MINISTRY OF EDUCATION

TECHNICAL TEACHERS ASSOCIATION OF GHANA

Automotive and Metal Technology

(Applied Technology)

for Senior High Schools

Year 3

Tetteh Bruce

Philip Kwesi Incoom

Dr. Sherry Kwabla Amedorme

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Ghana Education Service (GES)

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FOREWORD

Ghana's new Senior High School Curriculum aims to ensure that all learners achieve their potential by equipping them with 21st Century skills, knowledge, character qualities and shared Ghanaian values. This will prepare learners to live a responsible adult life, progress to further studies and enter the world of work. This is the first time that Ghana has developed a Senior High School Curriculum which focuses on national values, attempting to educate a generation of Ghanaian youth who are proud of our country and can contribute effectively to its development.

The Ministry of Education is proud to have overseen the production of these Learner Materials which can be used in class and for self-study and revision. These materials have been developed through a partnership between the Ghana Education Service, teacher unions (Ghana National Association of Teachers-GNAT, National Association of Graduate Teacher -NAGRAT and the Pre-Tertiary Teachers Association of Ghana- PRETAG) and National Subject Associations. These materials are informative and of high quality because they have been written by teachers for teachers with the expert backing of each subject association.

I believe that, if used appropriately, these materials will go a long way to transforming our Senior High Schools and developing Ghana so that we become a proud, prosperous and values-driven nation where our people are our greatest national asset.

Haruna Iddrisu MP
Minister for Education

SECTION

1 COMPUTER NUMERICAL CONTROL (CNC) MACHINES

UNIT 1: METAL TECHNOLOGY

Engineering Materials, Tools and Machines

INTRODUCTION

CNC stands for **Computer Numerical Control**, and CNC machines are computer-controlled tools used in manufacturing to cut, shape, and form materials such as metal, plastic and wood with high precision and speed. CNC machines use a programming language called G-code to control their operations. G-code gives the machine clear instructions such as where to move, how fast, when to cut, change tools, or turn the spindle and coolant on or off. CNC programming involves converting a 3D CAD (computer-aided design) model into machine-readable instructions that guide the cutting tool's actions to produce the final part. These instructions include tool selection, feed rate and precise movement paths. This unit presents the fundamental programming language for CNC machines, the types of CNC code and the description of common C and M codes.

In Year 2, we learned how to use the **lathe and shaping machines**, and we also worked on **milling machines and cutting fluids.** These machines can also be controlled by **Computer Numerical Control (CNC)**, which uses a special **coding language called G-code and M-code**. G-code and M-code functions by giving instructions to the machine in a language it understands. It tells the CNC machines **where to move, how fast, and what to do,** just like a teacher giving clear steps for a class project. By using these codes:

- The lathe machine can cut smooth, round shapes on its own.
- The shaping machine can move precisely to make flat surfaces.
- The milling machine can follow patterns to drill, cut, or carve materials exactly.
- Cutting fluids can be controlled automatically for cooking and cleaning during cutting.

So, CNC coding helps us to work faster, safer, and with greater accuracy.

KEY IDEAS

- CNC coding languages are specialised programming systems, such as a G-code, used to precisely control machine tools by providing step-by- step instructions for movement , speed, and operation.
- Purpose: These languages translate design data into instructions machines can follow.
- G-code: The most common CNC language; controls actions like cutting, drilling and milling.
- Machine Instructions: Include coordinates, feed rate, spindle speed, and tool path
- Automation: Enables consistent, accurate production without manual control.
- Variants: Some machines use proprietary or extended versions of G-code or high- level CAM software that generates the code.

PROGRAMMING LANGUAGE FOR CNC MACHINES

The main programming language used for Computer Numerical Control (CNC) machines is Geometric code (G-code) is a simple programming language that tells the CNC machine what to do. It controls:

1. movement (where and how fast to move)
2. cutting actions
3. tool changes
4. speed of the spindle
5. coolant on/off, etc.

Meaning of CNC Programming

CNC programming refers to converting a 3D CAD (computer-aided design) model into a set of machine-readable instructions that include; which cutting tools to use, the feed rate, and where to move the tool to create the final part. CNC programmes list instructions to be performed in the order they are written. They read like a book, left to right and top-down. Each sentence in a CNC programme is written on a separate line, called a Block. Blocks are arranged in a specific sequence that promotes safety, predictability and readability, so it is important to adhere to a standard programme structure.

ORDER OF ARRANGEMENTS FOR CNC BLOCKS

1. Programme Start
2. Load Tool
3. Spindle On
4. Coolant On
5. Rapid to position above part
6. Machining operation
7. Coolant Off
8. Spindle Off
9. Move to safe position
10. End programme

The steps listed **1-10** above represent the simplest type of CNC programme, where only one tool is used and one operation performed. Programmes that use multiple tools repeat steps two through nine for each.

Examples of Simple G-codes are shown below:

G21: Set units to millimetres

G90: Use absolute positioning

G00 X0 Y0: Move quickly to the starting point

G01 X50 Y0 F100: Cut in a straight line to X=50mm at a feed rate of 100mm/min

M05: Stop the spindle

M30: End the programme

Types of CNC Code

There are two main types of CNC code used for programming CNC machines. These are G-codes (Geometric Codes) and M-codes (Machine Codes). G-codes control the movement and positioning of the machine tool and M-codes control the machine's functions and actions, not movement. *See **Tables 1.1-1.2***.

Table 1.1: The Most Common G-Codes for Application

Code	Description
G00	Rapid motion used to position the machine for non-milling moves.
G01	Line motion at a specified feed rate.
G02	Clockwise arc.
G03	Counterclockwise arc.
G04	Dwell.
G28	Return to machine home position.
G40	Cutter Diameter Compensation (CDC) off.
G41	Cutter Diameter Compensation (CDC) left.
G42	Cutter Diameter Compensation (CDC) right.
G43	Tool length offset (TLO).
G54	Fixture Offset #1.
G55	Fixture Offset #2.
G56	Fixture Offset #3.
G57	Fixture Offset #4.
G58	Fixture Offset #5.
G59	Fixture Offset #6.
G80	Cancel drill cycle.
G81	Simple drill cycle.
G82	Simple drill cycle with dwell.

G83	Peck drill cycle.
G84	Tap cycle.
G90	Absolute coordinate programming mode.
G91	Incremental coordinate programming mode.
G98	Drill cycle returns to Initial point (R).
G99	Drill cycle return to Reference plane (last Z Height)

Table 1.2 : The Most Common M-Codes for Application

Code	Description
M00	Programme stops. Press Cycle Start button to continue.
M01	Optional stop.
M02	End of programme.
M03	Spindle on Clockwise.
M04	Spindle on Counter clockwise.
M05	Spindle stop.
M06	Change tool.
M08	Coolant on.
M09	Coolant off.
M30	End programme and press Cycle Start to run it again.

PROCEDURES FOR WRITING BASIC G-CODES

1. Start with Basic Settings:

These commands set up the unit system and positioning method.

G21: Use millimetres (G20 for inches)

G90: Use absolute positioning

2. Move to Starting Position (without cutting):

Use G00 for rapid movement (no cutting).

G00 X0 Y0: Move quickly to starting point (X=0, Y=0)

3. Start the Spindle:

Use M03 to turn the spindle on clockwise and set spindle speed.

M03 S1000: Spindle on at 1000 RPM

4. Begin Cutting:

Use G01 for straight line cuts and F to set feed rate.

G01 X50 Y0 F100 : Move to X=50mm with cutting at 100 mm/min
G01 X50 Y50: Cut up to Y=50mm
G01 X0 Y50: Cut to the left
G01 X0 Y0: Cut back to starting point

5. Stop the Spindle and End the Programme:
M05: Stop spindle
M30: End of programme

HOW TO DRAW A 50MM SQUARE

G21 : Set units to millimetres

G90 : Absolute positioning

G00 X0 Y0 : Go to starting point quickly

M03 S1000 : Spindle on at 1000 RPM

G01 X50 Y0 F100: Cut to the right

G01 X50 Y50: Cut upwards

G01 X0 Y50: Cut to the left

G01 X0 Y0 : Cut down to close square

M05: Spindle off

M30 : End programme

Conclusions

In conclusion, computing coding languages such as G-code and M-code play a crucial role in the operation of CNC machines. These languages serve as a bridge between human design and machine action, allowing CNC machines to follow precise instructions for cutting, shaping, and forming materials. The use of these coding languages ensures high accuracy and repeatability in manufacturing. It enables automation of complex tasks and reduces human errors and increases productivity. It further allows design flexibility, making it easier to change or improve a product by simply editing the code. As technology continues to advance, learning and understanding CNC coding languages has become an essential skill in modern manufacturing and engineering.

Activity 1.1 Exploring computing code languages

Your class has been assigned the task of researching, demonstrating, and presenting how computing coding languages (especially G-code and M-code) are used to control CNC machines.

1. With the help of your Applied Technology Teacher, organise a visit to a nearby industry to observe how the computing coding languages are used for operating Computer Numerical Control (CNC) machines.
2. During the visit, discuss how the G01 command differs from a G00 command in CNC programming.
3. Write a visit report and discuss in class in groups

Note: *Use ICT tools to facilitate your work.*

Activity 1.2 Practical application of G-code commands

In a metal workshop, you need to programme a CNC machine to cut a square with a side 40mm. The starting position is the top-left corner of the square at coordinates X10, Y10. Determine the sequence of G-code commands which would correctly create this square with the cutting tool ending at the starting position?

EXTENDED READING

S/N	ISSUE	LINK
1	Computing Coding Language	https://www.computerscience.org/resources/computer-programming-languages/
2	CNC Language	https://www.cnccookbook.com/cnc-programming-languages-list-g-code-m-code/
3	Programming Language for CNC	https://www.mastercam.com/news/blog/what-coding-language-is-used-on-cnc-machines/
4	Types of CNC Code	https://www.cadcamteacher.com/en/blog/types-of-cnc-programming
5	Common G-codes	https://www.machinistguides.com/g-codes/
6	Common M-codes	https://www.machinistguides.com/m-codes/
7	Procedure for writing basic G-code	https://cnccode.com/2025/06/14/cnc-programming-101-complete-beginners-guide-with-real-g-code-examples/
8	How to draw a 50mm square	https://www.youtube.com/watch?v=oTvuhC23HLU

REVIEW QUESTIONS

During an industrial visit, the Workshop Assistant assigned you to prepare a chart for learning simple G-Code and M-Code commands. The goal is to help learners or new operators understand and memorise the basic CNC commands used in manufacturing process.

1. Describe the G-code and M-code commands
2. Write a basic G-code programme
3. State the purpose of each command listed below:

    a. G01

    b. G00

UNIT 2: AUTOMOTIVE TECHNOLOGY

Introduction to Engine Technology

INTRODUCTION

This unit builds upon the concept of spark ignition and compression ignition engines you were introduced to in sections 1 and 2 of your first year Applied Technology course. Understanding how fuel gets to the engine is **a** key to knowing how vehicles work efficiently. The fuel supply system ensures that clean fuel is delivered in the right amount and at the right time for proper combustion. Whether a vehicle uses a petrol (spark ignition) or diesel (compression ignition) engine, the basic parts of the fuel supply system remain similar, though their operation may differ. In this unit, you will explore the major components, how they work together, and the different types of systems used in modern and older vehicles. You will also learn how improvements in fuel delivery contribute to better performance, fuel economy, and lower emissions. This knowledge will help you appreciate the vital role fuel systems play in engine operation.

KEY IDEAS

- Diesel engines use high-pressure injection systems for effective combustion.
- Different fuel delivery methods in automobiles have evolved over time.
- Modern fuel systems use advanced technologies for precision and improved efficiency.
- Spark ignition and compression ignition engines have similar components but different operations.
- The fuel supply system ensures efficient engine combustion.

FUEL SUPPLY SYSTEM FOR SPARK IGNITION (SI) ENGINE

The purpose of the fuel supply system for a petrol engine is to store; transfer and filter the petrol the engine uses to generate power. A typical petrol fuel supply system includes a fuel tank, fuel pump, fuel filter, carburettor or fuel injectors, and fuel lines.

Components of Fuel Supply System in Petrol Engine

Fuel tank

The fuel tank serves as a storage medium for the petrol. It is normally located at the rear of the vehicle. It is made from corrosive-free metal or aluminium alloy sheet metal. Many

modern vehicles use tanks made from durable moulded plastics, making them lighter in weight and corrosion-free. These plastic tanks are often protected by a guard to prevent damage from road debris. Modern fuel tanks usually have a number of baffles at the bottom to prevent violent surging of fuel during acceleration, braking or cornering.

Fuel tanks are vented to allow easy control of vapour and to prevent pressure buildup in the tank. They are also designed with a fuel level indicator, which is mechanically or electronically controlled. The size of the fuel tank depends on the size and functionality of the vehicle.

Fuel pump

The fuel pump lifts or extracts the fuel from the fuel tank, pressurises it and sends it to the point of delivery, either a carburettor or an injector. Fuel pumps are either mechanically or electromagnetically operated. The electromagnetically operated pumps are commonly called electric pumps. Mechanical pumps are operated by a cam lobe on the engine's camshaft.

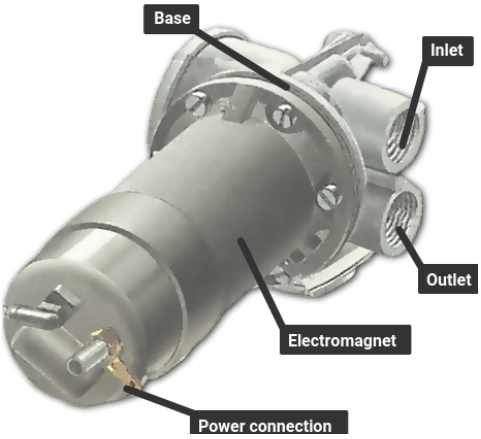


Figure 2.1: An electric fuel pump

Fuel lines

These are copper, tinned steel or plastic pipes which convey the fuel from the tank to the carburettor or injector. They are designed to maintain a constant flow of fuel under appropriate pressure and to ensure a steady, uninterrupted flow of fuel to the engine. The fuel lines connect all the components of the fuel supply system from the fuel tank to the carburettor or injectors. The connection points are fitted with secure connectors to prevent leaks and withstand engine vibrations

Air cleaner

An air cleaner is required for two main reasons. First, it traps particles like dust, pollen, and debris that flow with the air entering the engine. Second, it serves as a noise silencing device, which reduces engine induction noise to an acceptable low level. Besides these functions, all air cleaners also serve as flame arresters, helping to prevent the spread of flames in case the engine backfires through the intake system.

The air cleaner is mounted either directly on the engine, or away from it and connected by means of a flexible connection.

Fuel filter

The fuel filter ensures that the fuel delivered to the engine is clean and free of foreign particles and impurities, including water. The presence of particles, especially, can clog the fuel delivery system and cause damage to the fuel pump, the float valve mechanism of the carburettor and the entire fuel metering devices and internal passages.

Carburettor

The carburettor is a component of the spark ignition engine that atomises or breaks up liquid fuel into a fine mist and mixes it with air. It meters how much fuel and air are combined based on the operating condition of the engine. This process of breaking up the liquid fuel and mixing it with air is called *'carburetion'*. Figure 2.2.

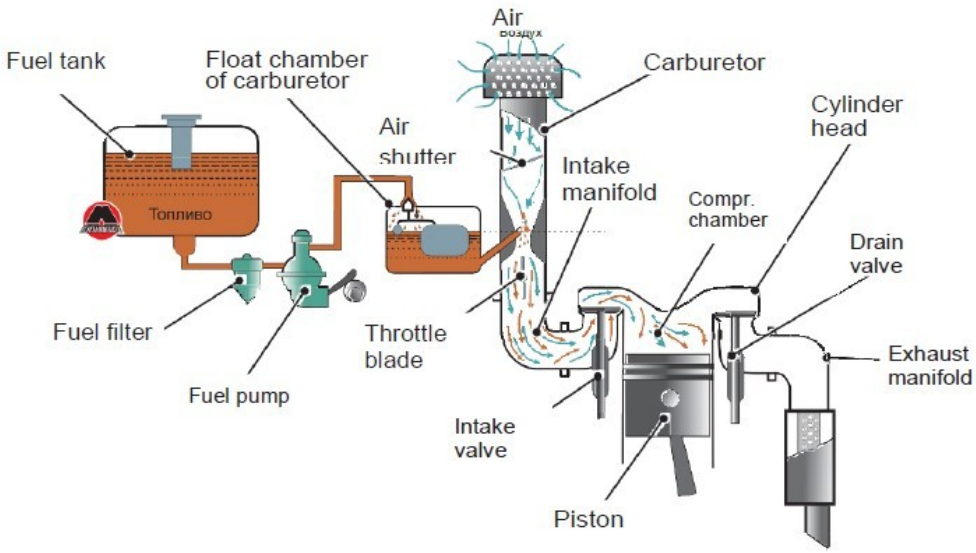


Figure 2.2: Layout of carburettor gasoline engine

Inlet Manifold

The intake manifold directs air into the engine's cylinders. In many vehicles, it also houses the fuel injectors. In older models without fuel injection or with throttle body injection, the manifold delivers the air-fuel mixture from the carburettor or throttle body to the cylinder heads. Intake manifolds on engines with throttle body fuel injection or a carburettor are called wet manifolds because they carry a mixture of both air and fuel.

Supply and Return Pipelines

These lines are used in fuel injection systems to manage the flow of fuel. The supply pipeline delivers fuel from the tank to the engine for combustion. The return pipeline carries any excess fuel back to the tank. This system helps regulate fuel pressure and prevents the fuel from overheating. Together, they ensure efficient and reliable fuel delivery to the engine.

Working of Fuel Supply System in Petrol Engine

The petrol fuel supply system starts with the fuel tank, where petrol is stored. A fuel pump delivers the petrol under pressure through fuel lines and a fuel filter, which removes dirt and rust from the fuel before it reaches the engine.

The air cleaner (filter) removes dust, particles and contaminants from the air before it passes through the throttle valve. This ensures that the air entering the engine is clean. This valve controls how much air goes in, depending on how the driver presses the accelerator pedal.

The fuel and air mix to form a combustible mixture and enters the combustion chamber during the intake stroke of the piston. In older cars, the mixing process takes place in a carburettor. Fuel injectors, controlled by sensors and the engine control unit (ECU), are used in modern cars to spray the right amount of fuel into the intake manifold or directly into the combustion chamber.

Inside the engine, this air-fuel mixture enters the combustion chamber. The piston compresses it, then a spark plug ignites it. The explosion pushes the piston down, creating power. Burnt gases then exit through the exhaust valve.

This process follows four steps—intake, compression, power, and exhaust—and happens thousands of times every minute. Modern engines also use sensors and the ECU to adjust things like fuel delivery and timing, helping the car run smoothly, save fuel, and pollute less.

Types of Fuel Supply Systems in Petrol Engine

Several types of systems are used in spark ignition engines, with each having its own advantages and disadvantages.

Gravity Feed System

The gravity system is among the earliest fuel delivery mechanisms used in small engines and older motorcycles. In this setup, the fuel tank is placed above the carburettor or engine, allowing fuel to flow downward purely under gravitational force. Its mechanical simplicity is its greatest advantage, as there are no pumps, sensors, or electronics involved in its construction.

Disadvantages

However, this simplicity comes with drawbacks. Gravity-fed systems are ineffective in vehicles where the tank can't be placed higher than the engine. They're also poorly suited to variable fuel demands, leading to inefficient fuel delivery at higher speeds or inclines. As such, gravity systems are largely obsolete in modern automobiles.

Pressure Feed System

The pressure system takes a step forward by introducing forced fuel delivery. Fuel is pressurised—either through air pressure or vacuum—and directed to the carburettor or fuel injector. This system improves fuel consistency compared to gravity feed and is used in some older carburetted vehicles where tank positioning demands greater push.

Disadvantages

On the downside, pressure systems often rely on simple mechanical pressure regulators that can be imprecise, making them less responsive to engine load variations. In colder conditions or high-performance settings, this imprecision can lead to misfires or poor fuel economy.

Pump Feed System

The pump system expands on pressure delivery by using mechanical or electric pumps to transport fuel from the tank to the engine. Mechanical diaphragm pumps were common in carburetted engines, while electric pumps have become the norm in fuel injection systems. The introduction of pumps marked a critical evolution in automotive fuel delivery, allowing greater flexibility in tank placement and improving fuel flow reliability.

While pumps enhance system control and consistency, they also introduce complexity. Mechanical pumps can suffer from diaphragm wear, while electric pumps require precise voltage and filtering to avoid failure. Additionally, pump-driven systems need supporting elements like pressure regulators and filters, which add maintenance considerations.

Petrol fuel injection system

Fuel injection systems revolutionised SI engine performance by precisely metering and atomising fuel. Rather than relying on vacuum and airflow, injectors spray fuel directly into the intake manifold or even the combustion chamber. The system is controlled by an ECU, allowing real-time adjustments based on speed, load, throttle input, and temperature.

The major advantage here is efficiency: fuel injection offers improved throttle response, reduced emissions, and better fuel economy. There are several types:

1. Single-Point Injection uses one injector for the entire engine, positioned in the throttle body. It's simple and cost-effective but lacks precision.
2. Multi-Point Injection places individual injectors at each cylinder intake, delivering superior atomization and balance across cylinders.
3. Gasoline Direct Injection (GDI) takes it a step further by injecting fuel directly into each combustion chamber, maximizing power and minimizing fuel consumption.

Despite their benefits, fuel injection systems are more complex and expensive to manufacture and maintain. They require high-pressure pumps, precision sensors, and robust software calibration. Faults can be harder to diagnose, and repairs may demand specialised equipment.

Activity 2.1 Explaining Petrol Fuel Supply System (Group Activity)

Materials needed

1. 1 Perfume sprayer (Transparent bottle)
2. 2 pieces of cardboard/paper,
3. Portable fan

Steps

1. Hold one tissue paper about 10 to 15 mm to the nozzle of the perfume and spurt one burst of the perfume onto it.
2. Observe the mist pattern, droplet size, and spread of the perfume.

3. Repeat step 1 using the second cardboard/paper and holding the cardboard about 50 to 75 mm away from the nozzle of the perfume. Use the fan to blow air on the cardboard while spraying.
4. Observe the mist pattern, droplet size, and spread of the perfume.
5. Explain the differences between the mist pattern, droplet size, and spread of the perfume in the two scenarios.
6. Touch the sprayed portion of the tissue and describe how it feels.
7. Discuss the following among your group:
   a. Why is fine mist important in petrol fuel supply?
   b. What happens if droplets are too large?
   c. How does airflow affect mixing and atomisation in petrol fuel supply system?

FUEL SUPPLY SYSTEM FOR COMPRESSION IGNITION (CI) ENGINE

Compression Ignition Fuel Supply System

In a typical compression ignition engine, fuel is drawn from the tank, pressurised by a fuel injection pump, and then forced through high-pressure lines into injectors, which spray it into the cylinders in a fine mist. The fuel then mixes with hot, compressed air inside the combustion chamber and ignites on its own due to the high temperature.

Compression ignition requires a fuel system capable of handling extremely high pressures, precisely metering fuel quantities, and synchronising injection timing with piston position to ensure efficient atomisation and proper combustion.

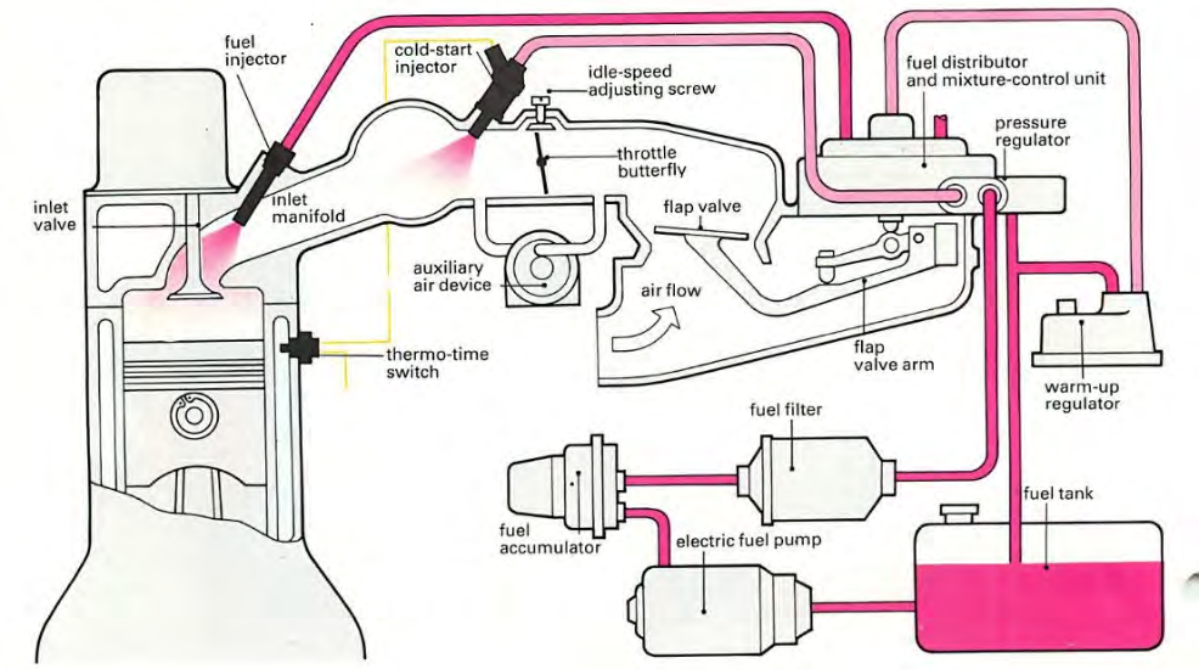


Figure 2.3: Compression ignition fuel supply system

Main Components and Their Functions

The parts of the compression ignition fuel supply system are very similar to those found on spark ignition (petrol or gasoline) engines. The few differences that exist primarily relate to the fuel type and the method of ignition.

1. **Fuel tank**

   The fuel tank stores the diesel fuel securely and maintains pressure balance through a breather. Its design ensures clean storage and steady flow of diesel fuel to the fuel pump.

2. **Fuel pump**

   The fuel pump draws fuel from the tank and pressurises it for delivery to the engine. Electric pumps, used in modern vehicles, offer stable performance, while mechanical ones are simpler but depend on the speed of the engine.

3. **Fuel filters**

   The filters ensure that the fuel delivered to the engine is clean. It achieves this through a two-stage filtration process (primary and secondary filtration). Removing large particles and moisture first (by means of a primary filter), then finer impurities to prevent the injectors from wear (secondary filter).

4. **Fuel injection pump**

   The injection pump delivers pressurised fuel to the engine cylinders at the correct timing. It also supply the right amount or volume of fuel for efficient combustion. The pump draws fuel from the tank, pressurises it, and sends it through the injectors into the cylinders. It is precisely timed with the engine's operation to ensure accurate fuel delivery. The pump may be mechanically operated directly by the crankshaft, the camshaft or by means of timing gears, timing belt or chain, or electronically controlled, as is commonly found on modern automobiles.

5. **Fuel injectors**

   Fuel injectors are small nozzles that spray fuel into the engine. They make sure the right amount of fuel is sent in at the right time for the engine to work properly. The fuel is sprayed in a fine mist so it can mix well with air and burn efficiently. Injectors are controlled either by mechanical means or an electronic system. They help the engine run smoothly, save fuel, and reduce smoke or pollution.

6. **High-pressure lines**

   The high-pressure lines in a diesel fuel supply system are strong metal pipes that carry fuel from the injection pump to the fuel injectors. They are designed to withstand the very high pressure needed to force fuel into the combustion chamber.

Working Principle of COMPRESSION Ignition Engines

A diesel engine uses heat from compressed air to ignite fuel, instead of a spark. First, clean air enters the engine during the intake stroke. Then the piston moves up and compresses the

air, making it very hot. Fuel is drawn from the tank and filtered to remove dirt and water. Next, it goes to a pump that increases its pressure so it's ready for the injection compression stroke. In modern engines, this system controls how much fuel is sent and when, based on engine speed and load. When the piston reaches the top of its stroke, the injector sprays the fuel into the hot air. The heat causes the fuel to ignite right away. This combustion pushes the piston down, which creates power to move the vehicle power stroke. At the end of the power stroke, the exhaust gases are expelled to the atmosphere (exhaust stroke). Any extra fuel goes back to the tank through return lines. Other parts like pressure regulators keep the system running smoothly under different conditions. (The fourth stage of CIEs combustion processes is missing)

Types of Solid Injection Systems

In a solid injection system, only liquid fuel is injected directly into the combustion chamber under high pressure. The fuel is delivered in a pure liquid form, without being mixed with air before it gets into the combustion chamber. This is the type of fuel supply system mainly used in diesel engines.

Some types of solid injection systems are:

1. Individual pump and nozzle system
2. Unit injector system
3. Common rail system
4. Distributor system

Individual Pump and Nozzle System

The Individual Pump and Nozzle System use a separate high-pressure pump and injector for each cylinder in a diesel engine. It delivers fuel precisely and mechanically, without electronic controls. Fuel is filtered, pressurised by each pump, and injected into hot compressed air for ignition. Though reliable and accurate, the system is more complex to maintain than newer centralised setups.

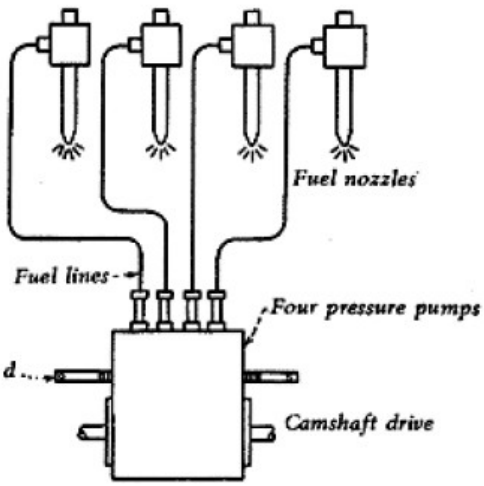


Figure 2.4: Individual pump and nozzle system

Unit Injector System

The unit injector system is a diesel fuel injection method that combines the fuel pump and injector into a single compact unit, installed directly in each cylinder's head. This design eliminates the need for separate high-pressure fuel lines, allowing for extremely high injection pressures often up to 2,200 bar and precise control over fuel delivery.

Each unit injector is mechanically driven by the engine's camshaft and electronically controlled by a solenoid valve. During operation, fuel is pressurised within the injector itself and injected directly into the combustion chamber at the optimal moment. This results in better atomisation, cleaner combustion, and improved engine efficiency. The system is known for its reliability, compactness, and ability to meet strict emission standards, though it has largely been replaced by common rail systems in newer engines. See ***Figure 2.5***.

Figure 2.5: unit injection assembly

Common Rail System

The common rail system is a modern diesel fuel injection setup that uses a single high-pressure fuel rail to supply fuel to all injectors. Unlike older systems where each injector had its own pump, this system separates fuel pressurisation from injection timing, allowing for more precise control.

Fuel is pressurised by a central pump and stored in the common rail at pressures often exceeding 2,000 bar. The injectors, controlled electronically by the engine control unit (ECU), receive fuel from this rail and inject it into the combustion chamber at exactly the right moment and quantity. This setup enables multiple injections per cycle such as pilot, main, and post-injection improving combustion efficiency, reducing emissions, and softening engine noise. It's now the standard in most modern diesel engines due to its flexibility, performance, and compliance with strict emission regulations.

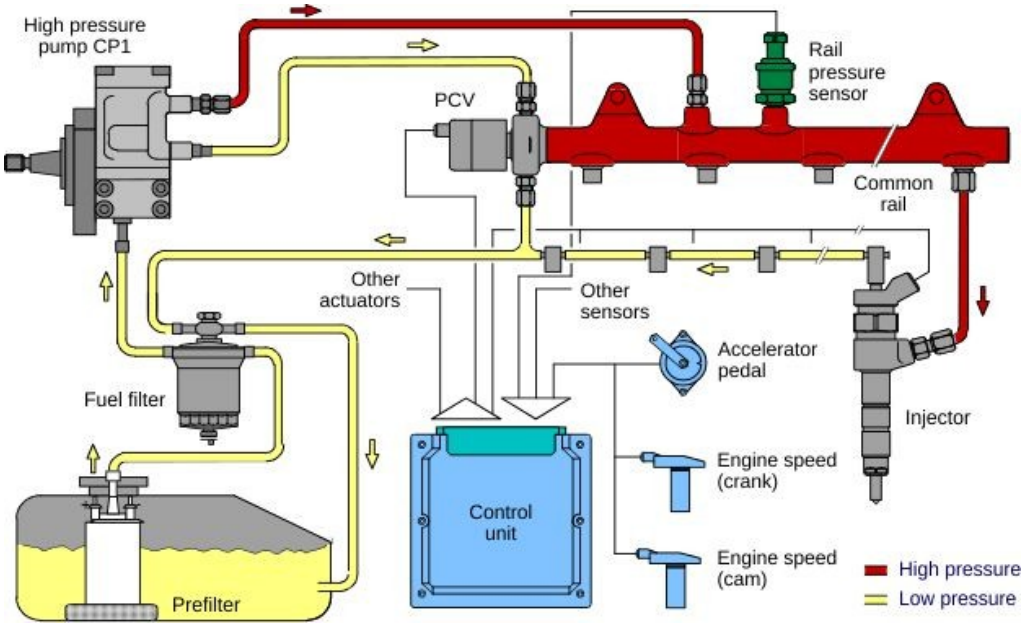


Figure 2.6: A common rail fuel injection pump

Distributor system

The distributor system is a type of diesel fuel injection setup commonly used in small to medium-sized engines. Unlike systems with individual pumps for each cylinder, this design uses a single injection pump that both pressurises and distributes fuel to all cylinders in the correct firing order.

Fuel flows from the tank through filters to a low-pressure pump, which sends it to a central metering and pressure pump. This pump then delivers the fuel to a rotating distributor unit, which directs the correct amount of fuel to each injector at the right time. The system is mechanically timed and often includes a governor to regulate fuel delivery based on engine speed and load. While simpler and more compact than individual pump systems, distributor setups are less flexible and precise than modern common rail systems.

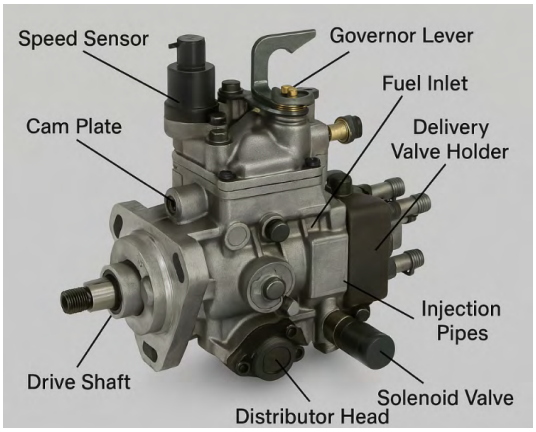


Figure 2.7: A distributor fuel injection pump

Activity 2.2 Explaining the Diesel Fuel Supply System

1. a. Examine the physical features of a diesel engine in the school auto workshop and explain how the diesel fuel supply system works.
   b. Search the internet for videos on how the diesel fuel supply system works and write on it.
2. Prepare a sketch of the diesel fuel supply system and label the major parts.
3. Briefly explain how the diesel fuel supply system works.
4. Describe how the diesel fuel supply system differs from the petrol type?

EXTENDED READING

1. What is a Fuel System? - Components, and Working (https://www.theengineeringchoice.com/what-is-fuel-system/)
2. How a fuel injection system works | How a Car Works (https://www.howacarworks.com/basics/how-a-fuel-injection-system-works)
3. Cleaning fuel-pump filters | How a Car Works (https://www.howacarworks.com/fuel-systems/cleaning-fuel-pump-filters)

REVIEW QUESTIONS

1. a. There is a mechanic at a workshop in your community. One day, a customer brings in a car complaining of poor acceleration, engine misfires, and difficulty starting—especially when the engine is hot. After a quick inspection, the mechanic suspects a fault in the fuel delivery system. As a student of Automotive Technology, evaluate how a clogged fuel filter could be responsible for the car's performance issues.

   b. Describe the steps you would take to diagnose and fix the problem in 1(a) above.

2. a. Design a simple maintenance schedule for the fuel supply system of a spark ignition engine.

   b. Explain why each step is important for engine reliability.

3. a. Evaluate the impact of modern common-rail fuel injection systems compared to traditional fuel injection pumps in CI engines.

   b. Propose two reasons one might be preferred in current vehicle designs.

4. Develop and justify a fault-finding procedure for diagnosing inconsistent fuel delivery in a CI engine, considering mechanical components of the system.

UNIT 3: METAL TECHNOLOGY

Engineering Materials, Tools and Machines

INTRODUCTION

A CNC Turning Machine is a type of Computer Numerical Control (CNC) machine used to shape round or cylindrical materials such as metals or plastic. It works by rotating the workpiece while a cutting tool moves in a straight line to shape it. This process is called turning. CNC turning machines are often used to make items like bolts, shafts, screws and pipe fittings. The CNC (Computer Numerical Control) machines are widely used in modern engineering because they allow for fast, accurate, and repeatable manufacturing of parts. Unlike manual machines, CNC machines follow programmed instructions to carry out cutting, drilling, or shaping operations with little human control.

In Year 2, you learned how to use the lathe and shaping machines annually, and you further studied the annual operations of the milling machines and how to use the cutting fluids to facilitate the operations. In year 3 you will study how these machines can be controlled by using CNC (Computer Numerical Controls- G-code and M-code).

The G-code and M-code function per instructions given to the machines in a language they understand. These codes communicate to the CNC machines the direction of operations, how fast, and what to do, just like an instructor facilitating in clear steps how to perform an activity. By using these codes:

- The lathe can cut smooth, round shapes on its own.
- The shaping machine can move precisely to make flat surfaces.
- The milling machine can follow patterns to drill, cut, or carve materials exactly.
- Cutting fluids can be controlled automatically for cooling and cleaning during cutting.

Therefore, using CNC coding helps the manufacturer to work faster, safer, and with greater precisions.

KEY IDEAS

- The CNC turning machines are computer-controlled machines used to rotate workpieces while cutting tools shape them into desired forms.
- The main features include a rotating spindle, tool turret, chuck, tailstock, and CNC controller.
- These machines specialise in producing cylindrical parts with high precision by performing operations such as facing, turning, threading, drilling and grooving, all controlled through programmed instructions (G-code).

MEANING OF CNC, CNC MACHINING AND CNC TURNING MACHINES

CNC means Computerised Numerical Control or computer numerical control. Numerical control is a programmable automation in which the process is controlled by numbers, letters and symbols.

CNC machining is a process used in the manufacturing sector that involves the use of computers to control machine tools like lathes, mills and grinders.

CNC machines are automated machine tools that use computer systems to control the movements of the machine's parts. Unlike conventional lathes, CNC lathes can perform complex machining tasks without the need for manual intervention, improving accuracy, efficiency, and repeatability.

The Importance of CNC Machining

CNC machining is beneficial because it**:**

1. is high accuracy
2. is fast and saves time
3. is repeatable (produces multiple components exactly the same)
4. reduces human error
5. handles complex shapes
6. is safer than manual work
7. works with many materials

Types of CNC Machine(s)

The most common CNC machines are milling, turning (lathe), drilling, boring and grinding. Milling machines cut materials, including metal, using a cutting spindle, which can move to different positions and depths as directed by the computer instructions. Lathes use cutting tools on a rotating work piece to cut material. They are commonly used to make detailed cuts in symmetrical pieces, like cones and cylinders.

The CNC Lathe Machine

The CNC Lathe Machine is a highly advanced machine used in modern manufacturing to perform precise cutting, shaping, and turning operations on materials such as metal, plastic, and wood. It is controlled by a computer programme instead of manual control.

Figure 3.1: CNC Lathe Machine

Basic Operations Performed on The CNC Lathe Machine

1. Turning: The workpiece rotates while a stationary cutting tool removes material to shape the piece.
2. Facing: The cutting tool moves perpendicular to the workpiece, creating a flat surface.
3. Drilling: used to create holes in the workpiece.
4. Boring: Enlarging or finishing an existing hole.
5. Thread Cutting: Cutting internal or external threads on a workpiece.
6. Parting: The process of cutting off a piece of material from the workpiece.
7. Knurling: Making patterns on a workpiece for easy gripping.

The Main Parts of CNC Lathe Machine

1. Computer controller- Uses G-code or M-code programming.
2. Automatic Tool Changer- Switches between tools without stopping the machine
3. High Precision- Produces parts with tight tolerance.
4. Machine Bed and Carriage: Provide a stable platform and tool movement.
5. Headstock- It houses the main motor and spindle and holds the workpiece in place while rotating.
6. Tailstock- This provides support for the other end of the workpiece and can be adjusted to accommodate different lengths of materials.
7. Carriage- This holds and moves the cutting tool. The carriage is responsible for moving the tool to the correct position to cut or shape the material.
8. Tool Post- The component where the cutting tool is mounted. CNC lathes typically use automatic tool changers to switch tools for different operations.
9. Control Panel- This is where the CNC programme is entered, and it displays the machine's operational parameters and status.
10. Chuck- The device that holds the workpiece. It can be a 3-jaw or 4-jaw chuck, depending on the type of workpiece.
11. Spindle- This rotates the workpiece at various speeds

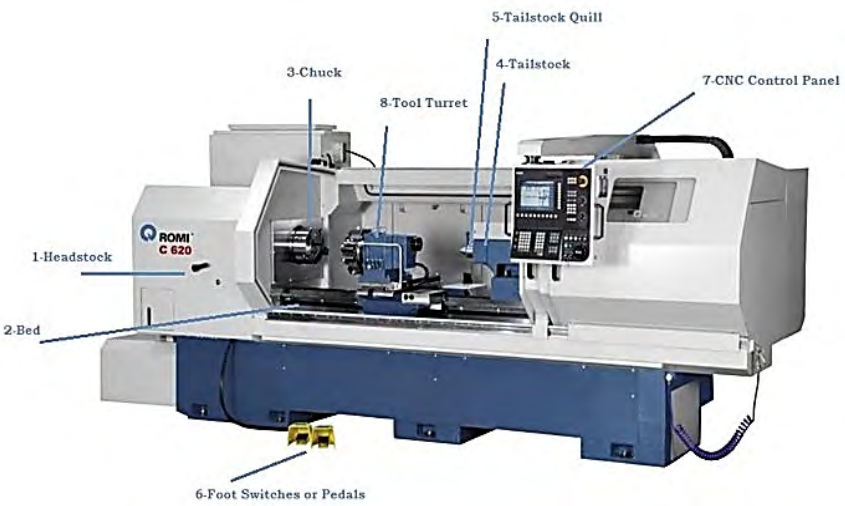


Figure 3.2: Main Parts of the CNC Lathe Machine

Working Principles of CNC Lathe Machine

The CNC machine uses G-codes and M-codes. G-codes define movements, while M-codes control machine functions such as starting/stopping the spindle, and coolant flow. The workpiece is placed in the chuck and securely clamped in position and the cutting tool is selected based on the desired operation and mounted in the tool post. The machine begins executing the programme, moving the cutting tool according to the instructions in the programme. The material is gradually shaped or cut based on the operations outlined. After the programme finishes, the workpiece is removed, and further finishing operations may be done manually or automatically.

Procedures for Using a CNC Lathe Machine

1. Know the Machine Parts
    a. Chuck: holds the material (workpiece).
    b. Tool turret: holds the cutting tools.
    c. Spindle: makes the workpiece spin.
    d. Control panel: where you start and stop the machine or load a programme.
2. Wear Safety Gear
    a. Put on safety glasses and appropriate clothing.
    b. Make sure long hair is tied back.
3. Clamp the Material
    a. Fix the round bar (metal or plastic) into the chuck.
    b. Tighten it properly so it doesn't move.
4. Choose the Right Cutting Tool
    a. Use the correct cutting tool for the job (e.g., turning or facing).
    b. Fit the tool into the tool turret.
5. Set the Zero Point: Tell the machine where the starting point is (this is called the work zero).
6. Load the CNC Programme
    a. The programme uses G-code (a special language for machines).
    b. Example: G01 means a straight cut.
7. Check with a Dry Run: Do a dry run (test run without cutting) to make sure everything works correctly.
8. Start the Machine
    a. Close the safety door.
    b. Press the cycle start button to begin cutting.
9. Watch the Process
    a. Keep an eye on the machine as it cuts.

b. Stop the machine if there is any problem.

10. Remove and Check the Part

    a. When finished, take out the part.
    b. Measure it with a rule or calliper to check the size.

11. Clean the Machine

    a. Remove any chips (small pieces of metal).
    b. Turn off the machine safely.

Table 3.1: The advantages and disadvantages of CNC lathe machines

Advantages	Disadvantages
1. Provide high levels of precision with minimal human error. 2. Produce identical parts without variation, making it ideal for mass production. 3. Operate continuously, increasing the speed of production and reducing interruptions. Can work continuously 24/7 4. Operators need to only programme the machine and monitor the process, reducing the need for manual labour. 5. Perform operations that are impossible or very difficult to do manually, such as intricate contours and profiles. 6. Fast production speed.	1. High Initial Cost- CNC lathe is expensive to purchase and install compared to manual lathes. 2. Skilled programming required- Operators must know how to write or understand G-code or CAD/CAM software. 3. Expensive to buy and maintain- Repairing and maintaining CNC systems can be costly and require specialists . 4. Power consumption is high- CNC machines use more electricity than traditional manual machines. 5. Job loss for manual machinist-Automation can reduce the need for manual machinist, affecting employment. 6. Software and system dependency- A software error or system crash can stop production entirely.

CNC Lathe Programming Codes (G-Codes and M-Codes)

G-codes (Geometric Codes)

1. G00: Rapid positioning
2. G01: Linear interpolation (cutting)
3. G02: Circular interpolation clockwise
4. G03: Circular interpolation counter clockwise
5. G04: Dwell (pause)
6. G20: Programming in inches
7. G21: Programming in millimetres

M-codes (Machine Codes)

1. M03: Spindle on clockwise

2. M04: Spindle on counter clockwise
3. M05: Spindle stops
4. M06: Tool change
5. M08: Coolant on
6. M09: Coolant off

The CNC Milling Machines

A CNC milling machine is a machine that cuts flat or shaped parts out of metal, plastic, or wood using a rotating tool. The machine follows a set of instructions from a computer programme. In another word, CNC milling is a machining process that employs computerised controls and rotating multi-point cutting tools to progressively remove material from the work piece in the form of chips and produce a final part. Milling is the process of machining using rotary cutters to remove material by advancing a cutter into a work piece.

Table 3.2: The functions of parts of CNC milling machine

Part	Function
Horizontal Spindle	Holds and rotates the cutting tool
Table	Holds the material (workpiece)
Tool Holder	Holds the tool in the spindle
Control Panel	Where you input or run the programme
Coolant System	Keeps the tool and workpiece cool

Table 3.3: Types of CNC Milling Machine(s)

Name	Image	Brief Description	Common Uses
Horizontal Milling Machine		A horizontal milling machine is a milling machine where the cutting tool is mounted on a horizontal spindle. This design allows the machine to perform heavy-duty cutting tasks efficiently, especially for removing large amounts of material.	1. Making slots and groove(s) 2. Gear cutting 3. Heavy material removal
Vertical Milling Machine		A vertical milling machine is a type of milling machine where the cutting tool is mounted on a vertically oriented spindle. The spindle moves vertically, allowing the cutter to remove material from the top of the workpiece.	1. Drilling, boring, and cutting slots 2. Surface milling 3. Engraving and light-duty milling

Universal Milling Machining		A universal milling machine is a versatile type of milling machine that can perform a wide range of milling operations. It features a swivelling table, allowing the table to rotate horizontally to different angles, which makes it ideal for angular milling, helical milling, and other complex tasks.	1. Angular milling 2. Helical gear cutting 3. General and complex tasks

CNC Milling Operations

The main operations of CNC milling are classified into two, namely

1. Planar milling. This operation involves point to point and straight cut motion control systems
2. Contour milling. This operation involves profile milling of cavities and cores, contour area machining, and machining of profile corners.

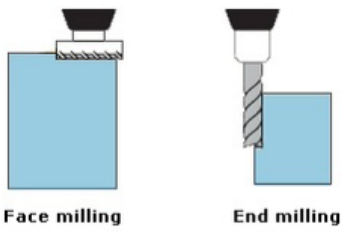
Procedures for Using a CNC Milling Machine

1. Design the Part: Use CAD software to create the part you want.
2. Convert to Code: Use CAM software to turn the design into G-code.
3. Load the Material: Place the workpiece on the machine table and clamp it.
4. Load the Programme: Send the G-code to the machine.
5. Set Zero Point: Tell the machine where to start cutting (called setting the origin).
6. Run a Dry Test: Make sure the programme runs correctly without cutting.
7. Start Cutting: Start the machine. It will cut the part automatically.

CNC Milling Machine Tools and Their Uses

A wide range of tools and configurations are available for CNC milling machines. Below are the most commonly used tools for prototype and short run production machining.

Table 3.4: CNC milling machine tools and their uses

S/N	Name of Tool	Photo/Sketch of Tool	Uses of tool
1	End mills and Face mills		Use end mills for detail and depth, and face mills for speed and surface

2	Corner rounding tools		They are used in machining to create smooth, rounded edges on parts instead of sharp corners.
3	Slot tools		They are used in machining to create precise grooves, slots, or keyways in a workpiece.
4	Spot-centre drill		It is used in machining to create a precise starting point for a larger drill bit.
5	Twist drill		A twist drill is one of the most common and versatile cutting tools used to create cylindrical holes in materials like metal, wood, plastic, and composites.
6	Tap		In machining, a tap is a cutting tool used to create internal threads inside a pre-drilled hole—basically turning a smooth hole into one that can accept a screw or bolt.
7	Reamer		A reamer is a precision cutting tool used in machining to enlarge and finish pre-drilled holes with high accuracy and a smooth surface finish.

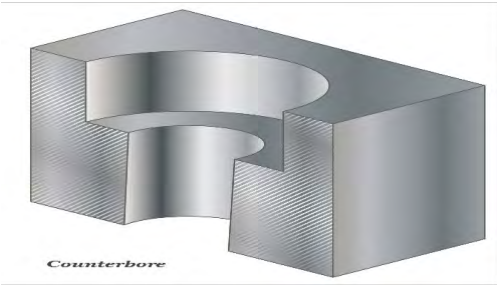
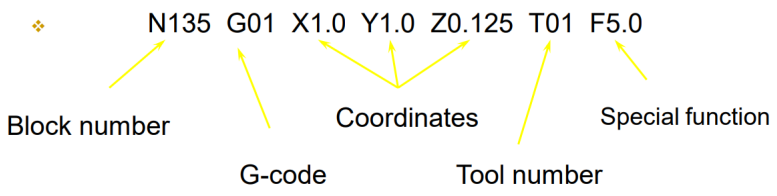
8	Counter bore		A counterbore is used in machining to create a flat-bottomed, enlarged recess at the top of a hole.

Table 3.5: Advantages and disadvantages of CNC milling machine

Advantages	Disadvantages
1. Follow programmed instructions very precisely. This makes the parts they produce very accurate. 2. Every part made is exactly the same. This is important when making many identical parts. 3. Work faster than manual machines and can run all day and night with little supervision. 4. Since the machine follows a programme, less chance of mistakes compared to manual. 5. Produce shapes that would be very difficult or impossible to make by hand. 6. Operators do not need to be close to moving tools, so the process is safer. 7. Once a design is programmed, it can be reused many times in the future. 8. Fewer skilled workers are needed because one operator can run several machines.	1. High initial cost 2. Need higher qualified and skill operators 3. It is expensive to repair/ high maintenance cost 4. Programming errors 5. Less flexible for simple jobs 6. Energy consumption 7. Loss of traditional skills

Basic Concept of Part Programming

1. Part programming contains geometric data about the part and motion information to move the cutting tool with respect to the workpiece.
2. Basically, the machine receives instructions as a sequence of blocks containing commands to set machine parameters; speed, feed and other relevant information.
3. A block is equivalent to a line of codes in a part programme.



Conclusion

In conclusion, the term CNC stands for Computer Numerical Control, which means the machines are operated using programmed instructions instead of being controlled manually. CNC turning machines are essential tools in modern manufacturing that use computer control to produce accurate and high-quality cylindrical parts.

Their main features, such as rotating spindle, automatic tool changer, and digital control system allow for efficient, safe, and repeatable operations. The step-by-step process, from design to final product, show how automation and precision work together to save time, reduce errors, and improve production quality.

With their computer control and automation features, they allow for fast, precise, and repeated production of cylindrical parts, making them essential in industries like automative, aerospace, and machinery.

In modern engineering and manufacturing, CNC machines have become essential tools. These machines are used to produce parts with high accuracy, faster speed, and greater consistency compared to traditional machines. There are several types of CNC machines, but two of the most commonly used in workshops and training centres are the CNC lathe machine and the CNC milling machine. A CNC lathe is mainly used for producing round or cylindrical parts. The workpiece is clamped in a chuck and rotated, while a cutting tool moves in different directions to shape the material. Unlike the lathe, a CNC milling machine works by keeping the workpiece still while the rotating cutting tool moves across it. Milling machines can produce flat surfaces, slots, holes, and even complex 3D shapes.

Activity 3.1 Hands-on Introduction to CNC Turning and Milling Machines

You are a technical student at a Secondary/Technical School. Your Applied Technology teacher has assigned you and your classmates to the school's CNC turning and CNC milling machines workshop to gain hands-on experience with the CNC turning and milling machines for the first time.

1. Take pictures of types of CNC turning and milling machines during the visits to refer to later
2. Make simplified sketches of some CNC turning and milling machines in the workshop.
3. Prepare a photo or sketch album and display it in class for appraisal.
4. Prepare a report to include the main components and features of the CNC turning and milling machines, and discuss in class with your classmates in groups of 2-4
5. Demonstrate the basic operations of CNC turning and CNC milling machines in the production of simple components such as a metal shaft with a slot.

Activity 3.2 Exploring, Documenting, and Demonstrating Basic CNC Operations

You are a student intern at Tech Plus Engineering Workshop, where you are working with the quality control team. The team just completed a batch of CNC-turned shafts intended for use in a small gearbox assembly. However, during inspection, several parts failed the quality check.

Your task in groups is to help identify, analyse, and suggest solutions for the defects found on the CNC turned parts.

Note

Use ICT tools to facilitate your work.

EXTENDED READING

S/N	ISSUE	LINK
1.	Main features and performing operations	Understanding CNC Turning Machines: What They Are and How They Work – TMC Technologies
2.	CNC lathe machines	https://www.3erp.com/blog/cnc-lathe/
3.	The need for CNC machining	The Importance of CNC Machining in Modern Manufacturing
4.	Types of CNC machine	https://www.theengineerspost.com/types-of-cnc-machine/
5.	Basic CNC lathe Operations	https://www.cnclathing.com/guide/different-operations-on-lathe-machine-what-is-a-cnc-lathe-used-for-cnclathing
6.	Basic components of CNC lathe machine	https://www.xometry.com/resources/machining/cnc-lathe-parts/
7.	Basic parts of CNC lathe machines	https://www.xometry.com/resources/machining/cnc-lathe-parts/
8.	Working principles of CNC lathe machine	https://www.yashmachine.com/blog/understanding-the-working-principles-of-a-cnc-lathe-machine/
9.	Steps for using a CNC lathe machines	https://artizono.com/step-by-step-guide-to-using-a-cnc-lathe-for-beginners
10.	Advantages of CNC lathe machines	https://powertoolsmag.com/cnc-lathes-advantages-disadvantages

11.	Disadvantage of CNC drilling machines	https://powertoolsmag.com/cnc-lathes-advantages-disadvantages
12.	CNC lathe programming codes (G-codes and M-code)	https://www.cnccookbook.com/cnc-lathe-gcode-mcode-reference-list-turning/
13.	CNC milling machines	https://tormach.com/machines/mills.html
14.	Main parts of a CNC milling machine	https://www.madearia.com/blog/parts-of-a-cnc-milling-machine/
15.	Types of CNC milling machines	https://www.cncsourced.com/cnc-machining/types-of-cnc-machines/
16.	Universal machining centre	https://www.grobgroup.com/en/products/product-range/universal-machining-centers/
17.	CNC milling operations	https://www.rapiddirect.com/blog/what-is-cnc-milling/
18.	CNC tools	https://www.cnc-tool.com/
19.	Advantages of CNC milling machine	https://www.china-machining.com/blog/cnc-milling-advantages-and-disadvantages/
20.	Disadvantages of CNC milling machine	https://www.china-machining.com/blog/cnc-milling-advantages-and-disadvantages/

REVIEW QUESTIONS

You are a technical student at Modern Skills Secondary/Technical School. Your instructor asks your class to evaluate whether the school workshop should continue using manual machines or invest in CNC lathe and milling machines for training.

1. Identify five (5) reasons CNC machining is necessary?
2. Identify five (5) main features of a CNC lathe machine
3. Identify five (5) main features of a CNC milling machine
4. Describe the main steps to follow when using the CNC lathe machine
5. Describe the main steps to follow when using the CNC milling machine

UNIT 4: AUTOMOTIVE TECHNOLOGY

Introduction to Engine Technology

INTRODUCTION

In this unit, you will explore two essential systems that help internal combustion engines work efficiently: the air intake system and the exhaust system. These systems manage how air enters the engine, how fuel is burnt, and how waste gases are safely removed. Understanding them will help you grasp key engineering principles from boosting power using turbochargers to reducing pollution through catalytic converters. As you read, pay attention to how airflow and emissions are carefully controlled to balance engine performance, fuel economy, and environmental impact. Whether you plan to service engines, study vehicle systems, or apply these concepts in real-world Ghanaian contexts, this knowledge is foundational. As you dive into the workings of each system, remember that the concepts in this unit are founded on the types of internal combustion engines you learned about in sections 1 and 2 of your first year Automotive Technology course.

KEY IDEAS

- Air filters remove or trap contaminants like dust and moisture from the incoming air before it enters the engine.
- The air intake system provides clean, oxygen-rich air to the engine to support efficient combustion.
- The exhaust system is designed to remove combustion gases and also reduce toxic emissions in the exhaust gases.
- The intake manifold evenly distributes air or an air-fuel mixture to the engine's cylinders to ensure balanced combustion and consistent performance across all cylinders.
- The mass airflow sensor measures the exact mass of air entering the engine and sends signals to the ECU to help adjust fuel delivery and optimise combustion.
- The throttle body controls how much air enters the engine by adjusting a butterfly valve in response to the driver's input through the accelerator pedal.

AIR INTAKE SYSTEM

The air intake system is a very important part of internal combustion engines. It is responsible for supplying clean, oxygen-rich air to the cylinders for combustion. Since it requires a good amount of air to properly burn the fuel, the air intake system serves to draw in outside air, filter it, and direct it into the engine. This could be done by natural aspiration, where air is admitted into the engine by atmospheric pressure, or by forced induction, where air

is admitted into the engine above atmospheric pressure using an air pump (supercharger). The system ensures the right air-to-fuel ratio is obtained for efficient combustion, power generation, fuel economy, and controlled emissions. The air intake system is located in the fender, car grille or hood scoop, where it can easily obtain cold, oxygen-rich air from outside the engine.

Main Components of the Air Intake System

The components of a modern air intake system include the following:

1. air filter
2. intake duct
3. mass airflow sensor
4. throttle body
5. intake manifold
6. turbocharger or supercharger

Air Filter

The air filter removes dust, dirt, debris and moisture from the incoming air to ensure only clean air is delivered to the combustion chamber and thus protect the internal components from wear. Filters are typically made of pleated paper, foam, or cotton gauze, and are located in the air filter housing or housing.

1. Paper air filter

Paper air filters represent the most widely used filtration type in modern automobiles. Their popularity is largely due to their price affordability. However, they are not suitable for all applications. These filters are particularly suitable for smaller vehicles and areas with low levels of airborne pollutants and dust. Paper filters are not reusable and so require regular replacement.

Figure 4.1: Paper air filter

2. Gauze air filter

Gauze air filters last longer than paper filters. Unlike paper filters, this type is reusable, as they can be washed when dirty. There are two main types: oiled gauze, which is the most commonly used and only needs care every 5,000 miles, and dry synthetic gauze, which requires regular cleaning.

Figure 4.2: Gauze air filter

3. **Foam air filter**

   Foam air filters are reusable and ideal for dusty conditions due to their ability to trap large particles effectively. Some come pre-oiled, while others need oiling to improve filtration performance. They require regular cleaning and re-oiling to keep airflow smooth and protect the engine. Though durable, they may not capture finer particles as well as paper or gauze filters.

Figure 4.3: Foam air filter

Air Flow Sensor/Mass Air Flow (MAF) sensor

The mass airflow (MAF) sensor is found within the intake pipe to ensure that it is able to monitor the amount of air entering the engine. It measures the mass of air entering the engine so the car can use the right amount of fuel. It is usually found between the air filter and the intake manifold. Most MAF sensors use a heated wire or a hot film that cools down as air flows over it. The sensor sends signals to the engine's computer (ECU) to help control fuel, performance, and emissions.

Figure 4.4: Mass Air Flow Sensor

Another device, called airflow meter, is also used to measure the volume of air that enters the engine. This system uses a mechanical vane or flap to measure the amount of air. This type is mostly found on older vehicles.

Figure 4.5: Vane-type airflow sensor

Throttle Body

The throttle body is a key component in a car's air intake system that controls the amount of air entering the engine. It is usually located between the air filter and the intake manifold. The throttle body contains a butterfly valve that opens and closes depending on how much

the driver presses the accelerator pedal. When the valve opens wider, more air flows into the engine, allowing it to burn more fuel and produce more power. A sensor attached to the throttle body also sends signals to the engine control unit (ECU) to help maintain proper engine performance and fuel efficiency.

Figure 4.6: Throttle body

Intake Manifold

The intake manifold is a part of the engine that directs air—or a mixture of air and fuel—to the combustion chambers. It is typically made of metal or plastic and is connected to the throttle body on one end and the engine's intake ports through the cylinder head. It ensures that the air or charge is distributed evenly to the various cylinders for proper and balanced combustion. In engines with fuel injection, the manifold usually carries only air, while in older, carburetted engines, it carries a mixture of air and fuel. See ***Figure 4.7***.

Figure 4.7: Intake manifold

Turbocharger or Supercharger

A turbocharger or supercharger is a type of forced induction device that increases the volume of air entering an internal combustion engine, thereby improving its torque and overall power output. Both systems compress the incoming air, allowing a greater mass of air-fuel mixture to be combusted within the engine cylinders.

The supercharger, in particular, is mechanically driven by the engine via a belt, gear, or chain connected to the crankshaft. Its direct link to the engine enables instantaneous throttle response and immediate power delivery, making it highly effective in performance

applications. However, this mechanical connection also means it consumes a portion of the engine's power to operate, leading to lower thermal and fuel efficiency compared to a turbocharger, which harnesses exhaust gases instead. In essence, the supercharger serves as an engine-powered air pump that prioritises responsiveness over energy conservation. Figure 4.8

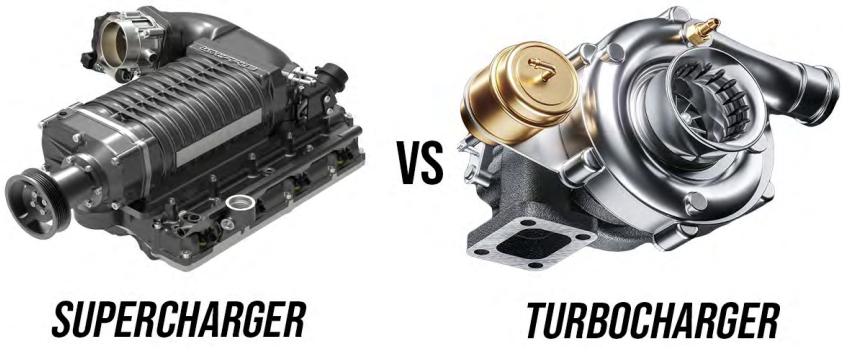


Figure 4.8: Turbocharger and supercharger

Exhaust System

The exhaust system is carefully designed to safely carry out combustion gases away from the engine and vehicle cabin, while also reducing harmful emissions and noise.

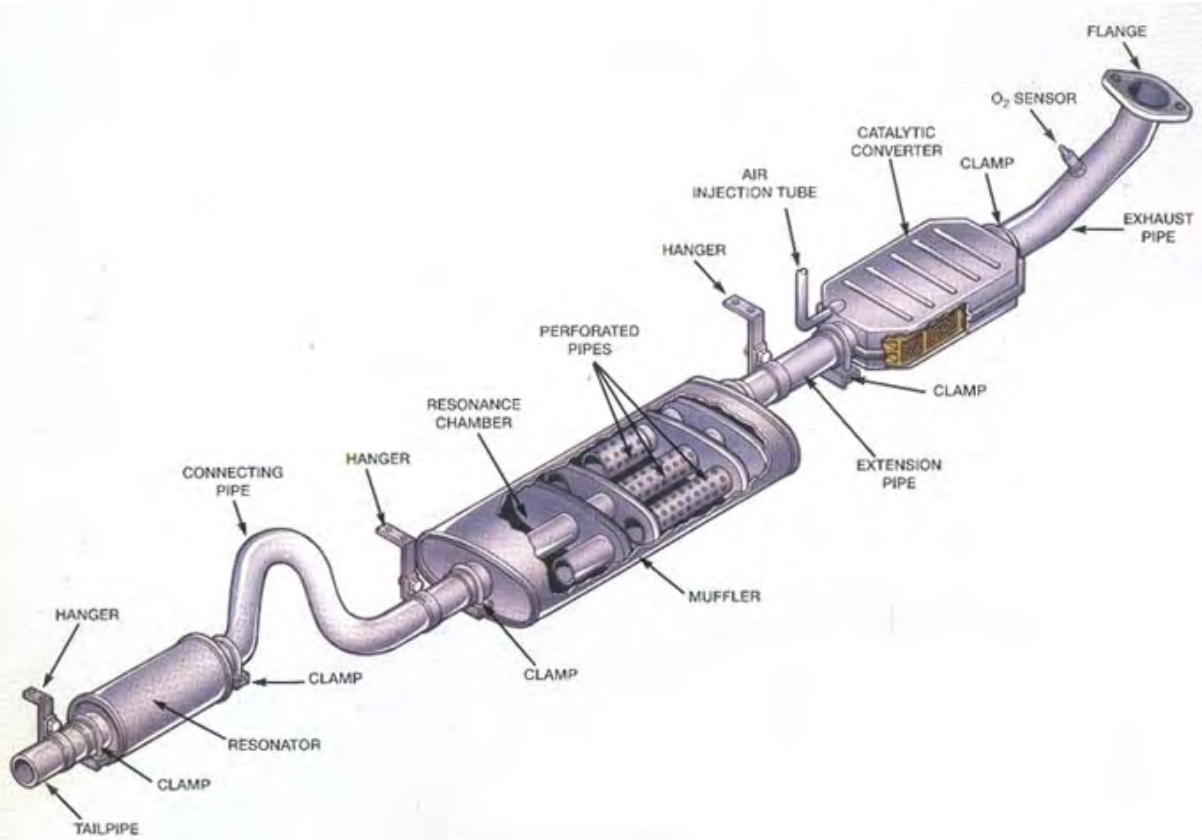


Figure 4.9: The vehicle exhaust system

Functions of the Exhaust System

The exhaust system provides the following functions: it

1. carries combustion gases away from the engine and vehicle occupants.
2. reduces harmful emissions by converting toxic substances into safer compounds.
3. reduces engine noise using components like the muffler and resonator.
4. maintains proper backpressure to support engine torque and fuel efficiency.
5. helps dissipate heat generated during combustion to protect engine parts.
6. contributes to fuel economy by improving overall combustion efficiency.
7. helps to regulate the air-fuel mixture for optimal performance.
8. enhances engine output by improving airflow and reducing restrictions in the exhaust path.

Components of the Exhaust System

A typical exhaust system consists of the following parts

1. Exhaust manifold

This component connects directly to the engine's cylinder head and collects exhaust gases from each cylinder. It channels these gases into a single pipe, which in turn directs the gases away from the engine.

Figure 4.10: Exhaust manifold

2. Oxygen sensor

The oxygen sensor monitors the oxygen content in the exhaust gases and sends the information to the engine control module (ECM) for interpretation. The data then helps the ECM to adjust the air-fuel mixture for efficient combustion and reduced emissions.

Figure 4.11: Oxygen sensor

3. Catalytic converter

This component is positioned after the manifold. It uses chemical reactions to convert harmful gases like carbon monoxide, hydrocarbons (HC), and nitrogen oxides (NOx) into less harmful substances such as carbon dioxide (CO_2), water vapour (H_2O), and nitrogen (N_2). The ability of the catalytic converter to remove these harmful gases helps to lower air pollution and make vehicles more environmentally friendly.

Figure 4.12: Catalytic converter

4. Muffler or silencer

This part reduces the overall noise produced by exhaust gases. It uses chambers, baffles, or sound-absorbing materials to quiet the explosive pulses from combustion.

Figure 4.13: Muffler

5. Exhaust pipes

These are metal tubes which connect all the exhaust system components and carry gases through the system. They are designed to withstand high temperatures and corrosion while maintaining proper backpressure.

Figure 4.14: Exhaust pipe

Activity 4.1 Identification and Description of Exhaust System Parts

Figure 4.15 shows the main component parts of a car exhaust system.

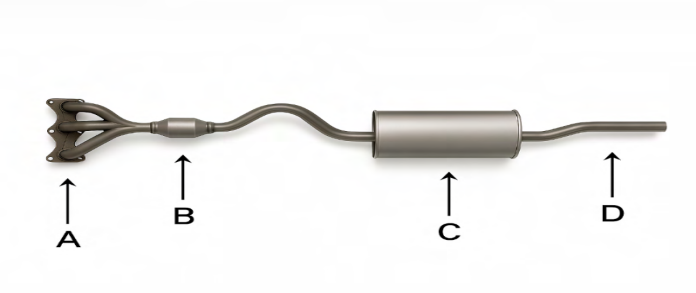


Figure 4.15: Parts of the vehicle exhaust system

1. Identify each of the parts indicated by the arrows A, B, C and D.
2. Describe each of the parts named in (1) above, stating clearly their functions.
3. Explain what might happen if the part labelled 'C' is damaged or removed?

Activity 4.2 Purpose of the Intake and Exhaust Systems

1. Watch the two videos below:
   a. Engine air intake system: https://youtu.be/6QyTkK1OC_8?si=Az6i_lRW30DhGhdB
   b. Engine exhaust system: https://youtu.be/W6dIsC_eGBI?si=6YgFSgFZOWIf947s
2. After watching the videos,
   a. prepare your own neat sketch of an integrated air intake and exhaust system of a car and label all the major parts.
   b. provide a brief description of each of the parts and what they do.

EXTENDED READING

1. What Does An Intake Do?
2. What Are the Parts of the Exhaust System? - AutoZone
3. What is an exhaust system: everything you need to know | Minit -Tune Brake & Auto Centres

REVIEW QUESTIONS

1. Explain how each component of the air intake system contributes to the overall performance of the engine.
   a. Air Filter
   b. Intake Duct
   c. Mass Air Flow Sensor
   d. Throttle Body
   e. Intake Manifold
   f. Turbocharger or Supercharger
2. a. Prepare a table for comparing three differences between naturally aspirated (or atmospheric) air and turbocharged air intake systems.
   b. Explain how each of the two air intake systems in 2(a) affects engine performance, fuel efficiency and emissions under varying driving conditions.
3. Design a process to diagnose and repair a malfunctioning exhaust system in a vehicle, taking into consideration the following areas:
   a. symptoms of failure
   b. safety precautions
   c. tools required
   d. troubleshooting steps
   e. repair action
   f. final check
4. a. Compare the functions of the muffler and catalytic converter.
   b. Describe how each contributes to the safety and efficiency of the exhaust system.

SECTION

2 CNC MACHINES AND ENGINES

UNIT 5: METAL TECHNOLOGY

Engineering Materials, Tools and Machines

INTRODUCTION

CNC (Computer Numerical Control) drilling and grinding machines are automated machines used in manufacturing to perform precise drilling and surface finishing tasks. These machines are controlled by computers using programmed instructions like G-code, which ensures highly accuracy, speed, and consistency. They are widely used in industries such as automotive, aerospace, metal fabrication, and electronics.

CNC machines are important tools in modern engineering and manufacturing. They use computer programmes to control the movement of tools with high accuracy. Two common types of CNC machines are the CNC drilling machine and CNC grinding machine. Each of these machines plays a key role in producing precise and high-quality parts, often used in automotive, aerospace, and industrial applications.

In Year 2, you learned about the description of twist drill and used the drilling grinding machines. You learnt the features of the twist, the drilling and grinding machines and their uses manually. In year 3 you will study how the drilling and grinding machines operate using CNC (Computer Numerical Controls- G-code and M-code).

These codes offer instructions to these machines in a language they understand. These codes communicate to the CNC machines the direction of operations, how fast to run, and what to do at a particular time, and systematically to perform actions. By using these codes:

- The twist drill fixes perfectly to the drilling machine.
- The drilling machine turns to make round holes perfectly.
- The grinding wheels are fixed perfectly to the grinding machine.
- The grinding machine performs automatically as directed by the codes.

Therefore, using CNC coding helps us to work faster, safer, and with greater precisions.

KEY IDEAS

- The CNC drilling and grinding machines are computer-controlled systems used to automate precise material removal.
- CNC drilling machines use rotating drill bits to create accurate holes in a work piece. Key features include a spindle, tool changer, drill bits, and a CNC controller.
- Common operations include centre drilling, deep-hole drilling, counterboring, and tapping.
- CNC grinding machines use abrasive wheels to smooth or shape surfaces.
- Their key features include a grinding wheel, worktable, coolant system and CNC controller.

- Operations include surface grinding, cylindrical grinding, and contour grinding, all done with high precision and fine finish.

COMPUTER NUMERICAL CONTROL DRILLING AND GRINDING MACHINES

CNC Drilling Machine

A CNC drilling machine is a computer-controlled machine used to make precise holes in materials like metal, plastic, or wood.

Drilling is making round/circular holes using a rotating drill bit. Drilling is commonly used for mass production. The drilling machine (drilling press) is used to create or enlarge holes.

There are two main CNC drilling machines for different jobs, these are CNC bech drill and CNC pillar drill.

CNC bench drill- Used for drilling holes through raw materials such as wood, plastic and metal.

Figure 5.1: CNC Bench Drill

CNC pillar drill- A larger version that stands upright on the floor. As the bench drill, it can be used to drill larger pieces of materials and produce bigger holes.

Figure 5.2: CNC Pillar Drill

Table 5.1: Functions of Parts of CNC Drilling Machine

Part	Function
Drill Bit	Cuts the hole
Spindle	Holds and spins the drill bit

Worktable	Holds the workpiece in place
Control Panel	Input for the CNC programme (e.g. G-code)
Drive Motors	Move the machine along X, Y, Z axes

How the CNC Drilling Machine Works

The process begins by writing a programme using commands, such as G-code. Once the material is securely fixed on the machine's table, the drill bit starts spinning and moves into the correct positions. The machine then drills holes according to the programmed instructions.

Table 5.2: Advantages and Disadvantages of CNC Drilling

Advantages	Disadvantages
1. High accuracy/precision 2. Fast and repeatable/faster production 3. Low human error 4. Can drill complex patterns/ complex operations are made easy 5. Consistency and repeatability 6. Automation 7. Reduced waste 8. Increased safety 9. Cost-effective for large batches 10. Integration with design software 11. Less skill required for operation.	1. High initial cost - The machine and setup can be expensive for small workshops or beginners. 2. Requires skilled operators- Operators must understand CNX programming and setup procedures. 3. Maintenance costs- Repairs and servicing of CNC drilling machines can be costly. 4. Not Ideal for all Jobs- Overkill for simple, low-volume drilling tasks where a manual drill would be faster. 5. Software issues- A small programming error or software crash can damage workpieces or cause delays 6. Energy consumption- CNC drills typically consume more power than manual drills

Main Uses of CNC Drilling Machine

1. Creating holes in metal parts
2. Creating holes in plastic and wood components
3. Tapping holes
4. Precision part manufacturing
5. Pipes and tubing industries
6. Car engine parts
7. Printed circuit boards (PCBs)
8. Metal frames and plates

Safety Precautions to be Observed When Using the CNC Drilling Machine

1. Wear protective gear (wear safety glasses at all times) .
2. Secure the workpiece
3. Avoid loose clothing
4. Keep hands away from the drill bit.
5. Make sure the material is properly clamped.
6. Never touch moving parts.
7. Keep the work area clean
8. Know where the emergency stop button is
9. Only proper trained personnel should operate the CNC Drilling machine
10. Do not leave machine unattended

CNC Grinding Machine

CNC grinding is a process where a computer controls a grinding machine to shape or finish metal or other hard materials. It is often used to give parts a smooth surface or to make them the exact size needed. Grinding metal process uses a coated wheel that slowly removes metal to create a part. Through the years, grinding was done on a manual machine, but with the advent of CNC technology, the grinding process has advanced.

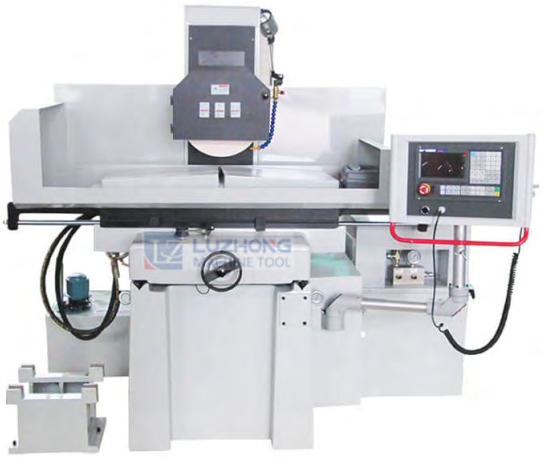


Figure 5.3: High Precision CNC Surface Grinding Machine

Table 5.3: Main Parts and Uses of CNC Grinding Machine

S/N	Part	Uses
1	Control panel	Where the operator inputs the programme (e.g. G-code).
2	Grinding wheel	The rotating wheel that does the cutting or shaping
3	Worktable	The surface where the workpiece is placed and fixed
4	Coolant system	Keeps the parts and tools cool during grinding

How the CNC Grinding Machine Works

1. A programme is written with specific instructions for grinding.
2. The workpiece (material) is fixed onto the machine's table.
3. The grinding wheel spins at high speed.
4. The machine moves the wheel accurately to remove material.
5. The part is shaped or finished exactly as programmed.

Table 5.4: Advantages And Disadvantages Of CNC Grinding

Advantages	Disadvantages
1. Very accurate and repeatable. 2. Can create very smooth finishes. 3. Can grind complex shapes. 4. Reduces human error 5. Less material waste 6. Faster production speed 7. Improved worker safety 8. Data storage and reuse	1. High initial cost-Expensive to buy and set up. 2. Skilled Operators needed -Trained personnel required. 3. High maintenance costs- Repairs, part replacements, and maintenance can be expensive. 4. High energy consumption -A lot of power is used during operations. 5. Tool wear and replacement - Grinding wheels wear out easily. 6. Software/ control failures- Any glitch in the CNC system or software can halt operations. 7. Limited flexibility in some designs- may not be suitable for very complex or irregular shapes.

Safety Precautions to be Observed When Using the CNC Grinding Machine

1. Wear personal protective equipment (always wear safety glasses).
2. Check the grinding wheel
3. Use the right wheel for the material
4. Set proper speeds and feeds
5. Use the machine guard
6. Keep your hands away from the moving wheel.
7. Make sure the workpiece is fixed properly.
8. Never touch the grinding wheel when it's moving.

Conclusions

In conclusion, CNC drilling and grinding machines are important tools in modern manufacturing that provide high precision, speed, and automation. The main features of these machines- such as the computer control unit, automatic tool changers, cooling systems, and enclosed work areas-allow for safe, efficient, and consistent operations. With CNC drilling machines, accurate and uniform holes can be made quickly, while CNC grinding machines are used to create smooth, polished, and precisely shaped surfaces. These machines reduce manual effort, improve product quality, and support mass production in industries like automotive, aerospace, and metalworking. Understanding how to use these machines

helps prepare students and workers for technology- driven careers in manufacturing and engineering.

Activity 5.1 Key Features and Basic Operations for Metalwork Components

1. You are currently taking a course in CNC machine technology. As part of your practical training, your teacher will guide you to form groups of 2-4 members to perform hands-on activities with two advanced machines: the CNC Drilling machine and the CNC Grinding machine

2. Identify the main features of the machines and perform basic operations to complete a simple metalwork component, a drilled plate with a smooth surface finish.

EXTENDED READINGS

S/N	ISSUE	LINK
1	Main feature and performing operations using drilling and grinding machines	https://themechanicalengineering.com/drilling-machine/
2	CNC drilling machines	https://www.3erp.com/blog/cnc-drilling/
3	Main parts of CNC drilling machines	https://proleantech.com/what-is-cnc-drilling-working/#:~:-text=The%20main%20components%20of%20the%20drill-ing%20process%20are,worktable,%20chuck,%20and%20radial%20arm,%20among%20other%20parts.
4	How the CNC drilling machine works	https://www.rapiddirect.com/blog/what-is-cnc-drilling/#:~:-text=CNC%20drilling%20is%20a%20computer-con-trolled%20subtractive%20machining%20process,,station-ary%20workpiece%20(maybe%20wood,%20metal,%20plastic,%20or%20composite).
5	Advantages of CNC drilling	https://prototool.com/cnc-drilling/#:~:text=Here%20are%20the%20key%20advantages%20of%20CNC%20drilling,seam-lessly%20work%20with%20other%20machining%20opera-tions,%20enhancing%20efficiency.
6	Disadvantages of CNC drilling machines	https://knowcnc.com/what-are-3-disadvantages-of-a-cnc-ma-chine/#:~:text=Some%20disadvantages%20of%20CNC%20machining%20include%20higher%20cost,complexity%20for%20small-scale%20productions,%20and%20limited%20design%20flexibility.

7	Common uses of CNC drilling	https://shop.machinemfg.com/cnc-drilling-process-types-and-applications/
8	Safety tips when using CNC drilling machine	https://knowcnc.com/8-advanced-safety-protocols-every-cnc-machinist-must-know/#:~:text=These%20include:%20wearing%20appropriate%20personal%20protective%20equipment%20(PPE),and%20staying%20alert%20and%20focused%20while%20operating%20machinery.
9	CNC grinding machines	https://www.cncmasters.com/cnc-grinding-machine-buyers-guide/
10	High precision, CNC surface grinding machine	https://www.chevalierusa.com/precision-cnc-surface-grinder-001-01-01.html
11	Main parts of CNC drilling machines	https://proleantech.com/what-is-cnc-drilling-working/#:~:text=The%20main%20components%20of%20the%20drilling%20process%20are,worktable,%20chuck,%20and%20radial%20arm,%20among%20other%20parts.
12	How the CNC grinding machine works	https://www.bing.com/videos/riverview/relatedvideo?q=How+the+CNC++grinding++machoine+works&mid=5423233B0396108234DC5423233B0396108234DC&FORM=VIRE
13	Advantages of CNC grinding	https://artizono.com/cnc-grinding-advantages-disadvantages-and-best-practices/
14	Disadvantages of CNC grinding	https://artizono.com/cnc-grinding-advantages-disadvantages-and-best-practices/#:~:text=Disadvantages%20of%20CNC%20Grinding%201%20High%20Initial%20Costs,Suitability%20Challenges%20...%208%20Production%20Scalability%20Limits
15	Safety precautions to be observed when using the CNC grinding machine	https://www.howengineeringworks.com/questions/what-are-the-safety-precautions-for-using-cnc-machines/

REVIEW QUESTIONS

Your class has been introduced to CNC drilling and CNC grinding machines in a metal workshop. The instructor assigns your group to prepare a report and class demonstration comparing the functions, differences, main parts, advantages and disadvantages of both machines.

1. Explain the functions of the CNC drilling machine.
2. Explain the functions of the CNC grinding machine.
3. In a table, state the difference between CNC drilling and CNC grinding machines
4. Identify and describe five (5) main parts of the CNC drilling machine.
5. Identify and describe five (5) main parts of the CNC grinding machine.

UNIT 6: AUTOMOTIVE TECHNOLOGY

Introduction to Engine Technology

INTRODUCTION

In modern automotive engines, boosting engine power without increasing engine size has become essential. Superchargers and turbochargers are devices that enhance engine performance by forcing more air into the combustion chamber. This operation allows more fuel to burn efficiently. While both systems increase power and torque, they operate differently. One uses mechanical drive, the other uses exhaust gases. This section will help you understand how these systems work, their types, advantages, and disadvantages. By learning how they function, you will gain insight into the role of forced induction in engine performance, fuel efficiency, and emissions control. The foundational concepts you gained from sections 1 and 4 in Applied Technology Year 1 will improve your understanding of these new ideas.

KEY IDEAS

- Both systems have pros and cons depending on application
- Different types of superchargers offer unique performance traits
- Intercoolers play a vital role in both systems
- Superchargers use mechanical power to increase engine output
- Turbochargers use exhaust gases to boost performance

SUPERCHARGER

A supercharger is a mechanically powered device that increases the density, volume and pressure of air that enters the combustion chambers to enhance the engine's power performance. It operates by compressing ambient air through an air compressor or blower and delivering it under pressure into the intake manifold. The increase in pressure ensures that a greater mass of air is available during the intake stroke, which allows more fuel to be mixed and burned.

An engine with a supercharger produces a more forceful power stroke, which translates into increased torque and horsepower (brake power). Superchargers are typically driven by the engine's crankshaft via belts, gears, or chains.

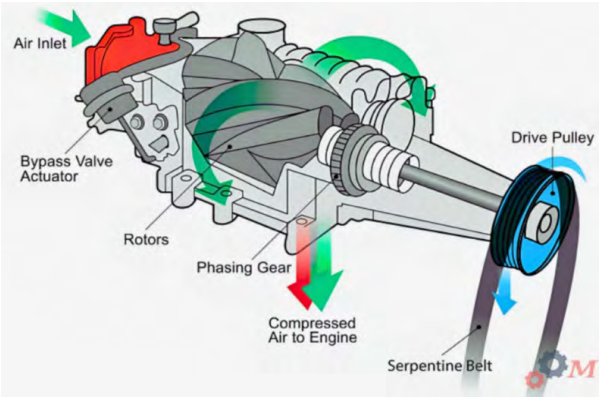


Figure 6.1: Supercharger

Working Principle of Supercharger

A supercharger works on the principle of forced induction, where it compresses ambient air and delivers it under pressure to the engine's intake manifold. This process increases the air density, allowing more oxygen to enter the combustion chamber. With more oxygen available, the engine can burn more fuel during each cycle, resulting in a stronger power stroke and increased torque and horsepower (brake power).

The supercharger is mechanically driven by the engine's crankshaft using a belt, gear, or chain. As the engine rotates, it powers internal components such as impellers, rotors, or screws—depending on the type of supercharger. These components compress the incoming air and push it into the intake manifold at a pressure higher than atmospheric levels.

Because the supercharger is directly linked to the engine, a supercharger provides instant boost without the lag typically associated with turbochargers. However, this mechanical connection also means it consumes some engine power to operate, which can affect overall efficiency.

Types of Superchargers

There are three main types of superchargers: Roots, twin-screw and centrifugal. The main difference is how they move air to the intake manifold of the engine. All three types provide a boost to the engine's performance, but they differ considerably in their efficiency. Each type of supercharger is available in different sizes, depending on the type of vehicle and the general performance of the vehicle.

1. **Roots Supercharger**

   The roots supercharger, also called a root-blower, uses two rotating lobes that mesh together to move air. These lobes spin in opposite directions, trapping air and pushing it toward the engine through the outlet valve. As more air enters the engine, it allows for more fuel to burn, which increases the engine's power and speed. However, this type of supercharger produces a lot of heat and is not very efficient. It is also large and heavy, usually placed on top of the engine, and it pushes air in pulses rather than a smooth, steady flow.

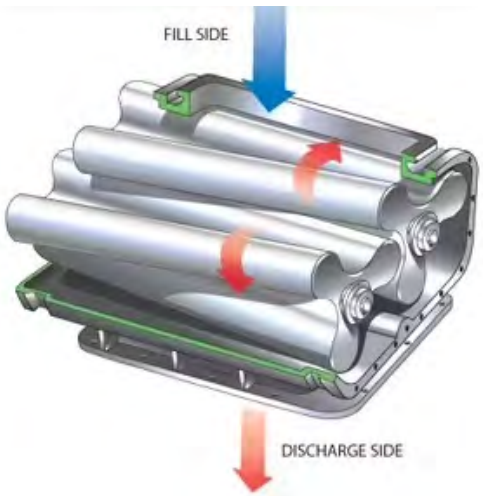


Figure 6.2: Roots supercharger

2. Twin-Screw Supercharger

A twin-screw supercharger uses two rotating screw-shaped parts called rotors instead of the usual lobe design found in other types. These rotors spin in opposite directions and work together to pull in air, compress it inside the unit, and push it out through the outlet. Because the air is compressed inside the supercharger, it provides a quick and powerful boost to the engine. This helps the engine respond faster and perform better, especially when extra power is needed.

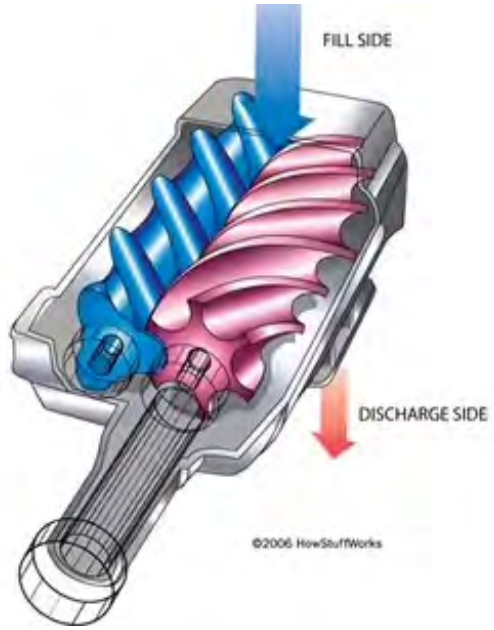


Figure 6.3: Twin-Screw supercharger

3. Centrifugal supercharger

A centrifugal supercharger looks like a snail shell, with an impeller wheel that compresses the air. It operates like a turbocharger but driven by a belt. This type of supercharger uses a spinning part called an impeller, which is powered by a belt connected to the engine's crankshaft. As the impeller spins, it pulls in air using centrifugal force. The fast-moving air then passes through a part called the diffuser, which slows it down and increases its pressure. This compressed air is then sent into the engine to improve performance.

However, compressing the air makes it hotter and less dense, which can reduce engine efficiency. To overcome this problem, a device called an intercooler is used to cool down the air before it enters the engine, helping the engine run more effectively.

Centrifugal superchargers offer better efficiency at higher RPMs, providing smooth power increase. Newer versions of this type of supercharger are electrically controlled, thus having the name electric superchargers.

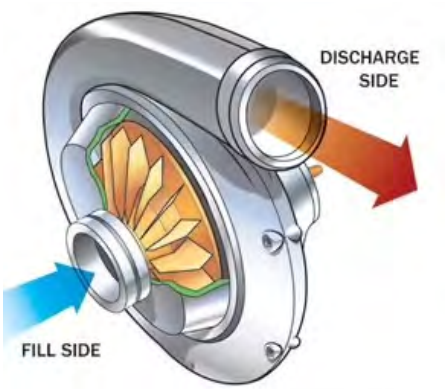


Figure 6.4: Centrifugal supercharger

Advantages of a Supercharger

1. It increases engine power by forcing more air into the cylinders, allowing more fuel to be burned during combustion.
2. It improves acceleration by delivering extra power quickly, without delay.
3. Because it is driven directly by the engine, it provides consistent performance across different engine speeds.
4. It enhances torque, which helps the vehicle pull heavier loads and climb steep hills more easily.
5. Superchargers work well at high altitudes, where the air is thinner, by maintaining strong engine performance.
6. It improves the mixing of air and fuel, which leads to smoother and more complete combustion.
7. It can help engines start more easily in cold weather by increasing air pressure during ignition.
8. It reduces exhaust smoke by promoting cleaner and more efficient burning of fuel.

Disadvantages of a Supercharger

1. It uses some of the engine's power to operate, which can reduce overall fuel efficiency.
2. It increases the temperature of the intake air, which may require extra cooling to prevent engine damage.
3. The added pressure can cause more stress on engine parts, leading to faster wear and tear.
4. Superchargers can make the engine more likely to experience knocking or detonation, especially in spark ignition engines.
5. Superchargers are generally less efficient than turbochargers because they do not use waste energy from exhaust gases.
6. The extra components add weight to the vehicle and take up space in the engine bay.
7. Supercharged engines may require more frequent maintenance to keep the system working properly.
8. The increased mechanical load can raise the engine's operating temperature, requiring a stronger cooling system.

Turbocharger

A turbocharger is a device that uses the engine's exhaust gases to boost performance. As the hot gases leave the engine through the exhaust manifold, they spin a turbine inside the turbocharger. This spinning turbine is connected to a compressor that pulls in fresh air and pushes it into the engine at higher pressure. This extra air allows the engine to burn more fuel and produce more power. Turbochargers operate on the principle of 'free energy'. Since it uses energy that would otherwise be wasted, the turbocharger provides a power boost without taking extra energy from the engine. The main parts of a turbocharger are:

1. Turbine
2. Compressor

3. Shaft
4. Intercooler

Turbine

The turbine is situated on the hot side of the turbocharger and operates using the energy from exhaust gases exiting the engine. As these gases flow into the turbine housing, they cause the turbine wheel to spin rapidly. This rotational energy is essential—it's transferred through a connecting shaft to power the compressor on the opposite end. By harnessing waste energy that would otherwise be expelled through the exhaust, the turbine plays a pivotal role in improving overall engine efficiency.

Compressor

The compressor resides on the cooler side of the turbocharger and is responsible for drawing in fresh air, compressing it, and delivering it to the engine's intake manifold. This compression increases the air's density, enabling a richer fuel-air mixture that supports more powerful combustion. The compressor wheel, driven by the turbine via the central shaft, must be carefully balanced to handle high-speed rotation and provide consistent airflow for optimal engine performance.

Shaft

The shaft is the mechanical bridge between the turbine and the compressor. Crafted with high-strength alloys and mounted on precision bearings, it's designed to handle extreme rotational speeds—often reaching beyond 100,000 RPM. Its job is to transmit the rotational energy generated by the turbine directly to the compressor. The shaft must maintain perfect alignment and minimal friction, as even a slight imbalance can lead to inefficiencies or mechanical failure within the turbocharger system.

Intercooler

The intercooler is positioned between the turbocharger's compressor outlet and the engine's intake system. Once the compressor compresses the air, it becomes hotter and less dense. The intercooler cools this charged air before it enters the combustion chamber, increasing its oxygen density and improving combustion efficiency. Cooler air also lowers the risk of engine knock caused by premature ignition. Whether designed as air-to-air or air-to-liquid, the intercooler plays a key role in keeping turbocharged engines reliable and high-performing.

Figure 6.5: Turbocharger

Working Principle of a Turbocharger

The working of a turbocharger begins when hot exhaust gases leave the engine after combustion. These gases are directed into the turbine side of the turbocharger. As they pass through, the fast-moving exhaust gases spin the turbine wheel. This turbine is connected by

a shaft to a compressor wheel on the other side of the turbocharger. So, when the turbine spins, it also causes the compressor to spin at high speed. The spinning compressor draws in fresh air from the atmosphere and compresses it. This compression increases the density of the air, meaning it contains more oxygen. The compressed air is then sent into the engine's intake system. Because there is now more air, the engine control system can also add more fuel. This creates a stronger explosion in the combustion chamber during each engine cycle. As a result, the engine burns more air and fuel together, which leads to the production of more power than a regular, naturally aspirated engine.

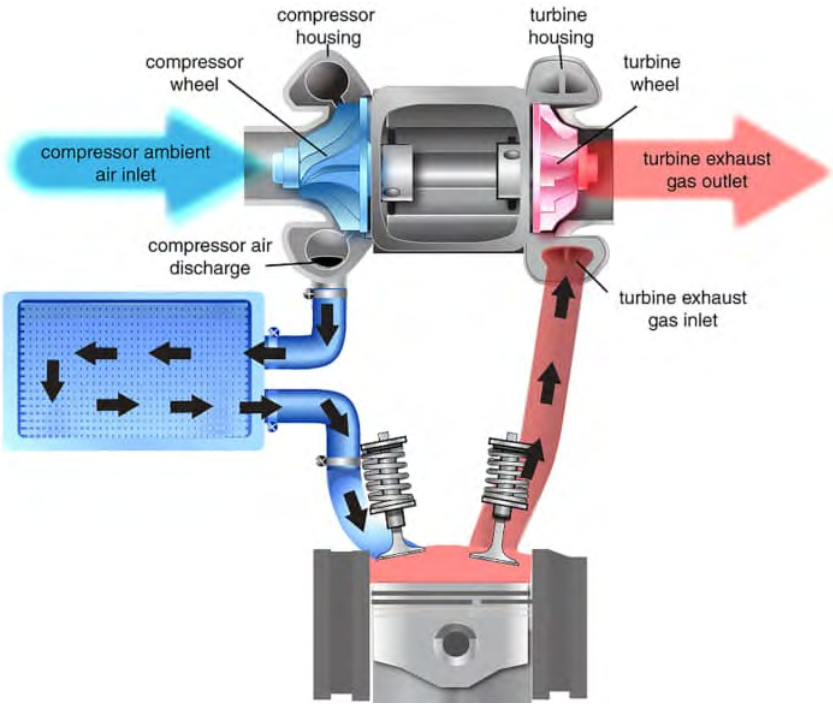


Figure 6.6: Operation of turbocharger

Advantages of Turbochargers

1. Turbochargers significantly increase an engine's power by compressing intake air, allowing more fuel to burn during combustion.
2. They improve fuel efficiency by enabling smaller engines to generate greater power while consuming less fuel.
3. Turbochargers help reduce harmful exhaust emissions by promoting more complete combustion.
4. At high altitudes, they maintain engine performance by compensating for reduced air density through air compression.
5. They allow for compact engine designs, which save space and reduce overall vehicle weight without sacrificing power output.
6. Turbochargers recover energy from exhaust gases that would otherwise be wasted, boosting overall thermal efficiency.
7. They enhance driving dynamics by providing quicker throttle response and greater torque at lower engine speeds

Disadvantages of Turbochargers

1. They increase engine complexity, making maintenance and repairs more challenging.
2. They often generate additional heat, which may require upgraded cooling systems to prevent engine damage.
3. Turbo lag can affect responsiveness, especially in older or poorly tuned systems.
4. The added pressure and temperature can accelerate engine wear if not properly managed or maintained.
5. They require higher-grade lubricants and more frequent oil changes.
6. The increased manufacturing and maintenance costs can make turbocharged vehicles more expensive over time.

Table 6.1: Differences between supercharger and turbocharger

Supercharger	Turbocharger
1. It is driven by the engine's crankshaft (mechanical linkage).	1. It is driven by exhaust gases .Not connected to the engine
2. It produces immediate boost with no lag	2. It may experience turbo lag before full boost.
3. It uses engine power, reducing fuel economy.	3. It uses waste energy, improving fuel efficiency.
4. It is less effective due to direct drive.	4. It performs better by compressing thinner air.
5. It is simpler setup and easier integration.	5. It has a more complex system with intercoolers, oil lines, etc.
6. It generates moderate heat.	6. It produces significant heat—requires advanced cooling.
7. It has lower maintenance cost due to durable parts.	7. It has a higher maintenance due to heat and component complexity.
8. It is generally costlier and less common in everyday vehicles.	8. It is relatively more affordable.

Activity 6.1 Functions of Superchargers and Turbochargers

Pair up to do this activity

Watch video on the difference between superchargers and turbochargers.

https://youtu.be/F-Iugo2lqvk?si=6qgV3Fm0Ag9J9181

1. Individually, write down what superchargers and a turbochargers do in a car.
2. Compare answers and discuss differences in your responses.

3. Share your thoughts as a class and discuss the following key terms as they relate to the working principle of the supercharger and turbocharger:
   a. engine power
   b. air compression
   c. ambient air
   d. boost
   e. exhaust gases

Activity 6.2 Differences Between Superchargers and Turbochargers

Perform this activity in a large group with 4 -6 of your classmates.

1. Prepare a diagram and use it to explain the following, as used in both supercharger and turbocharger:
   a. air flow
   b. compression
   c. delivery
2. Compare the procedure for supercharging vs. turbocharging.
3. Create a simple table comparing the advantages and disadvantages of each system, considering
   a. Performance
   b. fuel economy
   c. maintenance
   d. availability in Ghana.

EXTENDED READING

How Superchargers Work | HowStuffWorks

Supercharger- Working Principle, Types, Advantages, Disadvantages

3 Types of Supercharger: Application, Method, Working Principle & Diagram [Complete Details] - Engineering Learn

REVIEW QUESTIONS

1. Compare three advantages and disadvantages of using a supercharger versus a turbocharger in a high-performance vehicle consider factors such as engine efficiency, power delivery, fuel economy, and maintenance requirements.
2. With the aid of a diagram explain the main difference between supercharger and turbocharger

UNIT 7: METAL TECHNOLOGY

Engineering Materials, Tools and Machines

INTRODUCTION

3D printing is a modern manufacturing process that uses Computer-Aided Design (CAD) and Computer Numerical Control (CNC) technology to create three- dimensional objects layer by layer. This process is also known as additive manufacturing.

3D printers are used in industries like medicine, engineering, architecture, and education to make parts, tools, models, and even medical implants.

KEY IDEAS

- 3D printers are computer-controlled machines that create three-dimensional objects by building them layer by layer from a digital design.
- The main features include a print head (extruder), build platform, filament or resin feeder, and a CNC controller or slicer software.
- They perform operations such as melting and depositing material (like plastic, resin, or metal) in precise patterns to form shapes.
- The most common methods include Fused Deposition Modelling(FDM), Stereolithography (SLA) and selective Laser Sintering.

3D PRINTING

Procedures For Performing Operations Using a 3D Printer

1. Create or Load a 3D Model: Use CAD software(like Tinkercad or Fusion360) to design the object or download a ready-made model.
2. Slice the Model: Use a slicing software(like Cura) to convert the 3D model into layers and generate G-code, which tells the printer how to build the object.
3. Set Up the 3D Printer: Load the filament(usually plastic like PLA or ABS). Check the printer bed and calibrate it to make sure it's level.
4. Start the Print: Upload the G-code file to the printer via USB, SD, OR Wi-Fi, and start the printing process.
5. Monitor the Printing: The printer builds the object layer by layer from the bottom up. This may take minutes or several hours.
6. Remove and Finish the Print: Once printing is done, carefully remove the object. Do any necessary post-processing, like sanding or painting.

3d Printers

3D printing is a modern manufacturing process that creates three-dimensional objects by building them layer by layer from a digital design. It is also known as additive manufacturing because material is added, rather than cut away as in traditional machining.

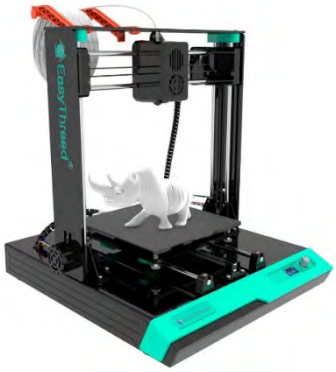


Figure 7.1: 3D Printer

Basic Terminologies in 3D Printing

1. Additive manufacturing refers to technologies that create objects through sequential layering.
2. Rapid prototyping is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using three-dimensional computer-aided design (CAD) data.
3. Subtractive processes are the removal of material by methods such as cutting or drilling.
4. Stereolithography is defined as the system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed.

3d Printing Methods and Methodologies

The following are the three broad types of 3D printing technology:

1. Sintering is a technology where the material is heated, but not to the point of melting, to create high-resolution items. Metal powder is used for direct metal laser sintering, while thermoplastic powders are used for selective laser sintering.
2. Melting methods of 3D printing include Fusion deposition modelling, powder bed fusion, electron beam melting and direct energy deposition. These use lasers, electric arcs or electron beams to print objects by melting the materials together at high temperatures.
3. Stereolithography utilises photopolymerisation to create parts. This technology uses the correct light source to interact with the material in a selective manner to cure and solidify a cross-section of the object in thin layers.

Table 1: Descriptions and Uses of Main Parts of a 3D Printer

S/N	Part	Description
1	Control Panel	Used to operate the printer and start the printing job.
2	Extruder/Print Head	Heats and pushes out the material (usually plastic).
3	Filament	The raw material is often in the form of a plastic wire (commonly PLA or ABS).
4	Build Platform (Print Bed)	The surface where the object is printed.
5	Frame	The main body that holds all parts together
6	Stepper Motors	Move the print head and platform precisely.

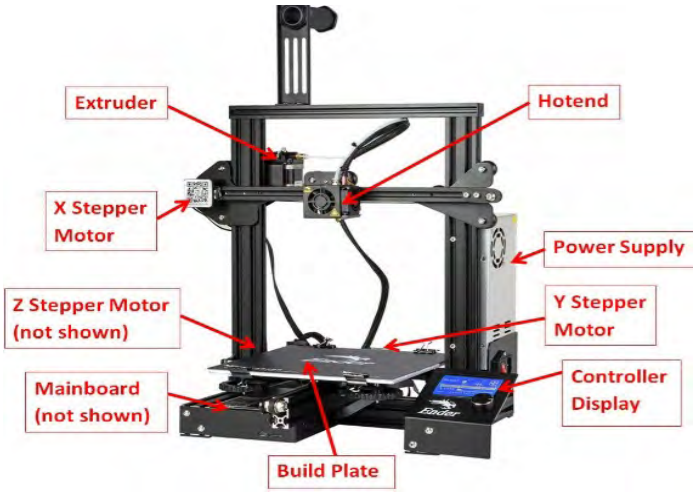


Figure 7.2: Parts of a 3D Printer

Working Principles of 3d Printing

To begin the 3D printing process, a design is first created using **CAD (Computer-Aided Design) software**. Once the design is complete, it is saved as a **STL file**, which is a common file format for 3D models. This file is then opened in a **slicer programme**, which breaks the model into thin layers and generates a set of instructions known as **G-code**. The G-code tells the 3D printer exactly how to move and what to do. After the G-code is uploaded to the printer, the machine heats the **filament**, usually a type of plastic, and pushes it through the **print head**. The printer then follows the instructions to build the object **layer by layer** continuing this process until the full shape is complete.

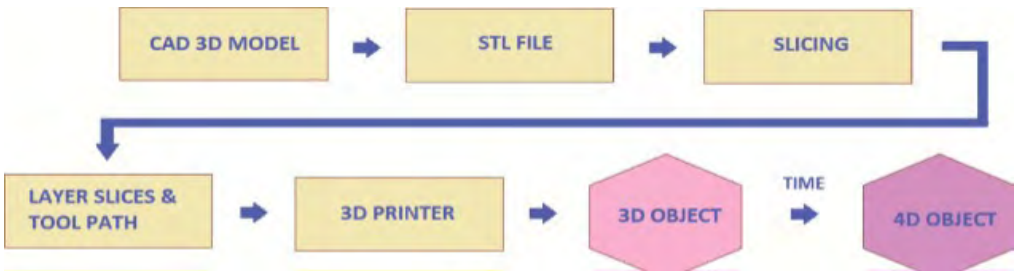


Figure 7.3: 3D Printing Process

Designing 3d Cad Model For 3d Printing

To develop 3D model, you will need to use a CAD (computer-aided design) programme. Cladding is the process of designing a 3D printer model in a CAD programme. There are many different CAD programmes available. Below are some of the CAD packages:

1. **Tinkercad** is a free browser-based CAD platform for 3D design, electronics, and coding that students and educators can access on any web-connected device.

Figure 7.4: Tinkercad

2. **Onshape** is a free browser-based CAD platform that students and educators can access on any web-connected device.

Figure 7.5: Onshape

3. **Solidworks** 3D CAD is a subscription programme that is great for engineering projects.

Figure 7.6: Solidworks

4. **AutoCAD** is used by architects, engineers, and construction professionals.

Figure 7.7: AutoCAD

5. **Fusion** is a design and make platform that incorporate CAD as well as simulation and manufacturing.

Figure 7.8: Fusion

STL File

A **stereolithography (STL) file** is a simple, portable format used by computer aided design (CAD) systems to define the solid geometry for 3D printable parts. An STL file provides the input information for 3D printing by modelling the surfaces of the object as triangles that share edges and vertices with other neighbouring triangles for the build platform.

3d Printing Materials (Metals)

Popular metal 3D printing materials are:

1. Titanium is lightweight and has excellent mechanical characteristics. It is strong, hard and highly resistant to heat, oxidation, and acid.
2. Stainless steel has high strength, high ductility, and is resistant to corrosion.
3. Aluminium is a lightweight, durable, strong, and has good thermal properties.
4. Tool steel is a hard, scratch-resistant material that you can use to print end-use tools and other high-strength parts.
5. Nickel alloys have high tensile, creep and rupture strength and are heat and corrosion resistant.

3d Printing Materials (Plastics)

FDM 3D printing materials are available in a variety of colour options. Various experimental plastic filament blends also exist to create parts with wood- or metal-like surfaces.

Figure 7.9: 3D Printing plastic materials

Table 2: Advantages and Disadvantages of 3D Printing

Advantages	Disadvantages
1. Fast Prototyping: Designs can be quickly turned into physical models. 2. Customisation: Each print can be easily modified. 3. Less Waste: Only the needed material is used. 4. Complex Shapes: Can produce shapes that are difficult with traditional methods. 5. Lower Costs for Small Batches: No need for expensive moulds or tools.	1. Can have a lower strength than with traditional manufacture 2. Increased cost at high volume 3. Limitations in accuracy 4. Post-processing requirements

Common Applications of 3D Printing

1. Aerospace and automotive industry
2. Prototypes for engineering and design projects
3. Robotics
4. Custom tools or parts
5. Medical models and aids

6. Educational models
7. Art and creative objects

Safety Precautions to be Observed When Applying 3D Printing

1. Wear protective gear
2. Keep the area well-ventilated when printing.
3. Avoid touching the hot extruder or print bed.
4. Wait for the print to cool before removing it.
5. Keep long hair and loose clothing away from moving parts
6. Keep the work area clean
7. Handle resins chemicals with care
8. Supervise the printer during operations
9. Avoid inhaling dust or particles
10. Follow manufacturer's guidelines.
11. Keep 3D Printer out of reach of children, unless supervise by adults

Laser

A laser is a device that produces a strong, focused beam of light. The word LASER stands for Light Amplification by Stimulated Emission of Radiation. Laser light is very powerful, precise, and travels in a straight line. It is used in many fields such as manufacturing, medicine, and communication.

Figure 7.10: Laser machines

Properties of a Laser Light

1. Monochromatic: Made of one colour or wavelength.
2. Coherent: The light waves move together in step.
3. Directional: Travels in a narrow, straight beam.
4. Intense: Much brighter and more focused than normal light.

Main Parts of a Laser System

1. Laser Medium: The material that produces the laser light (e.g. gas, crystal, or diode).
2. Energy Source: Supplies power to excite the medium (e.g. electrical current).
3. Mirrors: Reflect light to build up energy inside the laser.

4. Focusing Lens: Concentrates the beam for cutting or marking.
5. Cooling System: Keeps the laser from overheating.

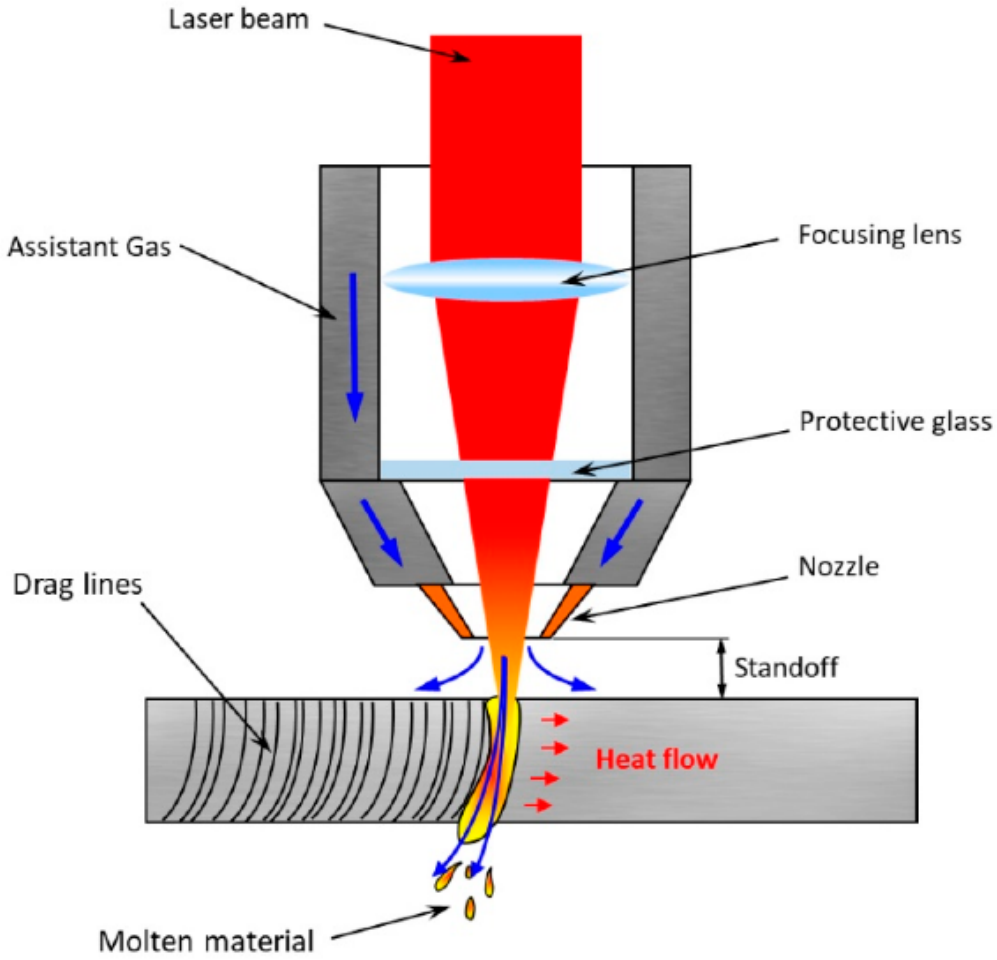


Figure 7.11: Parts of a Laser System

How the Laser Machine Works

1. Energy is supplied to the laser medium.
2. The medium gets excited and emits light.
3. The light bounces between mirrors, becoming stronger.
4. One mirror lets the beam out in a straight line.
5. The focused laser beam can then be used to cut, engrave, or measure materials.

Common Uses of Lasers in Technology

1. Cutting and Engraving: In CNC laser machines for metals, plastics, and wood.
2. Measuring and Alignment: In construction and surveying tools.
3. Communication: In fibre optic cables for fast data transfer.
4. Medical Applications: In surgery, eye treatment, and dental care.
5. Barcode Scanners and Printers: For reading and writing data.

Table 7.3: Advantages and Disadvantages of Laser Technology

Advantages	Disadvantages
1. High precision: Can cut or mark very small details. 2. Speed: fast processing of materials. 3. Contact-Free: No physical touch, reducing wear and tear. 4. Automation: Can be controlled by computer programmes (e.g. in laser cutters). 5. Clean and smooth finishes- Laser cutting produces sharp edges and smooth surfaces with little or no need for finishing. 6. Low waste production- accurate cutting reduces material waste, making the processes more efficiently. 7. Environmentally friendly- no use of hash chemicals, and the waste produced is often recyclable 8. Less risk of material deformation-since there is minimal mechanical force, delicate materials do not bend or break easily. 9. Works on many materials- Can be used on metal, plastic, wood, glass, fabric, and ceramics.	1. High initial cost - laser machines and systems are very expensive to buy and set up. 2. Health hazards- Laser beams can cause eye damage, skin burns, and even fire hazards if not handled properly. 3. High energy consumption -lasers use a lot of power, especially for industrial cutting or medical procedures. 4. Sensitive to economic conditions - Dust, moisture and temperature can affect laser performance and accuracy. 5. Material Limitations- Not all materials respond well to lasers. Some may burn, melt, or reflect the beam dangerously. 6. Complex Maintenance -lasers need regular calibration, alignment, and expert care to keep functioning properly. 7. Not Always Cost-Effective for small Jobs- For low-volume or simple tasks, traditional tools may be faster and cheaper.

Safety Precautions to be Observed When Using Laser Machine

1. Never look directly into a laser beam.
2. Wear proper safety goggles/glasses.
3. Use warning signs in the work area.
4. Make sure the laser machine has protective covers.
5. Follow manufacturer's guidelines
6. Ensure proper ventilation
7. Avoid reflective materials
8. Use machine guards and shields
9. Avoid wearing reflective jewellery
10. Use in a controlled area

Conclusion

Performing operations using a 3D printer involves designing a model, converting it to G-code, and letting the printer build the object layer by layer. This process allows for fast,

flexible, and creative manufacturing of complex items with less material waste. 3D printing is shaping the future of design, technology, and production. The 3D printing machines build up objects layer by layer from a digital design.

The main parts of a 3D printer include the extruder, the filament, the print bed, and the control panel. The laser **technology** is used in many areas such as **cutting, engraving, measuring, and communication. T**he **main parts of a laser system** include the **laser medium**, **energy source**, **mirrors**, and a **focusing lens**. You can therefore use 3D printers to make prototype parts, tools, models, and even small machine components, as well as use the laser system for marking parts and cutting materials in the workshops.

Activity 7.1

1. With the help of your Applied Technology teacher, visit a nearby industry to observe how the 3D printing machine and the laser machine operate.
2. Take pictures and make sketches of the 3D printing machine and laser machine.
3. Prepare a photo/sketch album and display it in class for appraisal.
4. Prepare a visit report and discuss in class with your classmates in groups.

Note

Use ICT tools to facilitate your work.

EXTENDED READINGS

S/N	ISSUE	LINK
1	3D Printing	https://3dprinting.com/what-is-3d-printing/
2	Engineering tools and computerised machines	https://www.engineeringenotes.com/industrial-engineering/machine-tools/computer-controlled-machine-tools-2-types-industrial-engineering/27130
3	3D printers	https://www.matterhackers.com/store/c/3d-printers
4	Computer-Aided Design	https://www.techtarget.com/whatis/definition/CAD-computer-aided-design
5	Steps to perform operations using a 3D printer	https://www.youtube.com/watch?v=2vFdwz4U1VQ
6	Basic Terminologies in 3D printing	https://all3dp.com/2/3d-printing-terminology-3d-printing-terms/
7	3D printing methods and methodologies	https://www.protolabs.com/resources/blog/types-of-3d-printing/

8	Main parts of a 3D printer	https://www.xometry.com/resources/3d-printing/3d-printer-parts/
9	Working principles of 3D printing	https://www.spiceworks.com/tech/devops/articles/what-is-3d-printing/
10	3D printing process	https://www.youtube.com/watch?v=a42znmU6BLE
11	Designing a 3D CAD model for 3D printing	https://www.cadcrowd.com/blog/how-to-design-3d-models-for-3d-printing/
12	3D printing material(metals)	https://markforged.com/resources/blog/metal-3d-printing-materials-1
13	3D printing materials (plastics)	https://www.youtube.com/watch?v=HNIn8v5V5ZI
14	Advantages of 3D printing	https://www.twi-global.com/technical-knowledge/faqs/what-is-3d-printing/pros-and-cons
15	Disadvantage of 3D printing	https://www.twi-global.com/technical-knowledge/faqs/what-is-3d-printing/pros-and-cons
16	Tips for applying 3D printing	https://www.youtube.com/watch?v=RmxGTst9XiE
17	Laser machine	https://wattsan.com/products/laser-machines/?srsltid=AfmBOop6-WPwQW1jk6dwBwEdrC7_cKefi8dXZd9kP-5eQAWI2AAw_W4t
18	Main Parts of the Laser System	https://www.youtube.com/watch?v=FGzecouF_60
19	How the laser machine works	https://www.youtube.com/watch?v=t4BfQGhhbOQ
20	Common Uses of Lasers in Technology	https://technixbycbs.com/blog/from-everyday-to-high-science-10-applications-of-lasers/

REVIEW QUESTIONS

1. In a table, identify six (6) main components of the 3D printer and state their uses.
2. Describe the correct processes of using the 3D printing machine.
3. In a table, identify six (6) components of the Laser machine and state their uses.
4. In a table, state five (5) safety precautions each to be observed when using the 3D printing and laser machines

UNIT 8: AUTOMOTIVE TECHNOLOGY

Introduction to Engine Technology

INTRODUCTION

Catalytic converters play a crucial role in reducing harmful vehicle emissions and protecting the environment. As exhaust gases leave the engine, they contain pollutants such as carbon monoxide, hydrocarbons, and nitrogen oxides. The catalytic converter, using precious metals as catalysts, transforms these gases into less harmful substances before they are released into the air. This lesson introduces you to the components, working principles, and types of catalytic converters used in petrol and diesel engines. By the end of the unit, you will understand how catalytic converters support cleaner air, improve engine performance, and meet environmental standards—while also considering their limitations and the technology behind them.

KEY IDEAS

- A catalytic converter reduces harmful exhaust emissions by changing them into less harmful gases.
- Although catalytic converters reduce pollution, they are expensive and only work well at high temperatures.
- Catalytic converters contain precious metals like platinum, palladium, and rhodium that speed up chemical reactions.
- Petrol engines mostly use two-way or three-way catalytic converters, while diesel engines use DOC, DPF, and SCR systems.
- The main reactions inside a catalytic converter are oxidation and reduction.

CATALYTIC CONVERTER

A catalytic converter is an emissions control device which converts the harmful pollutants in the exhaust gases into less harmful emissions before they are released into the environment. It contains two main types of catalysts: a reduction catalyst and an oxidation catalyst. The two catalysts work together to minimise harmful vehicle emissions. These catalysts are typically housed within a ceramic honeycomb structure and are coated with precious metals such as platinum, rhodium, or palladium, which facilitate the chemical reactions that clean the exhaust gases.

Figure 8.1: Catalytic converter

Main Parts of a Catalytic Converter

1. Metal casing (shell)

This is a durable, stainless steel outer casing that protects the internal components. It is carefully designed to withstand high temperatures and harsh conditions, including corrosion.

2. Ceramic or metallic honeycomb structure

This component is usually made from a ceramic honeycomb or a metal foil. It provides a large surface area for the catalyst to coat while allowing exhaust gases to flow through. Catalytic converter designs may be single block, commonly found in smaller or older vehicles, or dual-block, often used in modern or high-performance vehicles to meet stricter emission standards.

3. Catalyst coating

This is a thin layer of precious metals, typically platinum, palladium, and rhodium, which coat the substrate. These metals speed up the chemical reactions that convert harmful gases into less harmful ones without the metals themselves being consumed.

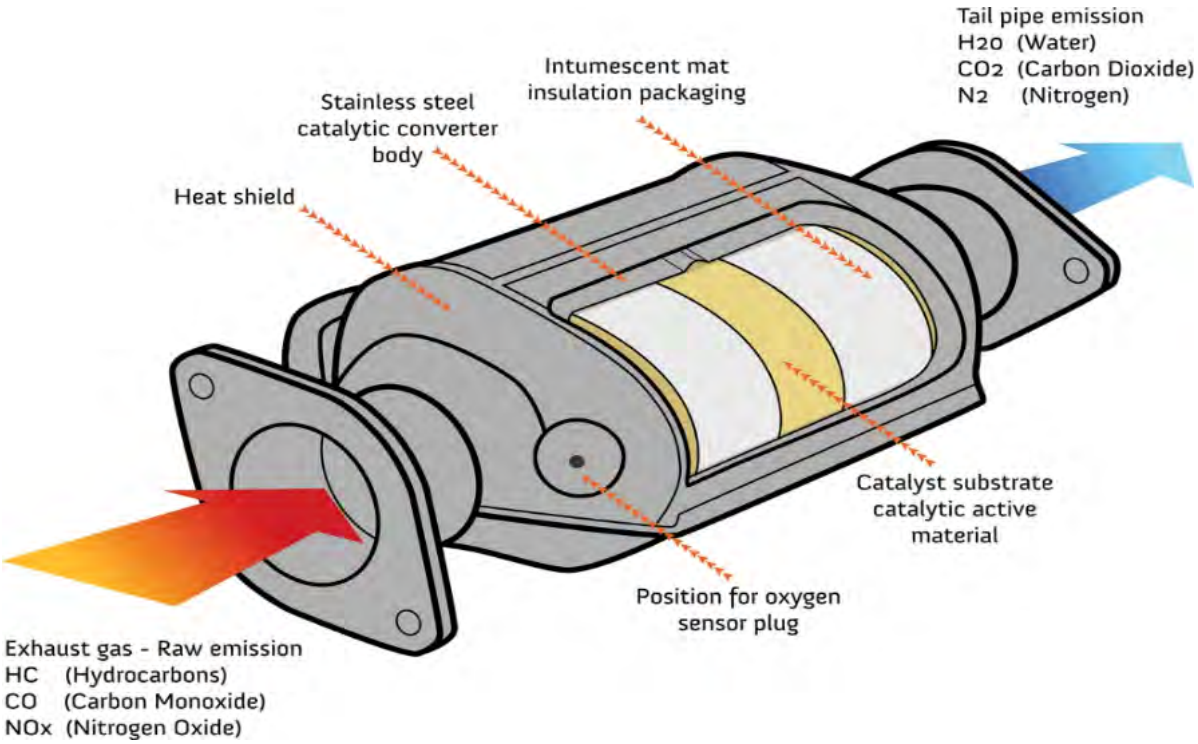


Figure 8.2: Parts of a catalytic converter

Working Principle of a Catalytic Converter

The catalytic converter utilises two different catalysts to overcome the exhaust system demands: a reduction catalyst and an oxidisation catalyst. Each version is constructed using a ceramic structure coated in a metal catalyst, commonly using platinum or even rhodium and or palladium. The design of the assembly is to create an internal structure that is fully exposed to the hot exhaust gases.

When fuel is burned in the engine, it produces exhaust gases, which contain several pollutants, including carbon monoxide, unburned hydrocarbons, and nitrogen oxides. These compounds contribute to air pollution. After combustion, the exhaust gases flow from the engine into the catalytic converter, where they pass through the honeycomb structure made of ceramic or metal.

The metal coatings act as catalysts, which trigger chemical reactions. As the hot exhaust gases pass through the converter, three main reactions take place. First, nitrogen oxides are broken down into harmless nitrogen and oxygen. Next, carbon monoxide is converted into carbon dioxide. Finally, any remaining hydrocarbons are turned into carbon dioxide and water vapour. Oxygen sensors help monitor the engine to ensure the right air-fuel ratio is achieved. Once the harmful substances have been converted into less harmful ones, the cleaned gases exit the exhaust system and are released into the atmosphere through the tailpipe.

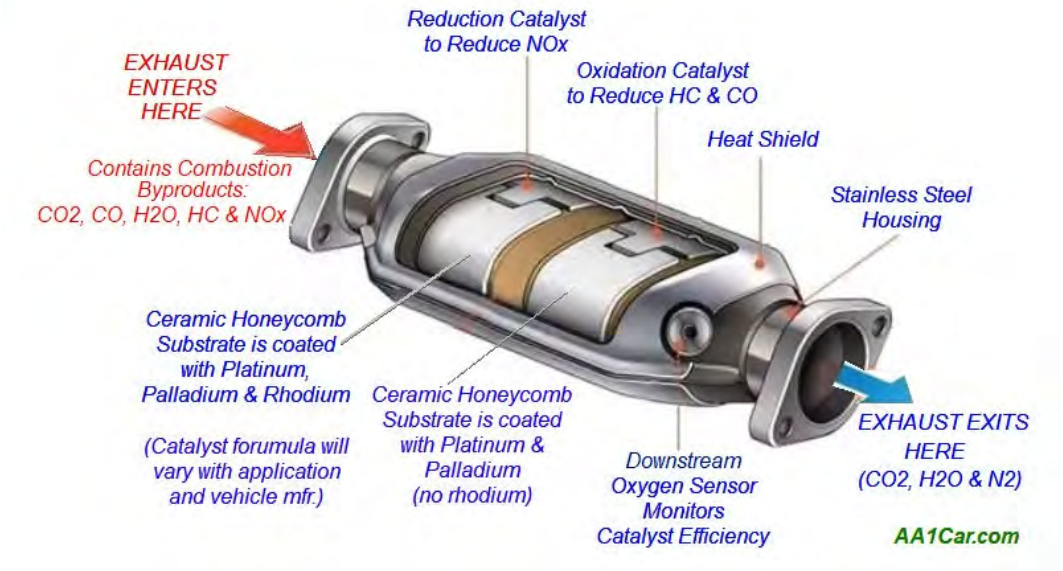


Figure 8.3: Operation of a catalytic converter

Reactions in the Conversion Process

The chemical reaction of the modern catalytic converter undergoes two stages in removing the harmful gases from the exhaust gases. These are oxidation and reduction.

Oxidation

Oxidation refers to the process of adding oxygen to a substance. Inside the catalytic converter, oxidation reactions help convert dangerous gases like carbon monoxide and unburned hydrocarbons into carbon dioxide and water vapour, which are much less harmful. These reactions take place in the part of the converter known as the oxidation catalyst, which is typically coated with platinum and palladium. Oxidation reaction takes place first when there is more oxygen to fuel in the exhaust gasses.

Reduction

This is the stage where oxygen is removed from the nitrogen oxides after breaking down and separating the compounds into nitrogen gas and oxygen gas. This process is actively

attributed to the rhodium. Exhaust gases with more fuel to air ratio will usually have reduction reaction taking place before oxidation.

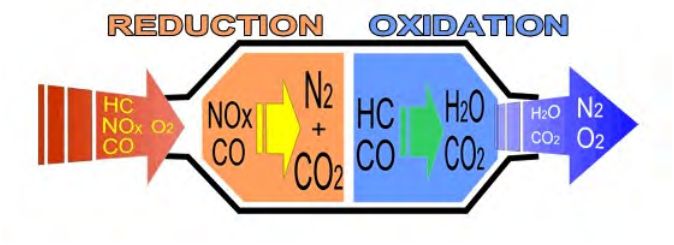


Figure 8.4: Reduction and oxidation

Pollutants and Their Conversion

1. Hydrocarbons (HC): These are unburned fuel particles that are oxidised into carbon dioxide and water.
2. Carbon Monoxide (CO): This is a toxic gas that is oxidised into carbon dioxide.
3. Nitrogen Oxides (NOx): These gases are reduced into nitrogen gas and oxygen gas.
4. Unburnt fuel and carbon monoxide: The oxidation catalyst converts these into carbon dioxide.

Petrol Catalytic Converters

Catalytic converters come in different types depending on how many pollutants they treat and the technology used. The most popular designs are two-way and three-way catalytic converters. These two types are used in petrol vehicles.

1. Two-way catalytic converter

A two-way catalytic converter is designed to process or reduce two major pollutants found in vehicle exhaust gases. Two-way converters perform oxidation only. The oxidation reaction converts carbon monoxide and unburned hydrocarbons into carbon dioxide and water, respectively. Due to their limitation of not being able to control nitrogen oxides emission, a major shift towards three-way catalytic converters began in the early 1980s. Two-way converters are commonly found in older vehicles with lean-burn technologies.

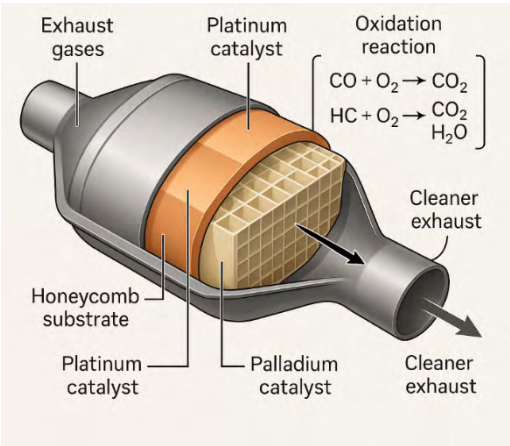


Figure 8.5: Two-way catalytic converter

2. Three-way catalytic converter (TWC)

A three-way catalytic converter is an upgrade over the two-way type. It uses platinum, palladium and rhodium as its catalyst materials. Catalytic converters of this combination are described as 'three-way' because they help to reduce the three most harmful pollutants in the exhaust of petrol engines, which are carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NO_x. The catalysts used in three-

way converters perform both oxidation and reduction reactions. Most modern petrol vehicles are installed with three-way catalytic converters.

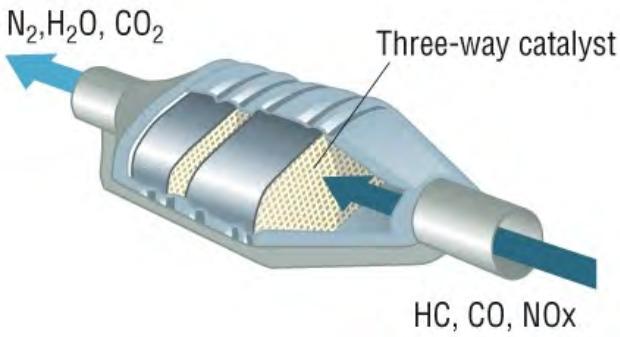


Figure 8.6: Three-way catalytic converter (TWC)

Diesel Catalytic Converters

Several catalytic converters are used in diesel vehicles. Three most common types are:

1. Diesel Oxidation Catalyst (DOC)
2. Selective Catalyst Reduction (SCR)
3. Diesel Particulate Filter (DPF)

Diesel Oxidation Catalyst (DOC)

Diesel oxidation catalyst functions as a two-way catalytic converter as it uses oxidation reaction to convert the harmful exhaust gases into less toxic compounds. As exhaust gases pass through the DOC, chemical reactions occur that turn carbon monoxide (CO) and hydrocarbons (HC) into carbon dioxide (CO_2) and water vapour (H_2O). It also helps to reduce the formation of soot and make it less sticky less sticky and easier to filter later.

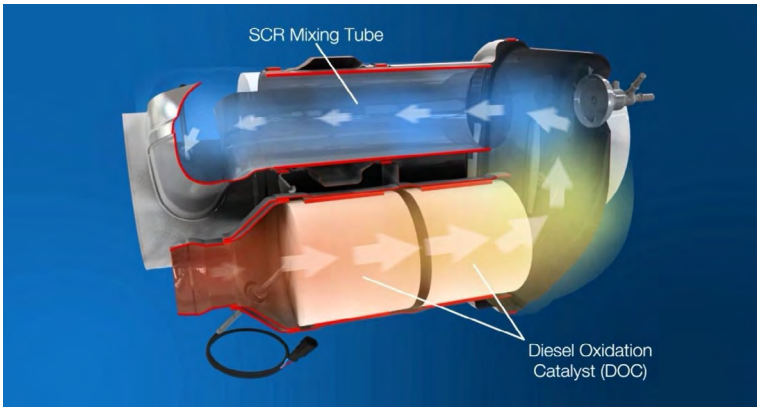


Figure 8.7: Diesel oxidation catalyst

Selective Catalyst Reduction (SCR)

Selective catalytic reduction helps to reduce nitrogen oxide (NO_x) emissions in diesel combustion. The system works by injecting a urea-based fluid, commonly called diesel exhaust fluid (DEF), into the hot exhaust gases. The fluid vaporises and reacts chemically with NO_x gases. The reaction converts NO_x into nitrogen gas (N_2) and water vapour (H_2O).

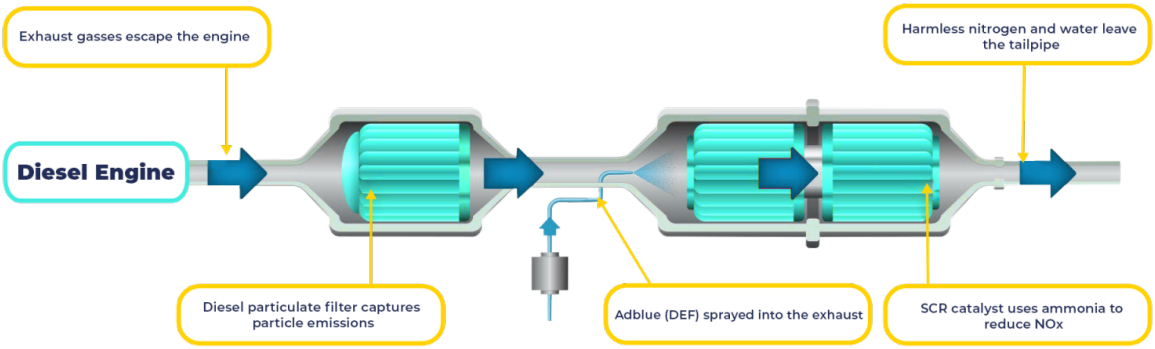


Figure 8.8: Selective Catalyst Reduction

Diesel Particulate Filter (DPF)

The diesel particulate filter traps soot from the diesel exhaust system. However, when used together with a diesel oxidation catalyst, it benefits from passive regeneration as the diesel oxidation catalyst produces nitrogen oxides (NO_2), which help to burn off soot more efficiently. When used together with a selective catalyst reduction, it acts as a protective barrier, keeping soot from reaching the selective catalyst reduction. In some exhaust system designs, the SCR catalyst is coated directly on the DPF, allowing it to trap soot and reduce nitrogen oxides at once.

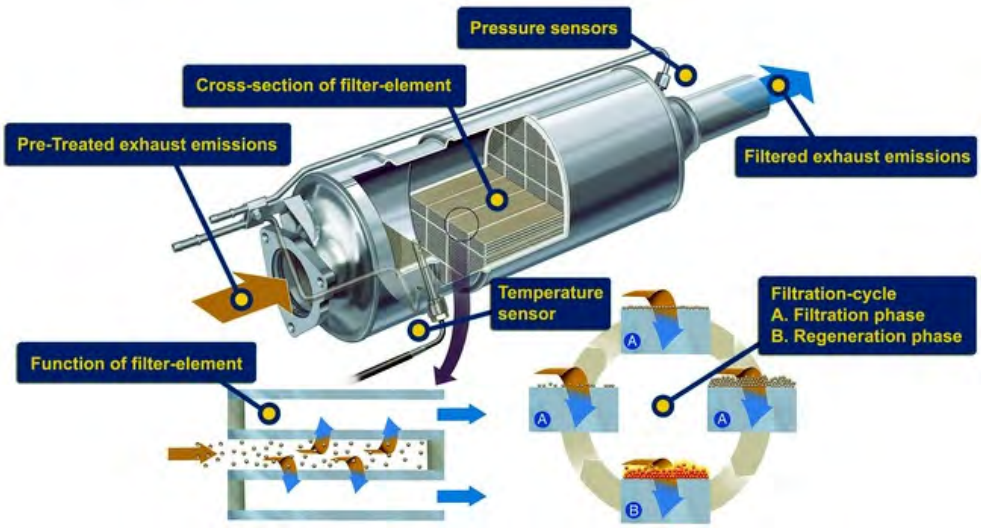


Figure 8.9: Diesel particulate filter

Advantages of Catalytic Converters

1. They reduce harmful emissions like carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x).
2. They help vehicles meet environmental regulations and pass emissions tests.
3. They improve air quality and reduce smog, especially in urban areas.
4. They lower health risks by minimising exposure to toxic exhaust gases.
5. They support better fuel efficiency through optimised combustion.
6. They enhance engine performance by reducing exhaust backpressure.
7. They contribute to climate change mitigation by reducing greenhouse gases.

Disadvantages of catalytic converters

1. They are expensive to manufacture and replace due to the use of precious metals.
2. They can slightly reduce engine performance by increasing exhaust backpressure.
3. Fuel consumption may increase if the converter or oxygen sensors malfunction.
4. They can become clogged over time, leading to overheating or reduced power.
5. They still produce carbon dioxide, contributing to greenhouse gas emissions.
6. Their valuable metal content makes them a target for theft.
7. They only work efficiently at high temperatures, reducing effectiveness during short trips.

Activity 8.1 Catalytic Converters – Function, Principles and Types

Perform the activity below in a group with 2-4 classmates.

1. You are a group of automotive technicians diagnosing emission problems in two vehicles. One of the vehicles was manufactured in 1995, and the other in 2020. Both vehicles use catalytic converters, but they are not the same.
   a. Brainstorm and write, in one sentence, your understanding of a catalytic converter and explain what it does.
   b. Based on the scenario above, what do you think is different about the converters in the two vehicles?
2. Prepare a sketch of a cut-away 3D model of a three-way catalytic converter. Label the following:
   a. Exhaust gas inlet
   b. Exhaust gas outlet
   c. Oxidation zone
   d. Reduction zone
   e. Ceramic substrate
   f. Catalyst materials (Pt, Pd, Rh)
3. Which gases enter the converter?
4. Which gases leave the converter?
5. What type of reactions take place inside?
6. Fill in the table to compare the two types of catalytic converters.

Table 8.1: Comparison of two-way and three-way converters

Feature	Two-way converter	Three-way converter
Pollutants removed		
Type of reactions taking place		
Typical vehicle type		

7. In one sentence, explain why modern vehicles use three-way catalytic converters.

EXTENDED READING

How do catalytic converters work? - Explain that Stuff
The Different Types of Catalytic Converters - Noble6
Everything You Need To Know About Car Catalytic Converter | Wuling
How Does a Selective Catalytic Reduction System Work?

REVIEW QUESTION

Design a maintenance and inspection routine for a vehicle's exhaust system focusing on the catalytic converter.

UNIT 9: METAL TECHNOLOGY

Engineering Materials, Tools and Machines

INTRODUCTION

Design for manufacture (DfM) is the process of planning and creating a product in a way that makes it easy, cost- effective, and efficient to manufacture. The main goal is to design products that are simple to produce using the right materials, tools, and methods.

This approach helps reduce waste, save time, lower costs, and Improve the quality of the final product.

In Year 2, Week 4, you explained the stages of the design process to include situation, brief, analysis, investigation, specifications, possible solutions, final solutions, and development of the selected solution. You also demonstrated making basic mock-ups, displayed the mock-up for appraisal.

In year 3, you will review what you studied in year 2 and go further to prepare working drawings to include orthographic projections and a cutting list. You will also learn about planning the workshop involving safety precautions, making the artefact, testing and evaluation for modifications. The importance of practically designing and making includes promoting:

- Problem-solving skills.
- Creativity and innovation.
- Skills development.
- Understanding materials and tools.
- Practical application of knowledge.
- Confidence and independence.
- Economics and career benefits.
- Environmental awareness.

Therefore, following the design and making process religiously will help you design and make artefacts that meet the needs and aspirations of the people.

KEY IDEAS

- Design for Manufacture(DFM) is the process of designing products in a way that makes them easy, cost-effective, and efficient to manufacture.
- It involves a series of stages that ensure the design is suitable for production with minimal errors, waste, and cost.

Stages in Design for Manufacture include the following:

- Concept Development: Define the product idea and basic requirements.

- Preliminary Design: Sketch initial layouts and choose suitable materials and processes.
- Design Analysis: Check for strength, function, safety, and performance (often using CAD/CAE tools).
- Prototype Development: Build a sample to test design feasibility and function.
- Design Optimisation: Improve the design to reduce material, simplify parts, and ensure manufacturing.
- Final Design and Documentation: Prepare detailed drawings, specifications and instructions for manufacturing.
- Planning and Production
  - Select tools, machines, and processes for actual manufacturing
  - Preparation of mock-ups
- Testing and evaluation.
  - Test for strengths and weaknesses of artefact
  - Make modifications

DESIGN AND MANUFACTURE

Design and Manufacture is the process of planning, creating, and making a product out of materials to solve a problem or meet a need. Design is the thinking and planning stage and is the practical making stage.

Stages in Design and Manufacture

Below are the various stages in Design and Manufacture:

1. Design Situation

   This is a short description of a problem or need that the product will solve. It explains why something needs to be made. Example*:* "Students need a safe place to hang their school bags in the classroom.

2. Design Brief

   A clear statement that tells you what you are going to design and make. It is based on the design situation. Example: "Design and make a metal wall hook that is strong, safe, and easy to use.

3. Analysis Questions

   These are questions you ask to understand the problem better. They help you think about what the design needs to do. Examples:

   a. What size should it be?
   b. What weight must it hold?
   c. What metal is best?

4. Investigation

   This is when you research before starting your design. You might:

   a. Look at similar products
   b. Study different materials
   c. Learn how joints or finishes are used

5. Specification

   A list of clear rules the design must follow. It tells what the final product must and should do. Example:

   a. Must hold at least 5kg
   b. Should be rust-resistant
   c. Must have no sharp edges

6. Possible Solutions

   Different ideas you draw or model to show how the product might look or work. You usually make 3 or more design sketches with notes.

7. Final Solution

   This is the best idea you chose from your designs. You improve it and make it ready for production.

8. Working Drawings

   These are detailed, labelled drawings that help you make the product:

   a. Orthographic projection – front, side, and plan views
   b. Detail drawing – shows a close-up of a part
   c. Assembly drawing – shows how parts fit together
   d. CAD drawing – Computer Aided Drawing

9. Cutting List

A cutting list in metal work is a detailed list or table that shows all the pieces of metal that need to be cut for a specific project, including their sizes, quantities, and types of material.

The Purpose of the Cutting List

- Helps to plan and organise materials before starting the projects
- Ensures accurate cutting of each part
- Reduces waste and saves time
- Helps to estimate costs and materials needed

Table 9.1: A Sample Cutting List for a Rectangular Metal Table Frame

Item No.	Material	Description	Length in mm	Quantity	Remarks
1	Mild steel Angle	Table Top Frame (long sides)	1000	2	Cut ends at 90 degrees
2	Mild steel Angle	Table Top Frame (short sides)	600	2	Cut ends at 90 degrees
3	Square Tube	Table legs	700	4	Square cut
4	Flat Bar	Lower brace support	550	2	Weld to bottom frame
5	Flat Bar	Top cross support	550	1	Weld at centre for strength

Manufacturing Process (Practical Procedures)

0.1. Step-by-step guide on how to make an artefact

a. Measuring and marking out
b. Cutting and drilling
c. Joining (e.g. soldering, welding, riveting)
d. Cleaning and checking

0.2. Finishes/Finishing: What you do to improve the look or protect the metal;

a. Painting
b. Polishing
c. Galvanising

0.3. Testing and Evaluation: After making the product, you;

a. Test if it works (Does it hold weight? Is it safe?)
b. Evaluate how well it meets the design brief and specification
c. Suggest improvements/modifications

0.4. Modifications: This refers to the process of changing, adjusting, or improving an existing object (artefact) to better suit a particular need, function, or appearance. To:

a. improve functionality- make the artefact work better
b. meet new needs-adjusting the artefact for a different use
c. enhance appearance
d. repair damage-fixing broken parts
e. reduce cost-replacing expensive parts with cheaper ones.

Table 9.3: Advantages and Disadvantages of Designing and Making Artefacts

Advantages	Disadvantages
1. Encourages creativity and innovation	1. Time consuming
2. Promotes problem-solving	2. Costly materials and tools
3. Enhances Practical Skills	3. Requires skills and training
4. Supports cultural presentation	4. Risk of wastage
5. Boots confidence and pride	5. Limited resources
6. Provides economic opportunities	6. Safety hazards
7. Improves teamwork and collaboration	7. Environmental impact
8. Connects theory and practice	8. Difficult to mass produce
9. Develops time management and planning	
10. Promotes environmental awareness	

Conclusion

Design for Manufacture ensures that products are not only useful and attractive but also practical and efficient to produce. By following the key stages; from generation of idea to final production, designers can create items that meet customer needs while saving time, materials, and money. This process is an important part of modern engineering and production. The design for manufacture (DfM) process is a critical approach that ensures products are designed not only to function well but also to be easily, efficiently, and cost-effectively manufactured. By following each stage, from identifying the need, researching, sketching ideas, selecting materials, making prototypes, testing, and final production, designers can create products that are practical, safe, and economical to produce.

Understanding and performing these stages helps reduce production errors, time and cost, and improves the overall quality of the final products. This knowledge is essential for students and professionals who want to succeed in engineering, product design, or manufacturing careers.

Activity 9.1 Design and Manufacturing in a Metal Workshop

Scenario: *In an Applied Technology metal workshop, students often leave their shoes scattered around the entrance when entering the lab for safety reasons (especially when changing into boots or protective footwear). This causes a tripping hazard.*

Form a group with three of your classmates and do the following.

1. Write a design brief for the above situation.
2. Identify areas you can visit to gather information for solving the problem.

3. Identify four methods each for gathering and recording data for solving the design problem.
4. Write two specifications each for the following factors: aesthetics, economics and construction
5. Prepare a folio to cover the following design stages:
   a. Design situation
   b. Design brief
   c. Analysis questions
   d. Investigations
   e. Specifications
   f. Generating three possible solutions and selecting one
   g. Developing the selected solution
   h. Drawing the final solution in pictorial (isometric)
   i. Preparing working drawings to include orthographic projections, detail drawings, assembly drawings, and CAD drawings.
6. Prepare a mock-up with any available compliant materials and test for modifications
7. Preparing a cutting list
8. Plan and prepare the workshop for production
9. Make the artefact using suitable resistant materials
10. Test and evaluate the artefact and make modifications.

EXTENDED READING

S/N	KEY ISSUE	LINK
1	The design process	https://www.interaction-design.org/literature/article/5-stages-in-the-design-thinking-process?srsltid=AfmBOooGNNZQ5K_TVAHXGyhJfTp5Fo-tDpZ1L1IJMlJOXYhXG-CXkUIQ
2	Stages in design for manufacture	https://news.ewmfg.com/blog/manufacturing/dfm-design-for-manufacturing
3	Design and manufacture	https://www.sqa.org.uk/sqa/45786.html
4	Stages in design and manufacture	https://engineeringproductdesign.com/knowledge-base/product-design-process/
5	Cutting list	https://wooddesigner.org/cutting-list-software-understanding-the-benefits/

6	Design situation	https://hwamypdesign.weebly.com/how-to-write-a-design-situation.html
7	Design brief	https://www.nuclino.com/articles/design-brief
8	Analysis question	https://ca.indeed.com/career-advice/career-development/analysis-questions
9	Investigation	https://www.academia.edu/4988450/The_Design_Investigation_Method
10	Specification	https://technologystudent.com/designpro/spec1.htm
11	Possible solution	https://dessign.net/design-thinking-process-steps/
12	Final solution	https://www.interaction-design.org/literature/article/5-stages-in-the-design-thinking-process
13	Working drawing	https://technologystudent.com/designpro/wkingd1.htm
14	Testing and Evaluation	https://magzletter.substack.com/p/testing-in-design-thinking-a-complete
15	Modifications	https://blog.johner-institute.com/regulatory-affairs/design-change/

REVIEW QUESTIONS

Your Applied Technology teacher has assigned you in groups to prepare materials for learning the topic ‘’ the design process’’.

1. Identify the first six (6) stages of the design process.
2. Explain the following terms in design stages:
   a. Situation
   b. Design brief
   c. Specifications
   d. Testing and Evaluation
3. Using a kitchen seating unit (kitchen stool) as an artefact, develop two analysis questions each on the following factors:
   a. function
   b. ergonomics
   c. construction
   d. safety
4. Using the same artefact in q3, develop two specifications each for the following factors:
   a. appearance
   b. construction
   c. finish
   d. economics
5. State four (4) methods each for carrying out the following activities:
   a. gathering data
   b. recording data
6. Using freehand sketches, generate three possible solutions of the kitchen seating unit with annotated notes.
7. State five (5) safety precautions to be observed when making the artefact in the workshop.
8. State four (4) reasons you will prepare a cutting list
9. State four (4) reasons the artefact must be tested and evaluated.

SECTION

3

DESIGN FOR MANUFACTURE, 3D PRINTERS, LASERS AND VEHICLE EXHAUST SYSTEM, CATALYTIC CONVERTER

UNIT 10: AUTOMOTIVE TECHNOLOGY

Introduction to Vehicle Technology

INTRODUCTION

This unit provides an overview of two critical vehicle systems: the charging system and the lighting system. The charging system ensures a steady supply of electrical power by converting mechanical energy from the engine into electrical energy, keeping the battery charged and powering various electrical components. It highlights the transition from dynamos to alternators and explains the roles of key components such as the rotor, stator, rectifier, voltage regulator, and charging indicator. The lighting section covers both mandatory and supplementary lighting systems, including exterior and interior lights designed to improve visibility, safety, and communication on the road. It also explores auxiliary systems that support comfort, safety, and control – ranging from entertainment units and air conditioning to sensors and instrument panels. Together, these systems play an essential role in vehicle performance, driver awareness, and passenger comfort. You will gain a solid understanding of automotive electrical technology from this unit.

KEY IDEAS

- Auxiliary and instrument panel systems provide comfort, safety, information, and control to support vehicle operation.
- Modern vehicles use alternators instead of dynamos because they are more efficient and reliable.
- The alternator produces alternating current (AC), which is converted to direct current (DC) by a rectifier for use in the vehicle.
- The charging system powers the vehicle's electrical components and keeps the battery charged while the engine is running.
- The lighting system improves safety by helping drivers see, be seen, and communicate with other road users.

CHARGING SYSTEM

As the engine operates, the vehicle's charging system supplies power to electrical components and ensures the battery remains in a fully charged state. To accomplish this, the charging system's generator converts mechanical energy produced by the engine into usable electrical energy. The generator for charging the battery may come in one of two forms: dynamo or alternator.

Dynamo

The dynamo has a stationary magnetic field with a conductor, made up of a coil of wire, rotating within it. As the coil spins, it generates alternating current (AC), which is then converted into direct current (DC) using a commutator. This mechanical rectification process made the dynamo suitable for powering the battery and vehicle's electrical components. However, due to limitations in efficiency and reliability, dynamos have been phased out in favour of more advanced systems and are rarely found in modern vehicles.

Alternator

The alternator, unlike the dynamo, uses a rotating magnetic field inside a stationary conductor to produce alternating current, but instead of using a commutator, the alternator employs semiconductor diodes to rectify AC into DC. This electronic rectification is more efficient and better suited to the higher electrical demands of modern vehicles.

Alternators typically have a more compact, lightweight design compared to dynamos. While shorter in overall length, they often have a larger diameter that corresponds to their broader stator assembly.

Components of the Charging System

The vehicle's charging system consists of several key components that work together to generate, regulate, and distribute electrical power. The main components are:

1. Alternator
2. Voltage regulator
3. Battery
4. Charging Indicator or warning lamp

The Alternator

The alternator changes mechanical motion into electrical power. When the engine is running, it produces electricity to operate the car's electrical systems and to keep the battery charged. The alternator generates this electricity in the form of alternating current (AC). See ***Figure 10.1***.

Figure 10.1: Alternator

Functions of an Alternator

The main function of the alternator is to recharge the car battery so that electrical items like the lights, radio, and power windows can be operated while the vehicle is moving. Once the battery is charged, it also supplies electricity to the starter motor, which helps to start the engine. The alternator has the following parts:

1. rotor
2. stator
3. rectifier
4. voltage regulator

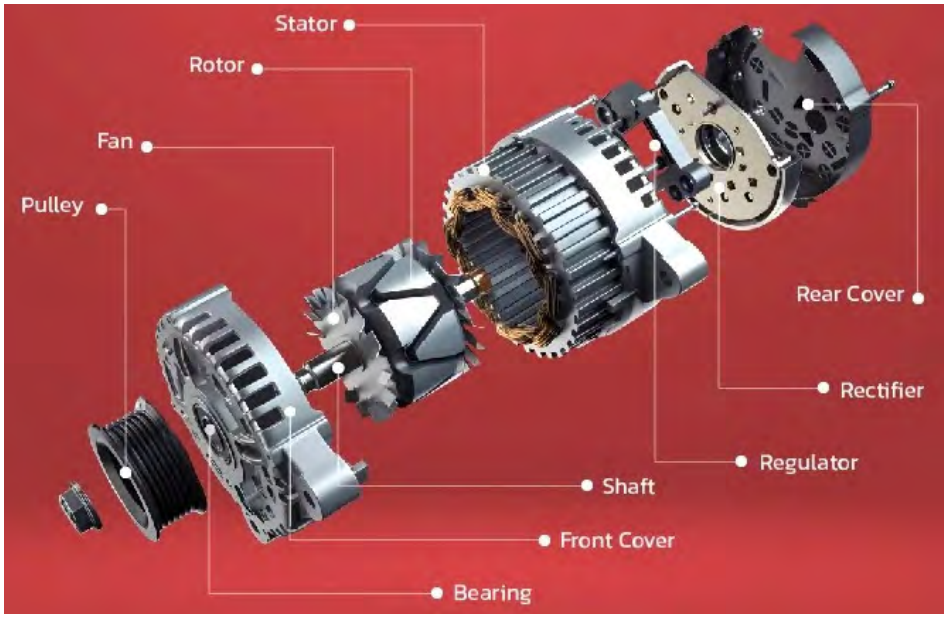


Figure 10.2: Exploded view of an alternator

Rotor

The rotor is the rotating centre piece of the alternator and serves as the source of the magnetic field. It contains the field coil wound over an iron core which is part of the shaft. When electricity flows through these windings—usually supplied by the battery via brushes and slip rings—the rotor becomes an electromagnet. As it spins, its magnetic field moves past the stator's coils, starting the process of electricity generation. The faster the rotor turns, the stronger the magnetic interaction and the more electricity can be produced.

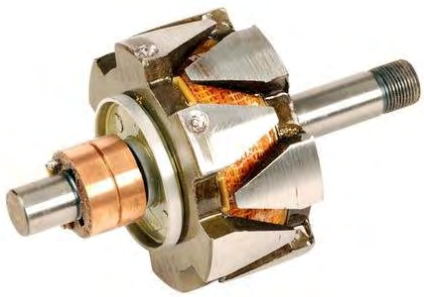


Figure 10.3: Rotor)

Stator

The stator is made of several coils of wire arranged in a circular pattern. It is attached to the casing or housing and completely surrounds the rotor. When the rotor spins, the movement of the rotor's magnetic field within the stator's coil windings, causes electrical current to

build up inside the stator windings. This current is alternating (AC), and it is the first usable form of electricity generated by the alternator.

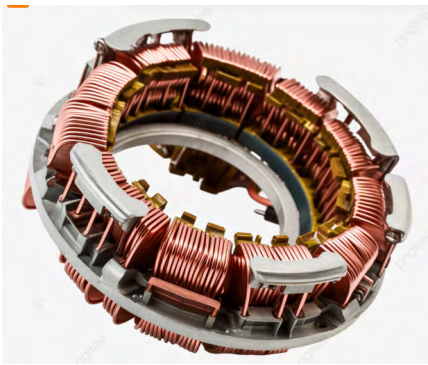


Figure 10.4: Stator

Rectifier pack

The alternating current produced by the alternator cannot be used by most automotive components such as the battery, starter motor, dashboard electronics, sensors, and lighting systems. These components are designed to work with direct current (DC), which provides a steady and predictable flow of electricity ideal for powering circuits that need consistent voltage levels. To achieve this desired purpose, the rectifier pack steps in to convert the alternating current (AC) into direct current (DC).

The **rectifier** is a type of **semiconductor device** that is built using **diodes. The diodes are** electronic components designed to allow current to flow in only one direction. Alternator diodes are usually six tiny electronic components, split equally into positive and negative terminals. The positive terminals are known as anode whilst the negative terminals are called cathode. Some alternators include extra two diodes known as '*diode trios'* or *'field diodes'* to power the voltage regulator or dashboard warning light circuit. To ensure proper working condition, diodes are mounted in a heat sink to dissipate the heat they generate.

Figure 10.5: Rectifier

Voltage Regulator

The voltage regulator makes sure the electrical output from the alternator stays within safe limits. If the alternator tries to produce too much or too little voltage, the regulator adjusts the current going to the rotor's windings. By doing so, it controls the strength of the magnetic field, which in turn affects how much electricity is generated. This keeps the car's electronics safe, and the battery properly charged.

Figure 10.6: Voltage regulator

Charging Indicator

The charging system includes a warning lamp which displays on the dashboard—usually shaped like a battery or labelled "ALT" (Alternator) or "GEN" (Generator). When the vehicle

is switched on, this light momentarily comes on to show that the system is being checked. If the lamp stays on while the engine is running, it signals a possible fault in the charging system. This could be due to a worn drive belt, a failing alternator, or a malfunctioning voltage regulator. The warning lamp acts as an early alert to let the driver know that the battery may not be charging properly.

Figure 10.7: Battery charging symbol

Activity 10.1 Exploring Parts of the Alternator and Its Functions

Perform this activity in small groups of 3 or 4 of your classmates. Choose the name of any automaker company for your group, for example, Audi.

1. Watch a video on the Car Charging System at:
   https://youtu.be/QXlOSRjJT8g?si=Fvn0ePBKamwZbOOz
   a. Based on the video watched, state clearly the function of the charging system in a vehicle.
   b. Sketch an alternator and label the main parts, including:
      i. rotor
      ii. stator
      iii. rectifier
      iv. voltage regulator
   c. Which other parts of the alternator did you observe in the video, apart from those you have provided in 1(b) above?
2. Provide a brief description of the function of each component in converting mechanical energy into electrical energy, as in question 1b.

LIGHTING, AUXILIARY AND INSTRUMENT PANEL

The lighting system in a car helps drivers see clearly, be seen by others, and communicate their intentions on the road. It includes different types of lights placed around and inside the cabin of the vehicle for safety, visibility, and control. All vehicles are required by law to have different types of lights installed at different positions. Supplementary lights, which are not obligatory, may be fitted on the vehicle for several other purposes. All the lights can be categorised under exterior or interior lighting.

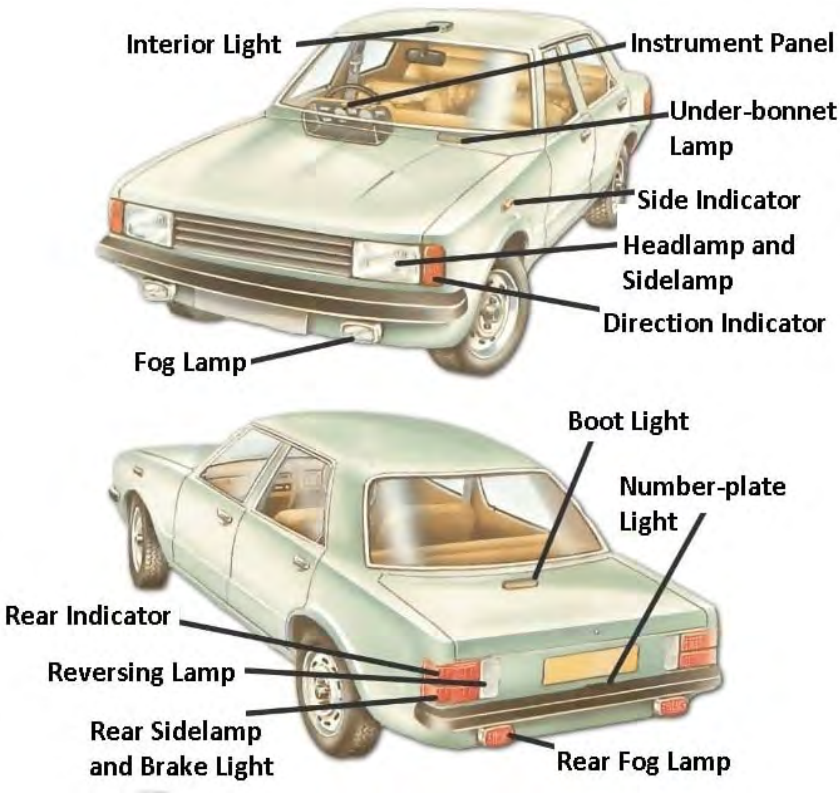


Figure 10.9: Types and positions of Vehicle lights

Exterior Lighting

1. **Headlights**

   Headlights are the primary forward-facing lights used to illuminate the road ahead in low-light conditions such as night driving or poor weather. They serve a dual function: helping the driver see the road and making the vehicle visible to other road users. There should be a minimum of two headlights on every automobile, one on each side. Most vehicles are equipped with both low beam and high beam settings—low or dip beams angle downward to prevent glare to oncoming drivers, while high beams cast a stronger, straight beam for use in dark driving conditions.

2. **Side and rear lights**

   These lights enhance the visibility of the vehicle from the sides and behind, especially during night time or reduced visibility. Side marker lights are typically amber and positioned along the vehicle's sides to help other drivers detect the vehicle's length and outline. Rear lights, or tail lamps, emit a red glow when the headlights or sidelights are turned on. They ensure that vehicles behind can identify and judge how close or far away the vehicle is. In addition, the number plate is illuminated with white lights. Red reflectors at the back serve as passive safety features that catch incoming headlights.

3. **Reverse lights**

   The reverse lights activate automatically when the driver selects reverse gear. They produce a bright white light at the rear of the vehicle, illuminating obstacles behind

the car and signalling to nearby road users that the vehicle is backing up. These lights are especially helpful in low-light environments or during parking manoeuvres.

4. **Daytime Running Lights (DRLs)**

   These are front-facing lights that turn on automatically when the engine starts. Though they are not as bright as headlights, their job is not to illuminate the road but to increase the vehicle's visibility during daylight hours. DRLs are especially effective in cloudy or shaded conditions and are often designed with energy-efficient LED technology.

5. **Hazard warning lights**

   These lights are used to alert other drivers that the vehicle poses a temporary or unexpected risk. When activated, typically by pressing a red triangle button, they cause all four turn indicators to flash simultaneously. Drivers use them during breakdowns, emergencies, or when pulled over in a potentially dangerous spot. In some regions, hazard lights are also used when driving slowly due to vehicle malfunction or towing.

6. **Directional indicator lights**

   These lights are also known as turn signals or blinkers. They show a driver's intention to change direction, whether through turning or lane switching. They are typically amber in colour and positioned at the front, rear, and often on the vehicle's sides or mirrors. Trafficators served this purpose in the past.

7. **Brake lights**

   Brake lights illuminate when the driver presses the brake pedal. They are red, like tail lights, but brighter and are mounted at the rear of the vehicle, usually in pairs or with a central high-mounted stop lamp. Their quick illumination alerts trailing drivers to deceleration, helping prevent rear-end collisions. These lights often use light emitting diodes (LEDs) for faster response and greater visibility.

8. **Auxiliary driving lamps**

   These are optional lights that add specialised illumination beyond what standard headlights offer. This category includes:

   a. fog lamps, which emit a wide, low beam to reduce glare in foggy or rainy conditions;
   b. driving lamps, which offer extended forward lighting for use on dark roads; and
   c. cornering lamps, which light up the vehicle's turning direction at slow speeds.

These are especially helpful in improving driving safety and visibility under challenging conditions.

Interior Lighting

Instrument panel lights

These lights are located inside the vehicle, behind the dashboard instruments. They are backlights that allow the driver to see important information such as speed, fuel level, and

engine temperature, especially during night time. Most vehicles allow brightness adjustment via a dimmer switch. Warning indicators within the panel are often designed with distinct colours and symbols to make it easy for the driver to notice when a fault occurs.

Dome light

The dome light is mounted at the centre of the car's ceiling to provide general illumination for the cabin. It typically switches on when doors open and helps passengers enter or exit safely in low-light conditions.

Map or reading lights

These are usually located near the front seats or in the overhead console. These offer focused beams for reading or accessing small items. They are often manually controlled and adjustable to avoid distracting the driver.

Footwell lights

Footwell lights are positioned near the pedals and under the dashboard to softly lighting the lower interior to improve visibility and comfort. They activate when doors open or the engine starts.

Door courtesy lights

These lights are installed on the inner lower edge of each door to illuminate the ground when the doors are opened. This helps passengers avoid puddles, curbs, or obstacles when entering or exiting the vehicle.

Glove compartment light

The glove compartment light is a small lamp inside the glove box that switches on automatically when the lid is opened. It helps the user find documents or small tools in dim environments

Trunk or cargo area lights

The trunk lights are placed inside the boot or luggage compartment and activate when the hatch is opened. They improve visibility for loading and unloading items, especially at night.

Vanity mirror lights

Vanity mirror lights are built into the sun visors and turn on when the mirror cover is flipped open. They assist with grooming or facial checks and typically use soft, diffused lighting.

Ambient or accent lighting

Ambient lighting adds subtle illumination to decorative areas like door panels, footwells, or dashboard trims. Though not essential for function, it enhances cabin atmosphere and driver comfort, especially in modern and premium vehicles.

Auxiliary Systems

Auxiliary systems in vehicles refer to all the electrical and electronic subsystems that support the main driving functions but are not directly involved in propulsion. They enhance comfort, safety, visibility, and convenience for both the driver and passengers. Some of the auxiliary systems on the vehicle are:

1. **Comfort systems**

   These include air conditioning, heating, power windows and seats, sunroof controls, and ventilation channels. All these systems are designed to enhance passenger comfort and ease of use.

2. **Safety systems**

   They cover central locking, remote keyless entry, anti-theft alarms, immobilizers, biometric access, parking sensors, and rear-view cameras – each contributing to vehicle security and situational awareness.

3. **Lighting systems**

   Consist of headlights, fog lamps, indicators, hazard lights, interior dome and map lights, ambient accents, instrument panel illumination, number plate lamps, and courtesy lights – serving visibility and communication.

4. **Information & entertainment systems**

   Provide driving data and multimedia access via instrument clusters, trip computers, touchscreens, radios, Bluetooth, GPS navigation, USB ports, and charging outlets.

5. **Control systems**

   Support secondary functions like windscreen wipers, washers, heated mirrors, defrosters, electric steering assist, and electronic throttle or brake control for operational safety and convenience.

6. **Instrumentation system**

   The instrument panel, commonly called the dashboard, is located in front of the driver and displays important information about the vehicle. It helps the driver monitor how the car is functioning and alerts them to any issues. It provides the driver with real-time information about the vehicle's performance and condition. Figure 10.10 shows an instrument panel

   The instrument panel consists of several tools and components. Table 10.1 below lists some of the popular ones.

Table 10.1: Vehicle instrument panel components

Component	Description
Speedometer	Measures and displays vehicle speed.
Tachometer	Shows engine RPM.

Odometer	Records the *total* distance the vehicle has travelled over its lifetime.
Trip meter	Measures the distance of a *specific journey* or trip segment.
Fuel gauge	Indicates fuel level.
Temperature sensors	Monitor engine coolant, air intake, exhaust, and cabin temperatures.
Oil pressure indicator	Alerts the driver of low engine oil pressure.
OBD (On-Board Diagnostics)	Logs faults and allows scanning with diagnostic tools.
Warning lights	Icons for low battery, check engine, airbags, ABS, etc.
Data bus systems (e.g., CAN)	Links sensors to ECUs for fast communication across vehicle systems.
Indicator lights	Includes signals for turn indicators, high beams, and hazard warnings.
Digital displays	Found in modern vehicles, showing navigation, entertainment, and vehicle diagnostics.
Control switches	Includes buttons and knobs for climate control, audio settings, and other features.

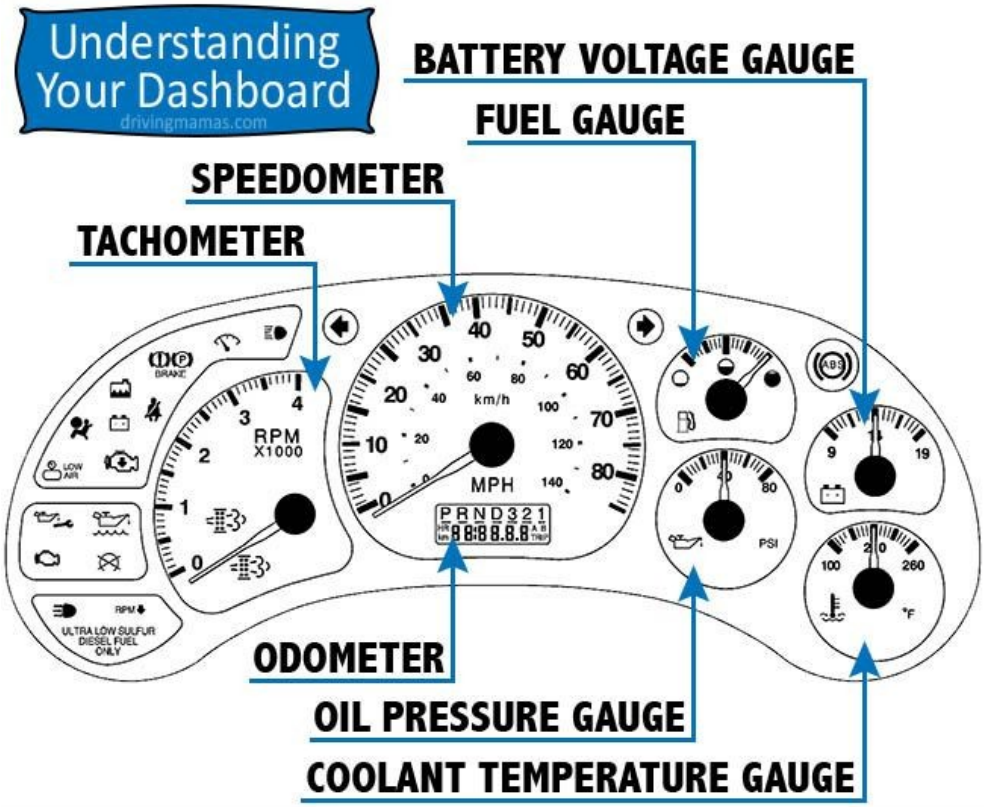


Figure 10.10: Instrument panel

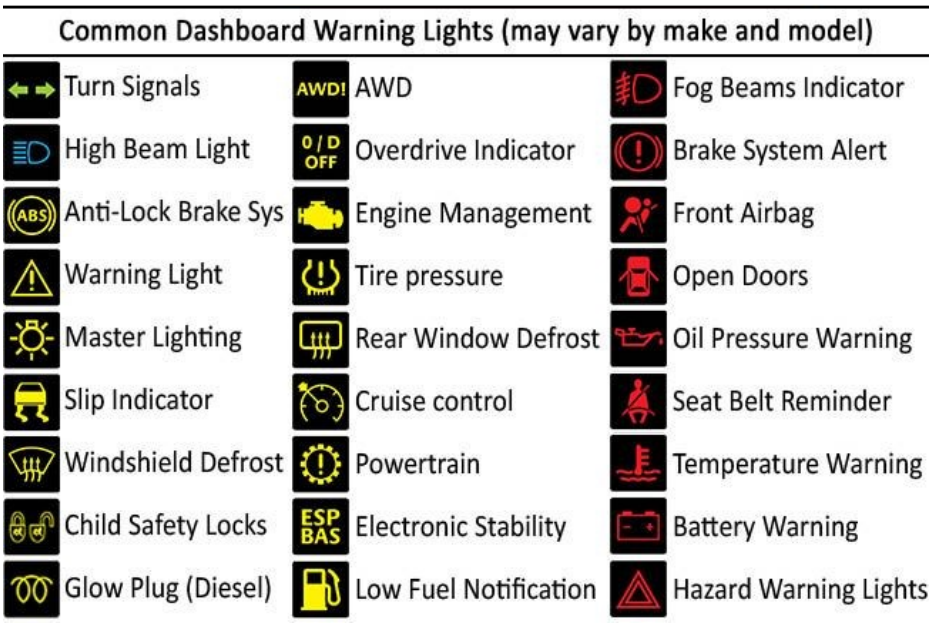


Figure 10.11: Instrument panel symbols

Activity 10.2 Vehicle Lighting and Instrument Panel Symbols

Perform this activity in a small working group of 4-6 of your classmates. Assume the role of the DVLA inspection team tasked to ensure drivers adhere to road traffic regulations involving vehicle lighting.

1. Search the internet and books/magazines for different lights installed on automobiles.
   a. In Table 10.2, provide the types of light for each of the functions stated.
   b. Indicate in the table whether a light you have provided is mandatory or optional.

Table 10.2: Description and function of different vehicle lights

No.	Function	Name of light	Mandatory/ Optional
1.	Light up the road ahead at night or in poor visibility.		
2.	Show the rear of the vehicle to other drivers when the headlights are on.		
3.	Glow when the driver presses the brake pedal—signal slowing or stopping.		
4.	Blink to show that the vehicle is turning left or right.		

5.	Come on when the vehicle is moving backward to alert people behind.		
6.	Flash all turn signals at once to warn others of danger or breakdown.		
7.	Shine low and wide to improve visibility in fog or heavy rain.		
8.	Light up the inside of the car when doors open or for nighttime use.		
9.	Illuminate the instrument panel for better readability during night driving.		
10.	Improve visibility for loading and unloading cargo at night.		

2. Prepare a public awareness presentation that highlights
   a. The importance of vehicle lighting for safety, visibility, and communication on the road.
   b. A clear distinction between mandatory (obligatory) lights required by law and supplementary (optional) lights that enhance function or comfort.
   c. The potential risks and consequences of driving with faulty, missing, or obscured lights.
   d. Simple advice for daily lighting checks and the role of periodic inspections.
   e. How proper lighting supports accident prevention, especially during night driving, poor weather, or heavy traffic.

3. Seek the guidance of your Automotive Technology teacher to have access to a vehicle in or around the school. Critically observe the instrument panel to identify the various symbols, their colours and where each symbol is located on the panel.

Complete the ***Table 10.3*** for different instrument panel signs/symbols. For each name provided, you are to draw the symbol and state the colour and meaning of that symbol.

Table 10.3: Instrument panel symbols and their meanings

Name	Symbol	Colour	Meaning
Oil pressure warning light/lamp			
Check engine light/lamp			
Battery			
Engine temperature			
Tyre pressure monitoring			

Handbrake			
Antilock braking system			
Traction/stability control			
Seat belt reminder			
Airbag system			
Low fuel			
Fog lamp indicator			
Cruise control			
Transmission temperature			
General warning			

EXTENDED READING

What Is A Charging System? Its Function and Components
What Is A Car Alternator, And How Does It Work? | Firestone Complete Auto Care
Automotive Exterior Lighting: Types, Materials, and Design - AutoProtoWay
What Is An Instrument Panel?

REVIEW QUESTIONS

1.

   a. Explain how a failure in the charging system could affect both the auxiliary and lighting systems during a night-time journey.
   b. Suggest two steps to diagnose the problem.

2.

   a. Design a maintenance checklist that includes tasks for inspecting the charging, lighting, and instrument panel systems.
   b. Justify why each item is important for road safety.

3.

   a. Analyse the relationship between the battery, alternator, and instrument panel in the vehicle electrical system.
   b. Illustrate the warning signs that might appear on the dashboard if the battery and alternator are not functioning.
   c. How should a driver respond to this sign?

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GLOSSARY

- **3D CAD Model**: A 3D CAD model is a digital, three-dimensional representation of a physical object created using Computer-Aided Design (CAD) software.
- **3D CAD**: 3D CAD stands for three-dimensional computer-aided design. It refers to software used by engineers, architects, and designers to create detailed digital models of real-world objects or structures in three dimensions.
- **3D printers**: 3D printers are machines that create three-dimensional objects by building them layer by layer from digital designs, kind of like sculpting in reverse.
- **3D printing**: 3D printing, also known as additive manufacturing, is a process of creating three-dimensional objects by building them layer by layer from a digital design.
- **Analysis question**: An analysis question is a type of question that asks you to break something down into its parts, examine how those parts relate, and interpret their meaning or impact.
- **Assembly drawing**: An assembly drawing is a type of technical drawing that shows how multiple parts fit together to form a complete product or system.
- **Atomisation**: The process of breaking up liquid fuel into a fine mist to help it mix with air for better combustion in the engine.
- **Automation**: is the use of technology, like machines, software, or systems to perform tasks with minimal or no human intervention.
- **Backpressure***:* Resistance in the exhaust system that can reduce engine efficiency if not properly managed.
- **Bench drill**: A bench drill, also known as a drill press, is a stationary power tool used to drill precise holes in materials like wood, metal, or plastic.
- **Block**: A block is a fixed-size chunk of data used to manage memory or disk space.
- **CAD drawing**: A CAD drawing is a digital blueprint created using Computer-Aided Design (CAD) software. It represents the geometry, dimensions, and technical details of an object or system, used widely in engineering, architecture, manufacturing, and product design.
- **Carburetion**: The process of mixing air and fuel in the correct ratio in a carburetor before it enters the engine.
- **Clockwise**: Clockwise describes movement in the same direction as the hands of a traditional clock, from the top, sweeping right, down, then left, and back up again.
- **CNC Code**: CNC code refers to the programming instructions used to control Computer Numerical Control (CNC) machines, automated tools that cut, drill, mill, or shape materials like metal, plastic, or wood with extreme precision.
- **CNC controller**: A CNC controller is essentially the brain of a CNC (Computer Numerical Control) machine.

- **CNC drilling machines**: CNC drilling machines are computer-controlled tools designed to create precise, repeatable holes in a wide range of materials like metal, plastic, or wood.
- **CNC language**: CNC language typically refers to the programming languages used to control CNC machines.
- **CNC Lathe machine**: A CNC lathe machine is a computer-controlled tool used to shape materials, typically metal, plastic, or wood, by rotating the workpiece against a stationary cutting tool.
- **CNC machines**: A CNC machine is a computer-controlled machine used to perform precise cutting, drilling, milling, turning, or shaping of materials like metals, plastic, or wood.
- **CNC milling Machine**: A CNC milling machine is a computer-controlled tool used to shape solid materials like metal, plastic, or wood by removing material with a rotating cutting tool.
- **CNC milling Operations**: CNC milling operations are the various machining techniques performed using a CNC milling machine to shape and finish materials with high precision.
- **CNC technology**: CNC technology, short for Computer Numerical Control, is the backbone of modern precision manufacturing.
- **CNC tools**: CNC tools refer to the cutting and shaping instruments used by the machine to remove material and form precise parts.
- **CNC turning machines**: A CNC turning machine, also known as a CNC lathe, is a computer-controlled machine used to produce precise cylindrical parts by rotating a workpiece while a stationary cutting tool removes material.
- **Components**: Components are the individual parts or elements that come together to form a larger system or machine.
- **Computer-controlled tools**: Computer-controlled tools are machines or devices that operate based on instructions from a computer program rather than manual input.
- **Computerised machine**: A computerised machine is any machine that uses a built-in computer or microcontroller to automate and control its operations.
- **Control panel**: A machine control panel is the central interface that allows operators to monitor, manage, and control the operation of industrial equipment.
- **Coolant system**: is a vital part of many machines, especially engines and industrial equipment, designed to manage and dissipate excess heat generated during operation.
- **Counter-clockwise**: Counter-clockwise (also called anticlockwise in some regions) means moving in the opposite direction to the way the hands of a clock move.
- **Cutting list**: A cutting list, also known as a cut list or parts list, is a detailed document used in manufacturing, woodworking, metalworking, and construction to specify all the individual pieces needed to build a project.

- **Design brief**: A design brief is a foundational document that outlines the objectives, scope, and requirements of a design project.
- **Design situation**: A design situation is the real-world context or problem that sparks the need for a design solution.
- **Designing**: Designing is the creative and strategic process of planning and shaping ideas into functional or aesthetic outcomes.
- **Detailed drawing**: A detailed drawing is a precise technical illustration that zooms in on a specific part or component of a larger design.
- **Dwell**: In applied technology; Especially in CNC machining or automation "dwell" refers to a brief pause or delay in the movement of a machine or tool.
- **Evaluation**: Evaluation is the process of carefully examining something to determine its value, quality, effectiveness, or significance.
- **Extruder**: An extruder is a machine that forces material through a shaped opening called a die, to create continuous objects with a specific cross-section.
- **Fast Prototyping**: Fast prototyping, more commonly known as rapid prototyping, is a process used to quickly create a preliminary version of a product or component to test its design, functionality, and usability before full-scale production.
- **Filament**: a filament is the thermoplastic material (like PLA or ABS) that's fed into the printer, melted, and extruded layer by layer to build objects.
- **Finish**: can mean a few different things depending on the context, but at its core, it refers to bringing something to an end or completing it.
- **Finishing**: refers to the final touches that elevate a project from "good" to "great." It's where refinement, polish, and attention to detail come into play, whether you're working on a product, graphic, interior, or architectural design.
- **Fixtures**: A fixture is a device used to secure, support, and precisely locate a workpiece during an operation like drilling, milling, or welding.
- **Fog lamp**: A light that improves visibility during foggy or misty weather by cutting through low-lying moisture.
- **Forced induction**: A method of increasing engine power by compressing the air entering the combustion chamber, typically using a supercharger or turbocharger.
- **Forced induction**: Technique using compressed air (via turbocharger/ supercharger) to boost engine performance.
- **Fusion**: Fusion often refers to Autodesk Fusion 360, a powerful all-in-one software used for designing, simulating, and preparing models for additive manufacturing.
- **G-code**: Short for Geometric Code; Is the primary programming language used to control CNC (Computer Numerical Control) machines and 3D printers.
- **G-codes**: G-codes are the core instructions used to control CNC (Computer Numerical Control) machines.
- **Head**: In 3D printing, the print head, also called the extruder head or tool head, is the part of the printer that deposits material to build your object layer by layer.
- **High precision**: refers to the ability to perform tasks or produce components with extremely tight tolerances and minimal deviation from exact specifications.

- **Impeller***:* A rotating component inside a supercharger or turbocharger that draws in and compresses air.
- **Instrument panel**: A display in front of the driver showing important indicators like speed, fuel level, and warning lights.
- **Intercooler**: A heat exchanger used to cool compressed air before it enters the engine, improving performance and reducing knocking.
- **Investigation**: The crucial first step where you explore and define the problem you're trying to solve.
- **Lathe operations**: Lathe operations are the various machining processes performed on a lathe machine, which rotates a workpiece while a cutting tool removes material to shape it.
- **Line motion**: Line motion is usually referred to as linear motion; The movement of an object or component along a straight path. It is a foundational concept in fields like automation, robotics, CNC machining, and mechanical engineering.
- **Manufacturing process**: The series of steps used to transform raw materials into finished products.
- **Mass airflow sensor**: A sensor measuring the quantity of air entering the engine to aid fuel management.
- **M-codes**: M-codes (short for *Miscellaneous codes*) are instructions that control the **non-movement functions** of a machine.
- **Modifications**: changes made to improve, adapt, or correct a design either during development or after a product is already in use.
- **Nickel Alloys**: Nickel alloys are metallic materials that contain a significant amount of nickel, often combined with elements like chromium, iron, copper, molybdenum, or titanium.
- **Obligatory lights**: Legally required lights on a vehicle, such as headlamps and brake lights, to ensure safety.
- **Onshape** is a cloud-native CAD (Computer-Aided Design) and PDM (Product Data Management) platform developed by PTC. Unlike traditional CAD software that requires installation and file management, Onshape runs entirely in a web browser, making it accessible from any device, anywhere, with no downloads or updates needed.
- **Orthographic projection**: A method used in technical drawing and design to represent a 3D object in 2D views. It's like flattening a 3D shape onto paper so that every side can be seen clearly and accurately without distortion.
- **Oxidation***:* A chemical reaction where oxygen is added to a substance; in catalytic converters, it turns carbon monoxide and hydrocarbons into safer compounds.
- **Pillar drill**: Also known as a drill press, is a powerful, free-standing machine used to drill precise holes in various materials like metal, wood, or plastic.
- **Possible design concepts**: Design concepts are the core ideas or themes that guide the look, feel, and function of a product or project.

- **Practical procedures**: Hands-on tasks or techniques that are performed to achieve a specific outcome, especially in fields like healthcare, engineering, science, and design.
- **Print bed**: Print bed (or build plate) is the flat surface on which the printer lays down material to build your object layer by layer.
- **Programming language**: A programming language is a formal system of communication used to write instructions that a computer can understand and execute.
- **Rapid motion**: Rapid motion (also called rapid traverse) refers to the fastest possible movement of a machine's tool or component when it is not cutting or performing a task.
- **Rapid Prototyping**: Rapid prototyping is a process used to quickly create a preliminary version of a product or component to test its design, functionality, and usability before full-scale production.
- **Reduction catalyst***:* A catalyst that removes oxygen from nitrogen oxides to produce nitrogen and oxygen gases, helping reduce air pollution.
- **Rotating spindle**: A **rotating spindle** is a central component in many machine tools like CNC lathes, milling machines, and drill presses that **spins either the workpiece or the cutting tool** at controlled speeds.
- **Selective catalytic reduction (SCR)**: A diesel emission control process that uses a chemical fluid (urea) to convert nitrogen oxides into nitrogen and water.
- **Sintering**: Sintering is a manufacturing process where powdered materials, typically metals, ceramics, or plastics, are compacted and then heated to a temperature below their melting point to form a solid, dense object.
- **Solenoid**: An electrical coil used to control a mechanical device, like opening a valve in fuel injectors.
- **SolidWorks**: SolidWorks is a professional-grade 3D CAD (Computer-Aided Design) software developed by Dassault Systèmes. It is widely used by engineers, designers, and manufacturers to create precise 3D models, assemblies, and technical drawings for everything from mechanical parts to complex machinery.
- **Specification**: In design and engineering, a specification is a detailed and precise description of the requirements, features, and standards that a product, system, or process must meet.
- **Spin**: Often relates to the rotation of tools or workpieces, like a spindle spinning a drill bit or grinding wheel.
- **Stages in design and Manufacture**: The design and manufacturing process unfolds in a series of structured stages that take an idea from concept to reality.
- **STL File**: An STL file (short for Stereolithography or Standard Tessellation Language) is a widely used file format in 3D printing and computer-aided design (CAD).
- **Substrate***:* The internal ceramic or metallic structure within a catalytic converter that provides a large surface area for catalyst coating.

- Supplementary lights: Extra lights like fog lamps or reversing lights that assist the driver but are not legally required.
- **Surface grinding machines**: A surface grinding machine is a precision tool used to produce smooth, flat finishes on metal or other materials.
- **Testing**: Testing in the design and manufacturing process is about verifying that a product or system works as intended before it reaches the user or the market.
- **Tinkercad**: a free, browser-based platform by Autodesk for 3D design, electronics, and coding.
- **Titanium**: Titanium is a chemical element with the symbol Ti and atomic number 22. It's a strong, lightweight, and corrosion-resistant metal, making it incredibly valuable in industries where performance under stress and exposure is critical.
- **Torque***:* A measure of the engine's twisting force, which helps in acceleration, climbing, and towing.
- **Turbo lag***:* The delay between when the accelerator is pressed and when the turbocharger starts providing a noticeable power boost.
- **Warning indicator**: A light or symbol that alerts the driver to a problem or status change in the vehicle system.
- **Working principles**: The **working principles** of CNC (Computer Numerical Control) machines revolve around the idea of using a computer to control machine tools with **high precision, automation, and repeatability**.