



# Engineering and Manufacturing

T LEVEL OCCUPATIONAL SPECIALISMS  
(8712/8713/8714)

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# ENGINEERING AND MANUFACTURING

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ISBN: 978 1 0360 1363 9

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First published in 2026 by  
Hachette Learning (a trading division of Hodder & Stoughton Limited)  
An Hachette UK Company  
Carmelite House  
50 Victoria Embankment  
London EC4Y 0DZ

www.hachettelearning.com

The authorised representative in the EEA is Hachette Ireland,  
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Impression number 10 9 8 7 6 5 4 3 2 1

Year 2030 2029 2028 2027 2026

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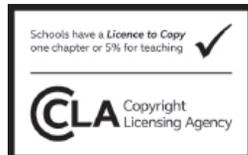
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Illustrations by Hyphen SA/Transforma

Typeset by Hyphen SA

Printed and bound in Great Britain by Bell & Bain Ltd, Glasgow

A catalogue record for this title is available from the British Library.



# 1 Maintenance, installation and repair: principles and techniques

This chapter covers the core principles and techniques that underpin practical skills in the maintenance, installation, servicing and repair of engineering systems. You will learn how to analyse technical requirements and specifications, how to apply mechanical and electrical principles, and how to use appropriate tools, equipment and joining methods safely. You will also explore power transmission systems, sensing and measurement techniques and the effects of environmental conditions on materials and components. This chapter brings together the essential knowledge needed to carry out maintenance tasks effectively, follow safe working practices and ensure systems operate reliably and efficiently.

Analyse requirements, specifications and technical information to enable the delivery of successful maintenance, installation, servicing and repair of mechanical plant and equipment

## Operation of mechanical principles and systems

### Motions and forces

Understanding how mechanical systems respond to static and dynamic forces is essential for safe operation and maintenance.

- ▶ **Static loading** occurs when stationary forces act consistently, such as a fixed load on a crane arm. Components under static loading must be regularly inspected to avoid long-term deformation or failure.
- ▶ **Dynamic loading** involves rapidly changing forces, such as machine vibrations. Dynamic loading increases wear and may lead to sudden failures, so regular checks and preventive maintenance are important.

### Stress and strain

Stress occurs when forces act on materials, causing internal resistance. Types include:

- ▶ tensile stress (pulling apart, such as cables or chains under tension)
- ▶ compressive stress (pressing together, common in pillars or support structures).
- ▶ shear stress (forces causing material layers to slide past each other, such as bolts experiencing lateral forces).

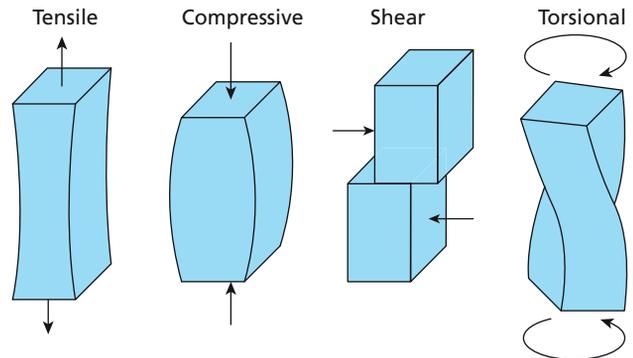
Strain means a material is changing shape because of pressure or force. Monitoring strain helps identify problems early, especially in parts that carry heavy loads. Strain gauges can be installed on equipment or a structure to monitor stress levels.

### Moments and torque

Moments are turning forces that happen when something pushes or pulls on a lever or beam. They help keep structures balanced and strong. **Torque** is a measure of **rotational force** and is essential for machinery such as engines and gearboxes.

### Thermal effects and friction

Friction is the resistance to motion between surfaces, and it is this resistance that generates heat. While friction is beneficial in brakes and clutches, excessive friction causes wear, reduces efficiency and leads to thermal issues.



▲ Figure 1.1 Examples of tensile, compressive and shear stresses

### System principles: input, process, output

Mechanical systems follow the input–process–output principle, where energy or motion input is processed through components (gearboxes, levers) and converted to useful output (rotational motion, lifting force). Efficient processing ensures minimal energy loss.

### Hydraulic and pneumatic systems

Hydraulic systems use liquids and pneumatic systems use compressed air to move things. They are excellent at making forces stronger and controlling movement accurately.

- ▶ Hydraulic systems use incompressible fluid and provide strong, accurate movements. They are used in vehicle lifts, for example.
- ▶ Pneumatic systems use compressed air and are suited to rapid, repetitive tasks with lower force demands such as assembly line tools.

### Activity

Research and compare the advantages and disadvantages of hydraulic and pneumatic systems. Consider cost, speed, maintenance, safety and applications, such as their use in car brakes, factory tools or aircraft controls. Present your findings in a table.

### Work done and efficiency

Work represents energy transferred by force to move an object. Efficiency measures how effectively energy

inputs convert to useful outputs, indicating energy losses such as heat or noise. Regular maintenance and equipment reviews enhance efficiency by ensuring the equipment is operating correctly. It also gives the opportunity to upgrade the equipment, for example, with more energy efficient heaters or motors etc.

### Mechanical advantage (MA)

**Mechanical advantage** quantifies a system's efficiency in multiplying force.

#### Improve your maths

Machines are used to help us do work more easily. But how much easier? MA allows this to be calculated.

Formula:

$$MA = \frac{\text{Load}}{\text{Effort}}$$

Load = the weight or force that you wish to move (newtons, N)

Effort = the force applied to it (newtons, N)

MA = how many times easier the machine makes the work

Worked example:

You are using a pulley to lift a heavy box.

The box has a weight of 500 N (this is your load).

You are pulling with an effort of 125 N.

Step-by-step:

$$MA = \frac{500}{125} = 4$$

In other words, the machine makes it easier for you as the use of a pulley makes your effort **4 times greater** or **4 times easier**.

### Operation of mechanical systems

Mechanical systems use specific parts to control force and movement.

- ▶ Pulleys help change the direction of force and make lifting easier.
- ▶ Levers make force stronger, depending on where the pivot (fulcrum) is.
- ▶ Gearboxes adjust torque and speed for different machinery needs.
- ▶ Torque converters smoothly transfer rotational energy.
- ▶ Clutches control power flow by engaging or disengaging moving parts.

Systems for cooling and lubrication are used to reduce heat, friction and component wear. Along with preventing materials from deteriorating and helping to remove heat, they also guarantee the safe and effective operation of machinery. For example, to keep an engine cool, a technician might check a radiator for leaks or obstructions.

Lubrication keeps moving parts from coming into contact with one another. This prolongs the components' service life and helps avoid overheating and component damage. Numerous moving parts, including bearings, shafts, gears and more, use lubrication systems. For example, high-speed machinery may use synthetic lubricants to reduce wear.

#### Key fact

Correct lubrication reduces frictional losses by up to 20 per cent, significantly increasing machinery efficiency and reliability.

#### Activity

- 1 Select a mechanical system in your workshop and detail its cooling and lubrication methods.
- 2 Explain their importance, the possible consequences of neglect and recommended inspection intervals.

#### Key terms

**Static loading:** a load that is applied slowly and does not change over time, such as a weight held in place.

**Dynamic loading:** a load that changes rapidly in magnitude or direction, such as vibrations or shocks from moving parts.

**Torque:** a twisting or turning force. It is what makes things rotate – such as turning a bolt with a spanner or the force that spins a car wheel. It is measured in newton metres (Nm) and is calculated using the formula: Torque = Force × Perpendicular distance.

**Rotational force:** a force that causes an object to spin or turn around a point or axis.

**Mechanical advantage:** calculates how much easier a tool or machine makes a task.

## Fundamentals of common mechanisms and lifting equipment

### Gears and gear characteristics

Gears transfer rotational motion, adjust force (torque) and control speed in machines. Key parts include:

- ▶ **teeth:** these move power between gears
- ▶ **pitch:** the spacing of the teeth
- ▶ **root:** the base of the tooth where strength matters most
- ▶ **meshing:** how well the teeth line up
- ▶ **backlash:** the small gap that stops gears from jamming but must be kept under control.



▲ Figure 1.2 Cross-section of a car gearbox

Gearboxes are assemblies that contain gear trains and are used to vary speed and torque in machinery (Figure 1.2). They allow smooth and controlled transmission of power between components.

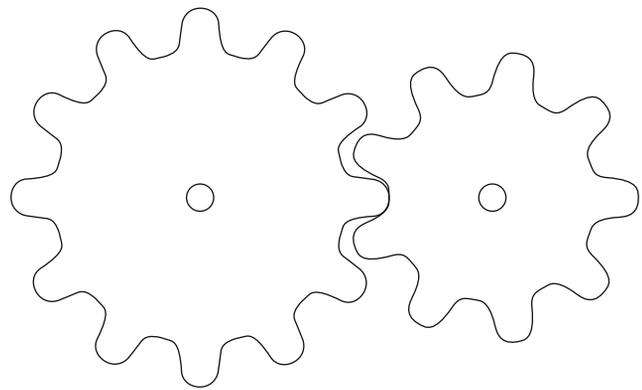
Gear trains transfer torque and speed across shafts and machinery. They are available in various arrangements:

- ▶ A simple gear train consists of two gears directly meshed, which change speed and torque (Figure 1.3).
- ▶ A compound gear train includes multiple gears mounted on shared shafts, which significantly alter speed or torque ratios.
- ▶ Idler gears maintain the rotation direction between driver and driven gears without affecting the overall speed ratio.

#### Activity

Research one piece of equipment or machine that uses an idler gear. Include:

- ▶ the name or type of equipment
- ▶ what the idler gear does
- ▶ why that use is important (e.g. smoother operation, longer lifespan, better alignment).



▲ Figure 1.3 A simple gear train

#### Improve your maths

**Gear ratio** describes the relationship between the speed and torque of two meshing gears. It is a ratio of the number of teeth on the driven (output) gear to the number of teeth on the driver (input) gear.

*Worked example:*

A gear train consists of a driver gear with 20 teeth and a driven gear with 40 teeth. What is the gear ratio, and how many revolutions will the driven gear make if the driver gear completes 10 revolutions?

##### Step 1: Calculate the gear ratio

$$\text{Gear ratio} = \frac{\text{Teeth on driven gear}}{\text{Teeth on driver gear}}$$

$$\text{Gear ratio} = \frac{40}{20} = 2:1$$

##### Step 2: Calculate revolutions of the driven gear

Since the gear ratio is 2:1, the driven gear turns once for every two turns of the driver.

$$\text{Driven gear revolutions} = \frac{\text{Driver gear revolutions}}{\text{Gear ratio}}$$

$$\text{Driven gear revolutions} = \frac{10}{2} = 5 \text{ revolutions}$$

#### Governors

Governors regulate engine speed or mechanical system performance automatically. **Centrifugal governors** adjust speed by varying fuel input or mechanical load, preventing system damage from excessive speeds.

#### Activity

Find one example of a machine or system that still uses a mechanical governor instead of an electronic one. In your answer, include:

- ▶ what the machine is

► why a mechanical governor is still used (think about cost, reliability, environment, simplicity). Be ready to share your example and reasoning with the class.

### Levers

Levers amplify applied forces based on their pivot (fulcrum) position, facilitating tasks requiring significant force with minimal effort. Lever effectiveness depends on the distance between the fulcrum, effort and load. Table 1.1 describes the function of different types of levers.

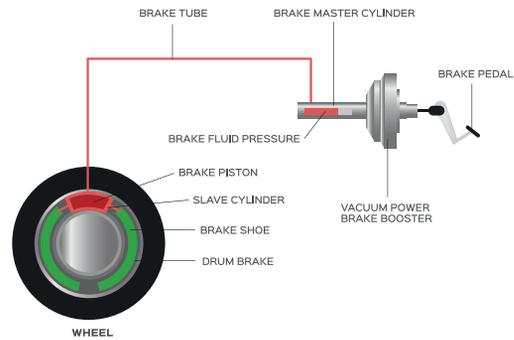
▲ Table 1.1 Function of different types of levers

Lever type	Function	Example
First-class lever	Fulcrum between load and effort	Seesaw, crowbar 
Second-class lever	Load between fulcrum and effort	Wheelbarrow, bottle opener 
Third-class lever	Effort between fulcrum and load	Tweezers, fishing rod 

### Brakes and friction devices

Brakes and friction devices are devices that slow or stop moving parts. Electronic brakes use magnetic fields to regulate the movement of the parts; hydraulic brakes use fluid pressure to apply the required force and mechanical brakes use friction pads to stop parts. **Electromagnetic clutches and brakes** use magnetic fields to engage or stop motion without physical contact, offering smooth and rapid response, which is especially useful in automated systems. Clutches (mechanical, hydraulic and electromagnetic) engage and disengage power transmission in machines, allowing smooth operation and control.

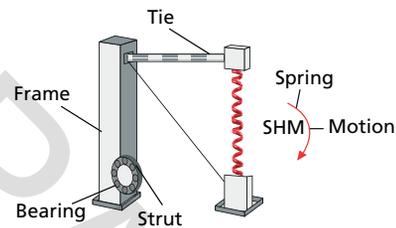
### BRAKE SYSTEM



▲ Figure 1.4 A brake system

### Structural components

Structural components keep systems strong and reliable. Frames give overall support. Within a frame, **ties** resist forces that try to pull parts apart, while **struts** resist forces that push parts together. Bearings help parts move smoothly and reduce friction during motion. Springs store and release energy, helping to control movement. Their motion is called **simple harmonic motion (SHM)**.



▲ Figure 1.5 Ties (tension) and struts (compression) in a mechanical framework

Springs show SHM by moving in a regular pattern around a central point. Technicians use this understanding to spot problems such as excessive vibration or wear in machines.

### Activity

Describe two real-world examples where springs in machinery perform SHM, explaining how motion affects the machinery's performance.

### Lifting equipment and their applications

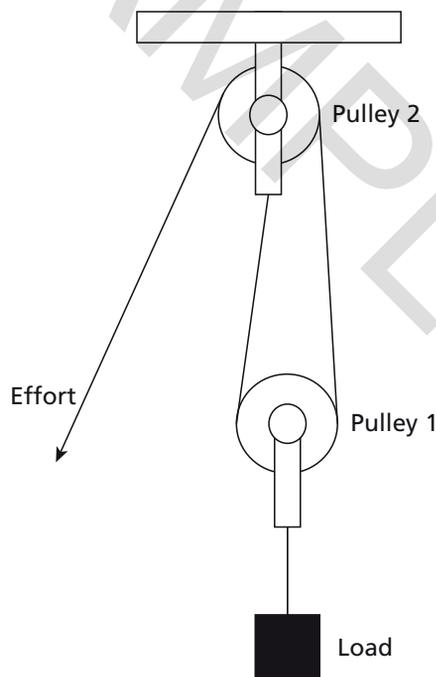
Lifting equipment helps move heavy things safely, which is important for repairs and other jobs. Common tools include pulleys, jacks, cranes and hoists.

Pulleys change the direction of force and make lifting easier. Using more than one pulley together (called a block and tackle) makes it even easier to lift heavy loads.

Jacks raise heavy objects using hydraulic or mechanical force.

- ▶ Hydraulic jacks provide smooth, precise lifting of heavy equipment.
- ▶ Mechanical jacks utilise screws or levers and are ideal for stable, controlled lifting tasks.

Hoists are used to lift things straight up. They can be powered by electricity, air or by hand, and are great for moving things exactly where they need to go.



▲ Figure 1.6 A two-wheel pulley system

Technicians must strictly follow **safe working loads (SWL)** to prevent equipment failure and ensure safety. SWL considers ultimate strength and applies safety factors based on potential risks and environmental conditions.

As well as routine inspections/maintenance of lifting equipment, regular testing and re-certifying by an independent person/company as per Lifting Operations and Lifting Equipment Regulations (LOLER) is required. Inspection includes checking gear conditions, lubrication and structural integrity, including ties and struts.

### Practical task

Choose a lifting tool from your workshop. Carefully check it and write down what you find such as:

- ▶ signs of wear and tear (e.g. frayed slings, worn gears or chains)
- ▶ corrosion or rust on metal parts
- ▶ cracks or deformation in structural parts
- ▶ loose bolts, fittings or connections
- ▶ label visibility (can you read the SWL / Safe Working Load?)
- ▶ test certification: is the inspection/test record attached and up to date?
- ▶ cleanliness and lubrication: is the tool clean and moving parts lubricated where needed?

### Key terms

**Gear ratio:** shows how many times the driver gear turns for one turn of the driven gear.

**Centrifugal governors:** equipment used for automatic regulation of the speed of an engine or other machine. Self-regulating by use of spinning weights moving outwards as speed increases to control the fuel or power, maintaining system stability and preventing damage.

**Electromagnetic clutches and brakes:** devices that use magnetic forces to connect or stop rotating or moving parts without physical contact.

**Ties:** structural elements specifically designed to resist tension forces or pulling.

**Struts:** structural components designed to resist compression forces or pushing.

**Simple harmonic motion (SHM):** a type of smooth, repetitive motion that oscillates back and forth around an equilibrium position.

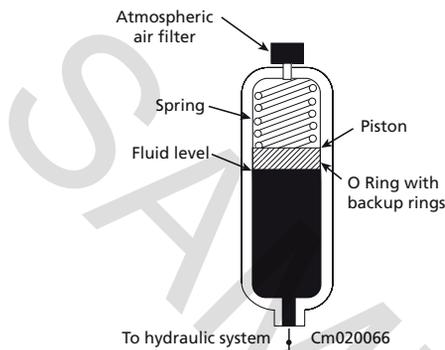
**Safe working loads (SWL):** the maximum load or weight that a tool, lifting device or piece of equipment is designed to handle safely.

## Key principles of energy storage and transfer

### Energy storage characteristics and methods

Energy is sometimes stored for later use when demand is low, or after a machine is switched off. Storage is used when the available supply of energy is finite or variable, such as from solar panels or wind turbines. Heat energy can be stored for later use in a hot liquid

or solid; pressure is stored in the form of compressed liquid or gas, often in **pressure vessels** designed to safely contain high forces. Hydraulic systems use pressurised liquid to create powerful, smooth motion while pneumatic systems use compressed air for fast action, such as in a robotic arm.



▲ Figure 1.7 Cross-section of a hydraulic accumulator

Electricity can be stored in batteries or **capacitors** that give quick bursts of energy, such as when starting a motor. **Flywheels** store energy by spinning and can release it fast when needed, for example, in systems that use braking to save and reuse energy.

Energy can change from one form to another so it can be stored or used efficiently.

- ▶ Generators turn mechanical energy into electricity.
- ▶ Motors turn electricity into movement.
- ▶ Turbines turn heat into motion to make power.
- ▶ Friction changes movement into heat, which may need cooling.

Selecting a storage option depends on the amount of energy required, how quickly it is needed and how much may be lost in transfer. Cost is always a consideration, as is the environmental impact of storage. All these factors help technicians and engineers to determine the best solution for the situation.

### Energy transfer methods

Energy has to flow in a controlled way through a system in order to effectively power a machine; if energy does not transfer correctly, it may be wasted or cause parts of a system to break or fail. Mechanical transfer uses mechanical parts to transfer energy through rotation or **linear motion**; these mechanical parts may be a shaft or a gear, and energy is transferred to other mechanical parts. Electrical

transfer uses wires to conduct electrical energy to a motor, sensor or other electrical part. Heat can transfer in three different ways:

- ▶ **Conduction:** the process of heat transfer through direct contact with a substance. For example, the transfer of heat through metal.
- ▶ **Convection:** the process of heat transfer through a liquid or gas. For example, the flow of heat in a radiator.
- ▶ **Radiation:** the process of heat transfer through infrared waves. For example, the infrared waves produced from a furnace.

Heat exchangers transfer thermal energy into or out of a machine, making it easier to maintain it at the ideal temperature for safe and efficient operation.

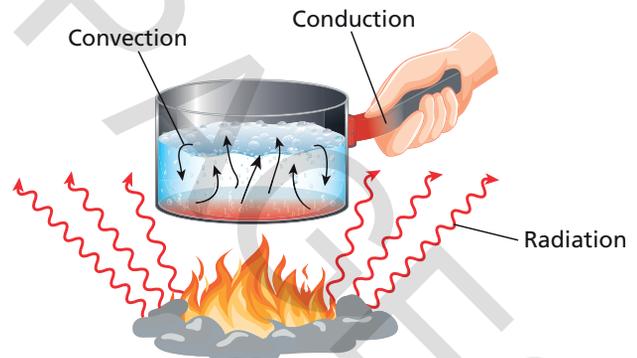
### Key terms

**Pressure vessels:** sealed containers designed to store gases or liquids under high pressure.

**Capacitors:** small electrical components that stores and releases electrical energy quickly.

**Flywheels:** heavy rotating disks that store energy as rotational momentum.

**Linear motion:** Motion that moves in a straight line, either forwards or backwards.



▲ Figure 1.8 Conduction, convection and radiation heat transfer methods

Hydraulics use a pressurised liquid to power a machine in order to move or lift heavy loads and are often found in heavy machinery, such as lifts. Pneumatics use compressed air to provide a quick and clean motion. Pneumatics are used in many tools and robots. Generators convert mechanical energy into electricity, enabling on-site energy generation. The coefficient of friction affects how efficiently parts move and how

much energy is lost to heat, especially in systems involving contact or motion.

### Activity

- 1 Identify two examples of hydraulic or pneumatic systems in your workplace.
- 2 Describe how each system stores and transfers energy to achieve its tasks effectively.

### Applications of energy storage and transfer

Technicians use energy storage and transfer in their everyday work. Emergency or backup power sources such as batteries or capacitors keep equipment working during an outage. In a workshop or on a job site, a hydraulic system may store pressurised fluid to lift a heavy component with ease and control. Flywheels store energy as rotational momentum, smoothing a machine's motion by soaking up excess energy and releasing it in a burst when demand is high, as in regenerative braking.

## Mechanical loadings on structures and components

### Types and effects of mechanical loadings

Mechanical loads affect how parts work and how long they last. Some loads stay the same (static), while others change with movement (dynamic). The direction of the force also makes a difference.

#### Tension loading

Tension occurs when something is pulled apart, causing it to stretch. This happens in things such as bridge cables, crane ropes or bolts holding parts together. If the pull is too much, the material can stretch too far, become thinner, or even break. If this is not spotted early, it can cause the part to fail.

#### Compression loading

Compression loading pushes materials together, shortening their length. Examples include columns supporting weight or machine frames bearing vertical loads. Excessive compression can result in **buckling** or **crushing**, compromising structural stability.

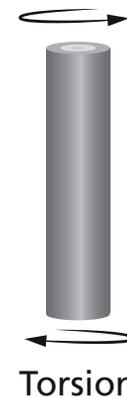
#### Shear loading

Shear loading applies parallel but opposite forces, sliding material layers past each other. Typical applications include bolts experiencing lateral forces or riveted connections. Excessive shear can lead to **component displacement** or **shearing failure**, especially at joints or connection points.

### Bending and torsion

Bending happens when a part is affected by both pulling and pushing forces at the same time. This can make it bend or curve. It is common in beams holding weight, shafts with pulleys and moving linkages. If bending happens too often or is too strong, it can lead to cracks or even cause the part to fail.

Torsion involves twisting forces acting on rotating shafts or components. Common examples include drive shafts, axles and rotating mechanical components. If torsion is too strong, it can bend or break parts. This can make the system work poorly or even stop it from working altogether.



▲ Figure 1.9 Torsional forces acting on a rotating shaft

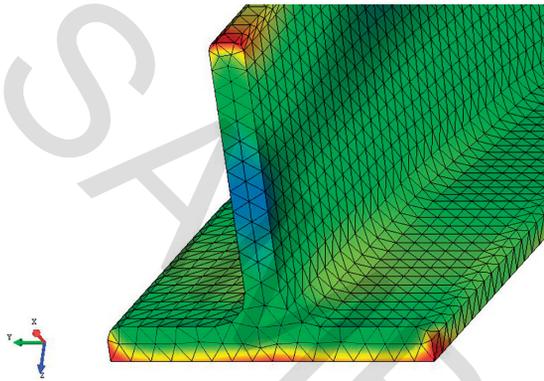
Dynamic loads are more challenging to calculate, whereas static loads are simple to measure and forecast. Increased wear on parts can also be caused by dynamic forces such as vibration or **cyclic motion**.

### Fatigue and associated conditions

The weakening of a part over time due to repeated dynamic loading is called fatigue. This may cause the part to crack or fail suddenly and unexpectedly. Fatigue is caused by several factors, including the magnitude of the load, how frequently it is applied and environmental conditions such as temperature cycling, exposure to corrosive substances and vibration. These environmental factors can accelerate material degradation and increase the risk of failure. To reduce fatigue, technicians can use strong materials, frequently check for damage and design parts to spread out stress.

To reduce fatigue, technicians can use stronger materials, frequently inspect for cracks or wear and design components to distribute stress more evenly.

To support this, Finite Element Analysis (FEA) is commonly used in engineering to simulate stress concentrations to predict potential fatigue areas. Based on the outcome, modifications can then be made to either change to an alternative material or the redesign of components, such as adding or increasing a radius instead of a sharp corner.



▲ Figure 1.10 Finite Element Analysis

### Torque

Torque is the rotational equivalent of force, often involved in torsion. It causes parts to twist and is crucial in systems such as engines, gearboxes and any rotating shafts.

#### Key terms

**Buckling:** when a part bends or collapses suddenly under pressure.

**Crushing:** a type of failure where a material is squashed or flattened under pressure.

**Component displacement:** when a part moves out of its correct position because of force or damage.

**Shearing failure:** a break that occurs when opposite forces slide across a material, causing it to split along a line or plane.

**Cyclic motion:** movement that repeats over and over again, such as a turning shaft or vibrating component.

## Construction and operation of power transmission systems

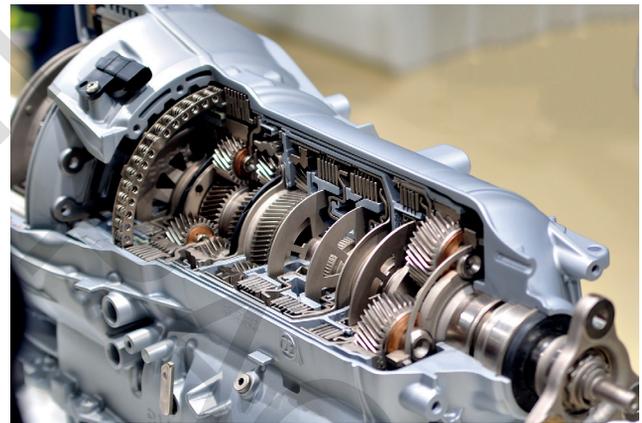
### Gears and gearboxes

Gears transmit power, change speed and adjust rotational speeds and torque in machines. There are

a number of different types of gears used in **power transmission** systems:

- ▶ Spur gears are efficient and have straight teeth.
- ▶ Helical gears have angled teeth and run smoothly and quietly.
- ▶ Bevel gears transmit at angles, typically 90 degrees.
- ▶ Worm gears are great for high torque and can be used as brakes.
- ▶ Rack and pinion transform rotary motion to linear motion and are often used in steering mechanisms.
- ▶ Gear tooth surface treatments such as shot peening, case hardening and electroless nickel plating improve wear resistance, reduce fatigue and enhance overall gear performance.

Gearboxes use groups of gears to transmit and transform speed/torque between shafts. Compound gear trains increase the ratio, using multiple gears on the same shafts. Idler gears maintain the same directionality without affecting speed.



▲ Figure 1.11 Typical gearbox showing gear types, gear trains and idler gears

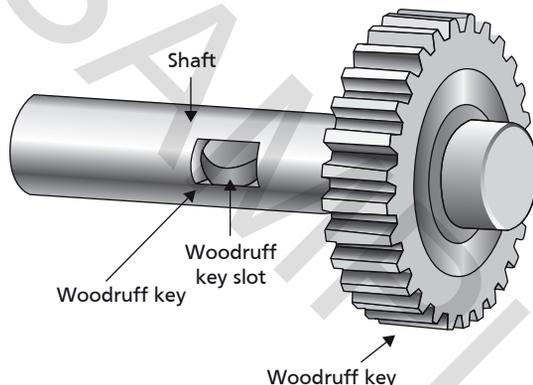
Key characteristics affecting gear efficiency include the following:

- ▶ **Material choice:** hardened steel gears offer strength but require precision lubrication.
- ▶ **Gear geometry:** tooth profile accuracy directly influences smoothness, noise level and efficiency.
- ▶ **Alignment:** correct gear alignment and precise backlash control reduce friction losses and wear.
- ▶ **Surface treatment:** techniques such as shot peening, case hardening and electroless nickel plating improve gear performance by increasing wear resistance, reducing surface fatigue and enhancing corrosion protection.

## Shafts, woodruff keys, cams and linkages

Shafts transmit rotational energy between system components. Correct shaft design ensures efficient power transfer and minimises bending and torsional stress.

**Woodruff keys** secure rotating components such as pulleys or gears to shafts, preventing slippage under load. The Woodruff key sits in a half-moon-shaped slot on the shaft and fits into a matching slot in the gear or pulley. This locks them together so they turn as one unit.



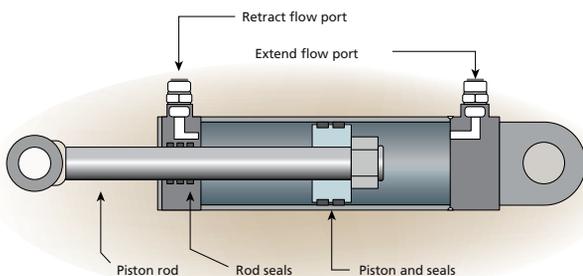
▲ Figure 1.12 Shaft with Woodruff key slot

**Cams** convert rotary input into precise linear or reciprocating output, which is useful in valves, automotive engines and automated machinery.

Linkages connect mechanical components, translating motion precisely and reliably from input to output.

## Fluid power systems and rams

**Fluid power** is the use of pressurised liquids or gases to effect mechanical motion. Hydraulic rams are oil driven and therefore create a very high, smooth force which is useful in powerful lifting and pressing applications. Pneumatic rams are air driven and hence are used for fast repeated motion, as in robots and factory automation equipment.

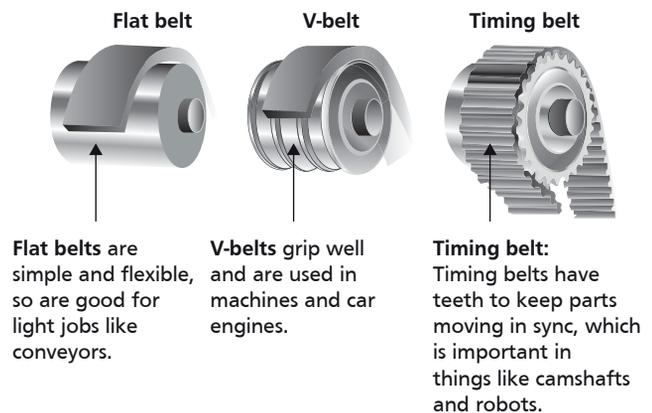


▲ Figure 1.13 Operation of a hydraulic ram, detailing fluid flow, piston movement and force generation

## Types of drive belts and applications

Drive belts move power between spinning parts.

- ▶ Flat belts are simple and flexible, so are good for light jobs such as conveyors.
- ▶ V-belts grip well and are used in machines and car engines.
- ▶ Timing belts have teeth to keep parts moving in sync, which is important in things such as camshafts and robots.



▲ Figure 1.14 Different types of drive belts

## Lubrication systems

- ▶ Manual lubrication is applied by hand, usually using a grease gun, and is often used for slow-moving, easily accessible parts.
- ▶ Gravity feed lubrication is where oil flows through a pipe by the force of gravity and is found in many older machines.
- ▶ Grease is a semi-solid lubricant made by mixing oil with a thickening agent (such as a soap). It stays in place and provides long-lasting lubrication, particularly in areas where oil would leak out or where relubrication is infrequent.
- ▶ A forced feed lubrication system is where a pump is used to circulate oil to the necessary components. This is often used in engines.
- ▶ Splash lubrication occurs when moving components splash oil around the interior and is often used in small engines and gearboxes.

### Activity

List three places where grease might be used instead of oil, and explain why grease is preferred in those situations.

▲ Table 1.2 Advantages and limitations of different types of lubrication

Type	Advantages	Limitations
Manual lubrication	Low-cost, straightforward	Requires regular manual intervention
Gravity feed	Simple, reliable, minimal maintenance	Limited to low-viscosity lubricants
Forced lubrication	Precise control, suitable for high speeds	Higher initial cost and complexity
Splash lubrication	Low-cost, self-contained	Less control, unsuitable for high speeds

### Key terms

**Power transmission:** moving mechanical energy within a machine.

**Woodruff key:** a half-moon metal piece that locks parts onto a shaft.

**Cams:** parts that turn rotation into back-and-forth movement.

**Fluid power:** using pressurised fluids or gases to move things.

## Systems, circuits and components of electrical installations, including properties, failure modes and protection methods

### Single-phase vs three-phase systems

Electrical circuits distribute electrical energy to components and devices. Electrical systems are commonly categorised as single-phase or three-phase, and each is suited to particular power requirements:

- ▶ Single-phase is one live wire and is most commonly used in residential or small commercial applications (for example, lights, heaters, small motors).
- ▶ Three-phase runs three live wires and balances the load, providing a constant supply of power for larger motors used in industrial applications. It allows equipment to operate more smoothly with less wear. A three-phase motor's rotation direction can be easily changed by swapping over any two of the three live wires.

## Components and operational characteristics

Each component's characteristics determine its suitability for specific applications, ensuring electrical systems operate efficiently and reliably.

- ▶ **Resistors:** control electrical current by providing a specific resistance value, protecting circuits and devices.
- ▶ **Capacitors:** temporarily store electrical energy, smoothing voltage fluctuations and providing rapid power surges in motors and power supplies. It is similar to the function of a hydraulic accumulator.
- ▶ **Diodes:** allow current flow in one direction only, converting AC to DC within **rectifier circuits**.
- ▶ **Transformers:** alter voltage and current levels without changing frequency and are essential for stepping voltage up or down in power transmission.
- ▶ **Motors:** convert electrical energy into mechanical motion, powering machinery, conveyors or pumps.

## Properties of electrical systems and circuits

Technicians must understand fundamental electrical properties affecting circuit and component operation. These are:

- ▶ **voltage (V):** electrical potential difference driving current through circuits
- ▶ **current (I):** flow rate of electrical charge measured in amperes (A)
- ▶ **resistance (R):** opposition to direct current (DC) flow, measured in ohms ( $\Omega$ )
- ▶ **impedance (Z):** total opposition (resistance plus **reactance**) to alternating current (AC), impacting current flow and circuit efficiency
- ▶ **power (P):** rate at which electrical energy is converted, measured in watts (W).

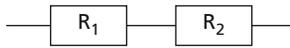
Common circuit configurations include:

- ▶ **series circuits:** components are arranged sequentially; the current flows through all components in a single path
- ▶ **parallel circuits:** components are connected across the same voltage source independently, providing consistent voltage across each component.

## Common failure modes

Electrical system failures commonly result from:

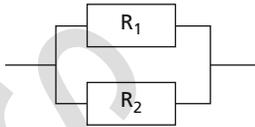
- ▶ **equipment failure:** components degrade due to overheating, poor maintenance or manufacturing defects
- ▶ **human error:** incorrect wiring, overloading circuits, inadequate maintenance procedures



**Resistors in series**

The total resistance of resistors connected in path calculated using the following formula:

$$(1/R_{tot}) = (1/R_1) + (1/R_2) + \dots$$



**Resistors in parallel**

- ▲ **Figure 1.15 Comparison diagram of series versus parallel circuits**
- ▶ **environmental conditions:** moisture, dust, temperature extremes or chemical exposure leading to corrosion or insulation breakdown.

**Protection methods and their importance**

To keep systems safe and avoid injury, technicians use a few key methods. **Isolation** means switching off the power completely so repairs can be done safely. Earthing helps by giving fault currents a safe path to the ground, which protects both people and equipment. Fuses melt and break the circuit if too much current flows, while circuit breakers do a similar job but can be reset once the fault is sorted.

**Fusible links**, often used in vehicles or high-heat environments, are wires designed to melt under excess heat, cutting off power and preventing damage or fire.

Choosing the correct protection method depends on factors including circuit load, environmental conditions and system voltage. Effective protection ensures minimal damage during faults, reduces fire risk and maintains operational reliability.

**Key terms**

**Rectifier circuits:** change alternating current (AC) into direct current (DC).

**Reactance:** the resistance to alternating current (AC) caused by capacitors or inductors in a circuit.

**Isolation:** the process of disconnecting a system (e.g. electrical, hydraulic) to ensure safety during inspection or repair.

**Fusible links:** safety devices that melt when they get too hot, stopping electricity or triggering a safety action such as opening a fire damper.

**Purpose and application of drive devices**

**Motors**

Motors power countless devices, machines and vehicles. They come in various types, each suited to specific applications. AC motors are commonly used for industrial machinery, pumps, compressors and conveyors due to their reliability and simple maintenance. DC motors are often used in precision applications such as robotics, automotive starter motors and variable-speed applications because of their controllable speed and torque characteristics.

▲ **Table 1.3 Advantages and limitations of motors**

Type	Advantages	Limitations
AC motors	Reliable, cost-effective, low maintenance	Limited speed control precision
Brushed DC motors	Simple design, precise control, low cost	Brush wear leads to higher maintenance
Brushless DC motors	Efficient, low maintenance, long lifespan	Requires electronic controller

**Belts**

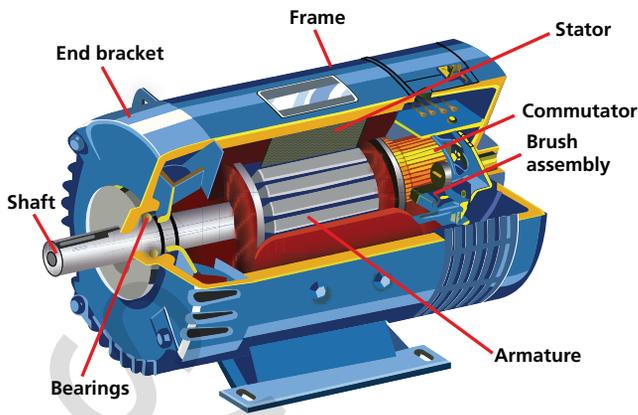
Belts are used to transmit rotational motion from one shaft to another when the shafts are separated by a distance. Belt drive systems use friction to transmit torque. V-belts are widely used in motor engines and other machinery because of the increased contact surface area of the V-belt. Flat belts are a simpler and less expensive option used in conveyors, farm equipment and some machine tools. Timing belts are used when precise positioning is required, such as in robotics and vehicles, because of the positive location of the toothed belt which prevents slipping.

**Activity**

Research the differences between brushed and brushless DC motors. Find out how each one works and a real-life example of where each motor might be used.

**Shafts**

Shafts are common in engines, pumps, conveyors and gearboxes, helping to move power between



▲ Figure 1.16 Internal components of an electric motor, indicating stator, rotor and bearings

▲ Table 1.4 Advantages and limitations of belts

Belt type	Advantages	Limitations
V-belts	High friction, reliable torque transmission	Require careful tensioning/alignment
Flat belts	Simple, economical, easily replaceable	Limited torque capacity, slippage risk
Timing belts	Precise control, no slippage	Sensitive to misalignment or wear

components. **Shaft couplings** connect shafts together and work well at high speeds and torque. However, they must be accurately aligned to avoid causing vibration and stress, which can shorten the life of a system.

**Key fact**

Correct lubrication can significantly extend gearbox lifespan, reducing wear and friction by up to 40 per cent.

**Gearboxes**

Gearboxes help match the motor’s power to the machinery’s needs, such as in cranes, conveyors and vehicles. Gearboxes are used in many types of machinery because they give good control. However, they need regular care, such as oiling and alignment checks, to keep working correctly. They can also be heavy, costly and tricky to install.



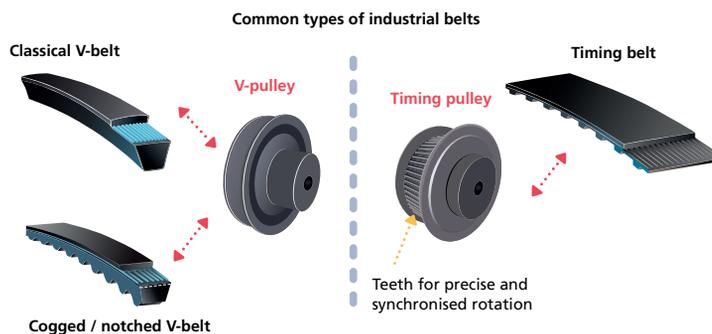
▲ Figure 1.18 Cross-sectional view of a gearbox showing internal gears and shafts

**Clutches**

Clutches enable controlled engagement and disengagement of drive power, which is critical for safely connecting and disconnecting rotating machinery components. They allow the smooth start-up of rotating machinery and disconnect power transmission during maintenance or emergencies.

Clutches are essential in automotive transmissions, industrial presses and heavy machinery. Types of clutches include the following:

- ▶ **Mechanical:** uses friction plates and is common in vehicles and mechanical equipment.



▲ Figure 1.17 Different belt configurations (V-belt, flat belt, timing belt)

▲ **Table 1.5 Advantages and limitations of clutches**

Clutch type	Advantages	Limitations
Mechanical clutch	Simple, reliable, inexpensive, easy to maintain	Wears out over time due to friction of moving parts
Hydraulic clutch	Smooth and precise, uses fluid pressure not mechanical linkage, easier on the engine, less prone to slip or jam	More complex, components such as cylinders, hoses and seals can leak or fail
Electromagnetic clutch	Activated by electric current, fast and precise <b>engagement and disengagement mechanism</b>	Requires a power source and control system to operate, more expensive

- ▶ **Hydraulic:** uses fluid to control engagement and is popular in automated machinery.
- ▶ **Electromagnetic:** an electrically-controlled magnetic force engages plates; this type of clutch is used in precise automation and conveyor systems.

### Improve your English

Write a short report explaining two practical examples of energy storage and transfer methods used within your workplace, clearly identifying the energy forms involved and their applications.

### Key terms

**Shaft couplings:** devices used to connect two shafts together so that power (such as rotation or torque) can be transferred from one to the other.

**Engagement and disengagement mechanism:** how a machine connects or disconnects rotating parts, usually with a clutch.

## Sensing and measurement techniques

### Sensing equipment

Sensing devices make sure that equipment functions optimally by converting physical variations such as heat, motion or pressure into electrical signals that a system can monitor. Sensors are used to monitor conditions, detect faults and maintain overall system health. They

are commonly known as transducers and convert an input into a different output. The sensors can be linked to not only live monitoring systems but also to simple, highly visible flashing beacons located on the machine. The operator can then quickly see that a parameter has gone out of specified tolerances.

- ▶ Temperature sensors such as real-time digital simulator (RTDS) and thermocouples are frequently used to track a component's temperature. These sensors monitor heat to prevent overheating or cooling.
- ▶ Vibration sensors identify unusual motion in gearboxes, motors, etc. A common early sign of equipment wear is vibration.
- ▶ Dimensional sensors are used to track the separation between two components or points. Parts can be correctly aligned by monitoring the clearance.
- ▶ Speed/position sensors monitor the location and speed of an object. In many systems, speed is frequently a crucial factor.
- ▶ Pressure sensors determine the force present in a gas or fluid. Low pressure may be a sign of pressure loss or leaks.
- ▶ Flow sensors track the flow of liquids within a system. This might be a sign that lubrication or cooling is failing.

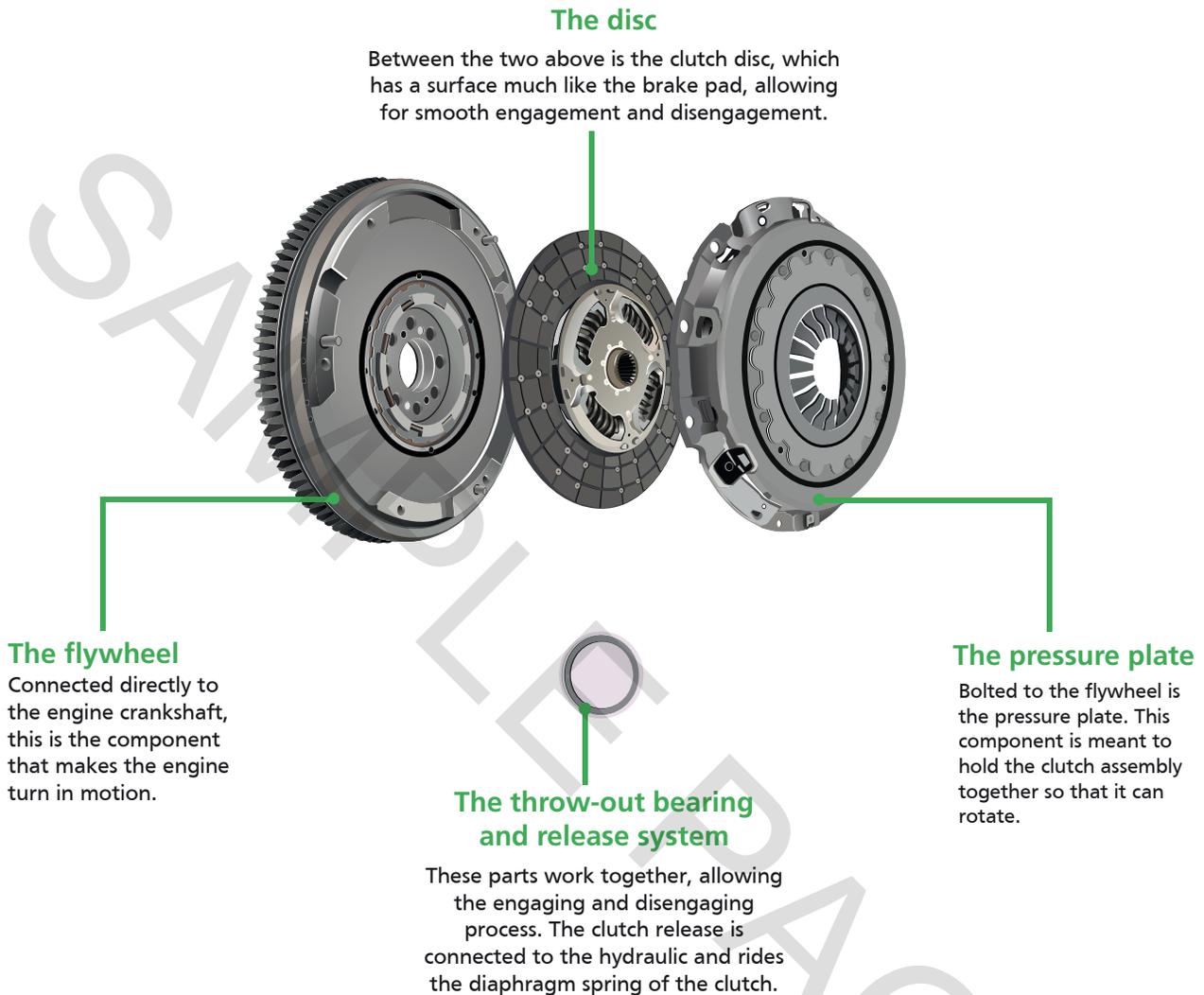
### Measurement techniques and instruments

Using the correct measurement instrument and technique is essential in engineering to ensure that parts meet design specifications and function correctly when assembled. If the wrong tool is used, it can lead to incorrect fits, poor performance or part failure. For example, a block of steel needs to be measured. It is 25 mm long with a tolerance of  $\pm 2$  mm. For this, a steel rule could be used as the allowable tolerance is high and well within the capability of a steel rule. If the steel block dimension was 25mm  $\pm 0.2$ , then the steel rule would not be sufficiently accurate and a vernier caliper would be used.

Precision measurement helps to ensure components meet design standards. Steel rules, dividers and engineer's squares are used for basic measuring and marking. Vernier callipers (internal, external and digital) and micrometers (internal, external and depth) provide precise measurements for part sizes, diameters and depths.

Feeler gauges check small clearances such as valve gaps. Pressure gauges monitor system pressure, and slip gauges help calibrate tools. Thread and plug gauges confirm thread sizes for good fitting, while height

## In any manual transmission car, the clutch is built up of five major components.



▲ Figure 1.19 The internal operation of a mechanical friction clutch



▲ Figure 1.20 A thermocouple controlling a heater

gauges measure vertical dimensions or ensure accurate marking and alignment.

For higher accuracy, **dial test indicators (DTIs)** spot small errors in alignment or surface shape. Co-ordinate measuring machines (CMMs) check complex parts by recording exact point positions. Laser levels and centre finders help with fast, accurate setup, especially on larger builds. **Thermocouples** monitor temperature changes, especially in high-heat environments. **Comparison plates** assist in visual inspection by comparing a part's surface finish or profile to a known standard.

For more accurate and consistent measurement, a machine called a talysurf can be used. It uses a stylus

and electronic sensors to trace and measure the surface profile, giving a precise digital readout of roughness and finish, removing ambiguity.

### Activity

Research what a talysurf surface measuring machine does. Find out:

- ▶ what parts it measures
- ▶ how it works (basic principle)
- ▶ what industries use it
- ▶ why it gives more reliable results than manual comparison plates.

Present your findings as a short paragraph or labelled diagram.



▲ Figure 1.21 A co-ordinate measuring machine (CMM) scanning a mechanical component

▲ Table 1.6 Advantages and limitations of measuring instruments/sensors

Instrument/sensor	Advantages	Limitations
Thermocouples	High temperature range, durable	Lower accuracy compared to RTDs
RTDs	High accuracy, stability	Higher cost, sensitive to vibration
Vibration sensors	Early <b>fault detection</b> , predictive maintenance	Can give false alarms if incorrectly placed
Vernier callipers	Versatile, precise, easy to use	Requires careful <b>calibration</b>
Micrometers	Very high precision, ideal for tight tolerances	Limited measurement range
Dial test indicators	High sensitivity, ideal for alignment checks	Fragile; sensitive to handling errors
CMMs	Exceptional precision, measures complex shapes	Expensive, requires skilled operators

### Practical task

- ▶ Perform precision measurements on a component in your workshop using at least three instruments.
- ▶ Record your measurements, note any discrepancies and propose corrective actions to maintain component specifications.

### Key terms

**Dial test indicators (DTIs):** precision measuring tools used to check small movements, alignment or surface variation in machine parts.

**Thermocouples:** temperature sensors made from two different metals joined at one end. When the joined end is heated or cooled, it produces a small voltage that indicates the temperature.

**Comparison plates:** reference surfaces or sample blocks used to compare surface finishes, flatness or texture visually or by touch.

**Fault detection:** the process of identifying when a system or component is operating outside normal or expected conditions.

**Calibration:** adjusting equipment so it gives accurate readings.

## Component identification and referencing systems

### Purposes and applications of numbering and referencing systems

Numbering and referencing systems provide a means of labelling and tracking components. Such systems make it faster to find the correct part when carrying out maintenance activities, therefore reducing down time and the risk of error. They also assist with reference for replacements, stock control and warranty/fault investigations. Numbering and referencing systems will often comprise classification number, specification data, part or product identification code and manufacturer reference. This ensures that everyone involved in the maintenance or production activity has the same accurate information.

### Types of component identification

Parts are commonly identified by special identification numbers or codes. They may indicate the component's size, material, purpose or manufacturer. This allows a technician to be certain they have the correct part and

enables them to more easily find suitable replacements. These identification methods may also be used along with technical data and manufacturer specifications to confirm suitability and compatibility with the system. Common component identification methods include the following:

- ▶ **Proof markings (also known as C of C or Certificate of Conformance):** show that the part meets special test standards.
- ▶ **Labels:** may include operating information such as voltage, pressure or direction of fittings.
- ▶ **Colour coding:** may indicate safety and function (e.g. red = danger, green = earth/safe).

### Technical data and manufacturer data sheets

Manufacturer data sheets give important technical details about a part. These usually include information about its size, tolerance limits, how it should be installed and maintained, and how it needs to be handled safely. They also show what standards the part meets. Checking these sheets regularly helps make sure the right parts are chosen and used correctly. Using the wrong part, or installing it the wrong way, can cause faults or safety risks. Data sheets often come with schematic diagrams to show how the part should be connected in the system.

### Bill of materials

A **bill of materials (BOM)** lists all the materials, components and sub-assemblies needed for a particular job. It usually includes:

- ▶ part numbers and identification codes
- ▶ quantities and descriptions
- ▶ specification data
- ▶ supplier or manufacturer information.

A BOM is often cross-referenced with technical data sheets and safety specifications to support correct part selection, storage and installation.

### Classification, numbering and referencing systems

Mechanical engineering standards often include classification and referencing schemes. These enable precise identification of component specifications and requirements across global supply chains.

- ▶ Classification numbers indicate component type, size or specification category.
- ▶ Reference codes provide a systematic method to refer to standards within documentation and communication clearly.

### Interpreting BS, EN and ISO standards

**British (BS), European (EN) and International (ISO) Standards** set shared rules to keep engineering consistent, safe and of high quality. Standards help make sure parts are reliable, safe to use and work well with others, even if they come from different manufacturers. Common examples include:

- ▶ BS 8888 (for technical drawings and specifications)
- ▶ ISO 9001 (for managing quality across processes)
- ▶ EN ISO 12100 (for machine safety and risk reduction).

#### Improve your English

Write a brief technical description explaining the importance of correctly using BOM documentation in your workplace. Clearly outline three potential consequences of inaccuracies in component identification.

#### Key terms

**Proof markings:** marks that show a part has been tested or approved.

**Bill of materials (BOM):** a detailed list of all the raw materials, components, assemblies and parts, along with their quantities, needed to manufacture a finished product or assembly.

**British (BS), European (EN) and International (ISO) Standards:** rules from UK, European and international bodies to ensure safety and quality.

Perform relevant maintenance, installation, servicing and repair of mechanical plant and equipment, using appropriate techniques and procedures to achieve the required quality outcomes and solutions

### Hand tools, power tools and equipment

#### Hand tools

Spanners and sockets (including **ratchet** types, extension bars and universal joints) are ideal for tightening fasteners, even in tight spaces, but using the

wrong size can damage them. Screwdrivers and Torx are ideal for screw work but need the correct match to avoid damage. Pry bars, punches and chisels help with levering or cutting but need care to avoid injury. Hacksaws, files and side cutters shape and cut metal but struggle with harder or large materials. Pliers, mole grips and bolt cutters are strong for gripping and cutting but may deform delicate parts. Hammers, mallets, **crimpers**, taps and dies help shape, join or thread, but need skill to avoid damaging work or tools.

### Power tools

Jigsaws and reciprocating saws cut through metal, plastic or wood quickly but are not suitable for detailed work. Angle grinders are great for cutting, grinding or polishing metal but require the use of personal protective equipment (PPE) because of sparks. Drills and multitools can handle drilling, fastening and more when fitted with the correct attachments; using the wrong ones or an incorrect speed can cause damage.

### Equipment

Lifts, jacks and hoists help raise heavy machinery safely. They give access beneath equipment but must never be overloaded and need to be regularly checked.

**Metal inert gas (MIG)** and **metal active gas (MAG) welding** are used to join metal parts. MIG works well on thin metals such as aluminium and gives clean results. MAG suits thicker steel and is stronger for industrial work.

▲ Table 1.7 Comparison of MIG and MAG welding

Aspect	MIG welding	MAG welding
Gas type	Inert (argon, helium)	Active (carbon dioxide, argon-carbon dioxide mixtures)
Application	Stainless steel, aluminium, thin metals	Steel structures, thicker metals
Spatter level	Low	Moderate to high
Penetration depth	Moderate	High

Before using any tools, technicians should always make sure they are in good condition. This entails making sure that parts are not worn out or damaged, handles are not cracked and cables are not frayed. To make sure it is rated for the intended load and in good condition, any lifting equipment should also be inspected. Tools should also undergo routine

maintenance, such as regular testing of lifting and welding equipment, power tool inspections, and hand tool cleaning and oiling. When a technician uses tools without the correct training or authorisation, they run the risk of being injured, damaging the equipment and breaking safety rules. Technicians should always operate within predetermined parameters and adhere to the manufacturer's instructions. A technician should ask for advice if they are unclear about a task.

### Key terms

**Ratchet:** allows movement in one direction only.

**Crimpers:** compress connectors onto wires.

**Metal inert gas (MIG) welding:** welding that uses a wire electrode and an inert gas (such as argon) to protect the weld. Good for thin metals and bodywork.

**Metal active gas (MAG) welding:** welding that uses a wire electrode and an active gas (such as CO<sub>2</sub> or gas mixes) that affects the weld. Good for thicker steels.

## Effects of environmental conditions on materials, components, wiring and equipment

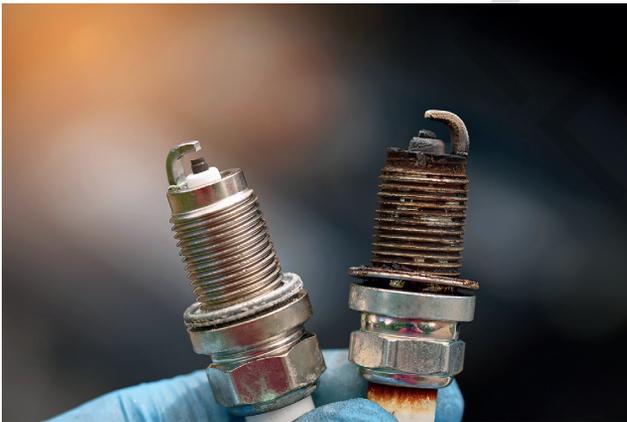
The operational environment which equipment is exposed to can have the following influences on its performance and life:

- ▶ **Humidity/water:** **corrosion**, electrical faults, short-circuits and insulation breakdown can result from exposure to water or humidity. Ingress of humidity/water on internal parts can occur. Also egress of oil and other protective fluids can result in leakages and loss of system balancing.
- ▶ **Temperature:** cracking and brittleness may occur due to changes in temperature and mechanical faults, or failure modes may result over time.
- ▶ **Thermal heating:** this will accelerate the rate of lubricant breakdown which in turn will increase the rate of wear and tear of moving parts as well as the protective lubrication of components and the resulting chance of blockages and error.
- ▶ **Dust, dirt and other debris:** this can accumulate and reduce airflow, cause overheating, false readings or sensor malfunction.
- ▶ **Ultraviolet radiation:** this can damage plastics and rubbers over time when exposed to normal sunlight.



▲ Figure 1.22 Cracking due to exposure to UV radiation

- ▶ **Chemicals:** these can erode plastic coatings and lead to corrosion, as well as a reduction in cleanliness, weakening of metal components and clarity of indicators and sight glasses.



▲ Figure 1.23 A new spark plug, next to a corroded one

Materials are the first line of defence against the environment. Key attributes of suitable materials include:

- ▶ **Corrosion resistance:** the material is resistant to moisture and chemicals.
- ▶ **Thermal stability:** the material maintains its strength over a range of temperatures.
- ▶ **Chemical compatibility:** the material is less likely to soften, crack or otherwise damage the surface.
- ▶ **Mechanical durability:** the material ensures the part can withstand stress, impact and fatigue.

### Practical task

- ▶ Inspect equipment in your workplace exposed to harsh environmental conditions (humidity, heat, chemicals).
  - ▶ Document any visible signs of corrosion, cracks, **ingress** or unusual operational behaviour.
  - ▶ Suggest appropriate maintenance actions to prevent further deterioration.
- Before carrying out this task, ensure you have received correct safety training and permission.
- ▶ Always wear appropriate PPE (e.g. gloves, eye protection, respiratory protection if needed).
  - ▶ Do not touch or interfere with equipment that is live, pressurised, or hazardous without supervision.
  - ▶ Report unsafe conditions immediately to a supervisor or qualified technician.

Cleaning equipment on a routine basis will help to remove the build-up of dirt, debris, dust and pollution, which can cause airflow restriction, overheating or contamination and loss of accuracy. Desiccation and dehumidification remove moisture to inhibit corrosion and electrical short circuits. Lubrication can reduce friction between moving parts and protect against heat damage and corrosion, prolonging the service life of components. Temperature and pressure cycling may lead to material and seal deformation, so monitoring and routine checks can prevent faults due to thermal expansion, cracking and leaks. Corrosion-resistant coatings provide additional protection against harsh chemicals, UV radiation and oxidation. The oxidised layer on the surface of materials such as copper and aluminium actually prevents further corrosion as the thin oxide layer prevents further ingress of moisture and oxygen. This is why these materials are termed as corrosion resistant.



▲ Figure 1.24 Driveshaft gaiters retain grease and prevent dirt and water ingress

### Risks of ignoring environmental conditions

Failure to manage environmental conditions can lead to serious consequences, including:

- ▶ equipment downtime due to unexpected failures
- ▶ increased maintenance and repair costs
- ▶ potential safety risks to personnel due to sudden equipment failures
- ▶ reduced equipment life and compromised operational efficiency.

#### Key terms

**Corrosion:** metal damage caused by the presence of oxygen, moisture or chemicals.

**Ingress:** unwanted entry of water, dust or chemicals into equipment.

### CAD/CAM systems and software

#### Application and purpose of CAD/CAM systems

**Computer-aided design (CAD)** and **computer-aided manufacturing (CAM)** programmes link design and manufacturing, improving accuracy, speed and consistency in production and maintenance.

CAD is used to create 2D drawings and 3D models with accurate visual, geometrical and sometimes functional details. CAM converts these CAD files into machine instructions for processes such as milling, turning or 3D printing. They can also be used as collaborative tools, allowing shared access and editing of projects. Their main features and functions include:

- ▶ **solid modelling:** viewing and working with 3D models from any angle
- ▶ **geometry manipulation:** changing shapes, sizes and features quickly
- ▶ **component drawing:** producing detailed part and assembly drawings with dimensions, notes and material details
- ▶ **integration with CAM:** generating instructions for **CNC machines** or other automated tools
- ▶ **detailing:** adding dimensions, annotations and specifications for manufacturing.
- ▶ **revision control:** CAD systems support version tracking, making it easier to manage design updates and avoid using outdated files, therefore improving safety and reducing errors.

#### Activity

Why does using CAD make revision control more robust than using paper-based or manual drawing systems? Discuss with your classmates.

These tools help engineers design, modify and produce components efficiently while maintaining accuracy.

#### Programming methods

Effective programming methods within CAM systems allow efficient, accurate and repeatable manufacturing processes. Manual programming requires technicians to input precise machining instructions directly into machine controls using G-codes and M-codes (numerical control languages). This type of manual programming is ideal for simple machining tasks and low volume runs and provides great precision and direct control.

**Conversational programming** simplifies instruction inputs through interactive prompts. The CAM system translates these inputs into machine instructions, significantly reducing programming time and complexity, making it ideal for mid-range complexity tasks or less experienced operators.

#### Data transfer and collaboration

Smooth data transfer between CAD and CAM helps move designs easily from idea to production. Using shared file types such as IGES (Initial Graphics Exchange Specification) or STEP (Standard for the Exchange of Product Data) keeps shapes accurate. Cloud tools enable teams in different locations to work together, making communication faster.

#### Manufacturing simulation and operations

**Manufacturing simulation** in CAM software allows engineers to test machining processes on-screen before making anything. It helps identify problems such as tool collisions, improves cutting paths to save time and material and gives better estimates for how long jobs will take. The process starts by importing a CAD model, setting up tools and steps, running the simulation, and then adjusting it to improve performance.

#### Practical task

- ▶ Use CAD software to design a basic mechanical part or a small assembly.

- ▶ Bring your design into CAM software and choose the correct machining steps (such as drilling or cutting).
- ▶ Run a virtual simulation to see how the part or assembly would be made. Look out for any problems, such as tools crashing or the machine taking a long route.
- ▶ Write down what went wrong and suggest how you could make the process better.

### Key terms

**Computer-aided design (CAD):** software for making detailed drawings and 3D models.

**Computer-aided manufacturing (CAM):** software that controls machines using CAD data.

**CNC machines:** automated tools that use coded instructions from a computer to cut, drill, mill or shape materials such as metal or plastic.

**Conversational programming:** a user-friendly way to program CNC machines using simple prompts and menus, instead of writing full G-code manually.

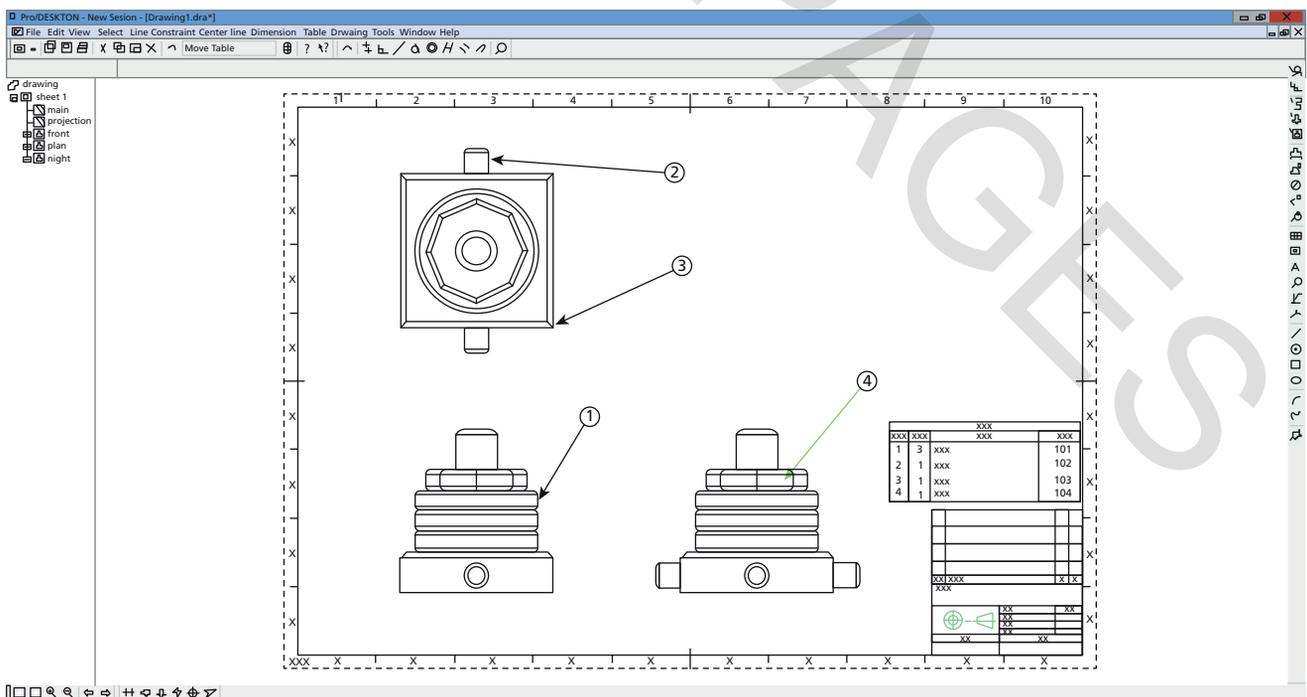
**Manufacturing simulation:** the use of digital models to virtually test and analyse manufacturing processes before they are carried out.

## Machine tools and machine elements

### Identification of machine tools, functions and capabilities

**Machine tools:** used to form and finish material for engineering work. Each has a purpose for a specific task:

- ▶ **Drills (pillar and bench):** used to drill holes into metal. Pillar drills are better for larger parts, while bench drills are used for lighter work.
- ▶ **Centre lathe:** rotates metal while a fixed cutting tool shapes it. It is used to make round parts and for tasks such as threading and boring.
- ▶ **Vertical milling machine:** removes material using a rotating cutting tool that moves downwards onto the workpiece. It is used for making slots, grooves and complex shapes.
- ▶ **Linisher:** smooths rough metal using a moving, continuous abrasive belt between two motorised wheels.
- ▶ **Polisher or buffer:** polishes metal to a shine using a spinning wheel.
- ▶ **Compressor:** blows out pressurised air to power pneumatic tools and remove dirt.



▲ Figure 1.25 CAD assembly drawing of the components in 3rd angle (orthographic) projection

### Identification and application of machine elements

Machine elements are important parts of machine tools that help improve accuracy, repeatability and how efficiently they work.

Computer numerical control (CNC) machines use computer programs to control tools. They help create parts with great accuracy. They are very precise and consistent, speeding up production with automation. However, they are expensive to set up and need trained operators.

The following are examples of work holding methods that keep the workpiece still and in place while machining:

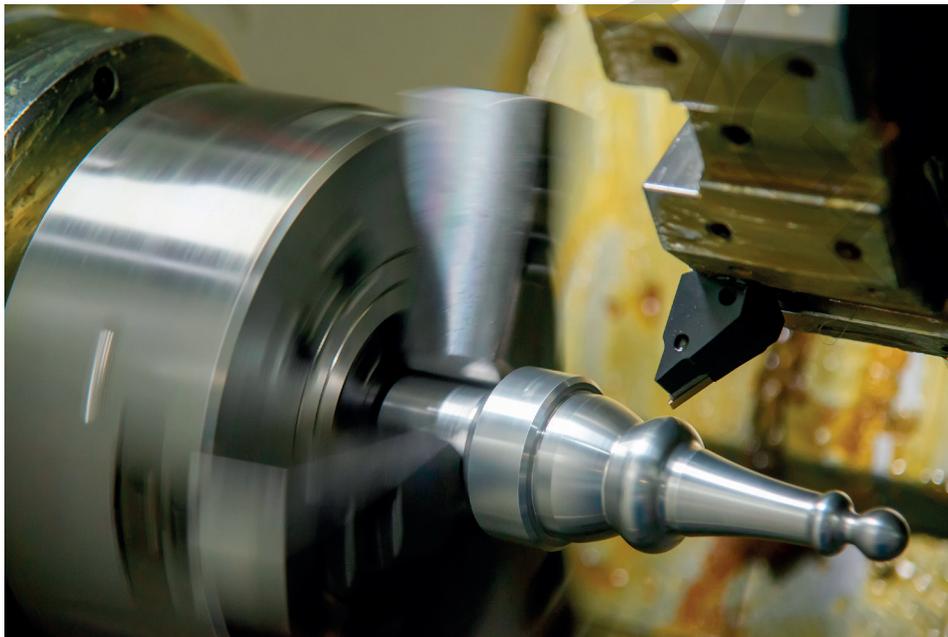
- ▶ **Chuck:** holds round parts on a lathe so they can be turned or shaped.
- ▶ **Machine vice:** holds parts on milling or drilling machines to keep them steady.
- ▶ **Jigs:** custom-made holders that guide and support parts. They are useful for repeat jobs to improve speed and accuracy.

Tooling refers to the cutting or shaping tools fitted to machines, such as drill bits, milling cutters, turning tools, cutting inserts, reamers and taps. Tooling is selected based on material type, required finish and machining process.

### Safe operation of machinery and technology

Safe use of machinery reduces the risk of accidents and avoids work disruption.

- ▶ Ensure machine guards are in place and are effective.
- ▶ Check machines are safe to use before starting (guards, tools, lubrication, emergency stop).
- ▶ Use the correct PPE such as safety glasses, gloves, ear protection and overalls.
- ▶ Do not use a machine without correct training and knowledge of how to stop it quickly.
- ▶ Follow the manufacturer's instructions, workplace safety guidelines and standard operating procedures (SOPs) for each machine or piece of technology.
- ▶ Work within the limits of your own authority and expertise – do not attempt adjustments, repairs or programming beyond your competence or authorisation.
- ▶ Seek advice and guidance from supervisors, experienced colleagues or technical manuals whenever you are unsure about a process, safety requirement or equipment setting.
- ▶ Be aware of hazards and risk assessments, and act promptly to report faults, unsafe conditions or accidents.



▲ Figure 1.26 Metal part being turned with a centre lathe

**Industry tip**

Follow all instructions and work within the limits of your role. If you are unsure, check with someone who has the correct skills.

## Installation, configuration and integration of mechanical engineering systems

### Requirements and procedures for installation

Client requirements explain what the system needs to do, such as its size, performance and safety features, and must be followed carefully to meet the customer's expectations. Regulation requirements are legal rules that cover things such as safety, environmental impact and quality standards. Following these is essential, as ignoring them can lead to serious safety risks or legal consequences.

When installing mechanical engineering systems, it is important to make sure they are easy to maintain and service in the future. Parts that need regular checks should be easy to reach, and important performance details should be easy to measure. During **commissioning**, equipment is tested to make sure it functions correctly, checking that everything is aligned and connected as per the manufacturer's instructions. System performance is recorded, and the client is taken through the system to confirm they accept that the equipment is performing to the specification.

**Industry tip**

Before starting any installation or maintenance work, remember to always isolate power, fluids and gases to prevent the system from starting up by accident and causing harm. The correct isolation methods can be found in the standard operating procedure (SOP). Following the SOP means the isolation will be carried out safely.

The correct installation of a system requires the use of the correct tools. Hand tools such as spanners are often employed to join components together and tighten fasteners. A spirit level would be used to make sure a machine is level. Power tools such as an angle grinder may be used to clean or prepare a surface or to remove stubborn bolts or nuts.



▲ Figure 1.27 Lock out, tag out (LOTO) is used to make sure hazardous energy sources are isolated before maintenance work begins

### Configuration

Measurement tools are necessary to check the correct installation of the system. The system also has to be rated correctly for the application's pressure, velocity and temperature. This will ensure that the system can be operated safely and will perform correctly.

Parameters of flow rate, operating pressure, temperature limits and system tolerances should be set before first use in accordance with the manufacturer's specification. Check these parameters against the design requirements and the specified limits for the design set out in the technical documentation.

Operators need to have knowledge of operating systems and controls that are associated with the equipment, including safe start-up, adjustment and shut-down of the system. If there is any uncertainty regarding specifications, and they are not covered by documentation, then a supervisor, engineer or the manufacturer should be asked to clarify. This ensures that the work will be performed within a safe range and the design specification will be adhered to. Calibration helps ensure that sensors and gauges operate correctly and give accurate readings. System testing provides feedback as to whether the system is operating as desired and can help troubleshoot problems. Training offsite or onsite is available from manufacturers of equipment for both operators and maintenance technicians. This is often carried out before the equipment is delivered.

It is important to always follow rigorous safety protocols to prevent accidents and ensure safe installations:

- **Personal protective equipment (PPE):** such as safety glasses, gloves, helmets and hearing

protection. This must always be worn. Check which PPE is required before starting any work as it can vary by equipment type or environment.

- ▶ **Tool inspection:** regularly check tools for defects, wear and correct functioning.
- ▶ **Correct tool usage:** ensure appropriate tools are used for each task; incorrect tools can cause injury and equipment damage. An SOP (Standard Operating Procedure) will often detail what equipment or tools are required.

### Key term

**Commissioning:** configuration, testing and verification to ensure a system meets its intended design and operational performance.

## Fault detection, diagnosis, resolution and isolation methods

### Fault detection methods and techniques

Fault diagnosis is the act of determining the reason for a system fault prior to the commencement of repair.

**Diagnosis** may consist of the following:

- ▶ **Sensory tests:** the sight, sound, touch or smell of the machine may be used to diagnose faults. Components that are broken or damaged can be spotted by sight. Unusual noises or smells are often an indicator of the cause of a fault. Machines that are too hot to touch are often overheating. Always be aware of safety when using sensory testing. Fumes can be hazardous, very hot surfaces can cause burns, excessive noise can damage hearing. Never taste anything to test for issues. For example: Coolant/antifreeze tastes sweet as it contains ethylene glycol but is highly toxic.
- ▶ **Collecting fault data:** logs, monitoring data and maintenance records can be analysed to spot the cause of a fault.
- ▶ **Self-diagnosis:** some systems run built-in tests and output diagnostic or error codes if a fault is detected.
- ▶ **Inspection:** visually or physically checking components, wiring, connections and assemblies for defects.
- ▶ **Material testing:** the properties of materials (hardness, pressure resistance, conductivity) can be measured and compared to specifications.

- ▶ **Tools and equipment:** diagnostic equipment such as multimeters, pressure gauges, oscilloscopes, thermal cameras or specialist test rigs can be used to detect and confirm the location of faults.

Discuss the fault with the machine operator first. They run the machine on a daily basis and can give vital information such as, the fault only occurs when the vacuum system is activated. This can save time and is also good at building engagement/team work with your colleagues. Some of the most common fault diagnosis techniques are as follows:

- ▶ **Unit substitution:** replacing a suspect component with a known good one to confirm the fault.
- ▶ **Input-output comparison:** checking that the inputs and outputs of a system have the values they should have.
- ▶ **Half-split method:** testing the system at the midway point between the known good and bad ends to determine the location of the fault.
- ▶ **End-to-end testing:** testing the complete system from beginning to end to check its performance.



▲ Figure 1.28 A thermal imaging camera

### Resolution methods based on diagnosis

To fix a fault, technicians choose a method based on how serious the problem is. Parts that are badly damaged are replaced. Smaller issues might be repaired or adjusted. If the same fault keeps happening, the part or design might be modified. Before starting any work, it is essential to safely isolate the equipment. This means turning off the power, locking controls and tagging them – known as LOTO (lock out, tag out) – and making sure any stored energy, such as compressed air or hydraulic pressure, is safely released. LOTO is a safety procedure used to ensure that machinery is completely shut down and cannot be restarted until maintenance or repair work is complete.

▲ Table 1.8 Advantages and limitations of fault resolution methods

Method	Advantages	Limitations
Self-diagnostic	Rapid fault identification, precise error codes	Limited to electronically monitored systems
Unit substitution	Quick identification of faulty units	Requires spare parts availability
Sensory checks	Immediate feedback, no equipment needed	Limited precision, dependent on experience
Half-split technique	Efficient fault localisation	Requires system familiarity
LOTO	High safety standard, clear communication	Requires strict compliance and training
Operator feedback	The knowledge of the operator can speed up fault diagnosis	Operator dependent

- ▶ **Isolation procedures:** use lock-outs and other safety steps to stop machines from turning on during maintenance.
- ▶ **Removing parts:** Follow the correct order and the manufacturer’s instructions when removing parts to avoid damage and make reassembly easier.
- ▶ **Identifying parts:** Label parts to ensure they go back in the correct place later. By adding alignment marks such as on two halves of a bolted flange, will show the original orientation or position of the flanges.
- ▶ **Disposing of parts:** throw away parts safely and follow environmental rules – remember to keep a record of disposals.
- ▶ **Keeping records:** write down actions taken, findings and parts removed to help with repairs and future checks.



▲ Figure 1.29 Identifying a flange

### Safely using tools, equipment and technology

Technicians must safely use diagnostic equipment to prevent accidents. It is important to:

- ▶ regularly inspect and calibrate diagnostic tools
- ▶ follow manufacturer’s guidelines for correct operation
- ▶ always use suitable PPE during diagnostic activities.

#### Key terms

**Diagnosis:** the process of finding out what is wrong with a machine or system by identifying the cause of a problem or fault before repairing it.

**Sensory tests:** using the senses – sight, sound, touch and smell – to detect signs of faults.

### Techniques for disassembly, modification and re-assembly

#### Methods and procedures for disassembly

The use of a camera or video equipment can help to accurately log the disassembly of components and makes an excellent reference tool as images or video can be stored with the SOP for future disassembly operations. The following actions should be taken when disassembling machinery or components:

- ▶ **Removing stored energy:** always release pressure, electricity or spring tension before taking machinery or components apart.

#### Methods and procedures for re-assembly

Some parts need to be built in sections first, called sub-assemblies. Make sure each section works correctly before putting it all together. Parts such as filters and belts wear out over time and are commonly called **lived items**. This is because they have a finite or limited useful performance period. After this recommended time has elapsed, the part no longer performs as it was originally intended to and needs to be replaced. It should be noted that some lived items are on a time or number of hours run recommendation. For example, a sealing gasket may state, change every 12 months or 6000 running hours whichever comes first. Change them on schedule and keep records (using barcodes or QR codes) to stay safe and meet maintenance rules.

Depending on the type of application the following tightening methods are used:

- ▶ **Torque tightening:** the tightening torque is calculated to deliver the correct force and fasten securely without damage to the material.
- ▶ **Angle tightening:** rotating the fastener to an angle beyond its tight position. Angle tightening provides more consistent bolt tension by holding the fastener at a certain angle after initial tightening. If tightened correctly, the fastener will not loosen due to vibration or shock, or create stress on the fastener or material, and will extend the equipment's reliability.

After the tightening and assembly process is complete, the system can be powered up according to the manufacturer's specifications. Safety precautions must be considered, and the system will then undergo an initial functional check and observation for unusual operation.

During the entire process, it is important to document all procedures in maintenance logs/job sheets. The torque/angle value used should be recorded, including power-up test results and any deviations from the standard procedure. Correct documentation allows for traceability and quality control.

It should be noted that corroded threads on nuts or bolts and cross threaded nuts or bolts can give a false impression that they are tight and that the correct torque reading has been reached. Always check the condition of threaded items before assembling.



▲ Figure 1.30 Torque wrench being used to sequentially tighten a cylinder head

### Practical task

- ▶ Take apart a mechanical unit (such as a gear housing or small engine part), following your teacher's demonstration or a provided step-by-step guide.

- ▶ Mark and check each part and record its condition; throw away anything if appropriate.
- ▶ Change any lified items that need replacing and record what you have changed.
- ▶ Reassemble the mechanical unit and tighten all fasteners correctly.

## Joining techniques

### Permanent joining techniques

When a joint must be strong and rigid and last the lifetime of the components involved, **permanent joints** are used. The base metal of the parts being joined is melted by heat during welding. Applications requiring a tight, load-bearing or rigid joint, such as machine frames or vehicle chassis, use welded joints because they are strong and inflexible. The surfaces of the parts are joined by brazing and soldering using a filler metal. Brazing is a higher-temperature method that is used for various metal types, whereas soldering is typically used at lower temperatures and is frequently used for plumbing or electrical connections. Adhesive bonding joins two surfaces with a substance that resembles glue. It is frequently used for lightweight or mixed material assemblies where a smooth, painted finish is needed because it does not require heat to form the joint. Heat or cooling is used in expansion fittings to create an **interference fit** between the components. Usually, shafts and bearings are mounted using them.

### Semi-permanent joining techniques

**Semi-permanent joints** are strong and long lasting but can still be taken apart when needed, usually with tools or effort. Riveting is a common method that fastens materials tightly and is often used in vehicles and aircraft because it holds up well under stress and vibration. Rivet nuts are inserts that allow screwing and unscrewing in thin materials, making them useful when normal threads will not work. Folding edges of metal or using compression fittings are also ways to make solid yet removable joints, often used in piping, ductwork or sheet metal.

### Temporary joining techniques

Temporary methods of joining parts are meant to make them easy to assemble and disassemble, for maintenance or other reasons. A variety of mechanical fastenings such as screws, bolts, nuts and

washers can be used to form strong, flexible joints, and they allow easy adjustment. Nuts and washers can keep joints tight and in place, even under vibration. Shims and anti-rattle design parts can provide alignment and reduce rattling and wear. An interference fit, or press fit, can be used to join parts by friction: bearings, gears and other parts are often joined this way. They can be disassembled, usually with special tools.

▲ Table 1.9 Advantages and limitations of different joining techniques

Technique	Advantages	Limitations
Welding	Strong, durable, rigid joints	Requires skilled operators, not reversible
Soldering and brazing	Suitable for delicate components, dissimilar metals	Lower mechanical strength than welding
Adhesive bonding	Lightweight, corrosion resistant	Surface preparation critical for bond strength
Riveting	High vibration resistance	Difficult disassembly and rework
Mechanical fastenings	Easily adjustable, reusable	Potential loosening due to vibration
Interference fit	Strong joint, no additional fasteners needed	Difficult disassembly, specialised tools required

### Practical task

- ▶ Select a method from the list above to join two sheets of mild steel with dimensions of 100 mm × 100 mm × 4 mm thickness. The two square sheets of steel require joining together but, every 6 months, they need taking apart for inspection purposes. Explain why you chose that method.
- ▶ Carry out the joining process, clearly writing down each step you take, the tools you use and any safety checks or extra equipment you required during the joining process.

### Key terms

**Lifed items:** components that must be changed after a set time or use.

**Permanent joints:** fixed joins not meant to come apart.

**Interference fit:** a tight join where one part is slightly bigger than the hole it goes into.

**Semi-permanent joints:** can be taken apart with effort; last a long time.

Review and evaluate activities to help improve workplace systems and processes associated with maintenance, installation, servicing and repair of mechanical plant and equipment, demonstrating commercial awareness and accountability

## Quality inspection, testing, and recording methods

### Purpose and importance of quality inspection and testing

Quality checks and tests help make sure parts and systems work correctly and meet standards. They ensure safety, compliance with legal regulations, reduce mistakes and costs, and maintain customer satisfaction. Without a robust quality system, products can fail, cause accidents or damage a company's reputation.

### Quality assurance processes

**Quality assurance (QA)** systems, processes and procedures are used to consistently provide quality products and processes. Quality systems are audited for compliance on a regular basis by internal auditors and also external independent auditors. These include the following:

- ▶ Policies, procedures and instructions to ensure that quality requirements are clearly communicated and understood.
- ▶ Organisational systems, policies and requirements to ensure that inspections and compliance are consistently applied.

- ▶ Second-line checks and verifications to ensure that checks and decisions have been applied correctly.
- ▶ Sensory checks to identify faults and abnormalities.
- ▶ Checklists and servicing instructions to standardise inspection and servicing activities.
- ▶ Use of data, reports and measurement instruments and devices to monitor activities and verify conformity.
- ▶ System testing and operation to verify that items are operating correctly under actual or simulated operating conditions.
- ▶ Internal communications to report problems, findings and co-ordinate corrective action.
- ▶ Reference to previous maintenance and history records to identify recurring faults and inform preventative maintenance action.
- ▶ Regular review of maintenance requirements and preventative maintenance action to reduce recurring faults and ensure quality.

### Recording methods and documentation

Recording is also a critical part of inspection to support compliance, quality control and continuous improvement. Typical documentation includes the following:

- ▶ **Maintenance logs:** recording routine inspections, work carried out and parts replaced.
- ▶ **Defect logs:** clearly recording defects found, root causes, corrective actions taken and preventative measures.
- ▶ **Inspection reports:** detailed record of inspection findings, observations, measurements, recommendations and missed equipment.
- ▶ **Statements:** a formal written record or confirmation of work completed, compliance status or issues identified.
- ▶ **Checklists:** standardising inspection and maintenance tasks to ensure no critical steps are overlooked.
- ▶ **Amending documentation:** updating or correcting records when new information is discovered, changes occur or errors are identified.
- ▶ **Digital technologies:** leveraging digital platforms to make inspection records more accurate, accessible, quicker to update and easier to track over time.

### Completing and recording quality processes

To ensure effective quality control, technicians must:

- ▶ accurately document each inspection step
- ▶ clearly record measurements, test outcomes and deviations



▲ Figure 1.31 Inspection is essential to verify dimensions and tolerances

- ▶ detail corrective and preventative actions taken
- ▶ regularly review and amend documentation to maintain accuracy and compliance.

### Practical task

- ▶ Carry out a **quality inspection** on a mechanical assembly using the relevant checklist and the following tools:
  - ▶ Vernier caliper – to measure internal and external dimensions
  - ▶ micrometer – to measure precise diameters (e.g. shafts or pins)
  - ▶ feeler gauges – to check clearances or gaps
  - ▶ steel rule – to measure lengths or check flatness/alignment
  - ▶ inspection torch or mirror – to inspect hard-to-reach areas.
- ▶ Record all your results clearly.
- ▶ If you find any faults or issues, fill out a defect log and suggest how they could be fixed.
- ▶ Once you have finished, get your results checked through second-line verification to confirm accuracy.

▲ Table 1.10 Advantages and limitations of different quality checks

Technique	Advantages	Limitations
Sensory checks	Immediate, low-cost detection	Limited accuracy, relies on technician experience
Measurement and analysis	Precise, data-driven identification of defects	Requires specialised equipment and skills
Second-line verification	Enhanced reliability, reduces errors	Time-consuming, increases labour costs
Preventative measures	Reduces future defects, proactive approach	Requires regular resources and planning

### Key terms

**Quality assurance (QA):** a structured system put in place to ensure quality is built in at every stage.

**Defect log:** a record of identified faults or non-conformities, including actions taken.

**Quality inspection:** checking parts or products to see if they meet the required standards.

Communicate mechanical operations, maintenance, installation, servicing and repair information, proposals and solutions, producing, recording and explaining relevant technical information

### Communicating technical information and data

Written records provide a permanent account for future reference. They track activity, enable compliance with legal and safety requirements and hold people accountable for their actions. Written records include detailed **technical reports**, inspection sheets, maintenance logs and clear procedural instructions.

Well-written technical documents ensure that work is completed safely and correctly, provide clear repair and maintenance instructions, track activity and rationales, comply with legal and company policies and preserve knowledge for future use.

Technical reports are documents that present information in a structured and detailed manner. They are important for ensuring transparency, accountability and clarity in technical activities. Key components of an effective technical report include:

- ▶ title, date and author identification
- ▶ purpose and scope of the activity
- ▶ detailed descriptions of the methodology and procedures used
- ▶ findings, observations and results
- ▶ clearly stated conclusions and recommendations
- ▶ supporting appendices such as documentation (test data, inspection sheets, and so on).

In addition to producing clear and accurate reports, important practices include:

- ▶ recording relevant data and observations in line with organisational requirements
- ▶ managing documentation to ensure it is up to date, organised and accessible
- ▶ securely storing records in either paper or digital format according to company policy and data protection requirements
- ▶ amending documents as necessary when updates, corrections or new information are identified
- ▶ uploading and sharing data via approved digital systems or company databases so information is accessible and usable by relevant stakeholders.

Reports and records should be clear, concise, logically organised and easily understandable by both technical and non-technical stakeholders.

### Collaborative technology for communication

These tools help teams share and manage technical information quickly and safely. Examples include:

- ▶ **cloud storage:** used for storing and sharing files such as reports and logs; examples include OneDrive and Google Drive
- ▶ **email and messaging:** sending updates and urgent information fast
- ▶ **video calls:** useful for live chats and solving problems as a team; examples include Teams and Zoom
- ▶ **specialist platforms:** provide access to manuals, databases and online support.

### Data management and confidentiality

Technicians need to follow the process of managing and protecting technical information and data in accordance with legal, regulatory and organisational requirements, including the **General Data Protection Regulation (GDPR)**. This includes:

- ▶ keeping the data secure in paper or electronic form so it cannot be lost, damaged or accessed by unauthorised persons
- ▶ restricting access to the data to those authorised to see it and maintaining a record of who has accessed the data and when
- ▶ defining policies and procedures that state how and when information can be shared both internally and externally.

Managing and protecting all technical information and data in any form, including:

- ▶ test data and results
- ▶ maintenance results and findings
- ▶ fault information
- ▶ inspection sheets and maintenance records
- ▶ repair methods and associated documentation.

Data must be retained for the appropriate length of time, amended where appropriate and securely destroyed when it is no longer required.

**Key terms**

**Technical reports:** written records of technical work and results.

**General Data Protection Regulations (GDPR):** rules to protect personal data and keep it safe.

- ▶ **Training and competence:** effective ICT usage requires regular training, potentially incurring costs and time commitments.
- ▶ **System costs:** implementation and maintenance of advanced ICT systems can be costly, particularly for small organisations or teams.

▲ **Table 1.11 Advantages and limitations of ICT applications**

ICT application	Advantages	Limitations
Electronic data systems	High accuracy, rapid retrieval	Vulnerable to data loss if not backed up correctly
Recording systems	Consistent, secure data capture	Dependent on reliable network connectivity
EDMS	Document security, efficient management	Requires regular maintenance and training
Collaborative technologies	Effective remote collaboration, instant updates	Cybersecurity risks, user dependency

**Digital and ICT**

**Using ICT to manage engineering data and documentation**

Information and communication technology (ICT) systems enable engineers and technicians to manage complex data efficiently. Effective management of digital information involves systems and software solutions that:

- ▶ streamline data entry and storage
- ▶ allow quick and reliable retrieval of information
- ▶ provide real-time access and remote collaboration capabilities
- ▶ ensure secure data storage and protection
- ▶ support regulatory compliance and reporting.

Engineering information, such as test and inspection results, preventive maintenance records and fault reports, are stored in **data systems** using a database, spreadsheet, file or the cloud. **Recording systems** are the systems or tools for storing detailed data, such as sensor data or repair history, and they are often implemented using digital logbooks or mobile applications. **Electronic document and management systems (EDMS)** tools or platforms, such as SharePoint, are used for document management, including version control, storage and sharing. ICT systems facilitate data entry and updates, data backup to the cloud and team collaboration through shared files and videoconferencing in real time.

Despite these advantages, ICT systems can present challenges that technicians must manage effectively

- ▶ **Dependency on technology:** ICT reliance can lead to operational disruptions during system outages or network issues.
- ▶ **Cybersecurity risks:** digital data systems are vulnerable to cyber threats, so require robust security measures, training and vigilance.

**Key terms**

**Data systems:** setups for storing and finding structured data.

**Recording systems:** tools for saving and tracking engineering data safely.

**Electronic document and management systems (EDMS):** software that manages documents from start to finish.

**Assessment practice**

- 1 Explain the difference between static and dynamic loading. Give one example of each type of loading.
- 2 Find the mechanical advantage (MA) of a pulley system, if a load of 600 N is lifted by applying an effort of 150 N.
- 3 Explain where a centrifugal governor would be used and how it functions in that application.
- 4 Name two types of levers. Give an example of each type of lever with reference to engineering and everyday life.
- 5 How is energy stored and transferred in a hydraulic system used in heavy machinery? Give one example with reference to a workshop.