fixture in *Figure 9.1b* should be 9 mm: BroachHt[14]– Keyway Depth [27–22].

The fixture is provided with a 110 diameter close-fitting spigot which engages with the machine location bore to position the fixture correctly on the machine table.
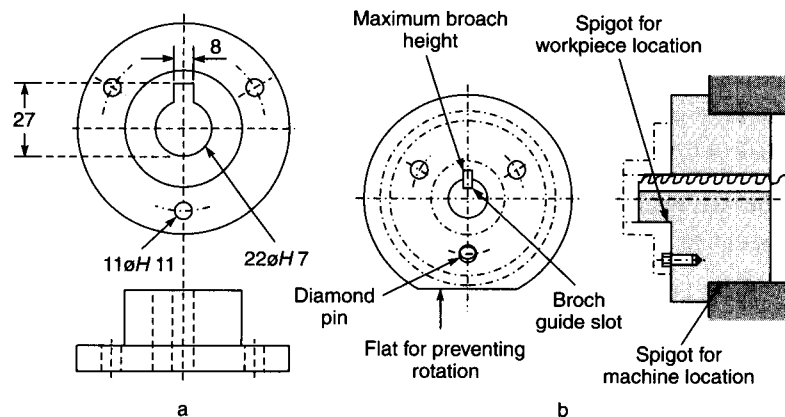
Figure **9.1**
Key-way broaching fixture

For tapered key-ways the workpiece should be held in the tilted position with respect to the machine axis (*Figure 9.2*). The tilt facilitates cutting of tapered key-way with a straight broach.
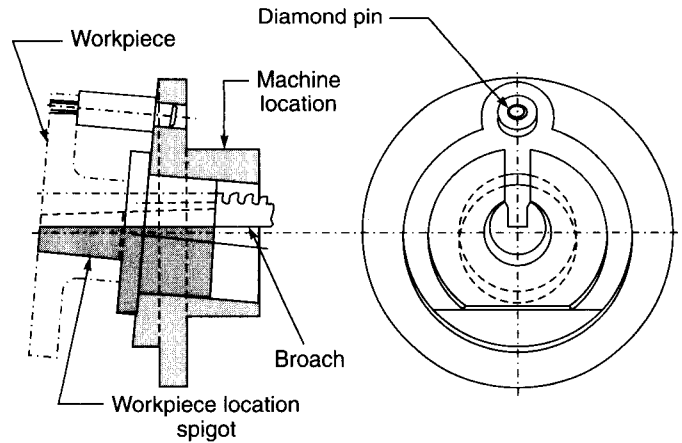
Figure **9.2**
Fixture for tapered key-way

External Surface Broaching

External broaching is used for producing external surfaces and profiles. The workpiece and broaches must be located properly with respect to each other and a supporting guide-way must be provided for the broaches. Often packing strips (also called shims or wedges) are used to control the depth of the profile and take care of the wear of the broaches).

Figure 9.3a depicts an arrangement for a broaching bore and mating faces of a connecting rod cap. *Figure 9.3b* shows the method of broaching the sides and the nut resting faces of the connecting rod.

Faces broached

Broach
guides

Broaches

Packing

a

Broaches

Faces
broached

Packing

Locator

b
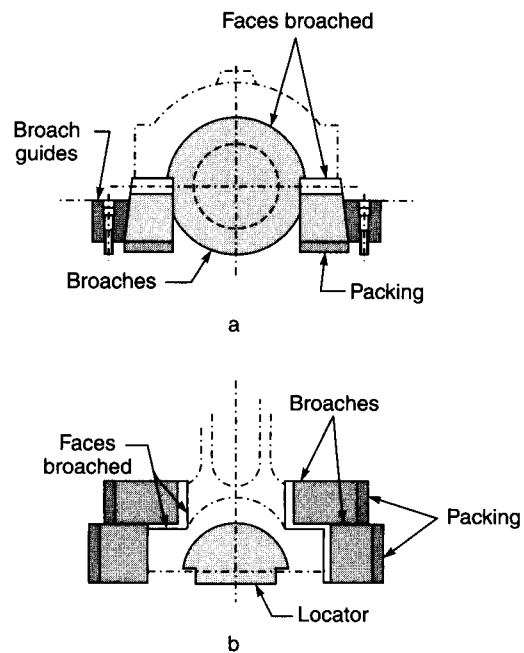
Figure **9.3**
External broaching
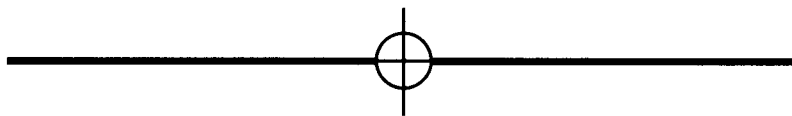
Welding and Assembly Fixtures

Fixtures for joining workpieces by welding comprise the usual locating and clamping elements used in other fixtures. However, effect of heat and prevalence of welding spatter must be taken into account while designing hot joining fixtures. The considerations for welding, brazing and soldering fixtures are given below:

1. Expansion of the heated workpiece and resulting distortion should not affect proper location, clamping, loading and unloading. There should be adequate clearance between the workpiece and locators to permit expansion, contraction and distortion of the workpiece without jamming the fixture. Handles subjected to heating should be made of insulating materials such as wood.

2. Welding spatter should not be allowed to fall on the threaded parts of the clamping elements. The parts near the welding area should not be threaded. Consequently, toggle clamps without the threaded elements are used widely in welding fixtures. These can be operated quickly and provide ample clearance in the unclamped position. *Figure 10.1* shows various types of clamps used in welding fixtures.

3. Spatter grooves must be provided below the line of welding to prevent the workpiece from getting welded to the base plate by the welding spatter.

4. Care should be taken to check that the joined workpiece do not get locked in the welding fixture after welding. It should
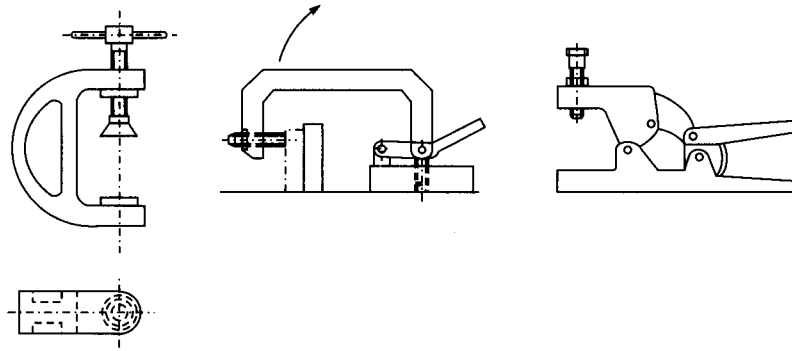
Figure **10.1**
Welding clamps

be possible to remove the welded workpiece from the fixture after welding.

5. For workpieces requiring welding from a number of sides, a provision for easy tilting or rotating the fixture should be made to ease welding from the various sides.

Figure 10.2 shows a welding fixture for a winged nut. The central boss is located by a loose female spigot to permit expansion due to heat during welding. The wings are located in loose slots which can permit expansion as well as distortion (bending) during welding. The wings are pushed towards the boss to touch it and are clamped in position by the clamping screws with wooden handles.

A spatter groove below the line of welding ensures that the spatter would not weld the boss or the wings to the base plate.

Figure 10.3 shows a fixture for welding four angles to a rectangular frame. Two longer angles are located lengthwise by four plates A. The cross-location is obtained by pushing the angles against four channels B. One face of each channel is also used to position the shorter cross angles. The other location in the cross direction is provided by the vertical faces of the longer angles.

The angles are clamped against the locators by eight cams which are hammered to the clamping position. For unclamping, the cams are
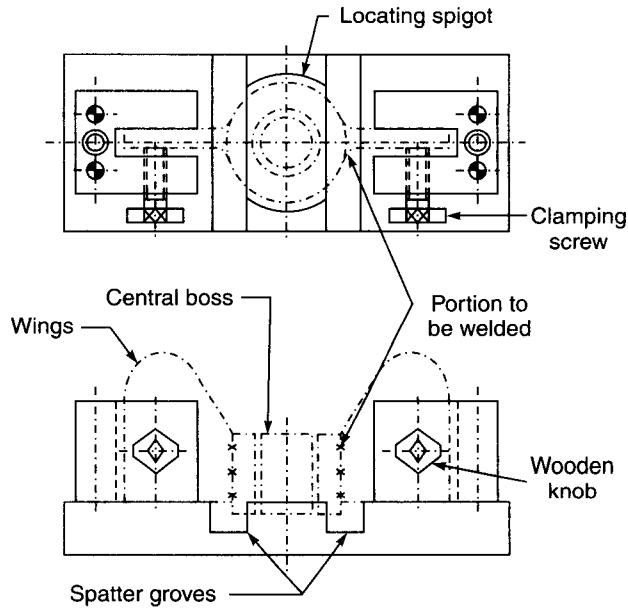
Figure **10.2**
Wing nut welding fixture

hammered in the opposite direction. The cams are pivoted on shoulder screws and are swung aside after unclamping to clear the path of loading and unloading of the workpiece.

The base plate is milled with pockets below the welding area to provide positive clearance between the workpiece and the base. This prevents the falling welding spatter from welding the workpiece to the fixture base.

Figure 10.4a shows another welding fixture for a pipe fabrication (depicted below the fixture). The pipes are located and supported by semicircular cutouts and clamped by strap clamps actuated by fly nuts. The channels and gussets are located and supported by suitable brackets and aligning pins.

Figure 10.4b shows a fabricated cover for an agricultural machine. Dimensions 154.0 and 41.0 for 8.5 ∅ holes indicate that the holes in the curved end angles should align precisely after welding.
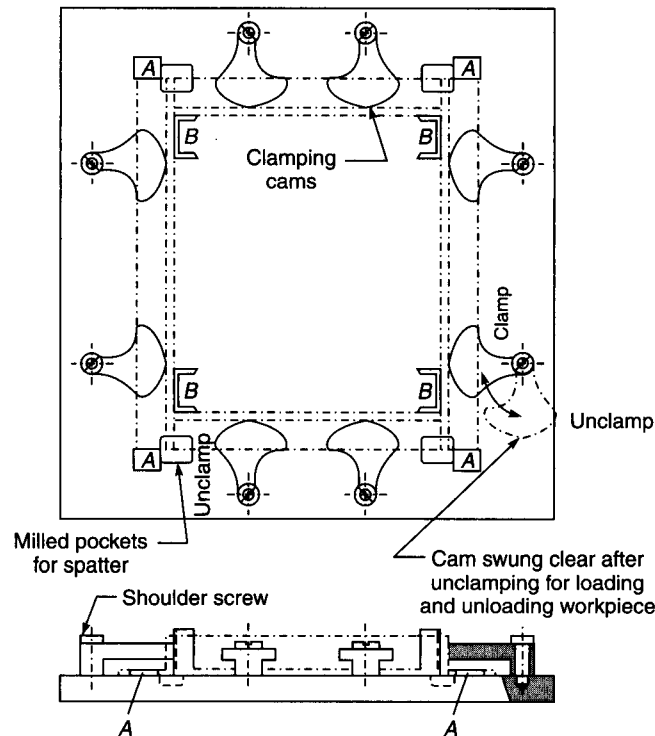
Figure **10.3**
Angle frame welding fixture

Figure 10.4c shows a welding fixture for the cover shown in *Figure 10.4b*. The curved end angles of the cover are located by pins with recesses equal to the angle width for longitudinal location of the curved angles (Section *BB*). The recessed diameter also provides rest for the angles. The unrecessed pins at the top are removable to allow unloading of the welded cover from the top. The key in the long base and the mating key-way in the end brackets (housing the location pins) facilitate alignment of the end-brackets to ensure that 8.5 ⌀ holes near the unwelded ends of the curved angles are aligned properly. The longitudinal angle connecting the curved end angles is located by a step in the rest on one side and by location pins on the other. The rests near the curved angles are far enough from the weld joint to avoid welding spatter from falling on the rests or the location pins.
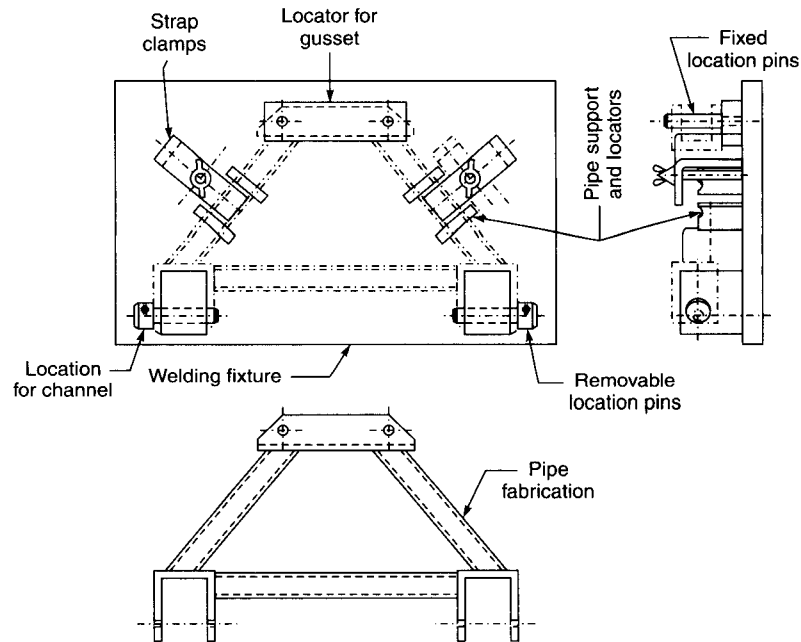
Figure **10.4a**
Welding fixture for pipe fabrication

Most of the welding fixtures are used mainly for tack-welding the constituents together. After tack-welding, the fabrication can be removed from the fixture for full welding without the fixture.

Pressing Fixtures

Assembly operations often involve pressing interference fit pins, bushes and other parts in the housings. The pressing fixtures used for these operations consist of:

1. Location arrangement for housing.

2. Locator for the part to be pressed.

3. System for alignment of the part to be pressed with the housing.
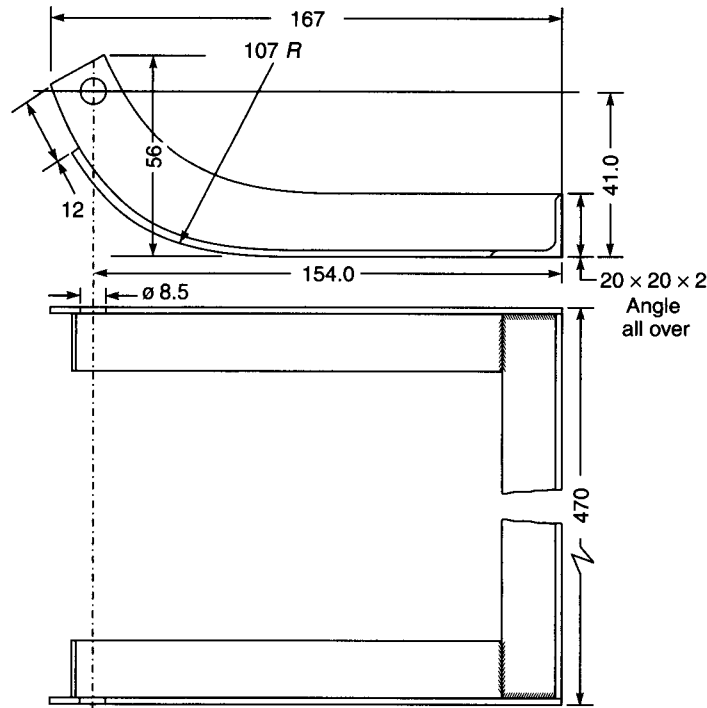
Figure **10.4b**

Machine cover: workpiece for welding fixture in Figure 10.4c

4. Arrangement for application of press force to drive the part into the housing.

Figure 10.5(a) shows a bushing pressing fixture. The housing is located by a slide fit locator in the hole mating with the outside diameter of the push. The housing locator has a smaller alignment bore at the top. This hole is slide fit with another locator which engages with bushing bore. As the bushing locator is longer than the bushing, the protruding length below the bushing engages with the alignment hole in the housing locator. This aligns the bushing outside diameter with the mating bore in the housing. The bushing locator houses a split ring of spring steel. The ring acts like a piston ring in an engine cylinder or like an internal circlip. The outside
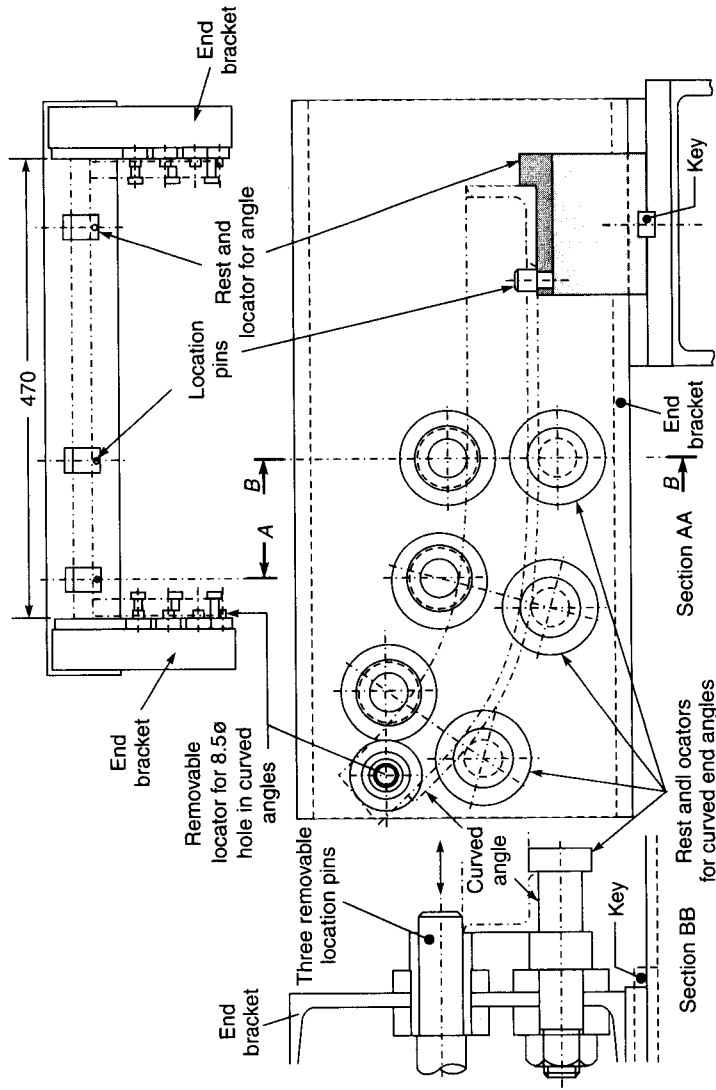
Figure **10.4c**
Welding fixture for cover in Figure 10.4b
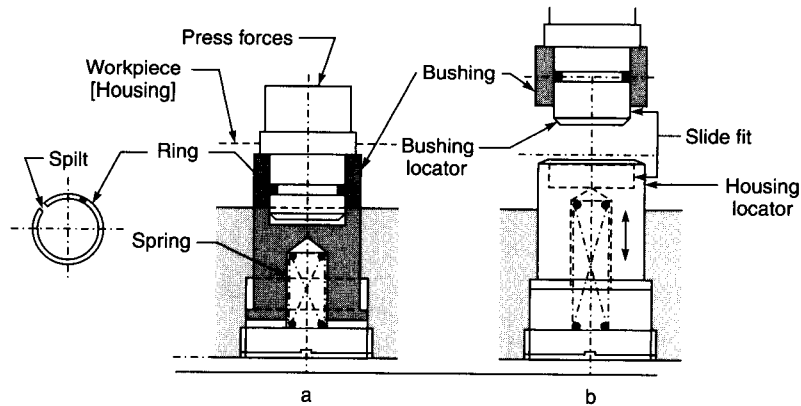
Figure **10.5**
Bushing pressing fixture

diameter of the ring is bigger than the bushing bore. The split ring holds the bushing from within the bore with spring action and prevents it from falling down due to gravity.

Press force is applied at the top of the bushing locator. The bushing locator enters the slide fit hole in the housing locator and aligns the outside diameter of the bushing with the bore in the housing. Further downward movement drives the bushing into the housing as the housing locator is pushed downwards against the spring.

During upstroke of the press, the spring pushes the housing locator and the bushing locator upwards to the position shown in *Figure 10.5b.*
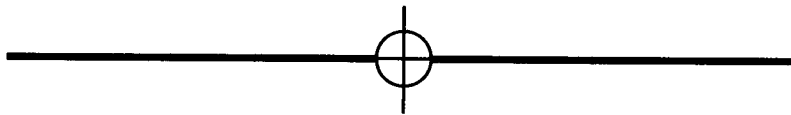
Inspection Devices

A long with the manufacturing, the inspection of the components must also be speeded up in the mass production. The skills required for inspection must be reduced to lower the labor costs. This is achieved by replacing standard measuring instruments such as the vernier and micrometer by gauges. The gauges do not measure the actual size of the manufactured component but merely check if the dimensions of the component fall within the high and low limits specified on the drawing. They ensure the desired fit in assembly.

Standard Gauges

Cylindrical holes can be inspected by simple plug gauges (*Figure 11.1*). A plug gauge consists of two hardened plugs with a connect-
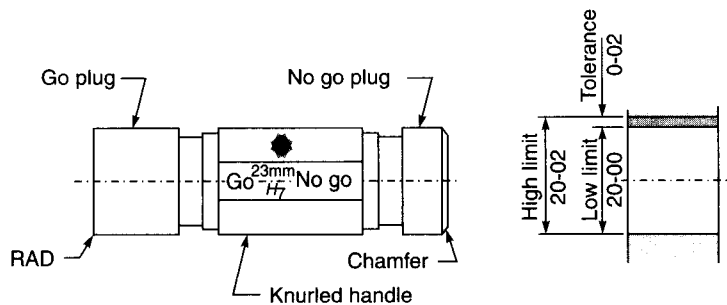
Figure **11.1**
Plug gauge

ing handle. The longer go plug is passed through the hole to ensure that the hole size is bigger than the low (minimum) limit. The shorter not go plug should not pass through the hole, if it is lesser than the high (maximum) limit specified on the drawing. Thus, an unskilled inspector can pass the component merely by checking that the go plug enters the component and the not go plug does not.

Similarly, outside diameters can be inspected by caliper or snap gauges. (*Figure 11.2*). Length gauges are also used in a similar manner. For the male parts in all the gauges, go gap through which the component must pass would be bigger than the no go gap into which the component should not enter.
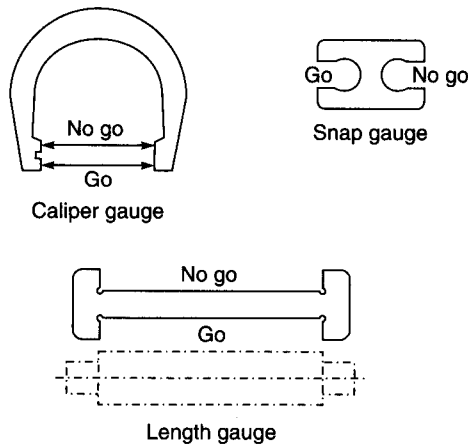
Figure **11.2**
Caliper gauges
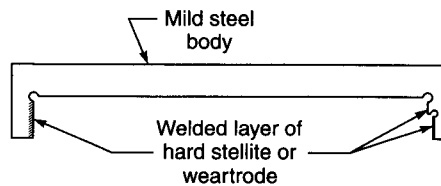
Figure **11.3**
Large caliper gauges

Plug gauges and outside diameter gauges (caliper and snap gauges) have been standardized by national and/or international technical societies and institutes. They are readily available by refering to the applicable published standards. Length gauges must, however, be manufactured to suit the components.

Special Gauges

Slots, gaps and key-ways are checked by gauges which function like plug gauges. They are made from plates and are rectangular in section (*Figure 11.4*).
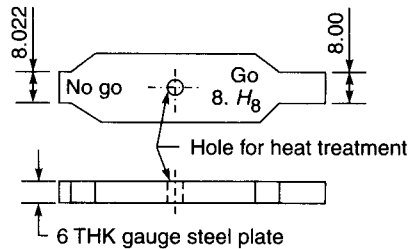
Figure **11.4**
Key-way and slot checking gauge

Tapered holes are inspected for the diameter of the bigger end by a tapered plug with a step at big end. The lower face of the step corresponds to the low limit of the hole size and the upper face with the higher limit. If the face of the workpiece falls within the upper and lower faces of the step, the workpiece is within the limits (*Figure 11.5*). The inspection is carried out by seeing or by the feel of the finger.

A similar method is used for checking distances between parallel faces of the workpieces. *Figure 11.6* shows a flush surface gauge for
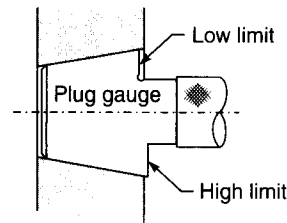
Figure **11.5**
Flush surface gauge for tapered hole

checking the shoulder to end face length of the pin. If the length is within the limits, the small end of the pin falls be-tween the two limiting faces of the gauge. Flush surfaces are sometimes built in a pin. Then, the gauge is called a flush pin gauge (See *Figure*

Figure **11.6**
Flush surface length gauge

11.7). Flush pin gauges can be used conveniently for inspection of the distance between two conical bores.
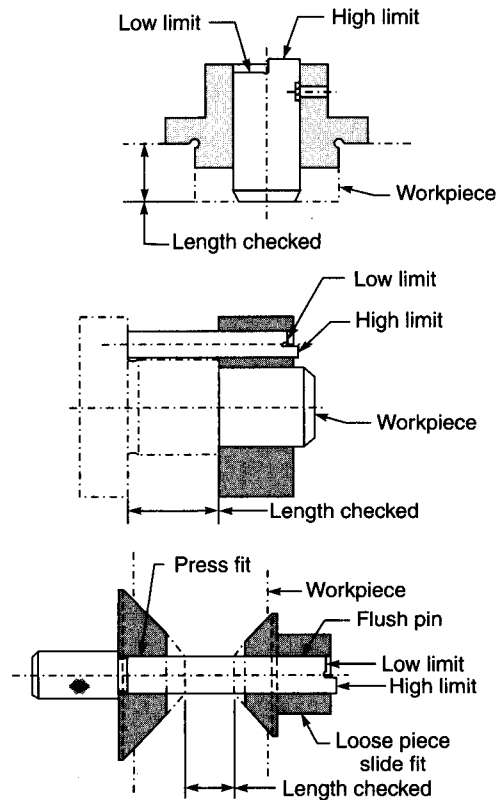
Figure **11.7**
Flush pin gauges

The Center distance between two cylindrical holes can be inspected with a snap gauge (*Figure 11.8*). The holes should be first inspected individually for accuracy of the diameters before the center distance is checked. In this type of center distance gauge, there is no *go*. Instead, there are two *no goes*. One inspects dimension. A for the minimum center distance limit and the other dimension. B for the maximum center distance. If none of the *no goes* enter the workpiece, the center distance is within the limits specified on the drawing.
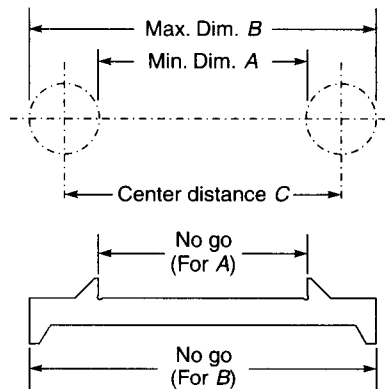
Figure **11.8**
Snap gauge for checking center distance

Receiver Gauges

The center distance as well as the diameters of the holes can be inspected at one go by using a receiver gauge. These are used for checking the suitability of the workpiece for assembly with other mating parts. If a receiver gauge accepts a workpiece, it can be assembled easily in the final product. A receiver gauge does not measure the extent of inaccuracies in the workpiece. The gauge just checks the possibility of easy assembly.

Figure 11.9 shows a receiver gauge for a gear box cover. Center distance C between the shafts A and B is exactly equal to the center
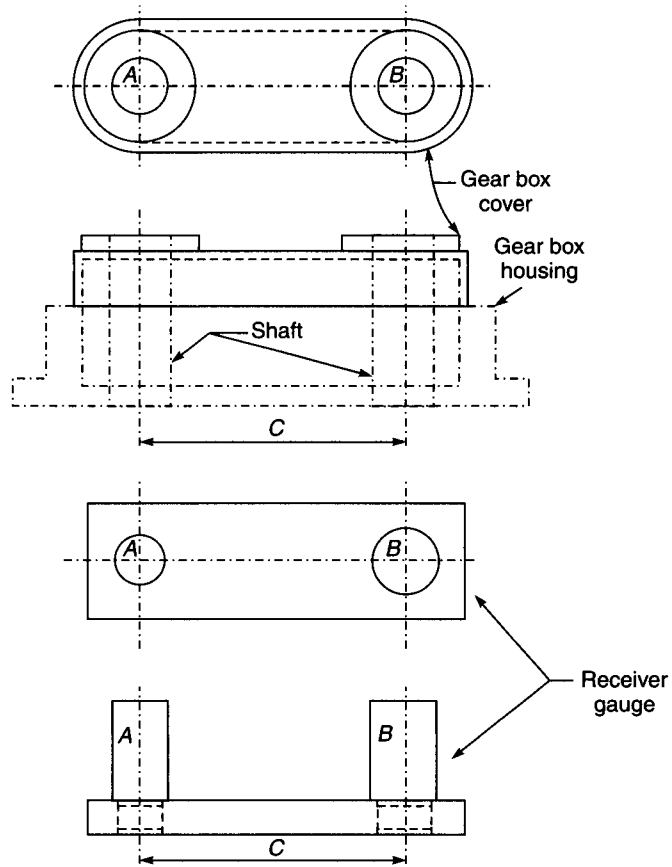
Figure **11.9**
Receiver gauge for gear box cover

distance of the shaft holes in the corresponding gear box housing. The diameters of the posts A and B are manufactured to the maximum limit of the shafts mating with the holes in the gear box cover. Thus, the receiver gauge is a plate fitted with two plugs A and B. If the gear box cover to be checked entries both plugs A and B we can be sure that the hole sizes as well as the center distance between the holes are suitable for easy assembly of the gear box cover with the mating shafts and gear box housing. If the receiver gauge does not accept the workpiece, it cannot be assembled with the corresponding mating parts.

Receiver gauges can be used conveniently to simultaneously check a number of dimensions in a workpiece in a single handling. a multi dimensional receiver gauge holds a number of locators which engage simultaneously with the workpiece to check its suitability for assembly.

Figure 11.10 shows an inspection device for checking the various dimensions of a workpiece. The workpiece is inserted into the flush surface gauge and a plug is inserted into the gauge and workpiece cross hole C. If these three can be assembled together we can be sure that:

1. Workpiece diameter d is less than the high limit;

2. Cross hole diameter C is more than the low limit, the plug acts as a go gauge; and

3. Cross hole C is at the centre of diameter d within the given centrality limits and the mating parts in the crosshole can be assembled without any trouble.

Thus, the flush surface gauge and the plug together act as a receiver gauge.
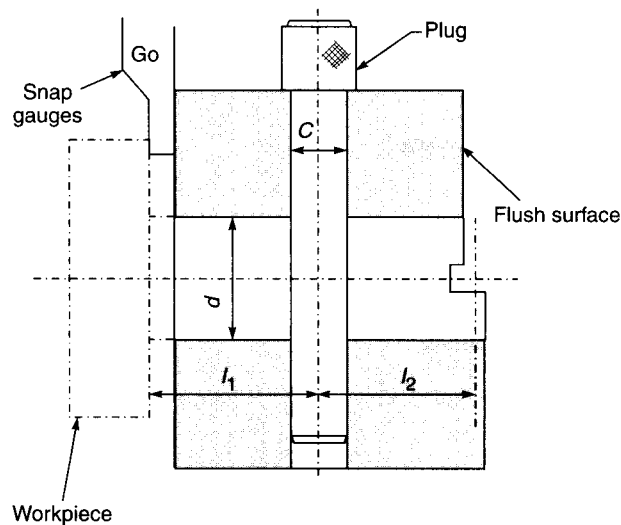
Figure **11.10**
Inspection device for checking four sizes

After the plug, flush surface gauge and the workpiece have been assembled together, the distances of crosshole C from collar (l_1) and end face of the small diameter (l_2) can be checked. The end face of diameter d should be within two flush steps of the gauge. The distance of crosshole C from collar (l_1) can be checked by checking the gap between the collar and the unstepped face of the flush surface gauge with go, not go snap gauges. During this inspection, the assembly serves as an inspection fixture.

Inspection fixtures often have workpiece holding and moving arrangement for convenience. *Figure 11.11* shows an inspection fixture for checking the concentricity of the angular seat of the valve with respect to its stem. The stem is guided in a hardened bush and there is an arrangement for mounting a dial gauge in the suitable position. The valve has to be simply loaded in the guide bush and rotated around the stem axis to measure the concentricity of the angular seat with the dial gauge. Thus, the inspection fixture simplifies and speeds up the inspection of the valve.
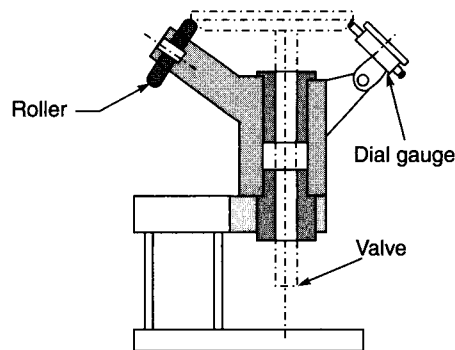
Figure **11.11**
Value concentricity inspection fixture

Workpiece marking and Setting Gauges

Machining allowances on castings and forgings often vary considerably. Consequently, the amount of material to be machined away

must be varied in such a manner that the holes in the workpiece would be at the centers of the corresponding bosses. So, we have to locate on the bosses while machining reference faces which would later be used as locations while making holes in the bosses. This can be done by using marking and setting gauges.

Figure 11.12 shows a marking gauge for a casting with two bosses *P* and *Q*. The casting is levelled with wedges and its height is adjusted in such a way that the pointers for bosses *P* and *Q* top and bottom are more or less symmetrical with respect to the bosses. The casting can be marked in this position by two markers for the top and bottom faces to be machined. The marking can be used for levelling the workpiece during machining operation. Furthermore, if there is insufficient machining allowance on either of the faces, the fact would be discovered before commencing costly machining operation which might turn out to be wasteful at a later stage when the workpiece is rejected due to insufficient machining allowance.
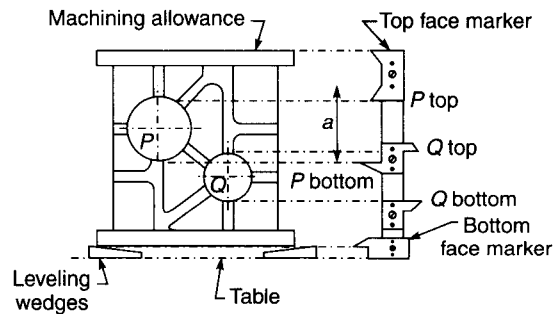
Figure **11.12**
Marking gauge for casting

Figure 11.13 shows a setting gauge for the workpiece shown in the fixture. The fixture has got two location pins *A* which can be engaged with guide bushings *B* in the loose setting gauge. The gauge has four small circular discs which serve as templates for positioning the workpiece in the fixture. After engaging pins *A* in bushings *B* of the setting gauge, the workpiece is moved in the fixture to align the workpiece bosses with the circular disc templates on the gauge.

After alignment, the workpiece is clamped in position in the fixture by four hexagonal headed bolts.
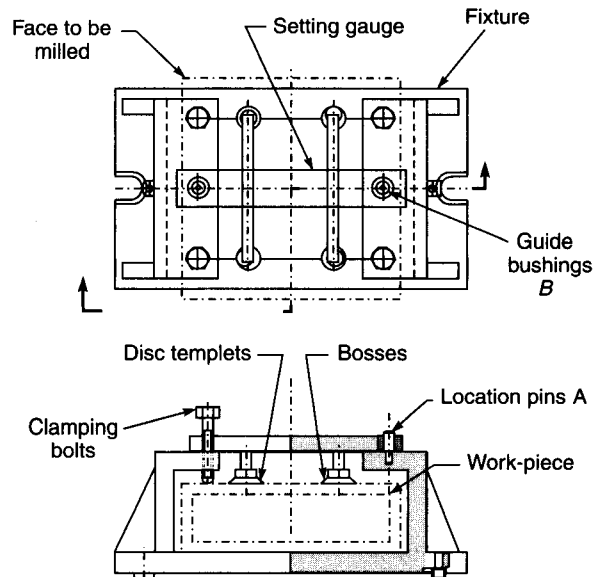
Figure 11.13
Setting gauge for casting

The gauge can then be removed and the end face of the workpiece can be machined. The loose setting gauge is used mainly to position (locate) the workpiece correctly in the fixture.

Materials and wear allowance

Since gauges might be used hundreds of times in every shift, they are subjected to abrasion and wear. This is countered by hardening the working surfaces of gauges. Over and above this, plug gauges are made slightly oversize and gauges for male parts are made slightly undersize to provide wear allowance. The allowance is generally

10 percent of the tolerance on the component. For example, a 70 mm ⌀ H7 hole has got a tolerance of + 0.03 mm. So, the go size plug would have wear allowance of 0.003 mm. The plug diameter would be 20.003 mm when new so that it can be used till the gauge wears by 0.003 mm.

The steel used for gauges should be suitable for hardening. Moreover, they should have low co-efficient of thermal expansion so that the gauge size does not change much due to climactic temperature variations. Many types of commercial gauge steel are readily available in the market. Most of them contain about 1 percent carbon.

For economy in material as well as hardening costs, gauges are designed in such a way that only the parts subjected to wear are made of hardened steel. Handles and unimportant constituents are made of cheaper mild steel. In bigger gauges, the entire body is made of mild steel and only the surfaces subjected to wear are deposited with a welded layer of hard material such as stellite or weartrode (*Figure 11.3*).

Gauges are often handled a large number times in every shift. Consequently, they should be made as light in weight as possible to reduce handling fatigue.
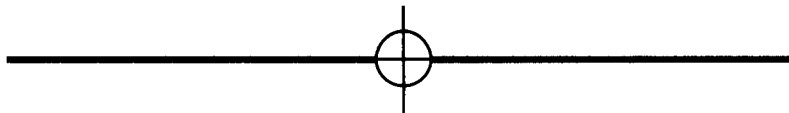
Shop Setups

The manufacture of sophisticated fixtures entails considerable machining, heat treatment, precision finishing and skillful assembly. The more sophisticated the fixture, the higher its manufacturing cost and longer its manufacturing time. On the other hand, prototype samples must be produced as fast as possible to procure orders for jobbing work. small enterprises engaged mainly in jobbing work, use ingenious methods to manufacture samples without manufacturing a costly sophisticated fixture. These temporary low cost arrangements are called shop setups. Even big organizations with ample resources, use shop setups, to produce a small number of sample pieces for checking their suitability in assembly.

A wide variety of standard setup elements have been developed for repeated usage in different shop setups. One of the principles of a good shop setup is to use a machine table as a base for resting a workpiece and avail the machine T slots for clamping.
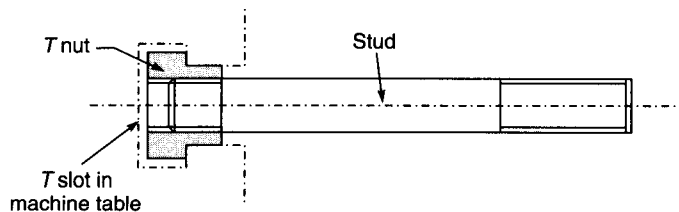
Figure **12.1**

Combination of T nut and stud as T bolt

The eye bolt or the combination of a T nut and a stud (*Figure 12.1*) is used widely. The combination of T nut, a heel pin and a lock nut can be used conveniently for heel support. *Figure 12.2* shows a swinging hook clamp with a special sleeve for mounting onto a T slot. *Figure 12.3* shows a cam-operated edge clamp suitable for a T slot. Most of the screws actuated clamps can be fixed onto the T slots.

Standard swinging hook clamp

Stud

Special sleeve

T Bolt

T
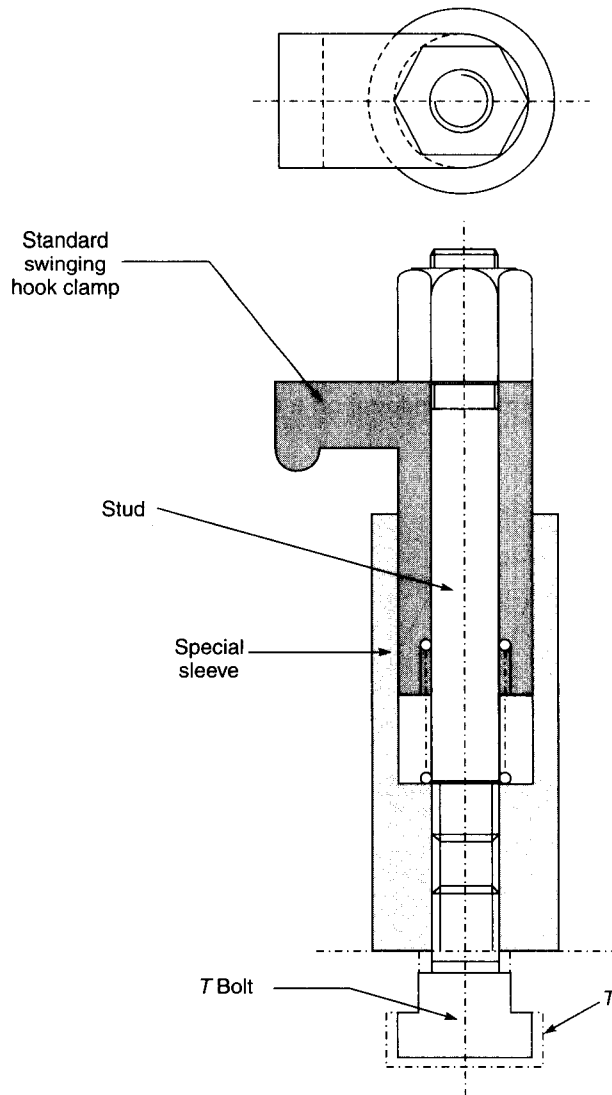
Figure **12.2**

Mounting of swinging hook clamp on a T slot
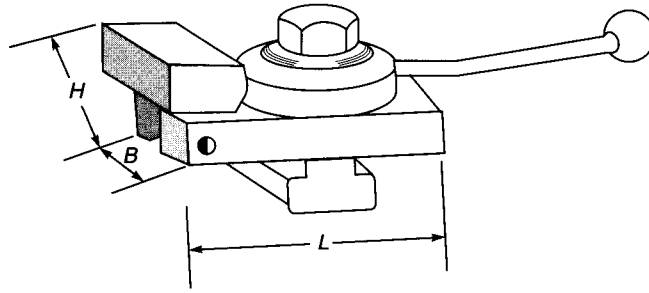
Figure **12.3**
Cam operated edge clamp

In turning machines such as lathes, the standard face plate (*Figure 12.4*) can be used as a fixture base. The slots in the plate serve as an anchorage for the clamping elements.

The slots are also used for securing location elements. *Figure 12.5* shows a shop setup for boring a pedestal on a lathe. A slotted plate is
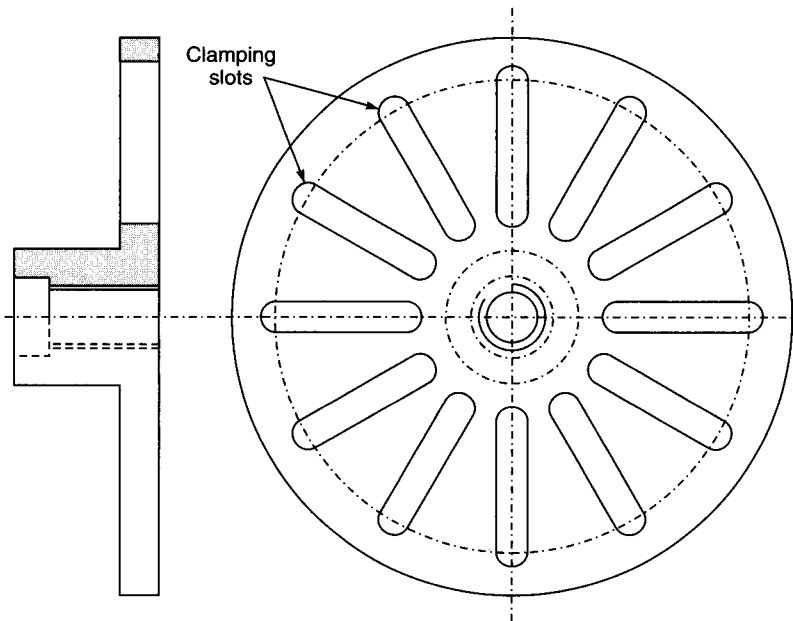
Clamping slots

Figure **12.4**
Face plate of a turning machine

Standard clamps

Clamping
screw

Special nut

Tenon

V block

Sect. *B-B*

Face
plate

Standard Clamp

Slotted
plate as
locator

Sect. *A-A*
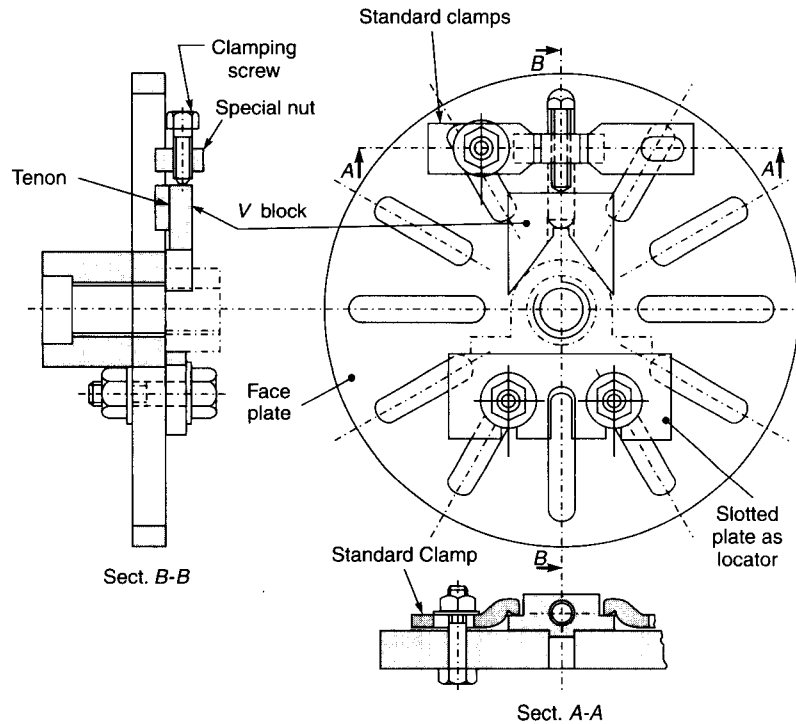
Figure **12.5**
Shop setup for boring a pedestal on lathe

used to locate the base of the pedestal. A special nut anchorable in the
T slot is used to house the clamping screw. The nut itself is clamped
on the face plate by two standard slotted clamps and hexagonal bolts,
nuts, and washers. A tenoned V block transmits the clamping force to
the pedestal.

Figure 12.6 shows various elements used in shop setups. The V blocks
are provided with slots at the bottom to enable fitting of a suitable
tenon. *Figure 12.7* shows another type of special nut used for housing
adjustable location screws. The integral tee simplifies clamping onto
the T slot. The tee also prevents rotation.

Figure 12.8 shows a shop setup for straddle milling of a workpiece
shown in *Figure 6.5*. The setup also requires a locator for the bore in
the bigger boss of the workpiece. The internal threads in the locator
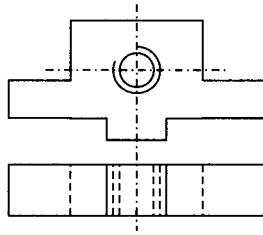
Figure **12.6a**
Special nut for setup in Figure 12.5

Tenon location
slot

b
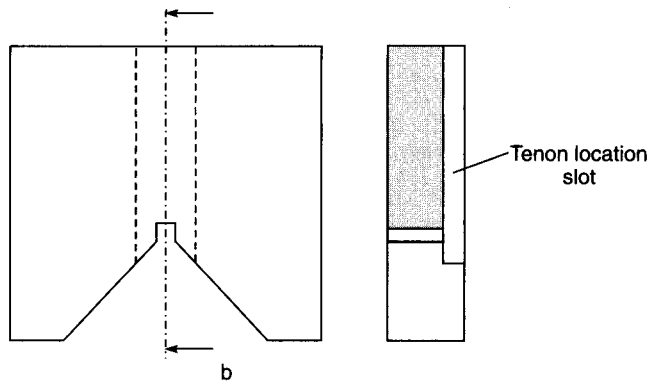
Figure **12.6b**
V block for setup in Figure 12.5
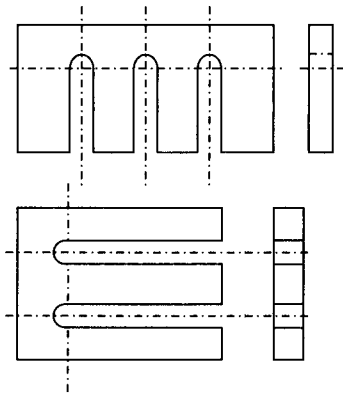
Figure **12.6c**
Slotted plates for shop setups
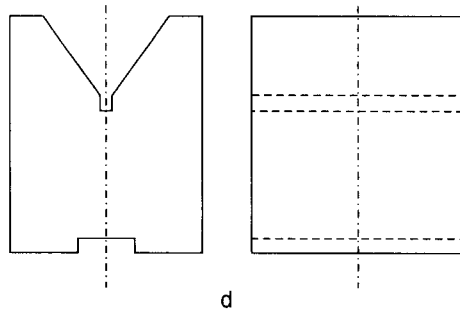
Figure **12.6d**
Tenoned V block for shop setups
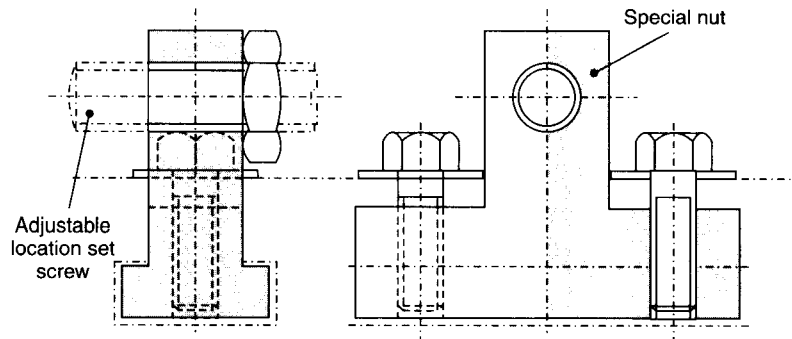
Figure **12.7**
Special nut for adjustable location screws in shop setups

are used for anchoring, and fixing workpiece clamping studs. All other elements in the setup such as slotted plate, special nut, standard clamp and C washer can be used for other shop setups too.

A pair of V blocks shown in *Figure 12.6d* can be used in setups for milling key-ways on cylindrical shafts. The V blocks are used for location only. Clamping is affected by *T* nuts, studs and standard slotted clamps.
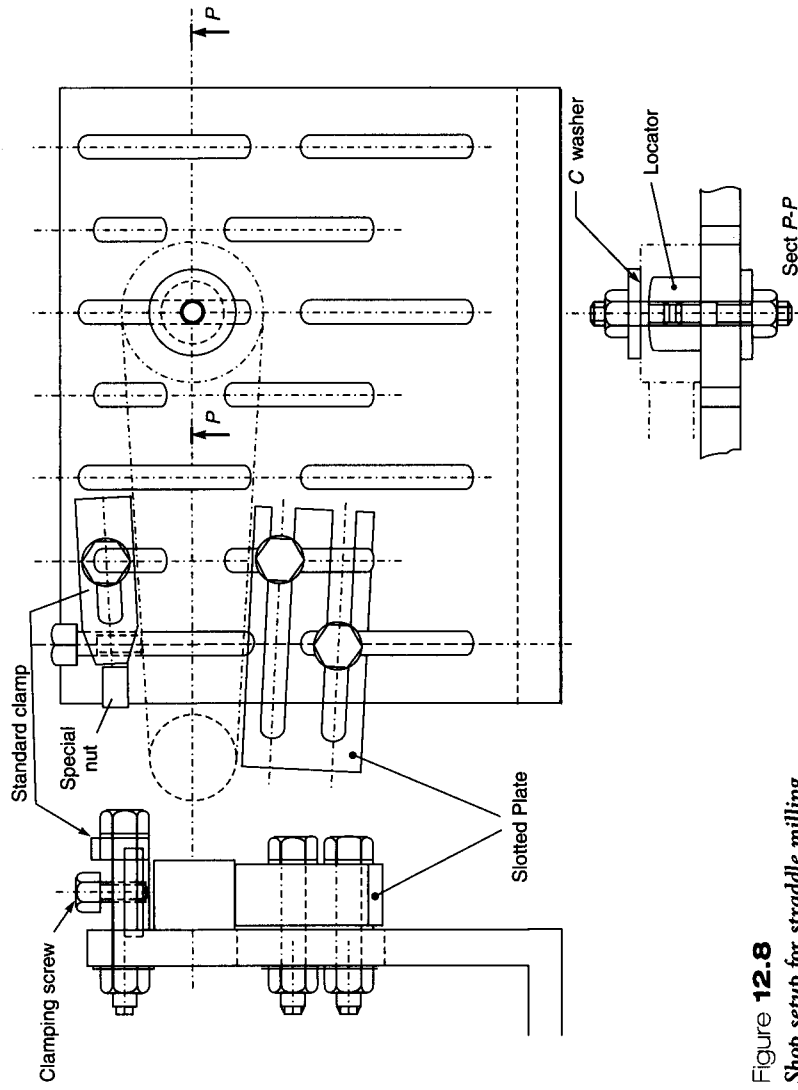
Figure **12.8**
Shop setup for straddle milling

Estimating

 n small enterprises, drafting personnel are, sometimes, told to
 estimate the cost of the designed jig/fixture. The cost comprises the
following constituents:

 1. Material costs

 2. Machining cost

 3. Heat treatment expenses

 4. Assembling and try-out cost.

Material Costs

Material costs are estimated by finding out the volume of the raw
material required. By multiplying the volume with the specific grav-
ity, the weight of the raw material is obtained. Tables giving
weight/meter length of cylindrical, hexagonal/square bars and plates
are readily available. Similarly, tables stating weight/sq. metre of the
various plate thicknesses can be used for finding out the weight of
the raw material. *Table 13.1* gives weight/metre of the standard sizes
of rolled steel—round, square, hexagonal bars and plates. The
weight of cast iron is nearly same as that of steel. Brass weighs about
10% more while aluminum weighs only one third (0.33%) of the
weight of steel.

The costs of raw materials also differ a lot. Medium carbon steel (RC
45–55) costs 1.5–2 times more than mild steel while high carbon

steel may cost four times the cost of mild steel. Non-shrinking tool steel can be 5–6 times costlier than mild steel. Further more, casting also involves pattern costs.

Inflation increases the costs as time passes. The cost of steel might be 10% higher after an year. So, it is advisable to find out the latest prices of the materials at the time of estimating.

* Table **13.1**   *Weights of Rolled Steel (7.843 gm/cc)*

Size S	Round S f kg/meter length	Square S Sq.	Hexagonal S A/F	Sheet S Thick kg/sq.meter
5	0.154	0.20	0.170	39.2
5.5	0.19	0.24	0.206	
6	0.222	0.28	0.245	
7	0.302	0.38	0.333	55
8	0.395	0.502	0.435	
9	0.50	0.64	0.551	
10	0.62	0.785	0.68	78.5
11	0.75	0.95	0.823	
12	0.89	1.13		94.2
14	1.21	1.54	1.33	109.9
16	1.58	2.01		125.6
17			1.96	
18	2.00	2.54		141.3
19		2.83	2.45	
20	2.47	3.14		
22	2.98	3.80	3.29	172.7
25	3.85	4.91		196.2
27		5.72	4.96	
28	4.83	6.15		219.74
32	6.31	8.04	6.96	251.14
35				274.67
36	7.99	10.17	8.81	
38				298.22
40	9.86	12.56		
41			11.4	

45	12.49	15.90		313.92
50	15.41	19.62	17.0	331.36
55	18.7	23.7	20.6	364.46
56	19.34	24.62		
60	22.2	28.3	24.5	397.63
63	24.47	31.16		
65	26.0	33.2	28.7	430.77
70	30.2	38.5	33.3	463.9
71	31.08	39.57		
75	34.7	44.2	38.2	497.04
80	39.46	50.24	43.5	530.18

* *Reader should consult applicable standards for specific steel to be used.*

Machining Costs ━━━━━━━━

Machining costs depend upon the type and size of the machine required. The hourly rates of bigger machines can be 2–3 times the rate of a smaller machine. The hourly rate for milling would be higher than that for turning. The rates for precision grinding machines are even more.

Furthermore, harder materials can be machined only with smaller cuts and require much more machining time than mild steel or aluminum. The range of cuts possible with the grinding machine are only a small fraction of the cuts possible with lathes or milling machines. The cuts made with grinders usually range from 0.005 to 0.025 while the cuts of the range of 3 is common with a lathe, shaping, or milling machine.

Computing precise machining time itself can be a costly affair. It is a must in mass production when a large number or similar pieces are produced. But a jig/fixture is usually manufactured only once. So, accurate computation of the machining costs is not warranted. A rough estimate is enough.

Graphs and tables come handy in quick estimation of machining time.

Heat Treatment Expenses ━━━━

Heat treatment cost depends upon the weight of the jig/fixture part at the time of heat treatment. It can cost as much as the cost of the material.

Assembling and Try-out costs ━━━━

Assembling and try-out costs comprise drilling and fitting costs. These are usually estimated on hours/shifts basis. As the required time depends upon the number of parts, precision and sophistication necessary in a jig/fixture, good judgement based on experience is necessary.

Small enterprises have small all around staff. So, the industry relies more on thumb rules rather than elaborate calculations for estimation.

Provided below are the thumb rules used by a small, competent, thriving tool room. The total cost of a part is taken as a multiple of the raw materials cost. The cost depends upon the operations involved. The following table encapsules the rules.

Table **13.2**   *Thumb Rules for Estimation*

Group No.	Operations involved	Total costs
1.	Only shaping, turning drilling and fitting.	Three times the raw materials cost.
2.	Shaping/turning, drilling, fitting and milling.	Four times the raw materials costs.
3.	Above operations plus heat treatment.	Five times the raw materials costs.
4.	Above operations plus precision grinding or lapping.	Six times the raw materials costs.

Although, the above method gives a very subjective estimate, the organization finds it satisfactory.

As manufacturing of the tools often entails retrofitting/adjustments after a try-out, the margin of profit in the manufacture of jig/fixture should be higher than mass production work.

The profit is rarely less than 30% of the manufacturing cost. It can be as high as 100% of the manufacturing cost.

Example 13.1: Find the manufacturing cost of 14 ∅ bore collared bushing shown in *Figure 14.11*. The bushing is to be manufactured from 28 ∅ × 35 long alloy steel bar which costs $1.60/kg. After rough turning, the bushing is to be hardened and finished by grinding.

Solution: Referring to *Table 13.1*, we note that 28 ∅ steel bar weights 4.83 kg/meter.

$$\therefore \qquad \text{Wt. of a 35 long piece} = \frac{35}{1000} \times 4.83$$

$$= 0.169 \text{ kg.}$$

$$\text{Cost of material at } \$1.60 = 0.169 \times 1.60$$

$$\text{kg} = \$0.27$$

Machining involves turning, hardening, and grinding.

Referring to *Table 13.2*, we notice that the bushing falls in Group 4, for which the total cost is approximately six times the raw material cost.

$$\therefore \qquad \text{Total cost } = \$0.27 \times 6$$

$$= \$1.62$$

If the bushing is to be sold, profit should be added.

$$\text{Selling cost at 30\% profit } = \$1.62 \times 1.3$$

$$= \$2.11 \text{ (min.)}$$

$$\text{Selling cost at 100\% profit } = \$1.62 \times 2$$

$$= \$3.24 \text{ (max.)}$$
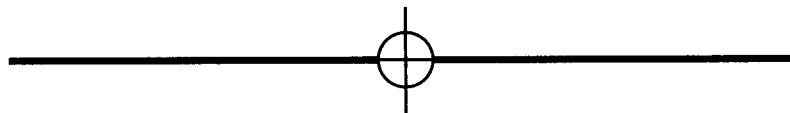
Reference Tables

Tolerance Limits for Selected Holes (Hole Basis)

Nominal sizes		H7		H8		H9		H11	
Over mm	Up to and incl. mm	ul +	ll	ul +	ll	ul +	ll	ul +	ll
6	10	15	0	22	0	36	0	90	0
10	18	18	0	27	0	43	0	110	0
18	30	21	0	33	0	52	0	130	0
30	50	25	0	39	0	62	0	160	0
50	80	30	0	46	0	74	0	190	0
80	120	35	0	54	0	87	0	220	0
120	180	40	0	63	0	100	0	250	0
180	250	46	0	72	0	115	0	290	0

ul = Upper limit; ll = Lower limit; Unit = 0.001 mm.

Figure **14.1**
Hole tolerance for common fits

Editor's Note: Some of the material contained in the following reference tables may not be compatible with current standards as published in North America. Therefore, the reader is advised to consult applicable references for specific projects to avoid potential design errors.

Tolerance Limits for Selected Shafts

Nominal sizes Over to mm mm		c11 ul −	c11 ll −	d10 ul −	d10 ll −	e9 ul −	e9 ll −	f7 ul −	f7 ll −	g6 ul −	g6 ll −	h6 ul −	h6 ll −	k6 ul +	k6 ll +	n6 ul +	n6 ll +	p6 ul +	p6 ll +	s6 ul +	s6 ll +
6	10	80	170	40	98	25	61	13	28	5	14	0	9	10	1	19	10	24	15	32	23
10	18	95	205	50	120	32	75	16	34	6	17	0	11	12	1	23	12	29	18	39	28
18	30	110	240	65	149	40	92	20	41	7	20	0	13	15	2	28	15	35	22	48	35
30	40	120	280	80	180	50	112	25	50	9	25	0	16	18	2	33	17	42	26	59	43
40	50	130	290																		
50	65	140	330	100	220	60	134	30	60	10	29	0	19	21	2	39	20	51	32	72	53
65	80	150	340																	78	59
80	100	170	390	120	260	72	159	36	71	12	34	0	22	25	3	45	23	59	37	93	71
100	120	180	400																	101	79
120	140	200	450	145	305	85	185	43	83	14	39	0	25	28	3	52	27	68	43	117	92
140	160	210	460																	125	100
160	180	230	480	170	355															133	108
180	200	240	530			100	215	50	96	15	44	0	29	33	4	60	31	79	50	151	122
200	225	260	550																	159	130
225	250	280	570																	169	140

ul = Upper limit; ll = Lower limit; Unit = 0.001 mm

Figure **14.1 (continued)**
Hole tolerance for common fits

Material: Mild Steel

A	B	C	D	E	F	G
10	13	1.5	3	12	60	10
12	16	2	4	15	70	12
16	20	2.5	5	18	90	16
20	25	3	6	24	110	20

Figure **14.2**
Cam clamps
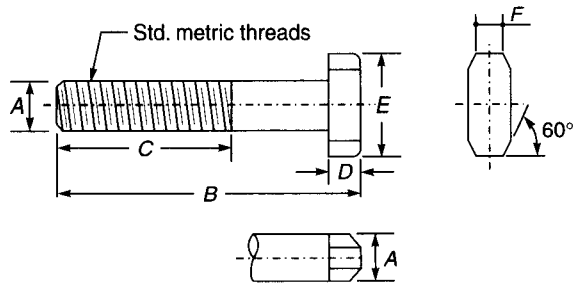
A	B	C	D	E	F
M 10	50	35	12	28	5
M 12	62	38	15	32	6
M 16	82	47	20	35	6
M 20	100	60	22	40	10

Figure **14.3**
Quarter-turn screw
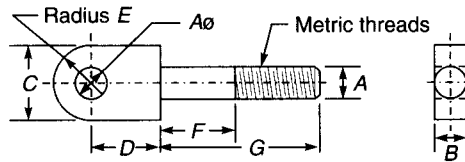
A	B	C	D	E	F	G
10	13	20	13	10	12	32
10	13	20	13	10	25	62
12	16	25	16	12	16	50
12	16	25	16	12	25	75
16	20	32	20	16	20	90
20	22	38	22	20	22	75

Figure **14.4**
Eye bolts
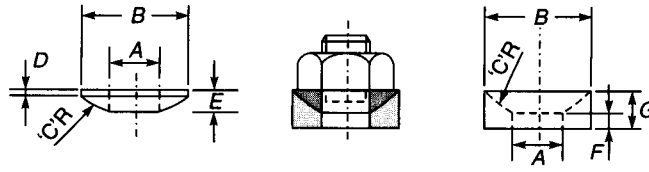
Material: mild steel

A	B	C	D	E	F	G
9	20	20	2.5	4.5	2.5	5
11	22	22	2.5	6	2.5	6
14	28	28	2.5	6.5	2.5	6.5
18	40	40	3	7	3	7

'C'R = Radius C

Figure **14.5**
Spherical washers
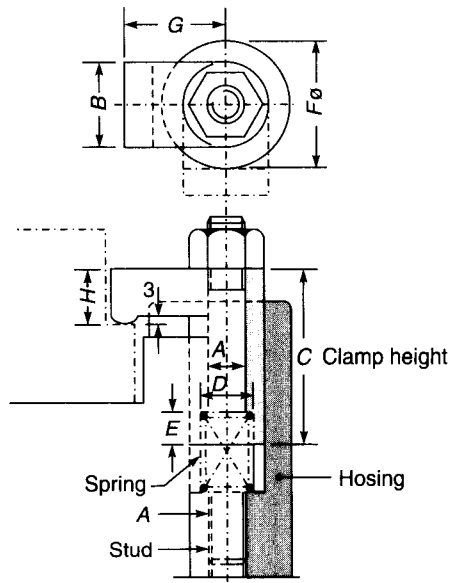
Material: Mild steel

A	B	C	D	E	F	G	H
M_8	14	44	11	6	26	24	11
M_{12}	21	66	16	9	40	34	16
M_{16}	28	88	22	12	52	44	22

Figure **14.6**
Swinging hook clamps
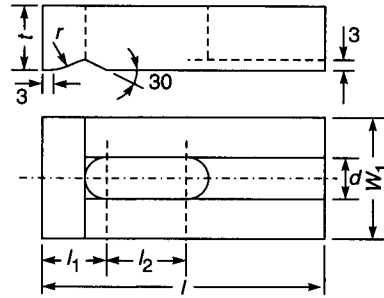
Material: Mild steel

dH 13	l	l_1	l_2	r	W_1	t	Screw size
6.6	60	13	13	12	20	12	M 6
9	68	15	15	14	25	14	M 8
11	75	18	20	16	30	16	M 10
14	90	20	25	20	40	20	M 12
18	110	23	30	25	50	25	M 16
22	125	25	35	30	60	30	M 20
26	150	30	40	30	70	35	M 24
33	200	35	50	35	80	40	M 30

Figure **14.7**
Slotted strap clamps
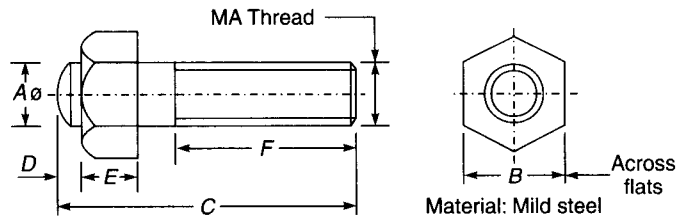
A	B	C	D	E	F
10	17	56	5	6	40
12	20	65	6	7	50
16	28	80	7	10	60
20	35	100	8	12	70
24	40	110	8	15	80

Figure **14.8**
Adjustable heel pins
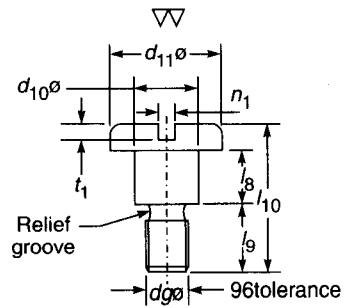
$\frac{d_6}{g_6}$	l_8	d_{10}	d_{11}	l_9	l_{10}	n_1	t_1
M_5	5	7.5	12	8	15.5	1.6	2
M_6	6	10	16	10	19.5	2	2.5
	7.5				21		
M_8	10	13	20	12	27	2.5	3

Figure **14.9**
Shoulder screws
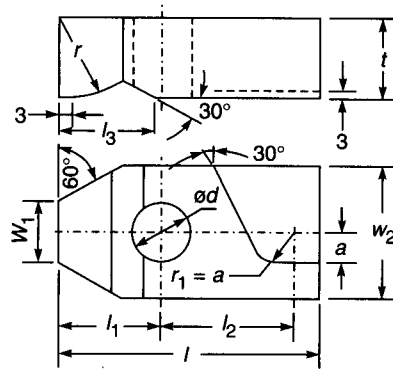
d H_{13}	w_2	w_1	t	l	l_1	l_2	l_3	a	r	Size of screw
6.6	20	7	12	52	20	25	14	4	12	M_6
9	25	9	14	60	22	30	18	5	14	M_8
11	30	11	16	70	24	35	20	6	16	M_{10}
14	40	15	20	80	26	40	22	7	20	M_{12}
18	45	18	25	90	32	45	28	9	25	M_{16}
22	60	23	30	100	38	50	32	11	30	M_{20}
26	60	26	30	125	50	60	32	13	30	M_{24}
33	70	34	35	150	60	70	40	17	35	M_{30}

Material: Mild steel

Figure **14.10**
Swinging strap clamps

Type *A* bore rounded on top only   Type *B* bore rounded on both ends

F_7 d_1		l_1		l_2	d_2	d_3	r_1	z
Over	Up to	Short	Long		n_6			
-	1				3	6		
1	1.8	6	9	2	4	7	1.2	
1.8	2.6				5	8		0.005
2.6	3.3				6	10	1.6	
3.3	4	8	12	2.5	7	11		
4	5				8	12		
5	6	10	16	3	10	14	2	
6	8				12	16		
8	10	12	20	4	15	19	2.5	
10	12				18	22		0.01
12	15	16	28	4	22	26	4	
15	18				26	30		
18	22				30	35		
22	26	20	36	5	35	40	6	
26	30				42	47		
30	35	25	45	5	48	55		
35	42				55	62		0.02
42	48	30	56	6	62	69	8	
48	55				70	77		
55	63	35	72	6	78	85		

Material: Steel hardened to 62–65 HRC

Figure **14.11**
Collared bushings

Type A fixed renewable bushing

Type B fixed renewable bushing

Type C fixed renewable bushing

All dimension sin mm
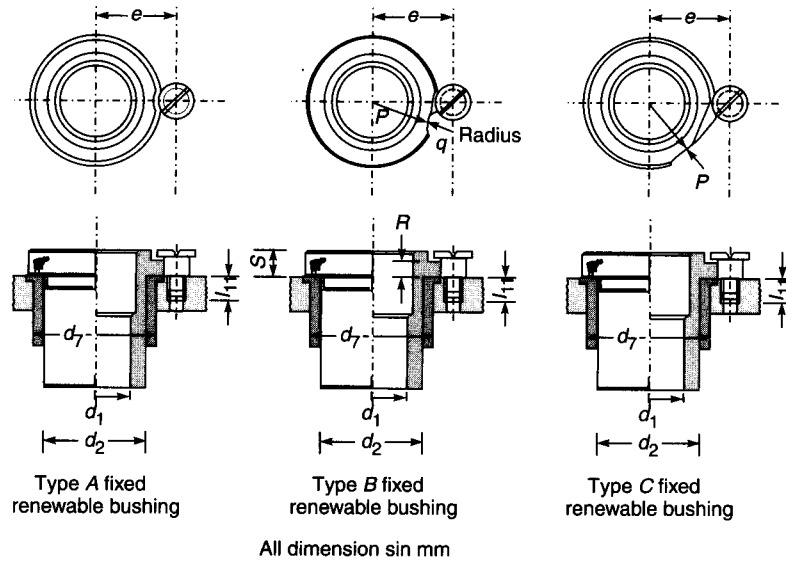
Renewable drill bushing		Liner bushing		e	l_{11}	Locking screw				
d_1 G_7	d_2	d_2	d_7		Min.		P	q	R	s
Over Up to	h_6	H_7	m_6							
— 2.65	8	8	12	11.5	10	M5 × 5	5	7	4	7
2.65 4.75	10	10	15	13			6.5	7	4	7
4.75 8.5	15	15	20	17.5		M6 × 6	9	9	5	9
8.5 14	22	22	28	21.5	12		13	9	5	9
14 19	28	28	36	25.5		M6 × 7.5	17	9	7	11
19 25	35	35	46	31			22.5	9	7	11
25 33.5	46	46	56	37	15	M8 × 10	26	11	9	14
33.5 45	58	58	70	44			33	11	9	14

Material: Steel hardended to 62–65 HRC

Figure **14.12**
Renewable and slip bushings

MATERIAL	REF. NO.		IMPORTANT CONSTITUENTS %						MAX. HARDNESS (RC)	APPLICATIONS
	INDIAN	BRITISH	C	Mn	Cr	Ni	W	V		
High speed steel 18%	T75W18 Co6Cr4V1	—	0.75	0.35	4.3	—	18	1.6	65	Metal cutting tools: drills
High speed steel 22%	—	—	0.8	0.35	4.3		22	1.6	66	High stress cutting tools: milling cutters
Cold working die steel (high carbon, high chromium) [HCHC]	T160Cr12	—	1.6	0.35	12			0.8	62	Cold working high impact press tools, threading rolls
Die steel [hot working]	T35Cr5 Mo100	—	0.32	0.35	5.0		1.4	0.3	48	Forging, extrusion and hot working dies
Carbon steel }	50Cr1V23	En44	0.85	0.87					61	Standard cutting tools
Spring steel }			1.0	0.5	1.2				47	Collets, springs
Medium carbon steel	C45	En8	0.45	0.75					45	Bolts, shafts, bigger gears.
High tensile steel	40Ni2Cr1 Mo28	En24	0.4	0.55	1.1	1.5			50	Highly stressed parts: piston rods, gears, shafts
Oil hardening non-shrinking tool steel [OHNS]	T110W2 Cr1	—	1.1	1.1	1.1		1.5			Fine engraving tool, taps, reamers, cutters, knives, gauges.
Nickel chrome steel	13Ni3Cr80	En36	0.14	0.5	0.9	3.3			62	Gears, case hardened parts
Carbon chromium bearing steel	103Cr1	En31	1.05	0.35	1.15				62	Cold forming tools, knurling tools, ball bearings
Carburising steel	17Mn1Cr95	—	0.17	1.15	0.95				59 [case]	Shafts, gears, spindles
Carburising steel	15Ni2Cr1M015	En354	0.15	0.8	1.00	1.75			59 [case]	Heavy duty components: gears
Nitriding steel	40Cr2Al1	En41b	0.4	0.55	1.65	0.3			66 [case]	High abrasion, high fatigue, low distortion, low stress parts: boring bars.
Free cutting Mild steel	14Mn1 S14	En202	0.14	1.4					can not be hardened	Parts needing good machinability and finish: threaded fasteners

Figure **14.13a**
Ferrous materials for jigs, fixtures and tools

Figure **14.13a** *(continued)*

CASTINGS

CLASS	GENERAL	MALLEABLE		NODULAR	GREY	MEEHANITE									
						HEAT RESISTANT				WEAR RESISTANT				CORROSION RESISTANT	
GRADE	GCI	MCI		SG		HR	HS	HSV	HE	W1	–	4	VSH	CC	CR	CRS
	15–25	A	B	370–800	30–40											
TENSILE STRENGTH KG/MM²	15–25	36	28	37–80	30–40	28	42	70	17	35	–	42	70	28	17	38

MEEHANITE GENERAL

GRADE/CLASS	GM	GA	GC	GE	GF	AQ	SF	SP	SH	AQS
	60	50	40	30	20		60	80	100	
TENSILE STRENGTH KG/MM²	38	35	28	21	14	35	42	56	63	56

1. **Aluminium**	Tensile strength 6.5–43 kg/mm². It is used for low stress parts needing light weight, corrosion resistance and good thermal and electrical conductivity.
2. **Brass**	Alloy of copper (54-73%) and zinc (remaining), tensile strength 28–68 kg/mm². It is used for parts needing corrosion resistance, fine surface finish and bearing properties: bushes for low speed shafts.
3. **Bronze**	Tensile strength 20–55 kg/mm². It is used for low speed bearings and parts calling for corrosion resistance. Phospher bronze is used widely for replaceable nuts mating with lead screws in machine mechanisms.

Figure **14.13b**
Non-ferrous materials
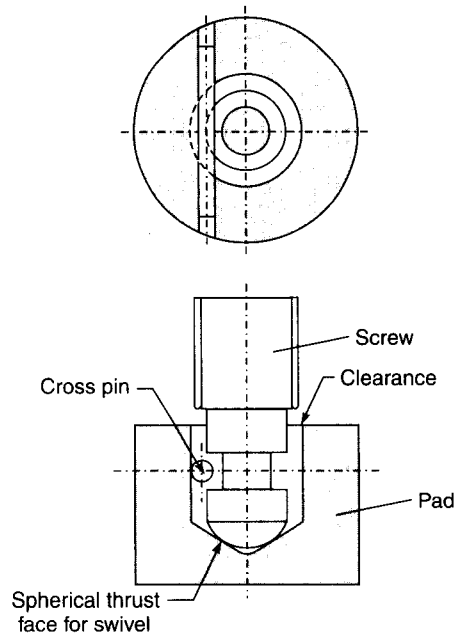
Figure **14.14a**
Floating pad assembly

Pressure pads

Pressure face
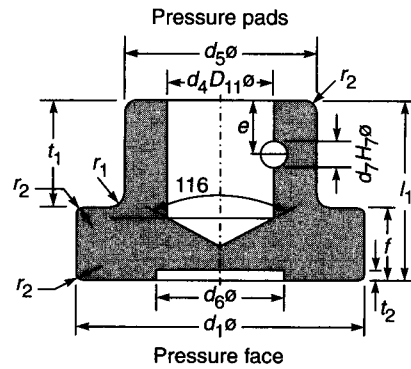
Dimensions												For screw with thread	Fastening pin
d_1	d_4	d_5	d_6	d_7	e	f	h	r_1	r_2	t_2	t_1		
10	3.8	8	4	1.5	2.5	2.5	7	1.2	0.3	0.5	4.5	M5	1.5m6 × 6
12	4.8	10	5	1.5	2.5	2.5	8	1.5	0.3	0.5	5	M6	1.5m6 × 8
16	6.4	12	7	2	3	3.5	9.5	2	0.4	0.5	6	M8	2m6 × 8
20	7.4	15	8	2	3.5	5	12	2	0.4	1	7	M10	2m6 × 14
25	9.5	18	10	3	4.5	6	15	3	0.6	1	9	M12	3m6 × 14
32	12.5	22	14	3	6	7	19	3	0.6	1	12	M16	3m6 × 16
40	15.5	28	18	4	7.5	9	24	4	0.8	1	15	M20	4m6 × 20

Figure **14.14b**

Floating pressure pads
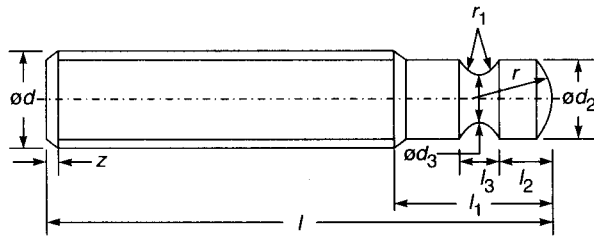
Material: Surface hardening steel

d_1	d_2	d_3	r	r_1	l_1	l_2	l_3	l	z
M6	4.5	3	3	0.6	6.5	2.2	2.2	30,50	1.0
M8	6	4	5	0.8	8.5	2.8	3	40,60	1.25
M10	7	5	6	0.8	10.0	3.2	3	60,80	1.50
M12	9	6	6	1.0	13.0	4.3	4.5	60,80,100	1.75
M16	12	9	9	1.0	17.0	6.3	4.5	80,100,125	2.0
M20	15	10	13	1.5	21	7.4	6	100,125,150	2.5

Figure **14.14c**
Screws for floating pressure pads
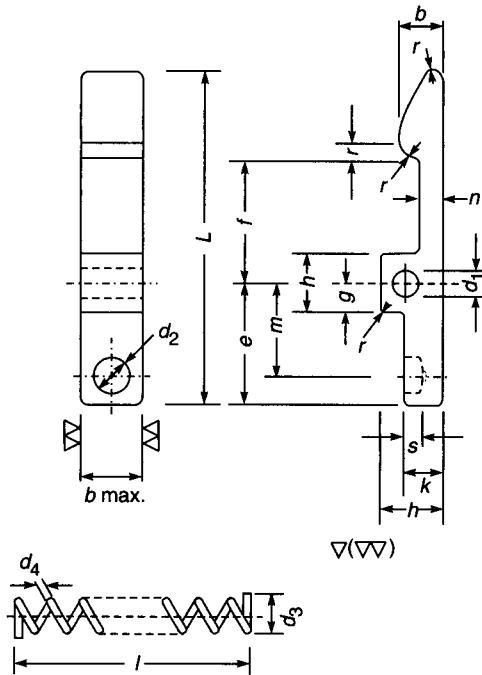
Springs Steel (IS: 727–1964) for Springs
All dimensions in mm

Length														Spring effective coils
		Locking dog												
		d_1												l
L	b	E_9	d_2	e	f -0.2	g	h	s	k	m	n	r	d_3	d_4	Free-length
45	8	4	5.5	15	15	4	9.5	2	5.5	11	4	1.6	4.6	0.6	16
60	10	5	7.0	20	20	5	12.0	3	7.0	15	5	2.5	5.8	0.8	18
80	14	6	9.0	30	30	6	15.0	5	9.0	23	7	4.0	7.4	1.0	22

Figure **14.15**
Locking dogs

Material: CI (Gr 20)
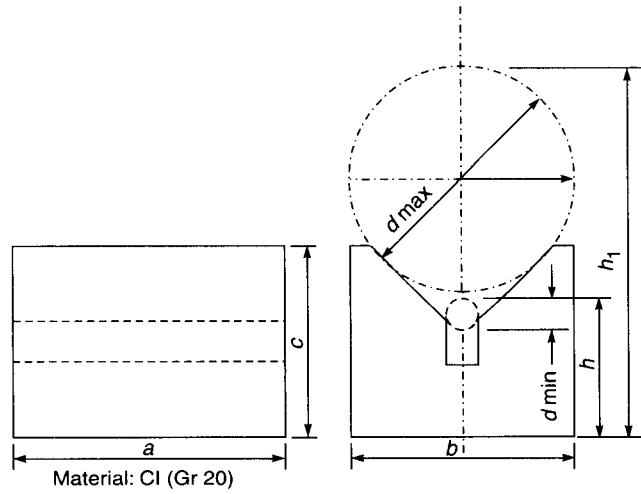
a	b	c	d_{max}	d_{min}
50	40	40	40	5
63	50	50	50	5
80	63	63	63	7
100	80	80	80	7
200	200	200	200	10
300	300	300	300	12

(a)

Figure **14.16a**
V Block for long cylinders
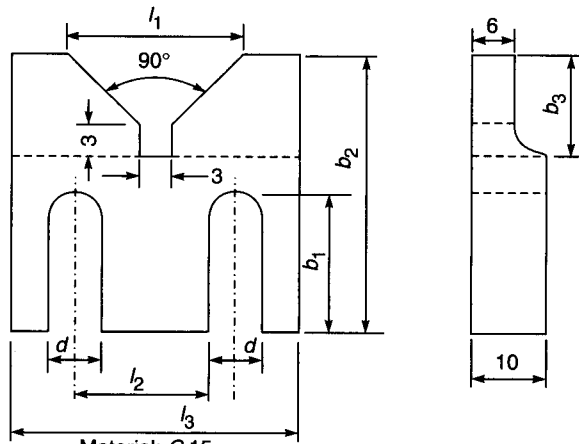
Material: *C* 15
case hardened

l_1	l_2	l_3	b_1	b_2	b_3	d
25	30	35	15	32	15	7
36	25	50	20	45	25	9
50	32	60	22	55	30	11

(b)

Figure **14.16b**
V locator for short cylinders

Exercises
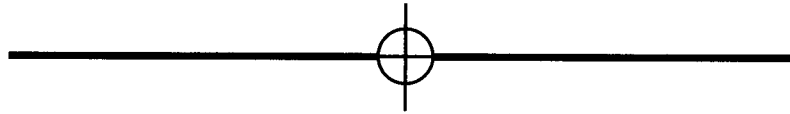
The introduction of new products or modifications in the existing ones calls for the manufacture of new jigs, fixtures, etc. In mass production, the method of manufacture is worked out carefully, long before the production commences. In fact, the equipment, jigs, fixtures and gauges required for the product are purchased/manufactured well before manufacture of products begins. This calls for careful planning of the manufacturing process. Generally, method engineers prepare a process plan called an operations sheet which is used as reference data by tool designers, tool room planners and workshop engineers.

Process Planning

Planning means thinking ahead of time. Process planning involves detailed planning of the operations necessary to convert the raw material into finished products. Process planning is done before commencing manufacture to achieve economy.

The work to be carried out at each stage is specified along with the details of equipment, tooling methods and procedures, number of personnel required and degree of skills necessary for the operation. Estimated operation time and machine/tool setting time are also computed. The operations are arranged in a sequence which is logical, economical and practical. The operations sheet serves as a medium of communication among the members of the production team.

In a big organization, process planning is entrusted to the methods department which compiles the process planning (operations) sheet. A copy of the process planning sheet is sent to the tool designer who designs the toolings or tools enlisted in the sheet and enters the corresponding numbers on the process planning sheet.

In smaller organizations, a tool designer might be assigned the task of preparing the operations sheet. He plans the process before commencing designing of the jigs, the fixtures, gauges and other tools necessary for manufacturing the product. The following principles should be taken into account while planning the manufacturing process.

Principles of Process Planning

1. *Establish Reference Datum Surfaces at Early Stage.* For cubical parts, the first operation is generally machining the resting face which can be used as datum for the subsequent operations. In cylindrical workpieces, the first operation is generally turning. The turned portion can be used as datum for the subsequent operations.

2. *Choose Cheapest Machining Process which can Accomplish the Tolerances Specified on Drawing.* Turning is cheaper than grinding, cylindrical workpieces having manufacturing tolerances above 0.05 mm should be finished on lathes rather than on cylindrical grinders. Similarly, unimportant faces can be machined cheaply on shaping machines. It might be necessary to use milling for better finish and flatness. For perfect parallelism and high degree of surface finish it is necessary to use a costlier surface grinding operation.

   The size of the machine should also be commensurate with the size of the workpiece. It would be uneconomical to machine a small workpiece on a large machine.

3. *Finishing Operations should be Carried out at Later Stages.* This prevents damage to finished surfaces in transit.

4. *Sequence of Operations should be Logical and Practicable.* For example, lighting a stove would precede cooking whereas cleaning utensils generally follows eating.

Similarly, for the pivot pin shown in *Figure 15.1*

(a) Turning to $12\phi \, {}^{-0.1}_{-0.02}$ must precede milling to $5 \, {}^{-0}_{-0.1}$ flats so that the turned diameter can be used as location for centrality of the flats. Radius 6 at the end can also be formed during turning.

(b) Face B must be machined to length 44mm before milling so that it serves as location face for maintaining dimension 31 mm for milled flats.

(c) Flats $5 \, {}^{+0}_{-0.1}$ must be milled before drilling 4ϕ hole so that the milled flats can be used for location during drilling. This would ensure that the drilled hole is square with the milled faces.

Workpieces for Practice ————

The following pages contain drawings of a number of engineering components for practicing jig/fixture designing (*Figures 15.2* to *15.25*). The reader is advised to work out a tentative process plan with operations arranged in a proper sequence. The designer should take into consideration the operations carried out on the workpiece, before it reaches the stage for which the jig/fixture is being designed. The chaindotted workpiece represented in the jig/fixture drawing should show the workpiece in the state it is when the operation is taken up. For example, the workpiece in the milling fixture for the pivot pin shown in *Figure 15.1* should be drawn as after turning (option no. 2). Note the absence of 4ϕ hole which is drilled after milling. Similarly, the workpiece in the drill jig for the pivot pin should be shown as it would appear after milling (option no.3). Naturally, the surfaces which would be machined later cannot be used for location in the jig/fixture meant for an earlier operation.
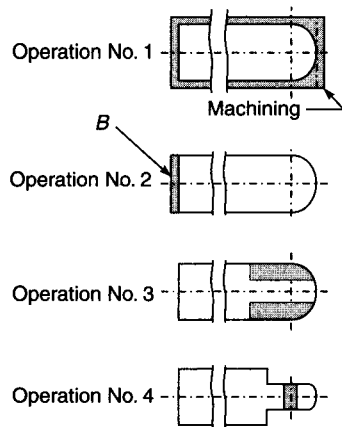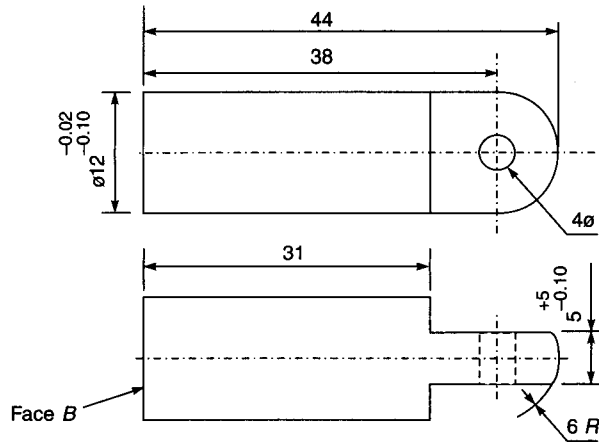
Operation	Tooling	Gauges
Turn12 ø, form 6 R, cut off	Form tool	Gauge12 ø templet 6 R
Machine face B to Length 44 mm	Milling fixture	Length gauge 44
Mill 5 mm wide flats to length 31 mm	Milling fixture	Gauge for width 5 mm
Drill 4 ø hole	Drill jig	

Figure **15.1**

Process plan for pivot pin
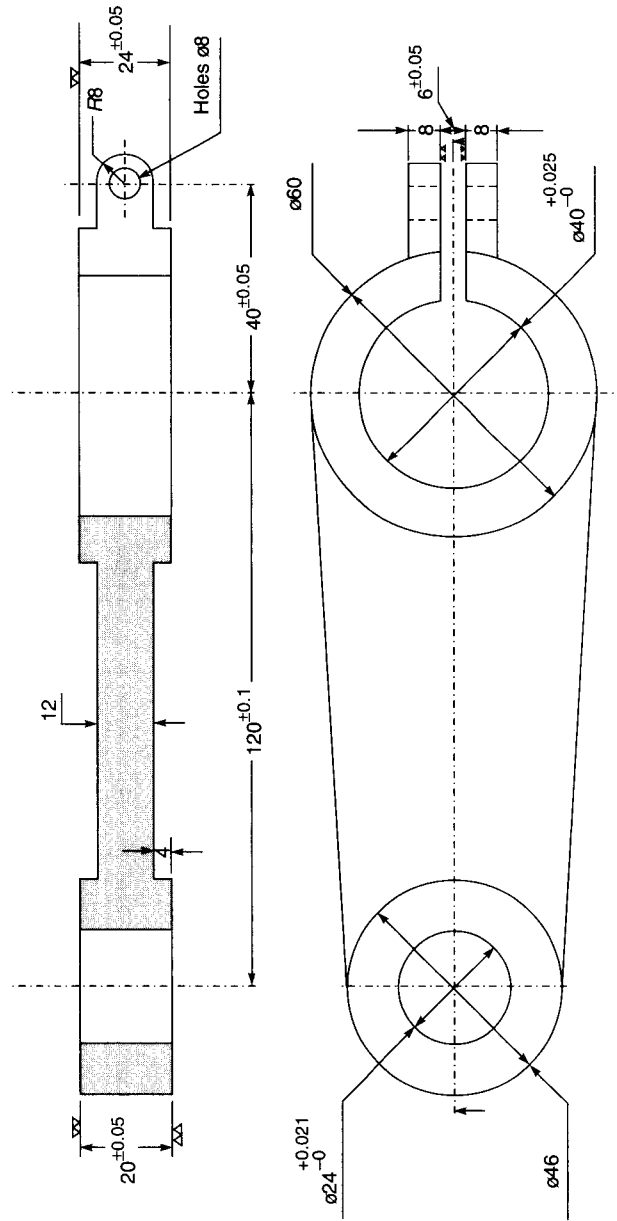
Design:
1. Turning fixture for 40ø bore and facing 60ø boss
2. Milling fixtures (a) bosses facing (b) 6 mm wide slot
3. Drill jig (a) 24ø (b) 8ø

Figure **15.2**
Workpiece for jigs and fixtures design practice
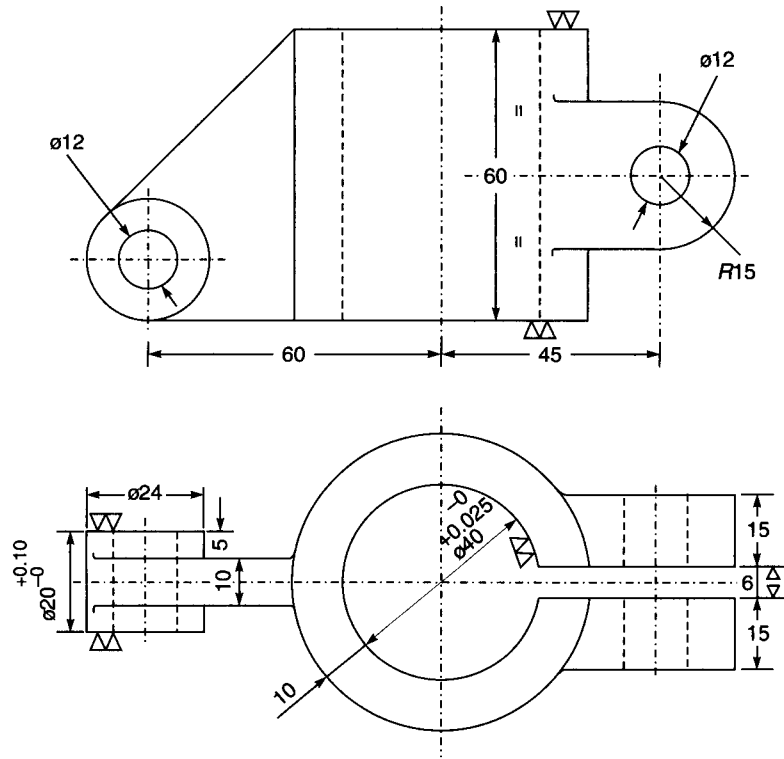
Design:

    1. Turning fixture bore 40 ø, face 60ø boss
    2. Milling fixture (a) Face 24ø bosses (b) Mill 6 wide slot
    3. Drill jig 12ø holes

Figure **15.3**
Workpiece for jigs and fixtures design practice
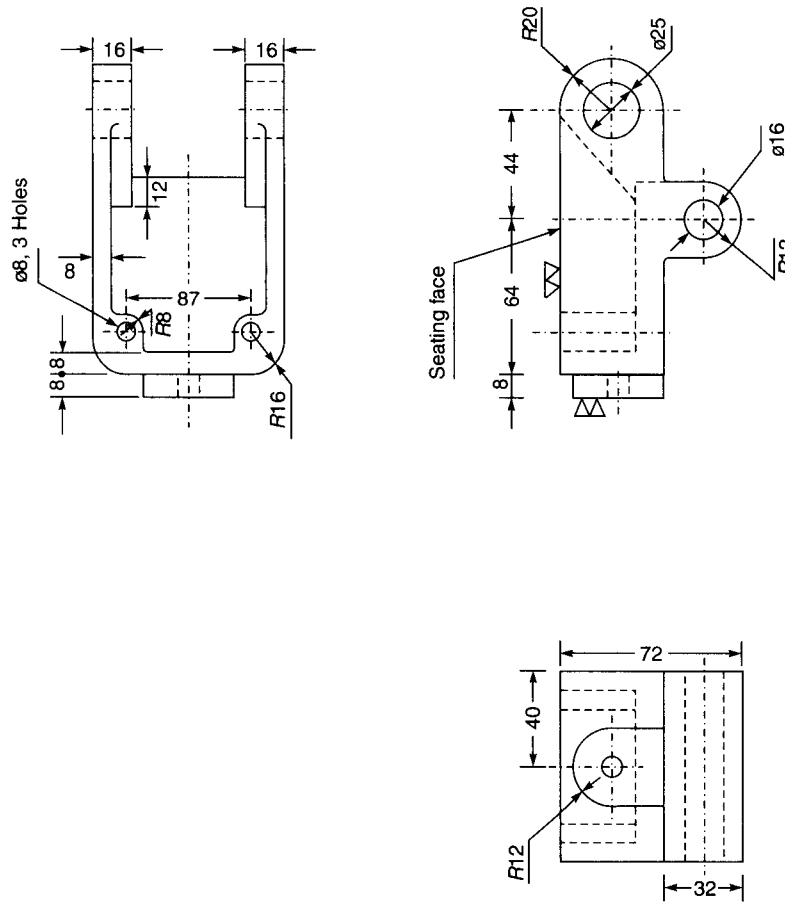
Design:
1. Milling fixtures (a) Seating face (b) 12*R* boss
2. Drill jig (a) 25ø,16ø holes (b) 8ø holes

Figure **15.4**
Workpiece for jigs and fixtures design practice
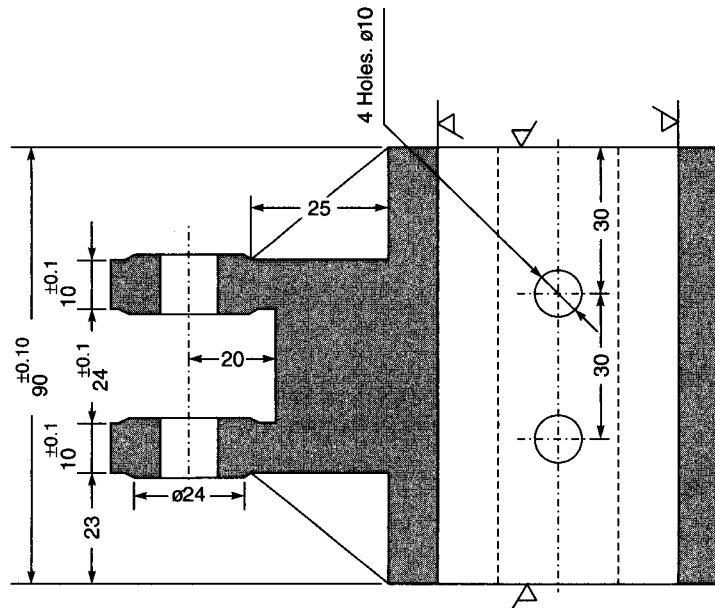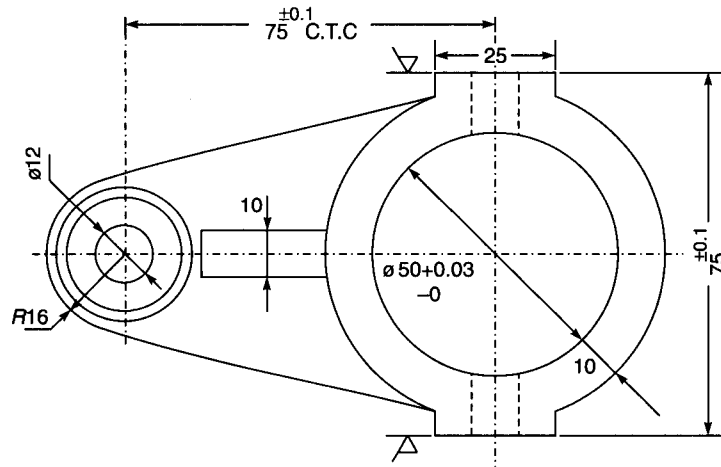
Design:
   1. Turning fixture for 50ø bore and 70ø face
   2. Milling fixture for (a) 24ø bosses (b) 25 × 90 pads
   3. Drill jig for 10ø,12 ø holes

Figure **15.5**
Workpiece for jigs and fixtures design practice
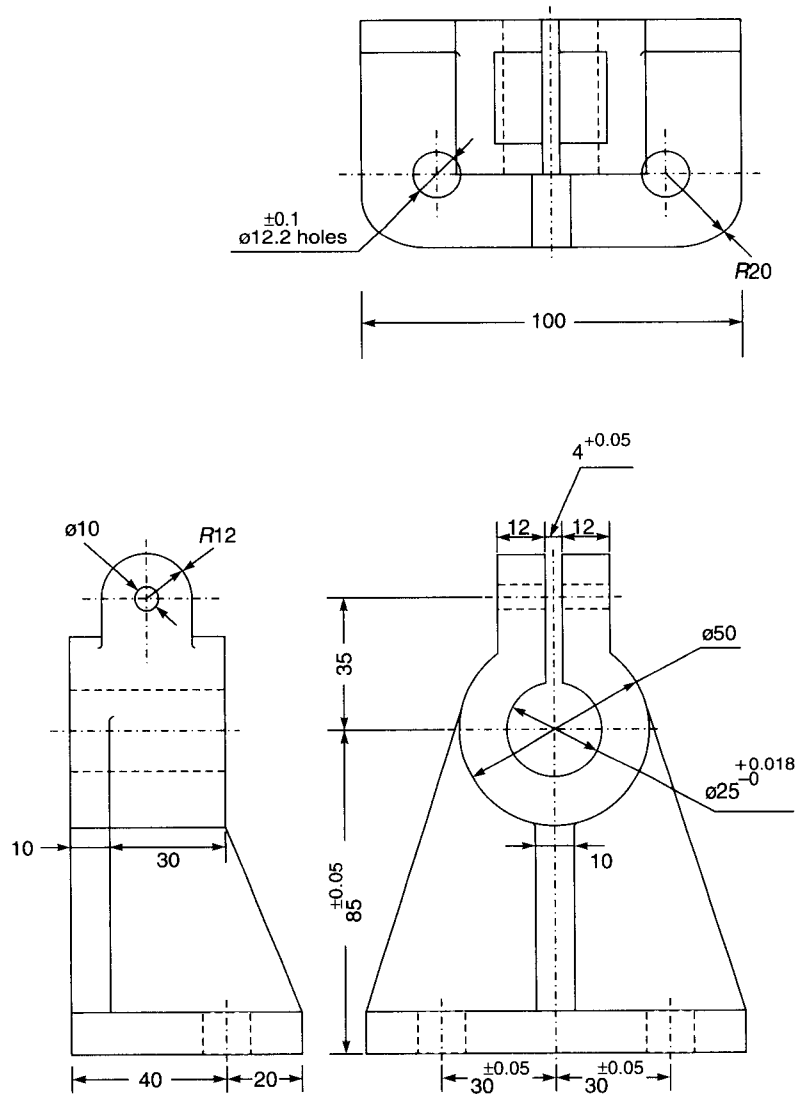
Design:
1. Milling fixtures (a) 60 × 100 base (b) 4 wide slot
2. Turning fixture 25ø bore and vertical face
3. Drill jig 12.2ø, 10ø holes

Figure **15.6**
Workpiece for jigs and fixtures design practice
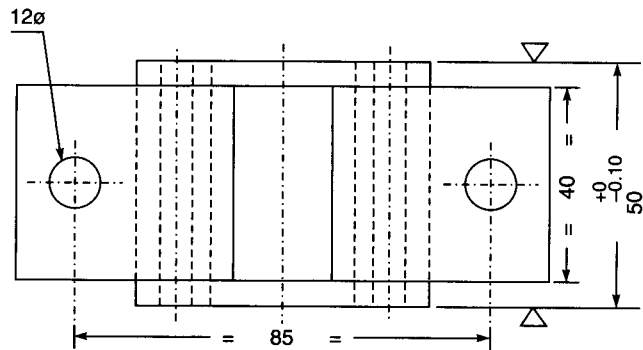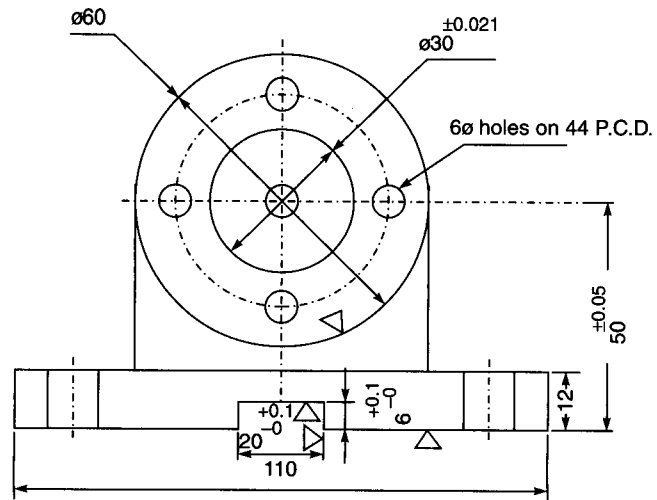
Design:
    1. Milling fixtures (a) 110 × 40 base (b) 20 × 6 slot (c) 60ø bosses
    2. Turning fixture bore 30ø face 60ø boss
    3. Drill jig (a) 12ø holes (b) 6ø holes

Figure **15.7**
Workpiece for jigs and fixtures design practice

6-hole score
drilled $\frac{11"}{32}$ Dia.

3 counter
bores $\frac{3"}{4} \times \frac{1"}{8}$
deep

$1\frac{5"}{16}$ $1\frac{5"}{16}$

$1\frac{7"}{8}$ P. C.D

$\frac{3"}{8}$ R

$1\frac{3"}{8}$ R

1"Cored

$2" + 0.0015$

$\frac{1"}{2}$ Ream

$1\frac{1"}{2}$ DIA

Ream

$1\frac{1"}{8} + 0.001"$

$2\frac{3"}{8}$ P. C.D

$3\frac{1"}{4}$

$1"$ $\frac{3"}{4}$

$\frac{1"}{2}$ Dia

$\frac{1"}{2}$

$2"$
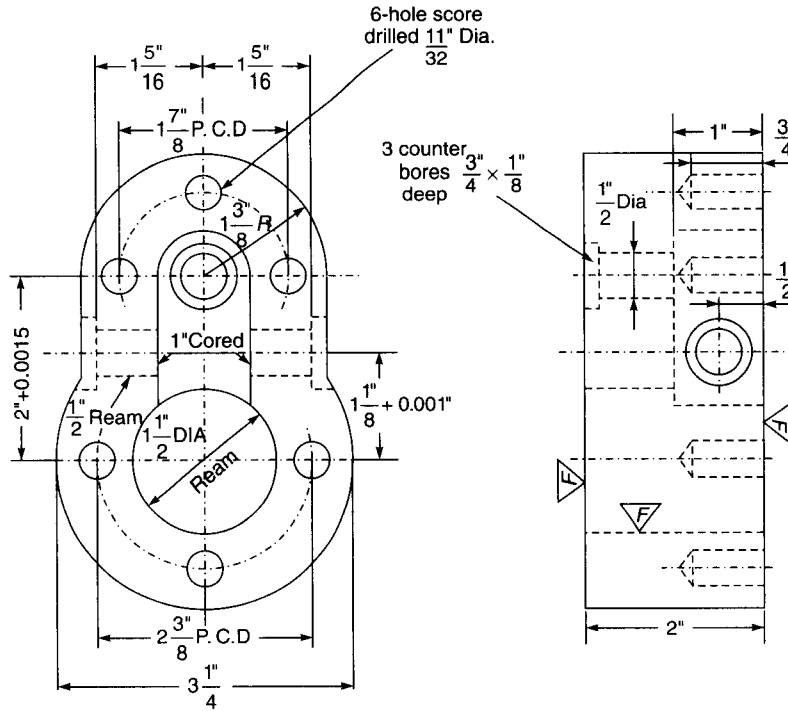
Design:
1. Turning fixture for $1^{1}/_{2}$" dia ream and one end facing
2. Milling fixture for other end face
3. Drill jigs (a) 11/32" holes
   (b) 1/2" ream, 3/4"C ' bore

Figure **15.8**
Workpiece for jigs and fixtures design practice

R 12

ø12-4 holes,13 deep

ø12-4 holes, thru

$\angle \varnothing 24^{-0}_{+0.018}$

68 PCD

80 PCD

15

12

68 CTC

ø102
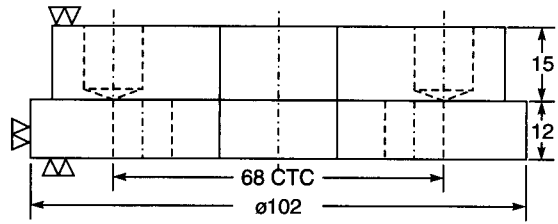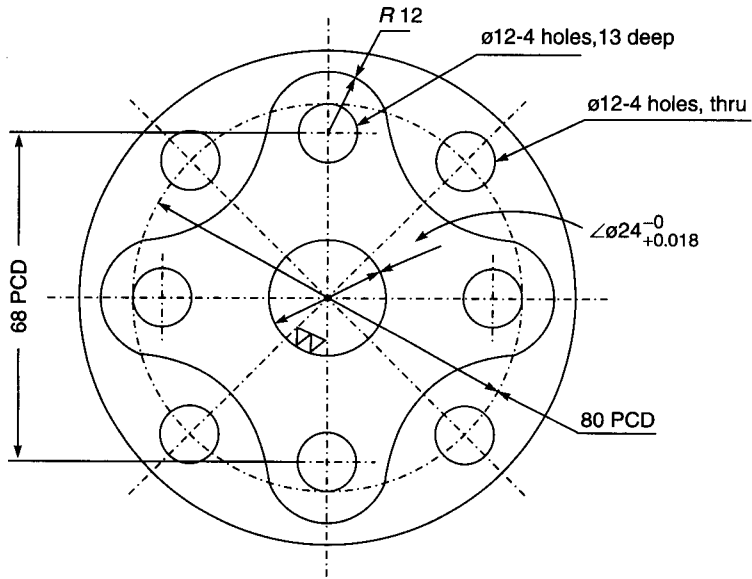
Design:
1. Turning chuck jaws 24ø bore, 102ø turn, face
2. Drill jig 12ø holes

Figure **15.9**
Workpiece for jigs and fixtures design practice
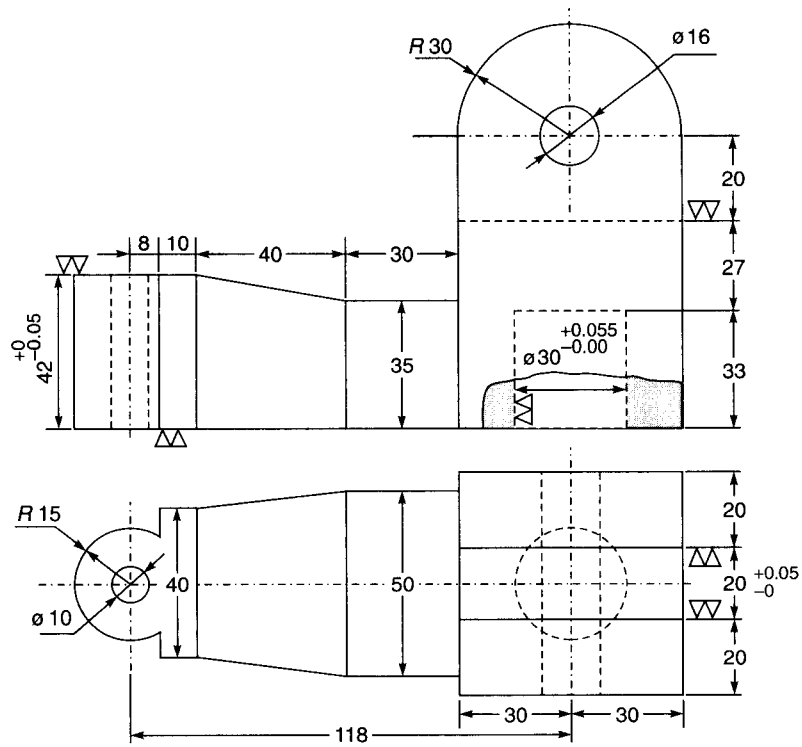
Design:
    1. Turning fixture bore 30 ø and face base
    2. Milling fixtures (a) 20 wide slot (b) 42 Thk boss
    3. Drill jig 10ø,16 ø holes

Figure **15.10**
Workpiece for jigs and fixtures design practice

3 holes 8ø Csk at 90°
to 14ø equi-spaced

6 holes 12ø equi-spaced

116 PCD

62 +0 −0.1

Slot 12 wide × 3 deep

ø136

1.5 U cut' to
minor diameter

M-76 × 2

3 × 45°

ø76

ø72 +0.1 −0

ø96 +0 −0.04

ø92

Face-A

12

20

14.5

4

15

20

2

48

64

10

ø95 +0 +0.09

ø82 +0.1 −0
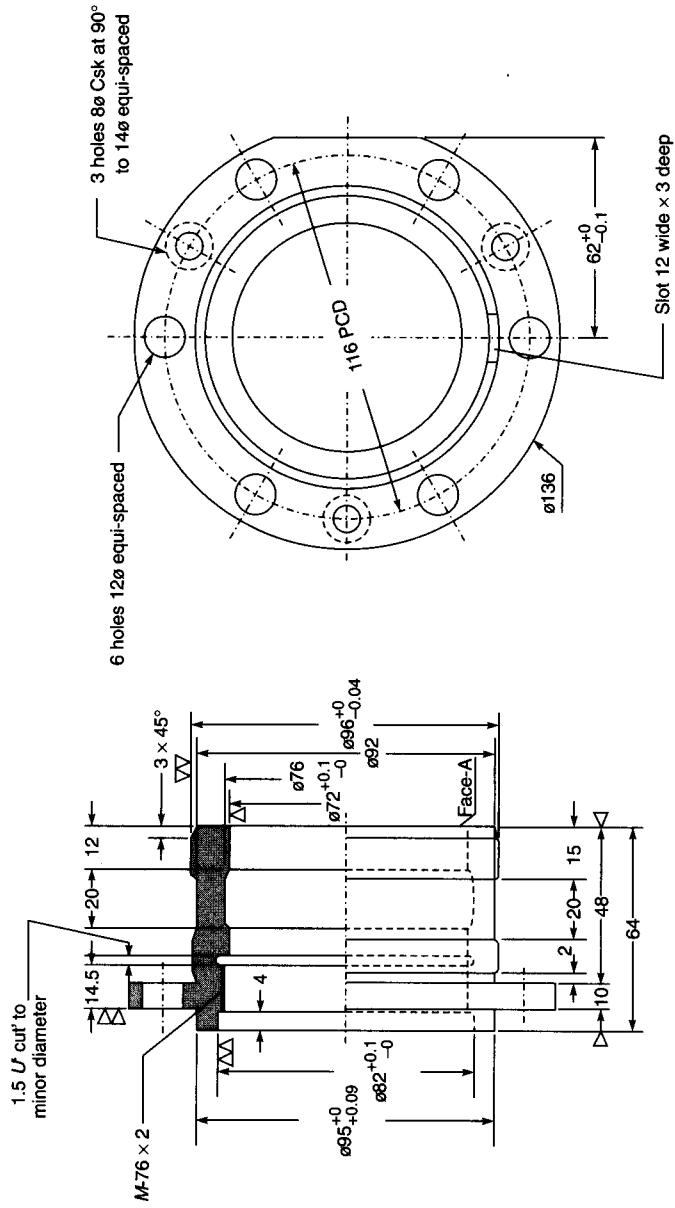
Design:
   1. Milling fixture flat at 62
   2. Drill jig 8 ø,12 ø holes and 14øc bores
   3. Milling fixture for 12 wide slot

Figure **15.11**

Workpiece for jigs and fixtures design practice
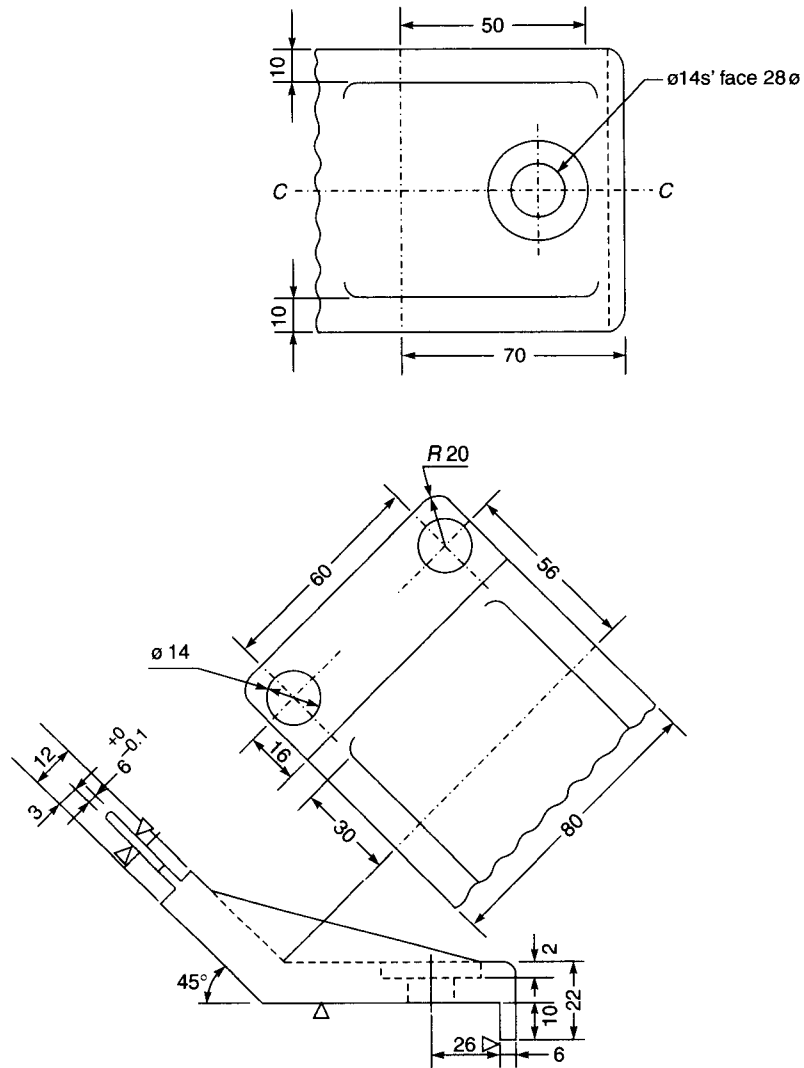
Design:
1. Milling fixture 6 THK flats
2. Drilljig 14 ø holes
3. Projection
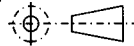
Figure **15.12**
Workpiece for jigs and fixtures design practice

Section B-B

5°

6

ø136

95

R 5

6

C

4 holes ø16
equi-spaced
on114 P.C.D.
C bore ø24 × 20
deep

R 10

B

ø 254
h 11

10

R 18

45°

8

4 holes ø26
H7
equi-spaced
on158 P.C.D.

A

A

4 holes ø12
equi-spaced
on192 P.C.D.

10

44

5

40

16

16

30

16

85

R 5

Section AA

R 15

50

R 5

70

Design:
1. Drill jig 12ø, 16ø, 26ø hole
2. Milling fixture 30 wide T slots
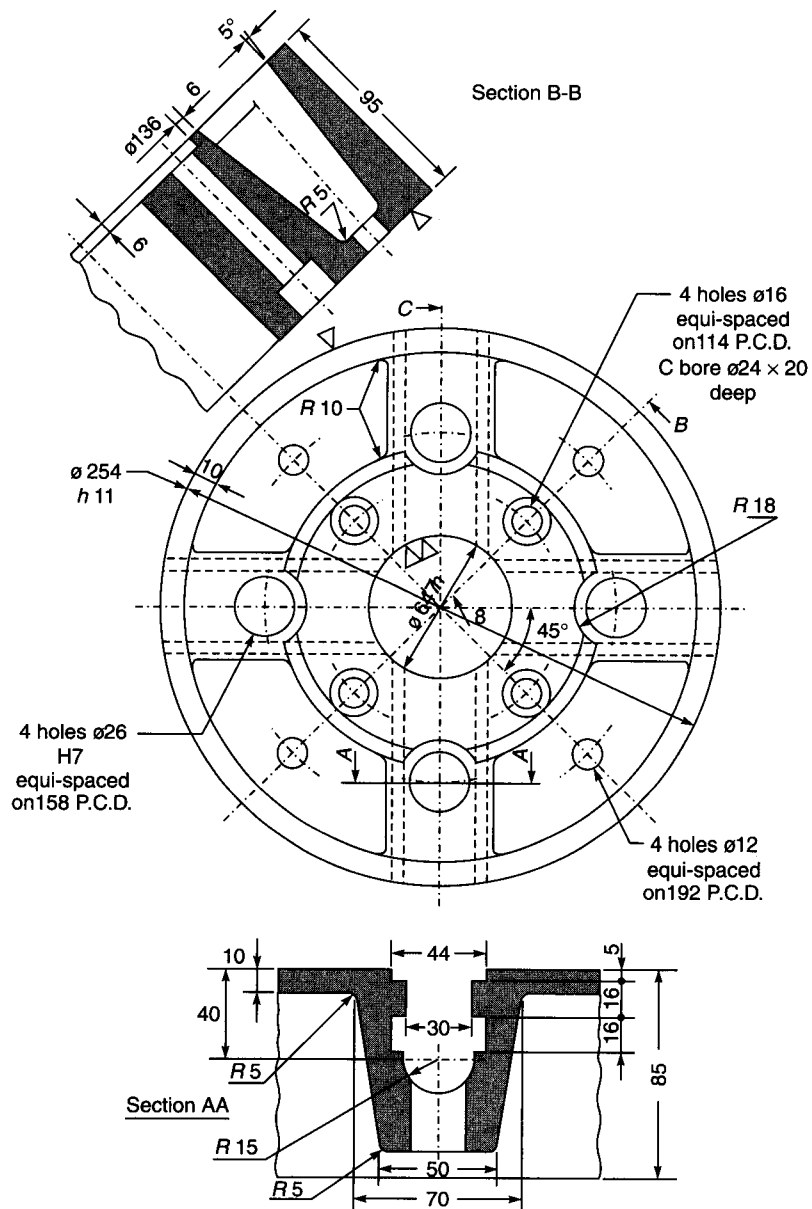
Figure **15.13**
Workpiece for jigs and fixtures design practice

Scale 1:2

Design:
1. Turning fixture 24∅ bore
2. Drill jigs (a) 6∅, 10∅ holes (b) 12∅, 16∅ holes
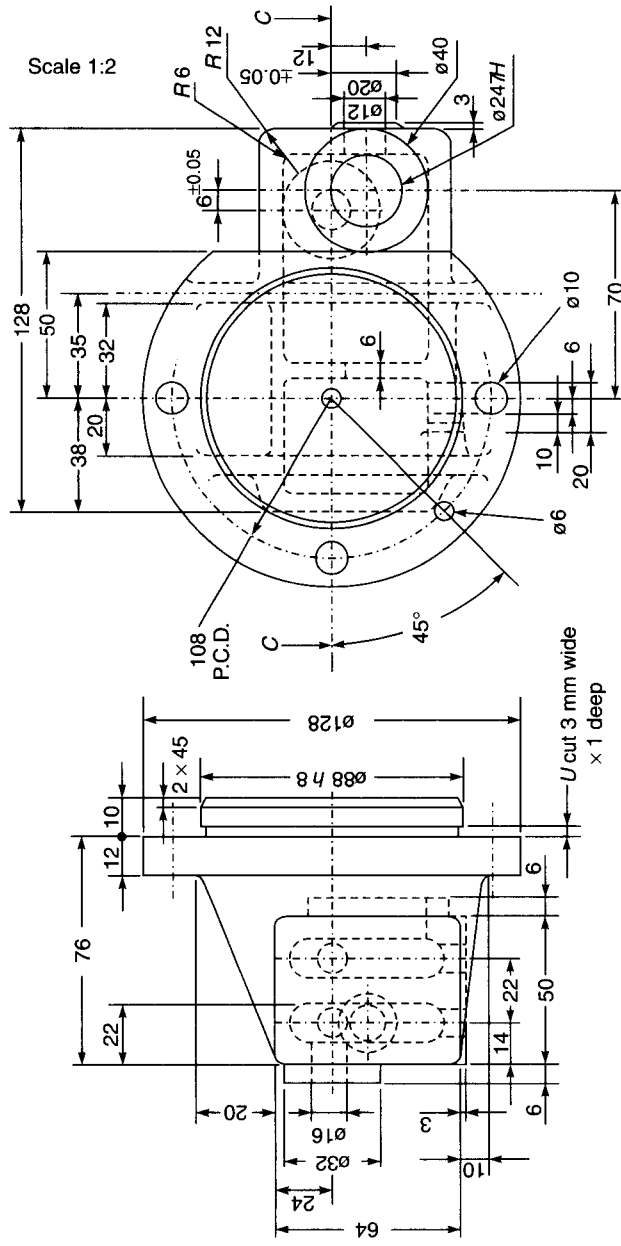
Figure **15.14**
Workpiece for jigs and fixtures design practice
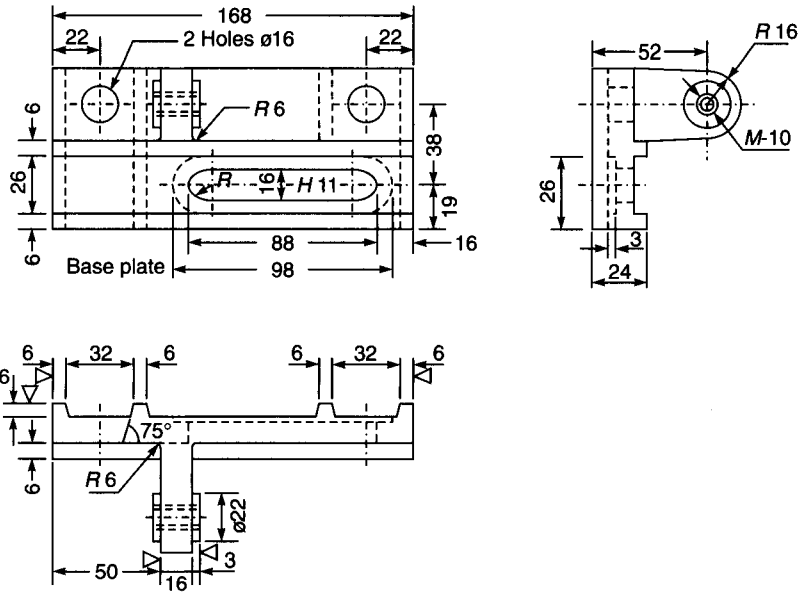
Design:
  1. Milling fixtures (a) ⌀22 bosses (b)16 wide slot
  2. Drill jigs (a) hole for M-10 (b) ⌀16 hole

Figure **15.15**
Workpiece for jigs and fixtures design practice

Figure **15.16**
Workpiece for jigs and fixtures design practice
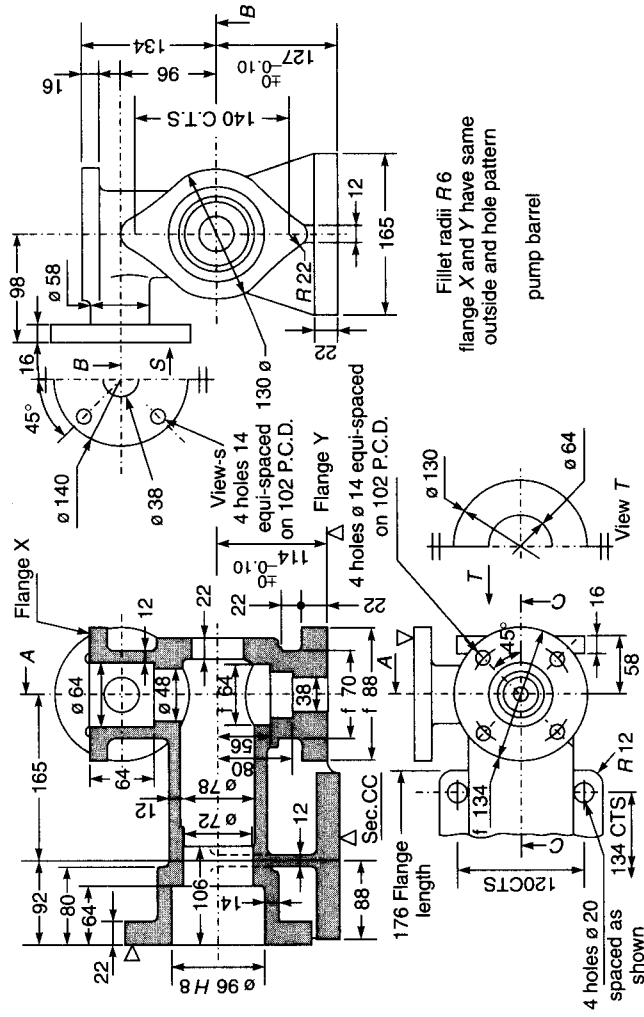
Design:
1. Turning fixtures (a) f 96and face (b) ø64 and face
2. Milling fixture 176 × 165
3. Drill jig (a) ø14 (b) f 20
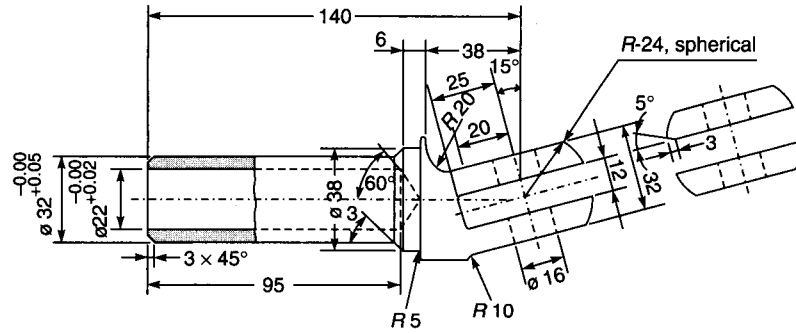
Design:
1. Milling fixtures (a) 12 slot and 32 flats (b) 3 × 5° angle
2. Drill jig 16ø hole
3. Turning fixture ø 32 and ø 22 bore

Figure **15.17**
Workpiece for jigs and fixtures design practice
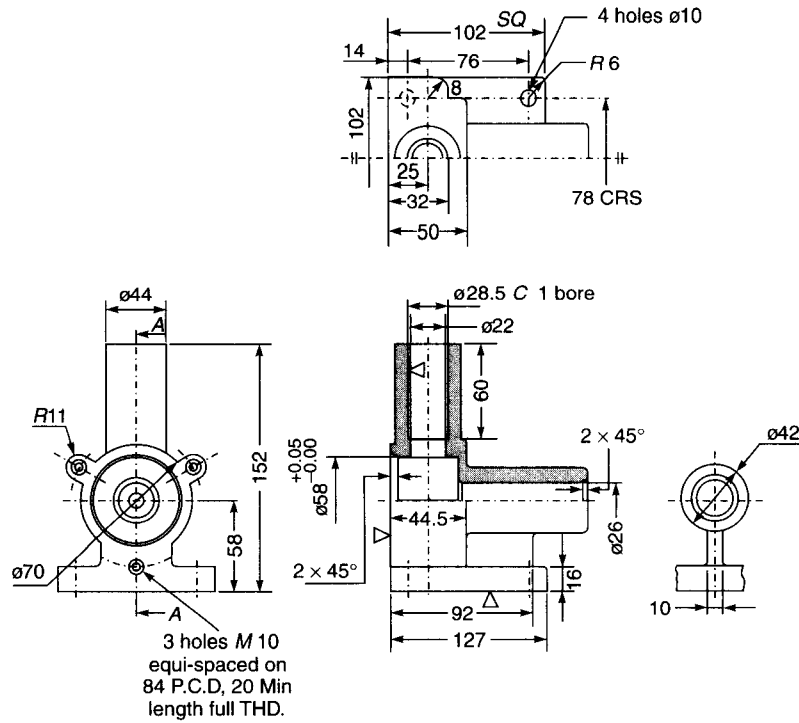
Design:
        1. Milling fixtures (a) 102 SQ base
        2. Drill jigs (a) 10; (b) *M* 10

Figure **15.18**
Workpiece for jigs and fixtures design practice

102 CRS

10

4 holes 20 ±
cored

66

42

38

19

6

P

Q

R

50

25 | 25 | WEP

R 10

6

108 CRS

2 holes *M8 6H*
15 min length full
thread

All bosses ø20 drilled
ø10 through

Fillet RADII *R*3

16

82

16

16

16

16

ø96

ø116

108 PCD

5-ø10

16

6

16

6

6

20

R70

B

B

102

70

Design:
    1. Milling fixtures for faces *P Q R*
    2. Drill jigs (a) 10ø holes (b) hole for *M8*
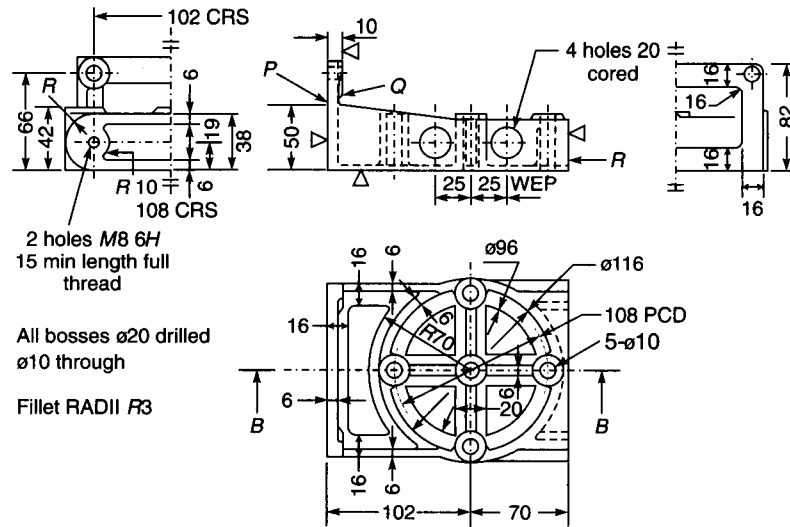
Figure **15.19**

Workpiece for jigs and fixtures design practice
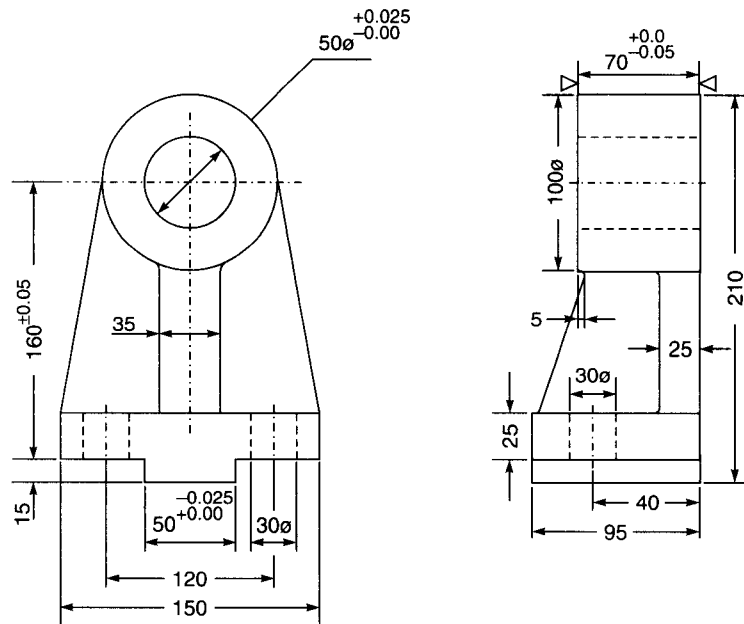
Design:
    1. Milling fixtures: 50 × 15
    2. Drill jig: 30ø holes
    3. Turning fixture: 50ø, face

Figure **15.20**
Workpiece for jigs and fixtures design practice
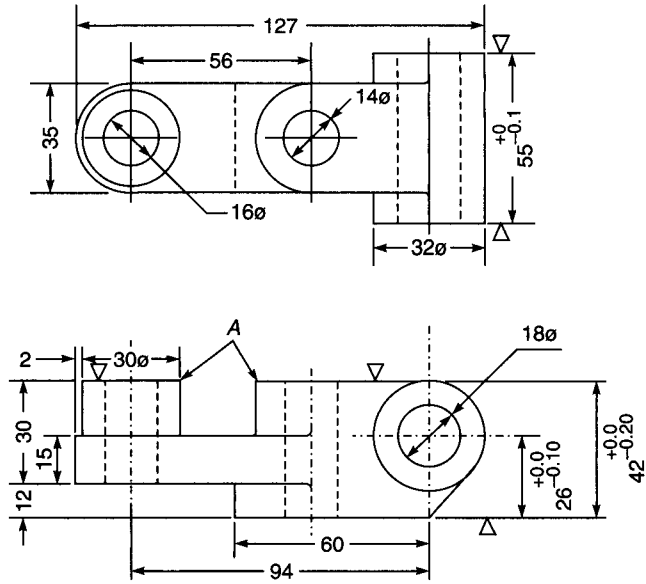
Design:
      1. Milling fixtures (a) face (b) dim 55
      2. Drill jigs (a) 14ø, 16ø (b) 18ø

Figure **15.21**

Workpiece for jigs and fixtures design practice
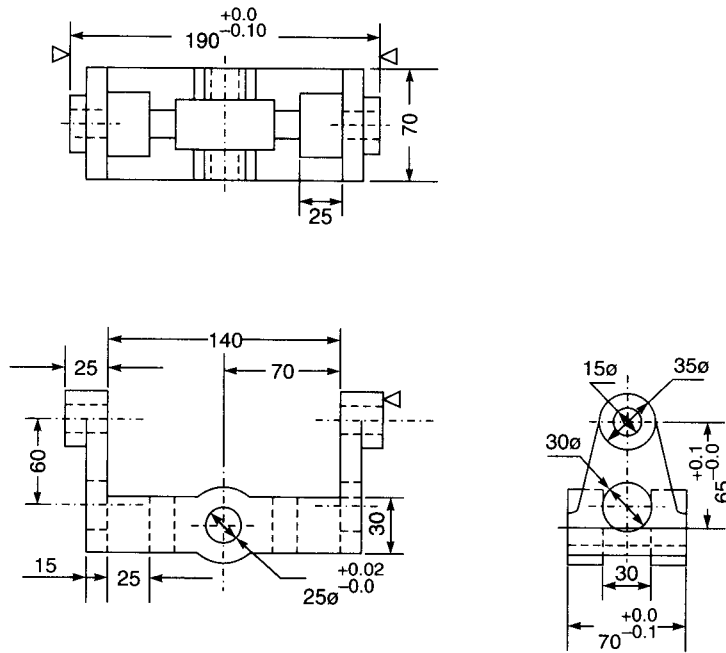
Design:

1. Milling fixtures (a) 35ø bosses (b) faces to $70^{+0.0}_{-0.1}$
2. Drill jigs (a) 15ø, 30ø (b) 25ø

Figure **15.22**
Workpiece for jigs and fixtures design practice
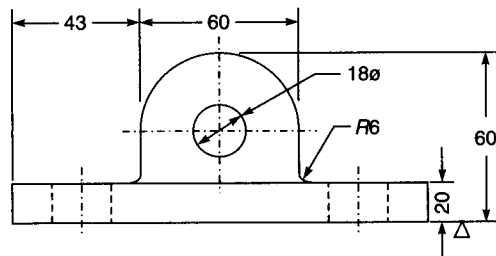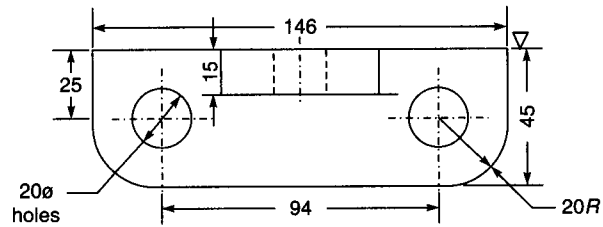
Design:
1. Milling fixtures (a) 146 × 45 (b) 146 × 60
2. Drill jig 18ø, 20ø

Figure **15.23**

Workpiece for jigs and fixtures design practice
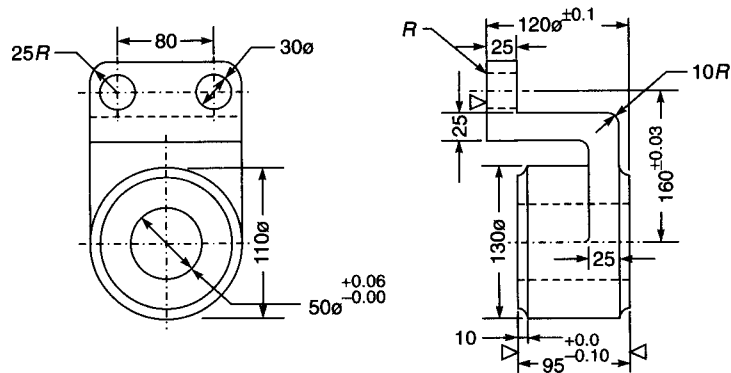
Design:
1. Milling fixtures face *R*
2. Drill jig 25ø holes
3. Turning fixture 130ø face, 50ø bore

Figure **15.24**

Workpiece for jigs and fixtures design practice
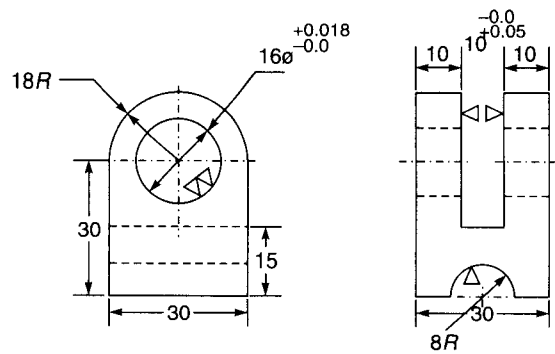
Design:
    1. Milling fixtures (a) 10 slot (b) 8 R
    2. Drill jig 16ø hole

Figure **15.25**

Workpiece for jigs and fixtures design practice
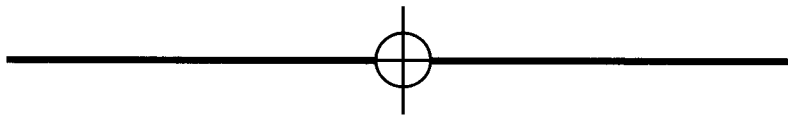
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Index