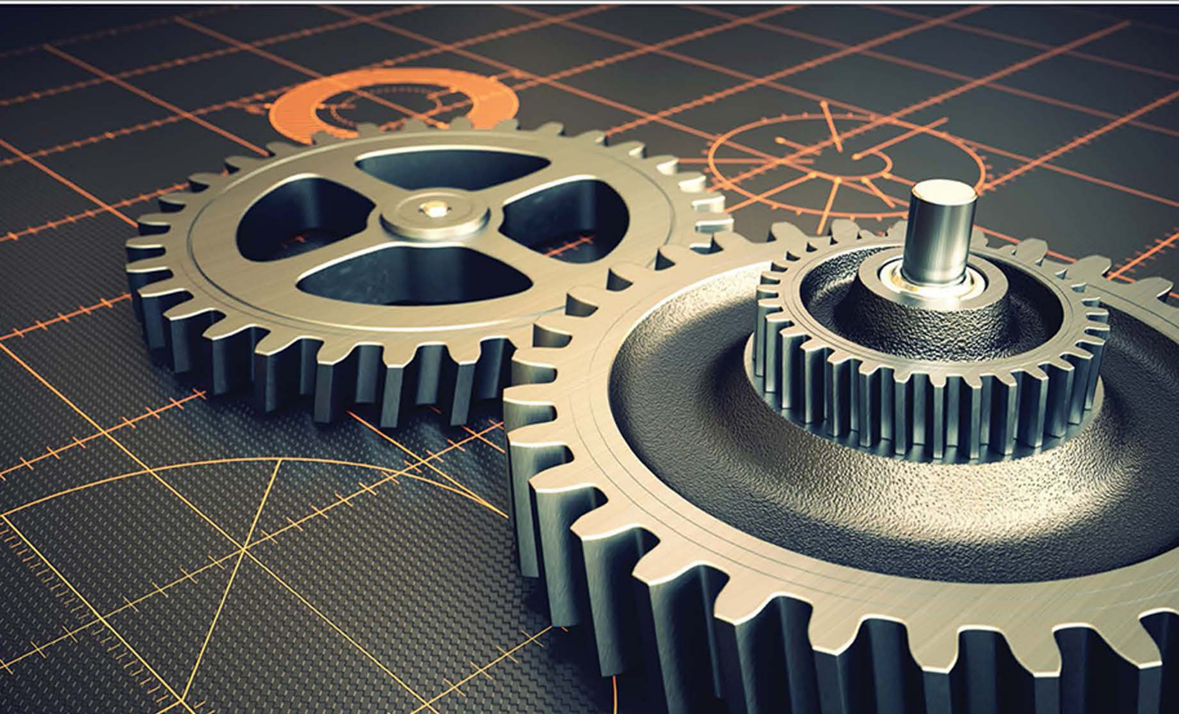
Geometric and Engineering Drawing

Fourth Edition



KEN MORLING AND STÉPHANE DANJOU

Geometric and Engineering Drawing

This introduction to descriptive geometry and contemporary drafting guides the student through the essential principles to create engineering drawings that comply with international standards of technical product specification. This heavily updated new edition now applies to CAD as well as conventional drawing. Extensive new coverage is given of:

- International drafting conventions
- Methods of spatial visualisation such as multi-view projection
- Types of views
- Dimensioning
- Dimensional and geometric tolerancing
- Representation of workpiece and machine elements
- Assembly drawings

Comprehensible illustrations and clear explanations help the reader master drafting and layout concepts for creating professional engineering drawings. The book provides a large number of exercises for each main topic. This edition covers updated material and reflects the latest ISO standards.

It is ideal for undergraduates in engineering or product design, students of vocational courses in engineering communication and technology students covering the transition of product specification from design to production.

Ken Morling trained as a mechanical engineer at Vickers Armstrong in 1956. He helped develop many aircraft including the TSR2 and Concorde. In 1963 he started teaching technical drawing to GCE O and A level students and wrote this book first published in 1969. In 1965 he became a graduate of the Institution of Mechanical Engineers and a Master of Philosophy in 1980 for development in education. During the life of his book there have been three editions and two translations into Spanish and Portuguese.

Stéphane Danjou is Professor of Mechanical Engineering and Plant Design at Rhine-Waal University of Applied Sciences in Germany, teaching Engineering Drawing, 3D CAD and Design. He started as a draftsman in a global acting company, studied mechanical engineering and worked as Technical Director in the packaging industry. With more than 25 years of experience in engineering drawing, he specialises in product development, particularly within the context of modern approaches in engineering design.

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Fourth Edition

Ken Morling
Stéphane Danjou

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Contents

Preface

Engineering drawings have been used to convey clear information about an object or system for many decades. They are graphic representations of products and depict how an object is designed, how it functions and how it is supposed to be manufactured and assembled. With the advent of comprehensive computer-aided design (CAD) programs, the way engineering drawings are created significantly changed. The introduction of three-dimensional (3D) CAD systems especially has revolutionised the approach for conveying the specifications of a technical product. Although the tools for creating engineering drawings have changed dramatically with time, the underlying principles are still the same. The fundamentals of descriptive geometry are still necessary for many applications of geometric drawing, and the same conventions and best practices still apply to the drafting process. Despite the rapid pace of computational improvements and the resulting possibilities of supporting and rationalising the drafting process, the basic concepts of geometric and engineering drawing have lost nothing of their relevance. Nowadays, geometric drawing is an essential skill for graphically solving geometric problems as part of a concept phase in a design process and for understanding the theory behind CAD systems. Although the current trend is to communicate product data exclusively with means of 3D CAD models for paperless production, we are far away from sending engineering drawings into retirement. Engineering drawings, no matter if resulting from manual drafting or as end products of a CAD modelling process, are still an efficient form of communication, required in all engineering disciplines.

This fourth edition has been entirely revised and heavily updated. While the fundamentals of geometric drawing have been taken from earlier editions, some completely new chapters are included that emphasise each part of the engineering drawing.

The new edition starts with an introduction to engineering communication and some basics of engineering drawing such as drafting equipment, internationally agreed conventions and principal techniques of technical sketching. The chapter on geometric constructions is almost unchanged from earlier editions. It shows specific drawing solutions to many geometric problems. Before introducing readers to the different types of views in engineering drawing, methods of spatial visualisation and basic concepts of descriptive geometry are presented. New chapters thoroughly address the important topics of dimensioning and tolerancing. Further, we introduce common representations of workpiece elements and frequently occurring machine elements as well as assembly drawings and their properties.

All chapters related to engineering drawing have been updated to the latest recommendations from the International Organization for Standardization (ISO), that is, best practices from the international standards developing organisation.

However carefully one checks a manuscript, errors creep in. We shall be very grateful if any readers who find errors let us know through the publishers.

S. Danjou & K. Morling
November 2021

Acknowledgements

To start with, I wish to express my sincere appreciation for the excellent work Ken Morling has provided with all previous editions of this book. I am deeply grateful for the opportunity to carry on with the success story he started more than 50 years ago.

My special thanks to the following examination boards for giving their permission to use questions from past papers. I am particularly grateful to them for allowing us to change many of the questions from imperial to metric units.

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Local Examinations Syndicate, University of Cambridge
Joint Matriculation Board
University of London School Examinations
Oxford Delegacy of Local Examinations
Oxford and Cambridge Schools Examination Board
Southern Universities' Joint Board

I especially thank the West Midlands Examinations Board, the Associated Lancashire Schools Examining Board and the Southern Universities' Joint Board for allowing us to draw solutions to questions set by them.

The extracts from BS 308, Engineering Drawing Practice and BS 3692, ISO Metric Precision Hexagon Bolts, Screws and Nuts are taken from a number of recent British Standards Institution Publications who have given their permission for the reproductions. Copies of the complete standards are available from BSI, 2, Park Street, London W1A 2BS.

My sincere thanks to the publisher, Taylor & Francis, and its editorial staff for making this fourth edition possible, and for showing so much sympathy during these difficult times which affected so many of us.

I would like to express heartfelt gratitude to my beloved wife, Marie-Kristin, and my children Lisanne and Eric for all their support, patience and encouragement. Finally, this edition became reality because they tolerated my incessant disappearances into my home office.

S. Danjou

The fourth edition has been compiled by Stéphane Danjou. I am very grateful that he has offered me many opportunities to make contributions where he thought they were appropriate. My thanks to S. Pagett for checking the manuscript of the original publication.

K. Morling

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Chapter 1

Introduction to Engineering Communication

1.1 PRODUCT DEVELOPMENT AND THE ENGINEERING DESIGN PROCESS

There are many different definitions for the engineering design process. However, they all share common attributes. In the broad view, engineering design, sometimes also referred to as technical design, is a systematic process where basic sciences such as mathematics and physics as well as engineering sciences are applied to solve a given problem. So it is about devising a component or a system while taking predetermined requirements into account to meet the desired needs.

Usually, engineering design follows a well-defined sequence of process steps. From a macroscopic perspective, the engineering design process can be broken down into four stages (see Figure 1.1).

At the very beginning, a design engineer is confronted with a problem statement. Note that a technical problem is given when the solution is not available with the help of already known means. As a result, it is the task of an engineer to establish a clear task description by clarifying the frame conditions and specifying the requirements. The latter can result from customer requirements such as performance, ergonomic or aesthetic requirements, from internal requirements such as considerations with respect to manufacturing or costs, or from external requirements like social and regulatory issues. The complete set of requirements represents constraints the developed technical solution will need to satisfy.

In a second step, the challenge is to develop one or more concepts that have the potential to solve the given problem. This is usually done by establishing a desired function structure and searching for working principles that fulfil the subfunctions. When combining the found working principles into so-called working structures while taking technical and economic constraints into consideration, we will get a set of principle solution variants.

Once principle solutions have been found that meet given evaluation criteria, the design process steps forward into an embodiment design phase where key modules are defined. At this stage, the size of product features or assembly components as well as their arrangement are determined. The outcome of the

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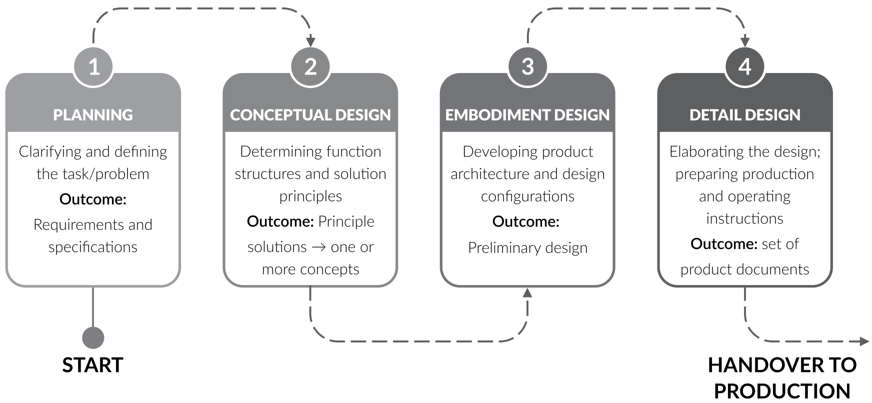

Figure 1.1 The engineering design process.

embodiment design are detailed layouts with respect to main function carriers and auxiliary function carriers. In addition to the basic rules of embodiment design 'clarity', 'simplicity', 'sustainability' and 'safety', numerous so-called principles of embodiment design and guidelines, depending on the selected manufacturing process, have to be taken into account. Further, the design is checked against errors, any kind of disturbing factors and possible risks.

A subsequent detail design process step, where all design details are finalised and where compliance with initial requirements are checked with the help of prototypes and tests, results into a set of product documents, partly needed for production and operation. This can include:

- Manufacturing drawings
- Assembly drawings
- Bill of materials (BOM), also known as parts lists
- Production/assembly/transportation instructions
- User manual
- Manual for maintenance
- Spare parts lists

All documents are then checked with regard to completeness, correctness and standards they need to comply with.

It can be seen that in the course of the engineering design process it is essential to communicate to others first ideas, concepts and preliminary design modules as well as the final design. The modern world of engineering is not a one-person show. Instead, it is the result of interdisciplinary teamwork. Therefore, providing a clear picture of such a technical idea and conveying it to various people, inside or outside an organisation, is of high importance and requires an effective and efficient mode of communication.

1.2 COMMUNICATION MODES

Since the beginning of humankind, people have developed several modes of communication. One of the first communication modes was sound. A variety of sounds had different meanings, such as warning others from an existing threat. As a drawback, sounds could be interpreted in different ways, if not commonly agreed on in a group. In addition, communication with the help of sound was limited to basic information.

As civilisation improved, humans used signs for communication. This could have been a fire signal, a pattern of stones, or symbols such as the ancient Sumerian cuneiform and the Egyptian hieroglyphics which were developed in 3500–3000 BC. With the development of alphabets, the written language became a versatile and sophisticated mode of communication.

In the same period, humans started to express themselves with the help of more complex sketches and pictures. Graphics language was born. Over the millennia, graphic representations became a basic and natural form of communication, regardless of the spoken language.

In the engineering field, the effectiveness of graphics language can be easily seen when trying to fully describe an object verbally or in writing. While this might be possible for simple objects, a precise verbal or written description without ambiguity of a more complex object seems to be impossible. As an example, see Figure 1.2 which shows a V8 engine block.

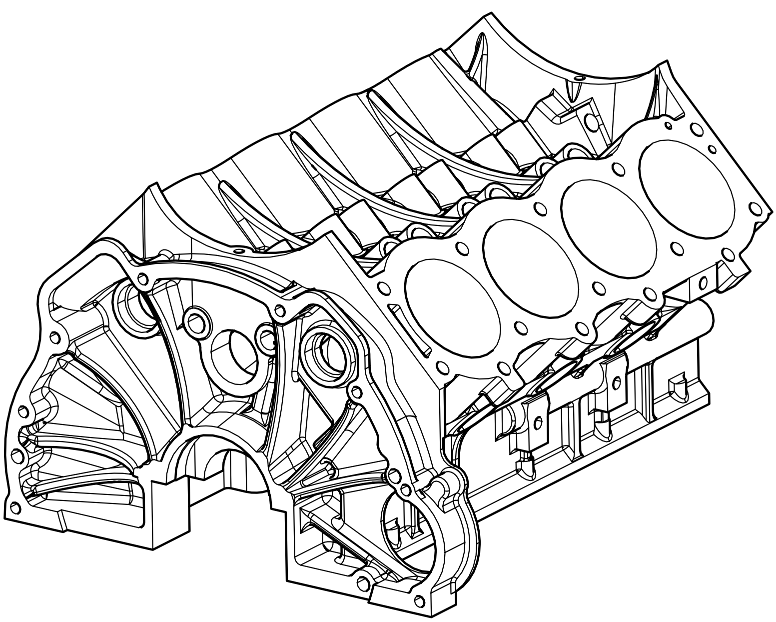

Figure 1.2 V8 engine block.

Graphic representations can be divided into artistic drawings, technical drawings and (technical) illustrations. Drawings from artists are a form of graphic expression of feelings or an idea and have appreciation as their focus. The purpose of an artistic drawing frequently is aesthetic. This kind of drawing is usually subjectively interpreted. In contrast, technical drawings have the purpose of conveying clear information about an object or system, especially how it is constructed or how it functions. As a result, technical drawings are not subject to interpretation but have an intended meaning with no room for misinterpretation.

While drawings and illustrations are both visual representations to convey a particular message by its creator, an illustration is neither purely artistic nor purely technical. Instead, an illustration usually supports the understanding of an accompanying textual content. Within the engineer's world, this kind of graphic representation typically can be found in product documentation such as user manuals, operator manuals or maintenance manuals, for example for machines, automobiles or consumer products. As an example, Figure 1.3 shows a technical illustration of a pillar drill.

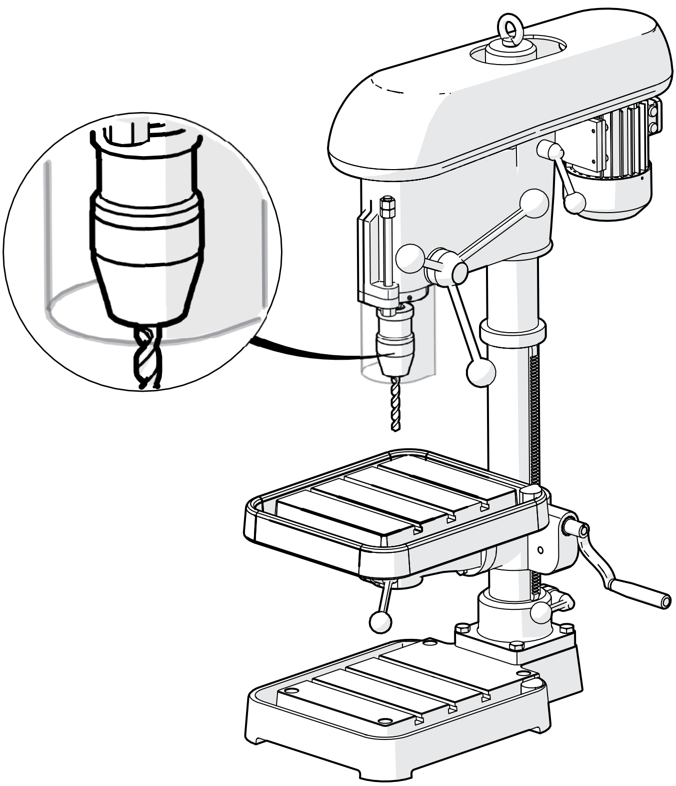

Figure 1.3 Technical illustration of a pillar drill.

Technical illustrations enable us to transfer product-related information or to convey complex matters. When communicating with the general public, this type of graphic representation can enhance the interest and understanding of a non-technical audience. Simplification of a product or assembly usually helps to draw attention to the area, feature or component of interest. For that reason, the illustration should resemble the product in question as much as possible but should also omit details which do not contribute to understanding.

The reason that illustrations are so much better than a mere verbal description is that text always needs to be processed in a sequential manner. Illustrations can be analysed within an instant and need no translation. In the end, the saying 'A picture is worth a thousand words' also applies to technical applications.

While technical illustrations can be the optimum communication mode for certain applications, in some cases a pure graphical representation is not precise enough and needs additional information, especially when it comes to communication on a more scientific level or between experts in the engineering field. So the graphic representation would need to be enriched by specialised technical terminology and symbols. This brings us to technical drawings. In contrast to artistic drawings and technical illustrations, this kind of graphic representation is a detailed and precise document that conveys information about how an object is designed and functions, and how it is supposed to be manufactured and assembled. The drawing is the road map which shows how a product functions, how it had been designed or how it is going to be manufactured. To guarantee that a technical drawing can be understood by any engineer, no matter of which origin or educational background, the elements of the graphic representation follow a set of international standards. By applying internationally developed and approved regulations to standardise the language used, ambiguous interpretation can be avoided. Figure 1.4 depicts a technical drawing of the previous example of a pillar drill. When comparing Figure 1.3 and Figure 1.4, one can realise that comprehension of the overall geometry and identification of individual components is much easier in the technical illustration. The technical drawing provides more information, such as the overall dimensions and the geometric relationships between the components due to the sectional view, which also enables identification of internal parts.

Nowadays, technical drawings are created with the help of computer-aided design (CAD) software packages. In the 1970s and 1980s, the main purpose of using a 2D CAD system was to create a technical drawing. With the introduction of 3D CAD systems in the late 1980s and early 1990s, the desired end product became a virtual three-dimensional model which contains a description of the geometry and serves as a common basis for downstream processes such as simulation, analysis and machining. While manual drafting required a large workspace, specific drafting equipment, and a lot of time to create and edit a drawing, computer-based drafting allows accurate and reproducible engineering drawings in a shorter time, since they can be automatically derived from the driving 3D model. As already mentioned, creating a technical drawing nowadays is not the sole advantage of such CAD systems. Further development

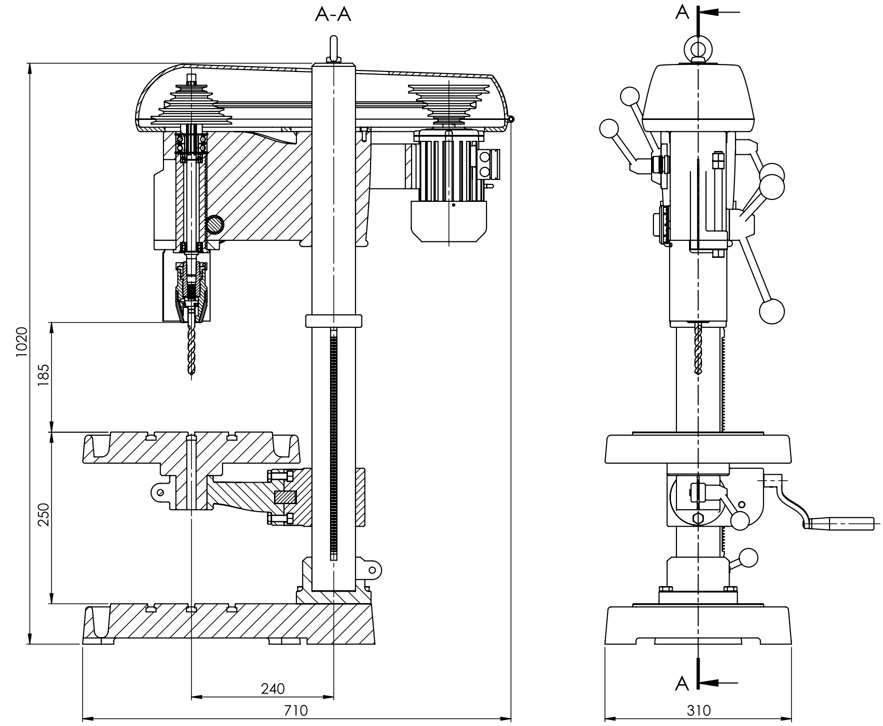

Figure 1.4 Technical drawing of a pillar drill.

of the functionality and increasing computing power led to expert systems for conceptualisation and the design of technical solutions. Regarding communication, 3D CAD systems meanwhile offer various possibilities to represent an object as realistically and as precisely as possible. Figure 1.5 demonstrates how realistic the pillar drill from previous paragraphs can look when a rendered model is created with the help of a modern CAD system.

If CAD systems can provide such impressive photo-realistic images of an object, why do we need (manual) drafting then? It seems that drafting skills are obsolete and that the necessary messages in an engineering design process can be transported via virtual models which show all the characteristics of an object to a very high level of detail.

1.3 IMPORTANCE OF ENGINEERING DRAWING

Engineering drawings still play a major role in the engineering design process since they can be easily understood, once the drafting conventions are known. They can also provide a lot of information regarding a technical solution, beyond the apparently visible. Accompanied by standardised ideograms or annotations, engineering drawings become the ideal mode of communication to

Figure 1.5 Rendered CAD model of a pillar drill.

convey information between the various parties involved in the design process and even the product development process. Owing to their versatile possible use, engineering drawings serve at minimum one of three purposes, frequently all of them at the same time:

- Communication
- Visualisation
- Documentation

As an example, companies use engineering drawings, in either paper or digital form, to convey how to fabricate a part while taking all necessary specifications into account. For that reason, precision needs to be the foremost quality of such a manufacturing drawing. However, communicating a part's manufacturing requirements and specifications is not the sole application. There are numerous interfaces across a company where a design solution needs to be communicated and visualised without ambiguity. This includes the following departments, depending on the specific industry branch:

- Mechanical design
- Electrical design
- Automation and control
- Research and development (R&D)
- Project management
- Purchasing
- Production
- Quality control
- Maintenance
- Service

Usually all these departments are somehow involved in a product's life cycle and therefore need a clear picture of the product. Engineering drawings represent the common communication medium and therefore can be considered to be one of the most important documents in an industrial company.

Once a design is finalised, the design process needs to be diligently documented. One reason is to communicate the rationales behind a design decision, which can be understood even after years. Another advantage of thorough documentation supported by engineering drawings is that future problem statements might be of similar nature so that a new design could be based on existing technical solutions. Apart from the internal usage of such documentation, engineering drawings are also created for legal and archival purposes. They can prove necessary compliance with safety regulations or support the patenting of a company's intellectual property.

Chapter 2

Fundamentals of Engineering Drawing

2.1 INTRODUCTION

As presented in Chapter 1, engineering drawings are never made up of graphics language alone. As a rule, they are a combination of graphics language and written language. Graphics in drawings use lines to represent edges, contours of an object and even surfaces. To distinguish between different types of edges or objects, a variety of different line types and line thicknesses is used. In addition to that, different projection methods help in visualising the object of interest in the best possible way in order to convey the necessary information. The types of projection will be explained in Chapter 4.

Graphics language used in engineering drawings mainly describes a shape and the appearance of an object. On the other hand, written language describes the many details, including the size, location and specification of an object.

From the next section on, an overview is provided of the fundamental elements of graphics and written language, used for any kind of technical drawing.

2.2 DRAFTING EQUIPMENT

2.2.1 Manual Drafting

Basic Tools

Someone who wants to create a technical drawing, such as a draftsperson or engineer, needs some basic tools for drawing. These should include the following:

- A range of pencils
- Rubber
- Ruler
- Set squares
- Protractor
- Compasses
- Dividers
- Drawing board

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- T-square
- Clips or tape
- Emery board or fine sandpaper

Pencils: You will need a selection of pencils. They are available with different hardness grades, suitable for different applications. In Europe and most parts of the world, pencil manufacturers use the HB grading system, based on the letters H (hard), B (black = soft) and F (firm). A number indicates the level of hardness. In the USA, the hardness scale is limited to five different grades only, indicated by a number. Figure 2.1 gives an overview of pencil lead hardness scales. For technical drawing purposes, a hard leaded pencil (5H) can be used for light lines, a less hard pencil (2H) for the outlines, and a medium soft pencil (HB) for printing. More than one pencil of each grade will save you from frequent resharpening.

Rubber: Choose a good quality rubber, one that does not smudge.

Ruler: It is advisable to have a transparent ruler. It is also recommended to have a ruler with metric and imperial units (Figure 2.2) since it might happen that you are confronted with different unit systems.

Set squares: You will need at least two set squares: a 60° and a 45° set square (Figure 2.3). It will be also useful to have an adjustable set square, which will enable you to set the angle on the set square to anywhere between 0° and 90°. If you have an adjustable set square, you can manage without the other two.

Protractor: Similar to set squares, the protractor is usually made of transparent acrylic plastic and is helpful for laying out specific angles or measuring an existing angle (Figure 2.4).

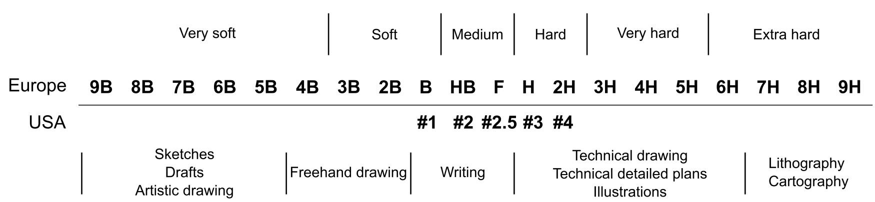

Figure 2.1 Pencil lead grades.

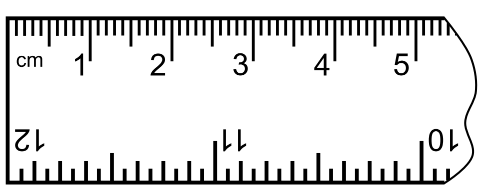

Figure 2.2 Ruler.

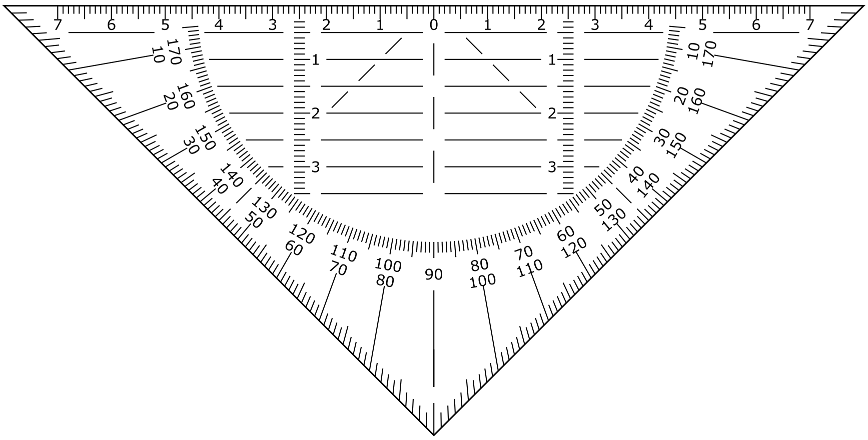

Figure 2.3 Set square (45°).

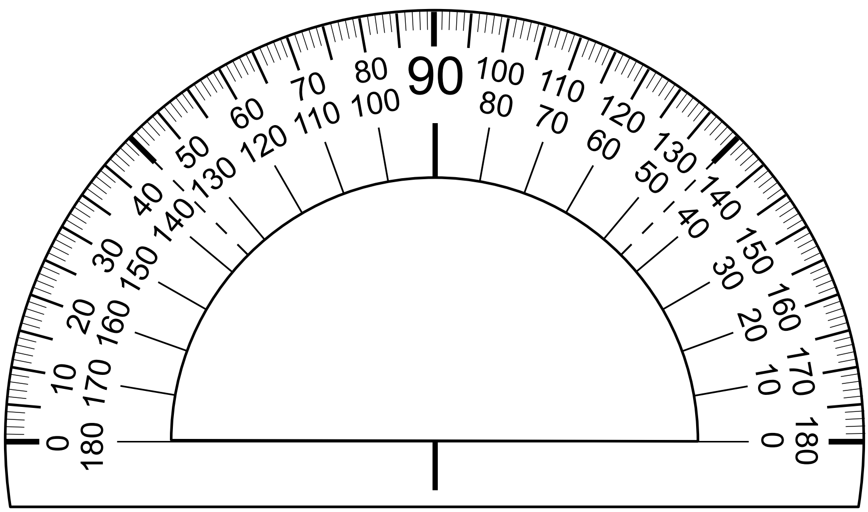

Figure 2.4 Protractor.

Compasses: Circles and arcs in your drawing are created with compasses. You will need at least two compasses: a small spring bow compass (Figure 2.5, left side) for small circles and one for larger circles.

Dividers: Dividers are similar to compasses, except that they are not used for drawing a circle or an arc. Instead, a pair of dividers (Figure 2.5, right side) is very helpful when precisely transferring a distance between views or from one drawing to another. A typical application is dividing a circle or a straight line into equal parts by setting a distance repeatedly. For that reason, both tips of the dividers are pointed.

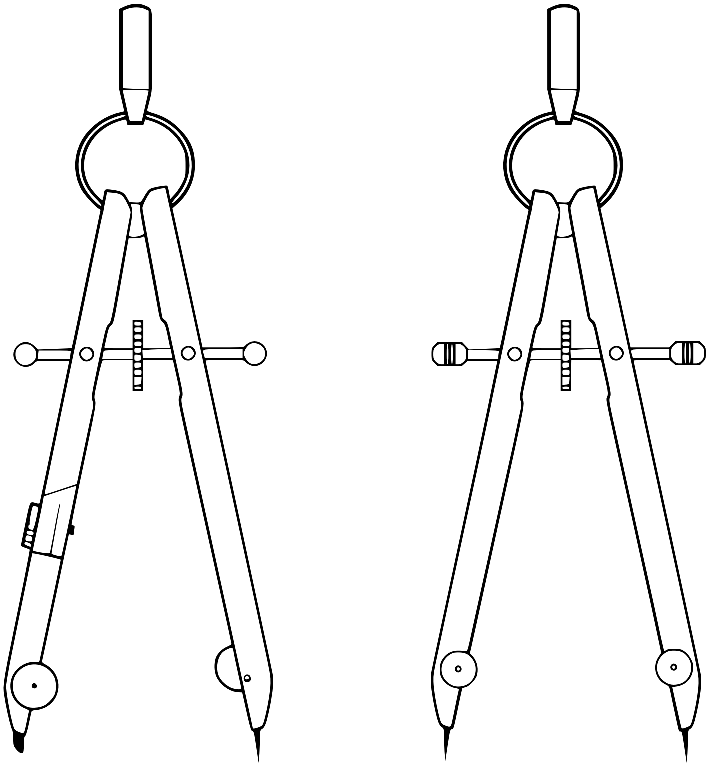

Figure 2.5 Compasses and dividers.

Drawing board and T-square: Drawing boards for size A2 paper can be bought with a fitted horizontal square which slides up and down on rollers. A less expensive board is one that is used with a separate T-square which slides up and down on the side of the drawing board and has to be held in place when used (Figure 2.6).

Clips or tape: The best tape to use to hold paper on the drawing board is masking tape, but metal drawing board clips are easier to use.

Emery board or fine sandpaper: This is used to ensure that the lead in the pencils is kept sharp.

There are other instruments that will help you to draw quickly and accurately. These include the following:

- *French curves* for drawing non-circular and irregular curves accurately (Figure 2.7).
- *Templates* such as circle templates, branch-specific symbol templates and templates with commonly used shapes (Figure 2.8).
- *Scales* (rulers with special markings for drawing items bigger or smaller than they are in real life).

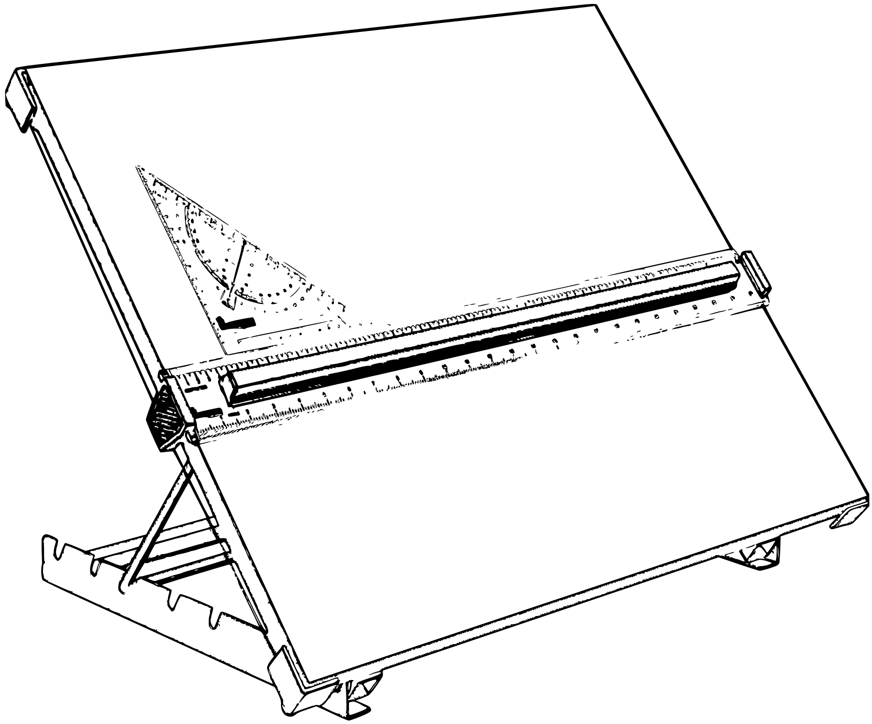

Figure 2.6 Drawing board with T-square and set square.

Figure 2.7 French curves.

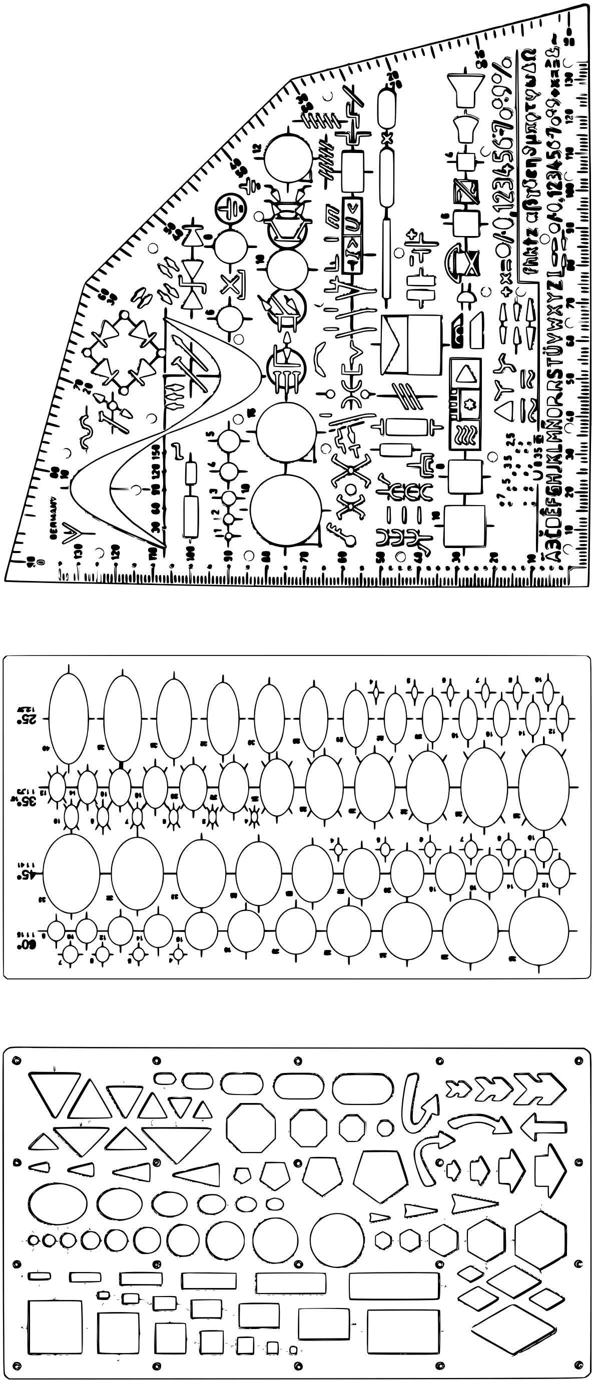

Figure 2.8 Templates.

Using the Equipment

First, fix the paper to your board, using clips or tape. Then sharpen your pencils, either to a point using a pencil sharpener or to a chisel shape using the emery board and use this shape for drawing lines, drawing from the ends of each line to meet in the middle. Use the emery board to sharpen your compass leads to a chisel point too. Finally, draw a frame on your paper if required (see Figure 2.20). Now you are ready to start drawing. Here are some exercises.

First construct an equilateral triangle (Figure 2.9).

Then find the centre of the circumscribing circle.

Draw the circumscribing circle.

Practice shading some parts with the 60° set square.

First draw a circle and step the radius around it six times, starting at the top (Figure 2.10).

Draw the regular hexagon.

Shade the parts of the hexagon with the 60° set square.

2.2.2 Computer-Aided Design (CAD)

Recent decades have been characterised by an accelerating pace in the development of computer technologies. Naturally, this advancement also affected engineering activities, especially the design process and how technical drawings are created. Software solutions for supporting such computer-aided design

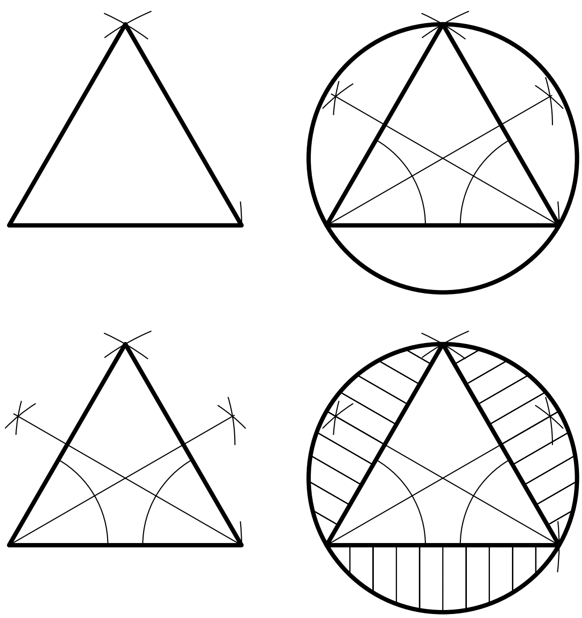

Figure 2.9 Circumscribing circle of an equilateral triangle.

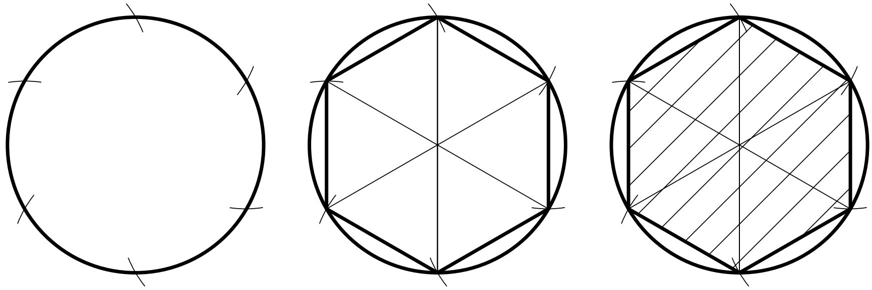

Figure 2.10 Regular hexagon.

process already exist since beginning of the 1960s. While at the beginning these IT solutions were very limited in their functionality, especially in the 1980s and 1990s CAD evolved into a very sophisticated tool to create legible and accurate technical drawings at considerable speed. With comprehensive advent of 3D CAD systems in the 1990s, companies were able to increase their productivity by creating virtual 3D models which can be used for numerous downstream engineering processes such as drafting, simulation and manufacturing. Nowadays, 3D CAD systems are considered to be so-called product lifecycle systems since they take different aspects from all stages of a product's lifecycle into account, i.e. from design through testing, production, commissioning, end use and maintenance to recycling or disposal.

While in the past specialised and expensive CAD workstations were necessary to run a CAD system, nowadays commercially available desktop computers or laptops for personal use can be used for standard CAD applications such as drafting or simple 3D modelling. However, depending on the complexity of the technical drawing, drafting can be a graphically and computationally intensive task. When using modern 3D CAD systems, it may even be recommended to consider a powerful graphics card, high-speed CPU and sufficient RAM. Most CAD software suppliers even offer an overview of certified, i.e. tested and approved, graphics cards to make sure that the hardware complies with the system-specific requirements.

Apart from standard computer input devices such as mouse, keyboard and scanner, there are many other available for CAD. As an example, graphics tablets with an attached stylus can be used to ease cursor movements and the selection of menu commands. Alternatively to standard computer mice, a trackball or 3D mouse can increase efficiency. Although the first CAD systems already support touch and multi-touch gestures, this kind of input is not yet standard for such applications.

As output devices, CAD applications require a monitor and a printer or plotter to put the drawings created on screen on paper. It is recommended to use a dual-monitor setup or a widescreen monitor to increase productivity.

Despite the potential advantage of increased efficiency by using modern CAD systems, manual drafting skills are still important, especially for sketching, quickly communicating and visualising an idea and for understanding the techniques behind computer-aided drafting commands.

2.3 DRAFTING CONVENTIONS

The first step a manufacturer must take when they intend to produce goods is to create a drawing. First, a designer will make a preliminary sketch and then a draftsperson or engineer will make a detailed drawing of the design. Since neither the designer nor the draftsperson will actually manufacture the product, the drawings must be capable of being interpreted by people in the workshops. These workshops may be sited a long way from the drawing office, possibly even overseas, so the drawings produced must be standardised so that anyone familiar with these standards could make the product required, independent of the local spoken language. This is why you will often see symbols used on a drawing instead of words or abbreviations.

National as well as international standards specify the rules for engineering drawing and should be carefully studied by every prospective engineer and draftsperson.

The following chapters explain, within the international framework of ISO 128 (*Technical product documentation and specification*), the language of engineering drawing.

2.3.1 Standardisation

To create clear, coherent and comprehensible drawings, an agreement regarding the commonly used graphics language and written language is required. This is mainly to make sure that a drawing can be understood by everyone without ambiguity. The effectiveness of such drafting language emerged due to the establishment of standards and conventions based on best practices. While the latter is considered to be an instruction set on how to create and read drawings, we use methods of descriptive geometry to implement graphics language. The consistent application of standards in the drafting process guarantees that all manufacturers, or others involved in the product development process, interpret the drawing in the same way. This is a fundamental requirement for interchangeability of parts. Modern industry has been developed on the basis of interchangeable manufacturing and therefore it requires national as well as international standards.

Written or spoken language had been continuously standardised over centuries and is still an ongoing process. The latest status of a standardised language can be found in a dictionary. Likewise, engineering standards are regularly revised and continuously updated. National as well as international organisations make sure that best practices are turned into standards for various industries.

With the transition to more elaborate manufacturing processes during the Industrial Revolution in the 19th century, the need for precise machine tools and interchangeable parts arose. Differences in local standards were making trade very difficult, sometimes even impossible in terms of cost. As a consequence, in 1901 the world's first national standards developing organisation was born, the British *Engineering Standards Committee*. After the First World War, numerous countries followed and set up their own national standard bodies. Finally, in 1947 the *International Organization for Standardization* (ISO) was founded by 25 national standards organisations to ease the exchange of goods and reduce trade barriers. Currently, ISO consists of 165 members. In 1961 the *European Committee for Standardization* (CEN) followed, which brings together the national standardisation bodies of 34 European countries. The idea of EN standards is to successively substitute national standards of the member states for European standards. Table 2.1 gives an overview of some standardisation organisations.

Some of the standards developing organisations are supported by national organisations such as the *Association of German Engineers* (VDI) in Germany and the *American Society of Mechanical Engineers* (ASME) in the USA.

Today, we are facing an almost innumerable variety of national and international standards, which complicates the appropriate selection. If not already restricted by requirements and specifications, ISO standards should take absolute precedence over regional (such as EN) or national standards. Within the European Community, EN standards take higher precedence over national standards of their member countries.

Sometimes we can observe a smooth transition from international to national standards. For instance, an international ISO standard can be transformed into an EN standard and finally into a national standard. The following list exemplifies some of the possible combinations:

- DIN xxxx – German standard with mainly national relevance.
- DIN EN xxxx – European standard which had been transformed into a national standard. Whenever European standards are taken over, they need to be adopted by the members of the European Committee for Standardization without any modifications.

Table 2.1 Examples of national and international standardisation organisations

Region/country	*Code*	*Name of developing organisation*
World	ISO	International Organization for Standardization
Europe	EN	European Committee for Standardization
Australia	AS	Standards Australia
Germany	DIN	German Institute for Standardization
Japan	JIS	Japanese Industrial Standards Committee
P.R. China	GB	Standardization Administration of China
United Kingdom	BS	British Standards Institution
USA	ANSI	American National Standards Institute

- DIN EN ISO xxxx – International standard, developed by ISO or CEN and published by both organisations, which is transformed into a German national DIN standard.
- DIN ISO xxxx – Directly from ISO adopted standard.

Within this book, we will mainly address international standards (ISO). All ISO standards addressed in this book can be found in Appendix A.

The reader may refer to their own national standards whenever requirements and specifications do not allow the application of international standards.

2.3.2 Line Conventions

Technical drawings usually consist of a variety of types of lines, each of them with a specific meaning. Part 2 of the international standard ISO 128 establishes the different lines, their designations and examples of application. Most commonly known line types are continuous lines, dashed lines and long-dashed dotted lines, each of them available as a narrow or wide line. In fact there are many more line types available for drafting. To get a clear overview, in ISO 128–2 the lines are classified according to the scheme shown in Figure 2.11.

The most important basic line types are shown in Figure 2.12. Note, this is just an extract out of 15 available basic line types and shows lines commonly used in mechanical engineering practice. Note that the long-dashed double-dotted lines are also referred to as *phantom lines*.

The basic types of lines can also vary with regard to their shape. As an example, instead of a straight continuous line, the basic line type 01 can also be shown as a wavy, spiral, zigzag or freehand continuous line.

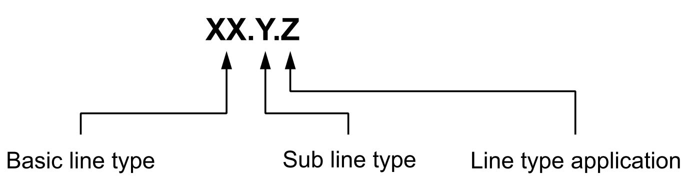

Figure 2.11 Line type designation according to ISO 128–2.

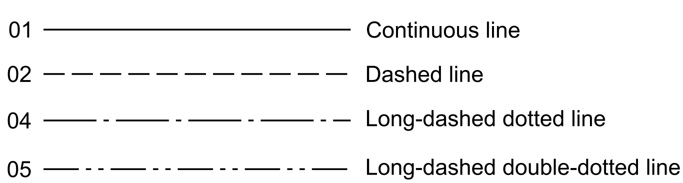

Figure 2.12 Basic line types.

Table 2.2 Line groups and line thickness values

Line group	*Wide lines (mm)*	*Dimensions, callouts, annotations (mm)*	*Narrow lines (mm)*
0.25	0.25	0.18	0.13
0.35	0.35	0.25	0.18
0.5	0.5	0.35	0.25
0.7	0.7	0.5	0.35
1.0	1.0	0.7	0.5
1.4	1.4	1.0	0.7
2.0	2.0	1.4	1.0

As line subtypes, ISO 128–2 distinguishes only between narrow (subtype 1), wide (subtype 2) and extra wide (subtype 3), whereas for most engineering drawings, only two thicknesses are needed, narrow and wide. The final thickness value depends on the selected so-called line group. The width of all types of lines can vary within a predefined series of thickness values, starting from 0.13 mm and ending at 2 mm, with a common ratio between two consecutive values. Table 2.2 gives an overview of the different line groups and the associated line thickness values for different line subtypes.

The line group shall be chosen corresponding to the drawing type, the paper size of the drawing and the applied scale. As a rule, in mechanical engineering applications line group 0.5 is used.

The last part of the line type designation consists of a number indicating the application of a line in technical drawings. As an example, the line type designation 01.1.5 indicates a continuous narrow line, which is used for hatching (application number 5). For details regarding the application number, see ISO 128–2.

In Figure 2.13 and Figure 2.14, different types of lines are exemplarily shown in technical drawing views. For clarity, according to the aforementioned classification, the visible outline is shown as a wide continuous line (basic line type 01, subtype 2).

When it comes to junctions between any non-continuous lines, they should meet at a dash. Otherwise, this could lead to confusion. In case of parallel lines of same line type, the lines should be shown staggered for clarity. However, while in manual drafting you have full control of how to draw any non-continuous line, in CAD systems the exact position of each dash is hard or even impossible to influence.

If two or more lines coincide in a view, a certain hierarchy of visibility needs to be followed. Visible edges and outlines always take precedence over all other line types. Hidden edges and outlines take precedence over cutting plane lines, centre lines and extension lines. Centre lines are of higher hierarchy than extension lines, which have the lowest precedence. Figure 2.15 shows some examples of overlapping lines and their hierarchy of visibility.

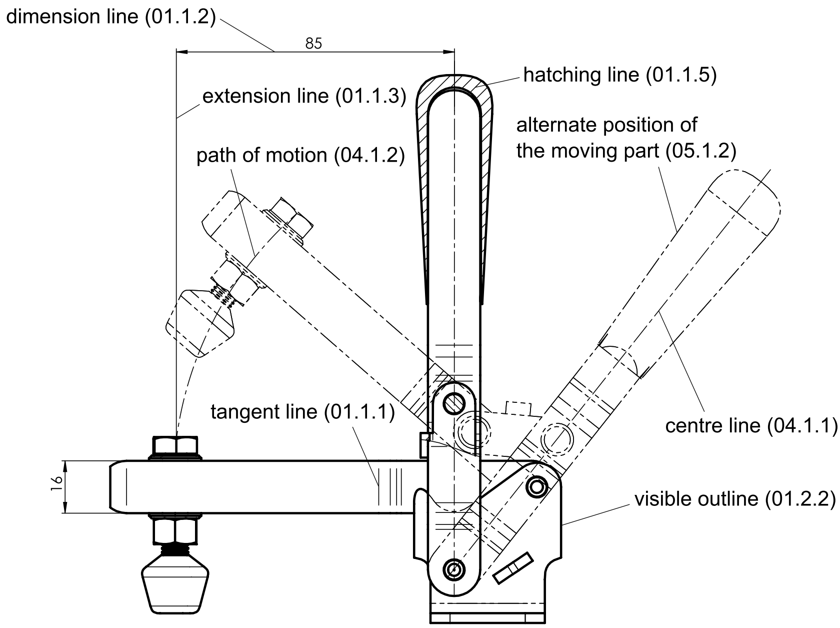

Figure 2.13 Examples of line types in a technical drawing of a toggle press clamp.

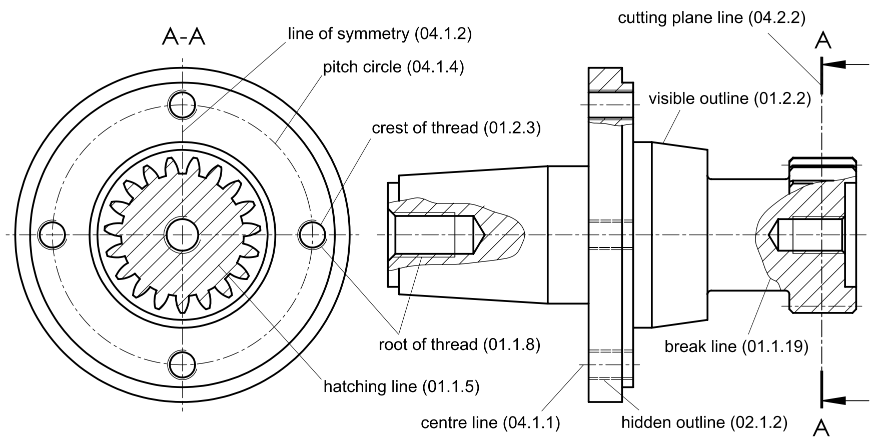

Figure 2.14 Examples of line types in a technical drawing of a tapered shaft.

In case (A) of Figure 2.15, a visible edge coincides with the centre line of the hole. Since the visible edge takes precedence over all other lines, the visible edge is shown and just outside of the outline the centre line is adumbrated. In case (B), a hidden edge and the centre line of the hole fall together. The hidden line is shown since the centre line has a lower precedence. In case (C), a visible edge and a hidden edge coincide.

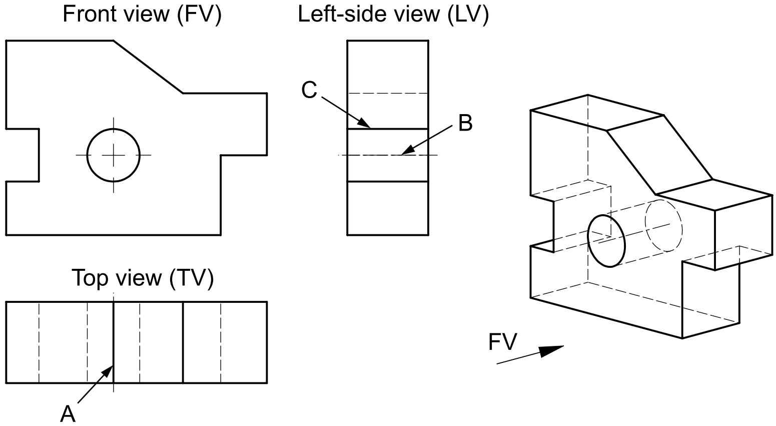

Figure 2.15 Precedence of lines.

2.3.3 Lettering

Owing to the fact that graphics language alone is not suitable to fully describe an object without ambiguity, engineering drawings generally contain some writing in the form of dimensions or notes. Since drawings sometimes need to be reproduced (e.g. photocopy, blueprint, scan), legibility is of utmost importance. To avoid having someone create a drawing using a personal handwriting style, whose interpretation highly depends on readability, lettering is standardised nowadays. The requirements for lettering can be found in the international standard ISO 3098.

Basically, we can distinguish the following lettering techniques:

- Freehand lettering
- Use of templates and manual lettering instruments
- Numerically controlled lettering and drafting systems (e.g. CAD)

Different styles of lettering can be applied in technical drawings. ISO 3098 considers different graphic character sets, inclination of lettering such as vertical and sloped and finally the kind of alphabet (Latin, Greek or Cyrillic). In most drawings, type style A (close-spaced) or type style B (normal) is used. Both styles can be drawn vertical or italic, i.e. slanted to the right by 15°. Vertical lettering style B is recommended by ISO 3098 for standard applications. Figure 2.16 shows a sample of Latin characters with lettering style A.

The height of upper case letters depends on the used line group. Since usually line group 0.5 is used, the line thickness for lettering is 0.35 mm (compare Table 2.2). Character height equals line thickness multiplied by 10 and therefore results in 3.5 mm.

Many draftspersons develop great skills in printing by hand. If you need to print manually, try both standard and italic and develop a style that suits you.

Figure 2.16 Lettering style A (vertical and italic) according ISO 3098.

2.3.4 Drawing Layout

Most paper comes in standard sizes. Metric sheet sizes are internationally standardised in ISO 216. The underlying principle is to have a basic size A0 and to derive the next smaller sheet size by halving (compare Figure 2.17). This leads to a set of geometrically similar sheet sizes. ISO 216 distinguishes a normal A series (regularly derived sizes) and an alternative B series.

Similarly, US customary sheet sizes are standardised by ANSI/ASME Y14.1 and range from ANSI A (smallest size) to ANSI E (largest size). In contrast to ISO 216, the aspect ratio is not constant but alternating.

The largest sheet you are likely to use in technical drawing is A0 and the smallest A4. If your drawing paper has no frame, then draw one. A minimum of 20 mm is used on A0 and A1 from the edge of the paper to the frame line and a minimum of 10 mm on A2, A3 and A4.

In order to space out the views that you will draw on your paper, use the following formulas (A, B and C are the maximum sizes of your views) and the p and q dimensions are the distances between the views.

You do not have to use exact dimensions which might complicate the sums; use sensible approximations for A, B and C (Figure 2.18).

You may well have to add information to your finished drawing, and this should be shown in a block. This information could include a drawing title, the drafter's name, the scale of the drawing, details of approval, the system of projection used, and the date of creation.

In order to ensure compatibility when exchanging drawings, data fields of such a title block are standardised in ISO 7200. It is recommended to have a minimum set of information to facilitate the use and also reuse of the technical drawing.

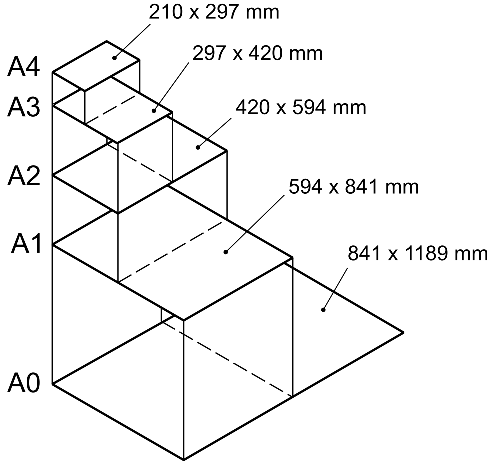

Figure 2.17 Sheet sizes according ISO 216.

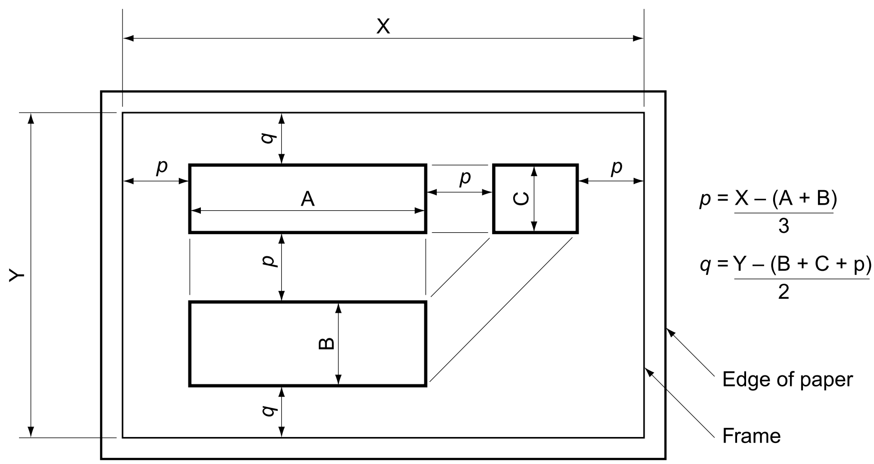

Figure 2.18 Positioning of views to be drawn.

Figure 2.19 shows a typical title block which can be found on a technical drawing. Note that the title is given prominence over all the other information. Also note that the system of projection is also given within the title block. This is because assuming the wrong projection method could lead to confusion. Optional data fields are highlighted in Figure 2.19. Although it is not mandatory to provide the data fields shown, it is at least recommended. Finally, it depends on the company size, the company structure and the internal processes.

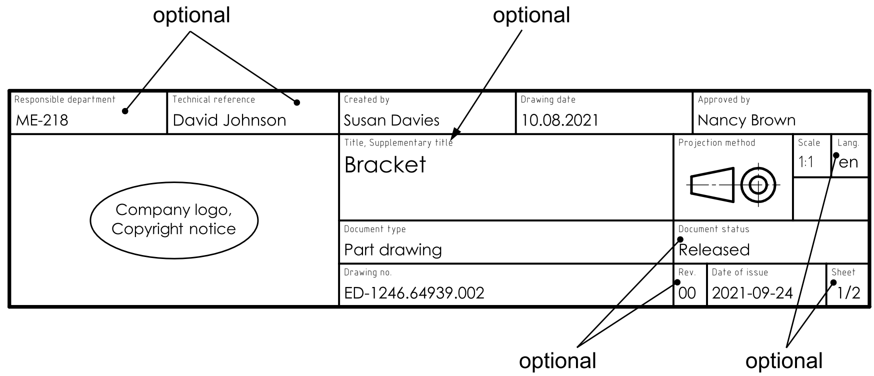

Figure 2.19 Example of a title block.

The same title block is used for all paper sizes. For all landscape oriented paper sizes (usually A0 to A3), the title block is located at the lower right corner of the drawing space. For the size A4 which usually is positioned vertically, the title block is situated in the lower part of the drawing space.

ISO 5457 provides details for drawing sheets such as the available sizes and recommended layouts. The sheet sizes depend on the paper sizes specified in ISO 216, but the available drawing space will be smaller since we have to consider a drawing frame which limits the drawing space and some margins. When a drawing becomes more complex, a grid reference system helps. Locating drawing details such as annotations or revisions will become easier when using a grid of equal zones, overlaying the drawing sheet. ISO 5457 recommends dividing each side of the drawing space into fields of 50 mm length. The fields are vertically referenced with capital letters and horizontally with numbers, located in the grid reference border and originating at the upper left corner (see Figure 2.20).

You might also show an assembly with numerous components on your drawing. For more detailed specification of the individual parts, a parts list can be included in the drawing either in conjunction with the title block (compare Figure 2.20) or placed at any other location. The list of part numbers would be used only if several parts were drawn on the same drawing and would not, therefore, be shown on every drawing.

2.4 SCALES

Before you start any drawing, you first decide how large the drawings have to be. The different views of the object to be drawn must not be bunched together or be too far apart. If you are able to do this and still draw the object in its natural size, then obviously this is best. This is not always possible; the object may be much too large for the paper or much too small to be drawn clearly. In either case it will be necessary to draw the object 'to scale'. The scale must

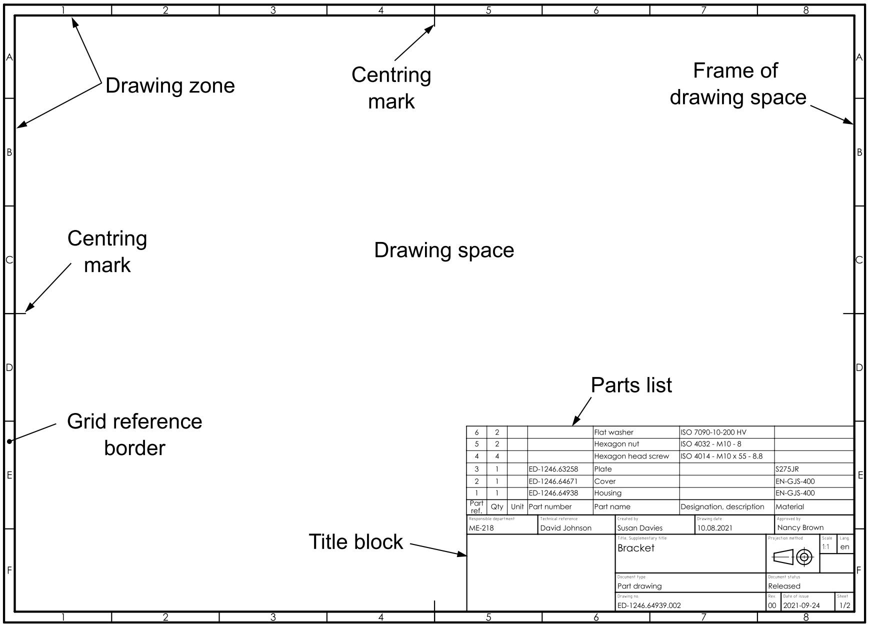

Figure 2.20 Drawing layout with grid reference system.

depend on the size of the object; a miniature electronic component may have to be drawn 100 times larger than it really is, whilst some maps have natural dimensions divided by millions.

There are drawing aids called 'scales' which are designed to help the draftsperson cope with these scaled dimensions. They look like an ordinary ruler, but closer inspection shows that the divisions on these scales are not the usual centimetres or millimetres, but can represent them. These scales are very useful, but there will come a time when you will want to draw to a size that is not on one of these scales. You could work out the scaled size for every dimension on the drawing but this can be a long and tedious business – unless you construct your own scale. This chapter shows you how to construct any scale that you wish.

The Representative Fraction (RF)

The RF shows instantly the ratio of the size of the line on your drawing and the natural size. The ratio of numerator to denominator of the fraction is the ratio of drawn size to natural size. Thus, an RF of $\frac{1}{5}$ or 1:5 means that the actual size of the object is five times the size of the drawing of that object.

If a scale is given as 1 mm = 1 m, then the RF is

$$\frac{1\,\text{mm}}{1\,\text{m}} = \frac{1\,\text{mm}}{1000\,\text{mm}} = \frac{1}{1000}$$

Plain Scales

There are two types of scale, plain and diagonal. The plain scale is used for simple scales, scales that do not have many subdivisions.

When constructing any scale, the first thing to decide is the length of the scale. The obvious length is a little longer than the longest dimension on the drawing. Figure 2.21 shows a very simple scale of 20 mm = 100 mm. The largest natural dimension is 500 mm, so the total length of the scale is $\frac{500}{5}$ mm or 100 mm. This 100 mm is divided into five equal portions, each portion representing 100 mm. The first 100 mm is then divided into 10 equal portions, each portion representing 10 mm. These divisions are then clearly marked to show what each portion represents.

Diagonal Scales

There is a limit to the number of divisions that can be constructed on a plain scale. Try to divide 10 mm into 50 parts; you will find that it is almost impossible. The architect, cartographer and surveyor all have the problem of having to subdivide into smaller units than a plain scale allows. A diagonal scale allows you to divide into smaller units.

Before looking at any particular diagonal scale, let us first look at the underlying principle.

Figure 2.22 shows a triangle ABC. Suppose that AB is 10 mm long and BC is divided into 10 equal parts. Lines from these equal parts have been drawn parallel to AB and numbered from 1 to 10.

It should be obvious that the line 5–5 is half the length of AB. Similarly, the line 1–1 is $\frac{1}{10}$ the length of AB and line 7–7 is $\frac{7}{10}$ the length of AB. (If you wish to prove this mathematically use similar triangles.)

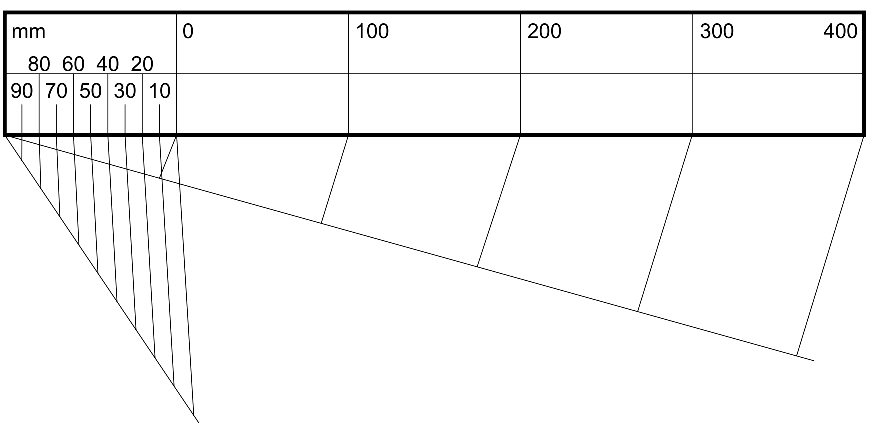

Figure 2.21 Plain scale 20 mm = 100 mm or 1 mm = 5 mm.

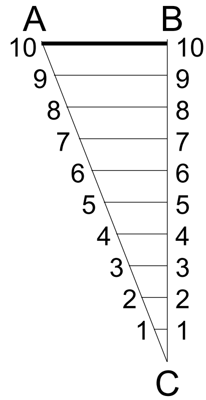

Figure 2.22 Showing how to divide a line AB into 10 equal parts.

You can see that the lengths of the lines 1–1 to 10–10 increase by 1 mm each time you go up a line. If the length of AB had been 1 mm to begin with, the increases would have been $\frac{1}{10}$ mm each time. In this way, small lengths can be divided into very much smaller lengths and can be easily picked out.

An example of diagonal scales follows.

This scale would be used where the drawing is twice the size of the natural object and the draftsperson has to be able to measure on a scale accurate to 0.1 mm.

The longest natural dimension is 60 mm. This length is first divided into six 10 mm intervals. The first 10 mm is then divided into 10 parts, each 1 mm wide (scaled). Each of these 1 mm intervals is divided with a diagonal into 10 more equal parts (Figure 2.23).

Proportional Scales

It is possible to construct one plain scale directly from another, so that the new scale is proportional to the original one. An example of this is given in Figure 2.24. The new scale is a copy of the original one but is $\frac{7}{4}$ times larger. The proportions of the scales can be varied by changing the ratios of the lines AB to BC.

2.5 TYPES OF DRAWINGS

There are various types of technical documents used in a company, mainly dependent on the type of production and the structural organisation of the company. Most common technical communication media are technical drawings and bill of materials (BOM). Freehand sketches are also important since they can contribute to solution finding, serve as a basis for a discussion or are necessary for measurements on site.