DEPARTMENT OF AEROSPACE ENGINEERING

DESIGN and COMPUTING

AENG11600

DETAIL DESIGN & MANUFACTURE

DESIGN and GRAPHICAL COMMUNICATION MANUAL

DETAIL DESIGN AND MANUFACTURE – Engineering Drawing

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1. INTRODUCTION

1.1 Course Overview

This manual contains reference notes for the Engineering Drawing lectures. The notes are intended to support the work done in the Design Office in which a series of exercises will be undertaken. Separate handouts detail these exercises. You will find it useful to bring this manual to the Design Office sessions each week.

In general, the objectives of the course are to:

- To contribute to the development of the student's graphical communication skills, and understanding of manufacturing processes.
- Provide an overview of the various drawing types through examples and a classification system. Relate best practice guidelines in the construction of sketches and pictorial drawings.
- Introduce the concepts of orthographic projection through demonstrations and case examples. Provide information on the creation of secondary views and orthographic view construction through best practice guidelines.
- To provide the methods to clearly and completely describe an object through efficient and effective dimensioning. Introduce the concepts and applications of tolerancing and surface roughness specification.
- Introduce the application of simplified part representation in graphical communication through the use of standard notation, drawings and symbols. Use examples to demonstrate the application to many engineering fields.
- To give an introduction to process planning and enable process plans to be created.

Give an awareness and understanding of:

- The influence of detail design in manufacturing
- The interaction between conceptual design, detail design and manufacture
- The use of standards in design
- The application of computers in design.

YOU MUST BECOME PROFICIENT AT ENGINEERING DRAWING IN ORDER TO DISSEMINATE AND DEMONSTRATE YOUR IDEAS TO OTHERS!

1.2 Coursework Assessment

There will be two assignments for you to complete. Assignment 1 relates to drawing practice, whilst assignment 2 focuses on manufacturing processes.

1.3 Course Attendance

- *Attendance at all Design Office sessions is required.*
- An attendance sheet will be handed round at the start of every session for you to sign.
- If you miss a Design Office session (except where a Doctor's note is supplied) you will not receive a mark for one of the assessed exercises.

1.4 Engineering Drawing Basics

Drawing Instruments

Each student should bring with them to the Design Office:

- **A 300mm rigid plastic scale rule**

- **Adjustable set-square (or one 30/60^0 set square and one 45^0 set square)**
- **Bow compass**
- **Protractor**
- **Selection of precision or technical pencils (0.3 and 0.5 mm are preferred sizes)**
- **Eraser**
- **Circle/radius template (not essential but makes drawing smaller circles and fillets easier)**
- **Calculator (see approved list in *Information Pack for 1st Year Students*).**

Notes:

- A drawing board with built-in horizontal motion is available for every student in the Design Office
- The alternative to manual drawing using the instruments described is CAD software, but basic skills still have to be mastered first. Tutorials for *Inventor*, the main and preferred CAD software package used in the Faculty of Engineering, will run in parallel with this course.

Drawing Standards

- The common language contained in all drawings made in the UK (line types, dimensioning, tolerancing, etc) can be referred back to a British Standard called BS 8888:2000, *Technical Product Documentation (TPD) - specification for defining, specifying and graphically representing products*. This standard has replaced BS 308.
- A shorter version of this standard has been prepared for students called PP 8888-1. There are many copies in the library.
- Use the standards at every opportunity when drawing.
- Other countries have their own standards for drawing practice, for example, in the US the American Society of Mechanical Engineers (ASME) Y14.1 standard is used.

Preferred Scales

Scales are used to enlarge or reduce the detail on drawings so they can fit the size of drawing frame used. The preferred scaling ratios are:

Enlarging – 2:1, 5:1, 10:1, 20:1 and 50:1.
Reducing – 1:2, 1:5, 1:10, 1:20, 1:50, 1:100, 1:500 and 1:1000.

Use of SI Units

- SI metric units must be used at all times for dimensions.
- The imperial system of inches and feet is mainly used in the US now.
- Units of metres (m), millimetres (mm) and micrometres (µm) (used for surface roughness) are preferred.
- Standard SI units should be used for angles, volumes, etc. where necessary.

Paper Sizes

Standard paper sizes that you might use are based on standards defined by International Organisation of Standards (ISO). These are:

A4 = 210 mm x 297 mm
A3 = 297 mm x 420 mm
A2 = 420 mm x 594 mm
A1 = 594 mm x 841 mm
A0 = 841 mm x 1189 mm.

- The sides of all sheets are in the ratio 1:$\sqrt{2}$
- A0 is nominally 1m^2 in area and forms the basis of the series.

Line Types

A variety of line thicknesses, types and patterns exist. See Figure 1 for the main types and Figure 2 shows their application in practice.

Line	Description	Application
	Continuous thick	Visible outline and edges
	Continuous thin	Dimension, projection and leader lines, hatching, outlines of revolved sections, short centre lines, imaginary intersections
	Continuous thin irregular Continuous thin straight with zigzags	Limits of partial or interrupted views and sections, if the limit is not an axis
	Dashed thin	Hidden outlines and edges
	Chain thin	Centre lines, lines of symmetry, trajectories and loci, pitch lines and pitch circles
	Chain thin, thick at ends and changes of direction	Cutting planes
	Chain thin double dashed	Outlines and edges of adjacent parts, outlines and edges of alternative and extreme positions of movable parts, initial outlines prior to forming, bend lines on developed blanks or patterns

Figure 1 Types of Line

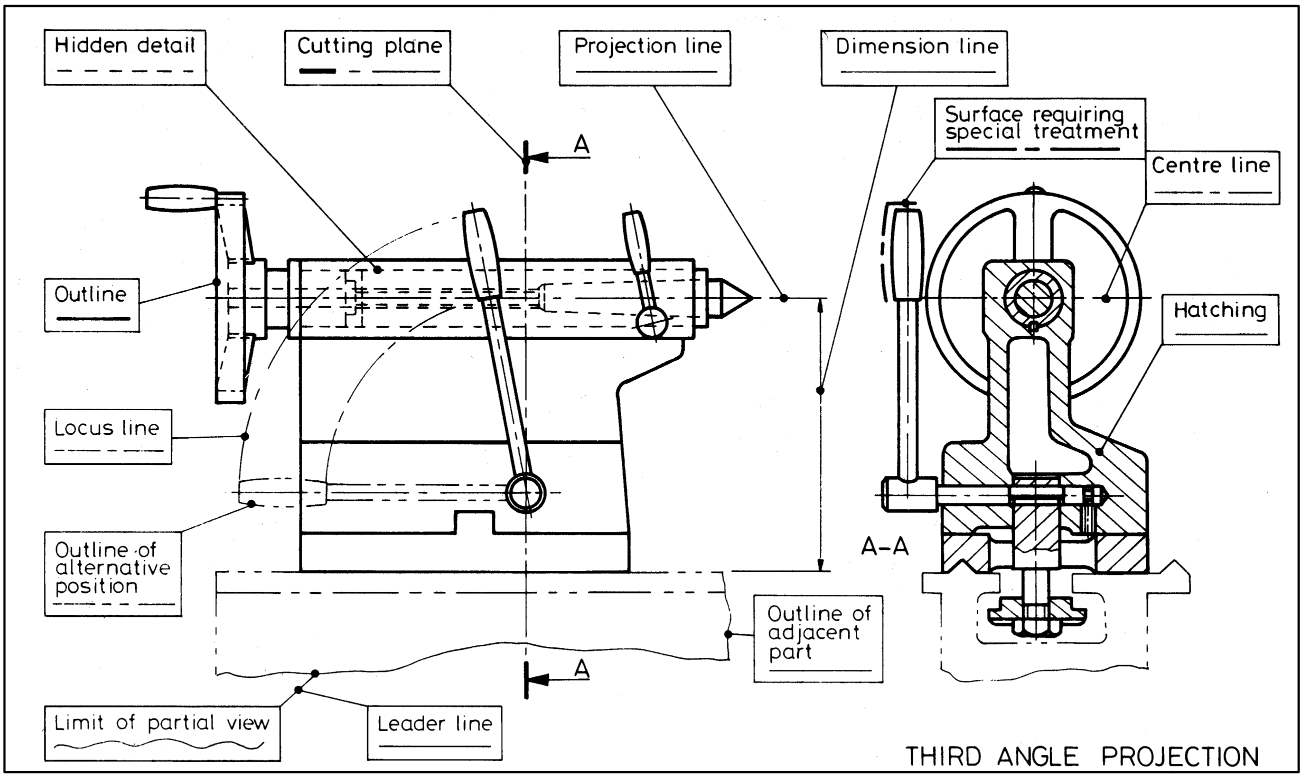


Figure 2 Use of Line Types

Line Precedence

Since each view of an object could have many features, they will at times interfere in the different views. Because showing all features in every view is confusing, Figure 3 gives the order of line precedence that has been established for engineering drawing practice.

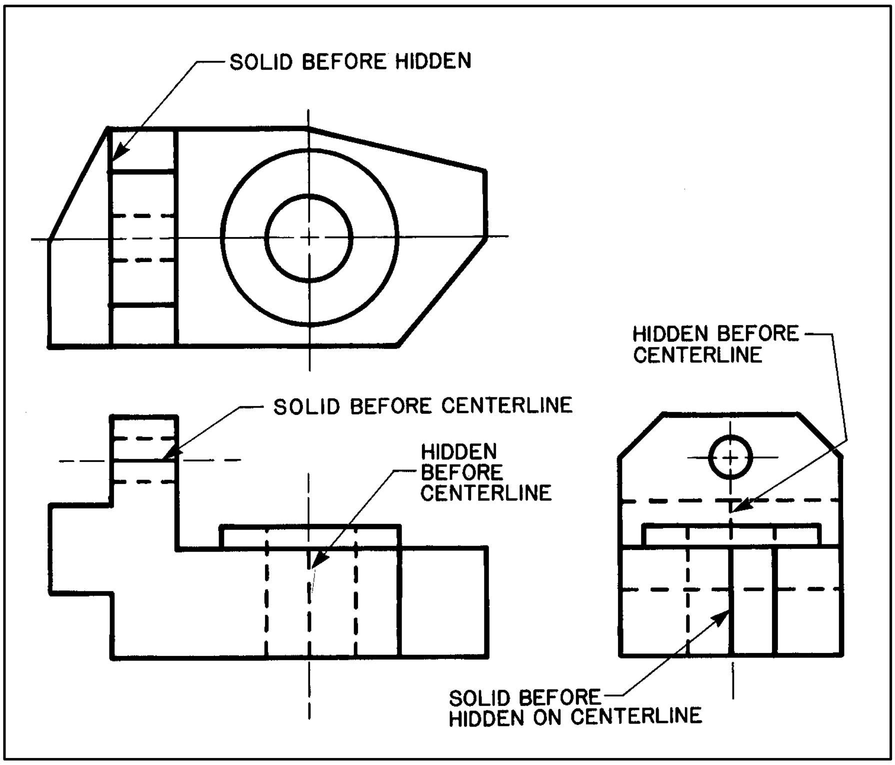


Figure 3 Precedence of Lines on a Drawing (Third Angle)

Standard Drawing Frame

A standard engineering drawing frame should look like Figure 4. Please use this format in all future drawing work. Appendix A provides a blank drawing frame.

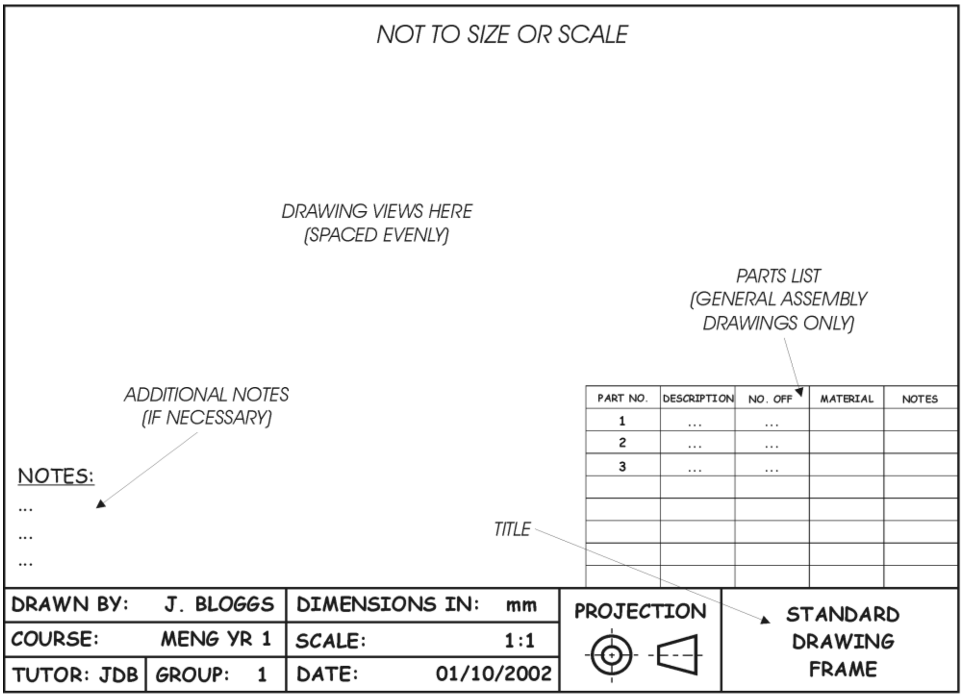


Figure 4 Standard Drawing Frame

Key Engineering Drawing Terms

- View – The projected image of the component or assembly in a drawing. Also called elevation.
- First Angle Projection – The view you are looking at is projected through to the other side of the object.
- Third Angle Projection – The view you are looking at is displayed at the same side.
- Dimension – Used in conjunction with geometry to define size, shape and position of features and surfaces. Dimensions may define linear distances, angles, diameters and radii. They are target values e.g. Ø20 or 5°. In practice, there is no such thing since no part can be made to an exact size. It is a numerical value expressed in SI units of measurement.
- Tolerance – The algebraic difference between the upper and lower limit of size about a target dimension.
- Datum – Origin of a dimension or a number of dimensions from a surface or axis typically. Designated in order that some other feature(s) may relate to it. Can also be associated with a tooling face, a plane that will be machined or manufactured precisely or related to a critical customer characteristic.
- Feature – e.g. hole, chamfer or shoulder on a component.
- Symbol – Notation or simplified picture with specific meaning. Can be a standardised graphical representation of an operation (weld, machine), requirement (geometrical tolerance), system/circuit component (resistor, bulb) or piece of equipment (pneumatic cylinder, pump).

Lettering

- All notes should be clearly printed with **UPPER CASE** (few exceptions, e.g. “mm”).
- Example: MACHINE ALL OVER.
- A consistent style should be maintained in a drawing or set of drawings.
- Notes should be grouped together in a convenient location in the drawing frame as shown in Figure 4.
- Notes and dimensions must be placed so that they can be read from the same direction: the bottom right hand side of the drawing frame.

Common Abbreviations used in Engineering Drawing

Across flats	A/F	Metre	m
British Standard	BS	Millimetre	mm
Centimetre (not a recommended SI unit)	cm	Minimum	MIN
Centres	CRS	Number	NO.
Centre line	CL or ℄	Pitch circle diameter	PCD
Chamfered	CHAM	Radius (preceding a dimension)	R
Cheese head	CH HD	Revolutions per minute	RPM
Countersunk	CSK	Right-hand	RH
Countersunk head	CSK HD	Round head	RD HD
Counterbore	C'BORE	Screwed	SCR
Cylinder or cylindrical	CYL	Specification	SPEC
Degrees (of angle)	°	Spherical diameter (preceding dimension)	SPHERE Ø
Diameter (in a note)	DIA	Spherical radius (preceding dimension)	SPHERE R
Diameter (preceding dimension)	Ø	Spotface	S'FACE
Drawing	DRG	Square (preceding a dimension)	□
Figure	FIG.	Square metre	m^2
Galvanised	GALV	Square millimetre	mm^2
Hexagon head	HEX HD	Standard	STD
International Standards Organization	ISO	Standard Wire Gauge	SWG
Kilogramme	kg	Système International d'Unités	SI
Kilometre	km	Volume	VOL
Left-hand	LH	Weight	WT
Maximum	MAX		

2. ENGINEERING DRAWING TYPES AND GUIDELINES

2.1 How and Why Designers and Engineers Draw

- All engineered products are 3D in reality.
- An engineering drawing is used to represent 3D artefacts on 2D surfaces – on paper or a computer screen.
- CAD can represent 3D artefacts, but can only display these in 3D effectively by shading of appropriate surfaces and creating a rendered 2D image.
- An engineering drawing is an extremely useful way of passing information on to the manufacturing department, installation personnel, fabricators, production schedulers, and, of course, other designers and engineers, and the customer.
- Information such as: material, dimensions, tolerances, surface finish, weld sizes and inspection requirements are all shown on drawings.
- "*A picture is worth a thousand words*" sums up why we use a graphical approach.
- Many different ways of displaying engineering drawings to other people:
  - "Blueprints" get their name from the white lines on blue paper/film format. Not used today, but many old drawings are kept on blueprints.
  - Paper is the most common format used to display drawings.
  - Microfilm using a photographic process to reduce drawings to 16mm or 35mm film. Still used in some companies, although superseded by CAD now.
  - With the advent of CAD, computer back-up systems and computer networking (LAN, Internet), engineering drawing has become easier in terms of displaying, retrieving and making design changes. Need training to use software packages though (+2 weeks).
  - 3D shaded or rendered drawings of CAD models using specific software file types or converted through print facilities to .gif, .jpeg, etc., for later importing into word processing software, PDFs etc..

2.2 Engineering Drawing Types

The main types of engineering drawing can be classified as:

Sketch

- Made freehand typically without the use of drawing instruments.
- Quick and simple.
- Ideal for conceiving new designs, disseminating ideas and arrangement of more complex drawings.

Diagrams

- Electrical circuits, hydraulic circuits and logic sequences (see Figure 5 for the symbols and an example), are not drawings, but diagrams.
- Diagrams have their own standards and specific nomenclature.
- Should comply with British Standards. See Bibliography for relevant standards.

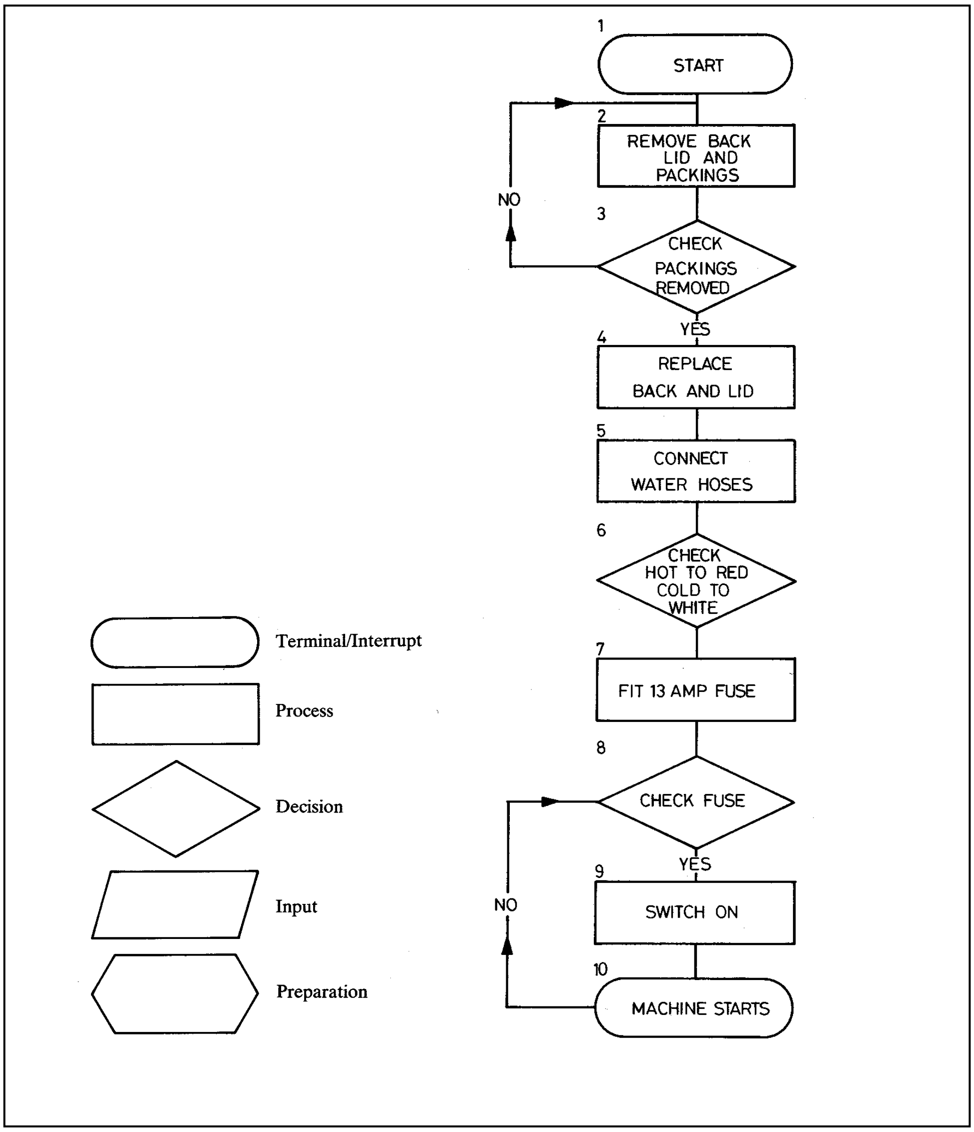


Figure 5 Logic Chart Symbols (BS 4058: 1987) and Example

Pictorial Drawing

- A sketch developed for ease of visualisation that shows an object's height, width and depth in a single view.
- Useful for non-technical audience.
- Dimensions not generally shown.
- Helpful in concept development.

Main types of pictorial drawing are:

- ***Isometric*** – Not fully realistic, but much easier than perspective. Horizontal lines are drawn on 30° planes; vertical lines drawn vertically. Both horizontal and vertical lines are drawn true length. Suitable for early stages of designing for 3D representation of parts/assemblies and sketching. All circles will appear as ellipses. See Figure 6 for a general isometric drawing and 7 for an example using standard isometric grid paper.

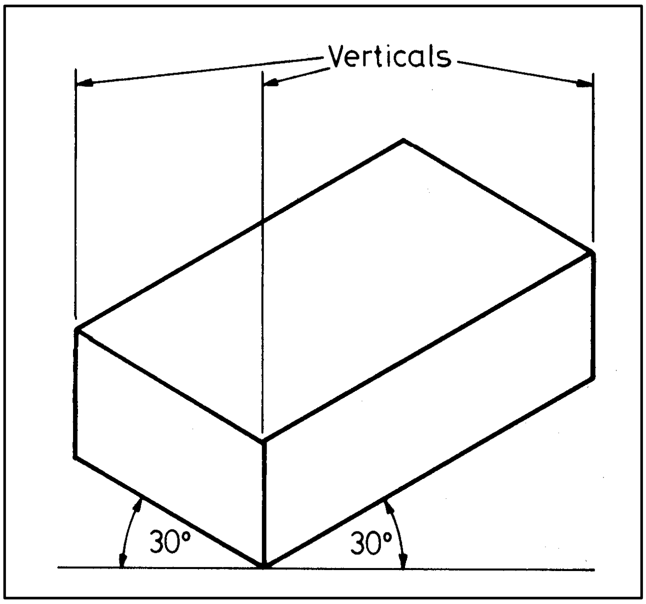


Figure 6 Isometric Drawing

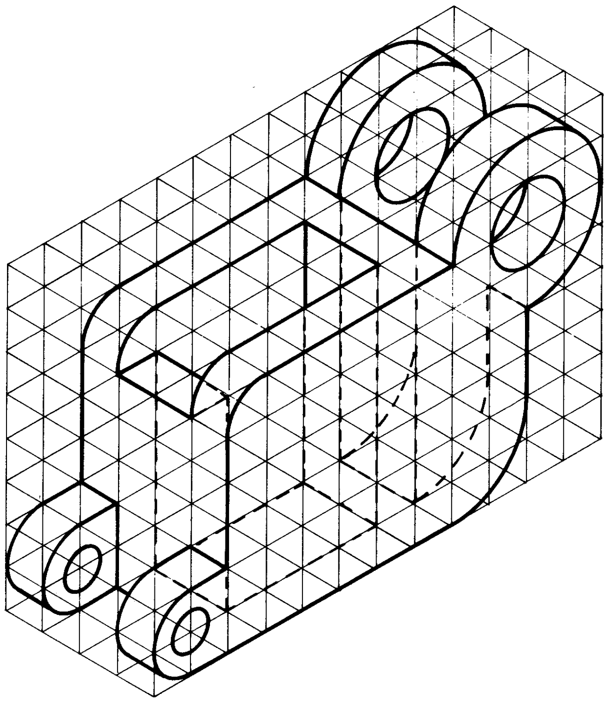


Figure 7 Example of Isometric Drawing using Isometric Drawing Paper

- ***Oblique*** – Very easy to draw. Front face is a true view, but receding edges are parallel to each other on a plane of 30°, 45° or 60° as shown in Figure 8. Standard oblique grid paper is also available. There are three types of oblique drawing, depending on the length of the receding line:
  - Cavalier (receding line length full size).
  - Cabinet (receding line length half size). Used by cabinetmakers!
  - General (receding line length quarter size).

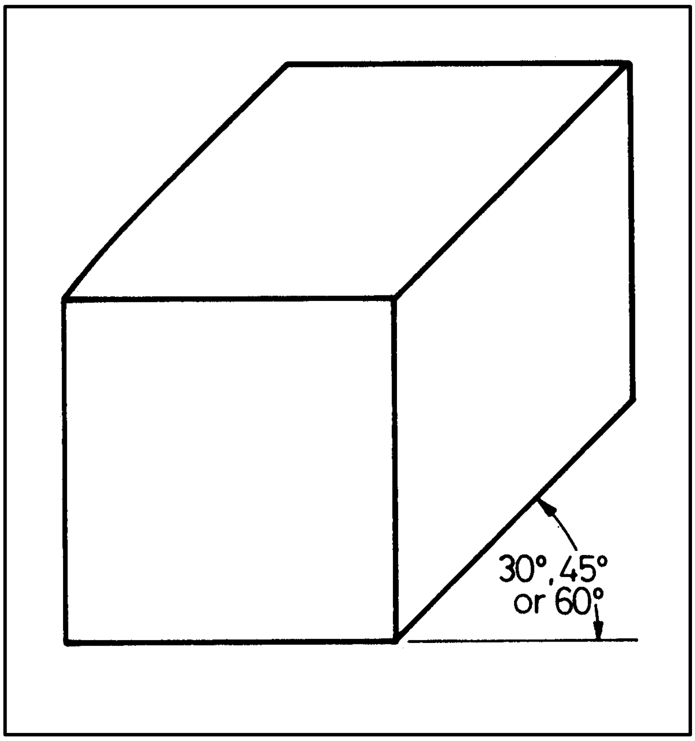


Figure 8 Oblique Drawing

- ***Axonometric*** (or Planometric) – Method of drawing a plan view with a third dimension. See Figure 9 for an example. Used by interior designers, architects and landscape gardeners. Axonometric works by drawing a plan view at 45° with the depth added vertically. All lengths are drawn as their true lengths unlike oblique. This gives the impression that you are viewing the object from above. One advantage of axonometric is that circles drawn on the top faces of objects can be drawn as a normal circle.

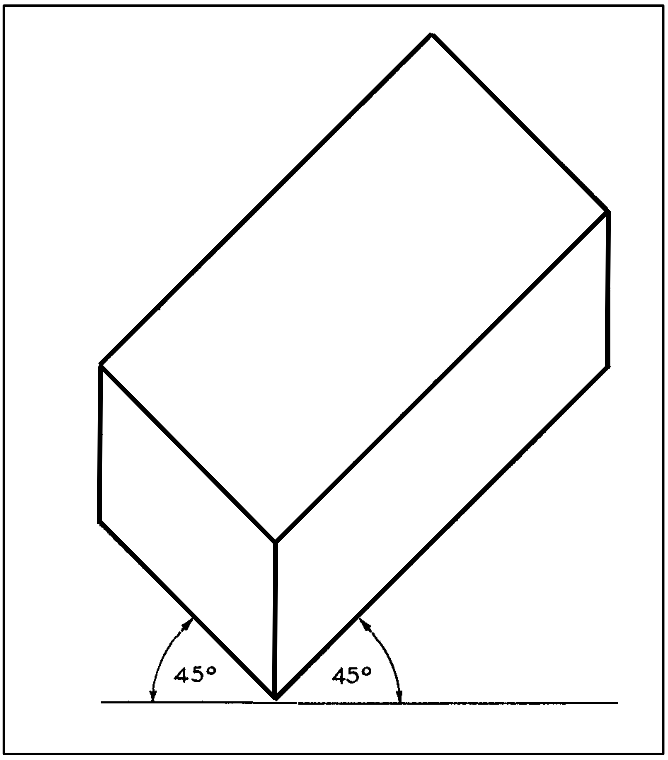


Figure 9 Axonometric Drawing

- ***Perspective*** – Photo-realistic impression. Drawn approximately as we observe it in reality, but with a theoretical vanishing point (VP). Horizontal lines tend to the VPs; vertical lines remain vertical. Can be one-, two- or three-point perspective construction. Examples are shown in Figures 10, 11 and 12 respectively.

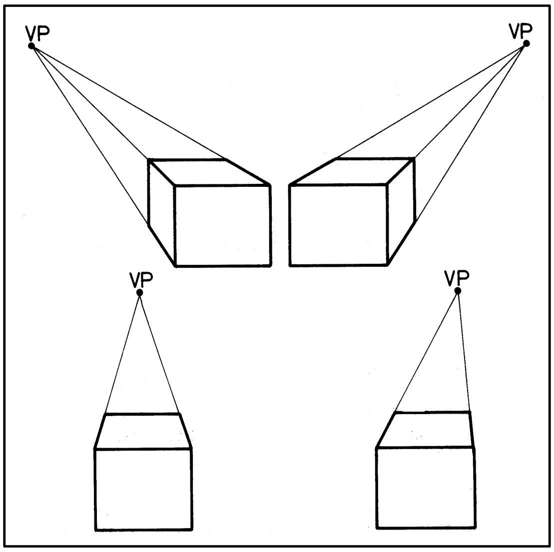


Figure 10 One-Point Perspective Drawing

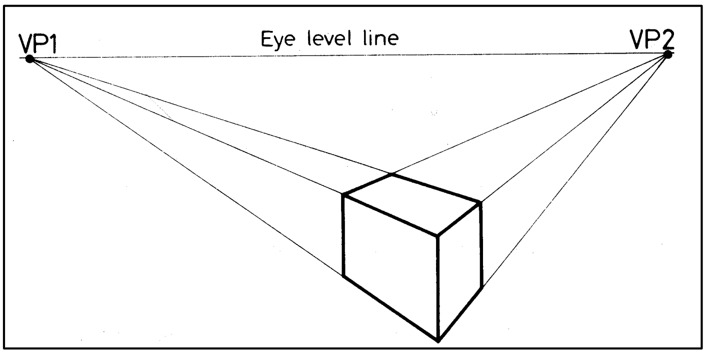


Figure 11 Two-Point Perspective Drawing

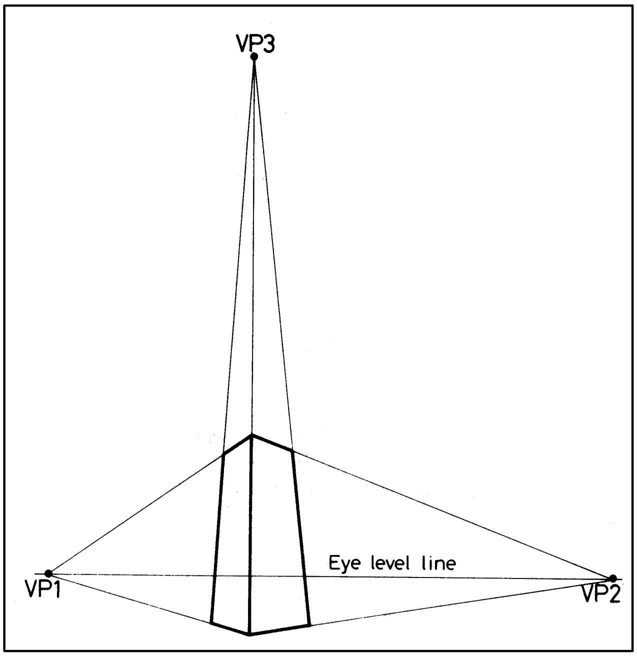


Figure 12 Three-Point Perspective Drawing

Orthographic Projection (or Multiview Drawing)

Commonly used for:

- Part/Detail Drawings – Components and sub-assemblies showing all the necessary information for manufacture, geometry, detail and form (see Figure 13 for an example).
- General Assembly (GA) Drawings (see Figure 14 for an example):
  - Shows an entire collection of parts that form a mechanism or assembly.
  - May consist of multiple views or a single profile.
  - Shows only major dimensions and some hidden, internal detail or sectioning.
  - May be drawn in full or half section.
  - Shows how the parts fit together.
  - Can provide a record of which parts are required using a parts list.
  - Can show additional operations e.g. mechanical fastening, welding, adhesive bonding.
  - Uses numbered balloons to identify the separate components and relates these to the parts list (see Figure 14 for an example of a parts list).
  - Three main types:
    - **Outline assembly** – exterior view only.
    - **Sectioned assembly** – gives a graphic description by passing a cutting plane through some or all portions.
    - **Pictorial assembly** – usually shows the assembly in isometric view in exploded or unexploded format. Exploded format useful because it shows the parts separated from one another and the orientation and order in which the parts are assembled.
- Fabrication Drawings – Parts that require subsequent joining (welding, brazing, riveting, etc) may need additional information for manufacturing, such as weld type and leg length. Special symbols are used to describe these requirements.
- Others – Architectural plans, installation drawings, printed-circuit board (PCB) layouts and structural drawings used in civil engineering for steelwork erection.

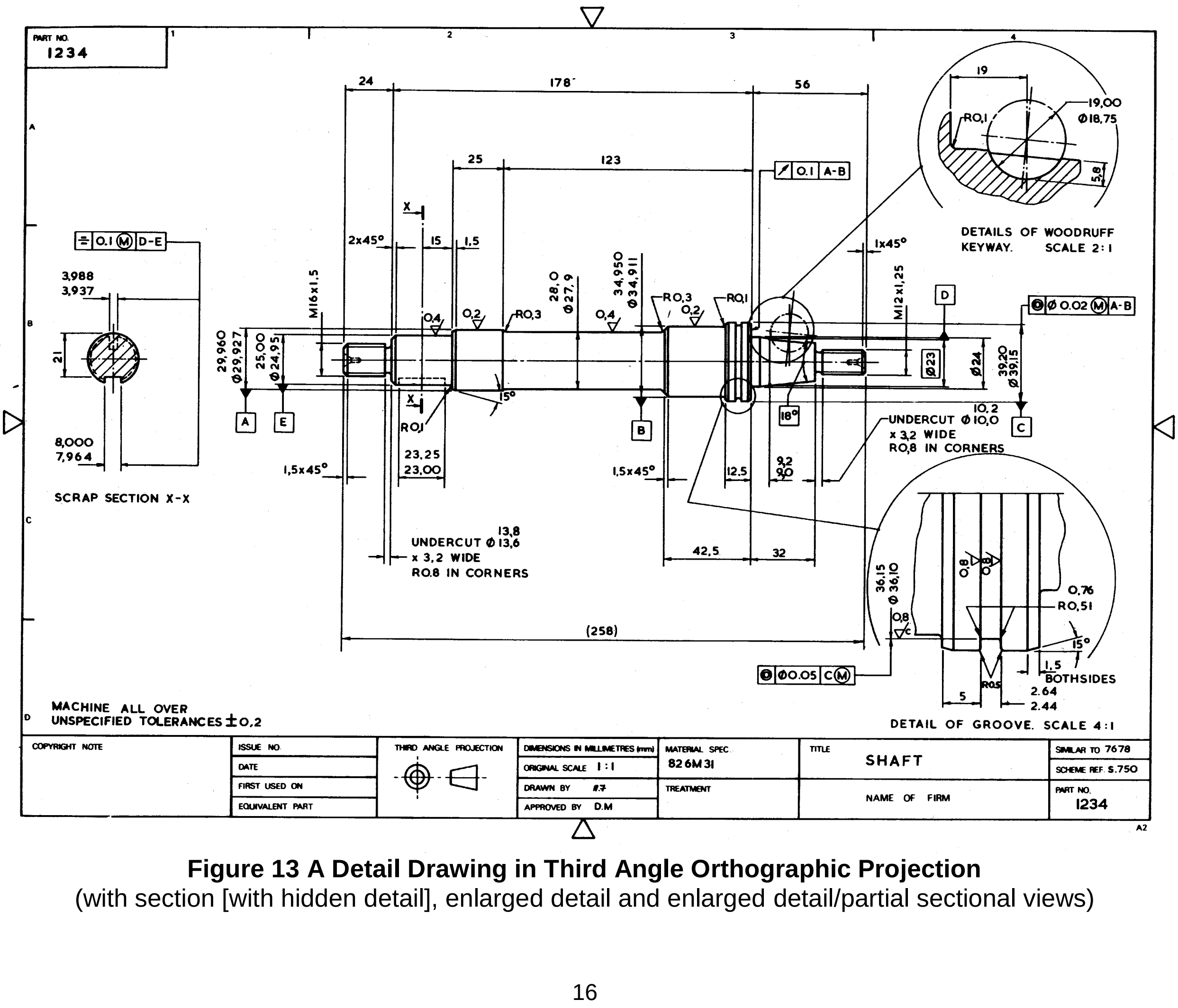


Figure 13 A Detail Drawing in Third Angle Orthographic Projection

(with section [with hidden detail], enlarged detail and enlarged detail/partial sectional views)

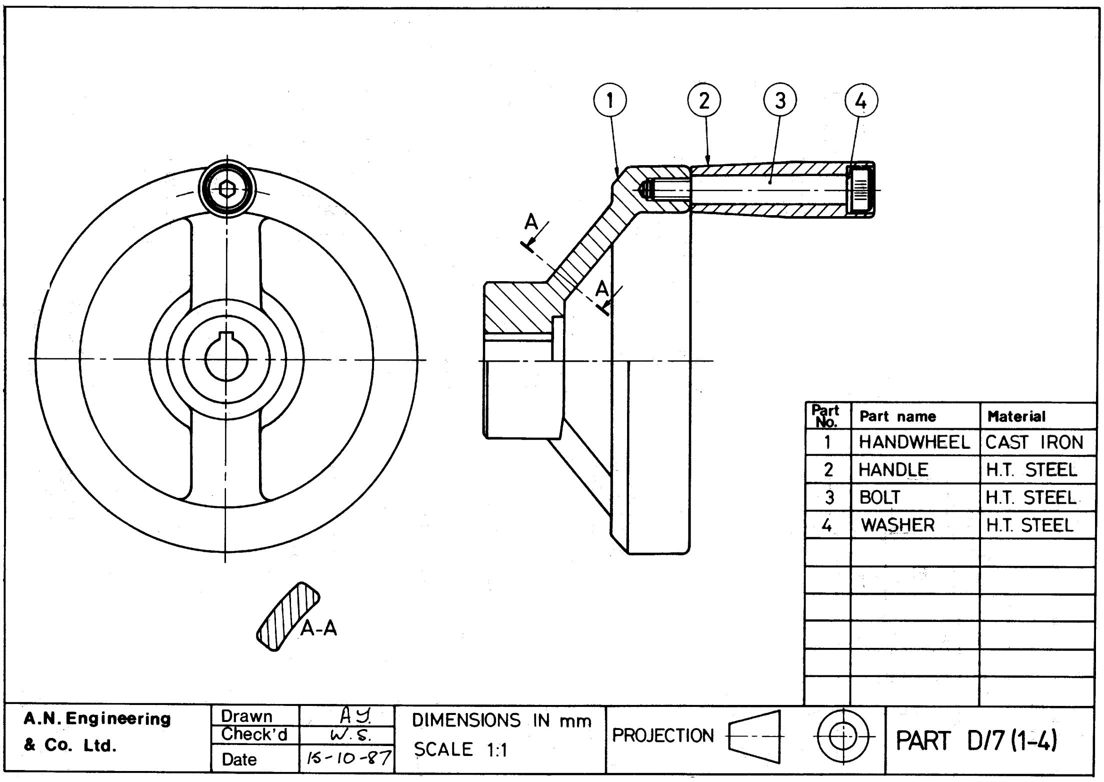


Figure 14 General Assembly (GA) Drawing in First Angle Orthographic Projection
(with parts list, auxiliary and sectional views, and section)

2.3 Best Practice Guidelines

Sketching

- Take time to look at an object, its perspective, shading and form. Observe from a few different angles.
- Freehand sketch from your shoulder, not your wrist.
- Use a pencil, but using a pen forces you to sketch neatly because it is difficult to erase.
- Construct complex shapes using standard shapes and elements such as prisms, conics, cylinders, spheres and cubes.
- Use sketches prior to more complex drawings to arrange views and spacing in the drawing cell.
- Use grid paper where appropriate (isometric, square or oblique) to aid representation and for clarity.

Diagrams

- Use standard symbols and notation (see Bibliography for relevant British Standards).
- Flow should be from left to right and top to bottom, generally.
- Use evenly spaced symbols and connections.
- Joining and crossing flow paths/circuit lines must follow conventions for clarity.

Isometric Drawing

- Use blank grid paper when available.
- Use faint lines for construction initially.
- Start by sketching the right or left surface first.
- Draw a surface that shares an edge with the previous surface.
- Repeat for other features of the object until all construction lines completed.
- Darken construction lines showing outline of object.
- If sketching isometrically viewed circles, use the ellipses in Appendix B as a guide or alternatively the procedure given next.

Constructing Isometric Ellipses

This method called the Four-Centre Method shown in Figure 15 does not create perfect ellipses, but is accurate enough for most purposes. It can be used to draw circles or portions of circles on any isometric plane. The following steps describe the construction of an isometric ellipse (see PP 8888-1 for oblique ellipse construction):

1. Draw lines DA and DC along the two receding isometric axes. Draw line AB parallel to DC, and line CB parallel to AD. The isometric square has sides equal to the diameter of the circle.
2. Draw construction lines from point D perpendicular to line AB at its midpoint and perpendicular to line CB at its midpoint. These lines are perpendicular bisectors of each side.
3. Repeat step 2 using point B and lines AD and CD.
4. Use points D and B to construct arc R1. Arc R2 originates at the intersection of the perpendicular bisectors for both R1 radii.

Perspective Drawing

- Select appropriate number of vanishing points (1, 2 or 3).
- Use faint lines for construction initially.
- For two-point perspective, draw a horizontal line relative to the centre of the horizontal viewing plane of the object.
- Draw a vertical line whose location is the front-most corner of the object as viewed.
- Draw lines from each VP to the ends of the vertical line.
- Draw other vertical lines to the right and left of the first vertical line to represent the far edges of the object.
- Repeat for other vertical features of the object until all construction lines completed.
- Darken construction lines showing outline of object.

Oblique Drawing

- Use blank grid paper when available.
- Use faint lines for construction initially.
- Draw front surface first.
- This should be the most irregular or complex face of the object, including faces with circles.
- Add lines showing approximate receding dimension (parallel to each other) depending on type of oblique drawing required (cavalier, cabinet or general).
- Repeat for other features of the object until all construction lines completed.
- Darken construction lines showing outline of object.
- If sketching oblique viewed circles, use the ellipses in Appendix C as a guide.

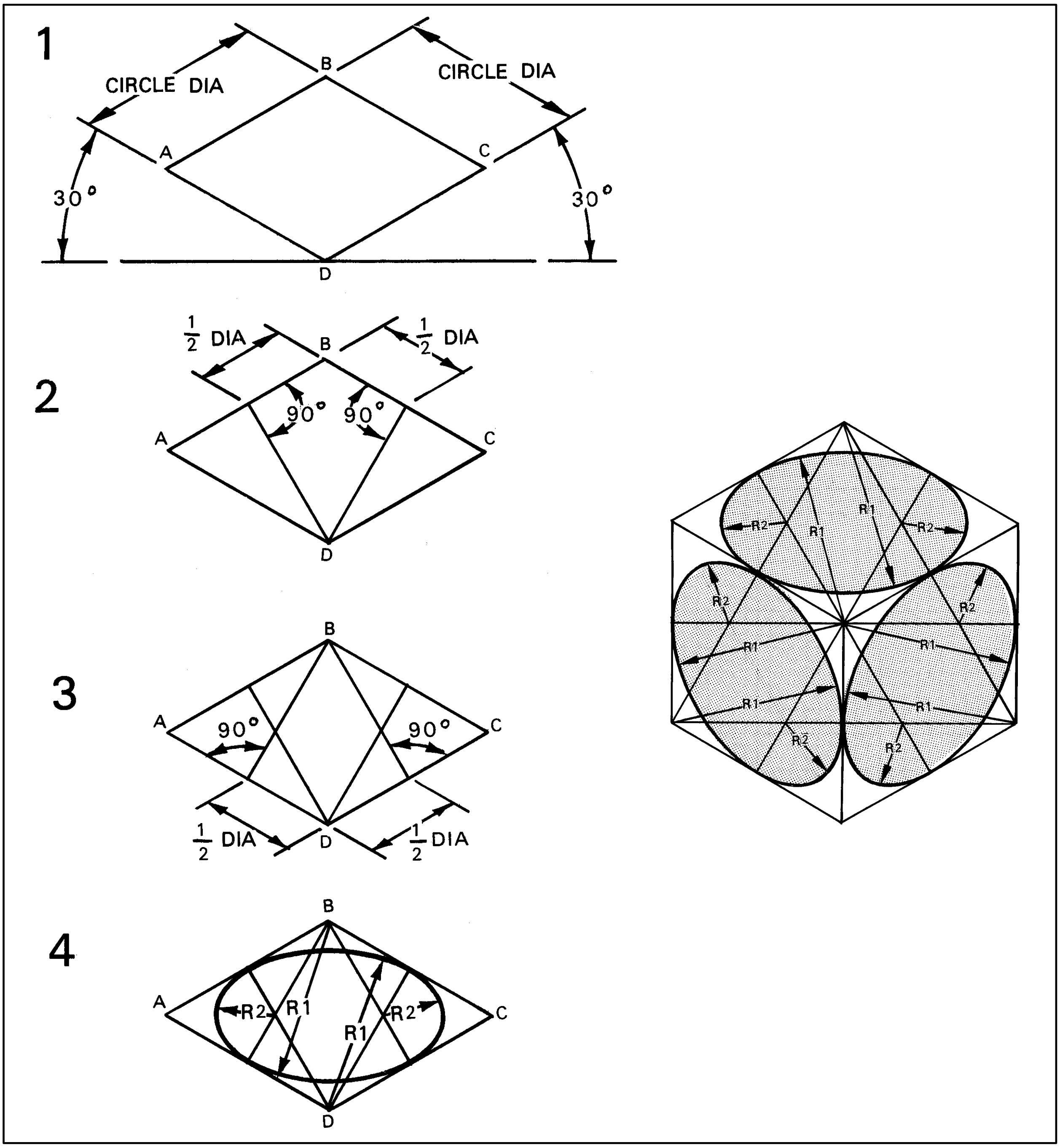


Figure 15 Ellipse Construction for Isometric Drawings

3. ORTHOGRAPHIC PROJECTION OF SOLIDS

3.1 First and Third Angle Projection

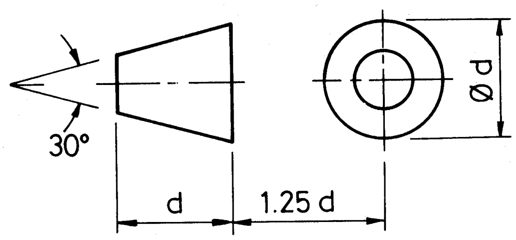
- Principal means of communication used in the engineering industry.
- Orthogonal line or plane means it is perpendicular to another line or plane.
- Projection is the representation of an object on a plane surface as a viewer observes it.
- When the object is viewed perpendicular to the Plane of Projection (POP) then the image is said to be in orthographic projection.
- Collectively, the views on these planes completely describe the object.
- Up to 6 separate main views are possible of one component/assembly.
- This method of projection is used by designers to specify the shape of a 3D object on the 2D plane of the drawing paper.
- Since the basic principles are universal it can be used to convey information across language barriers.
- No need to label the views – view conventions described by orthographic nature.

Two projection conventions are used:

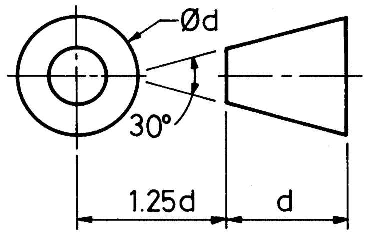
First Angle Projection – The view you are looking at is projected through to the other side of the object.

Third Angle Projection **–** The view you are looking at is displayed at the same side.

- First angle projection is generally used in Continental Europe.
- Third angle projection used in US.
- UK uses both first and third angle orthographic projection conventions.
- Therefore, you must show which is used on a drawing.
- Third Angle Projection has a certain visual logic and is therefore recommended.
- See Figure 16 for the symbol dimensions set by BS.



First Angle Projection Symbol



Third Angle Projection Symbol

Figure 16 BS Symbols for First and Third Angle Projection

Orthographic Projection Construction Concepts

- Figure 17 shows the basic concepts used to construct a third angle orthographic projection.
- Figure 18 shows a Universal Joint Yoke component and the first angle projection concept in practice. All six views in first angle are shown in Figure 19.
- Figure 20 shows all six views of the Universal Joint Yoke in third angle orthographic projection.

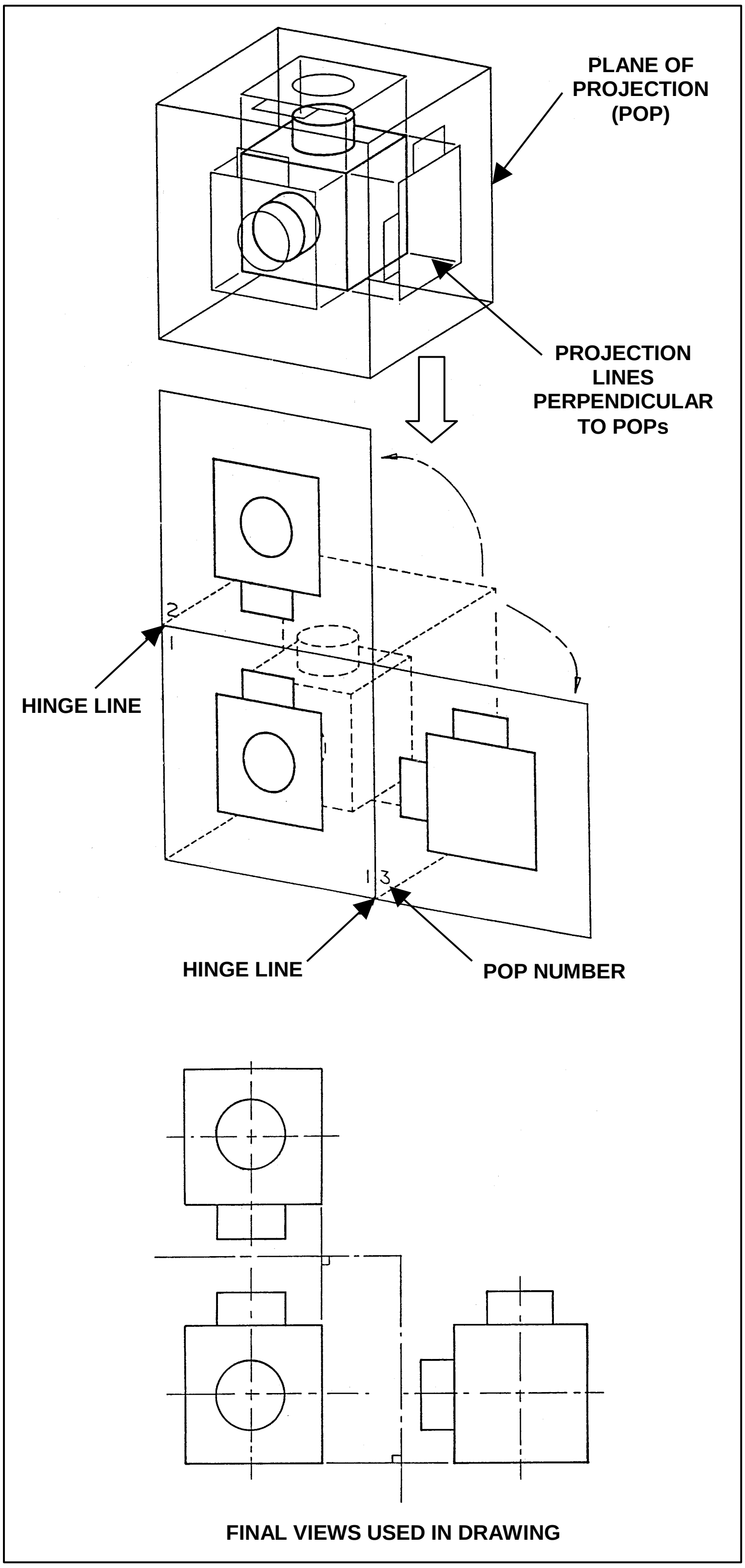


Figure 17 Third Angle Orthographic Projection

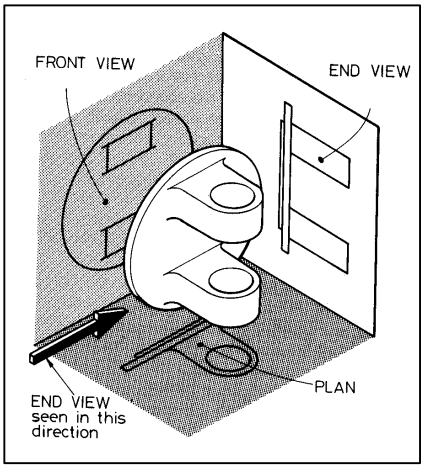


Figure 18 First Angle Projection Concept using a Universal Joint Yoke Component

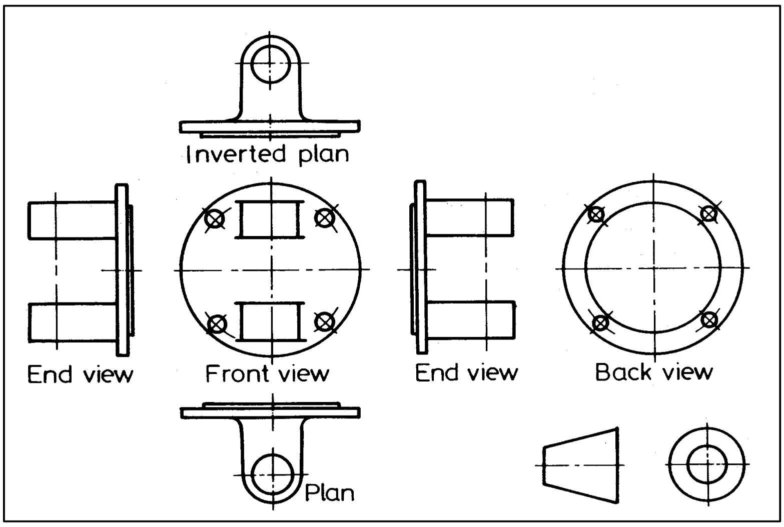


Figure 19 Six Views of the Universal Joint Yoke using First Angle Orthographic Projection

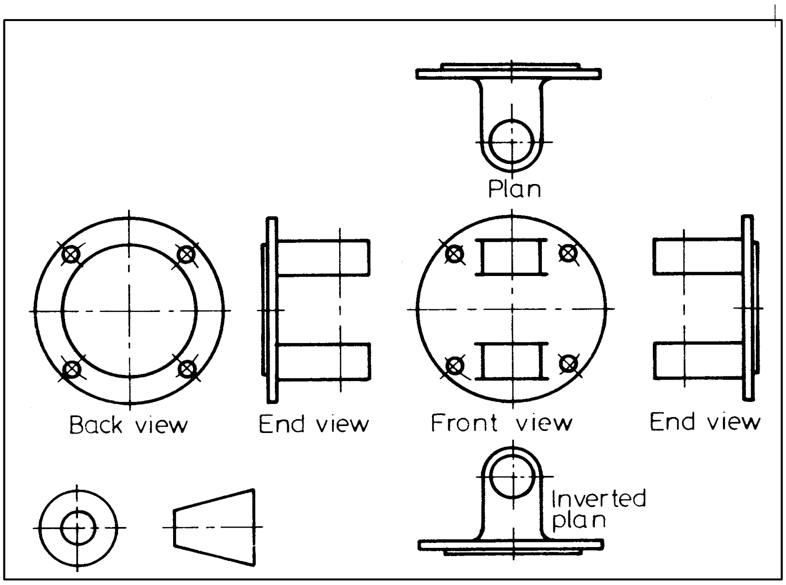


Figure 20 Six Views of the Universal Joint Yoke using Third Angle Orthographic Projection

3.2 Other Views Possible

- A separate projection, out of alignment with the main views, may assist object representation in some cases.
- The following are examples of the other view types possible on an orthographic projection drawing.
- There is no limit to the number of these other views shown on a single drawing and combinations of each may be needed in order to describe the component/assembly effectively.

Partial View

When it is not necessary to show full views, a partial view may be used. It is a special view showing part of what is seen in a defined direction of viewing. This viewing direction may be different from the orthographic conventions of first or third angle. See Figure 21 for an example.

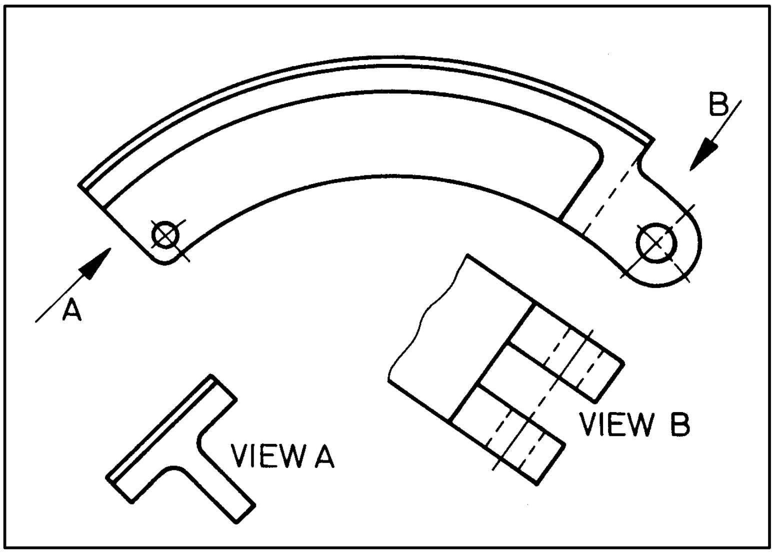


Figure 21 Partial View Example

Auxiliary View

These allow the true shape/dimension of features at any angle relative to the main views to be shown, e.g. true shapes of planar surfaces. Figure 22a) and b) show auxiliary views of the same object in first and third angle orthographic projection respectively. Figure 23 shows how to generate an auxiliary view for an arbitrary geometry at a plane of 45°

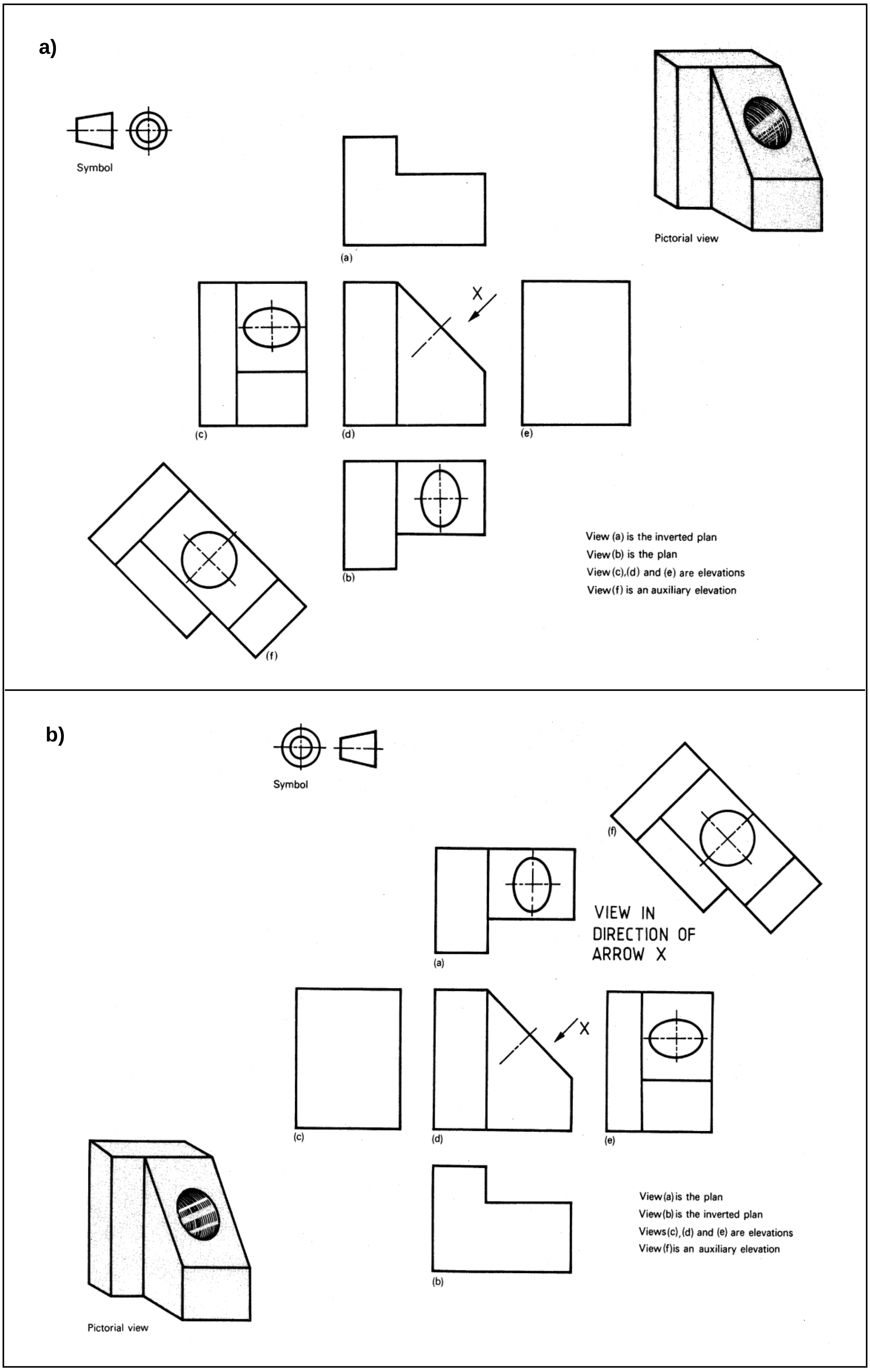


Figure 22 Auxiliary View Examples in a) First and b) Third Angle Orthographic Projection

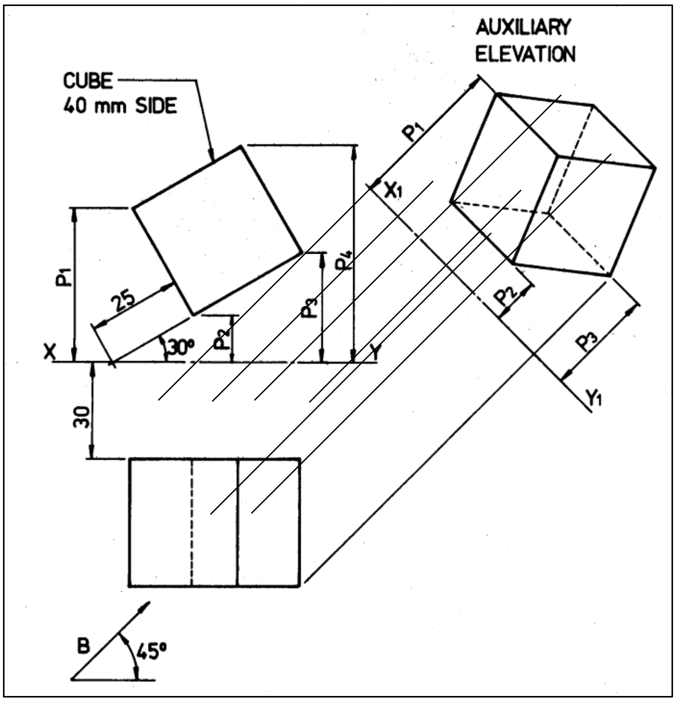


Figure 23 Auxiliary View Generation

Sectional View

In some cases it is not possible to see internal features of components/assemblies from the standard views, and so sectional views are needed. Hatching is used to indicate the plane sectioned. You must indicate on the drawing where the section plane is using standard convention. Can also have stepped sectional views on parallel planes, successive sectional views showing the profile through a part, and local or partial sectional views. An example of part sectioned on parallel planes is shown in Figure 24. Note that a 'section' is distinct from a 'sectional view' because it does not show background detail of the object being sectioned.

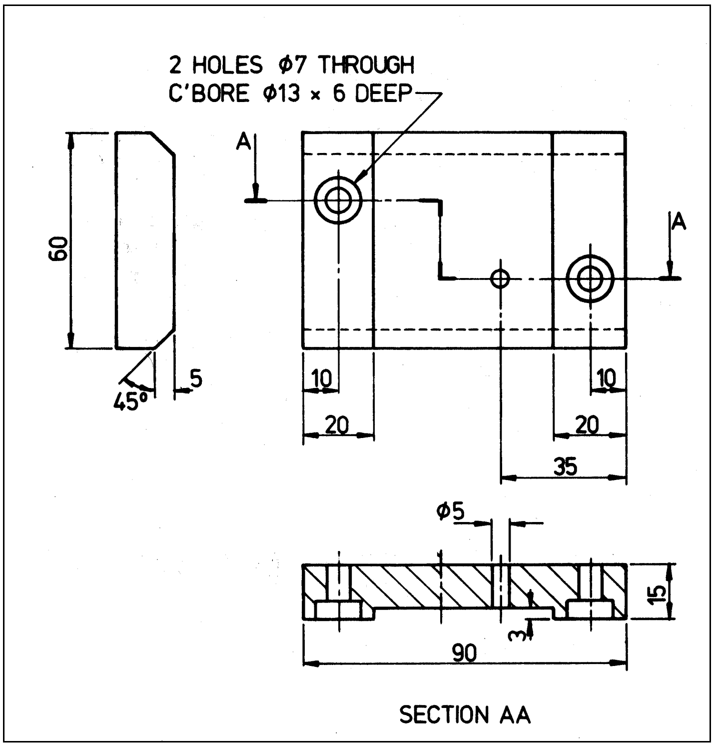


Figure 24 Parallel Planes Sectional View Example (First Angle)

Some examples of hatching convention are shown in Figure 25. The hatching lines should be drawn at 45°, should not be less than 4mm apart and should be spaced equally for the same component sectioned. Reverse hatching is used for assembled parts adjacent to each other.

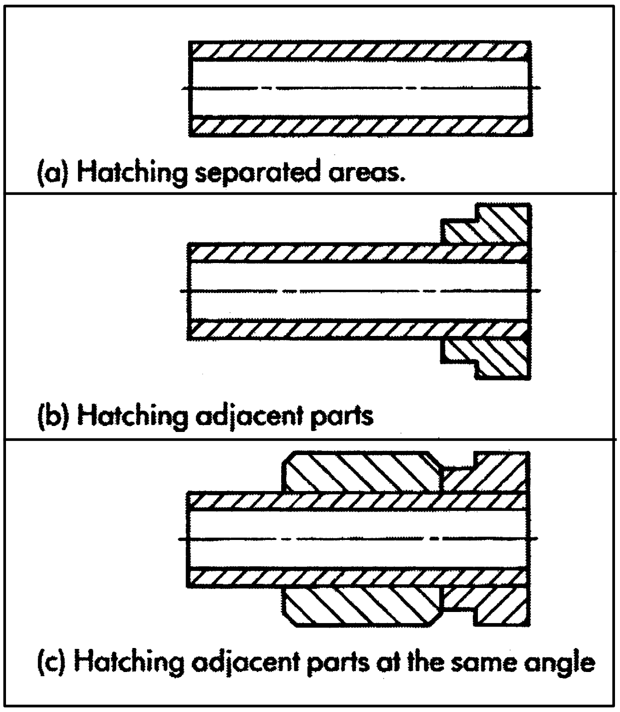


Figure 25 Hatching Convention for Components and Assemblies

Shafts, bolt, pins, nuts and webs on castings, should not be sectioned in assembly drawings when the sectioning plane is along its longitudinal axis (see Figures 14 and 26 for examples). Where it is appropriate on shafts and pins is when complex detail oblique to the length of the part requires separate views, as shown in Figure 27.

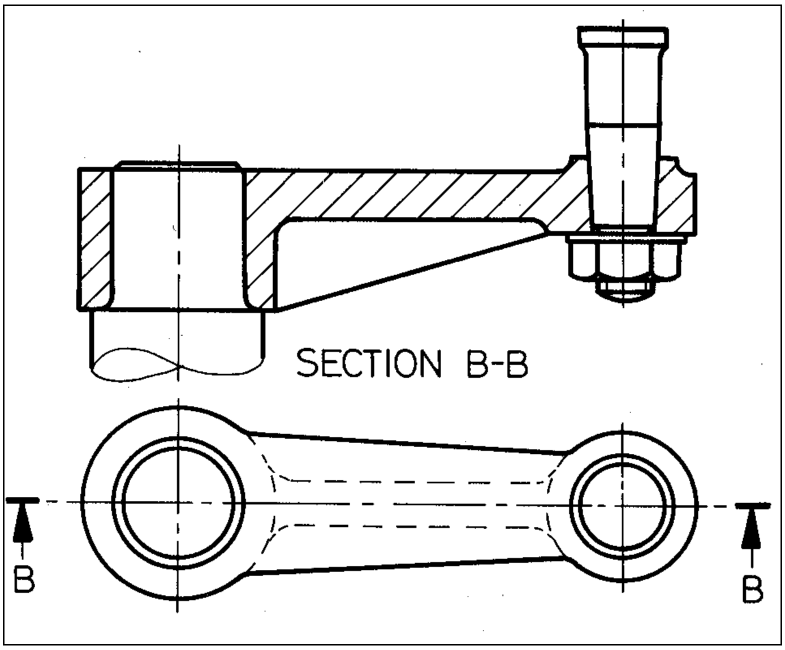


Figure 26 Pins, Shafts and Webs are Not Sectioned

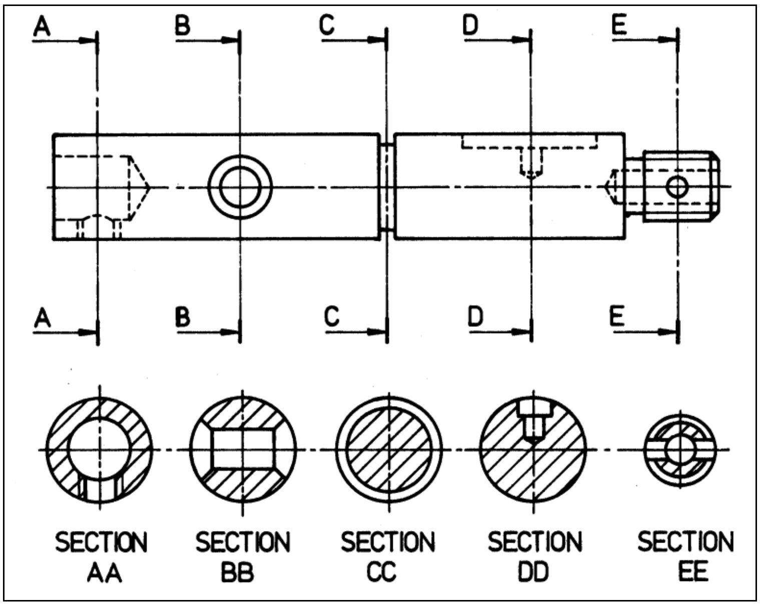


Figure 27 Section Views at Stages along a Shaft

Symmetrical View

Where symmetry exists in a component/assembly, e.g. about the centre line, quarter or rotational symmetry, it is not necessary to draw the full view. This saves time. See Figure 28 for two examples.

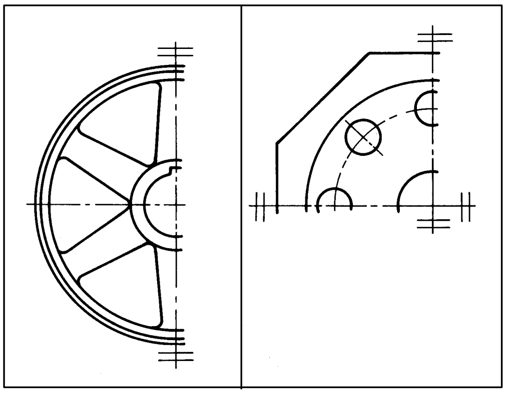


Figure 28 Symmetrical View Examples (Half and Quadrant)

Enlarged Detail

Useful if the original drawing scale is too small to allow features to be identified/dimensioned correctly. The feature to be enlarged is circled and labelled for identification. An appropriate scale should be chosen and given with the enlarged view, as shown in Figure 29.

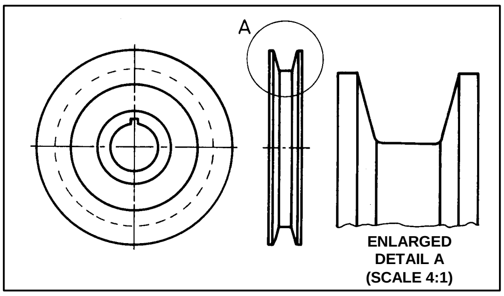


Figure 29 Enlarged Detail Example

Interrupted View

Used to make a drawing easier to construct and save space. Only portions of long or large objects where the detail needs to be shown close to each are simplified using interrupted views. Various break lines are shown in Figure 23.

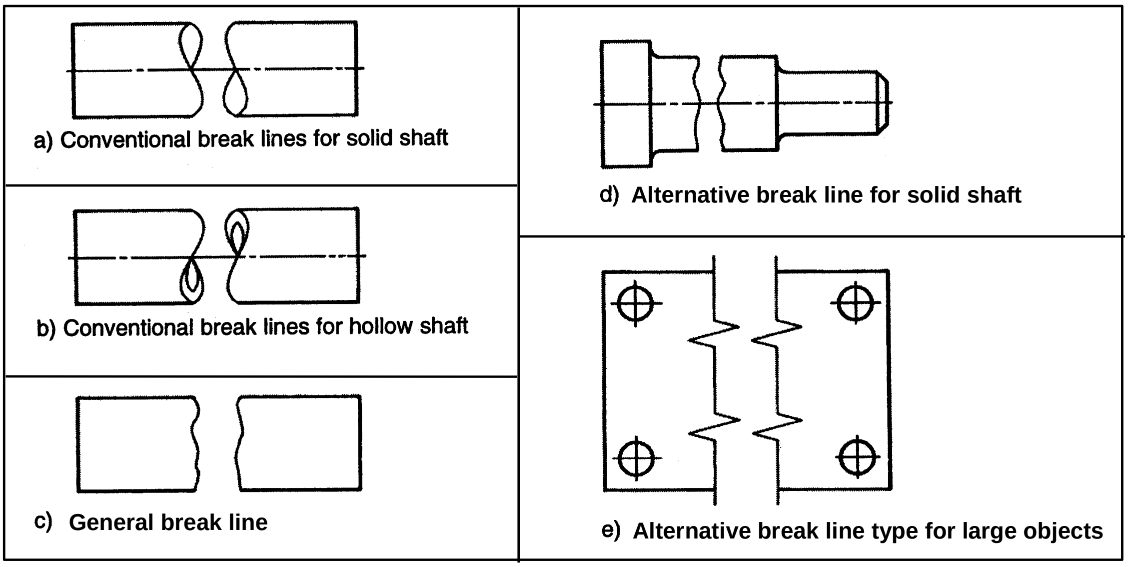


Figure 30 Examples of Interrupted View Break Line Types

Repetitive Features

It saves time not to have to draw a feature or detail that is repeated a number of times. A full view of one of the features can be shown and then centre lines, as shown in Figure 31, may represent the positions of other features of the same type.

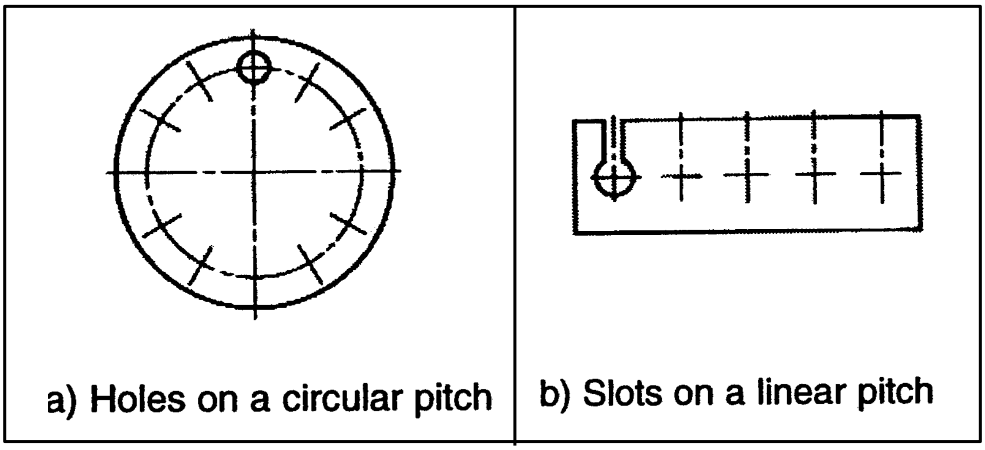


Figure 31 Examples of Repetitive Feature Representation

3.3 Additional Projections

Exploded Projections (Assemblies)

Exploded projections are used to illustrate how the *Parts* that constitute an *Assembly* fit together. Generally they are 3D projections, commonly Isometrics, where each part has been moved along an axis so that it does not obscure another part located behind it. On the attached drawing D0212-035 please note the following:

- The “drawing” is, in fact, sheet 5 of 5. The other 4 sheets contain conventional orthogonal projections. The exploded projection is used for reference
- The drawing has a Parts List (top right hand side of drawing frame) and each part in the exploded projection has been given a *Balloon* annotation indication its item/part number
- The drawing frame and title block indicate that it’s layout is third angle and the drawing conforms to BS8888 (see top left side of drawing frame)
- The drawing is *Issue* 1 as specified in *Change Note* CN203 and is issued for production purposes

Developed Projection (a.k.a Flat Pattern)

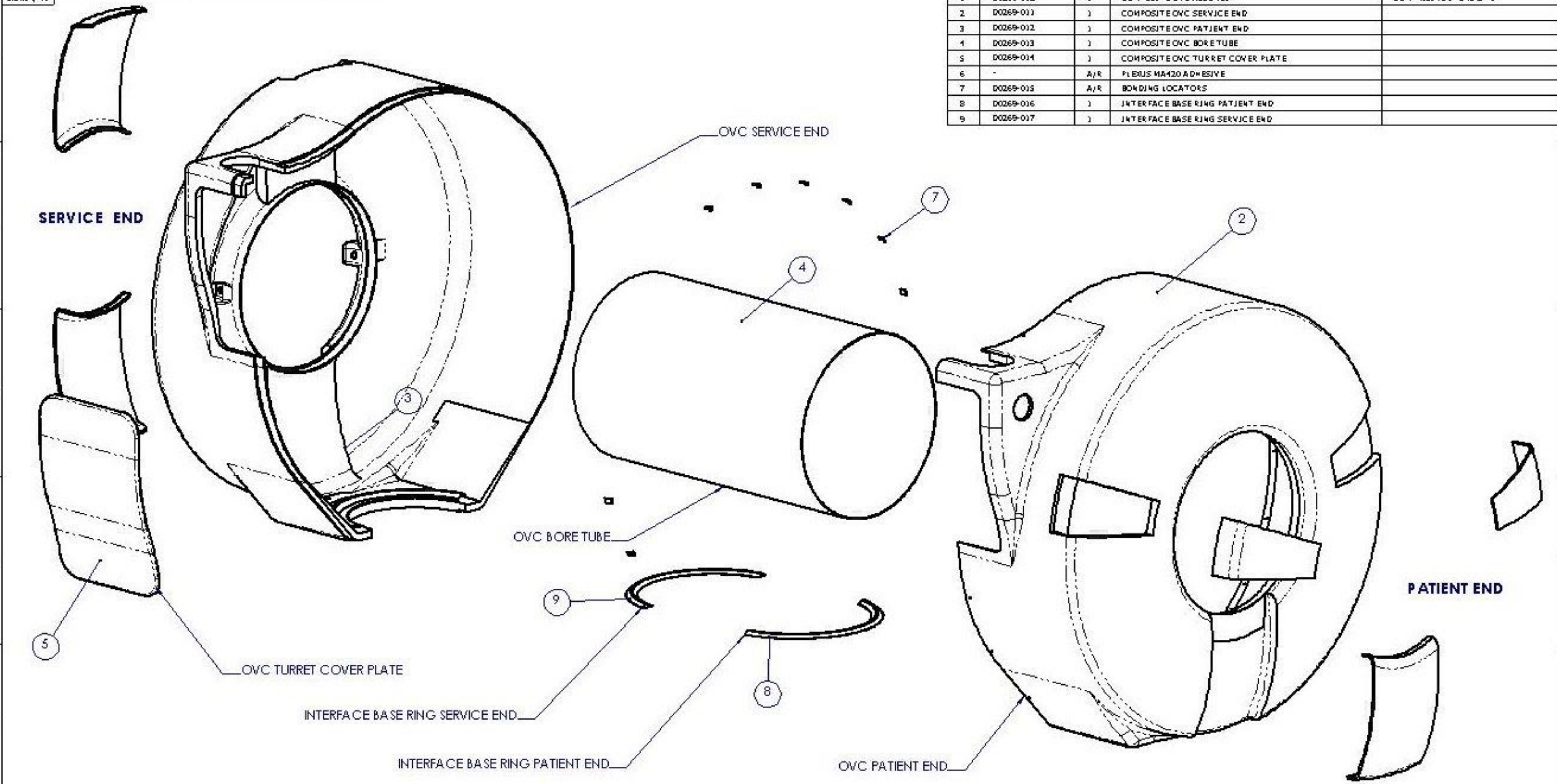
Many engineering parts or artefacts are manufactured from sheet metal folded as required to form a 3D shape. Thus any folded part may be drawn and dimensioned in its *Flat* state to assist its manufacture.

On the attached drawing D0212-036 please note the following:

- The drawing is *Issue* A and is issued for comment and cost estimation purposes only (i.e. not [yet] for manufacture)
- The holes, etc., are shown on the developed projection – it may be assumed, therefore, that these will be formed before the metal is folded
- A 3D projection is shown for reference (i.e. clarity). This is more common recently as engineering designers have migrated from manual drawing to CAD

Where Used	BS8888	DIMENSIONS IN mm	CAD Drawing	NO Manual changes	Do Not Scale
Drawing No					

Item No	Part No	Qty	Description	Remarks
1	D0269-002	1	COMPOSITE OVC ASSEMBLY	COMPRISING ITEMS 2 - 9
2	D0269-011	1	COMPOSITE OVC SERVICE END	
3	D0269-012	1	COMPOSITE OVC PATIENT END	
4	D0269-013	1	COMPOSITE OVC BORE TUBE	
5	D0269-014	1	COMPOSITE OVC TURRET COVER PLATE	
6	-	A/R	PLEXUS MA420 ADHESIVE	
7	D0269-015	A/R	BONDING LOCATORS	
8	D0269-016	1	INTERFACE BASE RING PATIENT END	
9	D0269-017	1	INTERFACE BASE RING SERVICE END	



3D EXPLODED VIEW FOR REFERENCE

Issue	Details	Date	Drawn	Checked	Stress	Approved
1	CN203 - FIRST PRODUCTION ISSUE	27/09/2006	DD	AIC	AIC	AIC
A	ISSUE FOR COMMENT & TOOLING	08/09/2006	DD	AIC	AIC	AIC

MATERIALS: SEE NOTES

FINISH: SEE NOTES

SURFACE FINISH:

DEBURR & BREAK ALL EDGES

TITLE: OVC ASSEMBLY

GENERAL TOLERANCE UNLESS OTHERWISE SPECIFIED:

LINEAR: +/- 0.5mm

ANGULAR: +/- 0.5°

EST. MASS: ....Kg

ANDREW COX LTD

Drg. No: D0269-002

A2

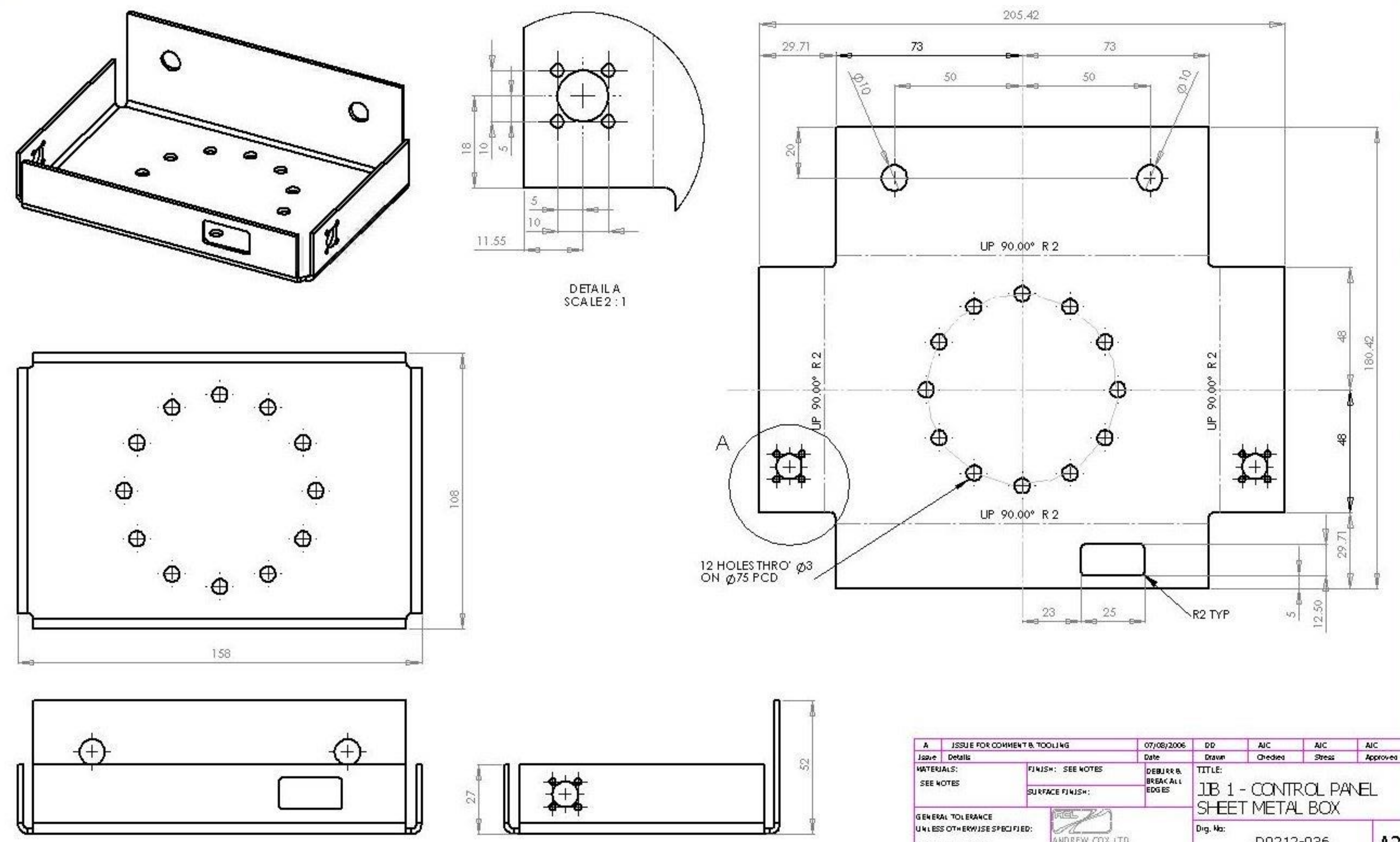
CUSTOMER REF:

SCALE: N.T.S.

SHEET No: 5 of 5

Where Used	BS8888	DIMENSIONS IN mm	CAD Drawing NO Manual changes	Do Not Scale
Drawing No				

Item No	Part No	Qty	Description	Remarks
1				



A	ISSUE FOR COMMENT & TOOLING	07/08/2006	DD	AIC	AIC	AIC
Issue	Details	Date	Drawn	Checked	Stress	Approved

MATERIALS: SEE NOTES	FINISH: SEE NOTES SURFACE FINISH:	DEBURR & BREAK ALL EDGES	TITLE: 1B 1 - CONTROL PANEL SHEET METAL BOX
GENERAL TOLERANCE UNLESS OTHERWISE SPECIFIED: LINEAR: +/- 0.5mm ANGULAR: +/- 0.5°	ANDREW COX LTD		Drg. No: D0212-036 A2
EST. MASS: ....Kg			CUSTOMER REF:
			SCALE: 1 : 1 SHEET No: 1 of 1

3.4 Drawing Construction

Orthographic Drawing Construction Steps *(please refer to Figure 32 on the next page)*

(a) Isometric view of object given.

(b) Establish the overall dimensions using a scale and space appropriately.

(c) Block-in the part using construction lines.

(d) Establish all the major features of the part.

(e) Block-in the secondary features using construction lines.

(f) Establish all holes and draw circles with construction lines using a compass or template.

(g) Darken arcs and circles.

(h) Darken drawing outline and remove construction lines.

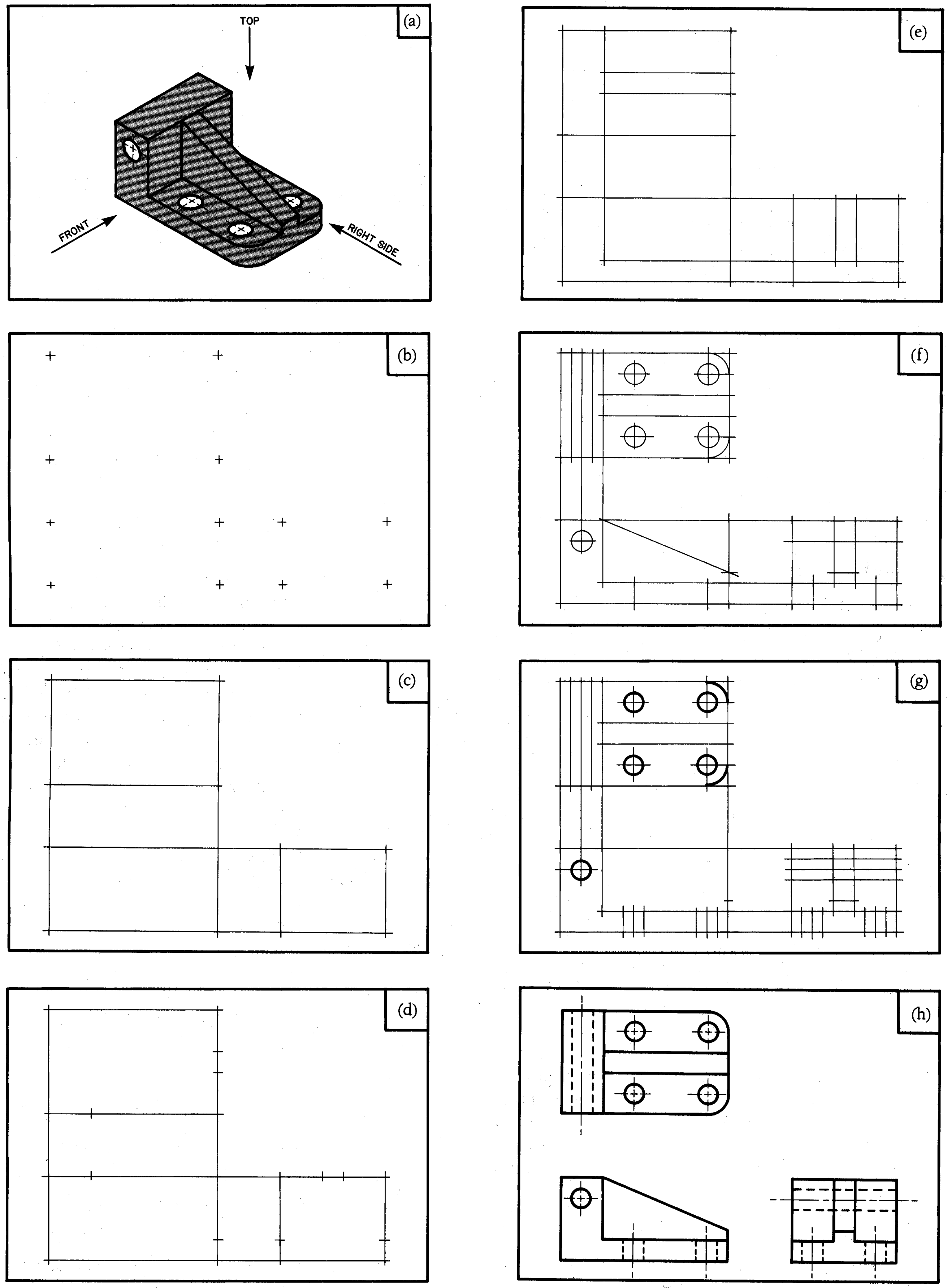


Figure 32 Main Steps in Orthographic Drawing Construction (Third Angle)

Best Practice Guidelines

- Establish most suitable paper size and scale to use.
- Use the minimum number of views required to define the component/assembly that will give all the information necessary for the product to be manufactured.
- For complex parts, three or more views may be required (e.g. an intricate casting), but for parts with symmetry (e.g. a shaft), or a flat component (thin sheet metal pressing) two or perhaps one view may be sufficient to describe the part.
- Organise your drawing frame with appropriate number and types of view and arrange equally within the drawing area (see Figure 33).
- Remember to keep enough space for the drawing's information as shown in Figure 4.
- Decide major dimensions and decisions on dimension placement before commencing drawing.
- Try to align dimensions, symbols and notes, where possible, vertically and horizontally in the drawing frame, and maintain a constant size and in proportion with size of drawing.
- Establish the main features first. Use construction lines to show outline of these main features in faint pencil or 0.3mm pencil thickness.
- Once the outline has been established, draw over the construction lines with 0.5mm pencil.
- If a part has features that are complex, make the view of that feature as large as possible somewhere convenient on the drawing.
- Use 0.3mm thickness line for dimensions.
- Do not erase with too much pressure – you will damage the paper.
- Do not use ink or coloured pens to enhance your drawings.
- On completion, store all drawings in your portfolios.

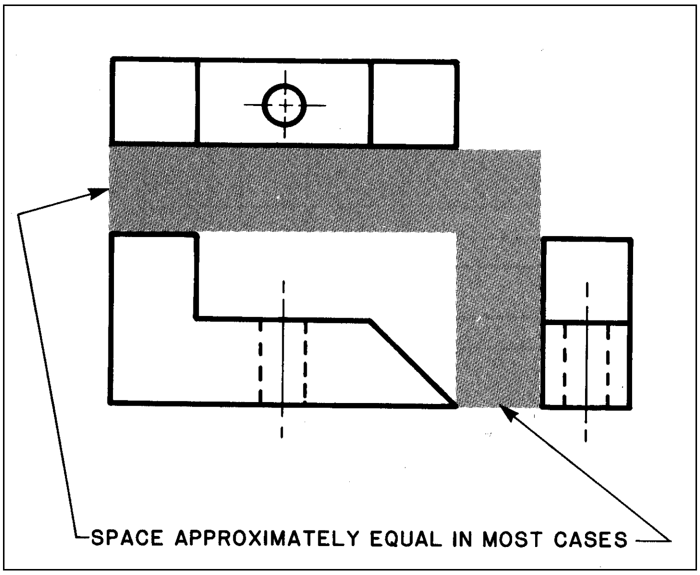


Figure 33 Spacing Views on a Drawing (Third Angle)

Line Projection Methods

It is often the case that the third view of an object is easier to construct using a line projection method than direct measuring, as used in the previous method. The exceptions are when the geometry is complex or profiled as shown in Figure 34. Several techniques exist, but the Mitre Line Method is perhaps the most straightforward to apply. Figure 35 shows its application in the construction of the third view (a side view) of an object. Other methods include the Radius Method and Scale Method (see Bibliography for more details).

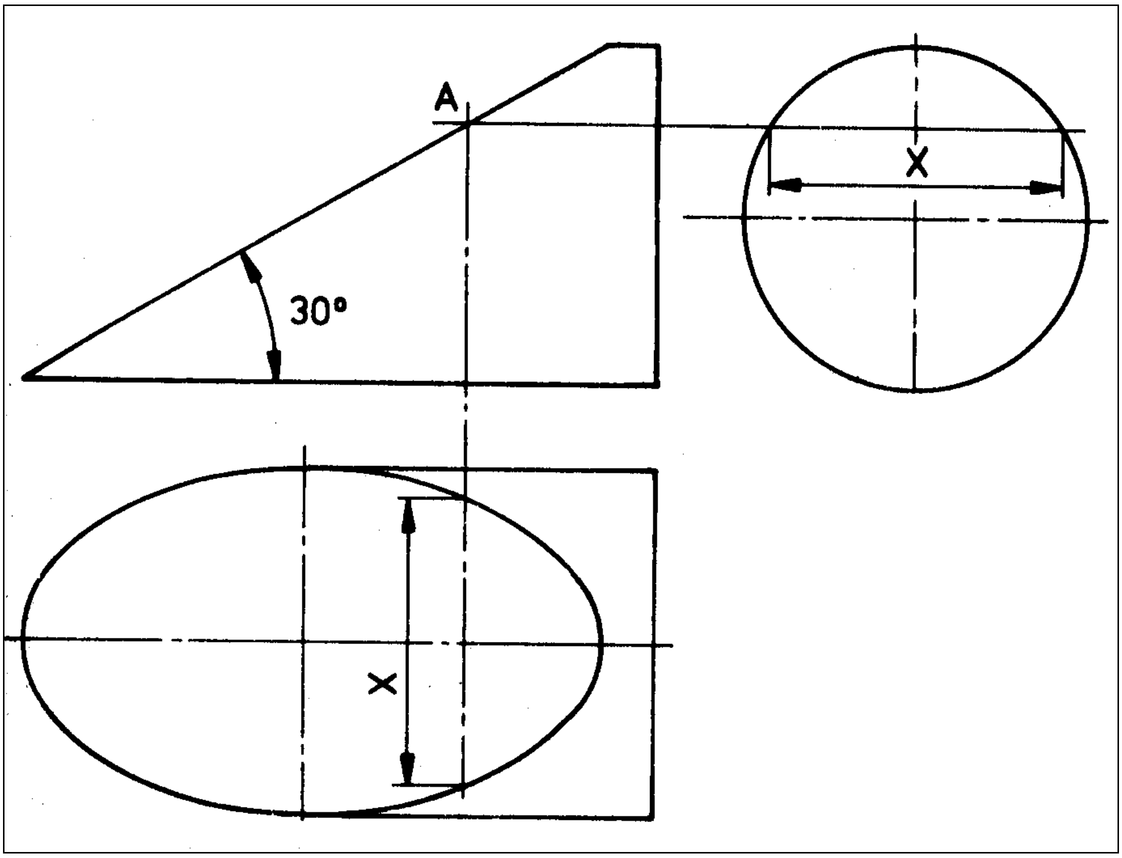


Figure 34 Projecting the Third View of a Complex Geometry using Direct Measuring (First Angle)

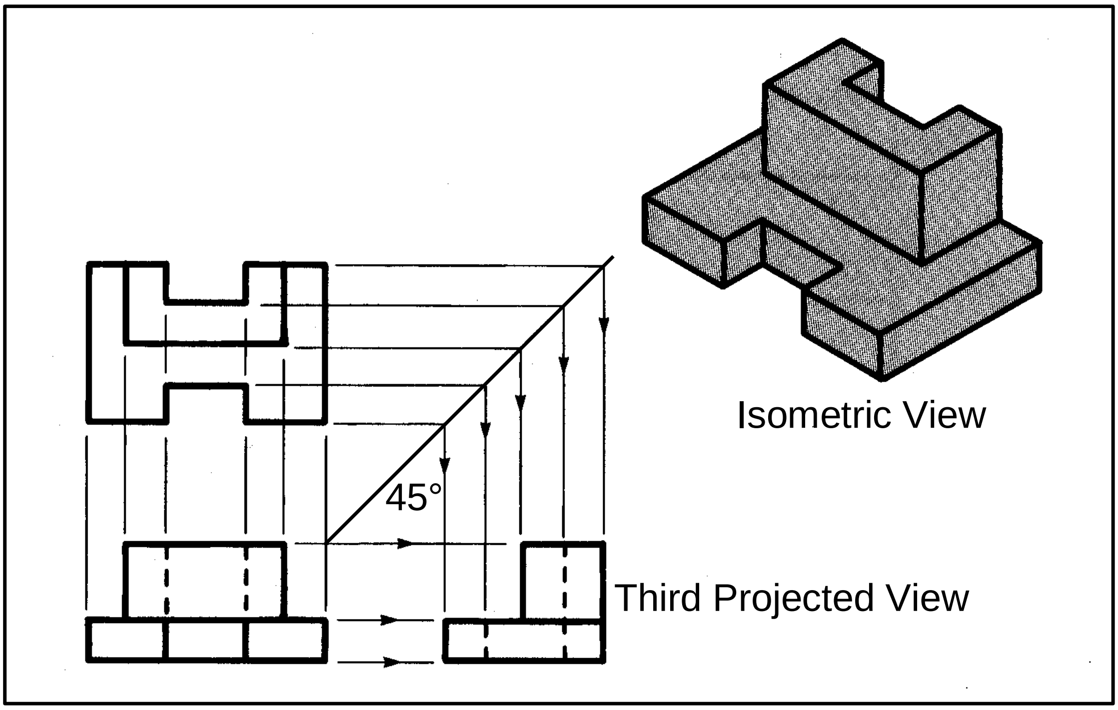


Figure 35 Mitre Line Method for Projecting the Third View of an Object from Previous Views (Third Angle)

4. DIMENSIONING AND TOLERANCING

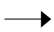
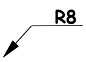
4.1 Dimensioning Guidelines

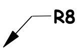
The purpose of dimensioning is to provide a clear and complete description of an object. A complete set of dimensions will permit only one interpretation needed to manufacture, install or fabricate a part. The guidelines below, and supported by Figures 36 and 37 (and Appendix D, which provides examples of how to dimension many standard features), provide a best practice approach when setting out dimensions.

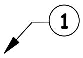
In general, the four main requirements are:

Accuracy – Correct values must be given.
Clarity – Dimensions must be placed in appropriate positions.
Completeness – Nothing must be left out, and nothing duplicated.
Readability – The appropriate line quality must be used for legibility.

Best Practice Guidelines

- Arrowheads approximately 3mm long and 1mm wide (not  or)
- Use thin lines (0.3mm), thick text, bold narrow arrows for dimensioning
- Do not use centre lines as dimension lines and avoid dimensioning to hidden detail
- Dimensions should be placed on the face that describes the feature the most clearly
- Dimension values should be viewable from the bottom right hand corner of the drawing
- Selection of datum surfaces should be considered with great care
- Always show full size values irrespective of scale
- Dimensions should not be repeated (redundant dimensions). Each dimension necessary for the definition of the finished product should be shown once only
- It should not be necessary to calculate a dimension from the other dimensions shown on the drawing, or necessary to scale the drawing to gain information on key dimensions
- Preferred sizes should be used whenever possible e.g. 120, not 118.6.
- Show units on drawing, not on each dimension
- Use SI units at all times (unless in US of course!)
- Dimensions should be expressed to the least number of significant figures, e.g. 45 not 45.0
- Where four or more numerals are to the left or right of the decimal marker a full space should divide each group of three numerals, counting from the position of the decimal marker, e.g. 12 500
- A zero should precede a decimal of less than unity e.g. 0.5
- Angular dimensions are preferred to be expressed in degrees and minutes, e.g. 200° and 220° 30', but occasionally in decimals of degrees, e.g. 0.1° (this is because most angular measuring equipment uses minutes)
- A full space should be left between the degree symbol and the minute numeral
- When an angle is less than one degree it should be preceded by a zero e.g. 0° 30'.
- A leader line is a thin line used to connect a dimension with a particular feature of the part. e.g. 

 or 

- Leader lines may also be used to indicate a note or comment about a specific feature or part number e.g. 

- Refer to PP 8888-1 for more information on dimensioning

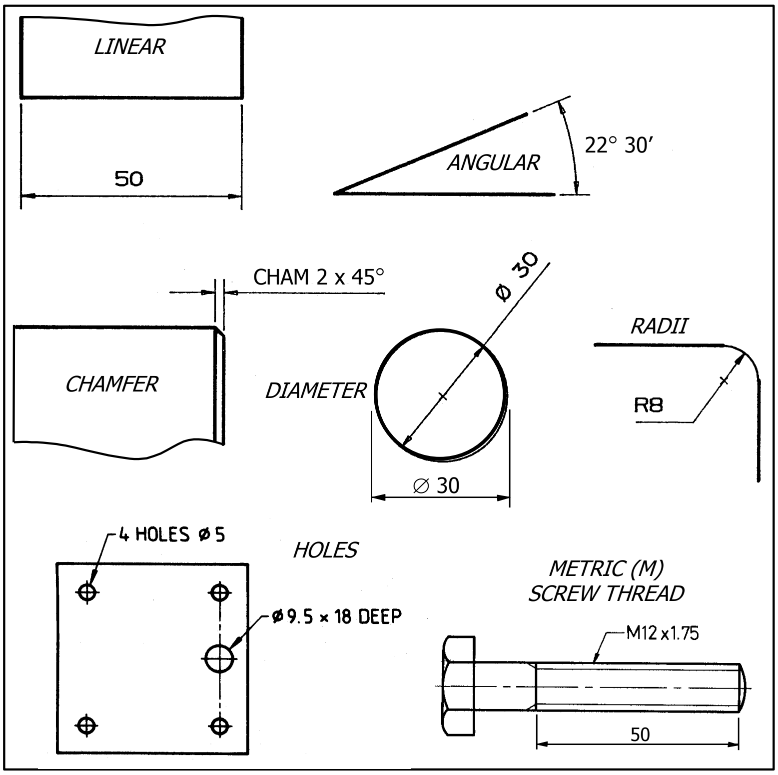


Figure 36 Dimensioning Convention for Some Common Features

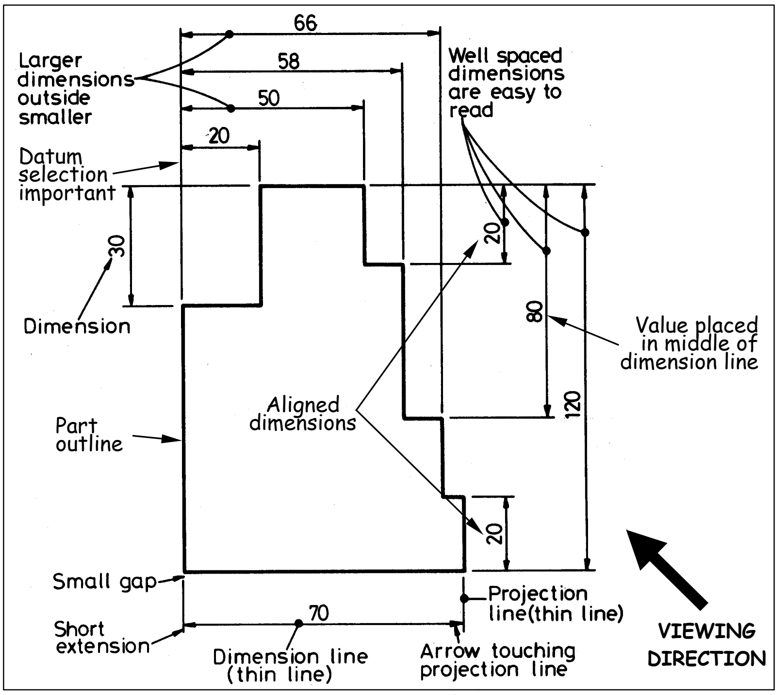


Figure 37 Linear Dimensioning Guidelines

Auxiliary Dimensions

Where an overall dimension spans a number of interconnected features, one of the intermediate dimensions will of course be redundant and should not be shown normally. The exception is when the main dimension may provide useful reference information e.g. where a component is parted off to length in a machine tool. It is then called an auxiliary dimension and is shown in brackets e.g. (110). These dimensions are not toleranced. See Figure 38 for an example.

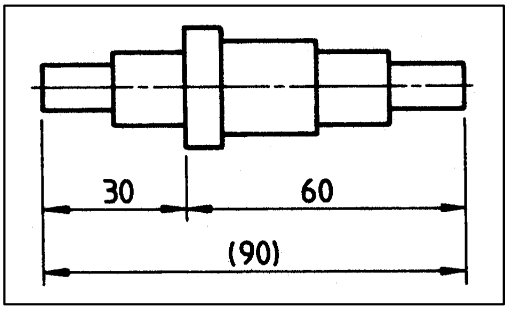
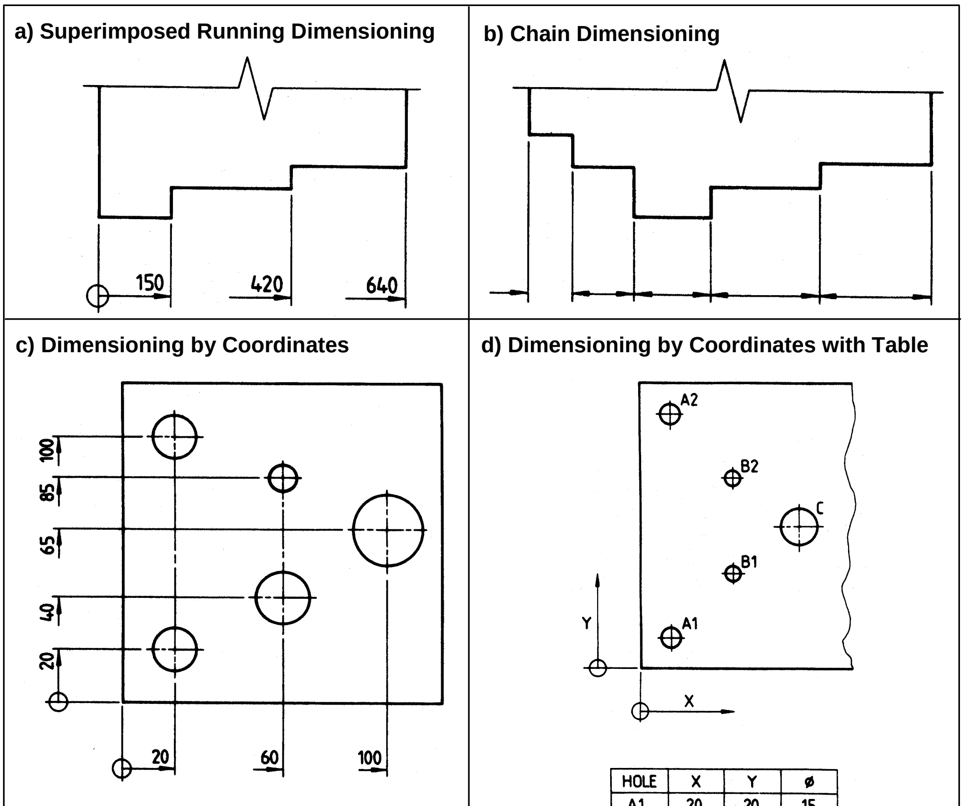


Figure 38 Auxiliary Dimensioning Example

Dimensioning Methods

- Parallel Dimensioning – Parallel dimensioning consists of a number of dimensions originating from a datum feature/surface (as shown twice in Figure 37).
- Superimposed Running Dimensioning – Simplified parallel dimensioning. May be used where space is limited. A common origin is indicated and dimensions may be placed near the arrowhead and either above and clear of the dimension line, or in line with the corresponding projection line. See Figure 39a) for an example.
- Chain dimensioning – Chains of dimensions should be used only where the possible accumulation of tolerances does not endanger the function of the part. See Figure 39b) for an example.
- Dimensioning by Coordinates – Superimposed running dimensioning may be used in two directions at right angles, as shown in Figure 39c). The common origin can be any suitable datum feature. May be simplified by using a table as shown in Figure 39d). Also possible to identify groups of holes (or other features) of common size separately.



HOLE	X	Y	ø
A1	20	20	15
A2	20	160	15
B1	60	60	10
B2	60	120	10
C	100	90	25

Figure 39 Linear Dimensioning Methods

4.2 Tolerancing Guidelines

It is difficult (actually impossible!) to produce a real shape exactly to dimensions, therefore tolerances are associated with geometry to indicate required precision in manufacture.

- ***Precision*** – Refers to the spread in repeated readings of a measured property of a physical part i.e. length, mass, angle
- ***Accuracy*** – Refers to the proximity of the measured value to the true value it is supposed to represent

Tolerance value depends on:

- Product/component function (what is it required to do?).
- Manufacturing process (different tolerances achievable with different manufacturing processes).
- Clearance/interference/interchangeability between components in terms of:
  - Type of motion needed
  - Assembly (will components assemble together for all possible tolerances?
- Dimensional variation within a tolerance may limit or impair performance e.g. balance, spatial constraints, weight, need for flexible joints due to misalignment.
- The accumulation of tolerances on a single part for a number of features toleranced sequentially from each other may lead to accumulated error on manufacture of the part. It is therefore important to choose a common datum from which all features are located from, as shown in the example in Figure 40.
- A system of limits and fits for holes and shafts has been standardised for the practical application of tolerances to meet these requirements.

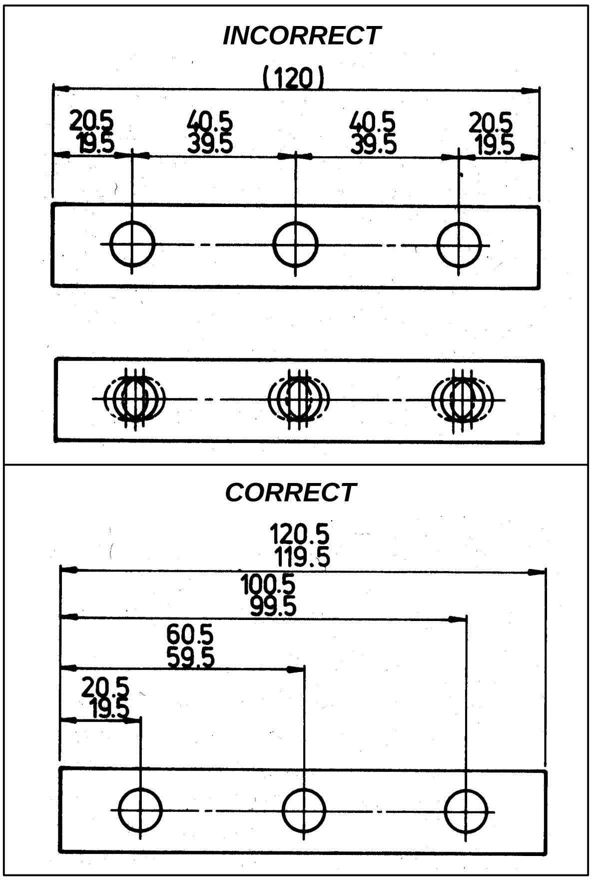


Figure 40 Incorrect and Correct Ways of Dimensional Tolerancing to Avoid Accumulated Errors

Best Practice Guidelines

- Tolerances are always associated with dimensions. Typically shown as a ±value about the target dimension e.g. $\varnothing 20 \pm 0.1$ (known as bilateral tolerances) or can be shown as upper and lower values e.g. $\begin{matrix}\varnothing 20.1 \\ 19.9\end{matrix}$ above the dimension line, or at the end of a leader line $\begin{matrix}\varnothing 20.1 \\ 19.9\end{matrix}$ with an adjacent arrow across the feature being dimensioned
- Also a unilateral tolerance system is sometimes used where the limits are set wholly above, below or a range spanning the nominal size e.g. +0.2, -0
- See Figure 41 for a schematic representation of both bilateral and unilateral tolerance systems
- There should be a tolerance for each dimension, but need not be placed with the dimension
- Can be shown as a general note on a drawing e.g. ALL TOLERANCES ±0.1mm UNLESS OTHERWISE STATED
- Figure 42 provides several examples of tolerancing practice

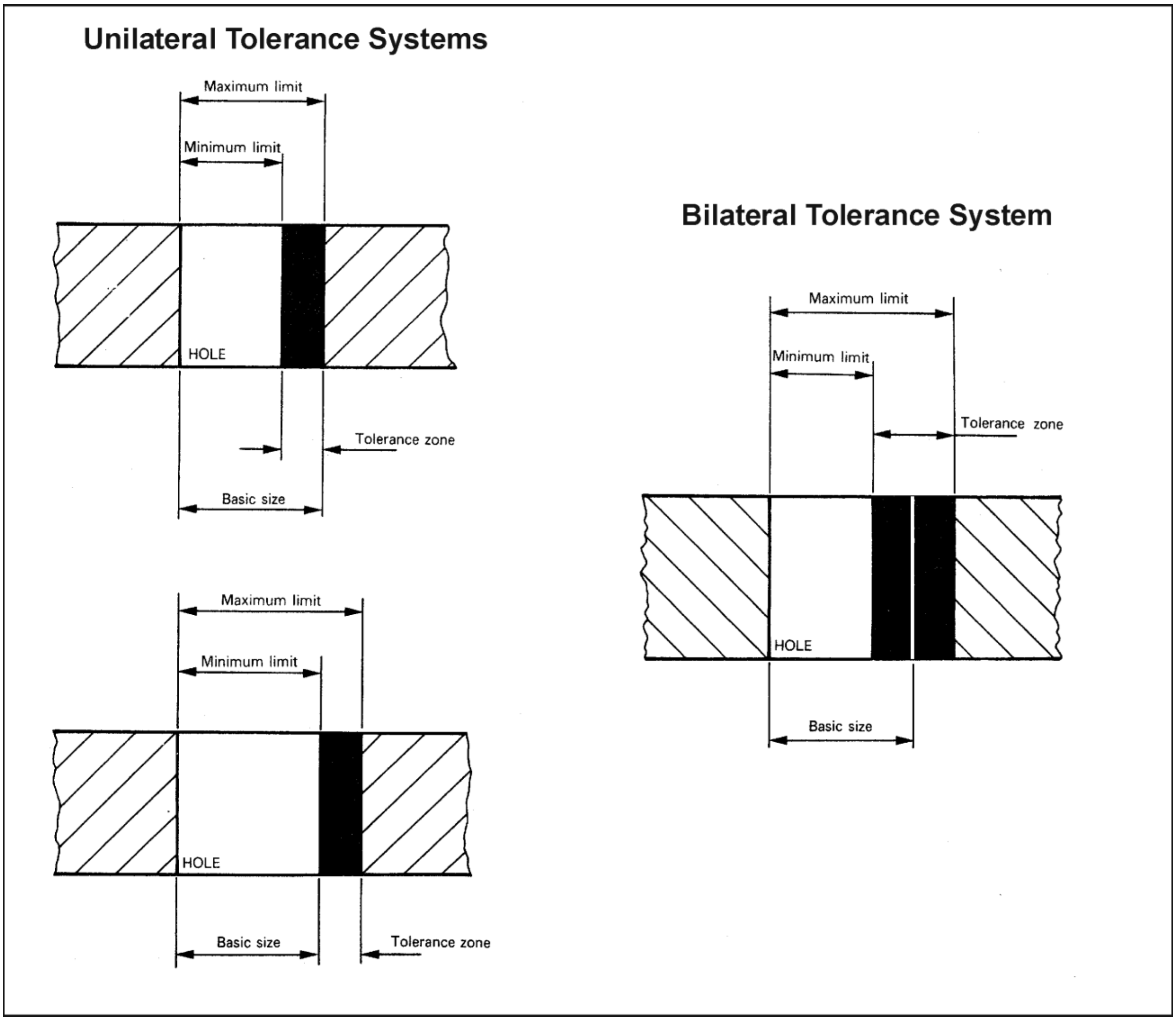


Figure 41 Unilateral and Bilateral Tolerance Systems

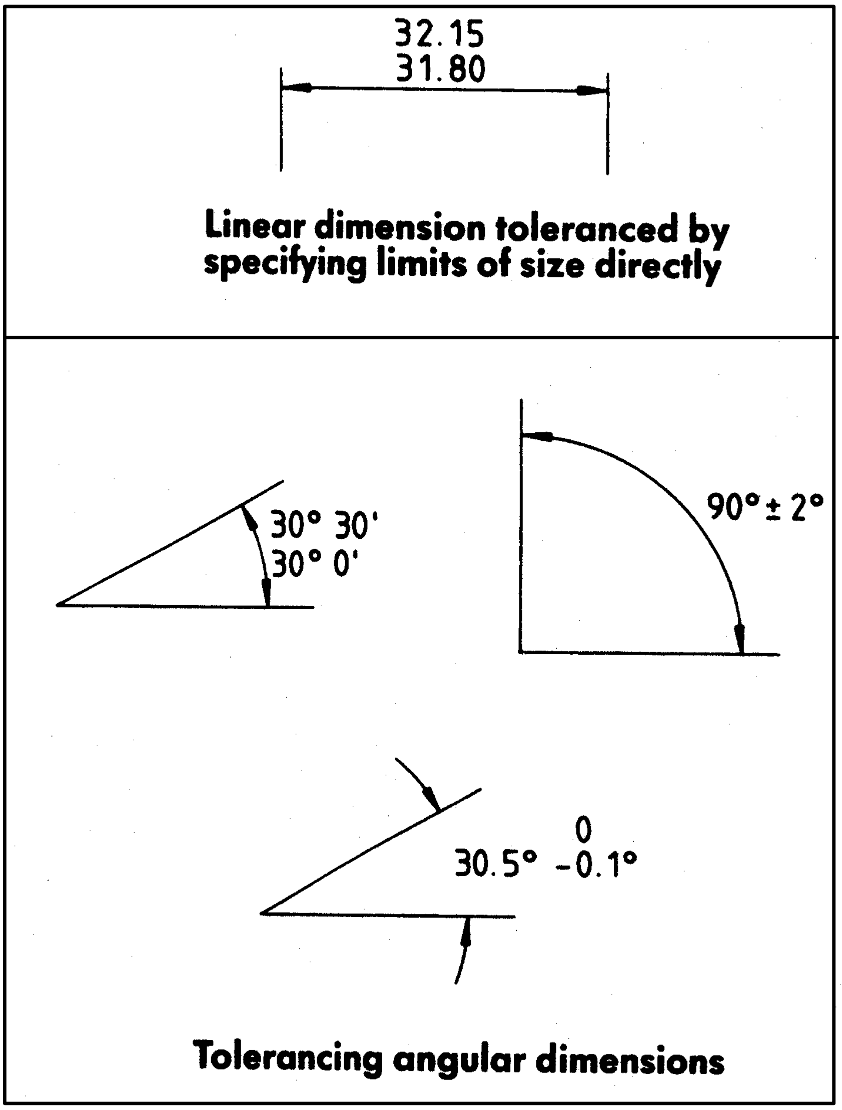


Figure 42 Linear and Angular Tolerancing Examples

4.3 Surface Roughness Notation

- Defines the quality of any finished surface in µm Ra (micrometres roughness average) or a corresponding alpha-numeric system (N1-fine to N12-rough)
- Specification of surface roughness value or range is related to the function and wear of a component
- Again, different manufacturing processes can achieve different surface roughness ranges
- Uses a series of surface roughness values or standard numbers designated to a symbol type e.g. $\overset{3.2}{\bigtriangledown}$ or $\overset{N4}{\bigtriangledown}$
- Symbol can be drawn on part surface or associated with a dimension line
- There should be surface roughness requirement for surface or feature to be manufactured, but again, this need not be placed on surface or feature. Can be shown as a general note on a drawing e.g. FINISH TO $\overset{3.2}{\bigtriangledown}$ ALL OVER EXCEPT WHERE STATED
- Figure 43 provides several examples of the placement of surface roughness symbols and values and ranges. Note that the rougher grade is also the first to be shown
- *Reference should also be made to BS 1134-2 (1990) for more detail*

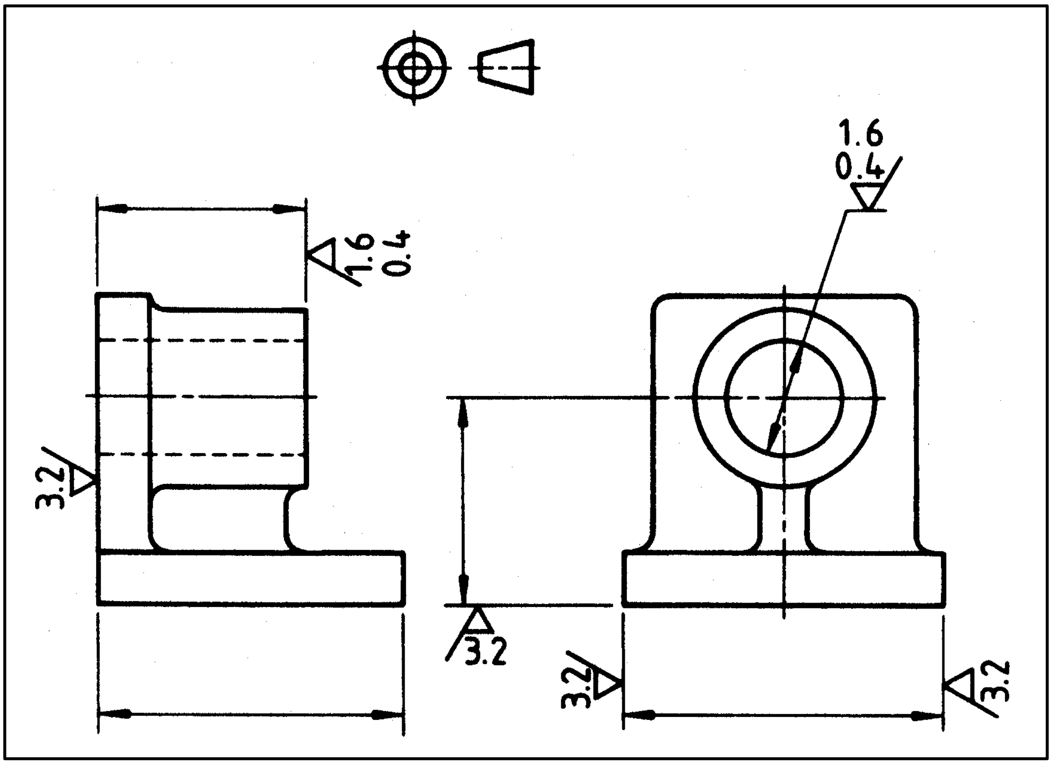


Figure 43 Placement of Surface Roughness Values and Surface Roughness Ranges

5. STANDARD PARTS AND SYMBOLS

5.1 Graphical Representation of Standard Parts

- Simplified representation of more complex geometries, form or features e.g. helix in screw thread or spring, involute gear tooth profile, spline on a shaft or knurl on a nut (see Figures 44 to 46 for some common examples)
- Appendix E provides further examples of simplified graphical representations of standard parts
- Used mainly on orthographic projection drawings
- Used to ensure consistent reproduction of parts on drawings and reduce drawing time
- Use these simplified representations at all times
- Refer to PP 8888-1 for more detail on standard parts representation

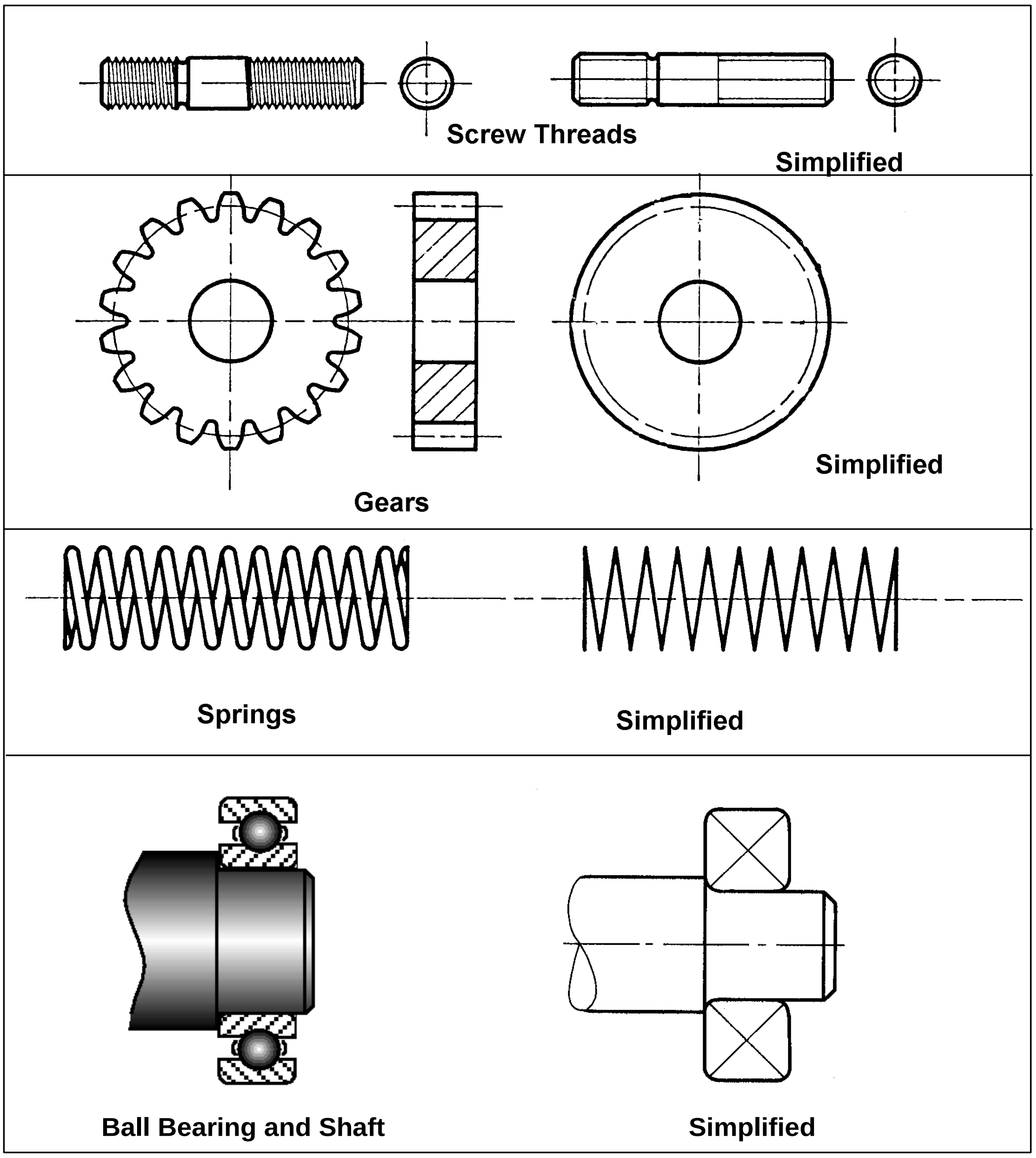


Figure 44 Simplifying Standard Part Graphical Representation

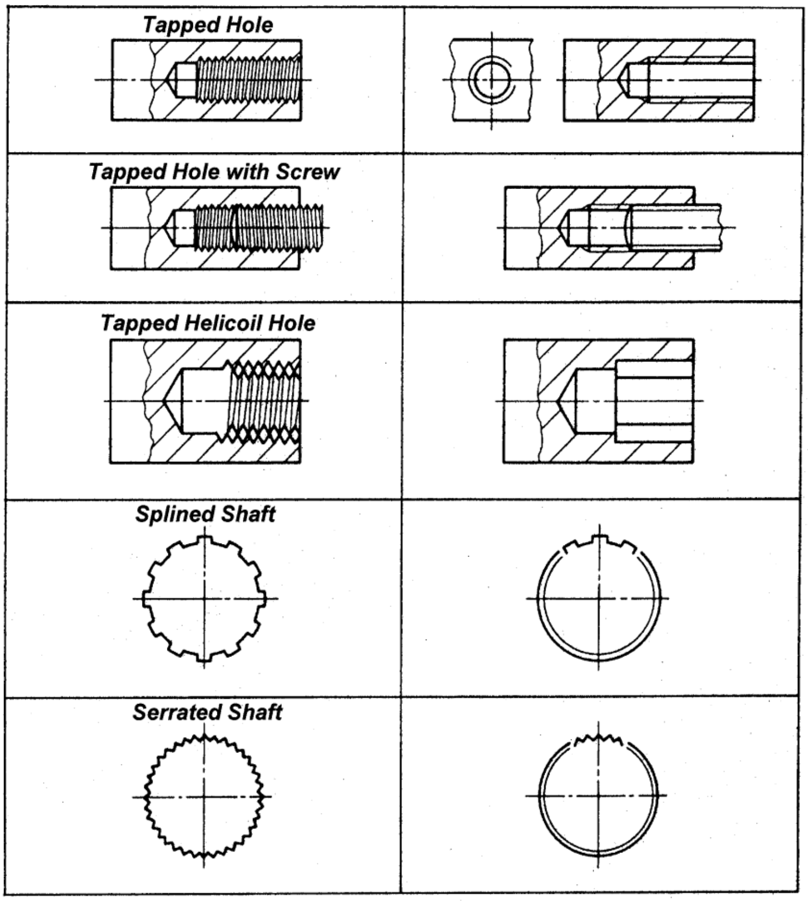


Figure 45 Simplifying Standard Part Graphical Representation (cont'd)

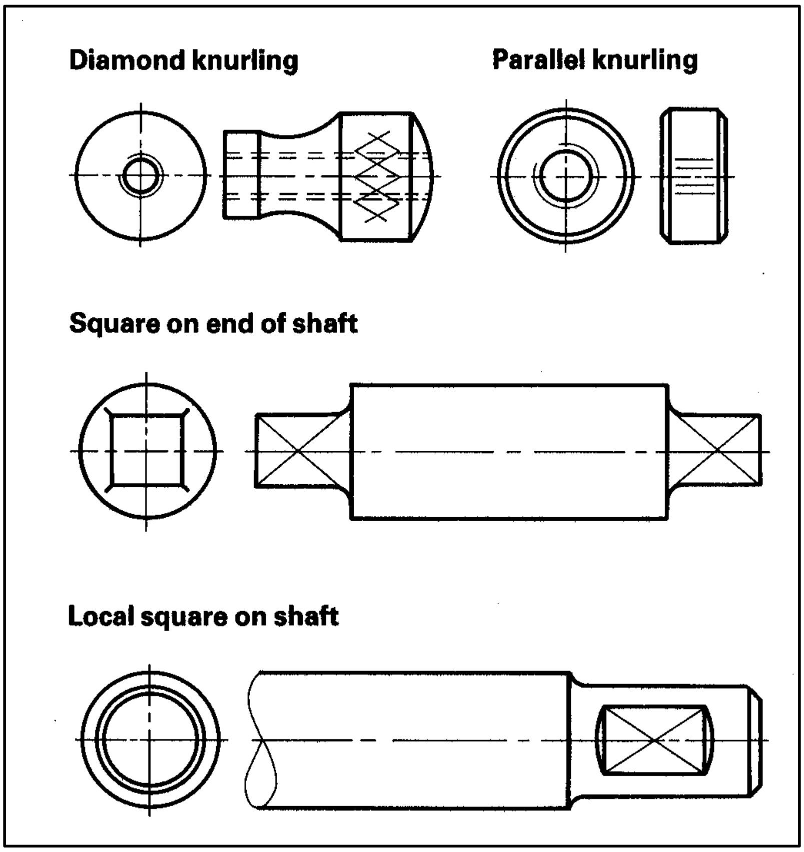


Figure 46 Simplified Graphical Representation of Several Machined Features

As you can see from Figure 45, it is not necessary to draw the complex helix of a screw thread each time you want to represent a threaded fastener on a drawing, typically on a general assembly drawing. However, some clarity is required when drawing and dimensioning features of both bolts and screws (male threaded parts in general) and tapped holes (female threaded parts such as nuts and blind tapped holes), as shown in Figure 47 respectively. Line thicknesses are important and preferred pencil line thicknesses are shown circled. Note also that end views of screw threads require a broken circle either on the inside of the major diameter if it is a male thread (at a diameter equal to the major diameter minus the pitch for Metric system threads), or for female threads, the broken circle is at the major diameter and the unbroken circle represents the core diameter.

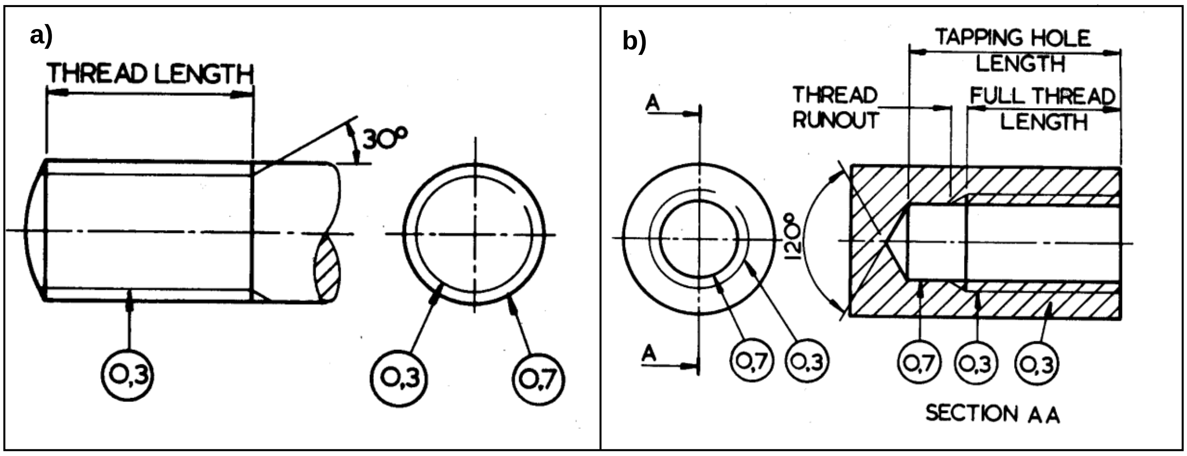


Figure 47 Drawing and Dimensioning a) Male and b) Female Threaded Features
(0.7 represents a bolder line weight, 0.5 may suffice)

The Metric thread system is the most common system in the world, and uses a series of standard sizes of screw threads based on a major diameter and a coarse, medium or fine pitch and associated tolerance class, as shown in Figure 48 for a major diameter of 20mm, or M20. The Metric coarse class is the most widely used. Another system called the Unified National system (based on Imperial units, inches) was first devised in the UK, but is really only used in the US. Figure 49 gives all the key dimensions and data required when specifying any of the Metric coarse screw threaded bolts, nuts and washers.

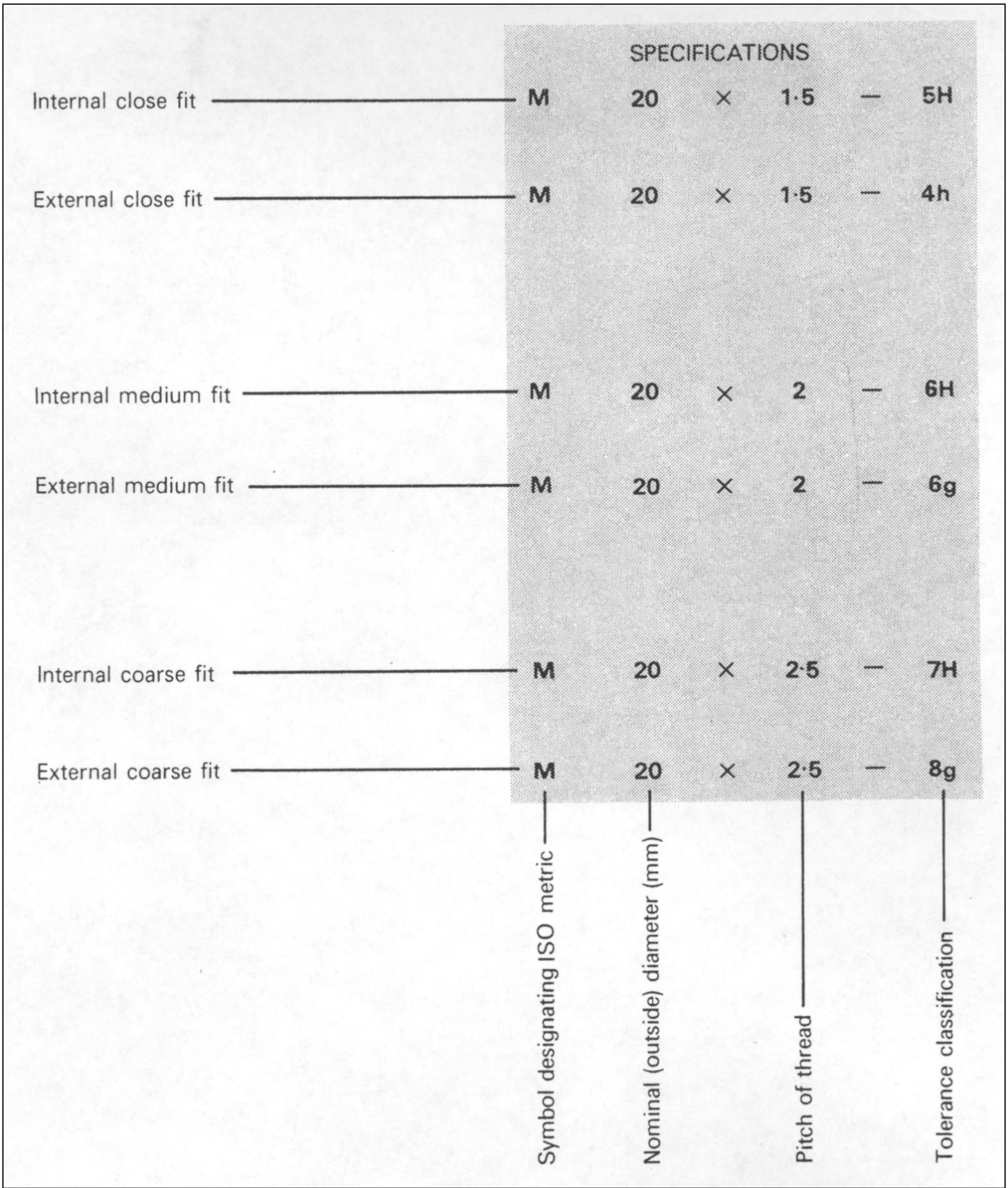
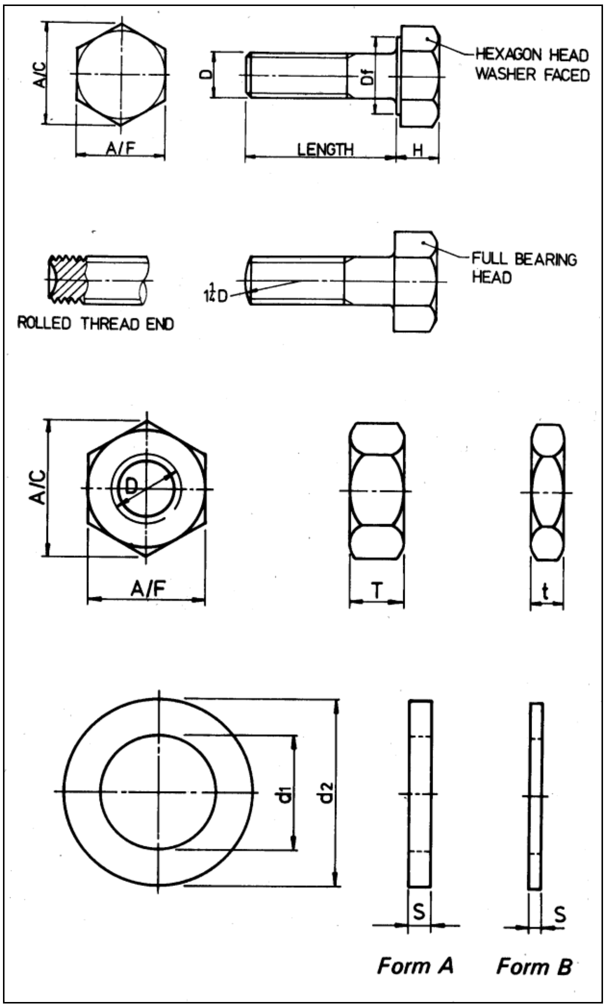


Figure 48 Metric Thread System Specifications for M20 Thread Size

The specification and correct representation of bolt, nut and washer assemblies is crucially important. Figure 50 shows the sectional view of a bolt assembly indicating the tapping depth created by a drill, the tapped hole (the method of manufacture for the female thread) longer than the bolt length, the bolt itself with a washer, in addition to the components to be fastened together. Note that for any Metric female threaded feature, the drilling diameter for tapping is usually equal to the major diameter minus the pitch. For example, for M10 Metric coarse, the pitch is 1.5mm, therefore the drill used prior to tapping is Ø8.5mm. Though not always precisely the case, this assumption is certainly adequate for draughting purposes.



Nominal size thread diameter D	Thread pitch	Minor diameter of thread	width across corners A/C	Width across flats A/F	Diameter of washer face Df	Height of bolt head H	Thickness of normal nut T	Thickness of thin nut t	Washer inside diameter	Washer outside diameter	Washer thickness Form A	Washer thickness Form B
M1.6	0.35	1.1	3.5	3.0		1.0	1.25		1.7	4.0	0.3	
M2	0.4	1.4	4.5	4.0		1.5	1.5		2.2	5.0	0.3	
M2.5	0.45	1.9	5.5	5.0		1.75	2.0		2.7	6.5	0.5	
M3	0.5	2.3	6.0	5.5	5.0	2.0	2.25		3.2	7.0	0.5	
M4	0.7	3.0	8.0	7.0	6.5	2.75	3.0		4.3	9.0	0.8	
M5	0.8	3.9	9.0	8.0	7.5	3.5	4.0		5.3	10.0	1.0	
M6	1.0	4.7	11.5	10.0	9.0	4.0	5.0		6.4	12.5	1.6	0.8
M8	1.25	6.4	15.0	13.0	12.0	5.5	6.5	5.0	8.4	17	1.6	1.0
M10	1.5	8.1	19.5	17.0	16.0	7.0	8.0	6.0	10.5	21	2.0	2.5
M12	1.75	9.7	21.5	19.0	18.0	8.0	10.0	7.0	13.0	24	2.5	1.6
M16	2.0	13.5	27.0	24.0	23.0	10.0	13.0	8.0	17.0	30	3.0	2.0
M20	2.5	16.7	34.0	30.0	29.0	13.0	16.0	9.0	21.0	37	3.0	2.0
M24	3.0	20.0	41.5	36.0	34.5	15.0	19.0	10.0	25.0	44	4.0	2.5
M30	3.5	25.5	52.0	46.0	44.5	19.0	24.0	12.0	31.0	56	4.0	2.5
M36	4.0	31.0	62.5	55.0	53.5	23.0	29.0	14.0	37.0	66	5.0	3.0

Figure 49 Data for Metric Coarse Threaded Bolts, Nuts and Washers

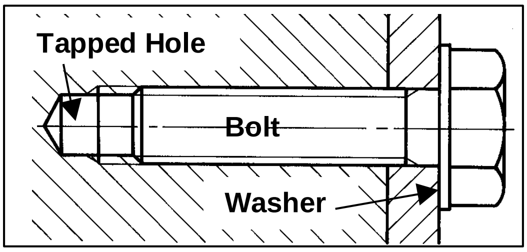


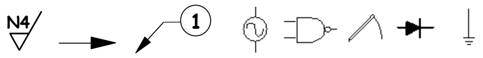
Figure 50 Simplified Graphical Representation of a Bolt Assembly

5.2 Use of Symbols in Diagrams and Drawing

- A symbol contains unmistakable coded information.
- Thousands of symbols are in use in our daily lives:

  e.g. ✂ ☎ © + 🚹 ⓘ ♿ @

- Thousands more exist in engineering:

  e.g. Ø  .

- Engineers make widespread use of symbols to reduce workload in drawing and diagram production.
- Helps communicate information about structure (where form is not important) in a simple and unambiguous manner.
- Mainly used with orthographic projection drawings to give instructions to the manufacturer on such matters as method of welding (see Figures 51 to 53), requirement for machining, assembly part number, etc.
- If the modelled property is structure not form then this can be modelled as a collection of system elements or sub-systems. Drawings that do this are diagrams or schematics.
- Diagrams are widely used in electrical and electronic engineering. Also fluid power, mechanism design, systems design, building services and process engineering (see Figure 54).
- Refer to various British Standards in Bibliography for more detail on diagram symbols.

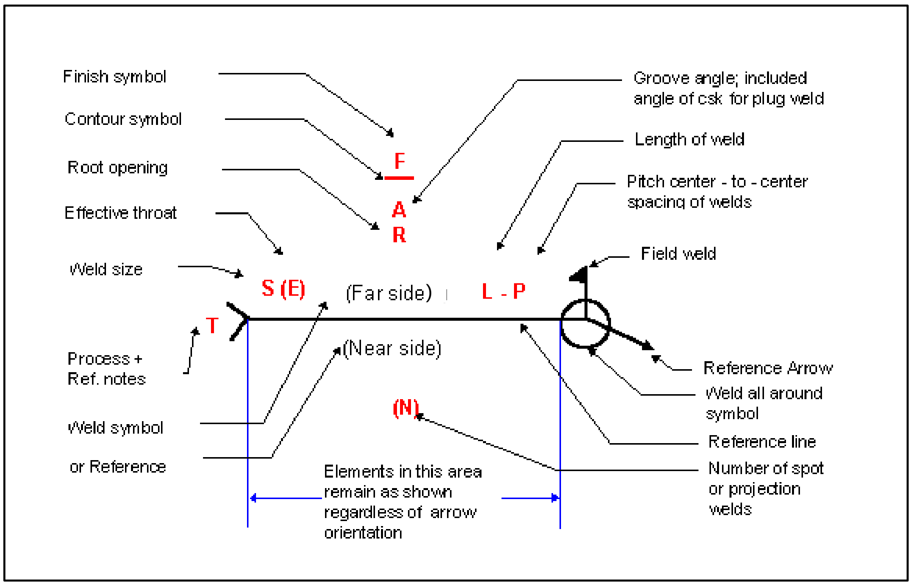


Figure 51 Welding Symbol Notation for Leader Lines

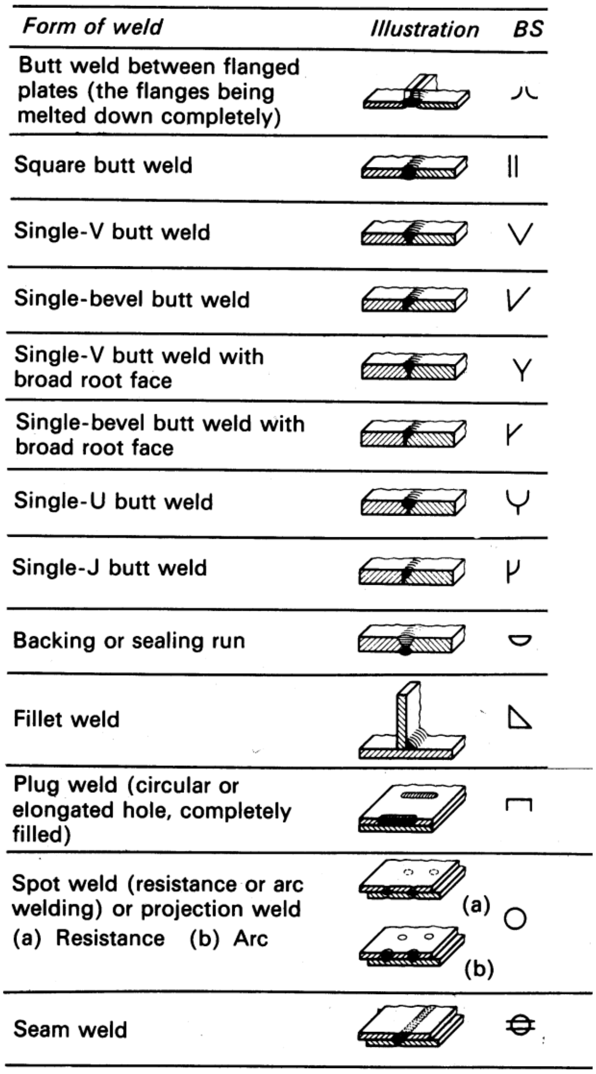


Figure 52 BS Welding Symbols for Different Joints and/or Welding Processes

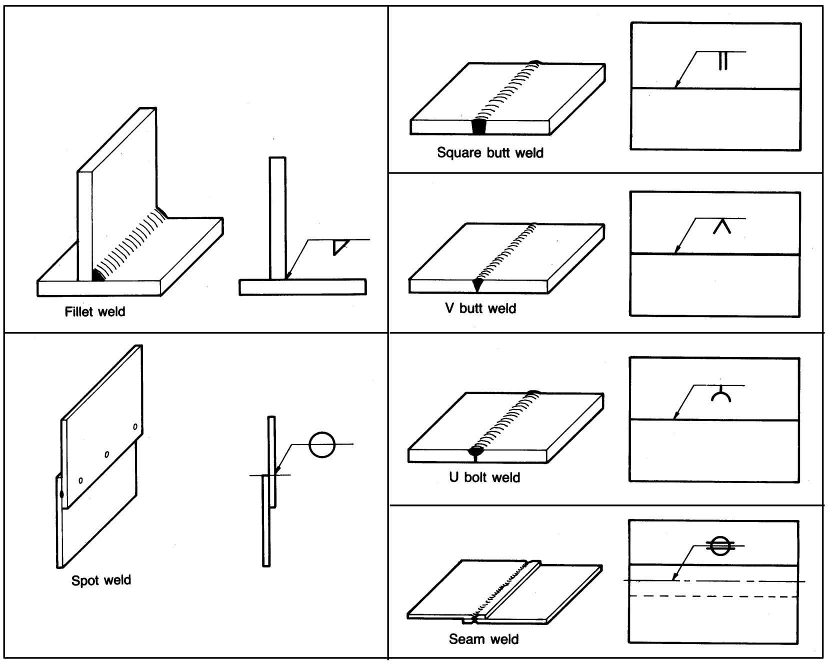


Figure 53 Specification of Welds for Some Common Joint Configurations

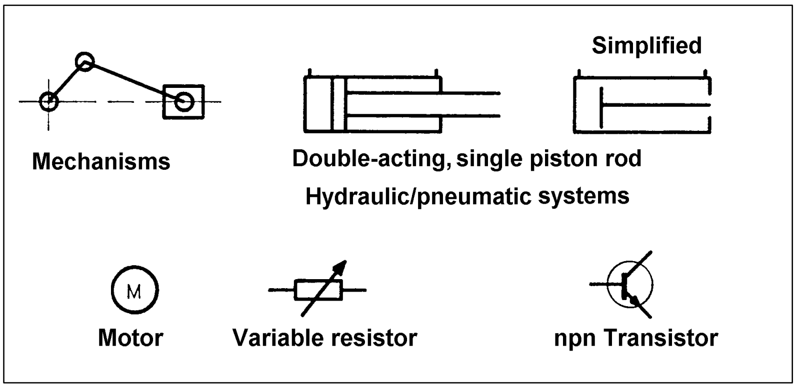


Figure 54 Some Symbols used in Diagrams

6. GEOMETRICAL TOLERANCING

6.1 The Need for Geometrical Tolerancing

- Here we can only provide an introduction to the concepts and practice of geometrical tolerancing which will be used in a future Design Office exercise.
- You should familiarise yourself with the possibilities of more complex geometrical tolerancing requirements.
- Geometrical tolerancing is a vast and sometimes complex field that requires expertise and in some countries, such as the US, recommended certification of engineers to practice it.
- Besides error in length, height, etc, error can occur in form and position of features due to the manufacturing processes involved in producing a part or assembly.
- Conventional tolerances define limits on dimensions as seen earlier, but generally not on form or position.
- A geometrical tolerance defines the shape and size of a tolerance zone within which a feature is to lie. A geometrical tolerance applies to the whole extent of a feature, unless otherwise stated.
- For example, consider the thickness of the bar shown in Figure 55. In reality, the bar will deviate in thickness and straightness along its length. This deviation may well be accommodated by the conventional dimensional tolerance. However, a tolerance of form (geometric tolerance) will also need to be defined in order that the part is manufactured to meet the straightness requirement if it is important to the part's functionality.

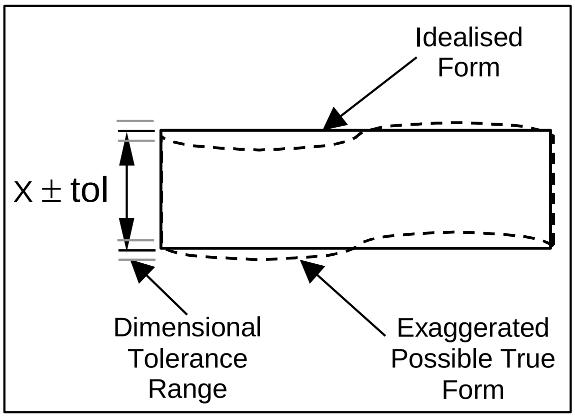


Figure 55 Inadequacy of Conventional Tolerances for Form Requirement

- Conventional tolerances may also be wasteful of machine positional capability. Consider the tolerances on the position of the centre of a hole, expressed as linear tolerances on a 'box' 0.2mm wide and 0.2mm height, as shown in Figure 56a). The diagonals of the 'box' are 0.28mm implying a positional error of approximately 0.14mm.
- If this is acceptable in two directions then why not all? However, tolerance area covered will now be bigger by over 50%.
- We can specify the diameter of a tolerance zone Ø0.28mm, with its centre at a theoretically exact position, $\boxed{30}$, from each side, as shown in Figure 56b). The boxed dimension value is now a theoretically exact value, and therefore does not carry a tolerance. The diameter symbol, in the tolerance frame indicates a circular or cylindrical tolerance zone.
- This is the basis of true position dimensioning and positional tolerances. These led on to geometric tolerances being used to provide tolerance of form, feature and position.

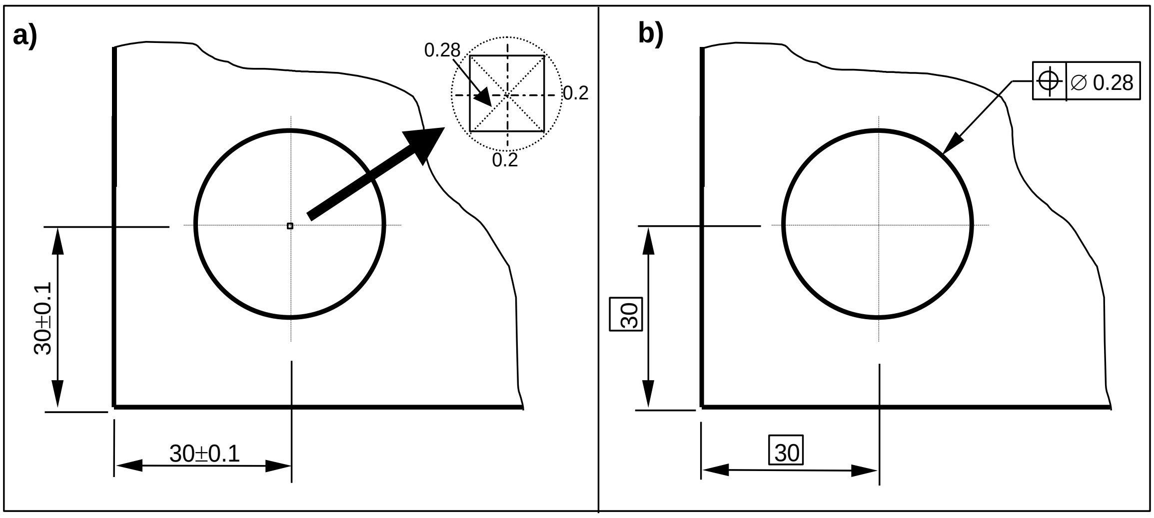


Figure 56 Concept of Positional Geometrical Tolerances

6.2 Geometrical Tolerancing Notation

A tolerance frame related to a feature or datum surface will provide all the necessary information relating to a particular geometric tolerance requirement. Tolerance frames are divided into two or more boxes in which the following details are given (refer to Figure 57(a) to (e)):

(a) The symbol for the characteristic to which the tolerance refers (see Figure 58 for a description of the most commonly used symbols).

(b) The tolerance value of the linear dimension. This value is the maximum allowable full indicator movement of a measuring device e.g. micrometer, Vernier caliper, Dial Test Indicator (DTI).

(c) The letter or letters identifying the datum on the object being dimensioned.

(d) Notes relating to the toleranced features may be placed near to the tolerance frame.

(e) More than one tolerance characteristic may be specified.

Figure 59 provides the further symbols and notation typically used in conjunction with a tolerance frame.

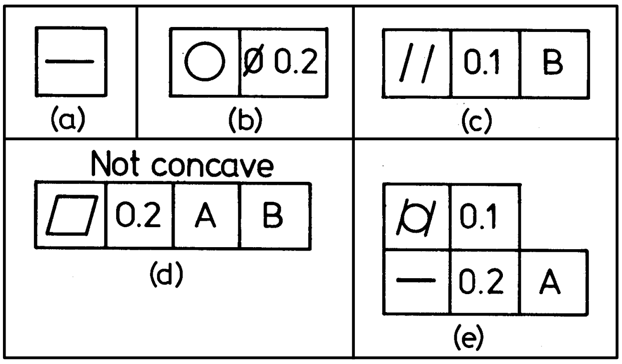


Figure 57 Tolerance Frame Notation

Tolerance characteristics			Symbol	Applications
Single features	Form tolerances:	Straightness	—	A straight line. The edge or axis of a feature.
		Flatness	▱	A plane surface.
		Roundness	○	The periphery of a circle. Cross-section of a bore, cylinder, cone, or sphere.
		Cylindricity	⌭	The combination of roundness, straightness, and parallelism of cylindrical surfaces. Mating bores and plungers.
		Profile of a line*	⌒	The theoretical or perfect form of profiles defined by true boxed dimensions.
		Profile of a surface*	⌓	The theoretical or perfect form of surfaces defined by true boxed dimensions.
Related features	Attitude tolerances:	Parallelism	//	Parallelism of a feature related to a datum. Can control flatness when related to a datum.
		Squareness	⊥	Surfaces, axes, or lines positioned at right angles to each other.
		Angularity	∠	The angular displacement of surfaces, axes, or lines from a datum.
	Composite tolerances:	Runout	↗	The position of a point fixed on a surface of a part which is rotated 360° about its axis.
	Location tolerances:	Position	⌖	The deviation of a feature from a true position.
		Concentricity	◎	The relationship between two cylinders or circles having a common axis.
		Symmetry	⌯	The symmetrical position of a feature related to a datum.

*** May be related to a datum when it is necessary to control position in addition to form.**

Figure 58 Various Geometrical Tolerance Characteristic Symbols

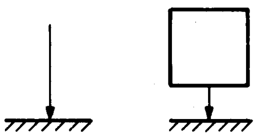
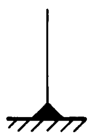
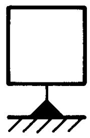
Description	Symbol
Feature indication	
Datum indication	
Datum indication	
Theoretical exact dimension	$\boxed{75°}$ $\boxed{75}$ $\boxed{Ø75}$

Figure 59 Other Symbols used in Geometrical Tolerancing

Feature indication is performed with a leader line and arrowhead that connects the tolerance frame to the controlled feature. The position of the arrowhead is important (refer to Figure 60):

(1). When the arrow touches the outline or extension of the outline (but not a dimension line), the tolerance refers to the surface, face, edge or line touched by the arrow.

(2). When the arrow touches a dimension line of a feature, the tolerance refers to the axis or median plane of the dimensioned feature only.

(3). When the arrow touches an axis or median plane, the tolerance refers to all features on that axis or median plane.

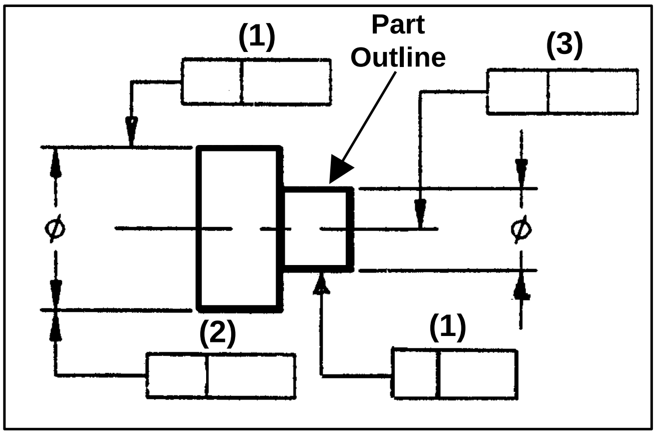


Figure 60 Leader Lines for Identifying Features

6.3 Examples

- Figure 61 provides a number of geometrical tolerancing cases.
- The interpretation for each type is also shown in order to help visualise the problem.
- Use these examples to understand the fundamentals of geometrical tolerance requirement, feature identification and tolerance frame construction.

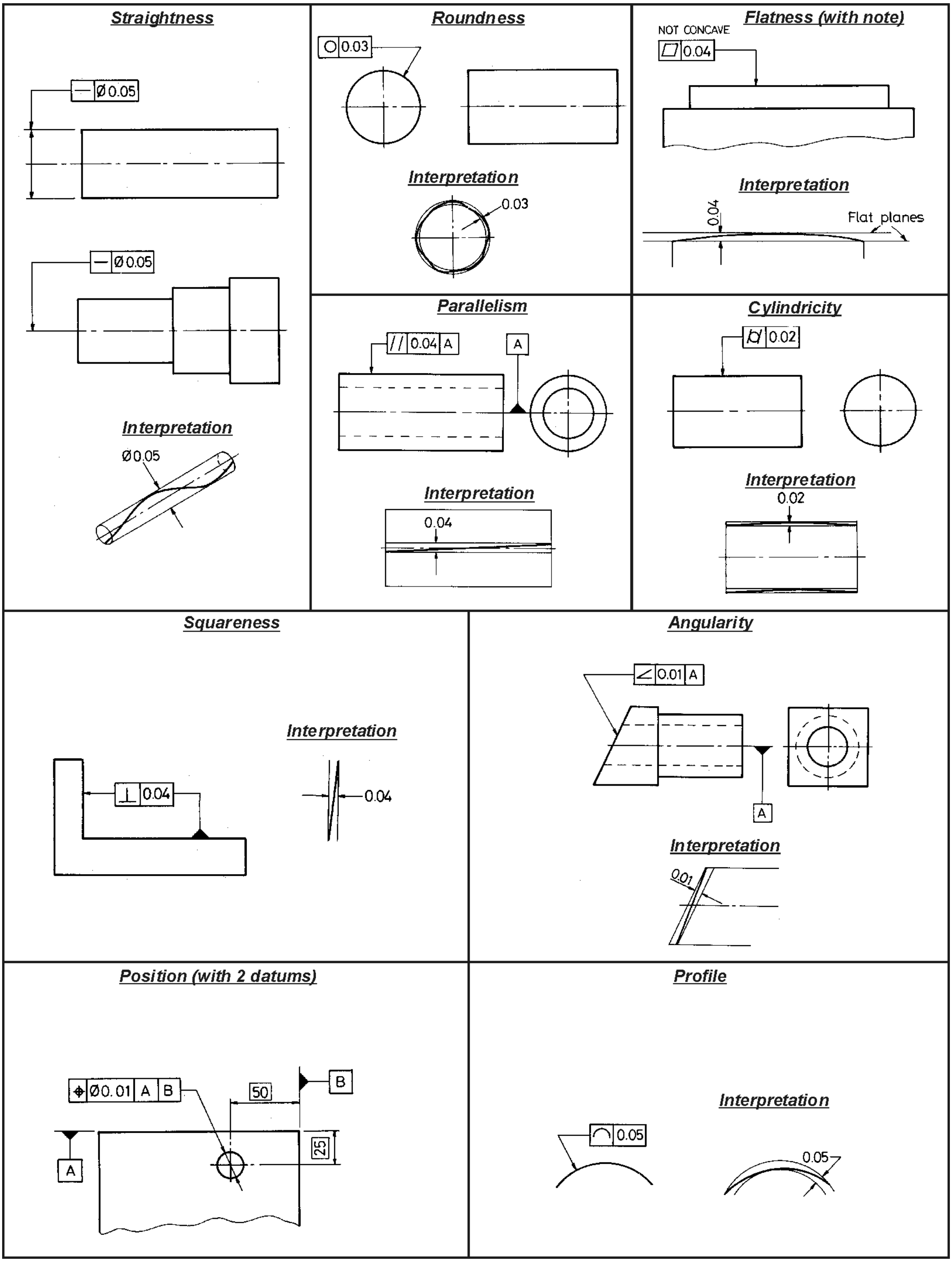


Figure 61 Examples in Geometrical Tolerancing

7. HISTORY OF DESIGN REPRESENTATION

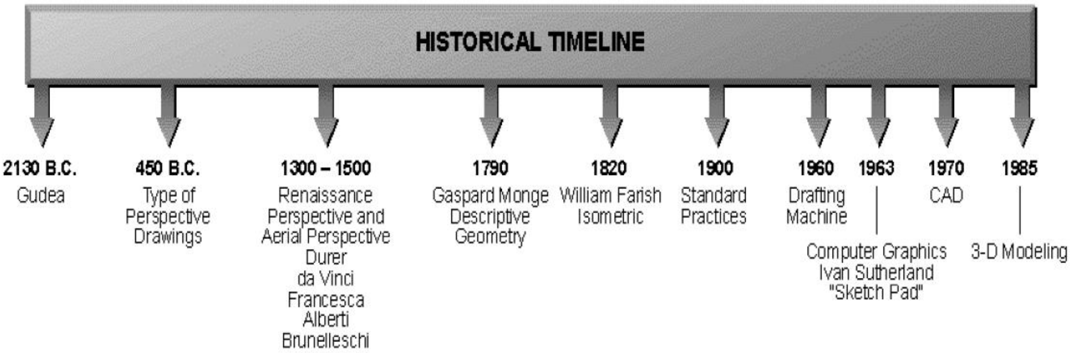


Figure 62 Timeline of Design Representation

7.1 Early Developments

- Perhaps the earliest known technical drawing in existence is the plan view for a design of a building drawn by a Chaldean King called Gudea, around 2130BC. It is engraved upon a stone tablet that is a part of a statue now in the Louvre, Paris. As the story goes, Gudea was assigned by God the task of building a temple in his honour. Gudea received the "blueprints" from the hands of God himself, and his statues show that blueprint spread upon his knees.
- Other early evidence of the use of drawings comes from the construction of pyramids and temples as far back as 1400BC by the Egyptians. Romans used drawings to convey bridge and fortress designs for their expanding Empire.
- Craft approach (in which no drawings were used) dominated still until the Renaissance.
- In the craft approach, artefacts would be based on what had been made previously, with only very small, incremental changes. Craftsmen would often keep designs "in their heads".
- Proper perspective drawings as drawn by Leonardo da Vinci started to be used in the 15th century. He also used pictorial sketches to develop his inventions.
- The Renaissance understanding of perspective had yielded the concepts of plan, elevation and section which were integral parts of architectural rendering by the time modern engineering drawing appeared in the late 18th century.
- As artefacts became more complex, drawings began to be used to record the designs, for example in naval architecture in the 17th and 18th centuries.
- The early 19th century saw the start of modern use of technical drawing practice.

Drawings were needed to deal with increasing complexity:

- By specifying dimensions it was possible to split artefacts into separate parts, which could then be made by different people. This allowed large objects such as buildings or ships to be planned.
- Drawings that "stored tentative decisions", allowed a faster pace of innovation (trial and error without physical realisation), but design in the abstract involved risk (things might not work) and meant that prediction was necessary (applies today of course).
- Drawings allowed calculations to be done to determine the adequacy of a design, e.g. to find the displacement of a ship. Also aided project planning and management.
- Drawings allowed reuse, existing designs added to, modified, adapted etc.
- The ability to specify dimensions before manufacture meant that a product could be divided into parts, spreading the manufacture of the parts among workers or machines meaning faster production.

7.2 Engineering Drawing and the Industrial Revolution

Pioneers in UK

- Engineering drawings provided a means of controlling production, but would not have existed without the Industrial Revolution and its division of labour.
- Drawings had long existed but did not provide manufacturing clues.
- With the Industrial Revolution in UK and Europe, engineering drawing came into its own.
- Its emergence is credited to Matthew Boulton and James Watt who founded the first stationary steam engine factory in 1773, and needed a way to divide up the various parts of their production process. Watt developed the simple and meticulously finished style found in engineering drawings until the mid-19th century.
- Marc Isambard Brunel, father of Isambard Kingdom Brunel, was also instrumental in getting industry to adopt standard drawing practice.
- Joseph Whitworth developed a method of standardising screw threads and metrology systems.
- Until the appearance well into the 19th century of colour engravings and chromolithography, drawings or prints of drawings were coloured by hand.
- In the early part of the nineteenth century engineers or skilled mechanics produced most engineering drawings.
- Engineering drawings became works of art and the artistic expression of the draftsmen.

Pioneers in the United States

- The United States Armoury and Arsenal, established at Harpers Ferry in 1799, transformed it from a remote village into an industrial centre.
- Between 1801 and the outbreak of the Civil War in 1861, the Armoury produced more than 600,000 muskets, rifles, and pistols, and employed, at times, over 400 workers.
- Inventor John H. Hall pioneered interchangeable firearms manufacture at his Rifle Works between 1820-1840, and helped lead the change from craft-based production to manufacture by machine.
- Until late in the 19th century, drawings mainly represented whole artefacts or large sub-parts (sub-assemblies), but the growth of production engineering (especially in the US) for interchangeable parts manufacture led to “detail drawings” being created to record the manufacturing requirements for each part.

7.3 Computer-Based Representation

Computer representation of geometry grew in the aerospace and automotive industries in the 1950s and 1960s:

- Mid-late 1950s – Automatically Programmed Tooling (APT) language for control of machine tools.
- 1950s – light pen.
- 1963 – Ivan Sutherland's Sketchpad system.
- 1964 – patent of mouse.
- Mid-1960s – surface patch techniques for complex geometry.
- Lockheed, Ford and McDonnell Douglas all start using early CAD systems.
- Early development of Finite Element Analysis (FEA) method.

Representations of solid geometry began to be developed in the late 1960s and 1970s:

- Early-mid 1970s – smooth shaded images and texture mapping in computer graphics.
- 1980s – Knowledge-Based Systems (KBS) development.
- 1990s – routine industrial use of solid modelling (AutoCAD, ProEngineer, I-DEAS commonly used in UK).
- End of the 20th century – computer representation of product designs had become the norm.
- The future…I hope, better integration of design methods in CAD.

7.4 3D Modelling

MANUAL REPRESENTATION VERSUS COMPUTER MODELLING

Computer software that enables engineering artefacts to be modelled in 3D has been available since the mid 1980's. Before this an engineering designer had no choice but to conceive a new artefact in his or her imagination and communicate this design by producing drawings. At best drawings are incomplete representations or projections of the 3D artefact. All designs would be drawn accurately in 2D but some would also be physically modelled either full size or to scale. Models are used to communicate design ideas but they may also be used to inspect the behaviour of the artefact and to test manufacturing processes and techniques. Such models are known as prototypes.

The development of 3D modelling software has revolutionised engineering design and manufacture. Designs of ever increasing complexity now reside in a computer's memory and this information can be communicated to others either in 3D model form or as conventional 2D drawings that are produced almost automatically. In some circumstances where, for instance, the model of an artefact can be communicated directly to a numerically controlled manufacturing machine, less dependence may be placed on 2D drawings.

THE ELEMENTS OF 3D MODELLING

When modelled in 3D using computer software an engineering artefact may be a single *part* or it may consist of 2 or more parts juxtaposed to form an *assembly*. The assembly may be static or may incorporate parts that are intended to articulate. Views of a part or an assembly may be extracted from the 3D model and placed on a *drawing*. Parts, assemblies and drawings then are the fundamental elements of a computer based 3D model.

PARTS

A part is manufactured as a single item and is made from a single material. It is modelled by drawing profiles in a selected plane (i.e. *sketches*) and then *extruding*, *lofting*, *rotating* about an axis or *sweeping* along another profile to create a "solid" 3D shape. The material, and therefore such properties as density, of a part may be defined from which its mass properties may be computed by the software. Similarly, from the geometric shape of the part, its section properties may be computed. The colour and surface texture of a part may be defined. This facility may be used either to help differentiate between parts in a complex assembly or to produce realistic visualisations of it. For each part there is a corresponding computer file.

ASSEMBLIES

Assemblies contain two or more parts. Each part is located precisely in relation to one or more other parts. These geometric relationships are known as *mates* and may be *linear*, *angle*, *planar*, *coincident* or *concentric*. Mates have a fixed value or may be defined as variable with or without upper and lower limits. Thus an assembly with moving parts can be modelled to behave precisely as intended in reality. An assembly may contain another assembly (traditionally known as a sub-assembly). For each assembly there is a record of it's corresponding parts and/or sub-assembly file dependencies.

DRAWINGS

A 3D model of a part or an assembly may be viewed orthogonally, i.e. top, front, right views, etc, or may be viewed in 3D projection, i.e. isometric, trimetric, diametric or perspective. Such views may be transferred to a *drawing*. A drawing consists of one or more views of a part or an assembly set out on a *sheet*. Additionally a drawing may contain a *drawing frame* and *title block*, *dimensions*, *annotation*, *specification notes*, *parts lists*, *conditions*, etc., and it is this information that must be added by the designer. A drawing may also contain more than a single sheet in which case the title block will indicate the number of the current sheet and the total number of sheets in the drawing. Drawing files are normally "associative", such that changes to the parent part or assembly file will be reflected in the drawing. In many systems, the associativity is bi-directional.

CHANGE MANAGEMENT

The design process is not linear and must accommodate change. Computer based 3D modelling systems help to manage developing design information but they are not "foolproof". Changing a part may result in spacial conflicts or clashes in the assembly to which it belongs. For many industries or product types it is vital to manage design information and the inevitable changes to it. For example an airframe is a large and very complex assembly where the effects of any modification must be traced accurately and comprehensively to ensure efficient manufacture and safety in operation.

THE BENEFITS OF 3D MODELLING

• **REALISM**	designing, modelling and viewing in 3D (thus matching the real world) eliminates more errors and oversights
• **SPEED**	modelling is a relatively quick process – generating views/drawings is semi-automatic – a designer will be able to produce more in less time
• **ACCURACY**	3D models are precise – there is no “artistic license”
• **COMMUNICATION**	3D models (and even 2D CAD produced drawings) can be shared electronically
• **VIRTUAL PROTOTYPING**	building a 3D model in a computer to inspect fit, tolerances and articulation can now be performed so competently that physical prototypes may not be necessary
• **MANUFACTURING**	design direct to manufacture – 3D model data can be output directly to NC machinery
• **CHANGE CONTROL**	many of the dependencies of a change will be processed automatically – imposing other checks is easier and more reliable
• **ERRORS**	generally computers only make catastrophic errors – these will be easily noticed
• **RADID PROTOTYPING**	For some products (size, but not complexity can be a limiting factor) a physical modal can be easily produced from a 3D CAD file. Also known as Additive Manufacture with specific processes known as Steriolithography, 3D Printing, Fused Deposition Modelling, etc.

8. ENGINEERING PROJECT MANAGEMENT

An overview of engineering modelling & drawing Projects

8.1 Assimilation

Understanding the Brief

Engineers either working in teams or independently are commissioned to design, fabricate, assemble and often test engineering artefacts. The instructions describing the artefact and how it must behave is know as a *brief* and it may be written or verbal. A well written brief is to be welcomed.

The wise engineer will take great care to understand the brief. It is good practice to reiterate the brief in writing particularly if the brief is verbal. Clarification must be sought for any aspect of the brief that is not crystal clear before work on the project starts in earnest.

Consideration of Assumptions

In most engineering design projects it will be necessary to make assumptions. It is recommended that every assumption made is documented. The original brief together with the assumptions made should explain why the design developed as it did.

Timescales

Even if a timescale remains undefined there is normally an expectation that an engineering design project will be completed by a particular date. The design process is not linear nor is it logical in some cases. In very many cases the timescale is critical (e.g. A380 delays in electrical wiring causing order cancellation). The timescale to completion may be well defined but each task or process must be considered, time estimates researched and all the processes necessary for completion planned in detail.

8.2 Strategy

Constraints

Understanding the constraints that apply to a project is vital. The design constraints are normally well understood but there are other constraints that may take many different forms and have effects that are just as serious:

- human, e.g. a skill shortage
- physical, e.g. the workshop door opening is 4,575mm high and 6,250mm wide
- time, e.g. a testing laboratory is fully booked at the time it is needed
- dependency, e.g. a task or process may not be able to start until another has been completed

Management of Resources

Having planned the project carefully and comprehensively it is necessary to monitor progress with equal diligence. Should a process or task take longer to complete than expected it is good

practice to study the likely effects on the remainder of the project. If this identifies a problem then it may be necessary deploy additional resources to accelerate one or more of the remaining tasks.
Project Management has become an essential element of major design and development projects. There are several sophisticated software applications that help to track progress and identify future problems.

Materials

It cannot be assumed that materials will be delivered immediately they are ordered. Very often there is a delay before an order is filled and this may affect progress. There have been many serious cases where an alternative material has had to be specified because the material originally specified is in short supply.

Manufacturing Processes

Most manufacturing processes in engineering are straightforward and swift. There are, however, some emerging technologies that are not. Artefacts made from composite materials, particularly if moulds are used, may require curing over extended periods of time, e.g. autoclaving a carbon fibre wing section. It should not be forgotten that designing, fabricating and preparing moulds may also be time consuming.

Parts

Assemblies consist of parts. By increasing the complexity of each part it may be possible to reduce the number of parts needed and this may have a beneficial effect on assembly issues and performance in use including reliability. By decreasing the complexity of each part their fabrication may be simpler and quicker.

Assemblies

Large and complex assemblies are likely to consist of parts and sub-assemblies. This structure may be termed a hierarchy. It is important to plan the hierarchy carefully and in detail during the design process so that the management of drawings and other design documentation is facilitated. This cannot be stressed enough. A poorly planned hierarchy of parts and assemblies can require much additional time and effort neither of which add to the quality of the project.

Drawings

A large and complex engineering design project may generate many thousands of drawings and other documents. Managing such a project requires dedication and skill.

Articulated Dynamic Modelling

Complex assemblies can be modelled accurately in modern 3D CAD systems. Where parts are designed to move relative to other parts this can also be modelled accurately. Such a model can be manipulated dynamically to ensure the intended movement can occur and will not result in a moving part *clashing* with another. A clash may be defined as that which occurs when two or more artefacts occupy the same three dimensional space at the same moment in time.

Virtual Prototyping

In the past, despite the incredible design skills and dedication of engineers, it was necessary to build a *prototype* or working model of a part or assembly before committing to full production. Such working models may be full size or, more commonly, scaled down.

3D CAD modelling systems have become so powerful and competent that it is now possible to build very complex assemblies and inspect their dynamic behaviour in minute detail. The reassurance provided by this modelling reduces the need for prototypes and many engineers today do not choose to fabricate them.

Rapid Prototyping or Additive Manufacture

There are a number of technologies whereby a computer controlled "printer" is able to produce a 3D artefact commonly using resin and fillers, metal powders or photo sensitive polymers. The process is often referred to as 3D printing as the 3D model is gradually built up in 2D layers. For example a printer applies the resin in layers but only where there is material, the remaining filler then falls or is blown away leaving a facsimile of the artefact. Even extremely complex artefacts can be modelled in this way.

CNC

The technology for controlling engineering machinery numerically has existed for a surprisingly long time (i.e. centuries). Computer Numerical Control continues to be developed and there are many processes in the machine shop that are largely automated.

8.3 Implementation

Precedence

There is a natural order for tasks and processes. This natural order may have to be adjusted particularly if timescales or deadlines are tight. Tasks or processes that depend on others are said to have a *precedence* and it is these that cannot be adjusted. If a series of tasks or processes have precedence then it may be sensible to start the first earlier in the overall process than it would normally occur, thus introducing some contingency which may be used if one or more tasks or processes take longer than estimated.

Monitoring Progress

No matter how well a project is planned unexpected problems may occur that will cause delays. It is good practice to monitor progress in detail and accurately. Unless it is known that the project is behind the expected schedule no corrective action can be taken.

Deliverables

At a very early stage of an engineering design project, usually as part of the brief, the documents or artefacts that must be produced are listed. These are commonly known as the *deliverables*. It is good practice to review the deliverables well before the end of the project and maybe several times during it. It is bad practice and possibly unsafe to generate a document or fabricate a part in a hurry. It is in this zone that mistakes are made and errors overlooked.

Thus, review the deliverables of the project and wherever possible complete items from the list ready for handover at the appropriate time.

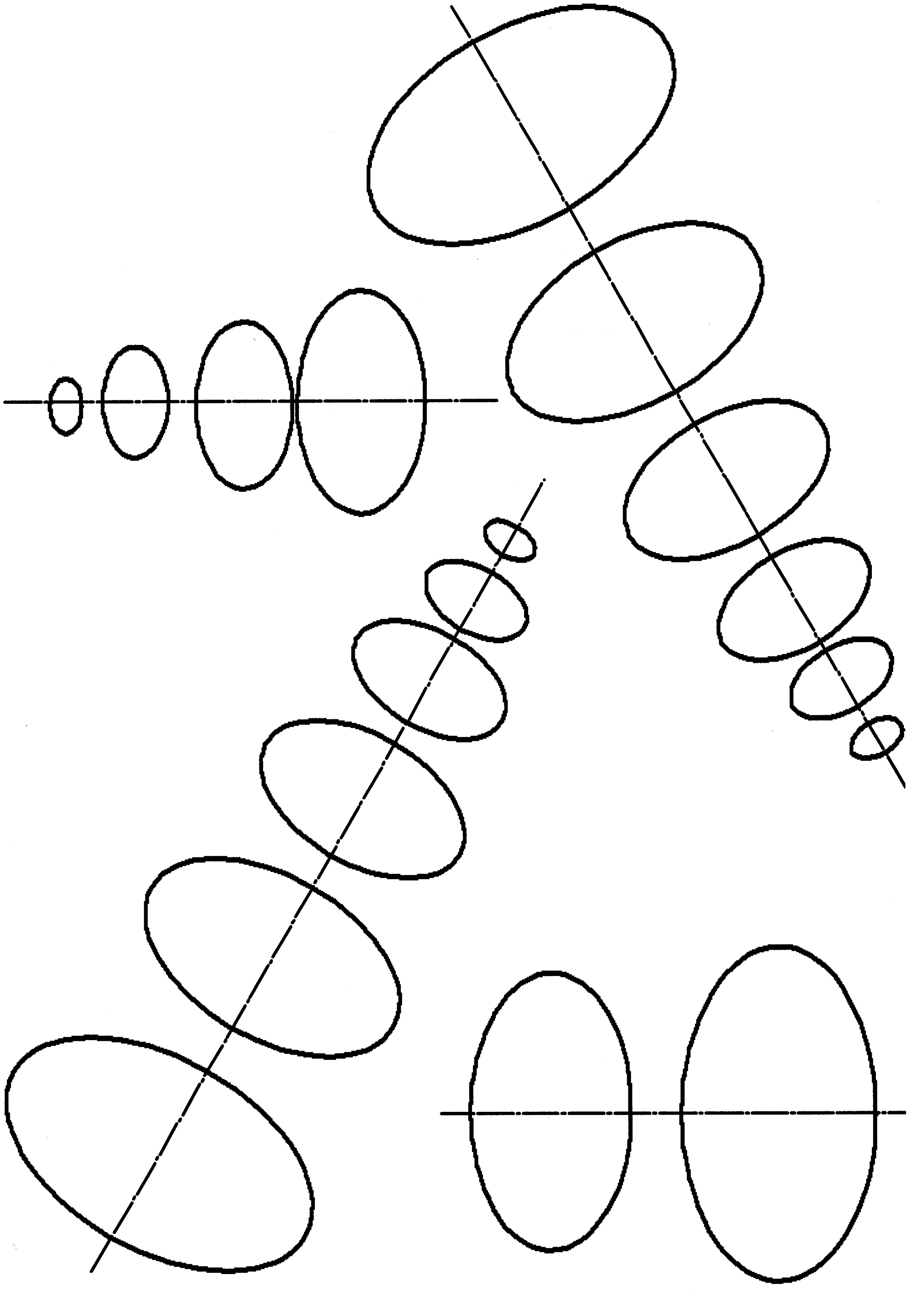
Bibliography

- PP 8888-1 (2001) Engineering Drawing Practice. Part 1: a guide for schools and colleges to BS 8888:2000, BSI (150798673X).
- BS 1134-2 (1990) Assessment of Surface Texture: guidance and general information, BSI.
- BS 1192 (1984) Construction drawing practice, BSI.
- BS 1553-1 (1977) Specification for graphical symbols for general engineering: piping systems and plant, BSI.
- BS 2917-1 (1993) Graphic symbols and circuit diagrams for fluid power systems and components: specification for graphic symbols, BSI.
- BS 3939-1 (1986) Graphical symbols for electrical power, telecommunications and electronics diagrams: general information, general index, BSI.
- BS 4058 (1987) Specification for data processing flow chart symbols, rules and conventions, BSI.
- BS 5070 (1988) Engineering diagram drawing practice: recommendations for general principles, BSI.
- McMahon, C. A. & Browne, J. (1998) CADCAM Principles, Practice and Manufacturing Management, Harlow Addison-Wesley (TS155.6 MAC).
- Simmons, C. H. & Maguire, D. E. (1995) Manual of Engineering Drawing, Arnold (T353 SIM).
- Parker M.A. & Dennis, L. J. (1992) Engineering Drawing Fundamentals, Cheltenham Stanley Thornes (T353 PAR).

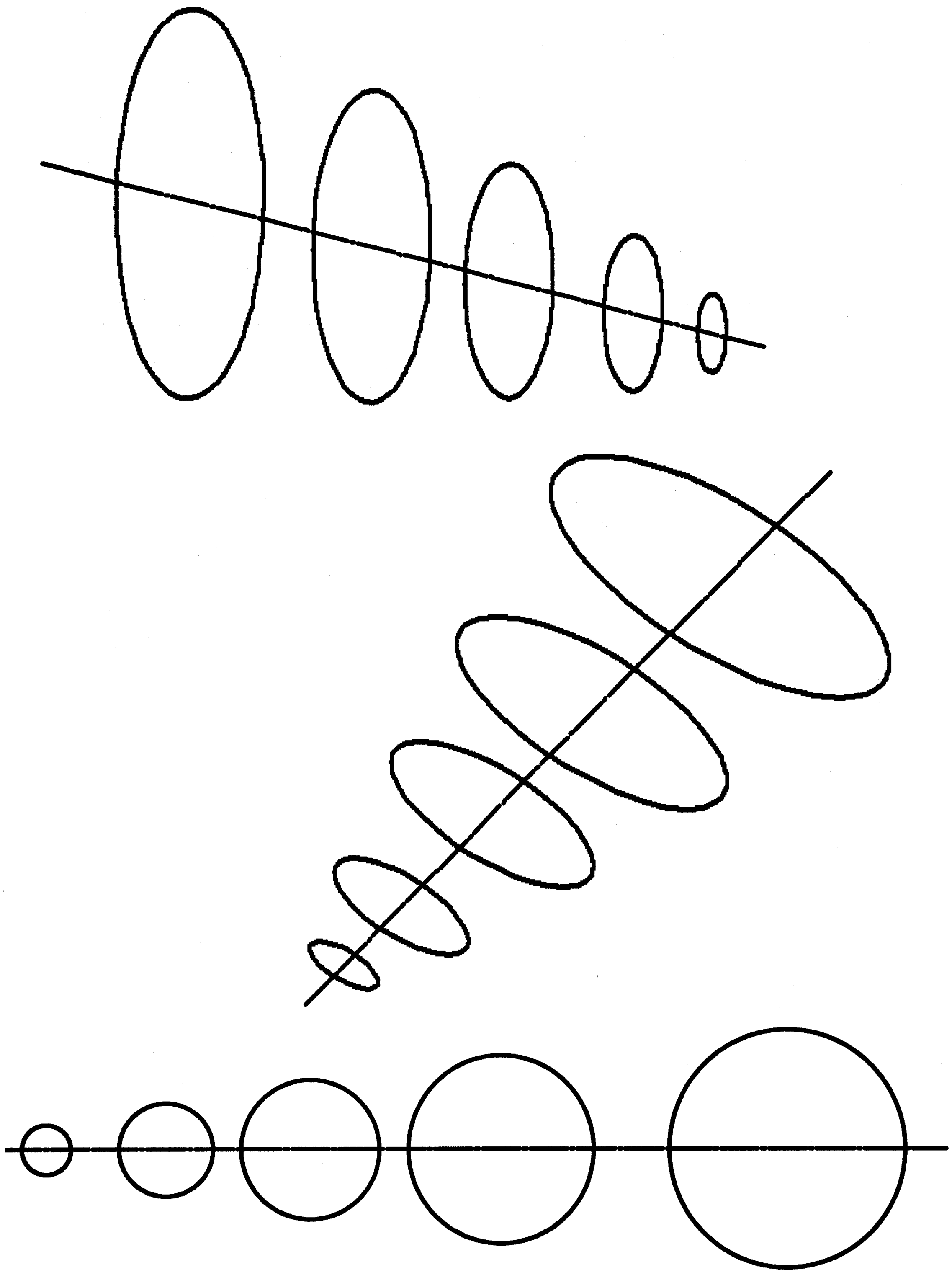
Appendix A – Blank Drawing Frame

DRAWN BY:	DIMENSIONS IN:	PROJECTION 
COURSE:	SCALE:	
TUTOR: GROUP:	DATE:	

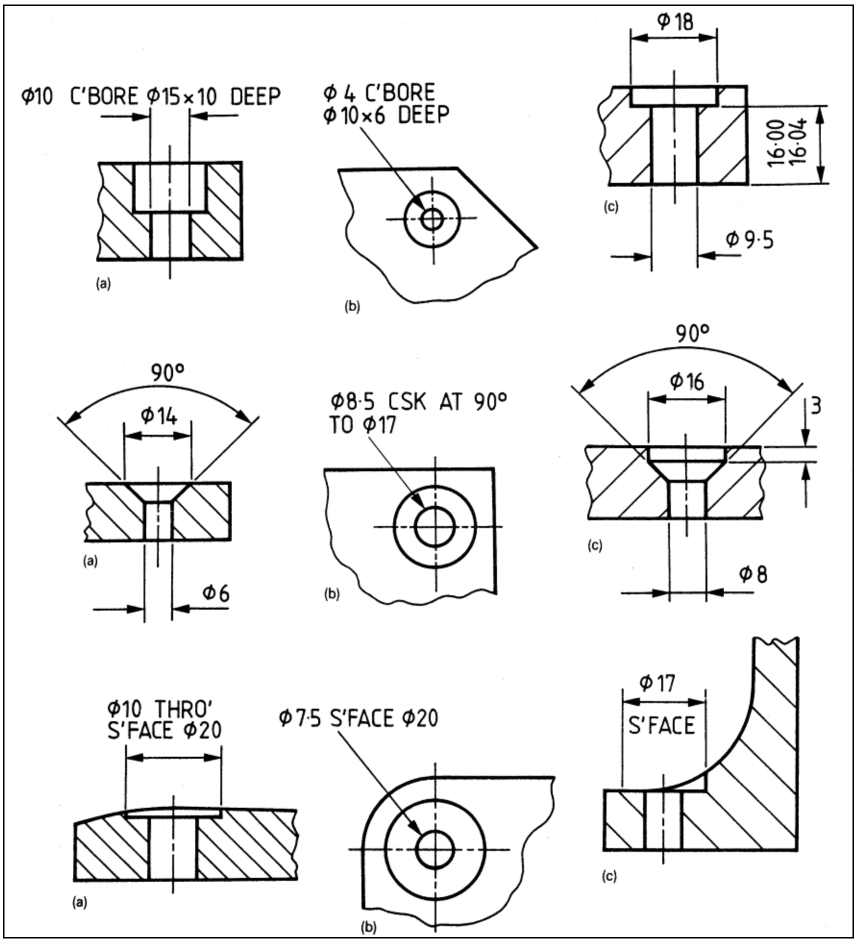
Appendix B – Isometric Circles



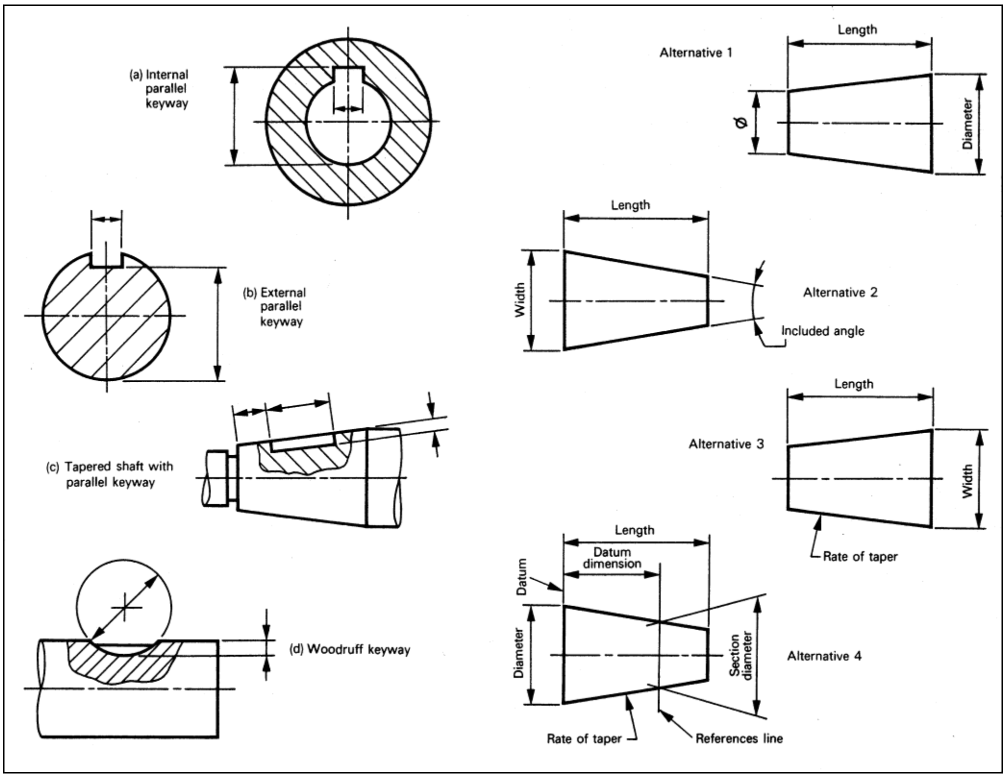
Appendix C – Oblique Circles



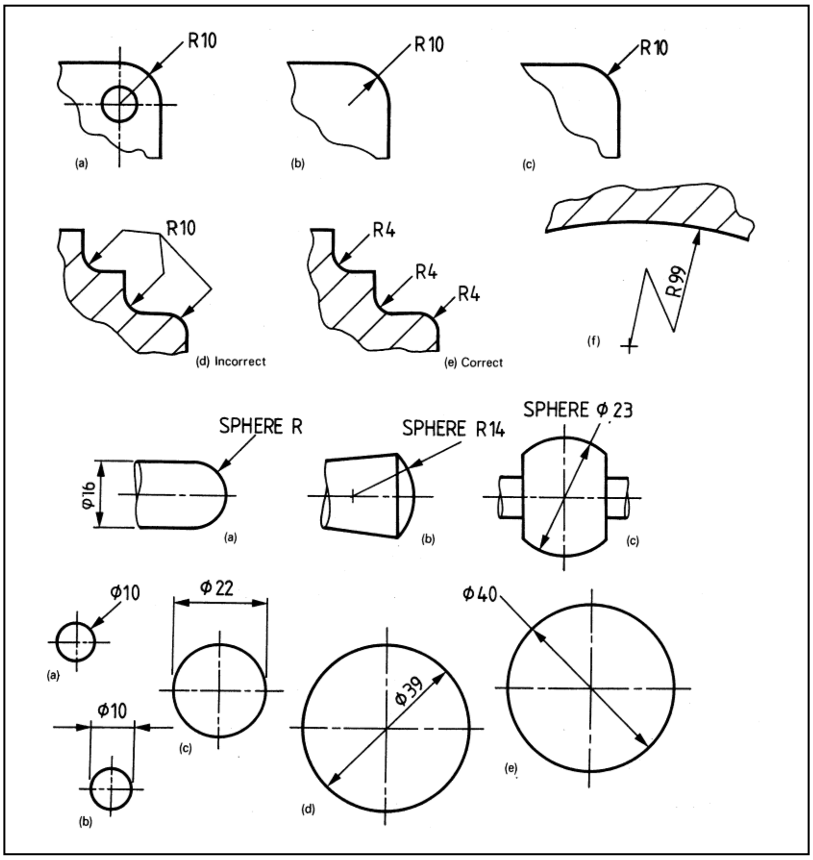
Appendix D – Dimensioning Common Features



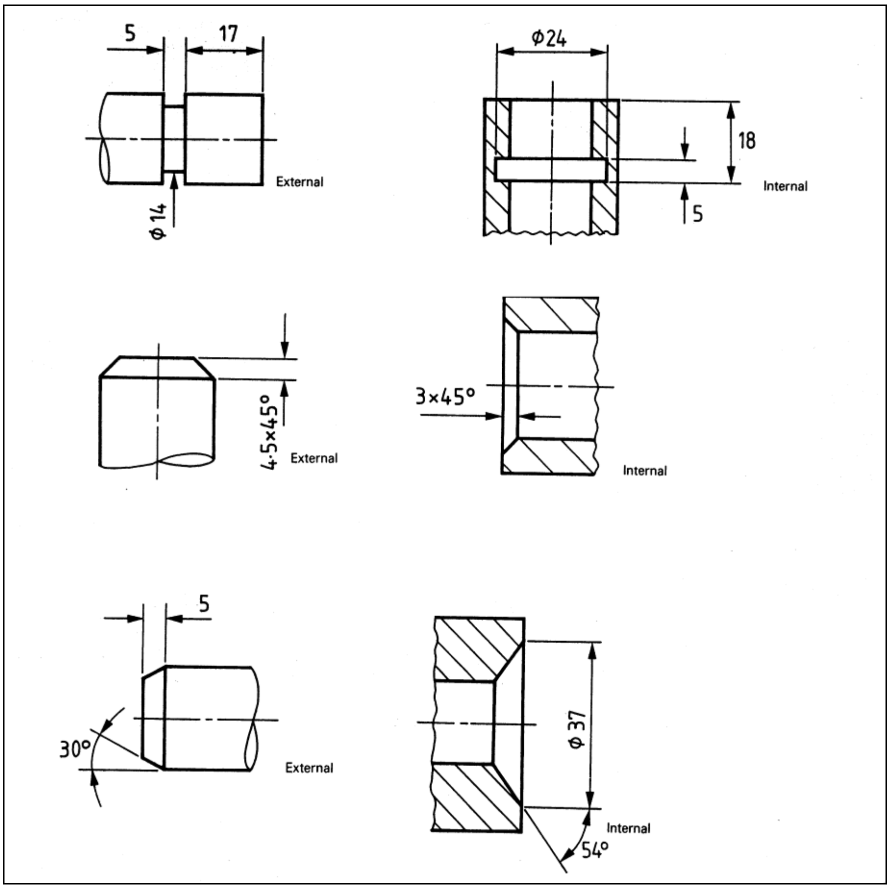
a) Counterbores, Countersinks and Spot Faces



b) Keyways and Tapers

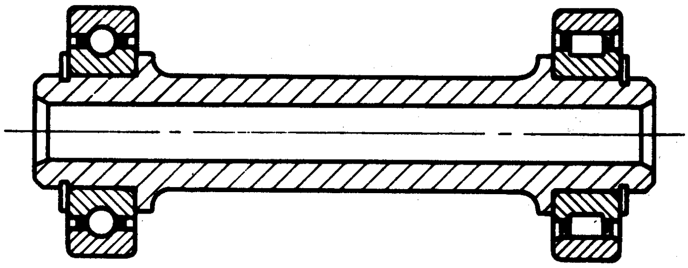


c) Radii, Spheres and Circles

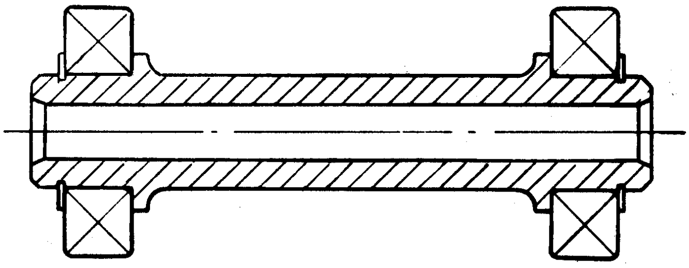


d) Recesses and Chamfers

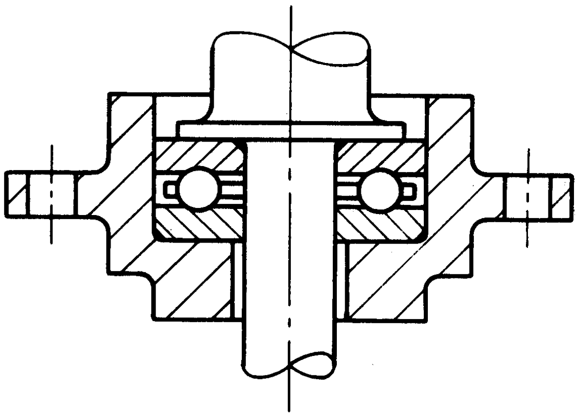
Appendix E – Further Simplified Graphical Representations of Standard Parts



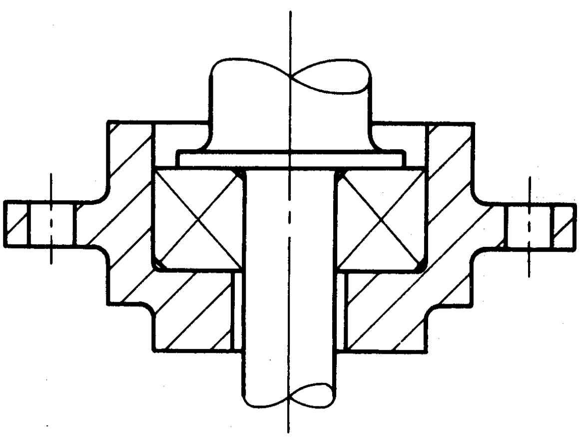
Ball and roller bearings



BS conventions

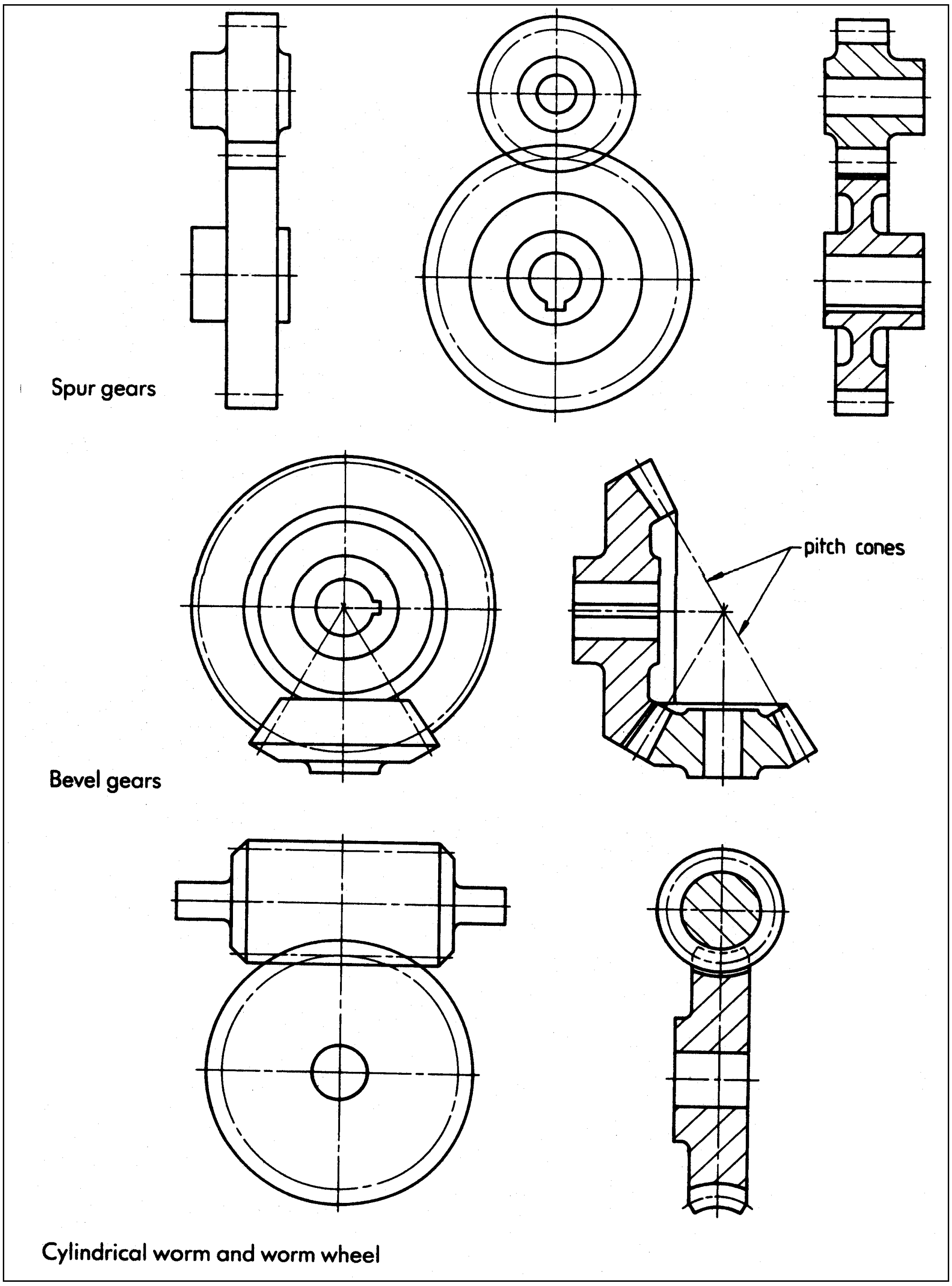


Single-direction thrust ball bearing



BS convention

a) Simplified Graphical Representation of Bearing Arrangements



b) Simplified Graphical Representation of Gears