SWARRNIM START UP AND INNOVATION UNIVERSITY

NAME OF INSTITUTE: - SWARRNIM INSTITUTE OF TECHNOLOGY, GANDHINAGAR

NAME OF COURSE:-

CIVIL engineering

Cross Section Design in Structural Engineering

Introduction

The design of cross sections in structural engineering is a crucial element in ensuring the safety, functionality, and efficiency of buildings and infrastructure. Cross sections are the components of structures that resist various loads and forces, including bending, shear, and axial loads. This chapter delves into the principles, methodologies, and considerations involved in cross section design, providing a comprehensive overview of its significance in structural engineering.

1. Fundamentals of Cross Section Design

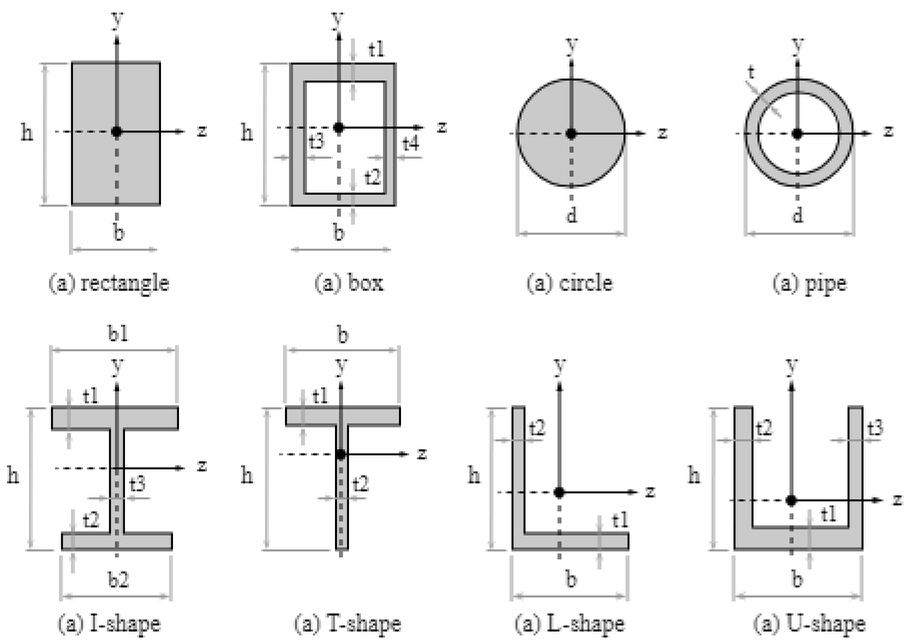
1.1 Definition and Purpose

A cross section is a vertical slice through a structural element, such as a beam, column, or slab, which shows the internal arrangement of materials and the geometry of the section. The purpose of cross section design is to ensure that structural elements can safely carry applied loads and resist forces without excessive deformation or failure.

1.2 Types of Cross Sections

- **Rectangular Sections**: Commonly used in beams and columns due to their simplicity and ease of analysis.
- **Tee Sections**: Often used in beams and channels to optimize material use and strength.
- **I Sections**: Known for their efficiency in resisting bending moments and are commonly used in steel structures.

- **Circular Sections**: Used in columns and shafts where uniform strength in all directions is required.
- **Custom Shapes**: Tailored to specific requirements of complex structures, including composite and non-standard cross sections.



Types of Cross sections

2. Design Principles

2.1 Load Considerations

The design of cross sections must account for various loads, including:

- **Dead Loads**: Permanent static loads such as the weight of structural elements and non-movable fixtures.
- **Live Loads**: Variable loads including occupants, furniture, and equipment.
- **Environmental Loads**: Loads due to wind, snow, seismic activity, and temperature changes.

2.2 Material Properties

The choice of materials and their properties significantly impact cross section design. Key material properties include:

- **Strength**: The maximum stress that a material can withstand.
- **Modulus of Elasticity**: A measure of a material's stiffness.
- **Ductility**: The ability of a material to deform under stress before failure.

2.3 Design Codes and Standards

Adherence to design codes and standards is essential to ensure safety and compliance. Codes provide guidelines for:

- **Minimum Dimensions**: Ensuring structural integrity and safety.
- **Load Factors**: Applying safety margins to account for uncertainties in loadings.
- **Material Strength**: Specifying material properties and testing requirements.

3. Analysis of Cross Sections

3.1 Moment of Inertia

The moment of inertia (I) is a critical property in cross section design, influencing the section's ability to resist bending. It is calculated based on the geometry of the cross section and affects the section's flexural rigidity.

3.2 Section Modulus

The section modulus (S) is derived from the moment of inertia and provides a measure of the strength of a cross section in bending. It is defined as:

S=IcS = \frac{I}{c}S=cI

whereccc is the distance from the neutral axis to the outermost fiber.

3.3 Shear Strength

Shear strength is crucial for preventing shear failure. The design must consider the shear capacity of the cross section, influenced by material properties and cross-sectional geometry.

3.4 Axial Load Analysis

Cross sections must also be designed to resist axial loads, which can be either compressive or tensile. The design process includes analyzing the section’s capacity to handle these loads without buckling or excessive deformation.

4. Design of Common Structural Elements

4.1 Beams

Beams are horizontal members that support loads and transfer them to supports. Key considerations in beam design include:

- **Bending Capacity**: Ensuring the beam can resist bending moments without failing.
- **Shear Capacity**: Designing for shear forces to prevent shear failure.

- **Deflection**: Controlling deflection to ensure serviceability and comfort.

4.2 Columns

Columns are vertical members that support axial loads and transfer them to foundations. Important aspects of column design include:

- **Buckling Analysis**: Assessing the potential for buckling under compressive loads.
- **Load Capacity**: Designing for the maximum axial load the column can safely carry.
- **Slenderness Ratio**: Evaluating the column's length-to-diameter ratio to prevent buckling.

4.3 Slabs

Slabs are flat, horizontal members used to form floors and ceilings. Key design considerations include:

- **Load Distribution**: Ensuring even load distribution across the slab.
- **Reinforcement**: Providing adequate reinforcement to resist bending and shear forces.
- **Serviceability**: Controlling deflection and vibration for user comfort.

5. Advanced Cross Section Design Techniques

5.1 Composite Sections

Composite sections combine different materials, such as steel and concrete, to enhance performance. Design considerations include:

- **Interaction Between Materials**: Ensuring that materials work together effectively.
- **Bonding and Connections**: Designing connections to transfer loads between materials.

5.2 Hollow Sections

Hollow sections, such as tubular sections, are used to reduce weight while maintaining strength. Key aspects include:

- **Structural Efficiency**: Maximizing strength-to-weight ratio.
- **Fabrication**: Ensuring ease of fabrication and connection.

5.3 Non-Standard Shapes

Custom or non-standard shapes are designed for specific applications. These may include:

- **Curved Sections**: Used in arches or curved structures.
- **Variable Sections**: Sections with varying dimensions along their length.

6. Design Optimization and Sustainability

6.1 Optimization Techniques

Optimization involves adjusting design parameters to achieve the best performance with minimal material use. Techniques include:

- **Structural Analysis Software**: Using advanced software to model and analyze different cross-sectional designs.
- **Design Iterations**: Performing iterative design processes to refine cross-sectional dimensions.

6.2 Sustainable Design Practices

Sustainability in cross section design focuses on reducing environmental impact and resource consumption. Strategies include:

- **Material Efficiency**: Using materials more effectively to reduce waste.
- **Lifecycle Assessment**: Evaluating the environmental impact of materials and design choices over the structure's lifespan.

7. Case Studies

7.1 High-Rise Building Design

A case study of a high-rise building illustrates the challenges and solutions in designing cross sections to support significant loads and resist bending and shear forces.

7.2 Bridge Design

Another case study explores the design of cross sections in bridge structures, focusing on load distribution, material selection, and durability considerations.

7.3 Industrial Structures

An examination of cross section design in industrial buildings highlights the need for robustness and resistance to heavy loads and dynamic forces.

8. Future Trends in Cross Section Design

8.1 Innovations in Materials

The development of new materials, such as advanced composites and high-performance concretes, will continue to influence cross section design. These materials offer enhanced properties and new possibilities for design.

8.2 Computational Design Tools

Advances in computational tools and software will further enhance the design process, allowing for more complex analyses and optimizations.

8.3 Integration of Smart Technologies

The integration of smart technologies, such as sensors and monitoring systems, will provide real-time data on structural performance, enabling more responsive and adaptive design approaches.

Conclusion

Cross section design is a fundamental aspect of structural engineering, encompassing a wide range of principles and methodologies to ensure the safety, efficiency, and functionality of structures. By understanding and applying the key concepts of cross section design, engineers can create robust and resilient structures that meet the demands of modern construction and infrastructure. As technology and materials continue to evolve, cross section design will adapt, driving innovation and advancing the field of structural engineering.

This chapter provides a detailed overview of cross section design, addressing fundamental principles, design methodologies, advanced techniques, and future trends. It serves as a comprehensive guide for understanding the complexities and considerations involved in designing effective and efficient cross sections for various structural applications.

High Performance Concrete: Advancements and Applications

Introduction

High Performance Concrete (HPC) represents a significant advancement in construction materials, offering superior durability, strength, and workability compared to traditional concrete mixes. The evolution of HPC has been driven by the need for more resilient structures, efficient construction practices, and sustainable building solutions. This chapter explores the fundamental characteristics, mix designs, applications, and future prospects of HPC.

1. Definition and Characteristics

High Performance Concrete is characterized by its exceptional properties, which include enhanced strength, durability, and resistance to environmental conditions. Unlike conventional concrete, HPC is designed to meet specific performance criteria that make it suitable for demanding structural applications. The primary characteristics of HPC include:

- **High Compressive Strength**: HPC typically achieves compressive strengths greater than 40 MPa (5800 psi), often reaching values in excess of 100 MPa (14,500 psi). This high strength allows for the use of less material while maintaining structural integrity.
- **Improved Durability**: HPC exhibits superior resistance to environmental factors such as freeze-thaw cycles, chemical attacks, and abrasion. This durability is achieved

through the use of advanced materials and admixtures that enhance the concrete's performance.

- **Enhanced Workability**: Despite its high strength and durability, HPC maintains good workability, which facilitates easier placement and finishing. This is particularly important in complex or intricate construction projects.
- **Reduced Permeability**: The low permeability of HPC helps prevent the ingress of harmful substances, contributing to its longevity and reducing maintenance needs.

2. Components of High Performance Concrete

The performance of HPC is largely influenced by the choice and proportioning of its constituent materials. The key components include:

- **Cementitious Materials**: Portland cement is the primary binder in HPC, but supplementary cementitious materials (SCMs) such as fly ash, slag, and silica fume are commonly used to enhance performance. These SCMs improve the strength, reduce permeability, and contribute to the sustainability of the mix.
- **Aggregates**: High-quality aggregates are essential for HPC. They should be clean, well-graded, and free from impurities. Fine aggregates are typically well-graded sand, while coarse aggregates may include crushed stone or gravel.
- **Admixtures**: Chemical admixtures play a crucial role in HPC by modifying its properties. Superplasticizers (high-range water reducers) improve workability without increasing water content, while air-entraining agents enhance freeze-thaw resistance. Other admixtures may include accelerators or retarders to adjust setting times.
- **Water**: Water quality affects the HPC mix. Clean, potable water is essential to achieve the desired strength and durability. The water-cement ratio is carefully controlled to optimize performance.

3. Mix Design and Proportioning

Designing a mix for HPC requires careful consideration of various factors to achieve the desired properties. The process generally involves:

- **Target Strength**: The compressive strength is a primary design criterion. Engineers determine the required strength based on the structural requirements of the project.
- **Workability Requirements**: Workability is adjusted using admixtures to ensure that the concrete can be placed and finished effectively. The slump test or other workability tests are used to monitor consistency.
- **Durability Specifications**: The mix must be designed to resist environmental challenges such as chemical exposure, temperature extremes, and mechanical wear. This often involves optimizing the aggregate grading and incorporating appropriate SCMs.
- **Trial Mixes**: Several trial mixes are prepared and tested to fine-tune the proportions of materials. This process helps in achieving the desired performance characteristics and ensures that the mix meets all specifications.

4. Applications of High Performance Concrete

High Performance Concrete is used in a variety of applications where its unique properties provide significant benefits:

- **Infrastructure Projects**: HPC is widely used in bridges, highways, and tunnels due to its strength and durability. The material's resistance to environmental conditions makes it ideal for structures exposed to harsh climates or heavy traffic.

- **High-Rise Buildings**: The high compressive strength of HPC allows for the construction of taller buildings with reduced column sizes and increased floor area. This is particularly advantageous in urban environments where space is at a premium.
- **Marine Structures**: HPC's resistance to seawater and marine environments makes it suitable for use in piers, docks, and offshore platforms. The reduced permeability of HPC helps protect these structures from corrosion.
- **Industrial Facilities**: In facilities where heavy machinery or chemical processes are involved, HPC's durability and resistance to abrasion are highly valued. The material ensures that floors, walls, and other structural elements withstand intense operational conditions.

5. Sustainability and Environmental Considerations

The development of HPC aligns with sustainable construction practices. By using SCMs and optimizing mix designs, HPC can reduce the overall environmental impact of concrete production. Additionally:

- **Reduced Carbon Footprint**: The use of SCMs and optimized mix designs can lower the carbon footprint associated with cement production.
- **Longevity and Maintenance**: The durability of HPC reduces the need for repairs and maintenance, extending the lifespan of structures and minimizing resource consumption over time.
- **Resource Efficiency**: High-strength mixes allow for the use of smaller quantities of concrete, contributing to resource efficiency and reducing waste.

6. Challenges and Future Directions

Despite its advantages, HPC presents some challenges:

- **Cost**: The use of high-quality materials and admixtures can increase the cost of HPC compared to traditional concrete. However, this cost is often offset by the long-term benefits of reduced maintenance and extended lifespan.
- **Complexity in Mixing and Handling**: The precise control required in HPC mix designs and the need for specialized equipment can pose challenges in terms of mixing and placement.
- **Research and Development**: Ongoing research is focused on improving the performance and sustainability of HPC. Innovations include new types of SCMs, advanced admixtures, and novel curing techniques.

Future directions in HPC research include the development of even more sustainable materials, enhanced performance under extreme conditions, and integration with advanced technologies such as smart sensors and monitoring systems.

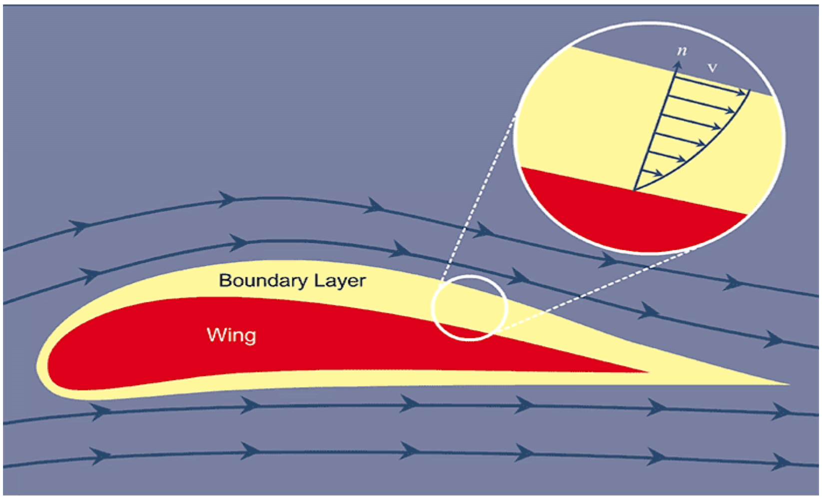
Conclusion

High Performance Concrete represents a significant leap forward in construction technology, offering superior strength, durability, and workability. Its diverse applications across infrastructure, high-rise buildings, marine structures, and industrial facilities underscore its value in modern construction. As research and development continue to advance, HPC is expected to play an increasingly important role in creating resilient and sustainable built environments. The continued exploration of innovative materials and technologies will drive the future of HPC, ensuring its relevance in meeting the evolving demands of the construction industry.

Boundary Layer

Introduction

In civil engineering, understanding the behaviour of fluids around structures is crucial for designing safe and efficient buildings, bridges, and other infrastructure. Boundary layer theory, a fundamental concept in fluid mechanics, plays a vital role in this context. This chapter delves into boundary layer theory, exploring its principles, applications, and significance in civil engineering.



5.1 The Concept of Boundary Layers

The boundary layer theory emerged from studies on fluid flow, particularly how fluids interact with solid surfaces. The boundary layer is the thin region of fluid adjacent to a solid boundary where effects of viscosity are significant. In civil engineering, this theory is pivotal in analysing how air or water flows around structures.

5.1.1 Definition and Formation

The boundary layer forms due to the no-slip condition, where the fluid velocity at the solid surface is zero. As you move away from the surface, the velocity increases until it reaches the free stream value. This transition occurs in a thin layer close to the surface, the thickness of which is known as the boundary layer thickness.

Ludwig Prandtl, a German physicist, introduced the concept of the boundary layer in 1904, which revolutionised the field of fluid dynamics and aerodynamics. Prandtl's boundary layer theory provided a solution to the challenges posed by the Navier-Stokes equations in describing the behaviour of viscous flows near solid surfaces. His work addressed the discrepancies between theoretical predictions and experimental observations in fluid flow, particularly around streamlined bodies and aircraft wings.

Key Concepts of Prandtl's Boundary Layer Theory:

Boundary Layer Definition: Prandtl proposed that when a fluid flows over a solid surface, a thin layer of fluid, known as the boundary layer, forms near the surface. Within this layer, viscous forces are significant, causing a velocity gradient from zero at the wall (due to the no-slip condition) to the free-stream velocity at the outer edge of the boundary layer.

Separation of Flow: Prandtl's theory suggested that the flow can be divided into two regions: the boundary layer, where viscosity plays a major role, and the outer flow, where inviscid (non-viscous) approximations can be applied. This separation allowed for the simplification of complex flow problems and more accurate predictions.

Reduction of Complexity: By recognizing the existence of the boundary layer, Prandtl demonstrated that the full Navier-Stokes equations need not be solved everywhere in the flow. Instead, simplified forms of these equations could be applied within the boundary layer, making it feasible to solve practical engineering problems.

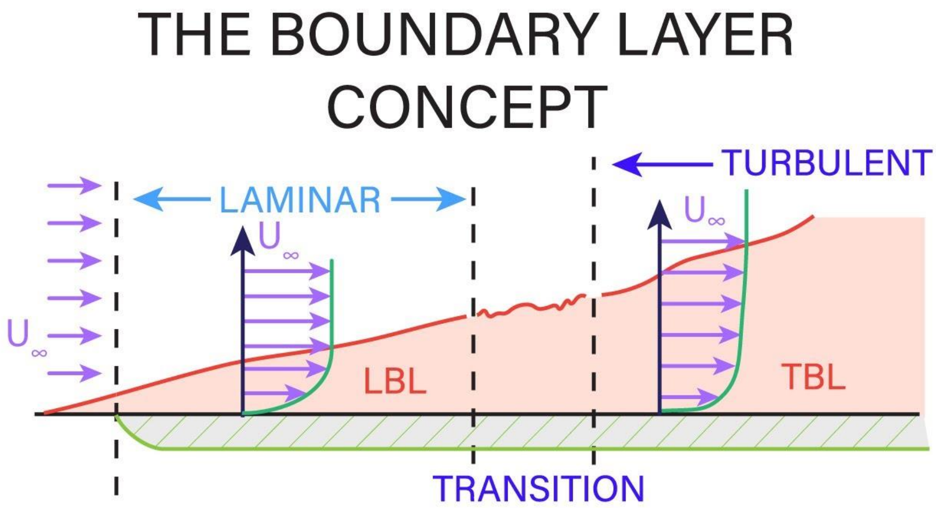
Applications: Prandtl's boundary layer theory had profound implications for the design of aerodynamic shapes, including aircraft wings and streamlined bodies. It helped engineers predict drag forces, understand flow separation, and enhance lift characteristics. The theory also laid the groundwork for further studies on laminar-turbulent transition and the development of methods for boundary layer control.

Impact on Fluid Dynamics: Prandtl's introduction of boundary layer theory marked a significant turning point in fluid dynamics, bridging the gap between theoretical analysis and practical observations. His insights provided a foundation for the development of modern aerodynamics and engineering, influencing a wide range of applications from aviation to automotive design and environmental fluid dynamics.

Prandtl's boundary layer theory remains a cornerstone of fluid mechanics, reflecting its fundamental role in understanding and predicting the behaviour of real-world fluid flows.

5.1.2 Types of Boundary Layers

1. **Laminar Boundary Layer**: Characterized by smooth and orderly fluid flow with parallel layers. This occurs when the Reynolds number, a dimensionless quantity representing the ratio of inertial forces to viscous forces, is low.
2. **Turbulent Boundary Layer**: Occurs at higher Reynolds numbers and is characterized by chaotic and irregular fluid motion. Turbulent boundary layers are thicker and exhibit higher momentum transfer.



5.2 Boundary Layer Theory Fundamentals

Boundary layer theory is grounded in the principles of fluid mechanics and involves solving the Navier-Stokes equations under specific conditions.

5.2.1 Governing Equations

The Navier-Stokes equations describe the motion of viscous fluid flow. In boundary layer theory, these equations are simplified to account for the thin boundary layer:

- **Continuity Equation**: Ensures mass conservation.
- **Momentum Equations**: Describe changes in fluid momentum in the boundary layer.

In the boundary layer, the velocity gradients normal to the surface are significant, while gradients along the surface are small.

5.2.2 Boundary Layer Thickness

The boundary layer thickness (δ\deltaδ) increases with distance from the leading edge of a surface. For a flat plate in a steady, incompressible flow.

5.3 Applications in Civil Engineering

5.3.1 Aerodynamics of Structures

For buildings and bridges, understanding how wind interacts with structures is critical. Boundary layer theory helps in predicting wind loads and designing aerodynamic shapes to minimize drag and improve stability.

- **Wind Load Calculations**: The boundary layer affects the pressure distribution on building surfaces, which is crucial for determining wind loads.
- **Aerodynamic Shape Design**: Structures are often designed to streamline the flow and reduce drag forces by considering the boundary layer effects.

5.3.2 Water Flow Around Structures

In civil engineering, analysing water flow around piers, dam structures, and other hydraulic components is essential for stability and erosion control.

- **Pier and Abutment Design**: The boundary layer influences the forces exerted by flowing water on structures. Accurate predictions of these forces help in designing foundations and protective measures.
- **Erosion Control**: Understanding boundary layer behavior aids in predicting and mitigating erosion around hydraulic structures.

5.3.3 Thermal Boundary Layers

In certain applications, such as cooling of structures or HVAC systems, thermal boundary layers are of interest. These layers impact heat transfer rates and overall thermal performance

5.4 Experimental and Computational Techniques

5.4.1 Experimental Methods

Various experimental techniques are used to study boundary layers, including:

- **Wind Tunnels**: To simulate and measure aerodynamic forces on scaled models.
- **Water Channel Tests**: To study fluid flow and boundary layer effects on hydraulic structures.
- **Laser Doppler Anemometry (LDA)**: To measure velocity profiles within the boundary layer.

5.4.2 Computational Fluid Dynamics (CFD)

CFD simulations provide a powerful tool for analyzing boundary layers in complex scenarios. Advanced CFD techniques allow engineers to model and visualize boundary layer behavior around structures, providing insights into flow patterns, pressure distributions, and forces.

5.5 Case Studies

5.5.1 Bridge Design

Consider the design of a suspension bridge where wind-induced vibrations are a concern. Boundary layer theory helps in predicting the wind-induced forces on the bridge deck and cables. By analyzing the boundary layer, engineers can design aerodynamic features to minimize wind resistance and enhance stability.

Boundary layer theory plays a crucial role in the design and analysis of bridges, particularly when considering aerodynamic stability, wind load effects, and the prevention of phenomena like vortex shedding. This case study will focus on how boundary layer theory influenced the design of the Tacoma Narrows Bridge, and how insights from this infamous failure have shaped modern bridge design.

Overview of the Tacoma Narrows Bridge

The original Tacoma Narrows Bridge, completed in July 1940 in Washington State, USA, was a suspension bridge with a span of 2,800 feet. Shortly after its completion, the bridge earned the nickname "Galloping Gertie" due to its tendency to oscillate in windy conditions. On November 7, 1940, just four months after opening, the bridge collapsed during moderate winds due to aeroelastic flutter, a phenomenon associated with unstable boundary layer behavior around the bridge deck.

Role of Boundary Layer Theory in Bridge Design

5.5.1.1. Understanding Wind Flow and Vortex Shedding

Vortex Shedding: Vortex shedding occurs when wind flows over the bridge deck, creating alternating low-pressure zones that generate periodic forces perpendicular to the flow direction. These vortices cause oscillations in the structure, which can become dangerous if they match the natural frequency of the bridge (resonance). Boundary layer theory helps in understanding the formation of these vortices and predicting their behavior.

Boundary Layer Separation: In the case of the Tacoma Narrows Bridge, the wind flow over the flat, solid plate-like deck caused boundary layer separation, leading to the formation of vortices. The bridge's slender design and lack of aerodynamically efficient shape made it highly susceptible to these effects.

5.5.1.2. Aerodynamic Stability and Flutter

Flutter: This is an unstable oscillation that grows with time when the aerodynamic forces interacting with the structure amplify the motion. Prandtl’s boundary layer theory provides insight into how airflow can interact with a structure’s surface, influencing its stability. For the Tacoma Narrows Bridge, inadequate consideration of boundary layer effects led to catastrophic aeroelastic flutter.

Damping and Stiffness: Post-collapse analysis revealed that the bridge lacked sufficient damping mechanisms and stiffness to counteract the dynamic effects caused by boundary layer interactions. Modern designs incorporate aerodynamic profiles and tuned mass dampers to mitigate these effects, informed by boundary layer theory.

5.5.1.3 Design Modifications Based on Boundary Layer Insights

Streamlining and Shape Optimization: Following the Tacoma Narrows collapse, bridge designs have incorporated streamlined shapes to ensure smoother airflow and reduce boundary layer separation. Streamlined sections help in maintaining attached flow, thereby reducing the formation of vortex-induced oscillations.

Open Truss Structures: The new Tacoma Narrows Bridge (1950) and other modern suspension bridges feature open truss structures that allow wind to pass through the deck, minimizing pressure differentials and reducing the boundary layer separation effects. This design effectively minimizes the forces that contribute to flutter and vortex shedding.

Wind Tunnel Testing: The use of scaled models in wind tunnels has become a standard practice in bridge design to observe boundary layer effects and vortex shedding patterns. Data from these tests help refine designs to improve aerodynamic stability.

5.5.1.4. Application of Computational Fluid Dynamics (CFD)

CFD Simulations: Advances in computational power have enabled the use of CFD to simulate boundary layer interactions around bridge structures. CFD allows engineers to predict how wind flow will interact with a bridge, providing valuable insights for optimizing design to prevent boundary layer separation, minimize vortex shedding, and ensure structural stability.

Iterative Design Process: Modern bridge design often involves iterative processes where CFD results inform changes to the bridge geometry, surface roughness, and structural details, ensuring that boundary layer effects are appropriately managed.

Conclusion and Modern Implications

The collapse of the Tacoma Narrows Bridge served as a critical lesson in the importance of understanding boundary layer effects in bridge design. Today, boundary layer theory is integral to the design and safety evaluation of bridges, especially long-span suspension, and cable-stayed bridges. By incorporating aerodynamic features, enhanced stiffness, damping mechanisms, and thorough wind tunnel and CFD analysis, engineers can design bridges that are safer, more stable, and resilient against wind-induced forces.

Key Lessons Learned:

Importance of Aerodynamic Shape: Smooth, streamlined shapes can reduce adverse boundary layer interactions.

Need for Sufficient Damping: Incorporating adequate damping mechanisms is crucial for controlling oscillations.

Comprehensive Testing and Simulation: Wind tunnel tests and CFD simulations are essential tools for assessing and optimizing aerodynamic performance.

Structural Modifications: Open truss designs and other modifications can help manage airflow and reduce the impact of vortex shedding.

These insights ensure that modern bridge designs, unlike the original Tacoma Narrows Bridge, can withstand the complex interactions between wind and structure, providing safe and reliable transportation infrastructure.

5.5.2 Skyscraper Wind Load Analysis

For skyscrapers, boundary layer theory is used to estimate wind loads on tall buildings. Wind tunnel tests and CFD simulations help in understanding how the boundary layer around the building affects the wind pressure distribution and overall structural stability.

Overview

Wind load analysis is a critical aspect of designing skyscrapers due to the significant forces that wind can exert on tall structures. Understanding how the boundary layer—the thin layer of air close to the building's surface—interacts with the structure helps engineers predict and mitigate wind-induced effects such as sway, vortex shedding, and structural fatigue. This case study examines the Burj Khalifa in Dubai, the world's tallest skyscraper, to illustrate how boundary layer theory informs wind load analysis and design strategies.

The Burj Khalifa

Location: Dubai, United Arab Emirates

Height: 828 meters (2,717 feet)

Floors: 163

Completion: 2010

Design Team: Skidmore, Owings & Merrill LLP (SOM)

Primary Architect: Adrian Smith

Wind Load Challenges in Skyscrapers

Skyscrapers like the Burj Khalifa face substantial wind load challenges due to their height and exposure to high wind speeds. These challenges include:

Wind Pressure: Direct pressure exerted on the building's surface by wind.

Vortex Shedding: As wind flows around the building, vortices are shed alternately from the sides, creating fluctuating forces perpendicular to the wind direction. This can cause vibrations and oscillations, especially if the shedding frequency matches the building's natural frequency (resonance).

Dynamic Response: Wind-induced vibrations can cause occupant discomfort and potential structural damage over time.

Wind-Induced Acceleration: High wind loads can lead to significant accelerations at the top of the structure, affecting comfort and stability.

Boundary Layer Theory in Wind Load Analysis

Boundary layer theory provides insights into how wind interacts with the building surface, affecting wind loads and the structural response. Key concepts include:

Wind Flow and Boundary Layer Formation: The atmospheric boundary layer near the earth's surface experiences changes in velocity and turbulence as it encounters the building. Understanding this interaction helps predict pressure distribution and forces acting on the structure.

Reynolds Number and Turbulence: The size and height of the skyscraper influence the Reynolds number, which determines whether the flow is laminar or turbulent. For tall buildings, the flow is typically turbulent, which increases the complexity of predicting wind load behavior.

Separation Points and Pressure Distribution: Boundary layer separation points along the building surface create regions of low pressure, which are critical for designing the facade and structural components to withstand varying loads.

Wind Load Analysis and Design Strategies for Burj Khalifa

5.5.2.1. Architectural Design and Shape Optimization

Y-shaped Plan: The Burj Khalifa's design features a Y-shaped footprint, which helps distribute the wind load more evenly across the structure. This shape reduces the impact of vortex shedding by disrupting the formation of coherent vortices along the height of the building.

Tapered Structure: The Burj Khalifa tapers as it rises, reducing the surface area exposed to wind at higher elevations. This tapered design decreases wind forces by minimizing the building’s cross-sectional area subjected to wind pressure, reducing vortex shedding, and the overall wind load.

5.5.2.2. Wind Tunnel Testing

Physical Wind Tunnel Models: Scaled models of the Burj Khalifa were tested in wind tunnels to study the effects of wind loads. These tests provided data on pressure distribution, vortex shedding patterns, and overall aerodynamic performance. Engineers could observe how the boundary layer interacted with the building’s surface and adjust design elements accordingly.

Boundary Layer Wind Tunnel: Special wind tunnels that simulate atmospheric boundary layer conditions were used to mimic real-world wind speed profiles and turbulence levels. These tests helped refine the design to ensure structural stability and comfort.

5.5.2.3. Computational Fluid Dynamics (CFD) Simulations

Simulating Wind Flow: CFD simulations were used to model the wind flow around the Burj Khalifa. These simulations provided detailed insights into pressure distribution, vortex formation, and potential points of boundary layer separation. Engineers could visualize airflow patterns and assess the dynamic response of the structure under different wind conditions.

Optimization: CFD results allowed for optimization of structural elements and facade design to minimize adverse wind effects. By adjusting parameters such as tapering angles, facade roughness, and aerodynamic shaping, engineers reduced wind loads and improved the building's performance.

5.5.2.4. Structural Damping Systems

Damping Mechanisms: To counteract wind-induced vibrations, the Burj Khalifa was equipped with damping systems such as tuned mass dampers. These devices absorb and dissipate energy from wind-induced motions, reducing the amplitude of oscillations and ensuring stability.

Concrete Core and Outrigger Systems: A central reinforced concrete core, combined with outrigger systems, provided additional stiffness and strength. This structural approach helps distribute wind loads efficiently and reduces lateral movements.

5.5.2.5. Material Selection and Construction Techniques

High-Strength Materials: The use of high-strength concrete and steel enhanced the building’s ability to withstand wind-induced stresses. These materials provide the necessary rigidity and flexibility to absorb and dissipate wind forces without compromising structural integrity.

Flexible Facade Design: The facade system was designed to accommodate movements caused by wind loads without cracking or damage. Flexible connections and materials ensured that the building envelope remained intact under varying wind conditions.

Conclusion and Modern Implications

The design and construction of the Burj Khalifa demonstrate the critical role of boundary layer theory in skyscraper wind load analysis. By understanding how the boundary layer interacts with tall structures, engineers can:

Enhance Structural Safety: Design buildings that can withstand high wind loads and dynamic responses, reducing the risk of structural failure.

Improve Occupant Comfort: Minimize wind-induced accelerations and sway, ensuring that residents and occupants experience a stable and comfortable environment.

Optimize Aerodynamic Performance: Develop shapes and structural systems that reduce wind loads and energy consumption, contributing to sustainable building practices.

Lessons Learned and Future Directions

Integration of Wind Load Analysis Early in Design: Incorporating boundary layer considerations early in the design process helps optimize building shape and structural systems for aerodynamic efficiency.

Advancements in Simulation Technology: Continued advancements in CFD and wind tunnel technology provide more accurate predictions and allow for innovative design solutions.

Adaptive Building Technologies: Future skyscrapers may incorporate adaptive technologies that respond dynamically to wind loads, further enhancing safety and comfort.

The Burj Khalifa serves as a benchmark for modern skyscraper design, showcasing how boundary layer theory and advanced engineering practices can address the challenges posed by wind loads on tall buildings.

6. Conclusion

Boundary layer theory provides essential insights into fluid behaviour near solid surfaces, with significant applications in civil engineering. By understanding and applying this theory, engineers can design more efficient and safe structures, from bridges and skyscrapers to hydraulic systems. Advances in experimental and computational techniques continue to enhance our ability to analyse and manage boundary layer effects in various civil engineering contexts.

SWARRNIM START UP AND INNOVATION UNIVERSITY

NAME OF INSTITUTE: - SWARRNIM INSTITUTE OF TECHNOLOGY, GANDHINAGAR

NAME OF COURSE:-

Computer Engineering

Advanced Topics and Future Directions

- **SageMath**: Comprehensive mathematics software system.
- **TensorFlow**: Library for numerical computation and machine learning.

Python in Computational Mathematics and Research

- **Research**: Use Python for developing new algorithms and mathematical models.

Interfacing Python with Other Mathematical Software

- **Integration**: Combine Python with tools like MATLAB or R for advanced analysis.

Future Trends in Python for Mathematics

- **AI and Machine Learning**: Emerging trends in mathematical research and applications.

Case Studies and Research Applications

- **Real-World Examples**: Detailed case studies showcasing Python's application in research and industry.

Appendices:

- **Python Programming Basics Refresher**
- **Useful Resources and Libraries for Mathematics**
- **Sample Code and Solutions**
- **Glossary of Mathematical Terms**

DB Application Development

DB Access from applications – embedded SQL

Embedded SQL is a method where SQL statements are embedded directly within the code of a host programming language, such as C, C++, Java, or COBOL. This approach allows applications to access and manipulate a database directly within the application code.

Key Concepts of Embedded SQL:

1. Embedding SQL Statements: SQL commands are embedded within the code of the host language using specific syntax. For example, in C, SQL statements are usually preceded by EXEC SQL and followed by a semicolon.
2. Preprocessor: The embedded SQL code is not directly understandable by the compiler of the host language. Therefore, a preprocessor converts the embedded SQL statements into function calls that the host language can execute, making the database operations possible.
3. Host Variables: These are variables declared in the host language that are used within SQL statements to pass data between the application and the database.
4. Connecting to the Database: Before executing SQL statements, the application must establish a connection to the database using a connection string or similar configuration.
5. Error Handling: SQL provides a way to handle errors, usually by checking the SQLCODE or SQLSTATE after each SQL operation, allowing the application to respond appropriately to database errors.

Example of Embedded SQL in C:

c

Copy code

```
#include <stdio.h>
#include <sqlca.h>

int main() {
    EXEC SQL BEGIN DECLARE SECTION;
    int employee_id;
    char employee_name[50];
    EXEC SQL END DECLARE SECTION;

    // Connect to the database
```

```
    EXEC SQL CONNECT TO mydatabase USER 'username' IDENTIFIED BY 'password';

    // Execute a SQL query
    EXEC SQL SELECT name INTO :employee_name FROM employees WHERE id =
:employee_id;

    // Display the result
    printf("Employee Name: %s\n", employee_name);

    // Disconnect from the database
    EXEC SQL COMMIT WORK RELEASE;

    return 0;
}
```

Advantages of Embedded SQL:

- Performance: Direct access to the database can be faster compared to other methods like ODBC or JDBC since it avoids the overhead of middleware.
- Ease of Use: Developers can use SQL directly within the programming language, making data manipulation straightforward.
- Type Safety: Host variables ensure that data types between the application and database match, reducing errors.

Disadvantages of Embedded SQL:

- Portability Issues: Code written with embedded SQL can be less portable across different database systems due to proprietary SQL syntax.
- Maintenance Complexity: SQL statements mixed within application code can make the code harder to read and maintain.
- Limited Scalability: Changes in the database structure may require significant changes in the application code.

Embedded SQL is ideal when tight integration with the database is required, especially in performance-critical applications. However, it requires careful handling of error management and application maintenance due to the close coupling of SQL and application logic.

Cursors

are database objects used in SQL to retrieve, manipulate, and navigate through rows of a result set one at a time. They are particularly useful when you need to process query results row-by-row, rather than working with the entire set at once.

Key Concepts of Cursors:

1. Definition: A cursor acts like a pointer that allows the application to fetch each row of a query result individually, perform operations on it, and then move to the next row.
2. Types of Cursors:
    - Implicit Cursors: Automatically created by SQL when a query that returns a single row is executed. These are usually managed internally by the database and do not require explicit declaration.
    - Explicit Cursors: Defined and controlled by the programmer when more control is needed, such as with multi-row queries.
3. Cursor Operations:
    - Declare: Define the cursor with the desired SQL query.
    - Open: Execute the query and make the result set available for fetching rows.
    - Fetch: Retrieve the next row from the result set into host variables.
    - Close: Release the cursor and free up resources once processing is complete.

Example of Using Cursors in SQL:

Here is an example using embedded SQL in a C-like pseudocode:

c

Copy code

```
#include <stdio.h>

#include <sqlca.h>


int main() {

    EXEC SQL BEGIN DECLARE SECTION;

    int employee_id;

    char employee_name[50];

    EXEC SQL END DECLARE SECTION;


    // Declare the cursor

    EXEC SQL DECLARE employee_cursor CURSOR FOR
```

```
        SELECT id, name FROM employees;

    // Open the cursor
    EXEC SQL OPEN employee_cursor;

    // Fetch each row and process
    while (SQLCODE == 0) {
        EXEC SQL FETCH employee_cursor INTO :employee_id, :employee_name;
        if (SQLCODE == 0) {
            printf("Employee ID: %d, Name: %s\n", employee_id, employee_name);
        }
    }

    // Close the cursor
    EXEC SQL CLOSE employee_cursor;

    return 0;
}
```

Advantages of Cursors:

- Row-by-Row Processing: Useful when individual processing of each row is required, such as complex calculations or updates.
- Control Over Data Retrieval: Allows fetching, updating, or deleting rows based on specific conditions.
- Support for Complex Logic: Can be used in stored procedures, triggers, and batch processing scripts to implement complex business logic.

Disadvantages of Cursors:

- Performance Issues: Cursors can be slow because they process rows one at a time rather than in bulk, which can be resource-intensive, especially with large datasets.
- Resource Consumption: Cursors use memory and server resources, which can affect overall system performance if not managed properly.
- Concurrency Problems: Cursors can lock rows while they are being processed, potentially leading to contention issues in a multi-user environment.

Best Practices:

- Minimize Cursor Use: Avoid using cursors when set-based operations (e.g., using JOIN, WHERE clauses) can achieve the same result more efficiently.
- Close Cursors Promptly: Always close cursors as soon as they are no longer needed to free resources.
- Use Read-Only Cursors When Possible: Read-only cursors can be more efficient than updatable ones.

Cursors provide a powerful tool for row-by-row data manipulation, but their impact on performance requires careful consideration, especially in high-transaction or large-scale database environments.

Dynamic SQL.

Dynamic SQL refers to SQL statements that are constructed and executed at runtime rather than being hard-coded into the application. This approach allows applications to build SQL queries dynamically, making them flexible and adaptable to various conditions that are only known during execution.

Key Concepts of Dynamic SQL:

1. Definition: Unlike static SQL, where the SQL statements are predefined and compiled at compile-time, dynamic SQL allows the creation, modification, and execution of SQL statements at runtime.
2. Use Cases:
    - Flexible Querying: When the structure of the query depends on user input, such as search filters that can vary widely.
    - DDL Statements: For executing Data Definition Language (DDL) commands like CREATE, DROP, or ALTER that are not usually allowed in static SQL within embedded environments.
    - Dynamic Reporting: Generating reports based on various parameters set at runtime.
3. Types of Dynamic SQL:
    - Direct Execution: Using functions like EXECUTE IMMEDIATE to directly execute a dynamically created SQL statement.
    - Using Prepared Statements: A safer approach that involves preparing the statement once and executing it multiple times with different parameters.

Example of Dynamic SQL:

Here's an example using embedded SQL with C:

c

Copy code

```c
#include <stdio.h>
#include <string.h>
#include <sqlca.h>

int main() {
    EXEC SQL BEGIN DECLARE SECTION;
    char query[256];
    char employee_name[50];
    int employee_id = 101;  // Example variable, can be set dynamically
    EXEC SQL END DECLARE SECTION;

    // Construct a dynamic SQL query as a string
    sprintf(query, "SELECT name INTO :employee_name FROM employees WHERE id = %d", employee_id);

    // Execute the dynamic SQL
    EXEC SQL PREPARE stmt FROM :query;
    EXEC SQL EXECUTE stmt;

    // Display the fetched result
    printf("Employee Name: %s\n", employee_name);

    return 0;
}
```

Advantages of Dynamic SQL:

- Flexibility: Allows building queries based on varying inputs or conditions, making applications adaptable to different scenarios.
- Support for Complex Operations: Enables execution of complex, variable, or rarely used SQL commands that would be cumbersome to manage statically.

- Powerful for DDL: Particularly useful for running DDL commands dynamically, such as creating or modifying database objects on the fly.

Disadvantages of Dynamic SQL:

- Security Risks: Prone to SQL injection attacks if not properly sanitized, especially when user input is directly incorporated into SQL statements.
- Performance Overhead: Parsing, compiling, and executing SQL at runtime can be slower compared to precompiled static SQL.
- Complex Error Handling: Error handling can be more complicated due to the dynamic nature of the SQL code.

Best Practices for Using Dynamic SQL:

- Use Bind Variables: To avoid SQL injection and improve performance, always use parameterized queries or bind variables instead of directly concatenating user inputs.
- Sanitize Inputs: Always validate and sanitize inputs used in dynamic SQL statements to protect against security vulnerabilities.
- Error Handling: Implement robust error handling to manage runtime errors that may arise from dynamically constructed queries.
- Limit Usage: Use dynamic SQL sparingly and only when absolutely necessary, preferring static SQL whenever possible for better performance and maintainability.

Dynamic SQL is powerful and flexible but requires careful handling to avoid performance pitfalls and security risks. Proper use of parameterized queries and validation techniques can help mitigate these challenges, making dynamic SQL an effective tool in complex database-driven applications.

Introduction to JDBC & SQL/J - Stored Procedures

JDBC (Java Database Connectivity) is an API (Application Programming Interface) in Java that provides a standardized way to connect and interact with various databases. It enables Java applications to execute SQL statements, retrieve results, and manage transactions, making it the primary interface for database interaction in Java.

Key Features of JDBC:

1. Database Independence: JDBC provides a uniform interface to interact with multiple databases (like MySQL, Oracle, PostgreSQL, etc.) without modifying the application code significantly.
2. Standard SQL Execution: Supports executing SQL queries, updating statements, and calling stored procedures.
3. Error Handling: Offers robust error-handling mechanisms using exceptions.
4. Transaction Management: Provides control over transactions with commit, rollback, and savepoint operations.
5. Support for Metadata: Allows access to database metadata, which can provide information about database tables, columns, and other database-specific features.

Basic Workflow of JDBC:

1. Loading the JDBC Driver: Load the appropriate JDBC driver for the database you intend to use.

java

Copy code

```
Class.forName("com.mysql.cj.jdbc.Driver");
```

2. Establishing a Connection: Use the DriverManager to establish a connection to the database.

java

Copy code

```
Connection conn =
DriverManager.getConnection("jdbc:mysql://localhost:3306/mydatabase", "user",
"password");
```

3. Creating a Statement: Create a Statement, PreparedStatement, or CallableStatement object to execute SQL commands.
4. Executing Queries: Execute SQL queries using the statement object.
5. Processing Results: Retrieve and process the results, often using ResultSet objects.
6. Closing Resources: Close the connection, statement, and other resources to prevent memory leaks.

Example of JDBC in Java:

java

Copy code

```
import java.sql.Connection;

import java.sql.DriverManager;
```

```
import java.sql.ResultSet;
import java.sql.Statement;

public class JDBCExample {
    public static void main(String[] args) {
        try {
            // Load the JDBC driver
            Class.forName("com.mysql.cj.jdbc.Driver");

            // Establish a connection
            Connection conn =
DriverManager.getConnection("jdbc:mysql://localhost:3306/mydatabase", "user",
"password");

            // Create a statement
            Statement stmt = conn.createStatement();

            // Execute a query
            ResultSet rs = stmt.executeQuery("SELECT id, name FROM employees");

            // Process the results
            while (rs.next()) {
                System.out.println("ID: " + rs.getInt("id") + ", Name: " + rs.getString("name"));
            }

            // Close resources
            rs.close();
            stmt.close();
            conn.close();
        } catch (Exception e) {
            e.printStackTrace();
```

```
        }
    }
}
```

SQL/J - Stored Procedures

Stored Procedures are precompiled SQL routines stored in the database that can be executed by applications. They are used to encapsulate business logic, reduce network traffic, and improve security.

Key Concepts of Stored Procedures:

1. Definition: Stored procedures are reusable SQL scripts saved in the database that can perform various tasks such as data manipulation, complex calculations, and conditional logic.
2. Advantages:
    - Performance: Precompiled and optimized, which can lead to faster execution compared to running raw SQL statements.
    - Security: Database permissions can be managed more effectively, limiting direct access to tables and allowing only specific stored procedures to be called.
    - Maintainability: Encapsulates complex SQL logic within the database, making application code cleaner and easier to maintain.
    - Reduced Network Traffic: Since the execution is done on the server, only the call to the procedure needs to be sent, rather than full SQL commands.
3. Usage in JDBC: In JDBC, stored procedures are called using CallableStatement.

Example of Calling a Stored Procedure using JDBC:

Suppose there is a stored procedure in the database named getEmployeeDetails that takes an employee ID as an input parameter.

sql

Copy code

```sql
-- Example Stored Procedure in SQL

CREATE PROCEDURE getEmployeeDetails(IN emp_id INT)

BEGIN

    SELECT id, name FROM employees WHERE id = emp_id;

END;
```

Here's how to call it using JDBC:

java

Copy code

```java
import java.sql.CallableStatement;
import java.sql.Connection;
import java.sql.DriverManager;
import java.sql.ResultSet;

public class StoredProcedureExample {
    public static void main(String[] args) {
        try {
            // Load the JDBC driver
            Class.forName("com.mysql.cj.jdbc.Driver");

            // Establish a connection
            Connection conn =
DriverManager.getConnection("jdbc:mysql://localhost:3306/mydatabase", "user",
"password");

            // Prepare a CallableStatement to call the stored procedure
            CallableStatement stmt = conn.prepareCall("{CALL getEmployeeDetails(?)}");

            // Set the input parameter
            stmt.setInt(1, 101); // Example employee ID

            // Execute the stored procedure
            ResultSet rs = stmt.executeQuery();

            // Process the result set
            while (rs.next()) {
                System.out.println("ID: " + rs.getInt("id") + ", Name: " + rs.getString("name"));
            }
```

```
            // Close resources
            rs.close();
            stmt.close();
            conn.close();
        } catch (Exception e) {
            e.printStackTrace();
        }
    }
}
```

Key Takeaways:

- JDBC provides a standardized way for Java applications to interact with databases, allowing the execution of SQL statements, management of transactions, and access to database metadata.
- Stored Procedures are powerful tools for encapsulating SQL logic within the database, enhancing security, performance, and maintainability.
- Using JDBC with stored procedures combines the flexibility of Java with the power of database-optimized routines, making it an ideal choice for complex data operations in enterprise applications.

Overview of Storage and Indexing

Data on external storage - File Organizations and Indexing

Data on external storage refers to data stored on physical storage devices such as hard drives, SSDs, or other external storage media. Efficiently managing this data involves organizing files and using indexing methods to enable quick data retrieval and updates.

File Organization

File organization determines how data is stored, accessed, and maintained on external storage. The method chosen directly impacts performance, including data retrieval speed, storage efficiency, and ease of maintenance.

Types of File Organizations:

1. Heap (Unordered) File Organization:
    - Description: Records are stored in no particular order, typically in the order they are inserted.
    - Advantages: Simple to implement and fast for bulk insertions.

- Disadvantages: Retrieval is slow, especially for searching specific records, as it requires a full scan of the data.
- Use Case: Suitable for small tables or situations where data retrieval speed is not critical.

2. Sequential (Ordered) File Organization:
    - Description: Records are stored in a sorted order, typically based on a key attribute.
    - Advantages: Efficient for range queries and ordered retrieval; easy to maintain sequential access.
    - Disadvantages: Insertions and deletions are slower due to the need to maintain the order.
    - Use Case: Ideal for applications that require frequent range queries, such as report generation.
3. Hash File Organization:
    - Description: Records are stored based on a hash function that determines the location of each record.
    - Advantages: Provides fast access for exact match queries (e.g., retrieving a record by its primary key).
    - Disadvantages: Not suitable for range queries; collisions can degrade performance.
    - Use Case: Best for scenarios where fast retrieval of records by a unique key is needed.
4. Clustered File Organization:
    - Description: Records that are frequently accessed together are stored near each other on disk.
    - Advantages: Reduces disk I/O for related data, enhancing query performance.
    - Disadvantages: Complex to maintain, especially during updates and insertions.
    - Use Case: Useful when a group of records is frequently accessed together, like in multi-table joins.
5. Indexed File Organization:
    - Description: Combines a sequential file with an index that allows faster access to specific records.
    - Advantages: Provides efficient data retrieval while maintaining a logical order.
    - Disadvantages: Index maintenance can add overhead during updates.

- Use Case: Suitable for large datasets where both random and sequential access is required.

Indexing

Indexing is a technique used to optimize data retrieval by creating additional data structures that provide quick access to the main data file. An index functions like a table of contents, allowing the database to locate data without scanning the entire file.

Types of Indexes:

1. Primary Index:
   - Description: An index on the primary key of a table, ensuring that each entry in the index corresponds uniquely to one record in the file.
   - Advantages: Speeds up retrievals by using the primary key.
   - Disadvantages: Maintenance overhead when the primary key is updated.
   - Use Case: Best for unique, frequently searched key values.
2. Secondary Index:
   - Description: An index on non-primary key columns, allowing multiple entries for the same key value.
   - Advantages: Provides fast access to records based on non-key attributes.
   - Disadvantages: Slower compared to primary indexes due to possible duplications.
   - Use Case: Ideal for attributes that are often used in search conditions but are not unique.
3. Clustered Index:
   - Description: Physically arranges the data rows in the table based on the key values. Each table can have only one clustered index.
   - Advantages: Improves performance for range queries as the data is stored sequentially.
   - Disadvantages: Insertions and updates can be slower due to the need to maintain order.
   - Use Case: Perfect for queries that return large ranges of values.
4. Non-Clustered Index:
   - Description: An index that does not alter the physical order of the records; instead, it maintains a separate structure pointing to the actual data.
   - Advantages: Multiple non-clustered indexes can exist on a table, providing flexibility.

- Disadvantages: Slower than clustered indexes for range queries but useful for quick lookups.
- Use Case: Frequently used for columns that are heavily queried but not used in a range search.

5. B-Tree Index:
   - Description: Uses a balanced tree structure to maintain sorted data and allow searches, insertions, deletions, and sequential access.
   - Advantages: Efficient for a wide range of queries, from exact matches to range searches.
   - Disadvantages: Slightly slower for exact matches compared to hash indexing but excellent for sequential data.
   - Use Case: Widely used in most relational databases due to its balance between read and write efficiency.
6. Bitmap Index:
   - Description: Uses bitmaps (arrays of bits) for indexing, especially useful for columns with a low cardinality (few unique values).
   - Advantages: Extremely fast for read operations and for complex queries involving multiple columns.
   - Disadvantages: Not suitable for high-cardinality data or environments with frequent updates.
   - Use Case: Effective for decision support systems where queries are frequent and complex.

Choosing File Organizations and Indexing Strategies:

- Performance Needs: Use indexing to speed up frequent queries, but balance against the overhead of maintaining the index during insertions and updates.
- Data Access Patterns: Sequential file organization suits range queries, while hash file organization suits point queries.
- Data Volume and Growth: Clustered indexes and file organizations may perform better for large datasets that require efficient storage and access.
- Update Frequency: For frequently updated tables, choose file organizations and indexes that minimize reorganization costs.

Index Data Structures

Index Data Structures are fundamental components of database systems that improve the speed of data retrieval operations by providing efficient access paths to data. By organizing pointers to data entries, these structures allow databases to quickly locate records without scanning entire tables, enhancing query performance significantly.

Common Index Data Structures

1. B-Tree (Balanced Tree) Index:
    - Description: A self-balancing tree data structure that maintains sorted data and allows searches, insertions, deletions, and sequential access.
    - Structure: Nodes contain multiple keys and pointers, with each node having a range of children (not just two, like binary trees), keeping the tree balanced.
    - Operations: Each search, insert, or delete operation is logarithmic in complexity, making B-Trees efficient for large datasets.
    - Advantages:
        - Supports range queries and ordered retrievals.
        - Balances nodes automatically to minimize height, keeping access times low.
        - Handles high data volume efficiently.
    - Disadvantages:
        - Slightly more complex and resource-intensive to maintain during updates.
    - Use Case: Ideal for general-purpose indexing in relational databases.
2. B+ Tree Index:
    - Description: An extension of B-Trees where all values are stored at the leaf level, and internal nodes only store keys for navigation.
    - Structure: The tree is balanced with all leaf nodes linked sequentially, facilitating fast range queries.
    - Advantages:
        - Efficient sequential access and range queries due to linked leaf nodes.
        - More consistent performance as all data entries are at the same level.
    - Disadvantages:
        - May require more space due to the duplication of keys in internal nodes.
    - Use Case: Commonly used in database indexing due to efficient range query support.
3. Hash Index:

- Description: Uses a hash function to map keys to locations where the corresponding records are stored, offering constant-time access on average.
- Structure: The hash function distributes keys uniformly across the index, allowing fast lookups.
- Advantages:
  - Extremely fast for exact match queries (e.g., finding a specific key).
  - Efficient for large datasets with high insert, update, and delete operations.
- Disadvantages:
  - Poor performance for range queries, as there is no inherent order to the data.
  - Handling hash collisions can introduce overhead.
- Use Case: Best for exact lookups like finding records by primary keys.

4. Bitmap Index:
   - Description: Uses bitmaps (arrays of bits) to index data, where each bit represents the presence or absence of a value.
   - Structure: Efficiently stores binary representations of data, especially useful for columns with low cardinality.
   - Advantages:
     - Performs exceptionally well for read-heavy and complex queries involving multiple columns.
     - Compact storage makes it ideal for columns with repeated values.
   - Disadvantages:
     - Not suitable for high-cardinality data or environments with frequent updates, as modifying bitmaps can be costly.
   - Use Case: Ideal for decision-support systems and data warehouses with large-scale, complex queries.
5. R-Tree (Rectangle Tree) Index:
   - Description: A spatial index structure used to index multi-dimensional information, such as geographical data.
   - Structure: Stores bounding rectangles of data entries; each node represents a space that encompasses its child nodes.
   - Advantages:
     - Supports multi-dimensional queries, including range searches and nearest-neighbor searches.

        - Efficient for spatial data like maps, coordinates, and geometric objects.
    - Disadvantages:
        - More complex to maintain compared to one-dimensional index structures.
    - Use Case: Commonly used in GIS (Geographic Information Systems) and applications requiring spatial data indexing.
6. Trie (Prefix Tree) Index:
    - Description: A tree-like data structure used to store dynamic sets of strings, typically used for text search and pattern matching.
    - Structure: Each node represents a character of the stored strings, with branches representing various strings.
    - Advantages:
        - Efficient for searching strings, prefixes, and autocomplete features.
        - Can store large dictionaries of text data efficiently.
    - Disadvantages:
        - Can consume a lot of memory, especially if not compressed or optimized.
    - Use Case: Useful in search engines, auto-suggestion, and word matching applications.
7. Skip List Index:
    - Description: A linked list variant that maintains multiple layers of sorted lists with different skip lengths to allow fast searching.
    - Structure: Multiple levels of linked lists, with higher levels containing fewer nodes, enabling efficient jumps through the list.
    - Advantages:
        - Simpler to implement and maintain compared to balanced trees.
        - Offers good average performance for search, insertion, and deletion operations.
    - Disadvantages:
        - May not perform as well as B-Trees for very large datasets.
    - Use Case: Suitable for in-memory databases and simple indexing needs where ease of maintenance is critical.
8. Inverted Index:

- Description: A data structure that maps content (e.g., words) to their locations in a database or document collection, commonly used in search engines.
- Structure: Maintains a list of occurrences for each term, facilitating quick lookups.
- Advantages:
  - Highly efficient for full-text searches and retrieval of documents containing specific terms.
  - Scalable to handle large text datasets.
- Disadvantages:
  - Complex to build and maintain, especially with dynamic data.
- Use Case: Widely used in search engines, text retrieval, and document indexing.

Choosing the Right Index Structure:

- Data Characteristics: Select an index based on the nature of the data (e.g., numerical, textual, spatial).
- Query Patterns: Match the index type to the expected query patterns (e.g., hash indexes for exact matches, B-Trees for range queries).
- Update Frequency: Consider the cost of maintaining the index during frequent updates, as some structures handle dynamic data better than others.
- Storage Constraints: Account for the storage overhead of indexes, especially in environments with large-scale data.

Comparison of File Organizations

File organization refers to the way data is stored in files on external storage devices, influencing access speed, storage efficiency, and maintenance overhead. Different file organization methods are suited to various application needs, and choosing the right one can significantly impact performance.

Here's a detailed comparison of common file organization techniques: Heap, Sequential, Hash, Clustered, and Indexed file organizations.

Feature	Heap File Organization	Sequential File Organization	Hash File Organization	Clustered File Organization	Indexed File Organization
Description	Unordered; records stored as inserted.	Ordered by a key field (e.g., primary key).	Uses hash function to determine record placement.	Stores related records together based on key values.	Uses indexes to access records quickly

Feature	Heap File Organization	Sequential File Organization	Hash File Organization	Clustered File Organization	Indexed File Organization
					without a strict order.
Data Storage	No specific order; records are added to the end of the file.	Records are stored in sorted order by a key.	Records stored based on hash function result.	Related records stored near each other physically on disk.	Main data may be unordered, but indexed for fast access.
Access Speed	Slow retrieval; requires full scan for search.	Fast for ordered retrievals and range queries.	Very fast for exact lookups but slow for range queries.	Fast for accessing related records and range queries.	Fast for indexed columns; slower if searching on non-indexed columns.
Insertion Speed	Fast; new records are simply appended.	Slow; records must be placed in correct order, requiring shifts.	Fast; insertion location is determined by hash function.	Moderate; may need reorganization if the clustering order is disrupted.	Moderate; index maintenance can slow down insertions.
Deletion Speed	Fast; records are deleted without reordering.	Slow; requires reordering to maintain sequence.	Fast; deletion only removes the record, may leave gaps.	Moderate; reordering may be necessary to maintain clustering.	Moderate; index entries must also be updated or removed.
Update Speed	Fast for updates; slow for search-modify operations.	Slow; requires maintaining the order after updates.	Fast for exact matches but complex if rehashing needed.	Moderate; updates can disrupt clustering, requiring reorganization.	Moderate; updates require index adjustments.
Range Query Support	Poor; requires full scan of the file.	Excellent; sequential access is fast and efficient.	Poor; not designed for range queries.	Good; efficient for accessing clustered data ranges.	Good; efficient for indexed ranges but depends on index type.

Feature	Heap File Organization	Sequential File Organization	Hash File Organization	Clustered File Organization	Indexed File Organization
Storage Utilization	High; simple structure but can be inefficient for retrieval.	Efficient; storage is optimized for sequential access.	High; depends on hash distribution but can waste space due to collisions.	Efficient; stored data optimizes access patterns.	Varies; additional space needed for index structures.
Complexity	Simple to implement; minimal overhead.	Complex; requires maintaining order during insertions and deletions.	Moderate; relies on a good hash function and handling collisions.	Complex; maintaining clustering can be challenging during updates.	Complex; managing multiple indexes requires additional overhead.
Best Use Cases	Best for small tables or bulk insertions where retrieval speed is not critical.	Ideal for scenarios with heavy sequential access, like report generation.	Best for exact match lookups, e.g., primary key searches.	Suitable for scenarios with frequent access to related records, e.g., joins.	Ideal when rapid access to specific data fields is required frequently.

Detailed Comparisons and Use Cases:

1. Heap File Organization:
   - Strengths: Fast for insertions and deletions; minimal overhead.
   - Weaknesses: Slow retrieval speed, especially for large datasets.
   - Best For: Temporary tables, small datasets, or where retrieval is not time-sensitive.
2. Sequential File Organization:
   - Strengths: Efficient for range queries and ordered retrievals; excellent for batch processing.
   - Weaknesses: Slow insertions and deletions due to the need for maintaining order.
   - Best For: Applications requiring frequent ordered data access, like payroll systems or log processing.
3. Hash File Organization:
   - Strengths: Rapid access for exact matches; handles large volumes of data well.

- Weaknesses: Poor performance for range queries and handling of collisions.
- Best For: Scenarios needing quick access via unique keys, such as database indexes for user authentication.

4. Clustered File Organization:
   - Strengths: Reduces I/O for related record access; efficient for multi-table joins.
   - Weaknesses: Complex to maintain; performance can degrade with frequent updates.
   - Best For: Applications that frequently access grouped data, such as data warehousing.
5. Indexed File Organization:
   - Strengths: Fast access for indexed fields; supports both exact and range queries.
   - Weaknesses: Additional overhead for maintaining indexes during updates.
   - Best For: Large tables where specific fields are queried often, such as e-commerce product databases.

Conclusion:

Choosing the appropriate file organization depends on the specific needs of the application, data access patterns, and the frequency of updates.

- Heap is simple and suitable for smaller or less frequently accessed data.
- Sequential is great for ordered and range-based queries.
- Hash is unmatched for exact lookups but not ideal for ordered access.
- Clustered works well when data locality is beneficial.
- Indexed provides a versatile balance for both ordered and random access patterns.\

Indexes and Performance Tuning

Indexes are essential tools in database performance tuning that significantly enhance query performance by providing quick access paths to data. However, while indexes can speed up read operations, they also introduce some trade-offs in terms of space and update performance. Effective performance tuning involves understanding how indexes work and how to use them optimally within a database.

Role of Indexes in Performance Tuning

Indexes improve query performance by reducing the amount of data the database needs to scan to retrieve the requested information. Instead of scanning the entire table, the database uses the index to quickly locate the required rows, making operations like SELECT, JOIN, ORDER BY, and WHERE more efficient.

Types of Indexes and Their Impact on Performance

1. Primary Index (Clustered Index):
    - Purpose: Directly affects the physical order of data in the table, storing data rows in the order of the primary key.
    - Performance Impact:
        - Advantages: Enhances performance of range queries and ordered retrievals due to physical sorting.
        - Disadvantages: Slower insert, update, and delete operations because the physical order must be maintained.
    - Use Case: Best when the key column is frequently used for ordering or range queries.
2. Secondary Index (Non-Clustered Index):
    - Purpose: Maintains a separate index structure that points to the physical data rows without altering their order.
    - Performance Impact:
        - Advantages: Supports quick lookups, and complex queries, and improves JOIN performance.
        - Disadvantages: Each index adds overhead to data modifications, slowing down insertions, updates, and deletions.
    - Use Case: Ideal for frequently queried columns that aren't primary keys.
3. Composite Index:
    - Purpose: An index on multiple columns, optimizing queries that filter on several fields simultaneously.
    - Performance Impact:
        - Advantages: Enhances multi-column search performance by covering multiple query conditions.
        - Disadvantages: May not be used if queries do not use the leading column in the composite index.
    - Use Case: Useful for complex queries with multiple WHERE clauses filtering on indexed columns.
4. Unique Index:
    - Purpose: Ensures that all values in the indexed column are unique, often used to enforce data integrity.

- Performance Impact:
  - Advantages: Prevents duplicate entries and speeds up searches for unique values.
  - Disadvantages: Extra overhead when checking uniqueness during insertions.
- Use Case: Best for columns that need to enforce uniqueness, like email addresses or usernames.

5. Bitmap Index:
   - Purpose: Uses bitmaps for each possible value, making it efficient for columns with low cardinality (few distinct values).
   - Performance Impact:
     - Advantages: Extremely fast for read-heavy queries, complex conditions, and aggregations.
     - Disadvantages: Not suitable for high-cardinality columns or frequently updated tables due to high maintenance costs.
   - Use Case: Ideal for decision support systems, data warehouses, or any read-heavy environment.
6. Full-Text Index:
   - Purpose: Specialized index designed for text-based data, enabling fast searches for words, phrases, or patterns.
   - Performance Impact:
     - Advantages: Efficient for large text searches and pattern matching, such as searching documents or descriptions.
     - Disadvantages: High maintenance overhead; indexing can be resource-intensive and slow during updates.
   - Use Case: Suitable for applications involving extensive text search, such as search engines.

Performance Tuning Techniques Using Indexes

1. Identify Query Patterns:
   - Analyze frequently run queries to identify columns that are often used in WHERE clauses, JOIN conditions, ORDER BY, or GROUP BY.
   - Create indexes on these columns to improve query response times.
2. Choose the Right Index Type:
   - Use clustered indexes for primary keys or columns frequently used in range queries.

- Apply non-clustered indexes on columns used in filtering but not necessarily sorted.

3. Index Selectivity:
    - Definition: Selectivity is the ratio of unique values to the total number of rows. Higher selectivity (closer to 1) means an index will be more efficient.
    - Optimization: Indexes on columns with high selectivity (many unique values) yield better performance as they reduce the number of rows the database must scan.
4. Covering Indexes:
    - Description: An index that includes all columns required by a query, allowing the database to retrieve all data from the index without accessing the table.
    - Performance Impact: Significantly reduces I/O by avoiding lookups in the main table.
    - Use Case: Best for queries that frequently retrieve data from the same columns.
5. Avoid Over-Indexing:
    - Issue: Excessive indexing can lead to performance degradation due to the overhead of maintaining indexes during data modifications.
    - Solution: Only create indexes on columns that are frequently used in searches or sorting operations.
6. Index Maintenance:
    - Rebuilding/Reorganizing Indexes: Over time, indexes can become fragmented, degrading performance. Regularly rebuilding or reorganizing indexes can optimize space usage and improve query speed.
    - Update Statistics: Ensure that index statistics are up-to-date to help the query optimizer make the best decisions about query execution plans.
7. Partitioned Indexes:
    - Description: Breaks down a large index into smaller, more manageable pieces, improving performance by limiting the amount of data scanned.
    - Use Case: Useful for very large datasets or when queries frequently target specific ranges of data.
8. Avoiding Index Scans:
    - Goal: Minimize full index scans, which can be expensive. Instead, ensure that queries can use index seeks, which directly locate relevant rows.

  - Technique: Rewrite queries to make them more index-friendly, using indexed columns in the WHERE clause and avoiding functions that prevent index usage.

9. Monitoring and Tuning:
   - Monitoring Tools: Use database monitoring tools (like SQL Server Profiler, Oracle AWR, or MySQL's EXPLAIN) to identify slow queries and assess index usage.
   - Tuning Actions: Based on analysis, adjust indexes, rewrite queries, or adjust database configurations to improve performance.

Balancing Indexing and Performance

While indexes are powerful tools for optimizing read operations, they also come with trade-offs:

- Storage Costs: Indexes consume additional disk space. Careful management and removal of unused or redundant indexes can help conserve resources.
- Update Overhead: Indexes slow down write operations due to the need to update the index structures. Minimizing unnecessary indexes can help maintain good write performance.
- Maintenance Needs: Regular index maintenance, such as rebuilding and updating statistics, is essential to prevent performance degradation over time.

SWARRNIM START UP AND INNOVATION UNIVERSITY

NAME OF INSTITUTE: - SWARRNIM INSTITUTE OF TECHNOLOGY, GANDHINAGAR

NAME OF COURSE:-

Electrical Engineering

Basic of Digital Electronics &NumberSystem

- INTRODUCTIONABOUTDIGITALSYSTEM

A Digital system is an interconnection of digital modules and it is a system that manipulatesdiscreteelementsofinformationthatisrepresentedinternallyinthebinary form.

Now a day's digital systems are used in wide variety of industrial and consumer products such asautomated industrial machinery, pocket calculators, microprocessors, digital computers, digitalwatches,TVgamesandsignalprocessingandsoon.

- CharacteristicsofDigitalSystems
  - Digitalsystems manipulatediscreteelementsofinformation.
  - Discreteelementsarenothingbutthedigitssuchas10decimaldigitsor26lettersofalphabetsandsoon.
  - Digitalsystemsuse physicalquantitiescalled signalstorepresent discreteelements.
  - Indigitalsystems,thesignalshavetwodiscretevaluesand arethereforesaidtobebinary.
  - Asignalindigitalsystemrepresentsonebinarydigitcalledabit.Thebithasavalueeither0or 1.

- AnalogsystemsvsDigitalsystems

Analogsystemprocessinformationthatvariescontinuouslyi.e.theyprocesstimevaryingsignals that can take on any values across a continuous range of voltage, current or any physicalparameter.

Digital systems use digital circuits that can process digital signals which can take either 0 or 1forbinarysystem.

- AdvantagesofDigitalsystemoverAnalogsystem

1. Ease of programmability: The digital systems can be used for different applications bysimplychangingtheprogramwithoutadditionalchangesinhardware.

2. Reduction in cost of hardware:Thecostofhardwaregetsreducedbyuseofdigitalcomponents and this has been possible due to advances in IC technology. With ICs thenumber of components that can be placed in a given area of Silicon are increased which helpsin cost reduction. High speed Digital processing of data ensures high speed of operationwhichispossibleduetoadvancesinDigital SignalProcessing.

3. High Reliability: Digital systems are highly reliable one of the reasons for that is use of errorcorrectioncodes.

4. Design is easy: The design of digital systems which require use of Boolean algebra and otherdigitaltechniquesiseasiercomparedto analogue designing.

5. Resultcanbereproducedeasily:Sincetheoutputofdigitalsystemsunlikeanaloguesystemsisindependen toftemperature,noise,humidityandothercharacteristicsof componentsthereproducibilityofresultsishigherindigitalsystemsthaninanaloguesystems.

- DisadvantagesofDigitalSystems
  - Usemoreenergythananaloguecircuitstoaccomplishthesametasks,thusproducingmoreheatas well.
  - Digital circuits are oftenfragilein thatif asinglepiece ofdigitaldatais lostormisinterpretedthemeaningoflargeblocksofrelateddatacancompletelychange.
  - Digitalcomputermanipulatesdiscrete elements ofinformationbymeansofabinarycode.
  - Quantizationerrorduringanaloguesignal sampling.

- NumberSystem

CommonNumberSystems

Therearemainlyfournumbersystemswhichareusedindigitalelectronicsplatform.

1. Decimalnumbersystem
   - Thedecimalnumbersystemcontainstenunique symbols0,1,2,3,4,5,6,7,8,9.
   - Thebaseorradixis10.
   - 9'sand10'scomplementsarepossibleforanydecimal number.
2. Binary numbersystem
   - Thebinarynumbersystemcontains twounique symbols0,1.
   - Thebaseorradixis2.
   - 1'sand2'scomplementsarepossibleforanybinarynumber.
3. Octalnumber system
   - Theoctalnumbersystemcontains eightuniquesymbols0,1,2,3,4,5,6,7.
   - Thebaseorradixis8.
   - 7'sand8'scomplements arepossiblefor anyoctalnumber.
4. Hexadecimalnumbersystem
   - Thehexadecimalnumbersystemcontainssixteenuniquesymbols0,1,2,3,4,5,6,7,8,9,A,B,C,D,E,F.
   - Thebaseorradixis16.
   - 15'sand16'scomplementsarepossible foranyhexadecimalnumber.

Ingeneral,ifradixorbaseofanumbersystemis"r",thenthereispossibilityofr'scomplementand(r-1)'scomplementofanumber.

- DecimaltoBinary Conversion
  - The decimal integer is converted to the binary integer number by successive division by 2,andthedecimalfractionisconvertedtothebinaryfractionnumberbysuccessivemultiplication by2.
  - In the successive division-by-2 method, the given decimal integer number is successivelydividedby2till thequotientis0.
  - Theremaindersread frombottomtotopgivetheequivalentbinaryintegernumber.

- In the successive multiplication-by-2 method, the given decimal fraction and the subsequentfractions are successively multiplied by 2, till the fraction part of the product is 0 or till thedesiredaccuracyisobtained.
- Theintegersreadfromtoptobottomgivetheequivalentbinaryintegernumber.
- To convert a mixed number to binary, convert the integer and fraction parts separately tobinaryandthencombinethem.
- Example:(125.6875)10=$()_2$

2	125	1
2	62	0
2	31	1
2	15	1
2	7	1
2	3	1
2	1	1
	0	

0.6875 x 2 = 1.3750 | 1 + 0.3750
0.3750 x 2 = 0.7500 | 0 + 0.7500
0.7500 x 2 = 1.5000 | 1 + 0.5000
0.5000 x 2 = 1.0000 | 1 + 0.0000

Hence, $(125.6875)_{10} = (1111101.1011)_2$

- BinarytoDecimalConversion
  - Binary numbers may be converted to their decimal equivalents by the positional weightsmethod. In this method, each binary digit of the number is multiplied by its position weight (2^n, where n is the weight of the bit) and the product terms are added to obtain the decimalnumber.
  - Example:$(101011.11)_2$ =$()_{10}$
    $=1 \times 2^5 + 0 \times 2^4 + 1\times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1\times 2^0 + 1\times 2^{-1} + 1 \times 2^{-2}$
    =32+ 0+ 8+ 0+ 2+ 1+ 0.5+0.25
    =43.75
    Hence,$(101011.11)^2= (43.75)_{10}$

- DecimaltoOctalConversion
  - The decimal integer is converted to the octal integer number by successive division by 8, andthe decimal fraction is converted to the octal fraction number by successive multiplication by8.
  - In the successive division-by-8 method, the given decimal integer number is successivelydividedby8till thequotientis0.
  - Theremaindersread frombottomtotopgivetheequivalentoctalinteger number.
  - In the successive multiplication-by-8 method, the given decimal fraction and the subsequentfractions are successively multiplied by 8, till the fraction part of the product is 0 or till thedesiredaccuracyisobtained.
  - Theintegersreadfromtoptobottomgivetheequivalentoctalintegernumber.
  - To convert a mixed number to octal, convert the integer and fraction parts separately to octalandthencombinethem.
  - Example:$(125.6875)_{10}$= $()_8$

8	125	5
8	15	7
8	1	1
	0	

0.6875 x 8 = 5.5000 | 5 + 0.5000

0.5000 x 8 = 4.0000 | 4 + 0.0000

Hence, $(125.6875)_{10} = (175.54)_8$

- OctaltoDecimal Conversion
  - Octalnumbersmaybeconvertedtotheirdecimalequivalentsbythepositionalweightsmethod.
  - Inthismethod,eachoctaldigitofthenumberismultipliedbyitspositionweight(8",wherenistheweightoft hebit) andtheproductterms areaddedtoobtainthe decimalnumber.

  - Example:$(724.25)_8 = (\ )_{10}$
    $=7 \times 8^2 + 2\times 8^1+4 \times 8^0 + 2 \times 8^{-1}+5\times 8^{-2}$
    =448+16+ 4+ 0.25+ 0.0781
    =468.3281
    Hence,$(724.25)_8 = (468.3281)_{10}$

- DecimaltoHexadecimalConversion
  - Thedecimalintegerisconvertedtothehexadecimalintegernumberbysuccessivedivisionby16,
  - andthedecimalfractionisconvertedtothehexadecimalfractionnumberbysuccessive
  - multiplicationby16.
  - Inthesuccessivedivision-by-16method,thegivendecimalintegernumberissuccessivelydividedby16till thequotientis0.
  - Theremaindersread frombottomtotopgivetheequivalenthexadecimalintegernumber.
  - In the successive multiplication-by-16 method, the given decimal fraction and the subsequentfractions are successively multiplied by 16, till the fraction part of the product is 0 or till thedesiredaccuracyisobtained.
  - Theintegersreadfromtoptobottomgivetheequivalenthexadecimalintegernumber.
  - To convert a mixed number to hexadecimal, convert the integer and fraction parts separatelytohexadecimalandthencombinethem.

  - Example:$(2598.675)_{10}=(\ )_{16}$

16	2598	6
16	162	2
16	10	10(A)
	0	

0.6750 x 16 = 10.8000 | 10(A) + 0.8000

0.8000 x 16 = 12.8000 | 12(C) + 0.8000

0.8000 x 16 = 12.8000 | 12(C) + 0.8000

0.8000 x 16 = 12.8000 | 12(C) + 0.8000

Hence, $(2598.675)_{10} = (A26.ACCC)_{16}$

- HexadecimaltoDecimalConversion
  - Hexadecimalnumbersmaybeconvertedtotheirdecimalequivalentsbythepositionalweightsmethod.
  - In this method, each hexadecimal digit of the number is multipliedby its position weight(16^n, where n is the weight of the bit) and the product terms are added to obtain the decimalnumber.
  - Example:$(A0F9.0EB)_{16}$ =$(\ )_{10}$
    $=10\times 16^3+0\times 16^2+15\times 16^1+ 9\times 16^0+ 0\times 16^{-1}+ 14\times 16^{-2}+ 11\times 16^3$
    =40960+0+240+ 9+ 0+ 0.0546+0.0026
    =41209.0572
    Hence,$(A0F9.0EB)_{16}= (41209.0572)_{10}$

- OctaltoBinary Conversion
  - To convert a given octal number to a binary, just replace each octal digit by its 3-bit binaryequivalentasperbelowtable.

OctalNumber	BinaryNumber
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111

- Example:-$(367.52)_8=(\ )_2$
  =011110111.101010
  =11110111.10101
  Hence,$(367.52)^8$ =$(11110111.10101)_2$

- Binary toOctalConversion
  - Toconvertabinarynumbertoanoctalnumber,startingfromthebinarypointmakegroupsof3bitseach(i.e. frompoint(".")inbinarynumber,groupof3bitsinleftsideandgroupof3bitsinright side),iftherearenot3bitsavailableatlast,juststuff"0"tomake3bits'group.
  - Replace each3-bitbinarygroupbytheequivalentoctaldigit.
  - Example:-$(110101.101010)_2=()_8$
    =110101.101010
    =65.52
    Hence,$(110101.101010)_2=(65.52)_8$

- HexadecimaltoBinaryConversion
  - To convert a given hexadecimal number to a binary, just replace eachhexadecimaldigit byits4-bitbinaryequivalentasperbelowtable.

HexadecimalNumber	BinaryNumber
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
A	1010
B	1011
C	1100
D	1101
E	1110
F	1111

- Example:-$(3A9E.B0D)_{16}=()_2$
  =0011101010011110.101100001101
  =11101010011110.101100001101
  Hence,$(3A9E,B0D)_{16}= (111010100111110.101100001101)_2$

- BinarytoHexadecimalConversion
  - To convert a binary number to a hexadecimal number, starting from the binary point makegroups of 4 bits each (i.e. from point (".") in binary number, group of 4 bits in left side andgroup of 4 bits in right side), if there are not 4 bits available at last, just stuff "0" to make 4bits'group.
  - Replace each4-bitbinarygroupbytheequivalenthexadecimal digit.
  - Example:$(1011111011.011111)_2 =()_{16}$
  =001011111011.01111100
  =2FB.7C
  Hence,$(01011111011.011111)_2$
  = $(2FB.7C)_{16}$

- OctaltoHexadecimal Conversion
  - To convertan octal numberto hexadecimal, the simplest way is to first convert the givenoctal number to binary and then the binary number to hexadecimal. (i.e. first from table of 3-bitandthentableof4-bit)
  - Example:-$(756.603)_8 =( )_{16}$
  = 7 5 6. 6 0 3
  111101 110 . 110 000 011

=	0001	1110	1110	.	1100	0001	1000
	1	E	E	.	C	1	8

Hence,$(756.603)_8$= $(1EE .C18)_{16}$

- HexadecimaltoOctal Conversion
  - To convert a hexadecimal number to octal, the simplest way is to first convert the givenhexadecimal number to binary and then the binary number to octal. (i.e. first from table of 4-bitandthentableof3-bit)
  - Example:$(B9F.AE)_{16}$=$(\ )_8$

=	B	9	F	.	A	
	E1011	1001	1111	.	1010	1110

=	101	110	011	111	.	101	001	100
	5	6	3	7	.	5	3	4

Hence,$(B9F.AE)_{16}$= $(5637.534)_8$

- AccuracyinBinaryNumberConversion
  - Example:- Convert$(0.252)_{10}$tobinarywithanerror lessthan1%
  - Absolute value of allowable error is found by calculating 1% of the number.E_{allow}= 0.01 x0.252= 0.00252_{10}
  - Maximum error due to truncation is set to be less than allowable error by solving from E10 =2^{-n}

    Thisequationis writtenas $2^{-n} < 0.00252$
  - Invertingbothsides oftheinequality

    $2^n > 397$
  - Takinglogofbothsidesandsolvingforn

    nlog2= log397

$$n = \frac{\log 397}{\log 2} = 8.63 \approx 9(\textit{next larger integer})$$

  - Thisindicatesthattheuseof9bitsinthebinarynumberwill guarantee anerror lessthan1%.
  - So,theconversioniscarriedoutto9places.

0.252 x 2 = 0.504	0
0.504 x 2 = 1.008	1
0.008 x 2 = 0.016	0
0.016 x 2 = 0.032	0
0.032 x 2 = 0.064	0
0.064 x 2 = 0.128	0
0.128 x 2 = 0.256	0
0.256 x 2 = 0.512	0
0.512 x 2 = 1.024	1

Therefore,(0.252)10=(0.010000001);

❖ ComplementForms

- 9'sComplement
  - The 9's complement of a decimal number is obtained by subtracting each digit of that decimalnumberfrom9.
  - Example:-782.54

```
   999.99
 - 782.54
   217.45    (9'scomplementof782.54)
```

- 10'sComplement
  - The10'scomplementof adecimalnumberisobtainedbyadding a1toits9'scomplement.
  - Shortcut:-SubtractLSB(LeastSignificant Bit)from10andrestofthe digitsfrom9.
  - Example:-1056.074

```
   9999.999
 - 1056.074
   8943.925
         +1
   8943.926    (10'scomplementof1056.074)
```

- 1'sComplement
  - The1'scomplementofabinarynumberisobtainedbysubtractingeachdigitofthatbinarynumberfrom1.
  - Shortcut:Change1'sto0'sandO'sto1'sinbinarynumber.
  - Example:-101101.1001

```
   111111.1111
 - 101101.1001
   010010.0110    (1'scomplementof101101.1001)
```

- 2'sComplement
  - The 2's complement of a binary number is obtained by adding a 1 to its 1's complement.Shortcut:Ashortcuttomanuallyconvertabinarynumberintoits2'scomplementistostartat the least significant bit (LSB), and copy all the zeros, working from LSB toward the mostsignificant bit (MSB) until the first 1 is reached; then copy that 1, and flip all the remainingbits.
  - Example:-110101.10100

```
   111111.11111
 - 110101.10100
   001010.01011
             +1
   001010.01100    (2'scomplementof110101.10100)
```

- SignedNumberRepresentation
- The2'scomplement systemforrepresentingsignednumbersworkslike this:
  1. Ifthenumberispositive,themagnitudeisrepresentedinitstruebinaryformandasignbit0isplacedinfront oftheMSB.
  2. Ifthenumberisnegative,themagnitudeisrepresentedinits2'scomplementformandasignbit1isplacedin frontoftheMSB.

- Example:-
  1. Express-45in8-bit2'scomplementform.
     Ans. +45 in 8-bit form is 00101101 (By taking decimal to binary conversion). take 2'scomplementofit,11010011
     Hence,-45in2'scomplementformis11010011
  2. Express-73.25in12-bit 2'scomplementform.
     Ans. +73.25 in 12-bit form is 01001001.1100 (By taking decimal to binary conversion). take2'scomplementofit,10110110.0100Hence,-73.25in2'scomplementformis10110110.0100

- SubtractionusingComplementForms
- Subtractionusing9'scomplementform
  - Toperformdecimalsubtractionusingthe9'scomplementmethod,obtain9'scomplementofthesubtrahen dandaddittotheminuend.
  - Callthisnumbertheintermediateresult.
  - Ifthereisa carry,itindicatesthattheansweris positive.
  - AddthecarrytotheLSDofthisresulttogettheanswer.
  - Ifthereis nocarry,itindicates thatthe answeris negativeand the intermediate resultis its 9'scomplement.
  - Takethe9'scomplementofthisresultandplaceanegativesigninfronttogettheanswer.
  - Example:-

```
(1) 745.81 – 436.62
Ans. 7 4 5 . 8 1                 7 4 5 . 8 1
    - 4 3 6 . 6 2  ----------> + 5 6 3 . 3 7 (9's complement of 436.62)
      3 0 9 . 1 9             (1) 3 0 9 . 1 8 (Intermediate result)
                                          + 1
                                3 0 9 . 1 9 (Answer)
(2) 436.62 – 745.81
Ans. 4 3 6 . 6 2                 4 3 6 . 6 2
    - 7 4 5 . 8 1  ----------> + 2 5 4 . 1 8 (9' complement of 745.81)
    - 3 0 9 . 1 9                6 9 0 . 8 0 (Intermediate result)
```

Thereisnocarryindicatingthattheansweris negative.So,takethe9'scomplementoftheintermediateresultandp utaminus sign.Therefore,theansweris-309.19

- Subtractionusing10'scomplement form
  - Toperformdecimalsubtractionusingthe10'scomplementmethod,obtainthe10'scomplementofthesubtrahendandadditttotheminuend.
  - Ifthereisa carry,ignoreit.
  - Thepresenceofthecarryindicatesthattheanswerispositive;theresultobtainedisitselftheanswer.
  - Ifthereisnocarry,itindicatesthattheanswerisnegativeandtheresultobtainedisits10'scomplement.
  - Obtainthe10'scomplementoftheresultandplaceanegativesigninfronttogettheanswer.
  - Example:-

```
(1) 2928.54 – 416.73
Ans. 2 9 2 8 . 5 4            2 9 2 8 . 5 4
   - 0 4 1 6 . 7 3  ------> + 9 5 8 3 . 2 7 (10's complement of 416.73)
     2 5 1 1 . 8 1        (1) 2 5 1 1 . 8 1 (Ignore the carry)

(2) 416.73 – 2928.54
Ans. 0 4 1 6 . 7 3            0 4 1 6 . 7 3
   - 2 9 2 8 . 5 4  ------> + 7 0 7 1 . 4 6 (10's complement of 2928.54)
   - 2 5 1 1 . 8 1            7 4 8 8 . 1 9 (No carry)
```

Thereisnocarryindicatingthattheanswerisnegative.So,takethe10'scomplementoftheintermediateresult andputaminussign.Therefore,theansweris-2511.81

- Subtractionusing1'scomplementform
  - Toperformbinarysubtractionusingthe1'scomplementmethod,obtain1'scomplementofthesubtrahend andadditttotheminuend.
  - Callthisnumbertheintermediateresult.
  - Ifthereisa carry,itindicatesthattheansweris positive.
  - AddthecarrytotheLSBofthisresulttogettheanswer.
  - Ifthere is nocarry,itindicates thatthe answeris negativeand the intermediate resultis its 1'scomplement.
  - Takethe1'scomplementofthisresult.
  - Example:-

```
(1) 11010 – 1101
Ans. 1 1 0 1 0             1 1 0 1 0
   - 0 1 1 0 1  ------>  + 1 0 0 1 0 (1's complement)
                       (1) 0 1 1 0 0 (Intermediate result)
                                 + 1
                           0 1 1 0 1 (Answer)

(2) 100 – 110000
Ans. 0 0 0 1 0 0              0 0 0 0 1 0 0
   - 1 1 0 0 0 0  ------>  + 1 0 0 1 1 1 1 (1's complement)
                              1 0 1 0 0 1 1 (Intermediate result)
```

There is no carry. The MSB is 1. Hence, the answer is negative. Take the 1's complementoftheremainingbits.So,itis101100(negative).

- Subtractionusing2'scomplementform
  - Toperformbinarysubtractionusingthe2'scomplementmethod,obtainthe2'scomplementofthesubtrahendandadditttotheminuend.
  - Ifthereisa carry,ignoreit.
  - Thepresenceofthecarryindicatesthattheanswerispositive;theresultobtainedisitselftheanswer.
  - Ifthereisnocarry,itindicatesthattheanswerisnegativeandtheresultobtainedisits2'scomplement.
  - Obtainthe2'scomplementoftheresult.
  - Example:-

```
(1)  11011 – 1101
Ans. 1 1 0 1 1              1 1 0 1 1
    - 0 1 1 0 1  ------->  +1 0 0 1 1 (2's complement)
                          (1)0 1 1 0 1 (Ignore the carry, result is positive)
(2)  100 – 110000
Ans. 0 0 0 1 0 0            0 0 0 1 0 0
    - 1 1 0 0 0 0 ------->  +1 0 1 0 0 0 0 (2's complement)
                             1 0 1 0 1 0 0 (Result is negative)
```

  Thereisnocarry.TheMSBis1.Hence,theanswerisnegative.Takeits2'scomplementandputaminussign.So itis,101100(negative).

❖ Binary Operation

- BinaryAddition

  0+ 0=0; 0+ 1= 1; 1+ 0= 1;1+ 1= 10i.e.O withacarryof1);1+1+ 1= 11

  Example:-Addthebinarynumbers1101.101and111.011.

```
  1 1 1 1   1 1 <---- Carry
  1 1 0 1 . 1 0 1
 +0 1 1 1 . 0 1 1
1 0 1 0 1 . 0 0 0
```

- BinarySubtraction

  0- 0= 0;1 - 1=0; 1 - 0= 1; 0- 1= 1withaborrowof1.

  Example:-Subtract111.111from1010.01

```
 0 1 10 1   1 10 10 <---- Borrow
 1 0 1 0 . 0 1 0
-0 1 1 1 . 1 1 1
 0 0 1 0 . 0 1 1
```

- BinaryMultiplication

  Example:-Multiply1011.101by101.01

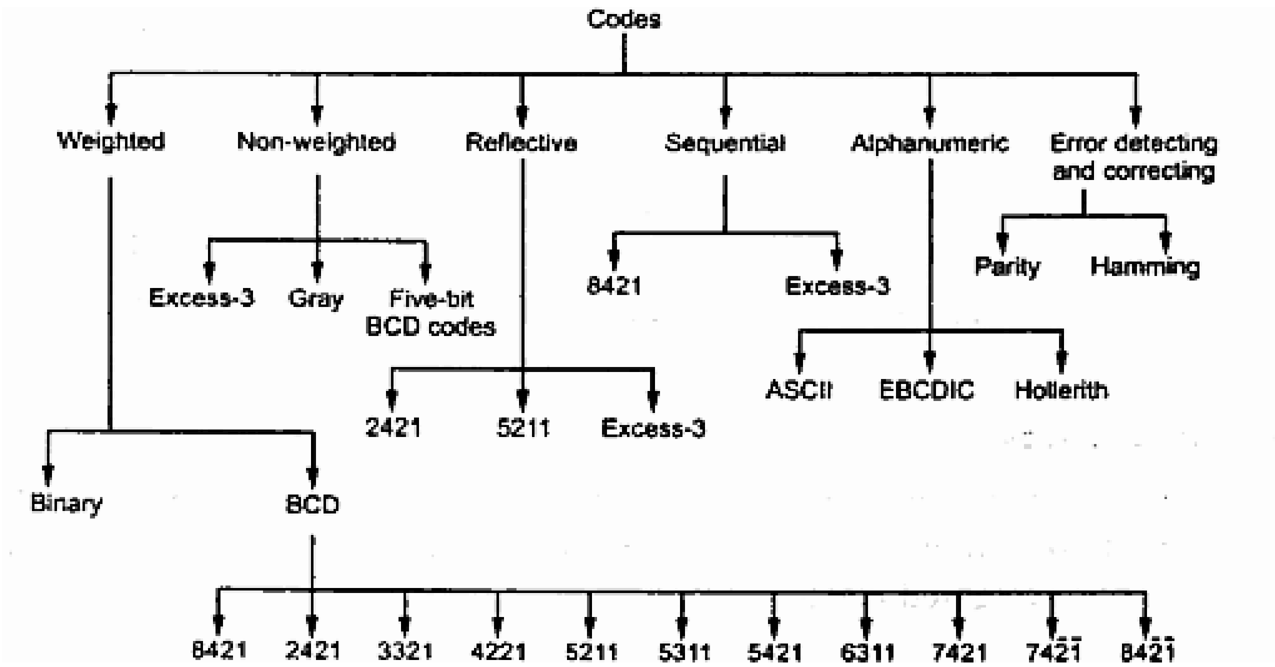
```
      1 0 1 1 . 1 0 1
    X   1 0 1 . 0 1 0
        1 0 1 1 1 0 1
      0 0 0 0 0 0 0 0
    1 0 1 1 1 0 1 0 0
  0 0 0 0 0 0 0 0 0 0
1 0 1 1 1 0 1 0 0 0 0
1 1 1 1 0 1.0 0 0 0 1
```

Therefore,1011.101x 101.010111101.00001

- BinaryDivision
  Example:-Divide101101by110

```
1 1 0)1 0 1 1 0 1(1 1 1.1
        1 1 0
        1 0 1 0
          1 1 0
          1 0 0 1
            1 1 0
              1 1 0
              1 1 0
              0 0 0
```

Therefore,101101/110111.1



- BCDCode
  - Inthiscode,eachdecimaldigit,0through9,iscodedby4-bitbinarynumber.
  - Itisaweightedcodeandisalsosequential.Therefore,itisusefulformathematicaloperations.
  - Themain advantageofthiscodeisits easeof conversiontoandfromdecimal.
  - Itislessefficientthanthepurebinary,inthesensethatitrequiresmore bits.
  - Forexample,thedecimalnumber14canberepresentedas1110inpurebinarybutas00010100
  - in8421BCDcode.
  - AnotherdisadvantageoftheBCDcodeisthat,arithmeticoperationsaremorecomplexthantheyareinpure binary.
  - Therearesixillegalcombinations1010,1011,1100,1101,1110and1111inthiscode.

- BCDAddition
  - Ifthereisno carryandthesumtermisnotanillegalcode,nocorrectionisneeded.
  - If there is a carry out of one group to the next group, or if the sum term is illegal code, then 6(0110) is added to the sum term of that group and the resulting carry is added to the nextgroup.
  - Example:-

```
(1)  25 + 13
Ans.    25              0010   0101  (25 in BCD)
       +13     ⇒      +0001   0011  (13 in BCD)
        38              0011   1000  (No carry, no illegal code. So, this is the correct sum)

(2)  679.6 + 536.8
Ans.  679.6             0110   0111   1001 . 0110  (679.6 in BCD)
     +536.8    ⇒      +0101   0011   0110 . 1000  (536.8 in BCD)
     1216.4             1011   1010   1111 . 1110  (All are illegal codes)
                       +0110  +0110  +0110 .+0110  (Add 0110 to each)
                0001    0010   0001   0110 . 0100  (Corrected sum = 1216.4)
```

- BCDSubtraction
  - Ifthereisnoborrowfromthenexthighergroup,thennocorrectionisrequired.
  - Ifthereisaborrowfromthenextgroup,then610(0110)issubtractedfromthedifferencetermofthisgroup.
  - Example:-

```
(1)  38 – 15
Ans.    38              0011   1000  (38 in BCD)
       - 15    ⇒      - 0001   0101  (15 in BCD)
        23              0010   0011  (No borrow. So, this is the correct difference.)
```

```
(2)  206.7 – 147.8
Ans.  206.7  ⟹   0010   0000   0110 . 0111 (206.7 in BCD)
    - 147.8    - 0001   0100   0111 . 1000 (147.8 in BCD)
      58.9       0000   1011   1110 . 1111 (Borrows are present, subtract 0110)
                      - 0110  -0110 .-0110
                        0101   1000 . 1001 (Corrected difference = 58.9)
```

❖ Excess-3Code

- TheExcess-3code,alsocalledXS-3,is anon-weightedBCDcode.
- Thiscodederivesitsnamefromthe factthateachbinarycodewordisthecorresponding8421codewordplus0011(3).
- Itissequentialcode and,therefore,canbeused forarithmeticoperations.
- Itisaself-complementingcode.
- TheXS-3codehassixinvalidstates0000,0001,0010,1101,1110and1111.

▪ XS-3Addition

- If there is no carry out from the addition of any of the 4-bit groups, subtract 0011 from thesumtermofthosegroups.
- Ifthereisacarryout,add0011tothesumtermofthosegroups.
- Example:-

```
(1)  247.6 + 359.4
Ans.  247.6  ⟹   0101   0111   1010 . 1001 (247.6 in XS-3)
    + 359.4    + 0110   1000   1100 . 0111 (359.4 in XS-3)
      607.0      1100   0000   0111 . 0000 (Add 0011 to 0000, 0111, 0000
               - 0011  +0011  +0011 .+0011  and subtract 0011 from 1100)
                 1001   0011   1010   0011 (Corrected sum in XS-3 = 607.0)
```

▪ XS-3Subtraction

- If there is no borrow from the next 4-bit group, add 0011 to the difference term of suchgroups.
- Ifthereisaborrow,subtract0011fromthedifferenceterm.
- Example:-

```
(1)  267 – 175
Ans.  267  ⟹   0101   1001   1010 (267 in XS-3)
    - 175    - 0100   1010   1000 (175 in XS-3)
      092      0000   1111   0010 (Subtract 0011 from 1111 and
             + 0011  -0011  +0011  add 0011 to 0000 & 0010)
               0011   1100   0101 (Corrected difference in XS-3 = 92)
```

❖ Gray Code

- Thegraycodeis anon-weightedcode.
- Itisacycliccodebecausesuccessivecodewordsinthiscodedifferinonebitpositiononly, i.e.itaunitdistancecode.is
- Itisalsoareflectivecode.

- Thenleastsignificantbitsfor2^nthrough2^(n+1)-1arethemirrorimagesofthosefor0 through 2-1. An N-bit gray code can be obtained by reflecting an N-1 bit code about an axisat the end of the code, and putting the MSB of 0 above the axis and the MSB of 1 below theaxis.
- Onereasonforthepopularityofthegraycodeisitseaseofconversiontoandfrombinary.
- Reflectionofgraycodeisshownintable.

Gray Code				Decimal	4-bit binary
1-bit	2-bit	3-bit	4-bit		
0	00	000	0000	0	0000
1	01	001	0001	1	0001
	11	011	0011	2	0010
	10	010	0010	3	0011
		110	0110	4	0100
		111	0111	5	0101
		101	0101	6	0110
		100	0100	7	0111
			1100	8	1000
			1101	9	1001
			1111	10	1010
			1110	11	1011
			1010	12	1100
			1011	13	1101
			1001	14	1110
			1000	15	1111

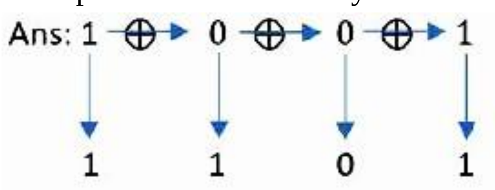
- BinarytoGrayConversion
  - Ifann-bitbinarynumberisrepresentedbyB_nB_{n-1}...,B_1anditsgraycodeequivalentG_nG_{n-1} ...$G_1$where$B_n$and$G_n$aretheMSBs,thenthegraycodebitsareobtainedfromthebinarycodeas follows:

$G_n = B_n$	$G_{n-1} = B_n \oplus B_{n-1}$	$G_{n-2} = B_{n-1} \oplus B_{n-2}$	…….	$G_1 = B_2 \oplus B_1$

Theconversionprocedureisas follows:

1. Recordthe MSBofthe binaryasthe MSBofthegraycode.
2. Perform X-ORing between the MSB of the binary and the next bit in binary. This answer isthenextbitofthegraycode.
3. Perform X-ORing between 2nd bit of the binary and 3rd bit of the binary, the 3rd bit with the4th bit,andsoon.
4. Recordthe successiveanswerbitsasthesuccessivebitsofthegraycodeuntilallthebitsofthebinary numberareexhausted.

- Example:-Convertthe binary1001toGraycode



- Gray toBinary Conversion

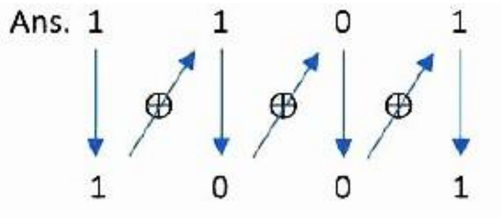
  - Ifann-bitgraynumberisrepresentedby$G_nG_{n-1}...G_1$anditsbinarycodeequivalentB_nB_{n-1} ...B_1,where$G_n$and$B_n$aretheMSBs,thenthebinarybitsareobtainedfromthegraybitsasfollows:

$B_n = G_n$	$Bn\text{-}1= Bn\oplus Gn\text{-}1$	$Bn\text{-}2=Bn\text{-}1\oplus Gn\text{-}2$	…….	$B_1=B_2\oplus G_1$

Theconversionprocedureisas follows:

1. TheMSBofthebinarynumberisthe sameastheMSB ofthegraycodenumber.
2. Perform X-ORing between the MSB of the binary and next significant bit of gray code. Thisansweristhenextbit of binary.
3. PerformX-ORingbetweenthe2ndbitofthebinaryand3rdbitofthegraycode,the3rdbitofthebinary withthe4thbitofgraycode,andsoon.
4. Recordthe successive answers as the successivebits ofthe binaryuntilallthe bits ofthe graycodeareexhausted.

- Example:-Convertthe graycode1101tobinary.



tinuous Assessment; ALA- ActiveLearningActivitie

CourseContent:

Unit No.	Coursecontent	Hrs	% Weight age
1	BasicsofDigitalElectronicsandNumbersystem. • FundamentalsofDigital Systems,AdvantagesandDisadvantagesofDigital over Analog • Numbersystems- Decimal,Binary,octalhexadecimalnumbersystems, • Binaryarithmeticoperations • 1s,2s,7s,9s(R,(R-1s))compliments • BinaryCodes - WeightedCodes,Nonweightedcodes,GrayCode,BCD Code, Excess-3 Code. • Numericalpractice.	12	25%

2	LogicGates,BooleanAlgebra&LogicFamilies • LogicGates:AND,OR,NOT,NAND,NOR,ExclusiveOROperation ,ExclusiveNOR Operation • NAND &NOR asuniversal gate • Booleanalgebra,Laws, PropertiesofBooleanalgebra • De-Morgan's Theorems • Booleanfunctions • Errordetectingandcorrectingcodes • CharacteristicsofdigitalICs • IntroductiontoDigitallogicfamilies,CharacteristicsofDigitallogicfamilies • TTLandCMOSlogic.	12	25%
3.	IntroductionandDesignofCombinationalLogiccircuit • CombinationalDigitalCircuits • Sumof products(SOP) &Productof Sum(POS), • ImplementationofSOPand POSequationusinguniversal gate. • K-map(2,3and4variable),Don'tcare-conditions • Tabulationmethod(Quinemccluskeymethod) • DesignofMultiplexerandDemultiplexer • Decoders-Encoder • Adder-Subtractor • Digital comparator, parity checker and generator, code converters,priorityencoders • 4 bitBinaryAdder,Carrylookaheadadder. • ImplementationofLogicFunctionusingMuxandDecoder.	12	25%
4.	Sequentialcircuit(FlipFlop,RegistersandCounter) • Sequentialcircuitsandsystems • Latch • Theclocked SRflip flop, JK, TandD typesflip flops, • Applicationsofflipflops • ShiftRegisters- Bi-directional,UniversalShiftRegister • Designofcounters • Modulo-n,SynchronousCounter:Ringcounter,Johnsoncounter. • AsynchronousCounter:RippleUPcounter,RippleDOWNcounter,Applications ofCounters.	12	25%

ContinuousAssessment:

SuggestedSpecificationtablewithMarks(Theory):60

DistributionofTheoryMarks (RevisedBloom’sTaxonomy)						
Level	Remembrance (R)	Understanding (U)	Application (A)	Analyze (N)	Evaluate (E)	Create (C)
Weight age	30%	40%	20%	10%	0	0

Note:Thisspecificationtableshallbetreatedasageneralguidelineforstudentsandteachers.Theactualdistribution ofmarks inthe question papermay varyslightlyfromabove table.

CourseOutcome:

Afterlearningthecoursethestudentsshouldbeableto:	
CO1	Solvethegivenproblem usingfundamentals ofNumbersystems
CO2	Analyzeworkingoflogicfamiliesandlogic gates anddesignthesimplecircuitsusingvariousgates fora givenproblem
CO3	Interprettheworkingof combinationalcircuitsanddesignthesimplecircuitsusingvariousgatesfor agivenproblem
CO4	Designofsequentialcircuitsandit’sworking

ListofPracticals:

Sr. No	Descriptions	Unit No	Hrs
1.	Toperformbasiclogicgates&Verification oftruthtable	1	2
2.	Tosolvevariousconversion ofnumbersystems.	2	2
3.	ToperformUniversal BuildingBlockImplementationofvarious Logicgates usingonlyNANDgates&verification oftruth Table.	2	2
4.	ToperformUniversal BuildingBlockImplementationofvarious Logicgates usingonlyNORgate & verificationoftruthtable	2	2
5.	TostudyandverifyDE- Morgan’sTheorem.	2	2
6.	Todesign &Implement HalfAdder& FullAddercircuits.	2	2
7.	Todesign &ImplementHalf-Subtractor&Full-Subtractorcircuits.	2	2
8.	TostudyEncoder &DecoderCombinational Circuits.	3	2
9.	ImplementMultiplexer&DemultiplexerCombinationalCircuit.	3	2
10.	TosolveandsimulateBoolean ExpressionusingK-MAP	3	2

11.	Tostudy&verifythefunctionofSR Flip Flops &DFlipFlop	4	2
12.	To study&verifythefunctionofJK FlipFlops. &T FlipFlops.	4	2
13.	Tovalidate thetruth tableof Ring &Johnson Counter	4	2
14.	Studyof differentType ofshift registers	4	2
15.	Design FlipFlopusingcombinationallogiccircuit.	4	2
	TOTAL		30

InstructionalMethod:

The course delivery method will depend upon the requirement of content and the needs of students. Theteacher, in addition to conventional teaching methods by black board, may also use any tools such asdemonstration,role play,Quiz, brainstorming, MOOCs etc.

Fromthecontent10%topicsaresuggestedforflippedmodeinstruction.

Students will use supplementary resources such as online videos, NPTEL/SWAYAM videos, e-courses,VirtualLaboratory

Theinternalevaluation willbe doneon thebasisofActive LearningAssignment

Practical/Vivaexaminationwillbeconductedattheendofsemesterforevaluationofperformanceofstudents in thelaboratory.

ReferenceBooks:

[1] "DigitallogicandComputerdesign",M.M. Mano,PearsonEducation India,2016.

[2] "FundamentalsofDigitalCircuits",A.Kumar,PrenticeHall India,2016.

[3] “DigitalPrinciplesandApplications”Malvino&Leach,McGraw-HillEducation

"ModernDigitalElectronics",R.P.Jain,McGra

Introduction& Design of Combinational Circuit

❖ **Standardrepresentationforlogicfunctions**

1. **Sum-of-products(SOP)form:**
   - Thisformis alsocalled theDisjunctiveNormal Form(DNF).
   - Forexample, $f(A,B,C) = \overline{A}B+\overline{B}C$

2. **Product-of-sums(POS)form:**
   - Thisformis alsocalled theConjunctiveNormal Form(CNF).
   - Thefunctionofaboveequationmayalsobewrittenintheformshowninequationbelow.
   - Byusingmultiplyingitoutandusingtheconsensustheorem,wecanseethatitisthesame as $f(A,B,C)=(A+B)(\overline{B}+\overline{C})$

3. **Standardsum-of-productsform:**
   - Thisformis alsocalled Disjunctive CanonicalForm(DCF).
   - ItisalsocalledtheExpandedSumofProductsFormor CanonicalSum-of-ProductsForm.
   - Inthisform,thefunctionisthesumofanumberofproducttermswhereeachproducttermcontainsallthevariablesofthefunctioneitherincomplemented oruncomplementedform.
   - Thiscanbederivedfromthetruthtablebyfindingthesumofallthetermsthatcorrespondtothosecombinations(rows) for which'f'assumesthevalue1.
   - Itcanalsobeobtained fromthe SOPformalgebraicallyasshownbelow.

$$f(A,B,C)=\overline{A}B+\overline{B}C=\overline{A}B(\overline{C}+C)+(\overline{A}+A)\overline{B}C$$
$$=\overline{A}B\overline{C}+\overline{A}BC+\overline{A}\,\overline{B}C+A\overline{B}C$$

   - Aproducttermwhichcontainsallthevariablesofthefunctioneitherincomplementedoruncomplemented formiscalledaminterm.
   - Amintermassumesthevalue1onlyforonecombinationofthevariables.Annvariablefunctioncanhaveinall2^nminterms.
   - Thesumofthemintermswhosevalueisequalto1isthestandardsumofproductsformofthefunction.
   - The minterms are often denoted as m0, m1, m_2, ..., where the suffixes are the decimal codesofthecombinations.
   - Fora3-variablefunction $m_0=\overline{A}\,\overline{B}\,\overline{C}, m_1=\overline{A}\,\overline{B}C, m_2=\overline{A}B\overline{C}, m_3=\overline{A}BC, m_4=A\overline{B}\,\overline{C}, m_5=A\overline{B}C,$ $m_6=AB\overline{C}, m_7=ABC.$

   - AnotherwayofrepresentingthefunctionincanonicalSOPformisbyshowingthesumofmintermsfor whichthefunctionequals1.
   - Thus $f(A, B, C)=m_1+ m_2+ m_3+ m_5$
   - YetanotherwayofrepresentingthefunctioninDCFisbylistingthedecimalcodesofthemintermsfor whichf=1.
   - Thus $f(A,B,C)=\sum_m(1,2,3,5)$

4. **Standardproduct-of-sumsform:**
   - ThisformisalsocalledConjunctiveCanonicalForm(CCF).ItisalsocalledExpandedProduct-of-SumsFormor CanonicalProduct-of-SumsForm.
   - Thisisderivedbyconsideringthecombinationsforwhichf=0.Eachtermisasumofallthevariables.
   - AvariableappearsinuncomplementedformifithasavalueofOinthecombinationandappearsincomplementedformifithasavalueofI inthecombination.

$$f(A.B.\overline{C})=\left(\overline{A}+B\right)(B+C)=\left(\overline{A}+B+\overline{C}C\right)\left(\overline{A}A+B+\overline{C}\right)$$

$$=\left(\overline{A}+B+\overline{C}\right)\left(A+\overline{B}+\overline{C}\right)\left(\overline{A}+B+C\right)\left(A+B+C\right)$$

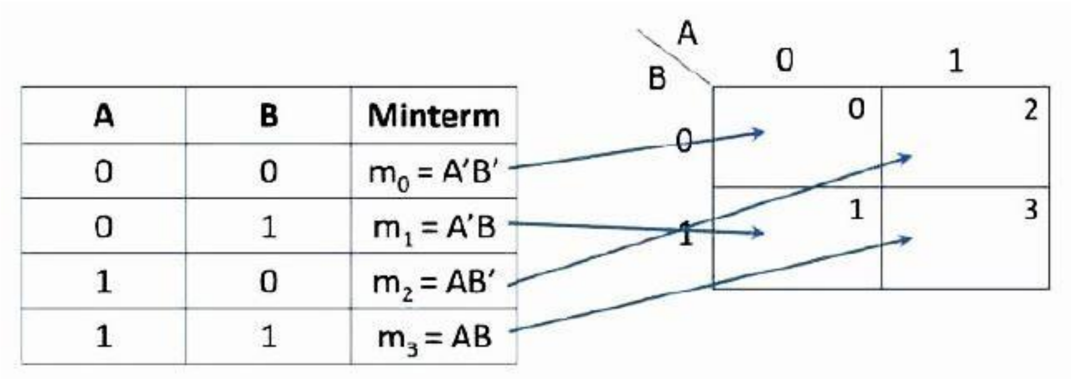
   - Asumtermwhichcontainseachofthenvariablesineithercomplementedoruncomplementedform iscalledamaxterm.
   - Amaxtermassumesthevalue0onlyforonecombinationofthevariables.Forallothercombinations itwillbe1.
   - Therewillbeatthemost2^nmaxterms.Theproductofmaxtermscorrespondingtotherowsforwhichf = 0isthestandardor canonicalproductof sumsformofthe function.
   - MaxtermsareoftenrepresentedasM$_0$,M$_1$,M$_2$,...,wherethesuffixesdenotetheirdecimalcode.
   - Thus, the CCF of functionf maybewrittenas$f$(A,B,C) = $M_0 \cdot M_4 \cdot M_5 \cdot M_7$
   - Expression can alsobeexpressedas f (A, B,C) =Π_M (0,4,6,7)
   - WhereΠrepresentstheproductofallmaxtermswhosedecimalcodeisgivenwithintheparenthesis.

❖ **KarnaughMap(K-Map)**

- TheKarnaughmap(K-map)methodisasystematicmethodofsimplifyingtheBooleanexpression.
- TheK-mapisachartoragraph,composedofanarrangementofadjacentcells,eachrepresentingaparticularcombinationofvariablesinsum or productform.
- TheoutputvaluesplacedineachcellarederivedfromthemintermsofaBoolean function.
- Amintermisaproducttermthatcontainsallofthefunction'svariablesexactlyonce,eithercomplementedornotcomplemented.

▪ **Two-variableK-Map**

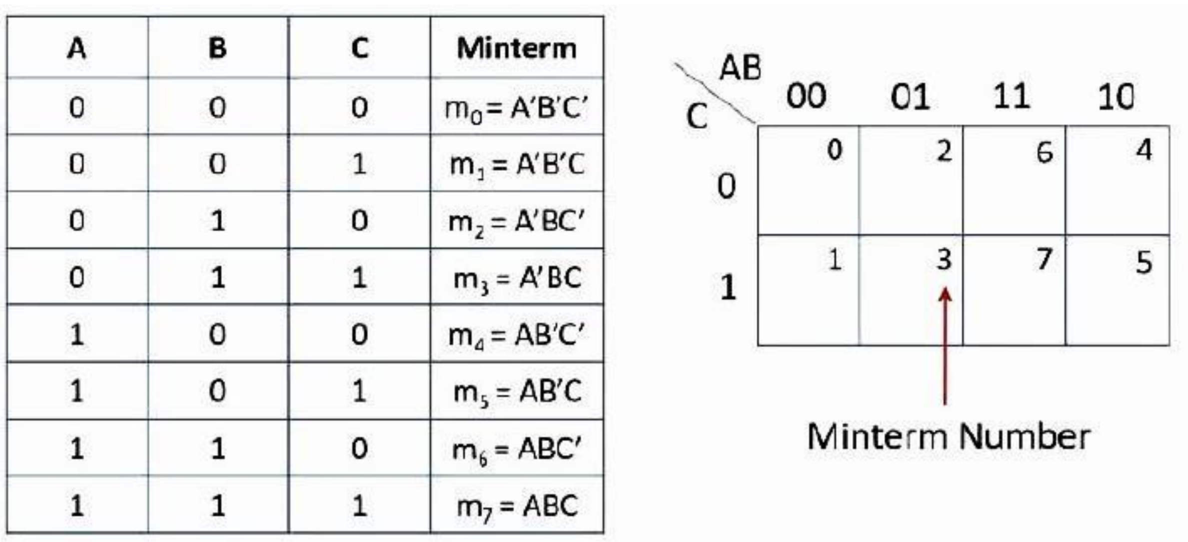
- Thetwovariableexpressioncanhave2^2=4possiblecombinationsoftheinputvariablesAandB.
- Eachofthesecombinations,A'B',A'B,AB',andAB(inSOPform)iscalledminterm.
- Thesepossiblecombinationscanberepresented intableandbythe mapasfollows:



A	B	Minterm
0	0	$m_0 = A'B'$
0	1	$m_1 = A'B$
1	0	$m_2 = AB'$
1	1	$m_3 = AB$

- **Three-variableK-Map**

- Afunctioninthreevariable(A,B,C)expressedinthestandardSOPformcanhaveeightpossiblecombinations:A'B'C',A'B'C,A'BC',A'BC,AB'C',AB'C,ABC'andABC.
- Eachoneofthesecombinationsdesignatedbym_0,m_1,m2,m_3,m_4,m_5,m_6,andm_7,respectively,iscalled minterm.
- InthestandardPOSform,theeightpossiblecombinationsare:A+B+C,A+B+C',A+B'+C,A'+B'+C',A'+B+C,A'+B+C',A'+B'+CandA'+B'+C'
- EachoneofthesecombinationsdesignatedbyM_0,M_1,M_2,M_3,M_4,M_5,M_6,andM_7,respectively,iscalled maxterm.



A	B	C	Minterm
0	0	0	$m_0 = A'B'C'$
0	0	1	$m_1 = A'B'C$
0	1	0	$m_2 = A'BC'$
0	1	1	$m_3 = A'BC$
1	0	0	$m_4 = AB'C'$
1	0	1	$m_5 = AB'C$
1	1	0	$m_6 = ABC'$
1	1	1	$m_7 = ABC$

- **Four-variableK-Map**

- ThefourvariablesA,B,CandDhavesixteenpossiblecombinationsthatcanberepresentedbythemapas follows

A	B	C	D	Minterm
0	0	0	0	m_0 = A'B'C'D'
0	0	0	1	m_1 = A'B'C'D
0	0	1	0	m_2 = A'B'CD'
0	0	1	1	m_3 = A'B'CD
0	1	0	0	m_4 = A'BC'D'
0	1	0	1	m_5 = A'BC'D
0	1	1	0	m_6 = A'BCD'
0	1	1	1	m_7 = A'BCD

A	B	C	D	Minterm
1	0	0	0	m_8 = AB'C'D'
1	0	0	1	m_9 = AB'C'D
1	0	1	0	m_{10} = AB'CD'
1	0	1	1	m_{11} = AB'CD
1	1	0	0	m_{12} = ABC'D'
1	1	0	1	m_{13} = ABC'D
1	1	1	0	m_{14} = ABCD'
1	1	1	1	m_{15} = ABCD

CD \ AB	00	01	11	10
00	0	4	12	8
01	1	5	13	9
11	3	7	15	11
10	2	6	14	10

- **ReductionusingK-Map**

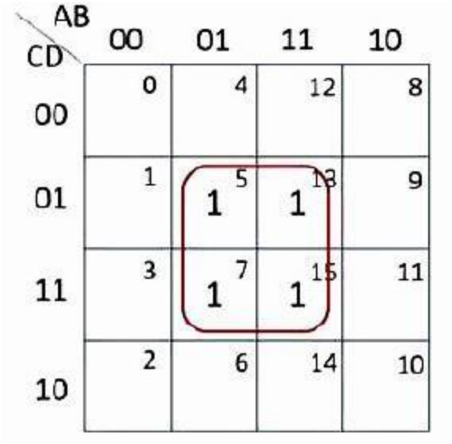
- Squareswhicharephysicallyadjacenttoeachotherorwhichcanbemadeadjacentbywrappingthemaparoundfromleft torightortoptobottomcanbecombinedto formbiggersquares.
- Thebiggersquares(2squares,4squares,8squares,etc.)mustformeitherageometricsquareorrectangle.
- Forthemintermsormaxtermstobecombinableintobiggersquares,itisnecessarybutnotsufficientthattheirbinarydesignationsdifferbyapowerof 2.

Example-1 Reduce f(A,B,C)=A'B'C+A'BC+ AB'C+ABC

C \ AB	00	01	11	10
0	0	2	6	4
1	1 (1)	1 (3)	1 (7)	1 (5)

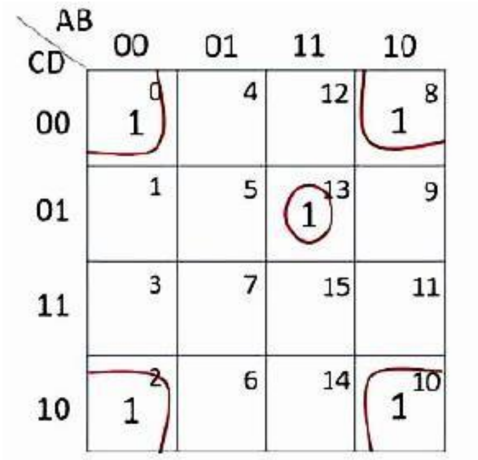
Answer:f=C

Example-2 Reduce f(A,B,C,D)=ABC'D+ABCD+A'BC'D+A'BCD



Answer: f=BD

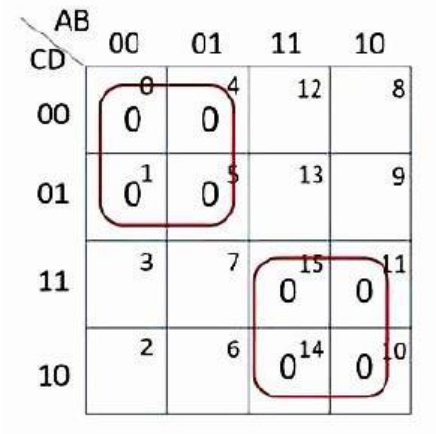
Example-3 Reducef(A,B, C,D)=$\sum_m$ (0,2,8,10,13)



Answer: f=B'D'+ABC'D

Example-4 Reducef(A, B,C,D)=Π_M(0,1,4,5,10,11,14,15)

- InPOSform,wehavetoput"0"inthegivennumberboxesinK-Map.
- MakegroupofOssameaswemakegroupof1s inSOP form.
- Forcommon"1"writecomplementedformandforcommon"0"writeuncomplementedformofvariable,e.g.1 - A'and0-A.

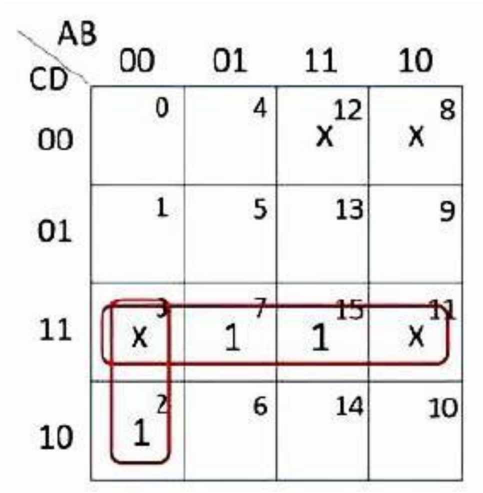


Answer:f= $(A+C)(A'+ C')$

❖ **K-Mapwithdon'tcarecondition**

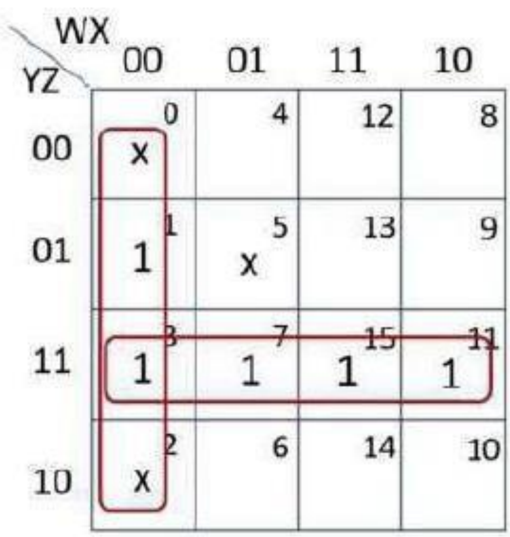
- Suppose we are given a problem of implementing a circuit to generate a logical 1 when a 2,7,or 15appearsonafour-variableinput.
- AlogicalOshouldbegeneratedwhen 0,1,4,5,6,9,10,13or14appears.
- The input conditions for the numbers 3, 8, 11 and 12 never occur in the system. This meanswedon'tcarewhetherinputsgeneratelogical1or logical0.
- Don't care combinations are denoted by 'x' in K-Map which can be used for the makinggroups.
- Theaboveexamplecanberepresentedas

Example-1 Reducef(A,B,C,D)= $\sum_m(2,7,15)+d\ (3,8,11,12)$



Answer:f=CD+A'B'C

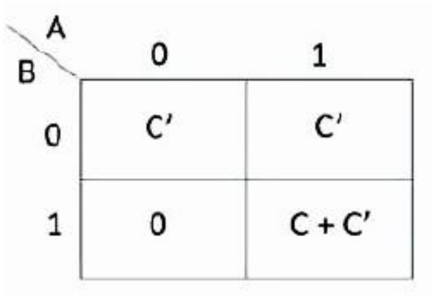
Example-2 Reducef(W,X,Y,Z)= $\sum_m$ (1,3,7,11,15) +d (0,2,5)



Answer: f=W'*X'+YZ

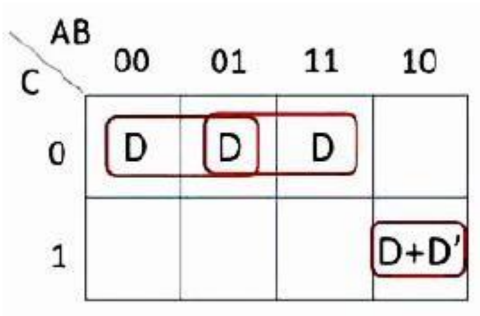
- **Variable-EnteredMap(VEM)**

- Variableentered mapcanbeusedtoplotannvariableproblemonn1variablemap.
- Possibletoreducethe mapdimensionbytwoorthreeinsomecases.
- AdvantageofusingVEMoccursindesignproblemsinvolvingmultiplexers.
- Forexample,Map-enteredvariablefor3variablefunction
- ConsiderthefunctionX=A'B'C' +ABC' +AB'C'+ABC
- Considering value of X to be function of map location and the variable C and plotting 2variableK- Map.



Example-1 Reduce: = AB'CD+ A'BC'D+AB'CD' +ABC'D+A'B'C'D

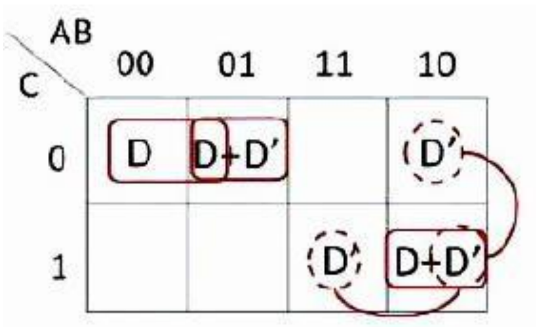
= AB'CD + A'BC'D + AB'CD' + ABC'D + A'B'C'D5 2 5 6 0



Answer:f= A'C'D+BC'D+AB'C

Example-2 Reduce f=A'B'C'D+A'BC'D' +A'BC'D+AB'C'D' +AB'CD+AB'CD+ABCD' usingVEM method.

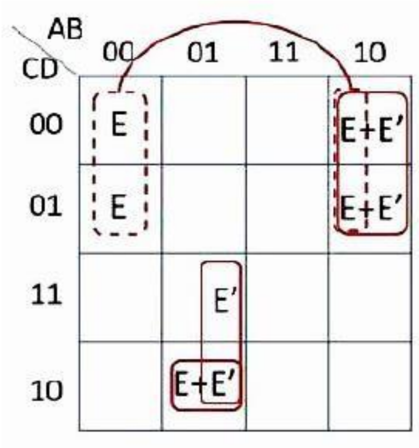
= A'B'C'D + A'BC'D' + A'BC'D + AB'C'D' + AB'CD + AB'CD + ABCD'0 2 2 4 5 5 7



Example-3 Reducef=A'B'C'D'E +A'B'C'DE+A'BCD'E' +A'BCD'E+AB'C'D'E' +AB'C'D'E +AB'C'D+A'BCDE'

= A'B'C'D'E + A'B'C'DE + A'BCD'E' + A'BCD'E + AB'C'D'E' + AB'C'D'E + AB'C'D + A'BCDE'0

1 6 6 8 8 9 7



Answer: f=B'C'E+AB'C' +A'BCD' +A'BCE'

❖ QuineMcCluskey Method(TabulationMethod)

- **Procedureforminimizationusingtabulationmethod**

1. Listallthe minterms.
2. Arrange all minterms in groups of the same number of 1s in their binary representation incolumn. 1. Start with the least number of 1s group and continue with groups of increasingnumberof1s.
3. Compare each term of the lowest index group with every term in the succeeding group.Whenever possible, combine the two terms being compared by means of the combiningtheorem. Two terms from adjacent groups are combinable, if their binary representationsdiffer by just a single digit in the same position; the combined terms consist of the originalfixed representation with the differing one replaced by a dash (-). Place a checkmark (V)next to every term, which has been combined. with at least one term and write the combinedterms in column 2. Repeat this by comparing each term in a group of index i with every terminthegroupofindexi+1,untilallpossibleapplications.ofthecombiningtheoremhavebeenexhausted.
4. Compare the terms generated in step 3 in the same fashion; combine two terms which differby only a single 1 and whose dashes are in the same position to generate a new term. Twotermswithdashesindifferentpositionscannotbecombined.Writethenewtermsincolumn3 and put a checkmarknext to each term which has beencombined incolumn 2.Continuethe process with terms in columns 3, 4 etc. until no further combinations are possible. Theremaininguncheckedtermsconstitutethesetofprimeimplicantsoftheexpression.
5. List all the prime implicants and draw the prime implicant chart. (The don't cares if anyshouldnotappear intheprimeimplicantchart).
6. Obtaintheessentialprimeimplicantsandwritetheminimalexpression.

Example-1 Simplifyf(A,B,C,D)=$\sum_m$ (1,2,3,5,6,7,8,9,12,13,15) usingtabulation method.

Step:-1 Listallminterm

Minterms	Binary Designation
1	0 0 0 1
2	0 0 1 0
3	0 0 1 1
5	0 1 0 1
6	0 1 1 0
7	0 1 1 1
8	1 0 0 0
9	1 0 0 1
12	1 1 0 0
13	1 1 0 1
15	1 1 1 1

Step:-2 Arrangeallmintermsingroupsofsamenumberof1s

Column-1		
Index	Minterms	Binary Designation
Index 1	1	0 0 0 1✓
	2	0 0 1 0✓
	8	1 0 0 0✓
Index 2	3	0 0 1 1✓
	5	0 1 0 1✓
	6	0 1 1 0✓
	9	1 0 0 1✓
	12	1 1 0 0✓
Index 3	7	0 1 1 1✓
	13	1 1 0 1✓
Index 4	15	1 1 1 1✓

Step:-3 Compare each term of the lowestindexgroupwitheveryterminthesucceedinggrouptillnochange

Column-2	
Pairs	A B C D
1,3	0 0 – 1 ✓
1,5	0 – 0 1 ✓
1,9	– 0 0 1 ✓
2,3	0 0 1 – ✓
2,6	0 – 1 0 ✓
8,9	1 0 0 – ✓
8,12	1 – 0 0 ✓
3,7	0 – 1 1 ✓
5,7	0 1 – 1 ✓
5,13	– 1 0 1 ✓
6,7	0 1 1 – ✓
9,13	1 – 0 1 ✓
12,13	1 1 0 – ✓
7,15	– 1 1 1 ✓
13,15	1 1 – 1 ✓

Step: -4 Compare the terms generated in step 3 inthesamefashionuntilnofurthercombinationsarepossible.

Column-3	
Quads	A B C D
1,3,5,7	0 – – 1 **T**
1,5,9,13	– – 0 1 **S**
2,3,6,7	0 – 1 – **R**
8,9,12,13	1 – 0 – **Q**
5,7,13,15	– 1 – 1 **P**

Step: -5 List all prime implicants and draw prime implicants chart.PrimeImplicants:P(BD),Q(AC'),R(A'C),S(C'D),T(A'D)

Minterms	1	2 ✓	3 ✓	5 ✓	6 ✓	7 ✓	8 ✓	9 ✓	12 ✓	13 ✓	15 ✓
T(A'D)	X		X	X		X					
S(C'D)	X			X				X		X	
R(A'C) ✓		X	X		X	X					
Q(AC') ✓							X	X	X	X	
P(BD) ✓				X		X				X	X

Step: -6 Obtain essential prime implicants and minimal expression.EssentialPrimeImplicants:P(BD)Q(A*C')R(A'*C)

Minimal Expression: P+Q+R+S = BD + A'C + AC' + C'D
P+Q+R+T = BD + A'C + AC' + A'D

As minterm 1 is covered by S and T.

Example - 2 Simplifyf(A,B,C,D) = $\sum_m$ (0,1,3,7,8,9,11,15)usingtabulationmethod.

Step:-1Listallminterm

Minterms	Binary Designation
0	0001
1	0010
3	0011
7	0111
8	1000
9	1001
11	1011
15	1111

Step:-2Arrangeallmintermsingroupsofsamenumberof1s

Column-1		
Index	Minterms	Binary Designation
Index 0	0	0000✓
Index 1	1 8	0001✓ 1000✓
Index 2	3 9	0011✓ 1001✓
Index 3	7 11	0111✓ 1011✓
Index 4	15	1111✓

Step:-3 Compare each term of the lowestindexgroupwitheveryterminthesucceedinggrouptillnochange.

Column-2	
Pairs	A B C D
0,1 0,8	000–✓ –000✓
1,3 1,9 8,9	00–1✓ –001✓ 100–✓
3,7 3,11 9,11	0–11✓ –011✓ 10–1✓
7,15 11,15	–111✓ 1–11✓

Step:-4 Compare the terms generated in step 3 inthe samefashion untilno further combinationsarepossible.

Column-3	
Quads	A B C D
0,1,8,9 1,3,9,11	–00– **R** –0–1 **Q**
3,7,11,15	– –11 **P**

Step:-
5Listallprimeimplicantsanddrawprimeimplicantschart.PrimeImplicants:P(CD),Q(B'D),R(B'C).

Minterms	0 ✓	1 ✓	3 ✓	7 ✓	8 ✓	9 ✓	11 ✓	15 ✓
P(CD)✓			X	X			X	X
Q(B'D)		X	X			X	X	
R(B'C')✓	X	X			X	X		

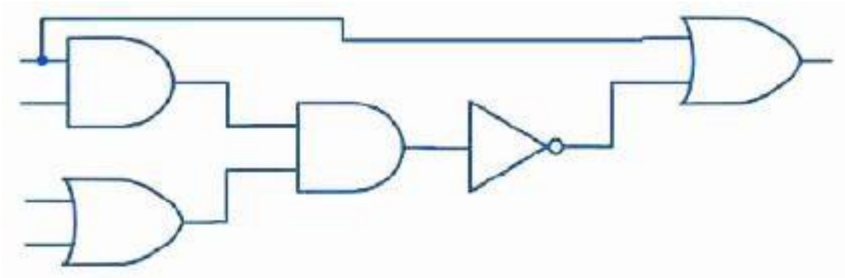
Step:-6 Obtain essential prime implicants and minimal expression.EssentialPrimeImplicants:P(CD),R(B'C')

MinimalExpression:P+R=CD +B'C'

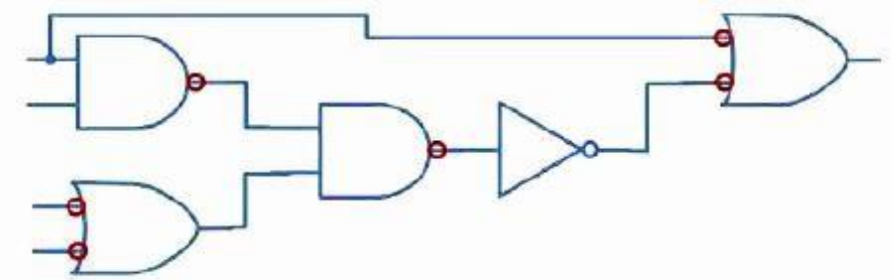
❖ **Realizationusinguniversalgates**

1. DrawthecircuitinAOIlogic.
2. IfNAND hardwareis chosen,add acircleatthe outputof each ANDgate andat theinputs toalltheORgates.
3. IfNORhardwareischosen,addacircleattheoutputofeachORgateandattheinputstoalltheANDgates .
4. Addorsubtractaninverteroneachlinethatreceivedacircleinsteps2or3sothatthepolarityofsignalsonthoselinesremains unchangedfromthatofthe originaldiagram.
5. Replace bubbledORbyNANDandbubbledANDbyNOR.
6. Eliminatedoubleinversions.

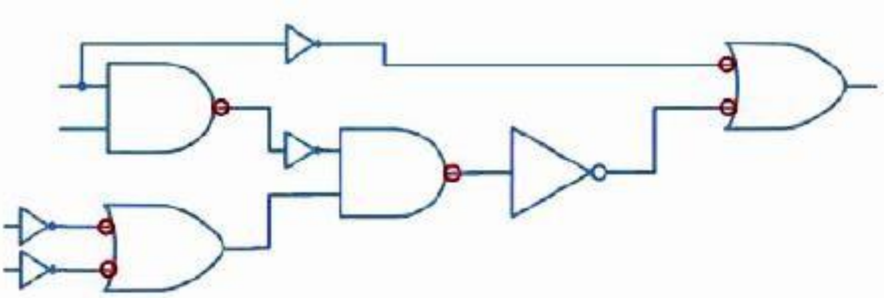
Example-1 ImplementthefollowingAOIlogicusingNAND.



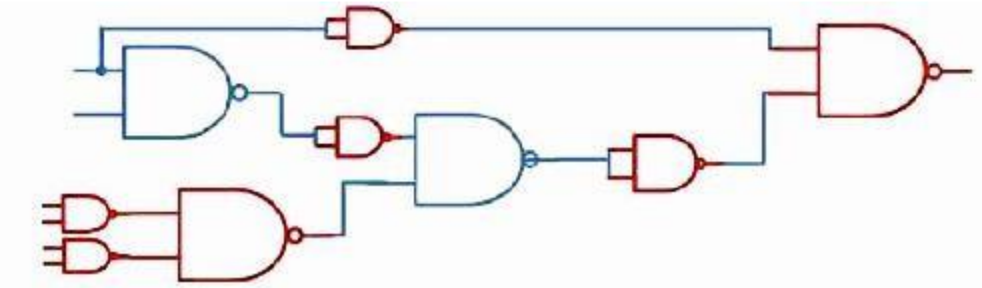
- PutacircleattheoutputofeachAND gateandattheinputstoallORgates



- Add an inverter to each of the lines that received only one circle at input so that polarityremains.unchanged.



- Replace bubbledORgatesandNOTgates byNANDgates.

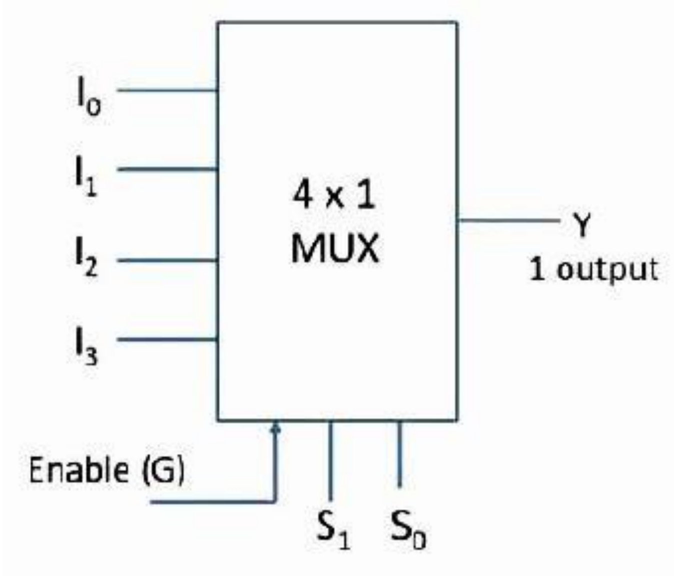


❖ Multiplexer

- Amultiplexer(MUX)isadevicethatallowsdigitalinformationfromseveralsourcestoberoutedontoa singlelinefortransmissionoverthatlinetoacommondestination.
- Consideraninteger'm',whichisconstrainedbythefollowingrelation:

  $m = 2^n$,wheremand narebothintegers.

- **A m-to-1** Multiplexer
  hasmInputs:$I_0, I_1, I_2, \ldots I_{(m-1)}$
  OneOutput:Y
  n Control inputs: $S_0, S_1, S_2, \ldots S_{(m-1)}$One(ormore)Enableinput(s)
  suchthatYmaybe equaltooneoftheinputs,dependinguponthecontrolinputs.
- Theblockdiagramof4x1multiplexerisasfollows



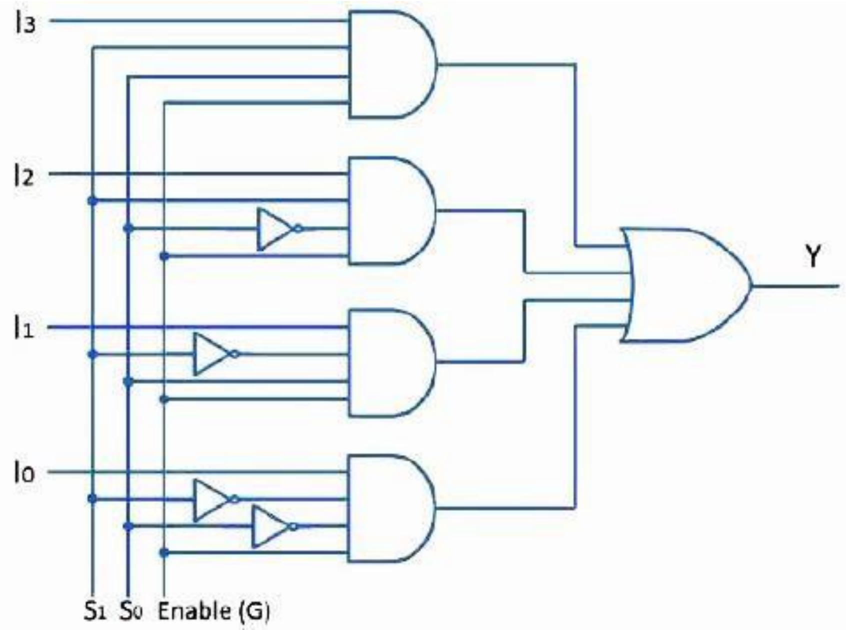
- Thefunctiontableforthe4x1multiplexercanbestated asbelow.

Select Inputs		Output
S_1	S_0	Y
0	0	I_0
0	1	I_1
1	0	I_2
1	1	I_3

- Thefollowinglogicfunctiondescribesthe abovefunctiontable.

$$Y=S_1'S_0'I_0+S_1'S_0I_1+S_1S_0'I_2+S_1S_0I_3$$

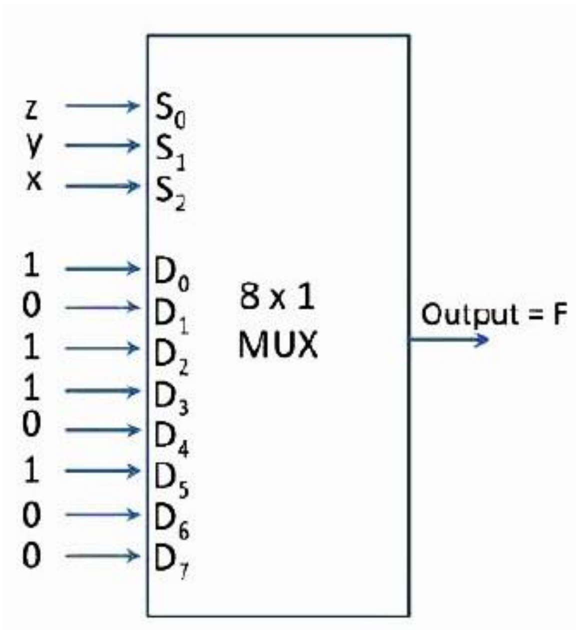
- Thefollowing figuredescribesthelogiccircuitfor4x1multiplexer.



- ApplicationsofMultiplexerisasfollows:
  1. Logicfunctiongeneration
  2. Dataselection
  3. Datarouting
  4. Operationsequencing
  5. Parallel-to-serialconversion
  6. Waveformgeneration

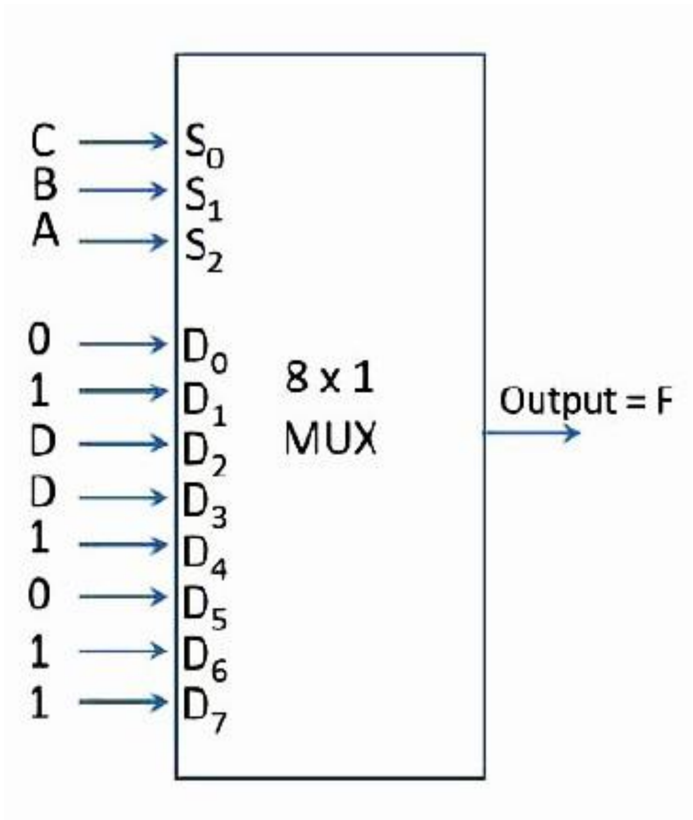
Example-1 Implementthefollowingfunctionusing 8to1mux:f(X,Y,Z)=$\sum_m$ (0,2,3,5)

S_2	S_1	S_0	F
x	y	z	
0	0	0	1
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	0



Example-2 Implementthefollowingusing8to1mux:f(A,B,C,D)=$\sum_m$ (2,3,5,7,8,9,12, 13,14,15)

S_2	S_1	S_0	D	F	
A	B	C			
0	0	0	0	0	F = 0
0	0	0	1	0	
0	0	1	0	1	F = 1
0	0	1	1	1	
0	1	0	0	0	F = D
0	1	0	1	1	
0	1	1	0	0	F = D
0	1	1	1	1	
1	0	0	0	1	F = 1
1	0	0	1	1	
1	0	1	0	0	F = 0
1	0	1	1	0	
1	1	0	0	1	F = 1
1	1	0	1	1	
1	1	1	0	1	F = 1
1	1	1	1	1	



- **HalfAdder**

- Ahalf-adderisacombinationalcircuitwithtwobinaryinputs(augendandaddendbits)andtwobinaryoutputs(sumandcarrybits).
- Itaddsthetwoinputs(singlebitwordsAandB) andproducesthesum(S) andthecarry(C) bits.
- Thetruthtableofahalf-adder areshownbelow:

Inputs		Outputs	
A	B	Sum	Carry
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

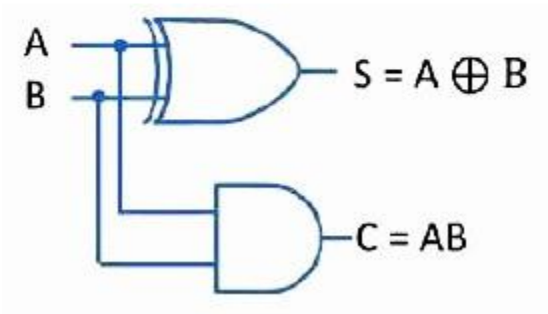
- TheSum(S)isthe X-ORofAandB(ItrepresenttheLSBofthesum).Therefore,

$$S=AB'+BA'=A\oplus B$$

- Thecarry(C) istheANDofAandB(Itis0unlessboththeinputsare1).Therefore,

$$C=AB$$

- Ahalf-addercan,therefore,berealizedbyusingoneX-ORgateandoneANDgateasshowninfigurebelow.



- **FullAdder**

- Afull-adderisacombinationalcircuitthataddstwobitsandacarryandoutputsasumbitandacarrybit.
- Whenwewanttoaddtwobinarynumbers,eachhavingtwoormorebits,theLSBscanbeadded.byusingahalf-adder.
- ThecarryresultedfromtheadditionoftheLSBsiscarriedovertothenextsignificantcolumnandaddedtothetwobitsinthatcolumn.
- Thefull-adderaddsthebitsAandBandthecarryfromthepreviouscolumncalledthecarry-inandoutputsthesumbitSandthecarrybitcalledthecarry-outmathcalCoutCin
- ThevariableSgivesthevalueoftheleastsignificantbitofthesum.
- ThevariableCoutgivestheoutputcarry.
- Thetruthtableofa full-adder areshowninfigurebelow

Inputs			Outputs	
A	B	C_{in}	S	C_{out}
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

- Theeightrowsundertheinputvariablesdesignateallpossiblecombinationsof1sand0sthatthesevariables mayhave.
- Whenallthebitsare0s,theoutputis0.
- TheS outputisequalto1whenonly1inputisequalto1or whenallthe inputsareequalto1.
- TheC_{out} hasacarryof1iftwoor threeinputsareequalto1.
- Fromthetruthtable,acircuitthatwillproducethecorrectsumandcarrybitsinresponsetoeverypossiblecombinationofA,B,andC_{in}describedby

$$S=A'B'C_{in}+A'BC_{in}'+AB'C+ABC_{in}$$

$$=(AB'+A'B)C_{in}'+(AB+A'B')C_{in}$$

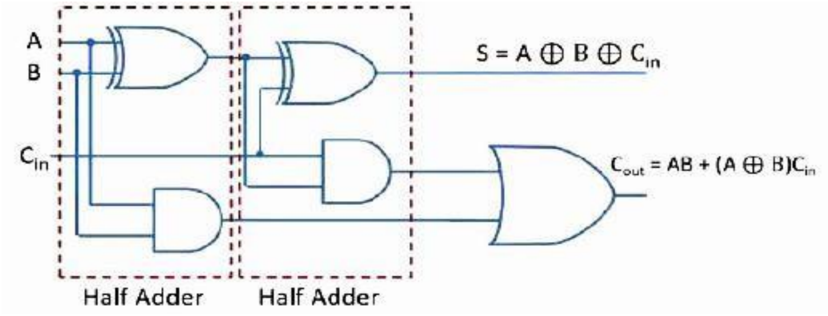
$$=(A\oplus B)C_{in}'+(A\oplus B)'C_{in}$$

$$=A\oplus B\oplus C_{in}$$

$$C_{out}=A'BC_{in}+AB'C_{in}+ABC_{in}'+ABC_{in}$$

$$=AB+(A\oplus B)C_{in}$$

- The sumtermofthefull-adderisthe X-ORofA,BandC_{in}i.e., thesumbitis themodulosumofthedatabitsinthatcolumnandthecarryfromthepreviouscolumn.
- ThelogicdiagramofthefulladderusingtwoX-ORgatesandtwoANDgates(i.e.,twohalf-adders)andoneORgateisshowninfigurebelow.



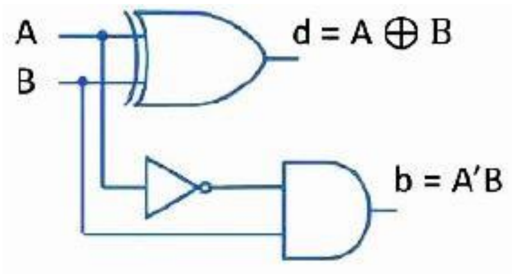
A
B
C_in
S = A ⊕ B ⊕ C_in
C_out = AB + (A ⊕ B)C_in
Half Adder
Half Adder

- **HalfSubtractor**

- A half-subtractoris acombinationalcircuitthatsubtractsonebitfromthe otherandproducesthedifference.
- Italsohas anoutputtospecifyifa1hasbeenborrowed.
- ItisusedtosubtracttheLSBofthesubtrahendfromtheLSBoftheminuendwhenonebinarynumberissubtractedfromtheother.
- Ahalf-subtractorisa combinationalcircuitwithtwoinputsA andBand twooutputsd andb.
- dindicatesthedifferenceandbistheoutputsignalgeneratedthatinformsthenextstagethata1hasbeenborrowed.
- Weknowthat,whenabitBissubtracted fromanotherbitA,adifferencebit(d)andaborrowbit (b)resultaccordingtotherulesgiven asfollows.

Inputs		Outputs	
A	B	d	b
0	0	0	0
0	1	1	1
1	0	1	0
1	1	0	0

- Acircuitthatproducesthecorrectdifferenceandborrowbitsinresponsetoeverypossiblecombinationofthetwo1-bitnumbersis,therefore,describedby
  $d=AB'+BA'=A\oplus B$and$d=A'B$
- Thatis,thedifferencebitisobtainedbyX-ORingthetwoinputs,andtheborrowbitisobtainedbyANDingthecomplementoftheminuendwiththesubtrahend.
- Figurebelowshowslogicdiagramsofahalf-subtractor.



- **FullSubtractor**

- Thehalf-subtractorcan beusedonlyforLSB subtraction.
- If there is a borrow during the subtraction of the LSBs, it affects the subtraction in the nexthigher. column; the subtrahend bit is subtracted from the minuend bit, considering the borrowfromthatcolumnused for thesubtractioninthepreceedingcolumn.
- Suchasubtractionisperformedbya full-subtractor.
- It subtracts one bit (8) from another bit (A), when already there is a borrow b, from this columnforthesubtractioninthepreceedingcolumn,andoutputsthedifferencebit(d)andtheborrowbit

(b)requiredfromthe nextcolumn.

- Soafull-subtractorisacombinationalcircuitwiththreeinputs(A,B,bi)andtwooutputsdandb.
- The1sand0sfor theoutputvariablesaredeterminedfromthesubtractionofA-B–b.
- Thetruthtableofa full-subtractorareshowninfigure.

Inputs			Outputs	
A	B	b_i	d	b
0	0	0	0	0
0	0	1	1	1
0	1	0	1	1
0	1	1	0	1
1	0	0	1	0
1	0	1	0	0
1	1	0	0	0
1	1	1	1	1

- From the truth table, a circuit that will produce the correct difference and borrow bits in responsetoeverypossiblecombinationofA,B,andb,isdescribedby

$$d=A'B'b_i+A'Bb_i'+AB'b_i'ABb_i$$

$$=(AB'+A'B)b_i'+(Ab+A'B')b_i$$

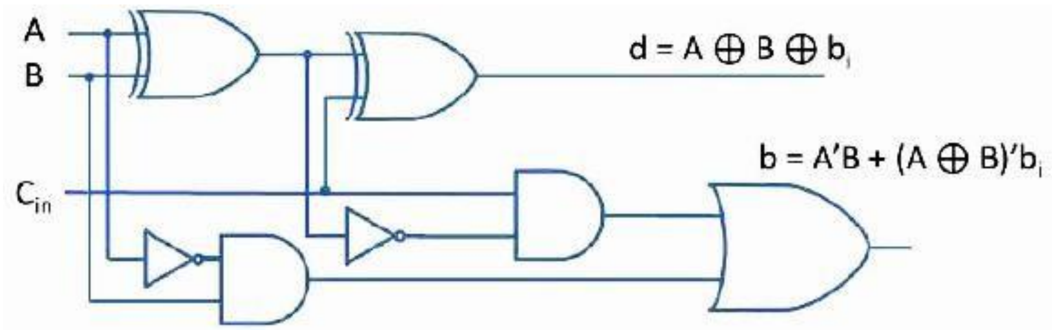
$$=A\oplus B\oplus b_i$$

$$b=A'B'b_i+A'Bb_i'+A'Bb_i'ABb_i$$

$$=A'B(b_i+b_i')+(Ab+A'B')b_i$$

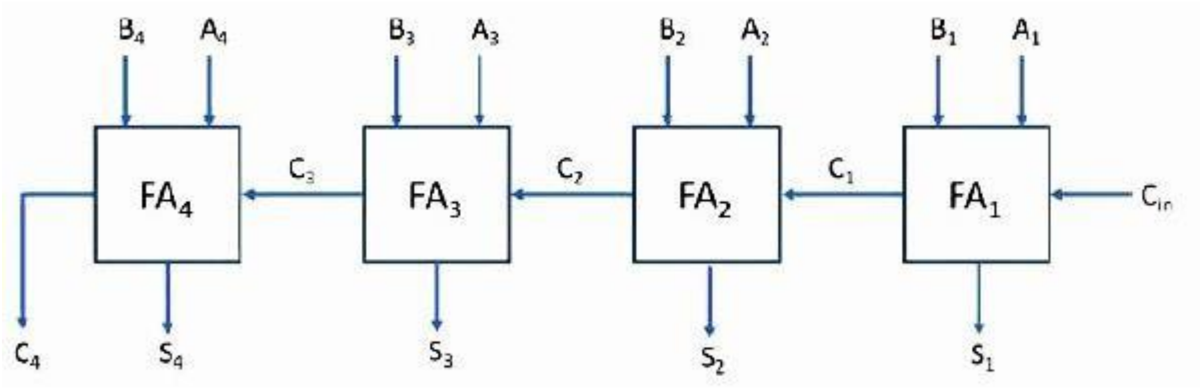
$$=A'B+(A\oplus B)'\oplus b_i$$

- Afull-subtractorcan,therefore,berealizedusingX-ORgatesasshown below.



- **Binary paralleladder**

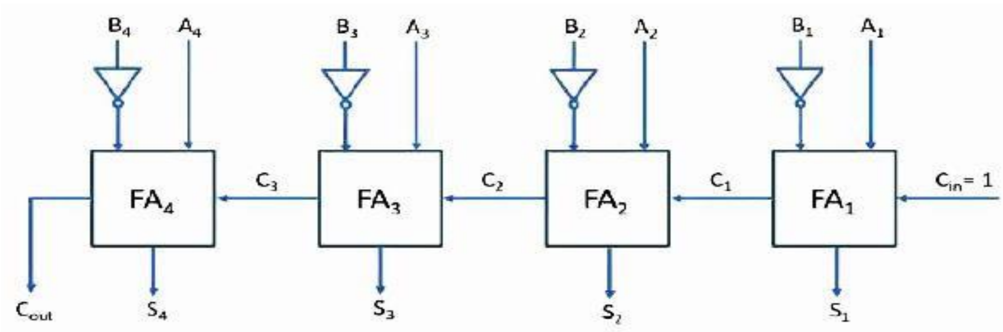
- Abinaryparalleladderisadigitalcircuitthataddstwobinarynumbersinparallelformandproducesthearithmeticsumof those numbersinparallelform.
- Itconsistsoffulladdersconnectedinachainwiththeoutputcarryfromeachfull-adderconnectedtotheinputcarryofthenextfull-adderinthechain.



- Figureshowstheinterconnectionoffourfull-adder(FA)circuitstoprovidea4-bitparalleladder.
- The augend bits of A and addend bits of B are designated by subscript numbers from right to left,withsubscript 1denotingthelower-orderbit.
- Thecarriesareconnectedin3chainthroughthe full-adders.
- TheinputcarrytotheadderisC$_{in}$andtheoutputcarryis C_4.
- TheSoutputsgeneratetherequiredsumbits.
- When the 4-bit full-adder circuit is enclosed within an IC package, it has four terminals for theaugend bits, four terminals for the addend bits, four terminals for the sum bits, and two terminalsfortheinputandoutputcarries.
- Ann-bitparalleladderrequiresn-full adders.
- Itcanbeconstructed from4-bit,2-bit,and1-bitfulladderICsbycascadingseveralpackages.
- The output carry from one package must be connected to the input carry of the one with the nexthigher-orderbits.
- The4-bitfulladderis a typicalexample ofanMSIfunction.

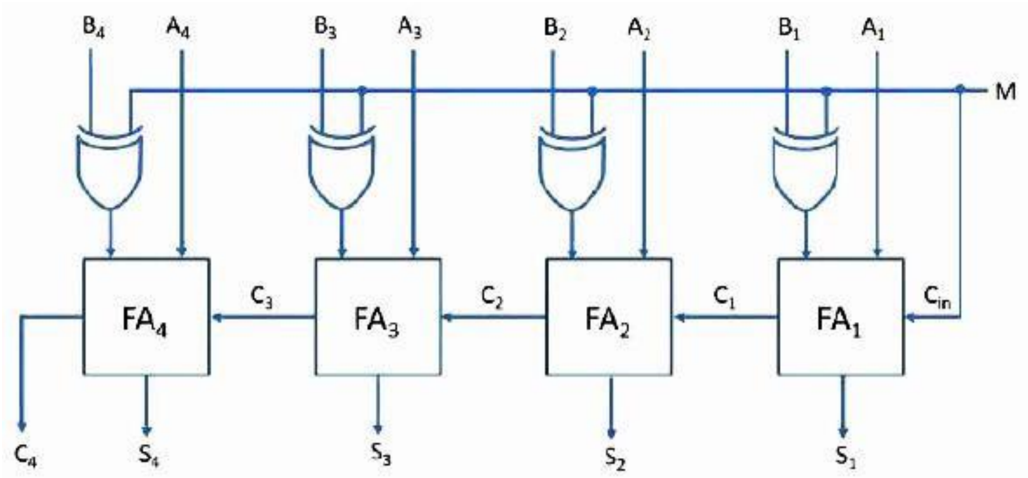
- **Binary parallelsubtractor**

- Thesubtractionofbinarynumberscanbecarriedoutmostconvenientlybymeansofcomplement.
- RememberthatthesubtractionA-Bcanbedonebytakingthe2'scomplementofBandaddingittoA.
- The2'scomplementcanbeobtainedbytakingthe1'scomplementandadding1totheleast.significantpair ofbits.
- The1'scomplement canbeimplemented withinvertersasshowninbelowfigure.



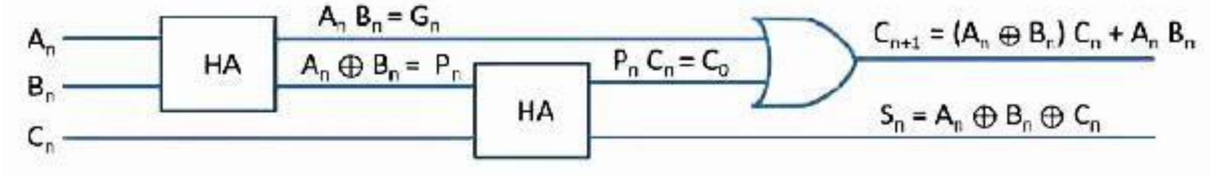
- **Binary addersubtractor**

- Figureshowsa4-bitadder-subtractorcircuit.
- Heretheadditionandsubtractionoperationsarecombinedintoonecircuitwithonecommonbinaryadder.
- ThisisdonebyincludinganX-ORgatewitheachfull-adder.
- ThemodeinputM controlstheoperation.
- WhenM= 0thecircuitisanadder,andwhenM= 1thecircuitbecomesa subtractor.
- EachX-ORgatereceivesinputMandoneofthe inputsofB.
- WhenM=0wehaveB⊕0=BThefull-adderreceivesthevalueofB,theinputcarryis0andthecircuitperforms A+B.
- WhenM=1wehaveB⊕1=B'andC_1=1TheBinputsarecomplementedanda1isadded.throughtheinputcarry.
- Thecircuitperformsthe operationA+B'+1(i.e.A-B).



- **Lookaheadcarryadder**

- Inthecaseoftheparalleladder,thespeedwithwhichanadditioncanbeperformedisgovernedbythetimerequiredfor thecarriesto propagateorripplethroughallofthestagesoftheadder.
- Thelook-ahead-carryadderspeedsupthe processbyeliminatingthisripplecarrydelay.
- Itexaminesalltheinputbitssimultaneously andalsogeneratesthecarry-inbitsforallthestagessimultaneously.
- Themethod ofspeedinguptheadditionprocessisbasedonthetwoadditionalfunctionsofthe
- full-adder, calledthe carrygenerate and carrypropagate functions.Consideronefulladderstage;saythenthstageof aparalleladder showninFigure.
- Weknowthatitismadeoftwohalf-addersandthatthehalf-addercontainsanX-ORgatetoproducethesumandanANDgatetoproducethecarry.
- IfboththebitsA$_n$andB$_n$are1s,acarryhastobegeneratedinthisstageregardlessofwhethertheinputcarryC_{in}isa0or a1.
- Thisiscalledgeneratedcarry,expressedas$G_n=A_n \cdot B_n$whichhastoappearattheoutputthroughtheORgate asshowninFigure.



- Thereis anotherpossibility ofproducing a carryout.X-OR gate insidethe half-adderattheinputproducesanintermediarysumbit-callit P_{n}whichisexpressedasPn= An⊕Bn.
- Next P_n and C_n are added using the X-OR gate inside the second half adder to produce the finalsum bit S_n = Pn⊕ C_n = A_n⊕ C_n and output carry $C_O = P_n \cdot C_n = (A_n \oplus B_n) \cdot C_n$ which becomesinputcarryfor the(n+1)thstage.
- ConsiderthecaseofbothP$_n$andC$_n$being1.TheinputcarryC$_n$hastobepropagatedtotheoutputonlyifP$_n$is1.
- IfP$_n$is0,evenifC$_n$is1,theANDgateinthesecondhalf-adder willinhibitC$_n$.
- WemaythuscallP$_n$as thepropagatedcarryasthisisassociatedwithenablingpropagationof C$_n$tothecarryoutputofthenthstagewhichisdenotedas C_{n+1}or C_{0n}.
- So,wecansaythatthecarryoutof thenthstageis1wheneitherG$_n$=1orP$_n \cdot$C$_n$=1orbothG$_n$andP$_n \cdot$C$_n$areequalto1.
- Forthefinalsumandcarryoutputsofthenthstage,wegetthefollowingBooleanexpressions.

$$S_n = P_n \oplus C_n \text{ where } P_n = A_n \oplus B_n$$

$$C_{on} = C_{n+1} = G_n + P_n C_n \quad \text{where } G_n = A_n \bullet B_n$$

- Observetherecursivenatureoftheexpressionfortheoutputcarryatthenthstagewhichbecomestheinputcarryfor the(n+1)thstage.
- Bysuccessivesubstitution,itispossibletoexpresstheoutputcarryofahighersignificantstageintermsoftheappliedinputvariables A,Bandthecarry-intotheLSBadder.
- Thecarry-intoeachstageisthecarry-outofthepreviousstage.
- Basedonthese,the expressionsforthecarry-outsofvarious fulladders areas follows:

$$C_2=G_1+P_1C_1$$

$$C_3=G_2+P_2C_2$$

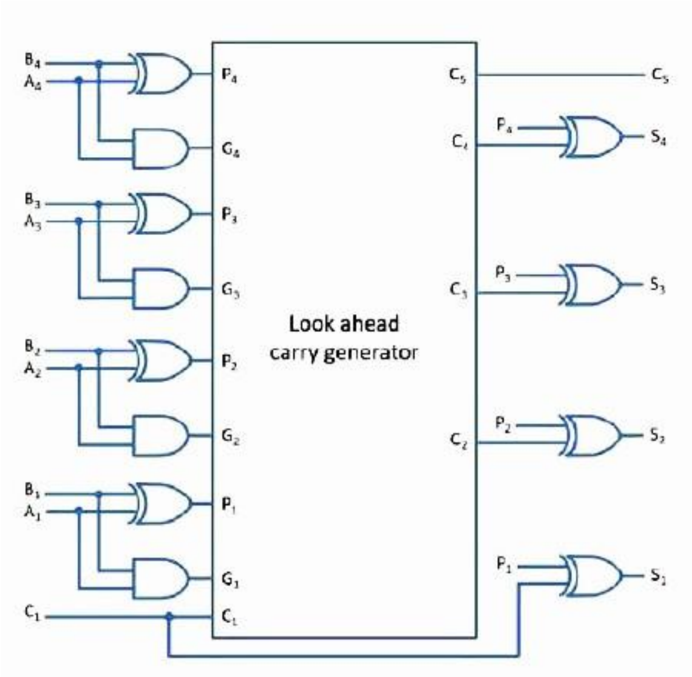
$$=G_2+P_2\left(G_1+P_1+C_1\right)$$

$$=G2+P2G1+P2P1C1$$

$$C_4=G_3+P_3C_3=G_3+P_3G_2+P_3P_2G_1+P_3P_2P_1C_1$$

$$C_5=G_4+P_4C_4=G_4+P_4G_3+P_4P_3G_2+P_4P_3P_2G_1+P_4P_3P_2P_1C_1$$

- Observethatthefinaloutputcarryisexpressedasafunctionoftheinputvariablesin SOPform,whichisatwo-levelAND-ORorequivalentNAND-NANDform.
- Toproducetheoutputcarryforanyparticularstage,itisclearthatitrequiresonlythatmuchtimerequiredfor thesignalstopassthroughtwolevelsonly.
- Hencethe circuitforlook-ahead-carryintroducesadelaycorrespondingtotwogatelevels.
- Theblockdiagramofa 4-stagelook-ahead-carryparalleladderis showninbelow figure
- Observethatthefulllook-ahead-schemerequirestheuseofORgatewith(n+1)inputsandANDgateswithnumber ofinputsvaryingfrom2to (n+ 1).



- **Binary tograyconverter**

- Theinputtothe4-bitbinarytograycodeconvertercircuitisa4-bitbinaryandtheoutputisa4-bitgraycode.
- Thereare16possiblecombinationsof4-bitbinaryinputandallofthemarevalid.The4-bitbinaryandthecorrespondinggraycodeareshowninbelowtable.

4-bit Binary				4-bit Gray			
B_4	B_3	B_2	B_1	G_4	G_3	G_2	G_1
0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	1
0	0	1	0	0	0	1	1
0	0	1	1	0	0	1	0
0	1	0	0	0	1	1	0
0	1	0	1	0	1	1	1
0	1	1	0	0	1	0	1
0	1	1	1	0	1	0	0
1	0	0	0	1	1	0	0
1	0	0	1	1	1	0	1
1	0	1	0	1	1	1	1
1	0	1	1	1	1	1	0
1	1	0	0	1	0	1	0
1	1	0	1	1	0	1	1
1	1	1	0	1	0	0	1
1	1	1	1	1	0	0	0

- Fromtheconversiontable,weobservethattheexpressionsfortheoutputsG_4,G_3,G_2,andG_1areasfollows:

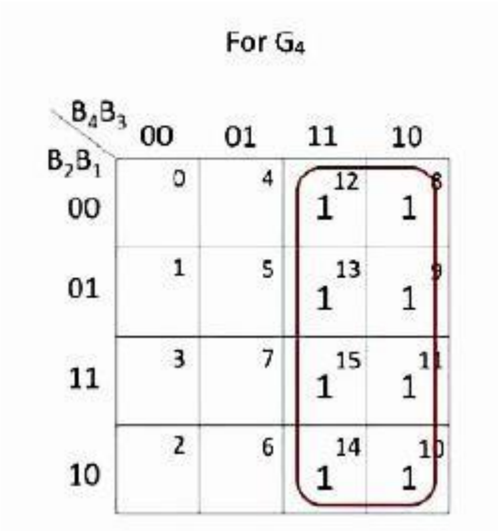
  $G_4=\sum_m(8,9,10,11,12,13,14,15)$

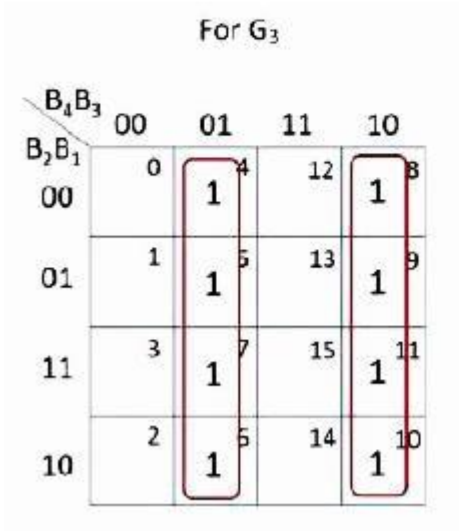
  $G_3=\sum_m(4,5,6,7,8,9,10,11)$

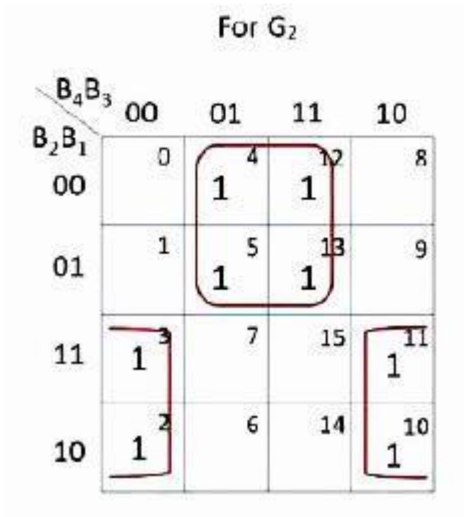
  $G_2=\sum_m(2,3,4,5,10,11,12,13)$

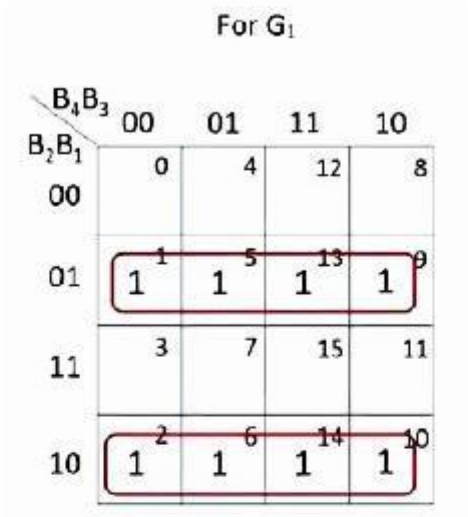
  $G_1=\sum_m(1,2,5,6,9,10,13,14)$

- TheK-maps for G_4,G_3,G_2,andG_1 andtheirminimizationareshownbelow









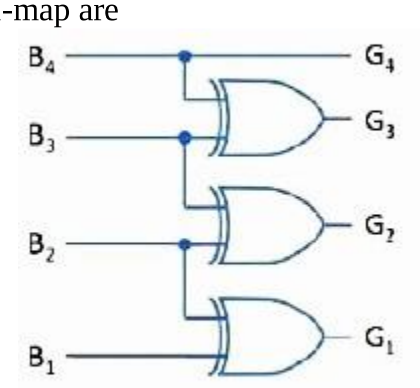
- Theminimalexpressionsfortheoutputsobtainedfromthe K-map are

$G_4=B_4$

$G_3=B_4'B_3+B_4B_3'=B_4 \oplus B_3$

$G_2=B_3'B_2+B_3B_2'=B_3\oplus B_2$

$G_1=B_2'B_1+B_2B_1'=B_2\oplus B_1$



- **BCDtoXS-3codeconverter**

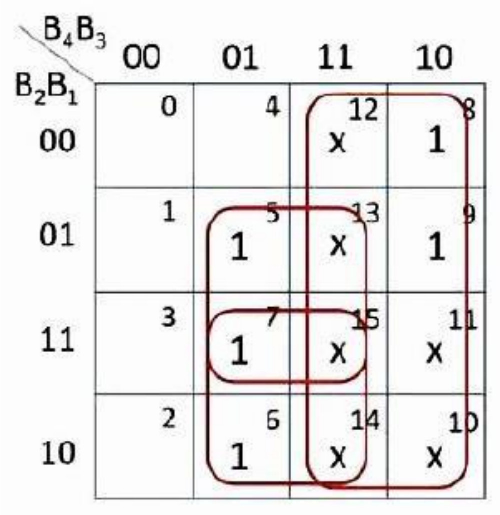
- BCDmeans8421BCD.
- The4-bitinputBCDcode(B4B3B2B1)andthecorrespondingoutputXS-3code(X4X3X2X1)numbersareshownintheconversiontableinfigure.

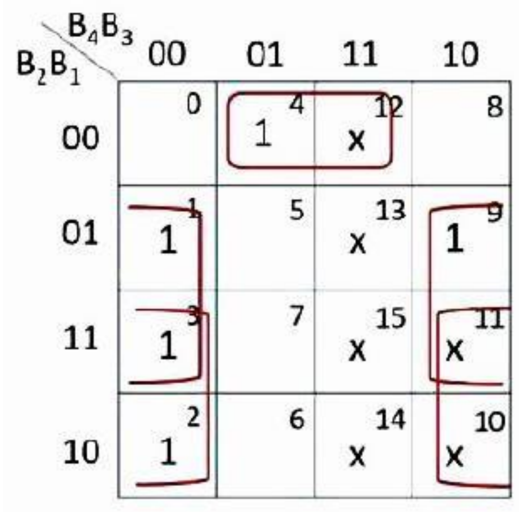
8421 code				XS-3 code			
B_4	B_3	B_2	B_1	X_4	X_3	X_2	X_1
0	0	0	0	0	0	1	1
0	0	0	1	0	1	0	0
0	0	1	0	0	1	0	1
0	0	1	1	0	1	1	0
0	1	0	0	0	1	1	1
0	1	0	1	1	0	0	0
0	1	1	0	1	0	0	1
0	1	1	1	1	0	1	0
1	0	0	0	1	0	1	1
1	0	0	1	1	1	0	0

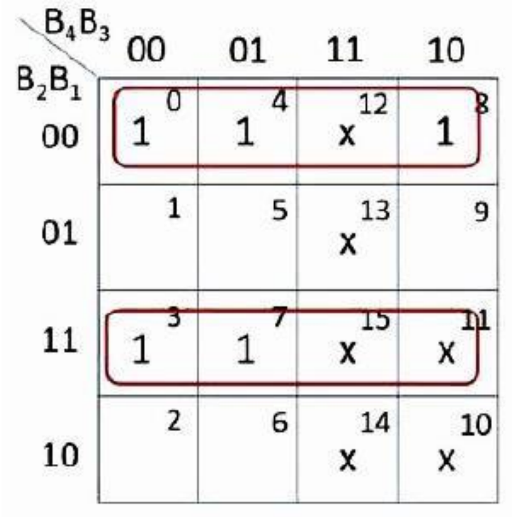
- The inputcombinations1010,1011,1100,1101,1110,and1111areinvalidinBCD.Sotheyaretreatedasdon't cares.

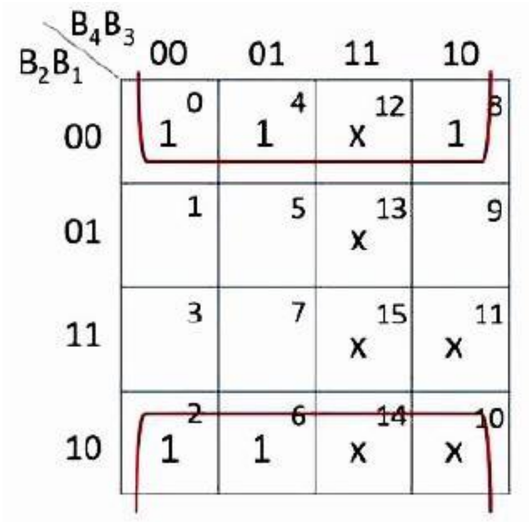
$$X_4=\sum_m(5,6,7,8,9)+d(10,11,12,13,14,15)$$
$$X_3=\sum_m(1,2,3,4,9)+d(10,11,12,13,14,15)$$
$$X_2=\sum_m(0,3,4,7,8)+d(10,11,12,13,14,15)$$
$$X_1=\sum_m(0,2,4,6,8)+d(10,11,12,13,14,15)$$

- DrawingK-mapsfortheoutputsX_4,X_3,X_2andX_1intermsoftheinputsB_4,B_3,B_2,andB_1,andsimplifyingthem,asshown









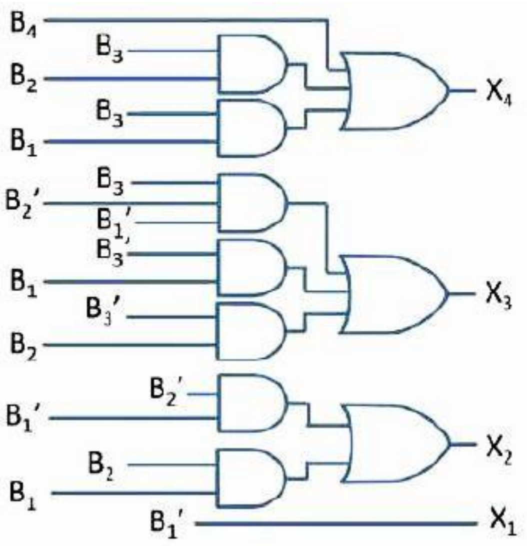
- Theminimalexpressionsare

$X_4 = B_4 + B_3B_2 + B_3B_1$

$X_3 = B_3B_2'B_1' + B_3'B_1 + B_3'B_1$

$X_2 = B_2'B_1' + B_2B_1$

$X_1 = B_1'$



- **1-bitmagnitudeComparator**

- Letthe1-bit numbersbeA=A0andB=B0
- IfA_0=1andB_0= 0thenA>B

$A>B : G=A_0B_0'$

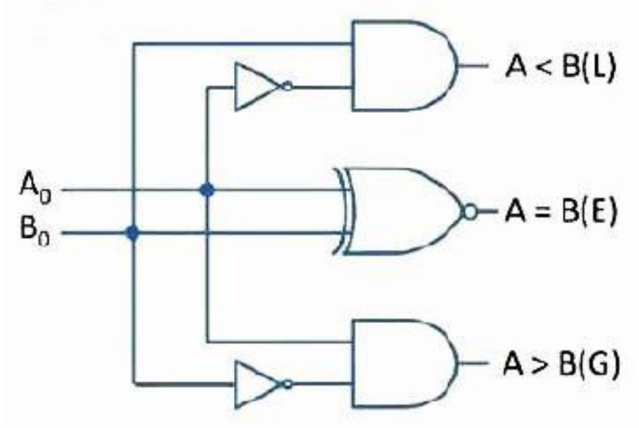
- If $A_0=0$ and $B_0=1$ then $A< B$

$A<B : L = A_0B_0$

- If A_0 =0 and B_0 = 1(coincides) then A =B

$$A=B : E = A_0 \odot B$$

A_0	B_0	L	E	G
0	0	0	1	0
0	1	1	0	0
1	0	0	0	1
1	1	0	1	0



- **2-bit magnitude Comparator**

- The logic for a 2-bit magnitude comparator: Let the two 2-bit numbers be $A=A_1A_0$ and $B=B_1B_0$.

1. If A_1 = 1 and B_1 = 0, then A>B or
2. If A_1 = 1 and B_1 coincide and A_0 = 1 and B_0 = 0 then A > B So the logic expression for A > B is

$$A>B: G=A_1B_1'+(A_1\odot B_1) A_0B_0'$$

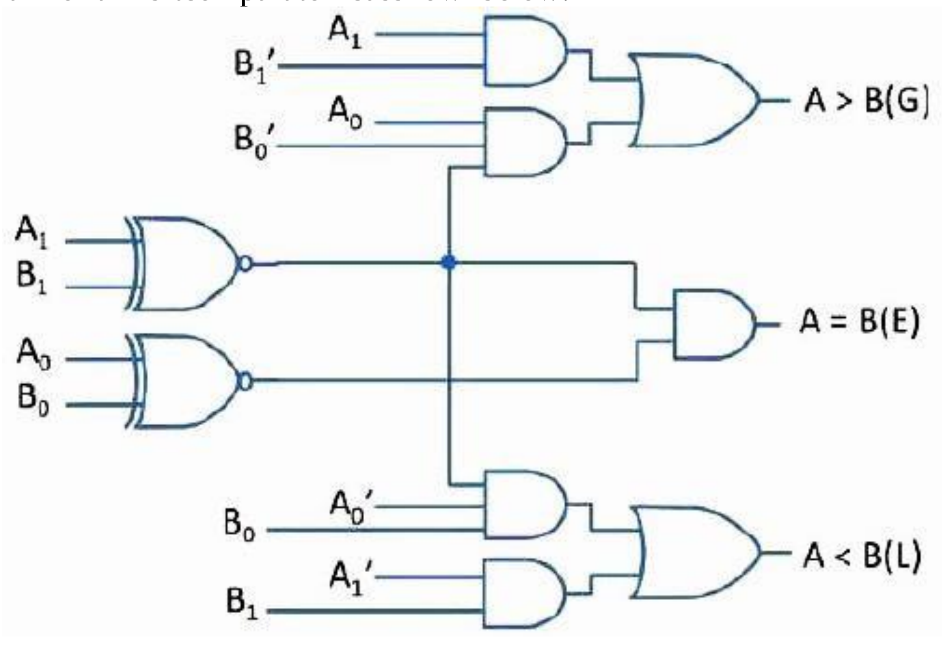
1. If A_1=0 and B_1 = 1 then A<B or
2. If A_1 and B_1 coincide and A_0 = 0 and B_0 = 1, then A<B. So the expression for A<B is

$$A<B: L=A_1'B_1 +(A_1\odot B_1) A_0'B_0$$

If A_1 and B_1 coincide and if A_0 and B_0 coincide then A = B So the expression for A = B is

$$A=B: E = (A_1\odot B_1) (A_0\odot B_0)$$

- The logic diagram for a 2-bit comparator is as shown below:



- **Parity generator**

- Exclusive-OR functions are very useful in systems requiring error detection and correction codes.
- Binary data, when transmitted and processed, is susceptible to noise that can alter its 1s to 0s and 0s to 1s.
- To detect such errors, an additional bit called the parity bit is added to the data bits and the word containing the data bits and the parity bit is transmitted.
- At the receiving end the number of 1s in the word received are counted and the error, if any, is detected.
- This parity check, however, detects only single bit errors.

- Thecircuitthatgeneratestheparitybitinthetransmitter iscalledaparitygenerator.
- Thecircuitthatcheckstheparityinthereceiveriscalledaparitychecker.
- Aparitybit,a0ora1is attachedtothedatabits suchthatthetotalnumberof1sinthewordis
- evenforevenparityand oddforoddparity.
- Theparitybitcanbeattachedtothecodegroupeitheratthebeginningorattheenddepending
- onsystemdesign.
- Agivensystemoperates witheitherevenoroddparitybutnotboth.

- So,awordalwayscontainseitheranevenoranoddnumberof1s.
- At the receiving end, if the word received has an even number of 1s in the odd parity system oranoddnumberof1sintheevenparitysystem,itimpliesthatan error hasoccurred.
- In order to check or generate the proper parity bit in a given code word, the basic principle usedis, "themodulosum of an even number of 1s is always a 0 and the modulosum of an oddnumberof1sisalwaysa1".
- Therefore,inordertocheckfor an error,allthebitsinthereceivedwordareadded.
- If the modulo sum is a 0 for an odd parity system or a 1 for an even parity system, an error isdetected.

Example- 1 Design3-bitparitygeneratorusingevenparitybit.

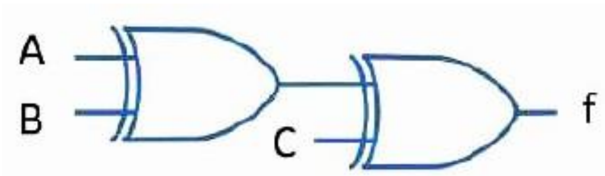
Inputs			Outputs parity bit (f)
A	B	C	
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	1

$f = A'B'C + A'BC' + ABC + AB'C'$

$f = A'(B'C + BC') + A(BC + B'C')$

$f = A'(B \oplus C) + A(B \oplus C)'$

$f = A \oplus B \oplus C$



- **Demultiplexer**

- Amultiplexertakesseveralinputsandtransmitsoneofthemtotheoutput.
- Ademultiplexerperformsthereverseoperation;ittakesasingleinputanddistributesitoverseveraloutputs.
- So,ademultiplexercanbethoughtofasa‘distributor’,sinceittransmitsthesamedatatodifferentdestinations.
- Thus,whereasamultiplexerisanN-to-1device,demultiplexerisa1-to-Ndevice.
- Consideraninteger‘m’, whichisconstrainedbythefollowingrelation:

$m = 2^n$, where m and n are both

integers.A**1-to-m**Demultiplexer has

One Input: D

m Outputs: $O_0, O_1, O_2, \ldots O_{(m-1)}$

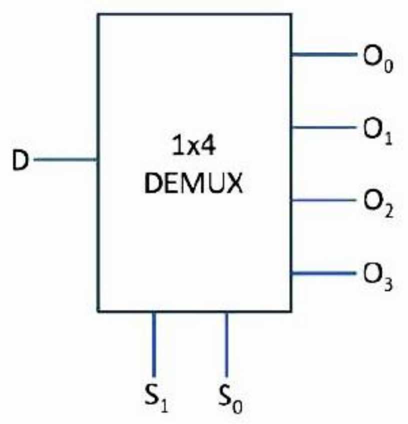
n Control inputs: $S_0, S_1, S_2, \ldots S_{(n-1)}$

One(or more)Enableinput(s)

- SuchthatD maybetransfertooneoftheoutputs,dependinguponthe controlinputs.

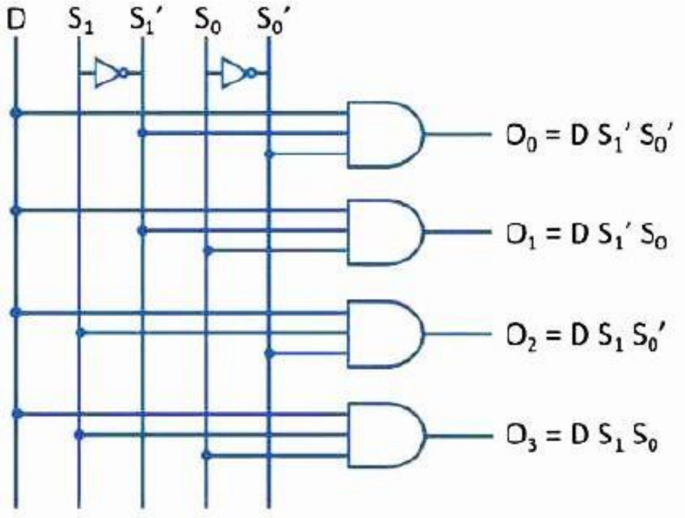
- **1×4Demultiplexer**

- Theblockdiagramandtruthtableof1×4demultiplexerisasfollows.



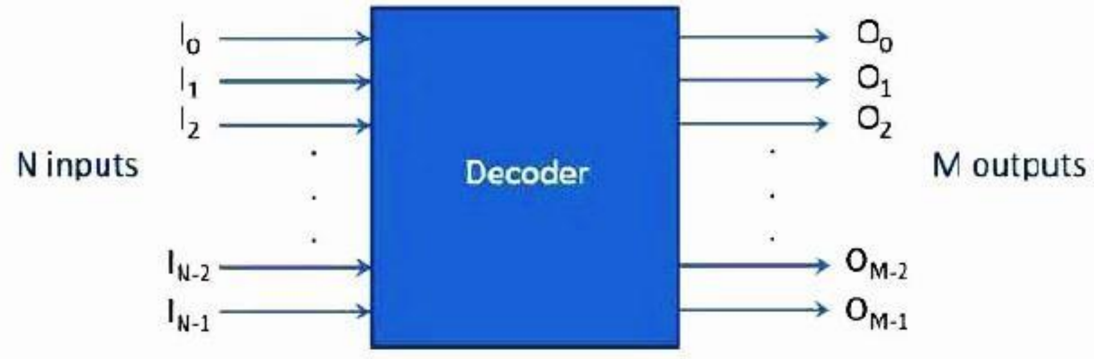
Select code		Outputs			
S_1	S_0	O_3	O_2	O_1	O_0
0	0	0	0	0	D
0	1	0	0	D	0
1	0	0	D	0	0
1	1	D	0	0	0

- Thefollowing figuredescribesthelogiccircuit for1 ×4demultiplexer.



- **Decoder**

- AdecoderisalogiccircuitthatconvertsanN-bitbinaryinputcodeintoMoutputlinessuchthatonlyoneoutputlineisactivatedfor eachoneofthepossiblecombinationsofinputs.
- Inotherwords,wecansaythatadecoderidentifiesorrecognizesor detectsaparticularcode.



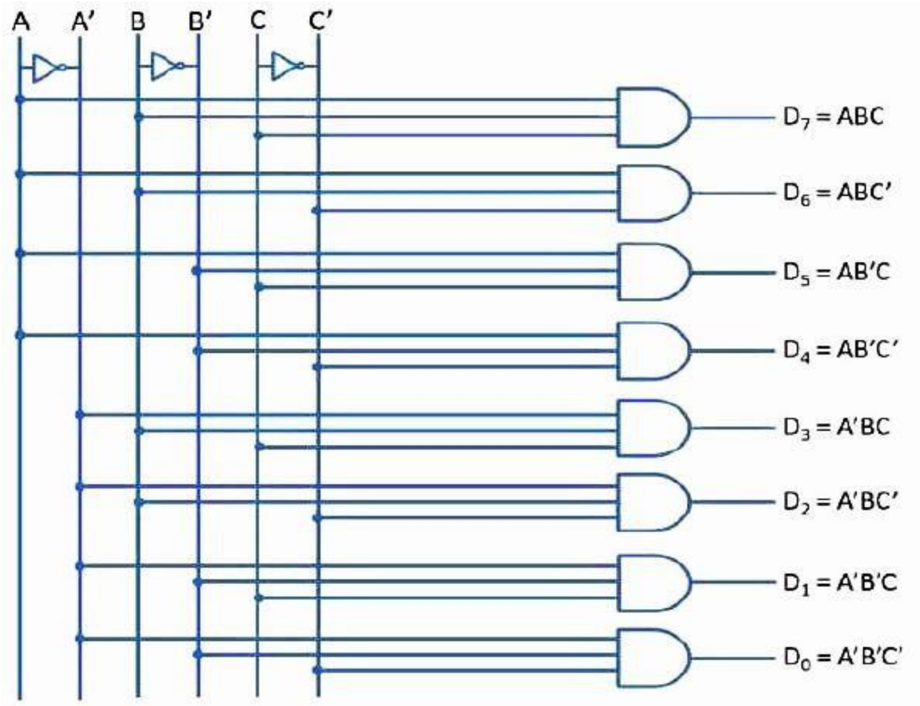
- Figureshowsthegeneraldecoder diagramwithNinputsand Moutputs.
- Sinceeachofthe Ninputscanbea0or a1,there2possibleinputcombinationsorcodes.
- Foreachoftheseinputcombinations,onlyoneoftheMoutputswillbeactive,alltheotheroutputswillremaininactive.

  - **3to8Decoder**

- Figureshowsthecircuitryforadecoderwiththree inputsandeightoutputs.
- ItusesallANDgates,andtherefore,theoutputsareactive-HIGH.Foractive-LOWoutputs,NANDgatesareused
- Thetruthtableofthe decoderisshownbelow

Inputs			Outputs							
A	B	C	D_0 A'B'C'	D_1 A'B'C	D_2 A'BC'	D_3 A'BC	D_4 AB'C'	D_5 AB'C	D_6 ABC'	D_7 ABC
0	0	0	1	0	0	0	0	0	0	0
0	0	1	0	1	0	0	0	0	0	0
0	1	0	0	0	1	0	0	0	0	0
0	1	1	0	0	0	1	0	0	0	0
1	0	0	0	0	0	0	1	0	0	0
1	0	1	0	0	0	0	0	1	0	0
1	1	0	0	0	0	0	0	0	1	0
1	1	1	0	0	0	0	0	0	0	1

- Thisdecodercanbereferredtoinseveralways.
- Itcanbecalleda3-lineto8-linedecoderbecauseithasthreelinesandeightoutput lines.
- Itisalsocalledabinarytooctaldecoderbecauseittakesa3 bitbinaryinputcodeandactivates.
- oneoftheeight(octal)outputscorrespondingtothatcode.
- Itisalsoreferredtoasa1-of-8decoderbecauseonlyoneoftheeightoutputsisactivatedatonetime.



- **Priority encoder**

- Apriorityencoderisalogiccircuitthatrespondstojustoneinputinaccordancewithsomeprioritysystem,amongallthosethatmaybesimultaneouslyHIGH.
- Themostcommonprioritysystemisbasedontherelativemagnitudesoftheinputs;whicheverdecimalinputisthelargest,istheonethatisencoded.
- Thetruthtableof4-inputpriorityencoderandexpressionaregivenbelow:

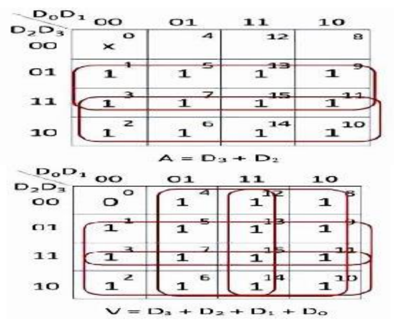
Inputs				Outputs		
D_0	D_1	D_2	D_3	A	B	V
0	0	0	0	x	x	0
1	0	0	0	0	0	1
x	1	0	0	0	1	1
x	x	1	0	1	0	1
x	x	x	1	1	1	1

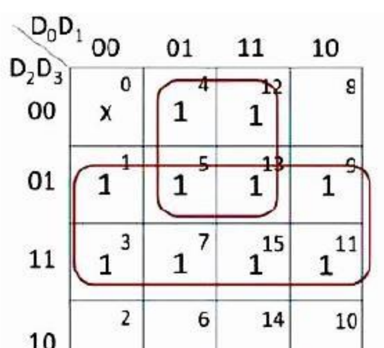
$A=\sum_m(1,2,3,5,6,7,9,10,11,13,14,15)$

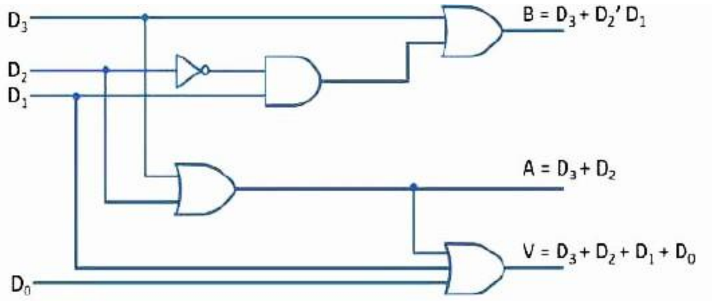
$B=\sum_m(1,3,4,5,7,9,11,12,13,15)$

$V=\sum_m(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15)$

- InadditiontotheoutputsAandB,thecircuithasathirdoutputdesignatedbyV.
- Thisisavalidbitindicator thatissetto1whenoneormoreinputsareequalto1.
- Ifallinputsare0,thereisnovalidinputandVisequalto0,thetwootheroutputsarenotinspected whenVequals0andarespecifiedasdon'tcareconditions.
- Accordingtothetruthtable,thehigherthesubscriptnumber,thehigherthepriorityoftheinput.TheK-mapforA,BandVwithminimizedexpressionareshownbelow:







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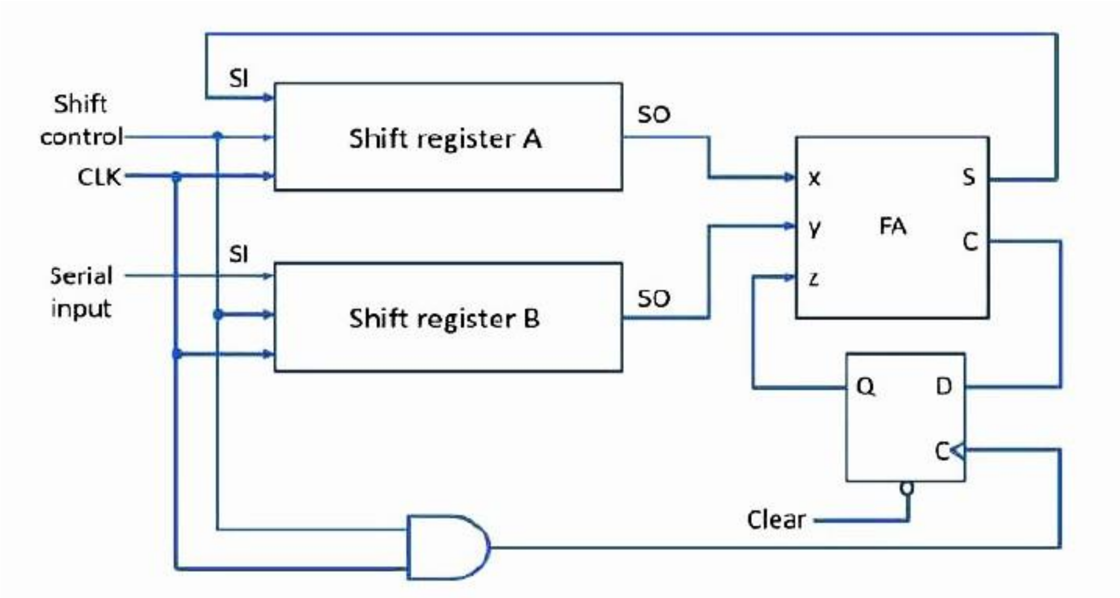
-
- **Serialadder**

- Aserialudder isusedtoaddbinarynumbersinserialform.
- Thetwobinarynumbers tobeaddedseriallyarestoredintwo shiftregistersAand B.
- Bitsareaddedonepairatatimethroughasinglefulladder(FA)circuitasshowninFigure.
- Thecarryoutofthefull-adderistransferredtoaDflipflop.
- Theoutputofthisflip-flopisthenusedasthe carryinputforthenextpairofsignificantbits.
- ThesumbitfromtheSoutputofthefulladdercouldbetransferredtoathirdshiftregister.
- ByshiftingthesumintoAwhile,thebitsofAareshiftedout,itispossibletouseoneregisterforstoringbothaugendandthesumbits.
- TheserialinputregisterBcanbeusedtotransferanewbinary numberwhiletheaddendbitsareshiftedoutduringtheaddition.
- Theoperationoftheserialadderisas follows.
- Initially register A holds the augend, register B holds the addend and the carry flip-flop is clearedto0.Theoutputs(SO) ofAandBprovideapairofsignificantbitsforthefull-adder atxandy
- Theshiftcontrolenablesbothregistersandcarryflipflop,so,attheclockpulsebothregistersare shifted once to the right, the sum bit from S enters the left most flip-flop of A, and the outputcarryistransferredintoflip-flopQ.
- The shift control enables the registers for a number of clock pulses equal to the number of bits oftheregisters.
- Foreachsucceedingclockpulseanewsumbitistransferredto A,anewcarryistransferredtoQ,andbothregistersareshiftedoncetotheright.
- Thisprocesscontinues untiltheshiftcontrolis disabled.
- Thus, the addition is accomplished by passing each pair of bits together with the previous carrythroughasinglefulladdercircuitandtransferringthesum,onebitatatime,intoregisterA.



- Initially,registerAandthecarryflip-flopareclearedto0andthenthefirstnumberisaddedfrom B. While B is shifted through the full adder, a second number is transferred to it through itsserialinput.
- The second number is then added to the content of register A while a third number is transferredseriallyintoregisterB.
- This can be repeated to form the addition of two, three, or more numbers and accumulate theirsuminregisterA.

SWARRNIM START UP AND INNOVATION UNIVERSITY

NAME OF INSTITUTE: - SWARRNIM INSTITUTE OF TECHNOLOGY, GANDHINAGAR
NAME OF COURSE:-

Mechanical engineering

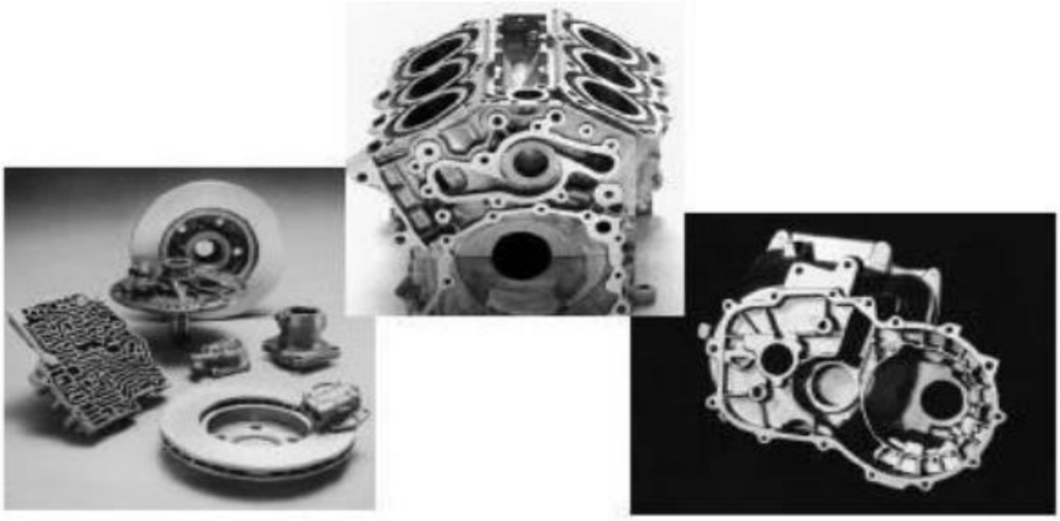
ManufacturingProcesses:

Casting processes: Moulding materials and their requirements; Patterns: Types and various patternmaterials. Variouscastingmethods,viz., sandcasting investment casting, pressuredie casting, centrifugal casting, continuous casting, thin roll casting; Mould design; Casting defects and their remedies.

Steps: - Making mould cavity - Material is first liquefied by properly heating it in a suitable furnace. - Liquid is poured into a prepared mould cavity - allowed to solidify - product is taken out of the mould cavity, trimmed and made to shape

Weshouldconcentrateonthefollowingforsuccessfulcastingoperation:

(i)Preparation of moulds of patterns (ii)Melting and pouring of the liquefied metal (iii)Solidification and further cooling to room temperature (iv)Defects and inspection



Advantages • Molten material can flow into very small sections so that intricate shapes can be made by this process. As a result, many other operations, such as machining, forging, and welding, can be minimized.

• Possibletocastpracticallyanymaterial:ferrousornon-ferrous.

• Thenecessarytoolsrequiredforcastingmouldsareverysimpleandinexpensive.Asa result, for production of a small lot, it is the ideal process.

• There are certain parts (like turbine blades)made from metals and alloys thatcan only beprocessed this way. Turbine blades: Fully casting + last machining.

• Sizeandweightoftheproductis notalimitationforthecasting process.

Limitations

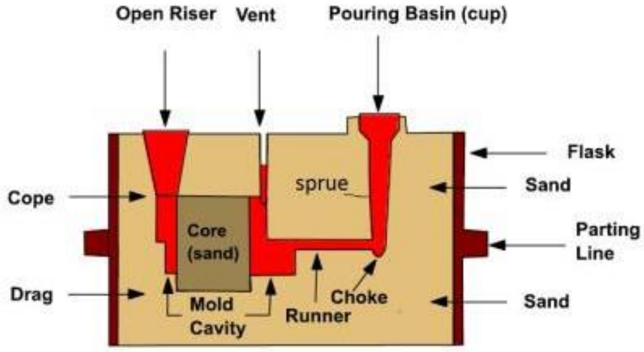
• Dimensionalaccuracyand surface finishofthe castings made by sand casting processes are a limitation to this technique.

• Many new casting processes have been developed which can take into consideration the aspects of dimensional accuracy and surface finish. Some of these processes are die casting process, investment casting process, vacuum-sealed moulding process, and shell moulding process.

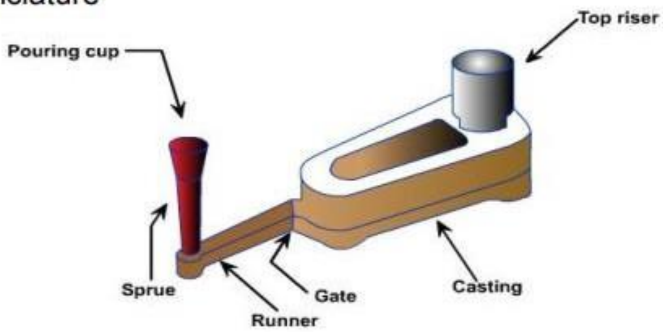
• Metalcastingisalabourintensiveprocess

• Automation:

Typical sand mould

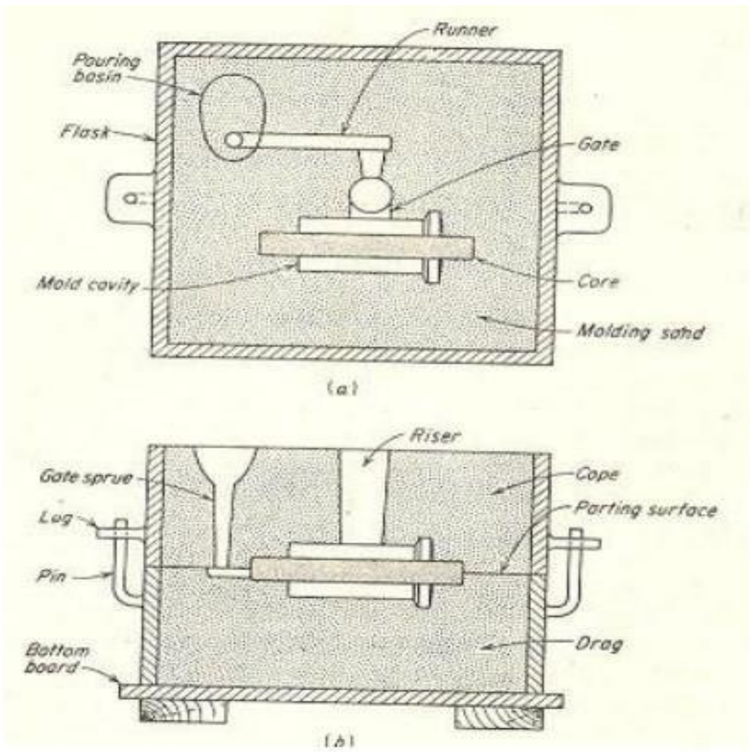


Mould Section and casting nomenclature



NPTEL course on Manufacturing processes – I, Pradeep Kumar et al.

pattern attached with gating and risering system



Mould Section and casting nomenclature, (a) top view, (b) front view

Flask: A metal or wood frame, without fixed top or bottom, in which the mould is formed. Dependinguponthepositionofthe flask inthe mouldingstructure, it isreferredto byvarious names such as drag – lower moulding flask, cope – upper moulding flask, cheek – intermediate moulding flask used in three piece moulding.

Pattern: It is the replica of the final object to be made. The mould cavity is made with the help of pattern.

Parting line: This is the dividing line between the two moulding flasks that makes up the mould.

Moulding sand: Sand, which binds strongly without losing its permeability to air or gases. Itis a mixture of silica sand, clay, and moisture in appropriate proportions.

Facing sand: The small amount of carbonaceous material sprinkled on the inner surface of the mould cavity to give a better surface finish to the castings.

Core: A separate part of the mould, made of sand and generally baked, which is used to create openings and various shaped cavities in the castings.

Pouring basin: A small funnel shaped cavity at the top of the mould into which the molten metal is poured.

Sprue: The passage through which the molten metal, from the pouring basin, reaches the mould cavity. In manycases it controls the flow of metal into the mould.

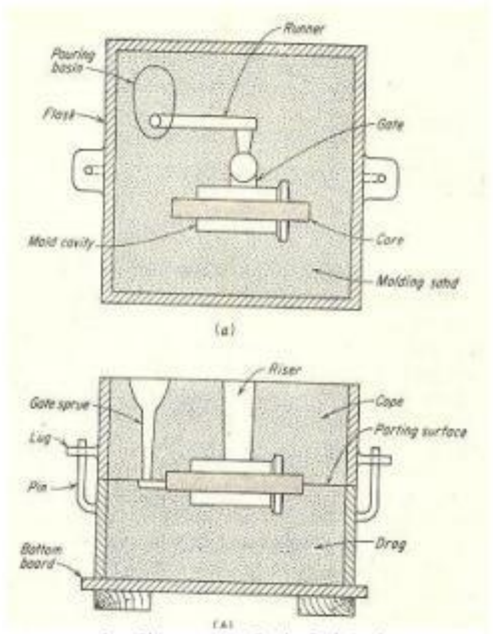
Runner: Thechannelthroughwhichthemolten metaliscarriedfromthesprueto the gate.

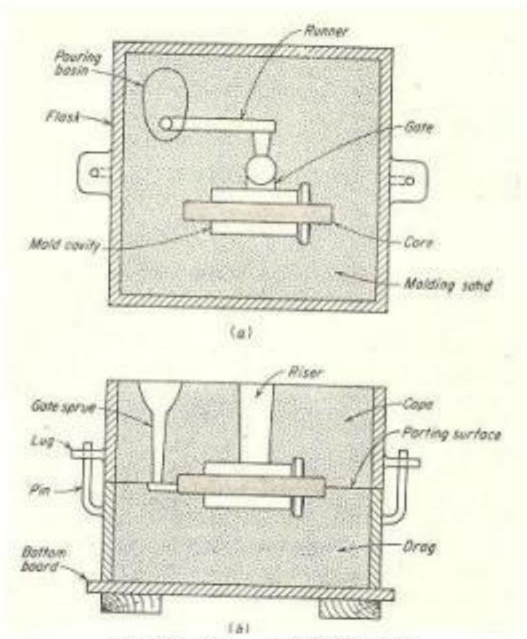
Gate: Achannelthroughwhichthemolten metalentersthemouldcavity.

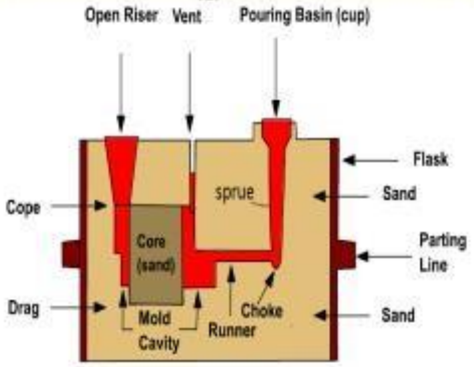
Chaplets: Chaplets are used to support the cores inside themould cavity to take care of itsown weight and overcome the metallostatic force.

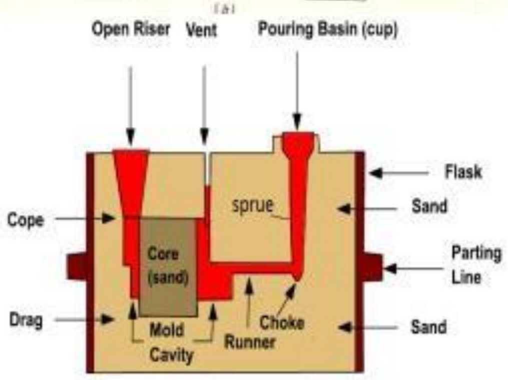
Riser:A column of molten metal placedin the mould tofeed the castings asitshrinks and solidifies. Also known as “feed head”.

Vent:Smallopeninginthemouldtofacilitateescapeofairand gases.



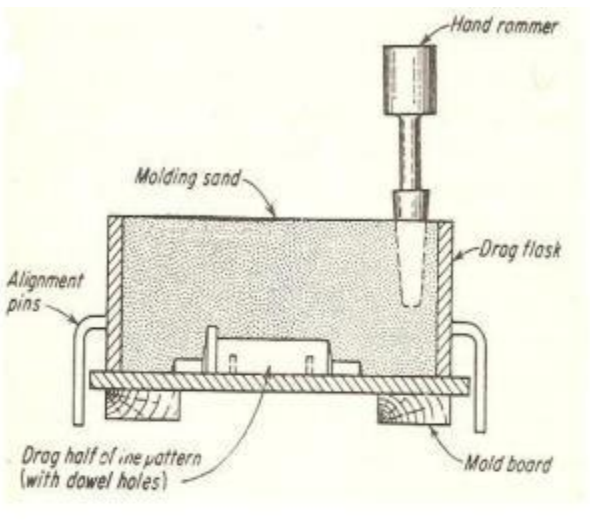






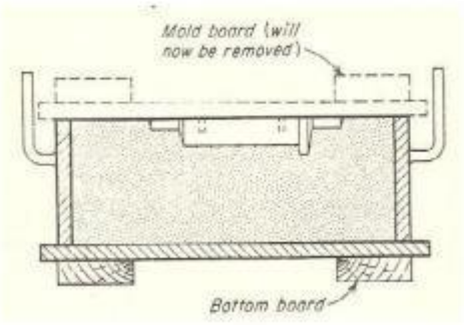
Makingasimplesandmould

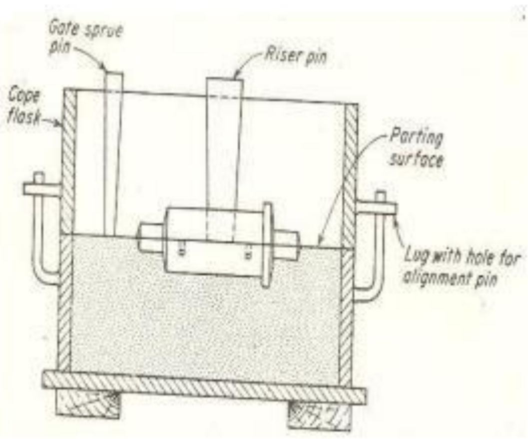
1) Thedragflaskisplacedontheboard
2) Dryfacingsandissprinkledovertheboard
3) Draghalfofthe patternis locatedonthe mould board. Dryfacing sand willprovide a non-sticky layer.
4) Molding sandis then poured in tocover the pattern with thefingers and then thedragis filled completely



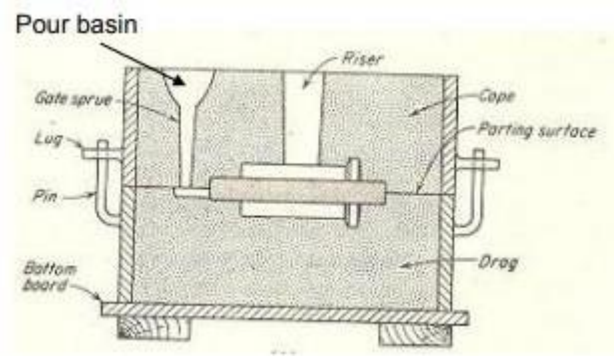
5) Sand is then tightly packed in the drag by means of hand rammers. Peen hammers (usedfirst close to drag pattern) and butt hammers (used for surface ramming) are used.

6) The ramming must be properi.e. it must neither betoo hardor soft.Too soft ramming will generate weak mould and imprint ofthe pattern will not be good. Too hard ramming will not allow gases/air to escape and hence bubbles are created in casting resulting in defects called ‘blows’. Moreover, the making of runners and gates will be difficult.
7) After the ramming is finished, the excess sand is leveled/removed with a straight bar known as strike rod.





8) Vent holes are made in the drag to the full depth of the flask as well as to the pattern to facilitate the removal of gases during pouring and solidification. Done by vent rod.
9) Thefinisheddragflaskisnowmadeupsidedownexposingthepattern.
10) Cope half of the pattern is then placed on the drag pattern using locating pins. The cope flask is also located with the help of pins. The dry parting sand is sprinkled all over the drag surface and on the pattern.
11) A sprue pin for making the sprue passage is located at some distance from the pattern edge. Riser pin is placed at an appropriate place.
12) Filling,rammingandventingofthecopeisdoneinthesamemanner.



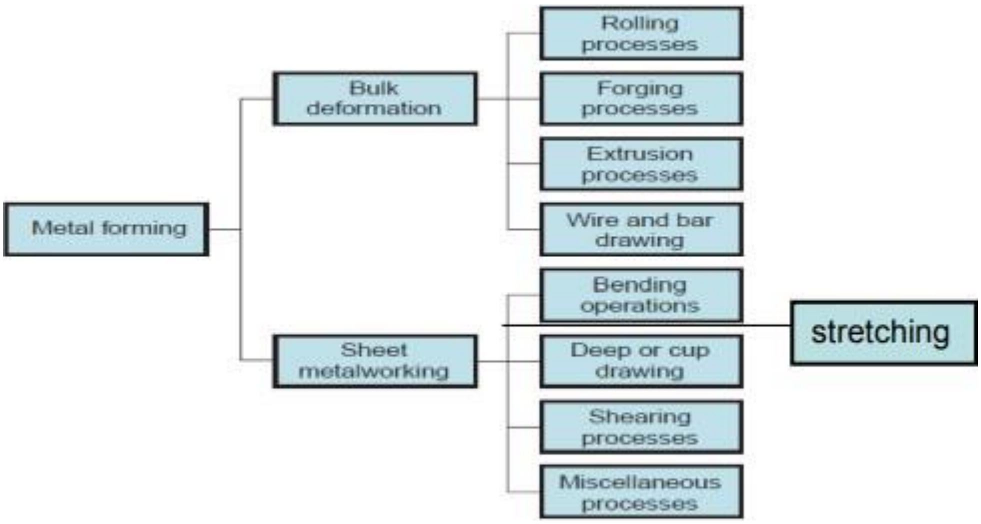
13) The sprue and riser are removed and a pouring basin is made at the topto pour the liquid metal. 14) Pattern from the cope and drag is removed.
15) Runnersandgatesaremade bycuttingthepartingsurfacewithagatecutter. Agatecutter is a piece of sheet metal bent to the desired radius.
16) The core for making a centralhole is now placed into the mould cavityin the drag. Rests in core prints.
17) Mould isnowassembledandreadyfor pouring.

Metalformingprocesses: Variousmetalformingtechniquesandtheiranalysis, viz.,forging, rolling, extrusion, wire drawing, sheet metal working, spinning, swaging, thread rolling; Super plastic deformation; Metal forming defects.

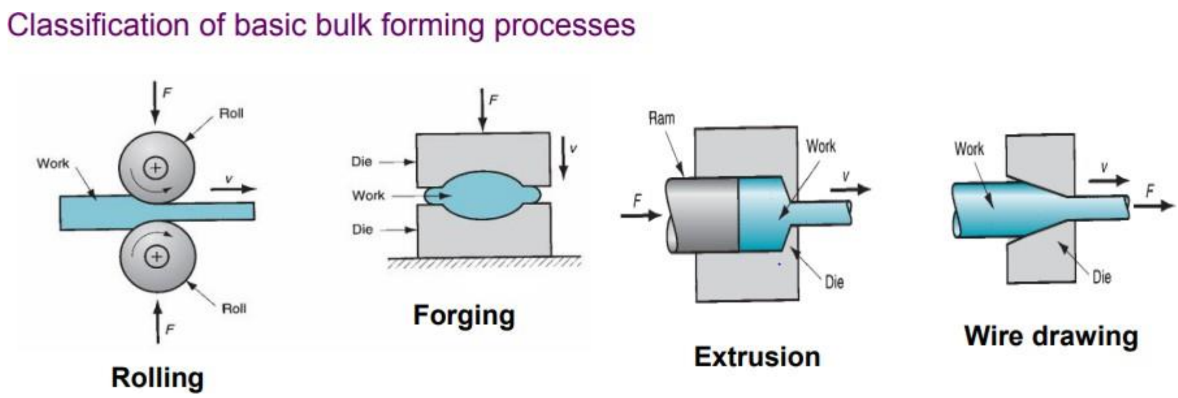
Metal forming: Large set of manufacturing processes in which the material is deformed plastically to take the shape of the die geometry. The tools used for such deformation are called die, punch etc. depending on the type of process.

Plasticdeformation:Stressesbeyond yieldstrengthoftheworkpiece materialisrequired.

Categories: Bulk metal forming, Sheet metal forming



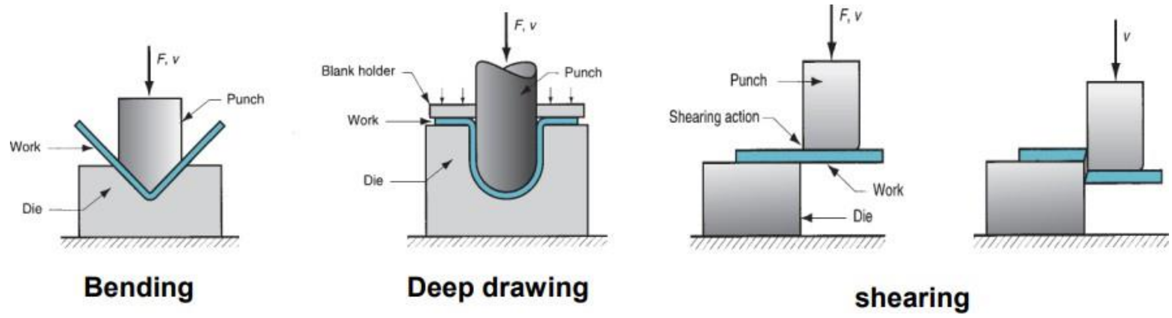
Generalclassification ofmetalforming processes



Rolling: In this process, the workpiece in the form of slab or plate is compressed betweentworotatingrolls inthethicknessdirection, sothatthethickness isreduced. Therotatingrolls draw the slab into the gap and compresses it. The finalproduct is in the formof sheet.

Forging: The workpiece is compressed between two dies containing shaped contours. Thedie shapes are imparted into the final part.

Extrusion: In this, the workpiece is compressed or pushed into the die opening to take the shape of the die hole as its cross section. Wire or rod drawing: similar to extrusion, except that the workpiece is pulled through the die opening to take the cross-section.

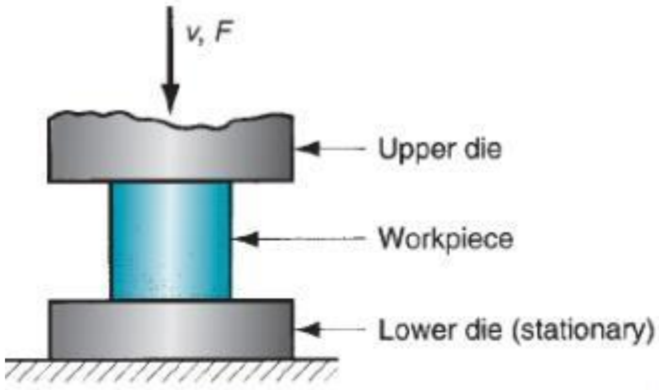


Sheet forming: Sheet metal forming involves forming and cutting operations performed on metal sheets, strips, and coils. The surface area-to-volume ratio of the starting metal is relatively high. Tools include punch, die that are used to deform the sheets.

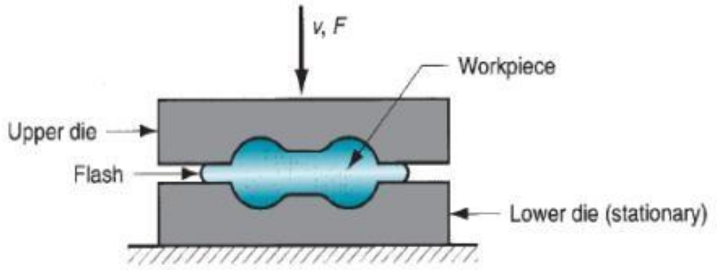
Bending: In this, the sheet material is strained by punch to give a bend shape (angle shape) usually in a straight axis.
Deep (or cup) drawing: In this operation, forming of a flat metal sheet into a hollow or concave shape like a cup, is performed by stretching the metal in some regions. A blank- holder isused to clamp the blank onthe die, while the punchpushes intothe sheet metal. The sheet is drawn into the die hole taking the shape of the cavity.
Shearing: This isnothingbutcuttingofsheetsbyshearingaction.

Bulkformingprocesses:

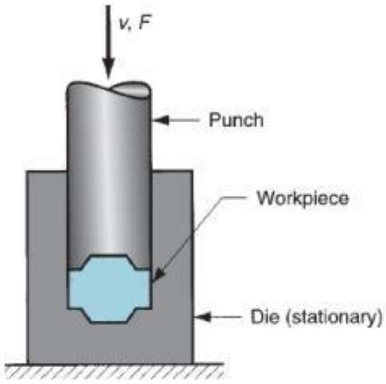
Forging:
It is a deformation process in which the work piece is compressed between two dies,usingeither impact load or hydraulic load (or gradual load) to deform it.
• It is used to make a variety of high-strength components for automotive, aerospace, and other applications. The components include engine crankshafts, connecting rods, gears, aircraft structural components, jet engine turbine parts etc.
Categorybasedontemperature:cold,warm, hot forging
Category based on presses:impactload => forging hammer; gradual pressure => forging press
Categorybasedontypeofforming: Opendieforging,impressiondieforging,flashless forging.



Inopendie forging,theworkpiece is compressed betweentwo flat platens or dies, thus allowing the metalto flow without any restriction in the sideward direction relative to the die surfaces.



impression die forging



flashless forging

In impression die forging, the die surfaces contain a shape that is given to the work piece during compression, thus restricting the metal flow significantly. There is some extra deformed material outside the die impression which is called as flash. This will be trimmed off later.

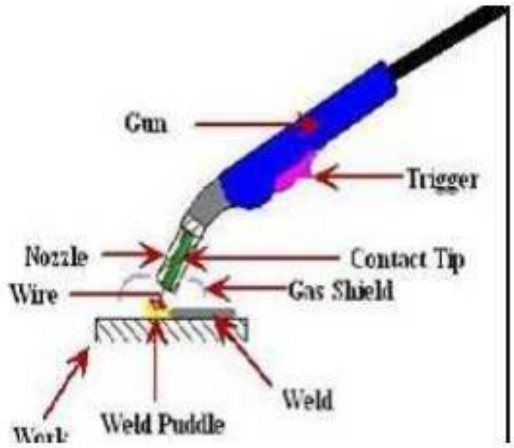
In flashless forging, the work piece is fullyrestricted within the die and no flash is produced. The amount of initial work piece used must be controlled accurately so that it matches the volume of the die cavity.

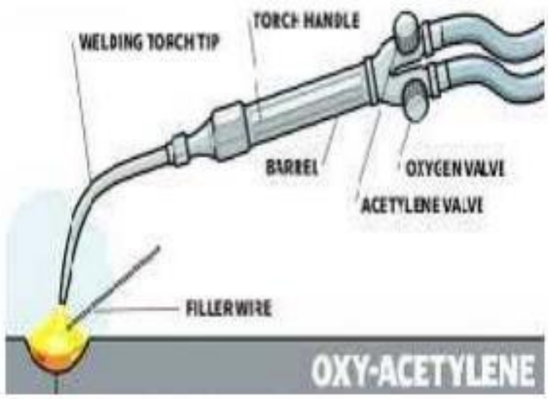
Metal joining processes: brazing, soldering, welding; Solid state welding methods; resistance welding; arc welding; submerged arc welding; inert gas welding; Welding defects, inspection.

WELDING

Welding: The process of joining similar metals by the application of heat is called "Welding". Welding can be obtained with or without application of pressure and with or without addition of filler metal which is known as 'electrode'.

Classification of welding process: 1. Fusion welding 2. Plastic welding. Fusion welding:The metalat the joint is heated to a moltenstate and then it is allowed to solidify. Pressure is not applieddduringtheprocessand hence it iscalled"nonpressurewelding". Filler materialis required for thiswelding. Plasticwelding: The metalpartsareheatedto aplastic stateand are pressed together to make the joint. It is called as "pressure welding". No filler material is required.
TYPES OF WELDING: Thermit welding Fusion welding ---- Arc welding ------ Submerged,Plasma,Automic hydrogen,MIG, Metal, Carbon, Electro slag WELDING.
Gas welding ------ Oxyacetylene, Oxyhydrogen Plastic welding ---- Explosive welding Ultrasonic welding Electric resistance—Butt, Spot, Seam, Projection,Percusion Friction welding Forge welding.





GASWELDING:

1.Oxy – acetylene welding 2) Oxy – hydrogen welding 3) Air – hydrogen Oxy acetylene Welding: The edges of the metal to welded are melted by using a gas flame. No pressure is applied. The flame is produced at the tip of the welding torch. The welding heat is obtainedby a mixture of oxygen and combustible gas. The gases are mixed in the required proportion in a welding torch which provides control for the welding flame. The gases used are acetylene, hydrogen, propane and butane. Common gas is oxy acetylene. The flame only melts the metal and additional metal to the weld is supplied by filler rod. A flux is usedduring welding to prevent oxidation and to remove impurities. Metal 2 mm to 50 mm thick are welded. The temperature of the flame is about 3200 oC. There are two types of oxy acetylene systems, one is High pressure and the other is Low pressure system.

GAS WELDING EQUIPMENTS: 1) Gas cylinders: Oxygen in Black colour, Acetylene in maroon colour. 2) Pressure regulators: Each cylinder is fitted with pressure regulator. It is used to controlthe working pressure ofthe gases. Oxygen0.7to 2.8kg/cm2 Ace 0.07to 1.03 kg/cm2
3) Pressure gauges: Each cylinder is fitted with two pressure gauges. One is for cylinder pressure and the other one is working pressure pressure for welding.
4) Hoses: Each cylinder is connected to the torch through two long hoses. It should be flexible, strong, and light. Oxygen is fitted with black colour and Ace in red colour.
5) Welding torch: Oxygenand ace enters thetorchthroughthe hose is separate passage. Both the gases are mixed in the mixing chamber of the torch. When it is ignited a flame will be produced at the tip of the torch called nozzle. Two control valves are used to control the quantityof oxygen and ace to adjust the flame.The nozzles are made of copper and available in different sizes depending upon the type of metal to be welded.
6) Goggles:Itisusedtheprotecteyes fromtheflameheat, ultravioletandinfrared rays.
7) Welding gloves: It is used to protect hand from the injury by heat and metal splashes. 8) Spark lighter: It is an igniter to start the burning of the oxy ace gases. 9) Wire brush: It isused to clean the weld joint before and after welding.

ARC WELDING: The heat isdeveloped byanelectricarc. Thearc isproducedbetweenand electrode and the work. It is a process of joining two metals by melting their edges by an electric arc. The electricalenergy is converted to heat energy. The gap between the electrode and the work is 3mm. The current is passed through the workpiece and the electrode to produce an electric arc. The workpiece is melted bythe arc. The electrode is also melted and hence both the workpieces becomes a single piece without applying any external pressure. The temperature of the arc is 5000 to 6000 o C. A transformer or generator is used for supplying the current. The depth to which the metal is melted and deposited is called Depthof fusion. To obtain better depthof fusion the electrode is kept at 70o inclination to vertical.

COMPARISION OF ARC WELDING AND GAS WELDING:

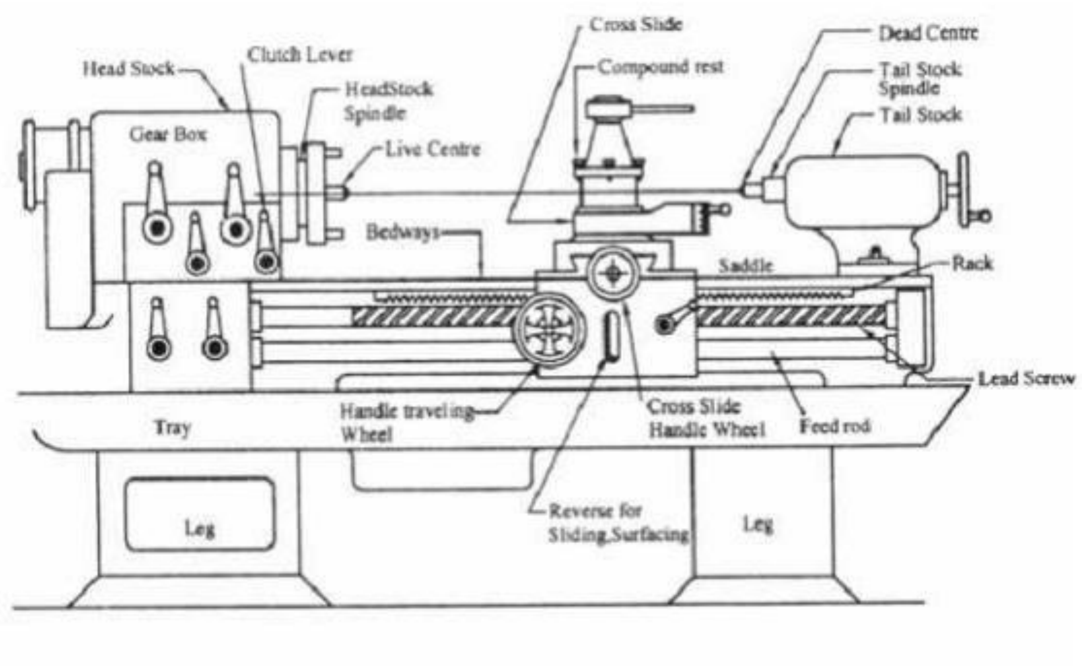
Arc welding	Gas welding
Heat is produced by electric arc	Heat is produced by the gas flame
The arc temperature is about 4000°C	The flame temperature is about 3200°C
Filler rod is used as electrode	Filler rod is introduced separately
It is suitable for medium and thick work	It is suitable for thin work
Arc weld joints have very high strength	Gas weld joints do not have much

SOLDERING: Soldering is a processofjoining two metalpartswitha third metal. Thethird metalhasaverylow meltingpoint. Itisknownas Solder. It isusedasa filler rod. Mostofthe solders are alloys of tin and lead. They melt at a temp of about 215oC. Thework pieces are not melted. Electrically heated soldering irons are available. The two sheets are properly cleanedto removeoil, grease, oxidesanddirt.This isdone bychemicalcleaning, filing, orby emery cloth. Two sheets are positioned. A flux is applied using a brush. The flux prevents oxidation. The flux used is in the formof liquid or paste. The flux used are zinc chloride and hydrochloric acid. The soldering iron is heated to proper temp. It is dipped in the flux and then rubbed on the solder. This is known as tinning of the tip.
Applications:Usedinelectricalappliances,computers,automobileradiators.

BRAZING: It is the process of joining two similar or dissimilar metals by using a fusible alloy called "spelter". Spelter is a harder filler rod. Its melting temp is about 600oC. This is below the melting point ofthe work materials. The most commonly used spelters are copper alloysand silveralloys. Forbrazing ferrousmetals copperalloys madeofcopper, zincandtin are used. Silver alloys made of silver and copper are used for any metals.

Comparisionof Soldering and Brazing:

Soldering	**Brazing**
Filler material is known as solder	Filler material known as spelter
Low melting point alloys used	High melting point alloys used
Alloys of tin and lead are used	Copper and silver base alloys used
Strength of the joint is relatively low	Relatively high strength
Fluxes are Zinc chloride and hcl acid	Flux is borax powder
Mostly used for elec connections, tins and cans	Joining of dissimilar metals,



Centre Lathe

Introduction:

Lathe is a machine tool, which is used to remove metal from work piece for required shape and size. This is done by holding the work piece firmlyonthe machine and turning it against the cutting tool, which will remove metal from the work in the form of chips.

Centerlathe: This lathe isthe most important member oflathe familyand most widelyused. This lathe is also known as engine lathe. The basic parts of center lathe are bed, headstock, tailstock, and carriages, cross slide, compound rest, tool post and apron.

Bed: It isthe base ofthe lathe;the headstockandtailstock are locatedat either end ofthe bed and the carriage rests over the lathe bed and slides on it.

Headstock: It carries a hollow spindle .A live center can be fitted in to hollow spindle. The live center rotates with the work piece and hence called live center.

Tailstock: It is mountedonthebedat right angles end. It isused forsupportingtheright end ofthe work piece by means ofa dead center. The dead center does not revolve with the work piece and hence called dead center.

Carriage: It is supported on the lathe bed ways and can move in a direction parallel to the lathe axis .It carries saddle, cross slide, compound rest, toolpost and apron. It is a H- shaped casting fitted over the bed. It moves along the guide way.

Cross slide: It carriesthecompound rest and toolpost.It is mounted onthetopofthe saddle. It may be moved by hand or may be given feed through apron mechanism.

Compound rest: It is mounted on the cross –slide .It carries a circular bar called swivelplate, which is graduated on degrees. The upper part is known as the compound slide, and it can be moved by means of the hand wheel.

Toolpost: The toolpost is fitted over the compound rest. thetoolis clamped inthe toolpost.

Apron: Lowerpartofthecarriageistermedastheapron.Itisattachedtothesaddleand hangs in front ofthe bed .It contains gear, clutchand lever for moving the carriage bya hand wheeler power feed.

Feed mechanism: The movement oftoolrelative to the work is termed as feed. A lathe may have three types of feed: longitudinal, cross, and angular feed. The feed mechanisms have different units through which motion id transmitted from the head stock spindle to the carriage. Following are the units: end of bed gearing, feed gear box, feed rod and lead screw, apron mechanism.

Specificationoflathe: Specifyinga latheshouldpossessthe followingdetails:The lengthof the bed

- The lengthbetweencenters
- Theheightofcentersfromthebed
- Theswing diameterofworkoverbed.
- Theswing diameterofworkoverbed
- Theswingdiameterofworkovercarriage
- Themaximumbardiameterwhichwillpassthroughthe holeof headstockspindle.

Importantoperationsofalathe:

Turning: Theworkpiece is held inthechuckor betweenthecenters. Theturningtoolis held parallel to the axis of the lathe spindle and a cylindrical surface is produced. For rough turning, the rateof feed ofthe tool is fast and the depth ofcut is heavy. For roughturning the depth of cut may be from 2 to 5mm.For finishing turning the feed and depth of cut will be small. For this a finish turning tool is used and the depth ofcut may be from0.5 to 1mm.

Facing: Facing is the machining of the end face of the work piece to make it flat. The work piece may be held in the chuck as between the centers. A facing too is fed perpendicular tothe axisofoperationofthe work piece. Onlythe face ofthe toolis machined in thisprocesses and hence called facing.

Chamfering: It is the process of leveling extreme end of the work piece. This is done to protect the end of the work piece from getting damaged. This operation is performed after turning, drilling, boring etc., It is a critical operation to be performed after thread cutting so that the end may pass firstly on the threaded work piece.

Knurling: The adjustment screw ofa micrometer is not smooth either axis cross or diamond shaped pattern is seen. The process by which such patterns are made is call knurling. It is done to give good gripped surface on the work piece. The teeth may be fine, medium or coarse. Very slow speeds are adapted for knurling.

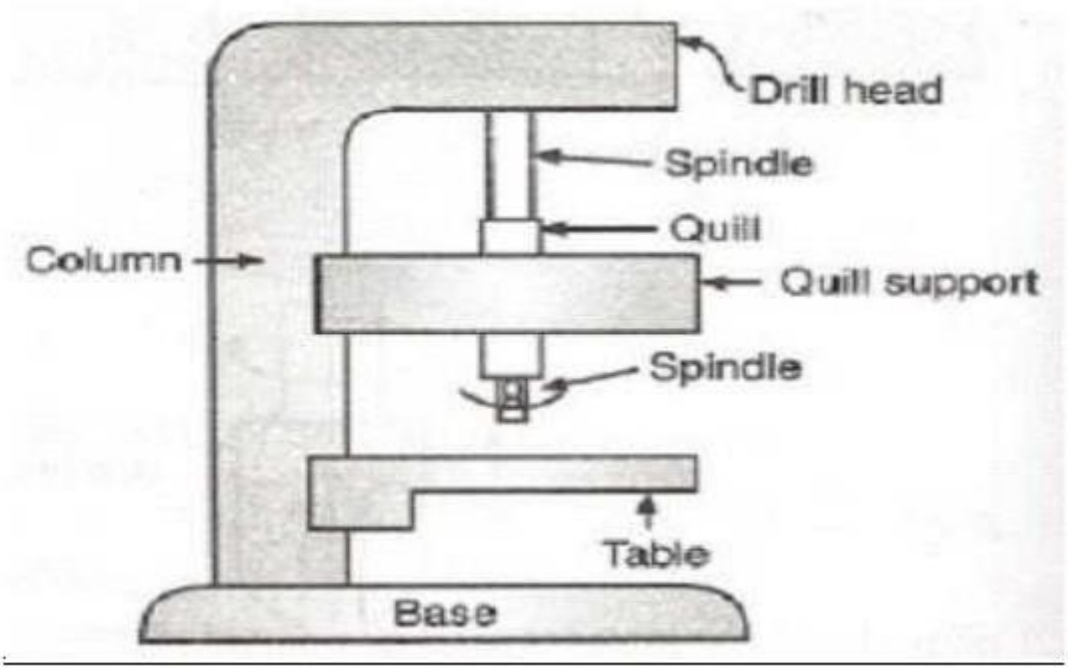
Reaming: The operations for finishing a drilled or bored hole for smooth finishing are called as reaming. The tool used is called as reamer. It has multiple cutting edges. The reamer is fitted in the tail stock spindle.

Drilling: Itisanoperationformakinga holeona workpiece. Fordrilling, workpiece is held in the chuck on one side where as the other side remains free. The tool for drilling is called drill. The drill is inserted onthe tailstock. When the job rotates, the drill bit is inserted in the tailstock by rotating the hand wheel.

Boring: It isa processfor enlarging a hole produced bydrilling. Boring itselfcannot produce a hole. The work piece is held in a chuck or face plate. The boring tool is fixed and fed into the job.

Taperturning: Alarge number ofcomponentsused inengineering have aconicalshapeor a tapered shape. A taper is defined as the uniform change in diameter measured along itslength.

DRILLINGMACHINE



DRILLING MACHINE

Introduction: In a drilling machine holes may be drilled quicklyand at a low cost. The hole isgenerated bytherotating edgesofacutting toolknownasthedrill, whichexertslarge force on the work clamped on the table.

Typesofdrillingmachine:1.Portable

2. Sensitive
3. Upright
4. Radial
5. Gang
6. Multiplespindle
7. Automatic
8. Deephole

PrinciplepartsofRadialdrillingmachine:

Base: The base is a large rectangular casting that it is mounted on its one end vertically it supports radial arm, electrical motor. Which impacts vertical adjustment of the arm by rotating a screw. **Column:** The column is a cylindrical casting, it supports radial arm which may slide up or down on its face. An electric motor is mounted at the top of the column, which impacts vertical adjustments of the arm by rotating a screw passing through a nut tothe arm.

Radial arm: Radial arm is mounted on the column horizontally over the base; the arm may be swung round the column. In some machines this movement is controlled by a separate motor.

Drill Head: Drill Head is mounted on the radial arm and drills spindle is driven. All the mechanism is housed with in a small drill head. The drill head is properly adjusted and clamped on the radial arm.

Introduction toCNCmachines:

Computer Numeric Control (CNC) is the automation of machine tools that are operated by precisely programmed commands encoded on a storage medium (computer commandmodule, usually located on the device) as opposed to controlled manually by hand wheels or levers, or mechanically automated by cams alone. Most NC today is computer (or computerized) numerical control (CNC), in which computers play an integral part of the control. In modern CNC systems, end-to-end component design is highly automated using computeraided design (CAD) and computer-aided manufacturing (CAM) programs.

The programs produce a computer file that is interpreted to extract the commands needed to operate a particular machine by use of a post processor, and then loaded into the CNC machines for production. Since any particular component might require the use of a number of different tools – drills, saws, etc. – modern machines often combine multiple tools into a single "cell". In other installations, a number of different machines are used with an external controller and human or robotic operators that move the component from machine tomachine. In either case, the series of steps needed to produce any partis highly automated and produces a part that closely matches the original CAD design.

Definition

Computer Numerical Control(CNC) is one in which the functions and motions ofa machine tool are controlled by means of a prepared program containing coded alphanumeric data. CNC can control the motions of the work piece or tool, the input parameters such as feed, depth of cut, speed, and the functions such as turning spindle on/off, turning coolant on/off.

Applications

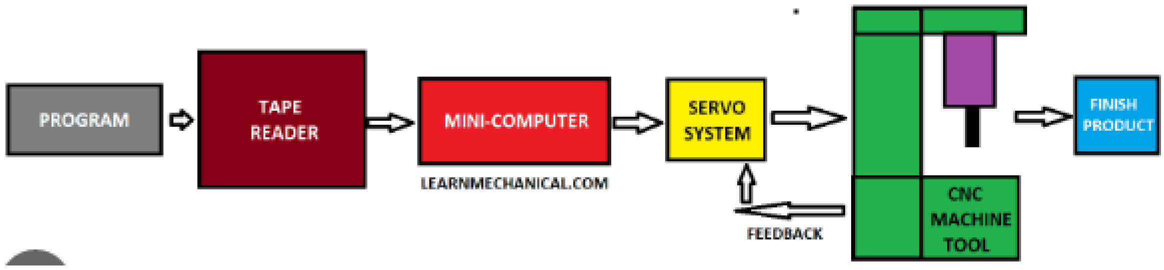
The applications of CNC include both for machine tool as well as non-machine tool areas. In the machine tool category, CNC is widely used for lathe, drill press, milling machine, grinding unit, laser, sheet-metal press working machine, tube bending machine etc. Highly automated machine tools such as turning centre and machining centre which change the cutting tools automatically under CNC control have been developed. In the non-machine tool category, CNC applications include welding machines (arc and resistance), coordinate measuring machine, electronic assembly, tape laying and filament winding machines for composites etc.

Advantages andLimitations

The benefits of CNC are (1) high accuracy in manufacturing, (2) short production time, (3) greater manufacturing flexibility, (4) simpler fixturing, (5) contour machining (2 to 5 -axis machining), (6)reducedhumanerror.The drawbacks include highcost, maintenance, and the requirement of skilled part programmer.

ELEMENTSOFACNCACNC

system consists of three basic components: Part Program 1 . Part program 2 . Machine Control Unit (MCU) 3 . Machine tool (lathe, drill press, milling machine etc) The part program is a detailed set of commands to be followed by the machine tool. Each command specifies a position in the Cartesian coordinate system (x,y,z) or motion (workpiece travel or cutting tool travel), machining parameters and on/off function. Part programmers should be wellversedwithmachinetools,machiningprocesses,effectsofprocessvariables,and limitationsofCNCcontrols.Thepartprogramiswrittenmanuallyorbyusingcomputer assisted language such as APT (Automated Programming Tool).



3Dprinting

Principle - Stacking two-dimensional layers toform three dimensional objects-Producing 2D layers is relatively simple - Parts usually need to be supported from below

STLfile – FromCAD, 3D-scan, etc. "Slicing" tomultiple layers, toolpathcalculated for each Part production using calculated paths.

Advantagesof3DPrinting–Freedom of design–complexityisfreeForm optimization, pre-assembly, easy customization..

– No need for tooling No cost from design changes & cheap small volume prod.– No need for inventory On-demand manufacturing, minimal investment,

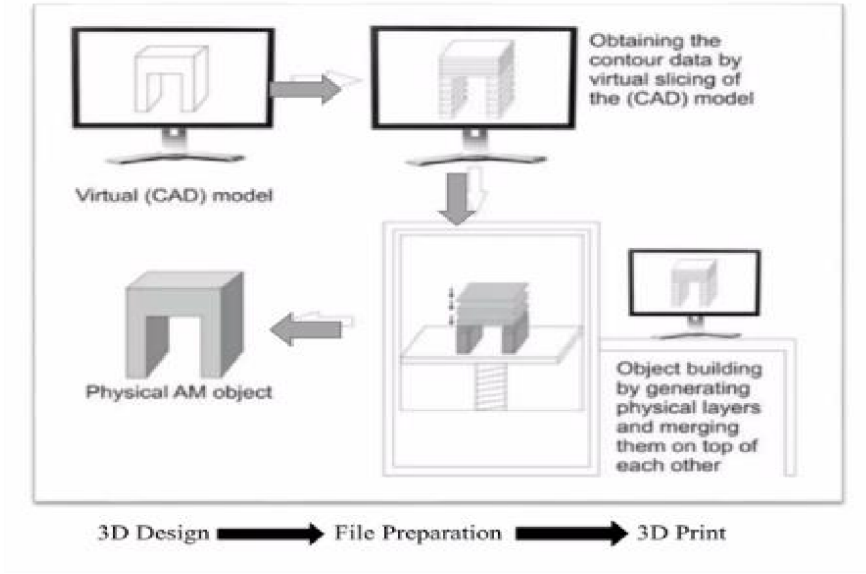
– Fastleadtimes&responsivenessQuickalterationindesignto respondtocustomerneeds

– LocalizedmanufacturingManufacturingwhereneeded,savingsinlogistics

– Widematerialrange

– seamlesstransitionsInnovationpotentialwithnew opportunities

– AffordablelowvolumeproductionPriceperpiececonstantregardlessofproductionsize.



- The design should be then converted into an Stl file format ie; StereoLithography format, based on which the 3D printer(s) works.
- This format slices the designed object or part into spatial orientations like x,y,z-axis and each orientations confirms the machine on how to proceed with the process of manufacturing.
- 3D CAD designs can be of any complex dimensions and shapes and wholly could be produced in a 3D printer within less time compared to the conventional methods.
- Thermoplastics are the raw materials commonly used globally were PLA is the prime material used. Other materials like ABS, NYLON, PLA etc.
- 3D printing could be also done using digital files from scanners that scans the object and produce the stl formats.
- The advantage of using a 3D printer is that there will be no wastage of materials used, since its controlled via a computer.
- There is no requirement of any moulding or casting for the production of designed prototype which saves money and time!

WhatIsSteamBoiler?

Steam boileris nothing but a closed vessel combustion chamber which generates steam at a desired pressure by the combustion of fuel to water. Steam is supplied to the ***steam boiler***in differenfield like steamengine,steamturbine,thermalpower plant,variousheating installation process,different cotton mills,sugar factories etc.

Workingprincipleofsteamboiler

Working principle of steam boiler is very very simple. Steam boiler is a cylindrical shape closed vessel which has sufficient capacity to contain water and steam. Generally,waterorother fluid isstoredinsteamboiler to generate steam.This waterorfluid is heatedby flames or hot gasses which are produced by combustion of fuels and consequently steam is generated in the boiler at different pressure according to boiler's size and it's specification.This steam is now passed through a pipe and supplied into different production unit,power plant etc.This is very basic **working principle of steam boiler**.

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Component ofsteamboiler

1. Boilershell
2. Combustionchamber
3. Grate
4. Furnace
5. Heatingsurface

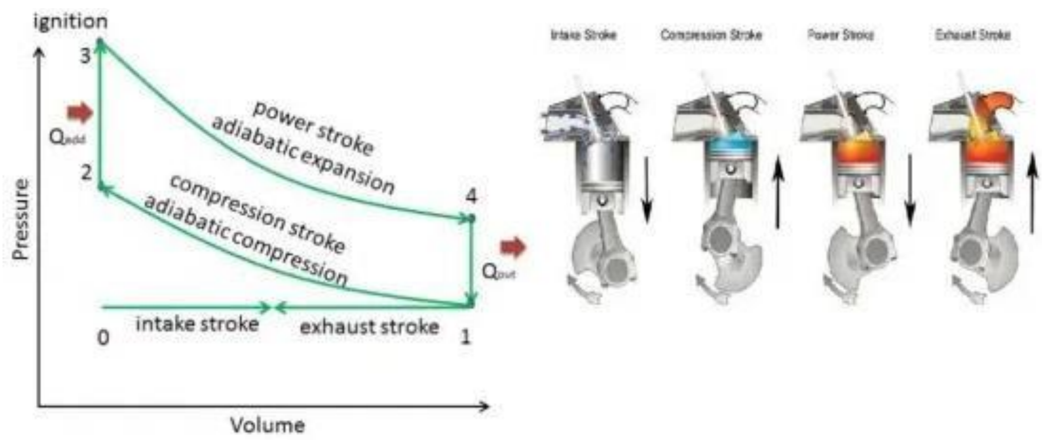
6. Mounting

7. Boileraccessories

a) Waterlevelindicator
b) Pressure gauge
c) Safetyvalve
d) Stopvalve
e) Blowoffcock
f) Feedcheck valve
g) Fusingplug

Otto cycle:

TheOttocycle,alsoreferredtoas the spark-ignitioncycle,isthefundamental thermodynamic cycle used inpetrol engines. It operates on the principle of constant volume combustion and consists of four processes: intake, compression, combustion, and exhaust.



1-2(Adiabaticprocess):Inthisprocesscompressiontakesplace, asthepistonmoves from BDC to TDC increasing its temperature

2-3(Isochoricprocess):Inthisprocess,ignitionistakingplace,combustionhappenswhen the piston is at TDC and pressure increases at a constant volume.

3-4(Adiabaticprocess):Inthisprocessexpansionistakingplace, theheat produceddueto the combustion pushes the piston down which rotates the crankshaft.

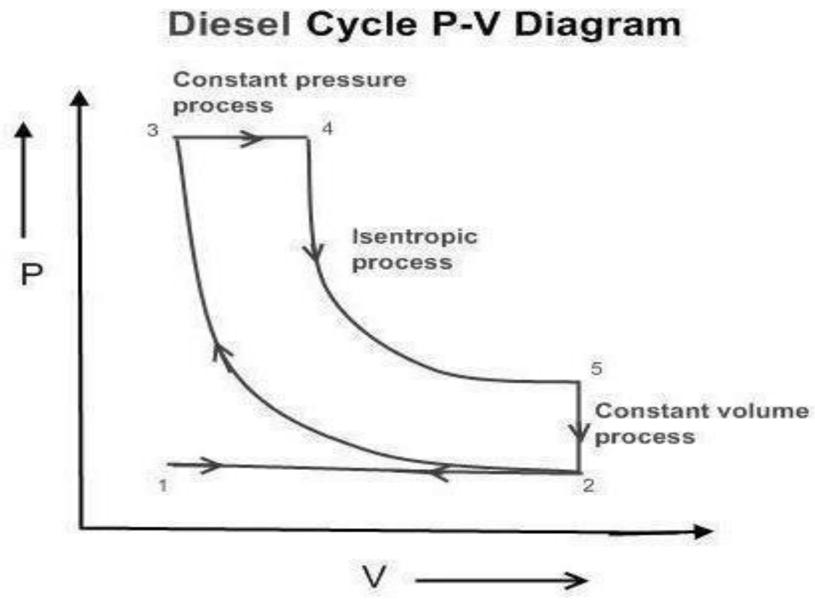
4-1(Isochoricprocess):Inthisprocess,heat rejectionistakingplaceat constant volume. The

compression ratio of the otto cycle is 8 to 12.

Theefficiencyofottocycleis

Dieselcycle:

TheDieselcycleisathermodynamicprocessthatiscommonlyusedin dieselengines for internal combustion. It operates on the principle of constant pressure combustion and consists of four distinct processes: intake, compression, combustion, and exhaust.



1-2Inthis process suctiontakes place

2-3 (Adiabatic process) Inthis process compressiontakes place. Boththe inlet and exhaustvalvesareclosedandthecompressiontakesplace whichis muchhigher thanthatofanotto cycle. This increases the pressure and temperature.

3-4 (Isobaric process) Inthis process, fuel is added, and combustion occurs due to high temperature,whilemaintainingaconstantpressurebecausethevolumeisalsoincreasing.

4-5(Adiabaticprocess) Inthisprocessexpansiontakesplace, dueto combustionthepiston moves from TDC to BDC and power is generated.

5-2(Isochoricprocess)Inthisprocess,heat rejectionistakingplaceat constant volume. Compression

ratio is 14 to 22.

TheRefrigerationandair-conditionCycle:

An air conditioner works using a thermodynamic cycle called the refrigeration cycle. It does this bychanging the pressure and stateof the refrigerant to absorb or release heat.

Therefrigerant(akacoolant)absorbsheatfrominsideofyourhomeandthenpumpsit outside.

Most air conditioners are **air-source, split systems**. What this means is that there is one unit inside and one unit outside, which is why it is called a split system.

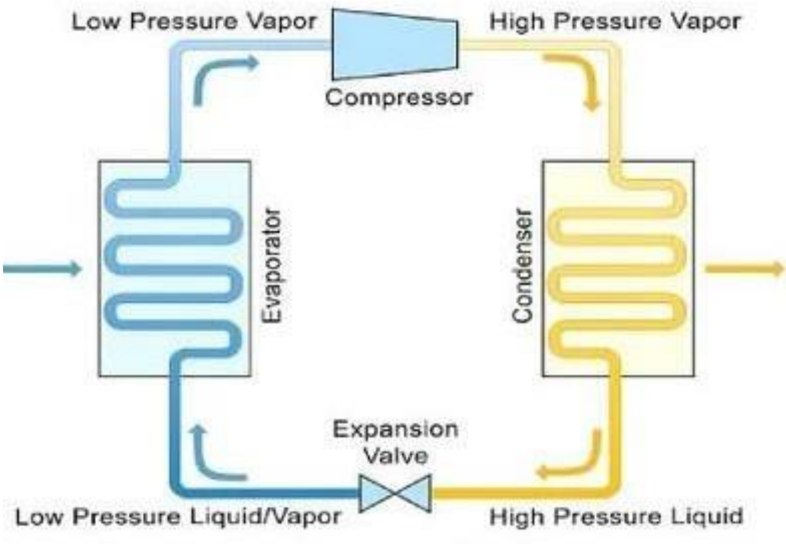
The air-source part refers to the place where the thermal energy is dumped, the outside air. There are other potential places where the heat can be transferred, such as water or ground, known as **water-source**, or **ground-source systems**.

The**inside unit**is normally inside the house somewhere, in the attic, basement, closet or crawl space. The **outside unit** is normally located onthe side or back of the building.

Other kinds of air conditioning systems, such as ground-source and water-source, follow the refrigeration cycle, but some of the specifics, such as location and parts may differ.

Here are the basic parts of the refrigeration cycle (the same process that your refrigerator used to keep food cold):

- Thecompressor
- Thecondenser
- Theexpansiondevice
- Theevaporator



Thecompressor

Compression is the first step in the refrigeration cycle, and a compressor is the piece of equipment that increases the pressure of the working gas. Refrigerant enters the compressor as low-pressure, low-temperature gas, and leaves the compressor as a high-pressure, high-temperature gas.

Thecondenser

Thecondenser,orcondensercoil, isoneoftwotypesofheatexchangers used in a basic refrigeration loop. This component is supplied with high-temperature high-pressure, aporized refrigerantcoming off the compressor. The condenser removes heat from the hot refrigerant vapor gas vapor until it condenses into a saturated liquid state, a.k.a. condensation.

Expansion device: create a drop in pressure after the refrigerant leaves the condenser. This pressure drop will cause some of that refrigerant to quicklyboil, creating a two-phase mixture.

Evaparator: Thishappenswhenrefrigerantentersthe evaporatorasa lowtemperatureliquid at low pressure, and a fan forces air across the evaporator’s fins, cooling the air byabsorbing the heat from the space in question into the refrigerant.

IC engines

CONSTRUCTION OF AN IC ENGINE I.C. engine converts the reciprocating motion of piston into rotary motion of the crankshaft by means of a connecting rod. The piston which reciprocating in the cylinder is very close fit in the cylinder. Rings are inserted in the circumferential grooves of the piston to prevent leakage of gases from sides of the piston. Usuallya cylinder is bored ina cylinder block and a gasket, made ofcoppersheet orasbestos is inserted between the cylinder and the cylinder head to avoid ant leakage. The combustion space is provided at the top of the cylinder head where combustion takes place. The connecting rod connects the piston and the crankshaft. The end of the connecting rod connecting the piston is called small end. A pin called gudgeon pin or wrist pin is provided for connecting the piston and the connecting rod at the small end. . The other end of the connecting rod connecting the crank shaft is called big end. When piston is moved up and down, the motion is transmitted to the crank shaft by the connecting rod and the crank shaft makes rotary motion. The crankshaft rotates in main bearings which are fitted the crankcase. A flywheel is provided at one end of the crankshaft for smoothing the uneven torqueproduced by the engine. There is an oil sump at the bottom of the engine which contains lubricating oil for lubricating different parts of the engine.

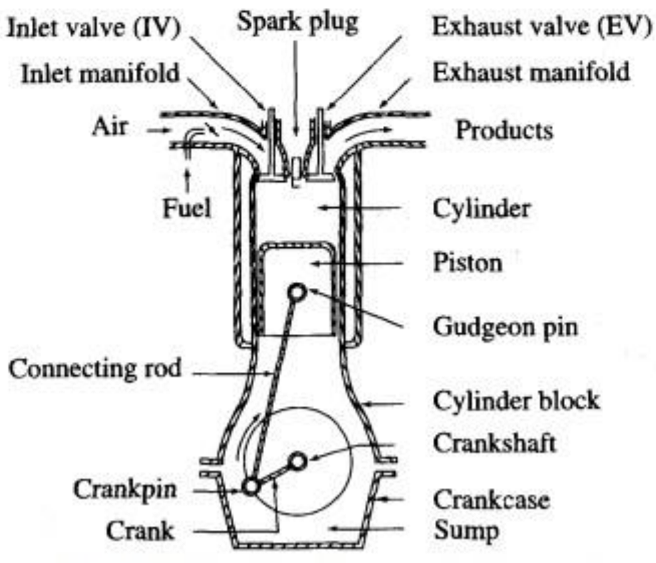


Fig. 1.2 Cross-section of spark-ignition engine

ENGINECOMPONENTS

Internalcombustionengineconsistsofanumberof partswhicharegivenbelow:

Topdeadcentre–

Whenthepistonisatthetopofitsstroke,itissaidtobeatthetop deadcentre(TDC),

Bottomdeadcentre-whenthepistonisat thebottomofitsstroke, itissaidtobeatitsbottom dead centre (BDC).

i) **Cylinder:** It is a part of the engine which confines the expanding gases and forms the combustion space. It is the basic part of the engine. It provides space in which piston operates to suck the air or air-fuel mixture. The piston compresses the charge and the gas is allowed to expand in the cylinder, transmitting power for useful work. Cylinders are usually made of high grade cast iron.

ii) **Cylinder block:** It is the solid casting body which includes the cylinder and water jackets (cooling fins in the air cooled engines).

iii) **Cylinderhead:** Itisa detachableportion ofan engine whichcovers the cylinderandincludes the combustion chamber, spark plugs or injector and valves.

iv) **Cylinder liner or sleeve:**It is a cylindrical lining either wet or dry type which is inserted inthe cylinder block in which the piston slides. Liners are classified as : (1) Dry liner and (2)Wet liner. Dry liner makes metal to metal contact with the cylinder block casing. wet liners come in contact with the cooling water, whereas dry liners do not come in contact with the cooling water.

v) **Piston:** It is a cylindrical part closed at one end which maintains a close sliding fit in the enginecylinder.Itisconnectedtotheconnectingrodbyapistonpin.Theforceofthe expandinggasesagainsttheclosedend of the piston,forcesthe piston down inthe cylinder. This causes the connecting rod to rotate the crankshaft . Cast iron is chosen due to its high compressive strength. Aluminum and its alloys preferred mainly due to it lightness.

vi) Head(Crown)ofpiston: It isthe topof thepiston. Skirt:It is that portion of the piston below the piston pin which is designed to adsorb the side movements of the piston. vi) Piston ring: It is a split expansion ring, placed in the groove of the piston. They are usually made of cast iron or pressed steel alloy (Fig.3). The function of the ring are as follows :

vii) **Compression ring** Compression rings are usually plain, single piece and are always placed in the grooves of the piston nearest to the piston head. They prevent leakage of gases fromthe cylinder and helps increasing compression pressure inside the cylinder. Oil ring: Oil rings are grooved or slotted and are located either in lowest groove above the piston pin or in a groove above the piston skirt. They control the distribution of lubrication oil in the cylinder and the piston. Piston Pin: It is also called wrist pin or gudgeon pin. Piston pin is used to join the connecting rod to the piston.

viii) **Connecting rod:** It is special type of rod, one end of which is attached to the piston and the other end to the crankshaft . It transmits the power of combustion to the crankshaft and makes it rotate continuously. It is usually made of drop forged steel.

ix) **Crankshaft:** It is the main shaft of an engine which converts the reciprocating motion of the piston into rotary motion of the flywheel . Usually the crankshaft is made of drop forged steel orcast steel.The space that supportsthecrankshaftin thecylinderblock iscalledmain journal, whereas the part to which connecting rod is attached is known as crank journal. Crankshaft is provided with counter weights throughout its length to have counter balance of the unit.

WORKINGPRINCIPLEOFI.C.ENGINE/FOURSTROKECYCLEENGINE/TWOSTROKE CYCLEENGINE

A mixture of fuel with correct amount of air is exploded in an engine cylinder which is closed at one end. As a result of this explosion, heat is released and this heat causes the pressure of the burning gases to increase. This pressure forces a close fitting piston to move down the cylinder. The movementofpistonis transmitted toa crankshaftby aconnectingrod so thatthe crankshaftrotates and turns a flywheel connected to it. Power is taken from the rotating crank shaft to do mechanical work. To obtain continuous rotation of the crankshaft the explosion has to be repeatedcontinuously.

Before the explosion to take place, the used gases are expelled from the cylinder, fresh charge offuel and air are admitted in to the cylinder and the piston moved back to its starting position. The sequences of events taking place in an engine is called the working cycle of the engine. Thesequence of events taking place inside the engine are as follows

1. Admissionofairorair-fuelmixtureinsidetheenginecylinder(suction)
2. Compressionoftheairorairfuelmixtureinsidetheengine(compression)
3. Injection of fuel in compressed air for ignition of the fuel or ignition of air-fuel mixture by an electric spark using a spark plug to produce thermal power inside the cylinder (power)

4. Removal of all the burnt gases from the cylinder to receive fresh charge (exhaust) Note: Charge means admitting fresh air in to the cylinder in the case of compression ignition engines (diesel engines)oradmitting amixtureofairandfuel intothecylinderinthecaseofsparkignitionengines.

FOUR STROKECYCLEENGINE(DIESEL/ PETROLENGINE) In four stroke cycle engines the four events namely suction, compression, power and exhaust take place inside the engine cylinder. The four events are completed in four strokes of the piston (two revolutions of the crank shaft). This engine hasgotvalvesforcontrollingtheinletofchargeandoutletofexhaust gases. Theopeningandclosing of the valve is controlled by cams, fitted on camshaft. The camshaft is driven by crankshaft with the help of suitable gears or chains. The camshaft runs at half the speed of the crankshaft. The events taking place in I.C. engine are as follows: 1. Suction stroke 2. Compression stroke 3. Power stroke 4. Exhaust stroke

Suctionstroke

During suction stroke inlet valve opens and the piston moves downward. Only air or a mixture of air and fuel are drawn inside the cylinder. The exhaust valve remains in closed position during this stroke. The pressure in the engine cylinder is less than atmospheric pressure during this stroke.

Compressionstroke

During this stroke the piston moves upward. Both valves are in closed position. The charge taken in the cylinder is compressed by the upward movement of piston. If only air is compressed, as in caseof diesel engine, diesel is injected at the end of the compression stroke and ignition of fuel takes place due to high pressure and temperature of the compressed air. If a mixture of air and fuel is compressed in the cylinder, as in case of petrol engine, the mixture is ignited by a spark plug.

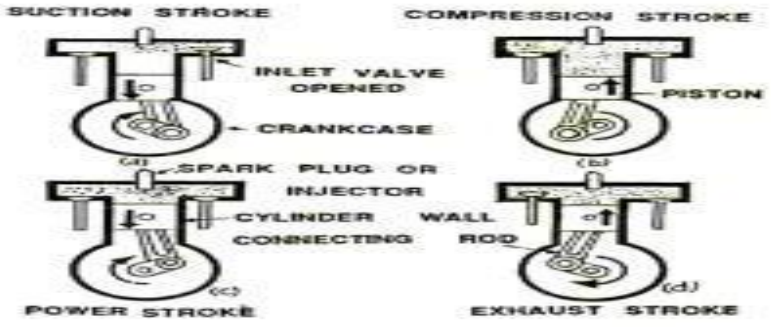
Powerstroke

After ignition of fuel, tremendous amount of heat is generated, causing very high pressure in the cylinder which pushes the piston downward .The downward movement of the piston at this instantis called power stroke. The connecting rod transmits the power from piston to the crank shaft and crank shaft rotates. Mechanical work can be taped at the rotating crank shaft. Both valves remain closed during power stroke.

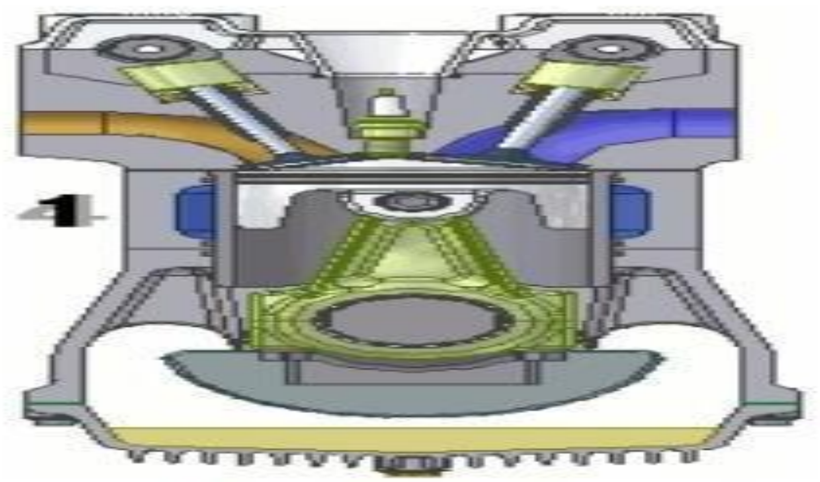
Exhauststroke

During this stroke piston moves upward. Exhaust valve opens and exhaust gases go out through exhaust valves opening. All the burnt gases go out of the engine and the cylinder becomes ready to receive the fresh charge. During this stroke inlet valve remains closed (Fig.1d). Thus it is found that outoffourstrokes,thereisonlyonepowerstrokeand threeidlestrokesinfourstroke cycleengine.

Thepowerstrokesuppliesnecessarymomentumforusefulwork.



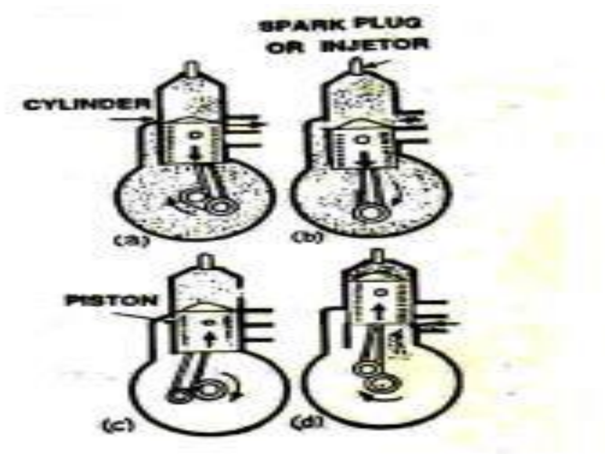
Four stroke cycle engine

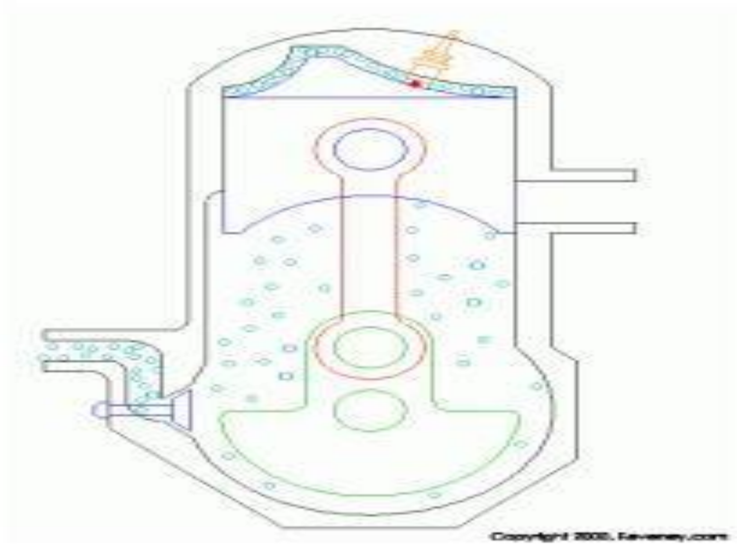


Four stroke cycle engine

TWOSTROKECYCLEENGINE(PETROLENGINE)

In two stroke cycle engines, the whole sequence of events i.e., suction, compression, power and exhaust are completed in two strokes of the piston i.e. one revolution of the crankshaft. There is no valve in this type of engine. Gas movement takes place through holes called ports in the cylinder.The crankcase of the engine is air tight in which the crankshaft rotates.





Upwardstrokeofthepiston(Suction+Compression)

When the piston moves upward itcovers two of the ports,the exhaustportand transfer port, which are normally almost opposite to each other. This traps the charge of air- fuel mixture drawn already into the cylinder. Furtherupward movementof thepiston compressesthe chargeand alsouncovers the suction port. Now fresh mixture is drawn through this port into the crankcase. Just before the end of this stroke, the mixture in the cylinder is ignited by a spark plug .Thus,during this stroke both suction and compression events are completed.

Downwardstroke(Power+Exhaust)

Burning of the fuel rises the temperature and pressure of the gases which forces the piston to move down the cylinder. When the piston moves down, it closes the suction port, trapping the freshcharge drawn into the crankcase during the previous upward stroke. Further downward movement of the piston uncovers first the exhaust port and then the transfer port. Now fresh charge in the crankcase moves in to the cylinder through the transfer portdriving outthe burnt gases through the exhaust port. Special shaped piston crown deflect the incoming mixture up around the cylinder so that it can help in driving out the exhaust gases . During the downward stroke of the piston power and exhaust events are completed.

COMPARISON BETWEEN SI AND CI ENGINES (GENERAL COMPARISON):

S. NO.	Spark Ignition Engines (SI)	Compression Ignition Engines (CI)
1	It draws air fuel mixture into the cylinder during suction stroke	It draws only air into the cylinder during suction stroke.
2	Petrol engines operate with low pressure and temperature	Diesel engines operate with high pressure and temperature
3.	Pressure ranges from 6 to 12 bar Temperature ranges from 250°C to 300°C	Pressure ranges from 35 to 40 bar Temperature ranges from 600oC to 700oC
4	It is fitted with carburettor and spark plugs	It is fitted with fuel injection pump and injectors
5	The burning of fuel takes place at constant volume	The burning of fuel takes place at constant pressure
6.	Ignition of air fuel mixture takes place by an electric spark produced by spark plug	Ignition of air fuel takes placed by a injection of fuel into the hot compressed air.
7	Petrol engines are quality governed engines. The speed of petrol engines are controlled by varying the quantity of air fuel mixture.	Diesel engines are quantity governed engines. The speed of diesel engines is controlled by varying quality of air fuel mixture. (rich or weak mixture)
8	Petrol engines are widely used in automobiles and aeroplanes etc.,	Diesel engines are widely used in heavy vehicles, such as buses, lorries, trucks etc.,

Difference Between 2 Stroke and 4 Stroke Engine

2 Stroke	4 Stroke
It can generate one revolution of the crankshaft within one power stroke, i.e.one power stroke per 360 degrees rotation of the crankshaft.	It can generate two revolutions of the crankshaft between one power stroke i.e., one power stroke in every 720 degrees rotation of the crankshaft.
Uses port for inlet and outlet of fuel.	Uses valve for inlet and outlet.
It requires a lighter flywheel to cause a more balanced force due to one revolution for one power stroke.	It requires heavy flywheel because it gives rise to unbalanced forces due to two revolutions for one power stroke.
Cheaper in price as they require less effort in manufacturing and are light by weight.	Hard to manufacture due to the heavy flywheel and valve mechanism and are expensive due to the valve and lubrication mechanism.
Generates more torque at a higher rpm.	Generates a higher torque at a lower rpm.
The charge is partially burnt and it gets mixed with the burnt gases during inlet.	The charge is fully burnt and doesn't get mixed with the gases inside the cylinder.
More power generation.	Less power generation.
Produces more heat so it requires greater cooling and lubrication.	Generates less heat.
Lower thermal efficiency	Higher thermal efficiency

HybridElectricVehicle(HEV):

A Hybrid Electric Vehicle is a type of vehicle that uses a combination of an Internal Combustion (IC) engine and an electric propulsion system. The electric powertrain may enhance fuel efficiency, increase performance, or independently propel the vehicle on pure electric power, depending on the type of hybrid system.

In simple words, an HEV is a vehicle that comprises a conventional fuel engine and an electric powertrain, wherein the electric motor assists the engine to extract moreperformance, and better fuel economy, depending on the type of the system. We will elaborate on the kinds of HEVs in the following sections of this article.

componentsofaHybridElectricVehicle

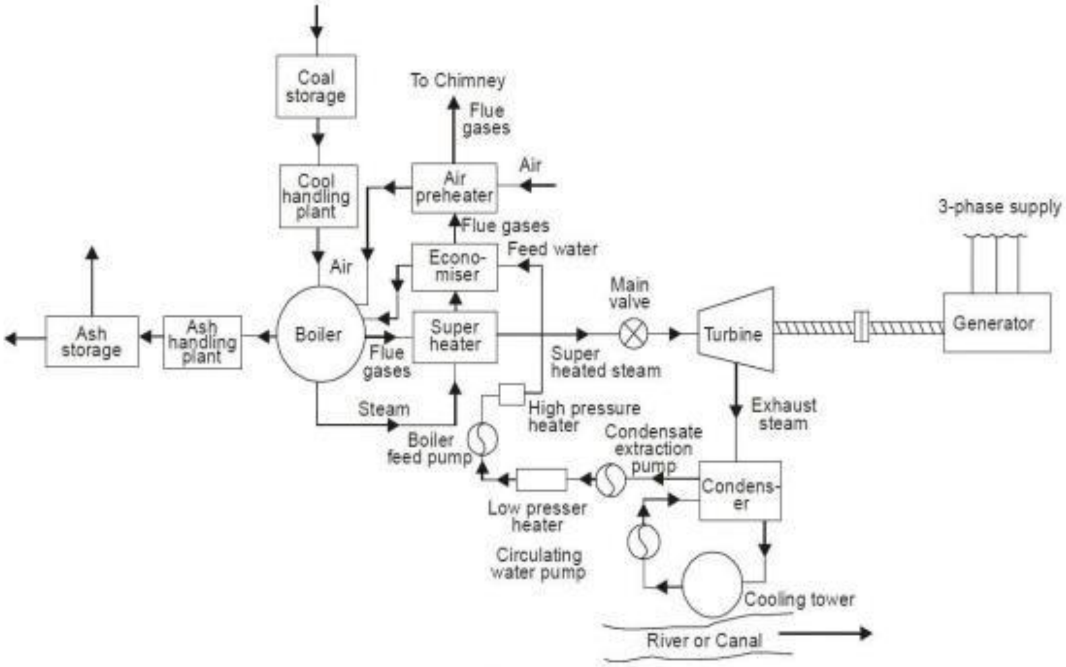
As mentioned before, an HEV combines a conventional engine and electric powertrain. Hence, you can find engine-related and electric powertrain components in an HEV. Beloware the key components of a Hybrid Electric Vehicle.

- **Internalcombustionengine:** Theprimary powersourceof anHEVisa conventional engine. Hence, it is the main component responsible for propelling the vehicle. An HEV cannot run alone on an electric powertrain without an engine.
- **Electric motor:** The secondary power source of an HEV is the electric motor. It assists the engine during initial acceleration to improve performance and fuel economy.Itruns onelectricalenergystoredinthebattery pack.Itcanalsocharge the battery when the vehicle is braking or coasting via the regenerative braking system.
- **Battery pack:** A battery pack powers the electric motor. Basically, it acts as a fuel tank for the battery, wherein it stores the electrical energy via regenerative brakingand the generator driven by the IC engine. The batterypack can also power auxiliary electrical components such as lights.
- **Generator:** It is an essential component found in the series hybrid vehicle. We will touch upon what series hybrid is in the upcoming sections. A generator draws power from theICenginetopowertheelectricmotorandchargethebatterypack.In simple words, a generator converts mechanical energy into electrical energy.
- **Transmission:** Typically, hybrid vehicles use conventional transmissions similar to petrol or diesel cars. It transmits the power produced by the IC engine to the drive shaft. Thebasic working principle of transmission remains thesame, even in anHEV. It is one of the crucial components required to propel the vehicle.
- **Fuel tank:** Similar to a conventional car,hybridelectric vehicles alsohave a fuel tank to store the conventional fuel. With the

electric powertrain involved in a hybrid car, the fuel consumption will be comparatively less than a vehicle purely relying on an IC engine.

1. Powerplants:

THERMAL/STEAMPOWERPLANT:



COMPONENTS • High pressure boiler • Prime mover • Condensers and cooling towers • Coal handling system • Ash and dust handling system • Draught system • Feed water purification plant • Pumping system • Air Pre-heater, Economizer, Super Heater, Feed Heaters.

HighpressureBoiler:

Steam generator is a device or equipment which burns the fuel and facilitates the exchange of heat produced to the water to generate required quantity and quality of steam. Thus, it is a heat exchanger which has the place for burning of fuel and flow of hot flue gases produced and also has space for storing of water and steam. As steam is produced & stored at high pressure than the atmospheric pressure, steam generator is also a pressure vessel. To handle the hot flue gases and to keep high pressure steam, certain other mountings and accessories are also required for its safe and efficient operation. In this way steam generator is not simply a vessel to boil water, but it is a complete unit performing the complete task of producing & handling the high-pressure steam by burning of the fuel and exhausting the flue gases efficiently and safely. Most of the boilers are actually a type of shell & tube type heat exchangers

COALDELIVERY The coal from supply points is delivered by ships or boats to power stations situated near to sea or river whereas coal is supplied by rail or trucks to the power stations which are situated away from sea or river. The transportation of coal by trucks is used if the railway facilities are not available.

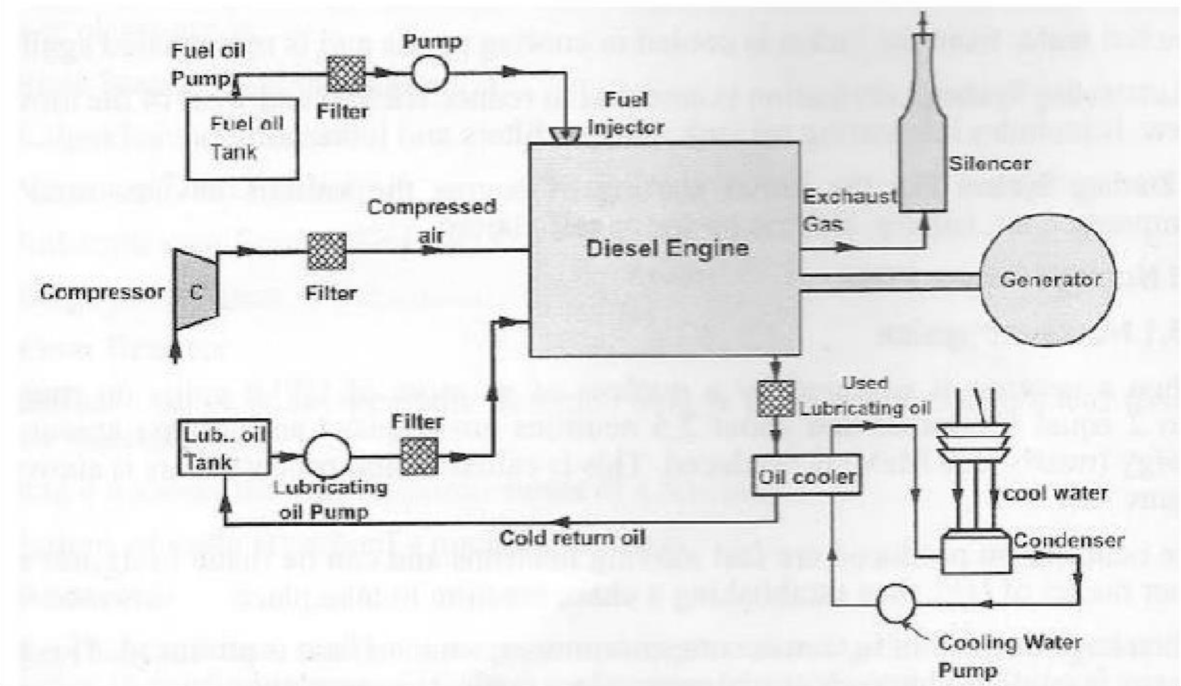
Superheater:

WORKING Steam stop valve is opened. The steam (wet or dry) from the evaporator drum is passed through the super heater tubes. First the steam is passed through the radiant super heater and then to the convective super heater. The steam is heated when it passes through these super heaters and converted into super-heated steam. This superheated steam is supplied to the turbine through valve

Condenser: Working of condensers In a jet condenser, the steam to be condensed and the cooling water come indirect contact and the temperature of the condensate is the same as that of the cooling water leaving the condenser? For jet condensers the recovery of the condensate for reuse as boiler feed water is not possible. Depending upon the arrangement of the removal of condensate, the jet condensers are subdivided into the following categories.

COOLING TOWERS: A cooling to weirs semi-enclosed device for evaporativecoolingofwater by contact with air. It is a wooden, steel, concrete structure and corrugated surfaces ortroughs or baffles or perforated trays are provided inside the tower for uniform distribution and better atomization of water in the tower. The hot water coming out from the condenserare fed to the tower on the top and allowed to ticklein the form of thin sheets or drops. The air flows from the bottom of the atmosphere after effective cooling. An evaporative cooling tower is a machine of relatively simple conception and operation. The water tobe cooledfora chiller, industrial process or refrigeration installation is pumped and distributed through spray nozzles over a fill pack or heat exchange surface through which passes an air current commonlygenerated buya fan. Asmall fractionofthiswater evaporatesand theremainder is cooled thanks to the absorptionof latent heat ofevaporationbythe passing air, and fallunder gravity into a basin fromthere it is pumped back to the heat load source

DIESELENGINEPOWERPLANT



A generating station in which diesel engine is used as the prime mover for the generation of electrical energy is known as diesel power station. In a diesel power station, diesel engine is used as the prime mover. The diesel burns inside the engine and the products of this combustion act as the working fluid to produce mechanical energy. The diesel engine drives alternator which converts mechanical energy into electrical energy. As the generation cost is considerable due to high price of diesel, therefore, such power stations are only used to produce smallpower. Although steampower stations and hydro-electric plants are invariably used to generate bulk power at cheaper costs, yet diesel power stations are finding favour at placeswheredemandof powerisless,sufficientquantity of coal andwaterisnotavailable andthetransportationfacilitiesare inadequate. Thisplantsarealso standbysets forcontinuity of supply to important points such as hospitals, radio stations, cinema houses and telephone exchanges.

Advantages(a)Thedesignandlayoutoftheplantarequitesimple.

(b) Itoccupieslessspaceasthenumber and sizeoftheauxiliariesis small.

(c) Itcanbelocatedatanyplace.

(d) It canbestartedquicklyanditcanpickuploadinashort time.

(e) Therearenostandbylosses.

(f) Itrequireslessquantityofwaterforcooling.

(g) Theoverallcostismuchlessthanthatofsteampowerstationofsame capacity.

(h) Thethermalefficiencyofthe plantishigherthanthat ofasteampowerstation.

(i) Itrequireslessoperatingstaff

Disadvantages

(a) Theplanthashighrunningchargesasthefuel(diesel)usediscostly.

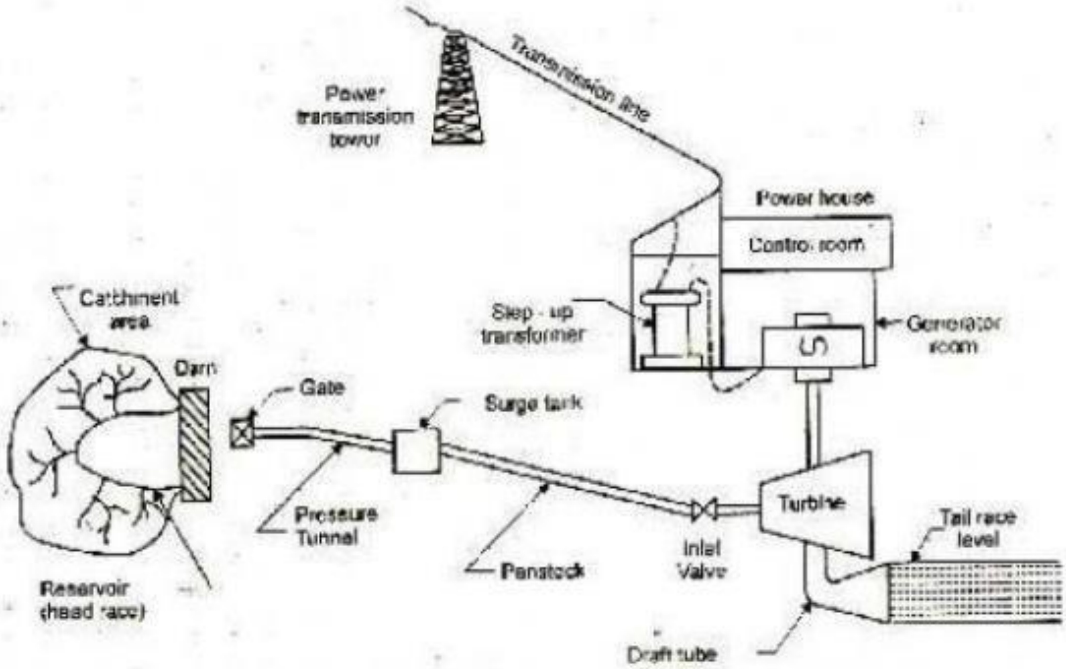
(b) Theplantdoesn'tworksatisfactorilyunderoverloadconditionsforalonger period.

(c) Theplantcanonlygeneratesmallpower.

(d) Thecostoflubricationisgenerallyhigh. (e)Themaintenancechargesaregenerallyhigh

HYDELPOWERPLANT:

Water reservoir Continuous availability of water is the basic necessity for a hydro-electric plant. Water collected from catchment area during rainy season is stored in the reservoir. Water surfaces in the storage reservoir us knownas head race. DamThe function ofa dam is to increase the height of water level behind it which ultimately increases the reservoir capacity. The dam also helps to increase the working heat of the power plant.



Spillway: Waterafteracertainlevelinthereservoiroverflowsthroughspillwaywithout allowing the increase in water level in the reservoir during rainy season.

Pressuretunnel:It carrieswaterfromthereservoirtosurgetank.

Penstock: Water from surge tank is taken to the turbine by means of penstocks, made up of reinforced concrete pipes or steel.

Surge tank : There is sudden increase of pressure in the penstock dueto sudden backflow of water, as loadontheturbine is reduced. The suddenrise ofpressure inthe penstock is known as waterhammer. The surgetank is introducedbetweenthe damand the power houseto keep in reducing the sudden rise ofpressure in the penstock. Otherwise, penstock will be damaged by the water hammer.

Water turbine :Water through the penstock enters into the turbine through and inlet valve. Prime movers which are in common use are Pelton turbine, Francis turbine and Kaplan turbine. The potential energy of water entering the turbine is converted into mechanical energy. The mechanical energy available at the turbine shaft is used to run the electric generator. The water is then discharged through the draft tube.

Draft tube It is connected to the outlet of the turbine. It allows the turbine to be placed over tail race level.

Tail race: Tailrace is a water wayto lead the water discharged fromthe turbine to the river. The water held in the tail race is called tail race water level.

Power house: The power house accommodates the turbine, generator, and transformer and control room

NUCLEARPOWER PLANT:

Basics Atoms consist of nucleus and electrons. The nucleus is composed of protons and neutrons. Protons are positively charged whereas neutrons are electrically neutral. Atomswithnucleihaving same number ofprotons but difference intheir masses are called isotopes. They are identical in terms of their chemical properties but differ with respect to nuclear properties.

Natural Uranium consists of $92U^{238}$ (99.282%), $92U^{235}$ (0.712%) and $92U^{234}$ $92U^{235}$ is used as fuel in nuclear power plants

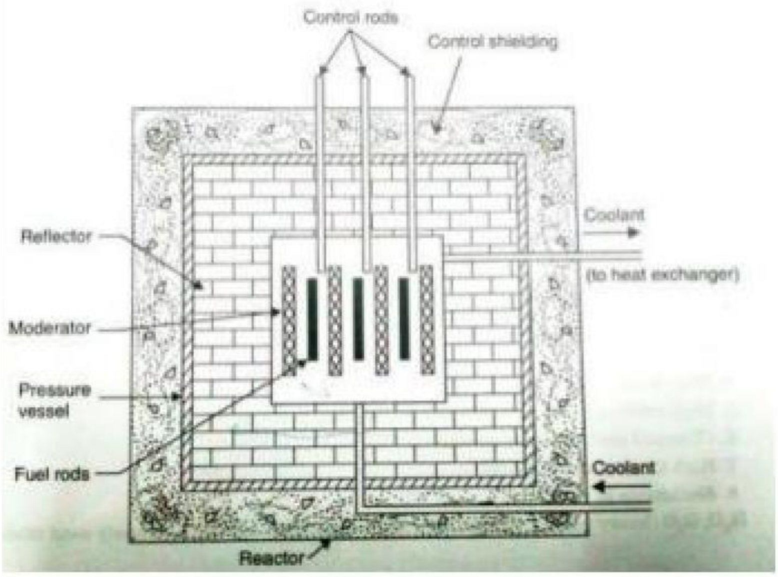
Energy from Nuclear Reactions: The sum of masses of protons and neutrons exceeds the mass ofthe atomic nucleus and this difference is called mass defect Δm. Ina nuclear reaction the mass defect is converted into energy known as binding energy according to Einstein's equation (E=Δm c2). Fissioning one amu of mass results in release of 931 MeV of energy. It has been found that element having higher and lower mass numbers are unstable. Thus the lower mass numbers can be fused or the higher mass numbers can be fissioned to produce more stable elements. This results in two types of nuclear reactions known as fusion and fission. The total energy per fission reaction of U235 is about 200 MeV. Fuel burn-up rate is the amount of energy in MW/days produced by each metric ton of fuel.

Nuclear Fission When unstable heavy nuclei are bombarded with high energy neutrons, it splits into severalsmaller fragments. These fragments, or fission products, are about equalto half the original mass. This process is called Nuclear Fission. Two or three neutrons are also emitted.Thesumofthe massesofthese fragmentsis lessthantheoriginalmass. This missing mass (about 0.1 percent of the original mass) has been converted into energy. Fission can occur when a nucleus of a heavy atom captures a neutron, or it can happen spontaneously.

Nuclear Fusion Fusion :is the opposite of fission, it is the joining together of two lightnuclei to form a heavier one (plus a small fragment). For example if two 2H nuclei (two deuterons) can be made to come together they can form He and a neutron

NUCLEAR POWER REACTORS A nuclear reactor produces and controls the release of energy from splitting the atoms of elements such as uranium and plutonium. In a nuclear power reactor, the energy released from continuous fission of the atoms in the fuel as heat is used to make steam. The steam is used to drive the turbines which produce electricity (as in most fossil fuel plants).

There are several components common to most types of reactors: Fuel Usually pellets of uranium oxide (UO2) arranged in tubes to form fuel rods. The rods are arranged into fuel assemblies in the reactor core. Moderator This is material which slows down the neutrons released from fission so that they cause more fission. It is usually water, but may be heavy water or graphite.



ControlRods These are made withneutron-absorbing materialsuchas cadmium, hafniumor boron, and are insertedor withdrawn fromthe core to controlthe rateofreaction, orto halt it. (Secondaryshutdownsystems involve adding other neutron absorbers, usually in the primary cooling system.)

Coolant A liquid orgas circulating throughthe core so astotransfer the heat fromit. Inlight water reactors the moderator functions also as coolant.

Pressure Vessel or **Pressure Tubes** Usually a robust steel vessel containing the reactor core and moderator/coolant, but it may be aseries of tubes holding the fuel and conveying the coolant through the moderator.

Steam Generator Part ofthe cooling systemwhere the heat fromthe reactor is used to make steam for the turbine.

Reflectors Some of the neutrons produced during fission will be partly absorbed by the fuel elements, moderator, coolant and other materials. The remaining neutrons will try to escape from the reactor and will be lost. Such losses are minimized by surrounding (lining) the reactor core with a materialcalled a reflector which will reflect the neutrons back to the core. They improve the neutron economy. Economy: Graphite, Beryllium.

Shielding During Nuclear fission σ α γ particles and neutrons are also produced. They are harmfulto human life. Therefore it is necessaryto shield the reactorwiththick layers oflead, or concrete to protect both the operating personnel as well as environment from radiation hazards.

MechanicalPowerTransmission:

BELT,ROPEANDCHANINDRIVES:

The belt or ropes are used to transmit power from one shaft by means of pulley which rotates at same speed or different speed. The amount of power transmission depends upon the following factors:

1. Velocityofbelts.
2. Thetensionunderwhichthebeltisplacedonthepulley.
3. Thearcof contactbetween thebeltandthesmallerpilley.
4. Theconditionsunderwhichthebeltisuseditmaybenoted:

a. Theshaftsshouldbe properlyinlinetoinsureuniformtensionacrossthebelttension.

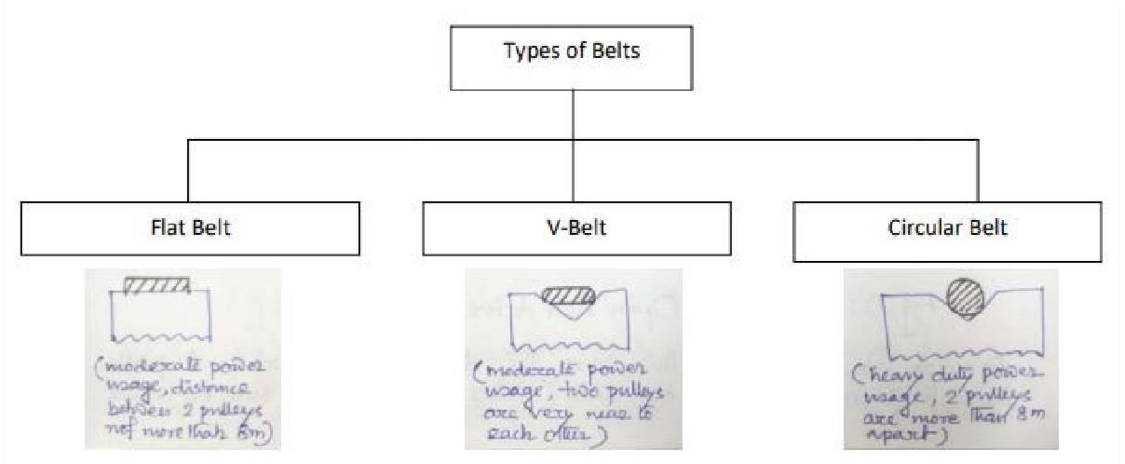
b. Thepulleyshouldnotbetooclosetogetherinorderthatthearcofcontactonthesmaller pulley may be as large as possible.

c. The pulleys should not be so far apart as to cause the belt to weigh heavily on the shafts, thus increasing the friction load on the bearing.

d. Along belttends to swing from side to side causingthe beltto run outof the pulleys,which in turn develops crooked spot in the belt.

e. Thetightsideofthebeltshouldbeatthebottom,sothatwhateversagispresentonthe loose side will increase the arc on the pulley.

Selection ofBelt Drive: Followings are the various importantfactors upon which the selection of a belt drive depends: a) Speed of the driving and driven shafts. b) Speed reduction ratio. c)Power to be transmitted. d) Centre distance between the shafts. e) Positive drive requirements.
f)Shaftslayout.g)Spaceavailable.h)Serviceconditions.



Materials used for Belts:

a. Leather belts
b. Cotton or fabric belts
c. Rubber belts
d. Balata belts (Similar to rubber bets, only balata gum is used in place of rubber. It generally works at a temperature below 40^{o} for optimum use.)

Types of flat belt drives:

1. **Open belt drive:** The open belt drive as shown in the below fig. is used with shafts arranged parallel and rotating in same direction. In this case, the driven A pulls the belt from one side (lower side RQ) and delivers it to the other side (upper side LM). Thus the tension in the lower side belt will be more than that of the upper side of belt. The lower side due to more tension is known as tight side & the upper side is known as slack side.

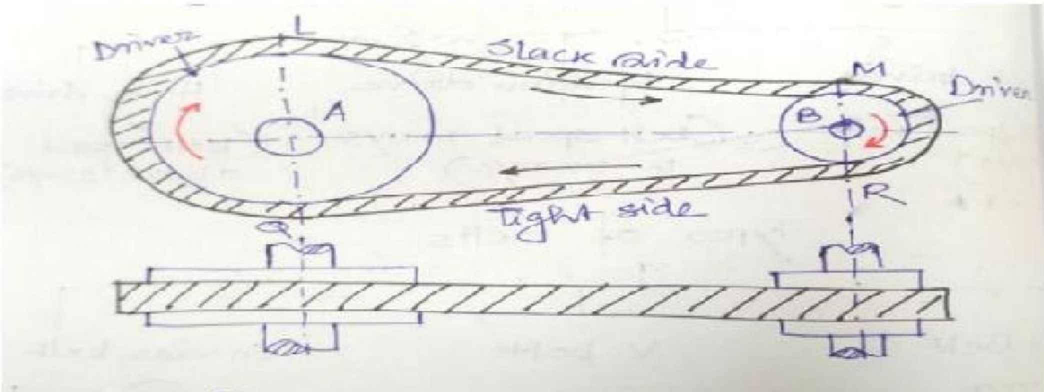
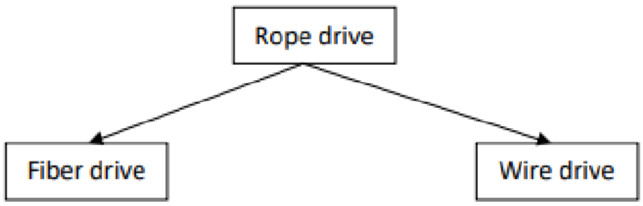


Fig (1): Open belt drive

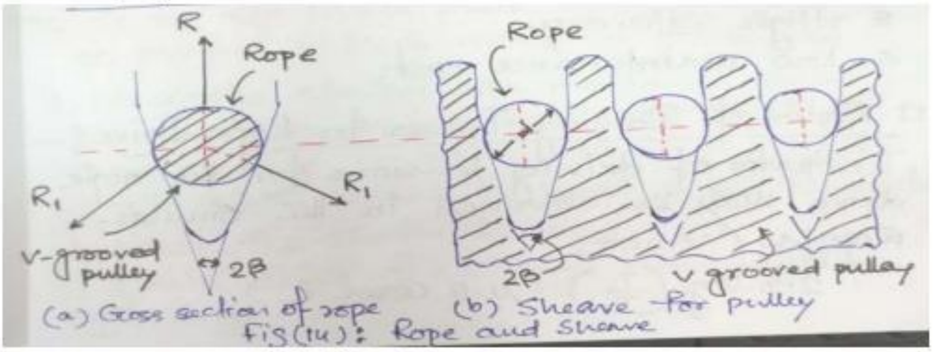
Rope drive: the rope drive widely used where a large amount of power is to be transmitted from one pulley to another, over a considerable distance. One of the main advantages of rope drives is that a number of separate drives may be taken from one driver pulley.



Advantages of fiber rope drives:

- They give smooth, steady and quite service.
- They are little effected by the outdoor condition.
- The power may be taken off in any direction and in fractional parts of the whole amount.
- The shaft may be out of strict alignment.
- They give high mechanical efficiency.

Sheave for fiber ropes:



The fiber ropes are usually circular is cross section as shown in fig. The sheave for fiber ropes shown in fig. 14(b). the groove angle of the pulley for rope drives is usually 45^0. The groves in the pulleys are made narrow at the bottom and the rope is pinched between the edges of the V-groove on the pulley.

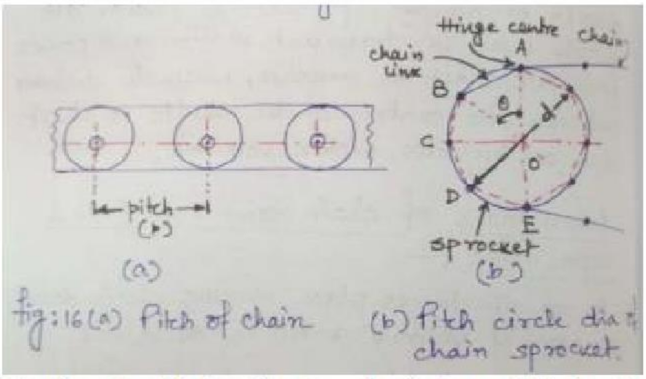
Wire ropes: When a large amount of power is to be transmitted over long distance from one pulley to another (that is if two pulleys are 150m apart) then wire ropes are used. The wire ropes are widely used in elevators, mine hoist, cranes, hauling devices etc.

Advantages:

- Lighter in weight
- These offer silent operation
- Can withstand shock load
- More efficiency

Chain drive terms & definition:

- Pitch of Chain: It is the distance between two consecutive hinge centers of two adjacent links as shown in the fig.16(a)



- Pitch circle diameter: It is the diameter of a circle on which the hinge centers of the chain lie, when the chain is wrapped around a sprocket as shown in fig. 16(b)

The points A,B,C,D,E etc. are the hinge centers of the chain and the circle drawn through these centers is called <u>pitch circle</u> and its dia. is known as pitch circle dia.

Length of Chain: An open chain drive system, connecting two sprockets shown fig.

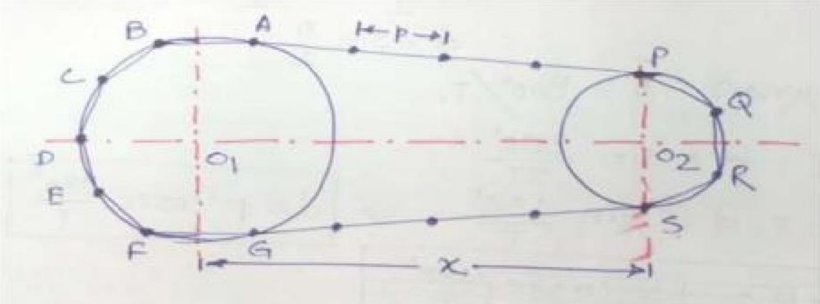
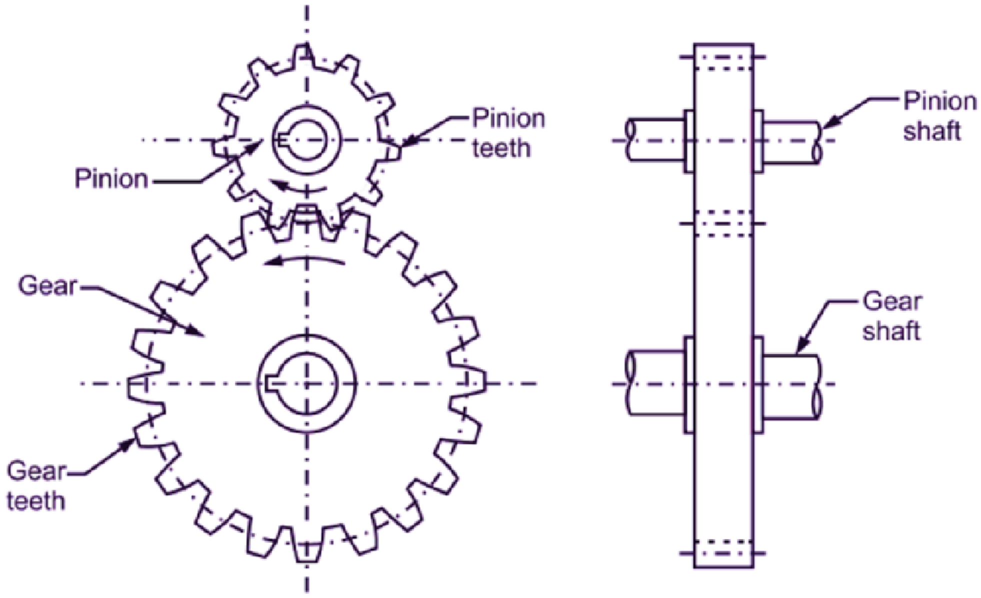


Fig 1E: Length of chain

Geardrive:

Gear drive is used, when centre to centre distance between driver and driven shafts is very small. Gears are defined as, "toothed wheels, which can transmit power and motion from one shaft to another shaft by means of successive engagement of teeth. "



It is important to note that, both the gears, which are engaged, always rotate in opposite direction. Gear drive consists of two wheels. The smaller wheel is called as pinion and the larger wheel is called as gear. Refer Fig. 1. In gear drive, slip is absent. Therefore, it gives exact and uniform velocity ratio. Due to this ability of maximum power transmission and exact velocity ratio, gear drive is called as perfect positive drive.

Advantages of Gear Drive

1. Exact velocity ratio.
2. High efficiency.
3. Compact layout.
4. Ability of transmitting large power.
5. Reliable service.

Applications of Gear Drive

1. Gear box of vehicle,
2. Machine tools,
3. Dial indicator,
4. Gear mechanism of wrist watches,
5. Differential mechanism of automobile,
6. Cement mixing unit.

IntroductiontoRobotics

DefinitionforRobot: TheRobotInstituteof America(1969)definesrobot asa re-programmable, multifunctional manipulator designed to move materials, parts, tools or specialized devices through various programmed motions for the performance of a variety of tasks‖. Asimov’s laws of robotics:

1. Arobotmaynotinjureahumanbeingor,throughinaction,allowahumanbeingtocome toharm.
2. Arobotmustobeytheordersgivenitbyhumanbeingsexceptwheresuchorders wouldconflict with the First Law.
3. Arobotmustprotectitsownexistenceaslongassuchprotectiondoesnotconflictwith theFirst or SecondLaws.

ROBOT ANATOMY

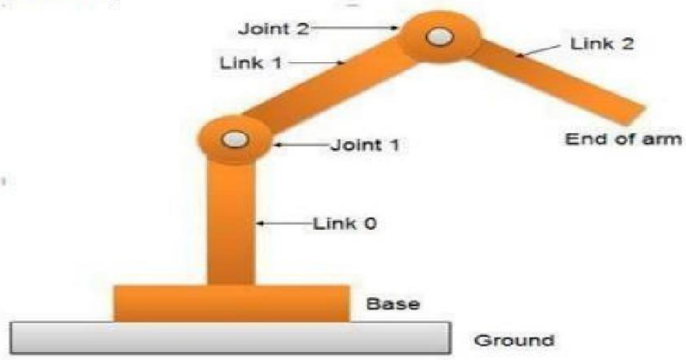


Fig. 1.1 Joint-link scheme for robot manipulator

Joints and Links:

The manipulator of an industrial robot consists of a series of joints and links. Robot anatomy deals with the study of different joints and links and other aspects of the manipulator's physical construction. A robotic joint provides relative motion between two links of the robot. Each joint, oraxis, provides a certain degree-of-freedom (dof) of motion. In most of the cases, only one degree-of- freedom is associated with each joint. Therefore the robot's complexity can be classified according tothe total number of degrees-of-freedom they possess.

Each joint is connected to two links, an input link and an output link. Joint provides controlled relative movement between the input link and output link. A robotic link is the rigid component of the robot manipulator. Most of the robots are mounted upon a stationary base, such as the floor. From this base, a joint-link numbering scheme may be recognized as shown in Figure 1.1. The robotic base and its connection to the first joint are termed as link-0. The first joint in the sequence is joint-1. Link-0 is the input link for joint-1, while the output link from joint-1 is link-1 which leads to joint-2. Thus link 1 is,simultaneously, the output link for joint-1 and the input link for joint-2. This joint-link-numbering scheme is further followed for all joints and links in the robotic systems

Typesof joints:

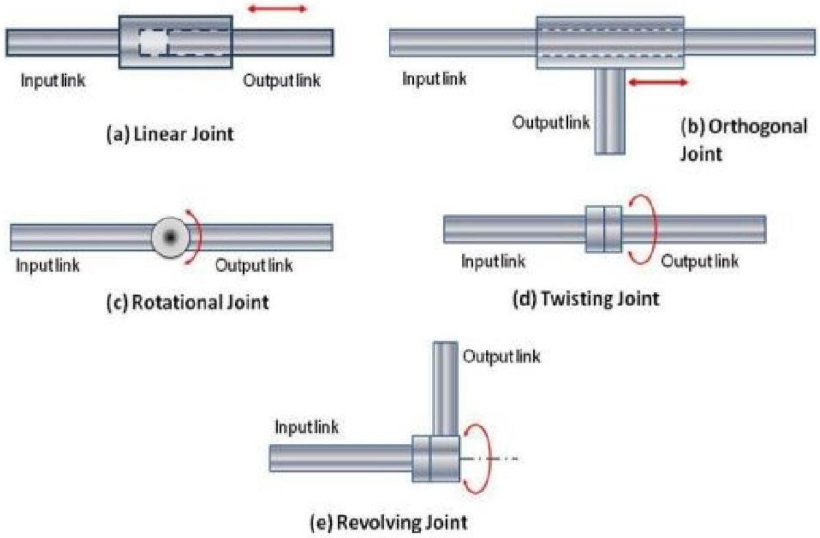
a) Linear joint (typeLjoint)Therelative movement betweenthe input linkandtheoutput link is a translational slidingmotion, with the axes of the two links being parallel.

b) Orthogonaljoint (typeU joint)Thisisalso atranslationalsliding motion, butthe input and output links are perpendicular toeach other during the movement.

c) Rotational joint (type R joint) This type provides rotational relative motion, with theaxis of rotation perpendicular to the axesof the input and output links.

d) Twistingjoint(typeTjoint)Thisjointalsoinvolvesrotarymotion,buttheaxisor rotation is parallel to the axes of the twolinks.

Nearly all industrial robots have mechanical joints that can be classified into following five types asshown in Figure 1.2.

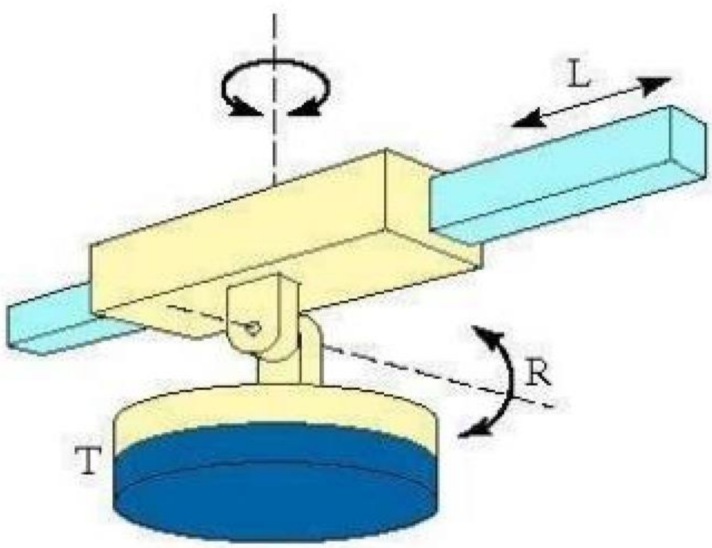


e) Revolving joint (type V-joint, V from the "v" inrevolving) In this type, axis of input link is parallel tothe axis of rotation of the joint. However the axis ofthe outputlink is perpendicular to the axis of rotation.

Robotic arm configurations: For body-and-arm configurations, there are many different combinations possible for a three-degree-of-freedom robot manipulator, comprising any of the five joint types. Common body-and-arm configurations are as follows.

1) Polarcoordinatearmconfiguration
2) Cylindricalcoordinatearmconfiguration
3) Cartesiancoordinatearmconfiguration
4) Jointedarmconfiguration.

1) Polar coordinate arm configuration(RRP):

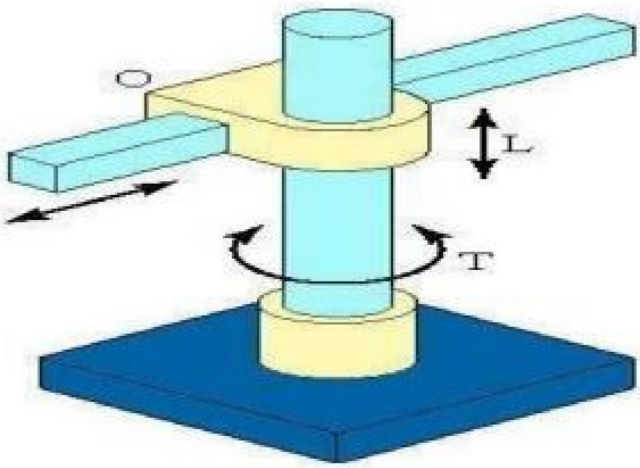


The polar arm configuration is shown It consist sof a prismatic joint that can be raised or lowered about a horizontal revolute joint. The two links are mounted on a rotating base. These various joints provide the capability of moving the arm endpoint within a partial spherical space. Therefore it is called as Spherical coordinated configuration. This configuration allows manipulation of objects on the floor.

Drawbacks: i. Low mechanical stiffness ii. Complex construction iii. Position accuracy decreases with the increasing radial stroke.

Applications: Machining, spraypaintingExample:Unimate2000series,MAKER110.

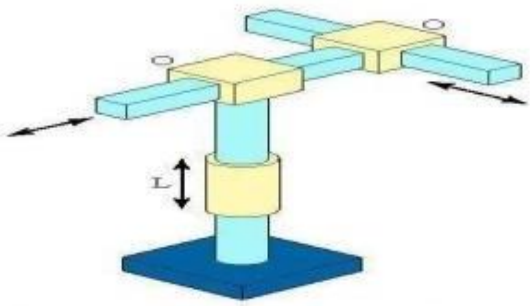
2) Cylindrical coordinate arm configuration (RPP):



The cylindrical configuration uses two perpendicular prismatic joints and a revolute joint as shown in This configuration uses a vertical column and a slide that can be moved up or downalong the column. The robot arm is attached to the slide, so that it can be moved radially with respect to column. By rotating the column, the robot is capable of achieving a workspace that approximates a cylinder. The cylindrical configuration offers good mechanical stiffness.

Drawback: Accuracydecreasesasthehorizontalstrokeincreases.
Applications:suitabletoaccessnarrowhorizontalcapabilities,henceusedformachine loadingoperations.
Example:GMFmodelM-1A

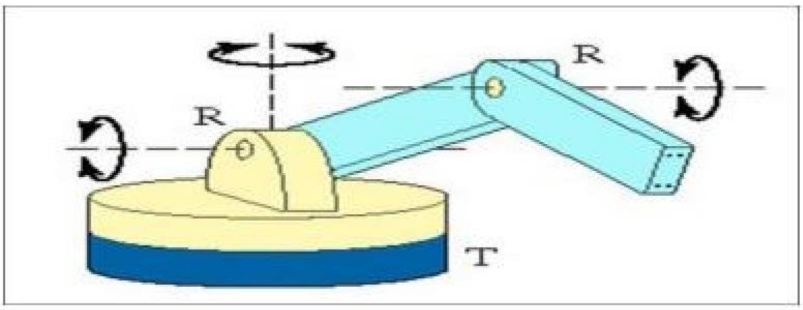
3) Cartesian coordinate arm configuration (PPP):



Cartesiancoordinateorrectangularcoordinateconfigurationisconstructedbythree perpendicularslides,givingonlylinearmotionsalongthethreeprincipalaxes.Itconsistsof threeprismaticjoints. Theendpointsofthearmarecapableofoperatinginacuboidalspace.Cartesian arm gives high precision and is easy to program.

Drawbacks:olimitedmanipulatabilityolowdexterity(notabletomovequicklyandeasily)
Applications:usetoliftandmoveheavyloads.Example:IBMRS-1.

4) Jointed arm configuration (RRR) or articulated configuration:



jointed arm configurations are similar to that of human arm. It consists of two straight links, corresponding to human fore arm and upper arm with two rotary joint 11 corresponding to the elbow and shoulder joints. These two are mounted on a vertical rotary table corresponding to human waist joint. The work volume is spherical. This structure is the most dexterous one.

Thisconfigurationisverywidelyused.
Applications: Arc welding, Spray coating. Example: SCARA robot (Selective compliance Assembly Robot Arm

Introduction to Operations Research

1.1 Introduction

Operations Research (OR) is a discipline that deals with the application of advanced analytical methods to help make better decisions. The roots of OR can be traced back to World War II when scientists and mathematicians were called upon to solve complex military problems. Today, OR is used in a wide range of industries, from logistics and manufacturing to healthcare and finance.

1.2 Definition and Scope of Operations Research

Operations Research is often defined as the application of mathematical models, statistical analyses, and optimization techniques to decision-making processes. It involves the use of various scientific tools and techniques to solve problems that involve the allocation of limited resources.

The scope of OR is broad and includes:

1. **Optimization:** Finding the best possible solution among a set of feasible solutions.
2. **Simulation:** Modeling complex systems to understand their behavior and evaluate the impact of different strategies.

3. **Decision Analysis:** Using structured techniques to evaluate and compare different decision alternatives under uncertainty.
4. **Queuing Theory:** Analyzing waiting lines or queues to optimize service efficiency.
5. **Inventory Theory:** Managing stock levels to minimize costs while meeting demand.
6. **Game Theory:** Studying strategic interactions where the outcome for each participant depends on the actions of others.
7. **Network Analysis:** Optimizing networks such as supply chains, telecommunications, and transportation

1.3 History of Operations Research

The formal beginning of OR is usually traced back to the Second World War. During the war, military leaders sought the expertise of scientists to solve complex logistical and strategic problems, such as optimizing the deployment of radar, improving the effectiveness of anti-aircraft systems, and maximizing the efficiency of supply chains. The success of these efforts led to the post-war expansion of OR into the civilian sector.

1.4 Key Concepts and Techniques in Operations Research

Operations Research involves a variety of mathematical and analytical techniques:

1. **Linear Programming (LP):** A mathematical method for determining the best allocation of resources in a problem where the objective and constraints are linear.
2. **Integer Programming:** A type of LP where some or all the decision variables are constrained to take on integer values, often used in scheduling, routing, and allocation problems.
3. **Non-linear Programming:** Deals with optimization problems where the objective function or constraints are non-linear, making them more complex to solve.
4. **Dynamic Programming:** A method for solving complex problems by breaking them down into simpler subproblems, particularly useful for multistage decision processes.
5. **Stochastic Models:** These models incorporate randomness and uncertainty, making them suitable for problems where outcomes are not deterministic.
6. **Network Models:** Involves the optimization of networks, focusing on problems like the shortest path, maximum flow, and minimum spanning tree.

1.5 Applications of Operations Research

OR has been successfully applied in various industries:

- **Manufacturing:** Optimizing production schedules, minimizing waste, and managing supply chains.
- **Transportation:** Planning routes, scheduling flights, and managing logistics networks.
- **Healthcare:** Improving patient flow, optimizing resource allocation, and managing inventory in hospitals.
- **Finance:** Portfolio optimization, risk management, and pricing strategies.
- **Telecommunications:** Network design, traffic management, and capacity planning.

1.6 The OR Process

The typical OR process involves several key steps:

1. **Problem Definition:** Clearly defining the problem to be solved, including identifying the objectives, constraints, and decision variables.

2. **Model Construction:** Developing a mathematical model that represents the problem, including the objective function and constraints.
3. **Data Collection:** Gathering the necessary data to populate the model, including historical data, estimates, and expert opinions.
4. **Model Solution:** Applying appropriate techniques to solve the model and obtain an optimal or satisfactory solution.
5. **Validation and Testing:** Ensuring that the model accurately represents the real-world problem and that the solution is feasible and effective.
6. **Implementation:** Applying the solution in the real world and monitoring the results to ensure it achieves the desired outcomes.

1.7 Challenges and Limitations of Operations Research

While OR offers powerful tools for decision-making, it is not without its challenges:

- **Data Quality:** The effectiveness of OR models depends heavily on the accuracy and completeness of the data used.
- **Complexity:** Some problems are too complex to model accurately, or the models may be too computationally intensive to solve in a reasonable time.
- **Uncertainty:** Many real-world problems involve uncertainty, making it difficult to predict outcomes with precision.
- **Human Factors:** The implementation of OR solutions often requires changes in human behavior, which can be difficult to achieve.

1.8 Future Trends in Operations Research

The field of OR continues to evolve, with several emerging trends:

- **Big Data:** The increasing availability of large datasets is providing new opportunities for more accurate and comprehensive OR models.
- **Artificial Intelligence (AI):** Integrating AI with OR techniques is leading to more adaptive and intelligent decision-making systems.
- **Sustainability:** OR is being increasingly applied to environmental and sustainability challenges, such as optimizing resource use and reducing waste.
- **Globalization:** The growing interconnectedness of the world economy is creating new opportunities and challenges for OR, particularly in supply chain management.

1.9 Conclusion

Operations Research is a dynamic and evolving field that offers powerful tools for solving complex problems and making better decisions. Its applications are diverse, spanning industries and sectors, and its importance is only expected to grow as new challenges and opportunities emerge in our increasingly complex world.

Manufacturing Process- Casting

Metal Casting

Virtually nothing moves, turns, rolls, or flies without the benefit of cast metal products. The metal casting industry plays a key role in all the major sectors of our economy. There are castings in locomotives, cars trucks, aircraft, office buildings, factories, schools, and homes. The following Fig

1. shows some metal cast parts.

Metal Casting is one of the oldest materials shaping methods known. Casting means pouring molten metal into a mold with a cavity of the shape to be made, and allowing it to solidify. When solidified, the desired metal object is taken out from the mold either by breaking the mold or taking the mold apart. The solidified object is called the casting. By this process, intricate parts can be given strength and rigidity frequently not obtainable by any other manufacturing process. The mold, into which the metal is poured, is made of some heat resisting material. Sand is most often used as it resists the high temperature of the molten metal. Permanent molds of metal can also be used to cast products.

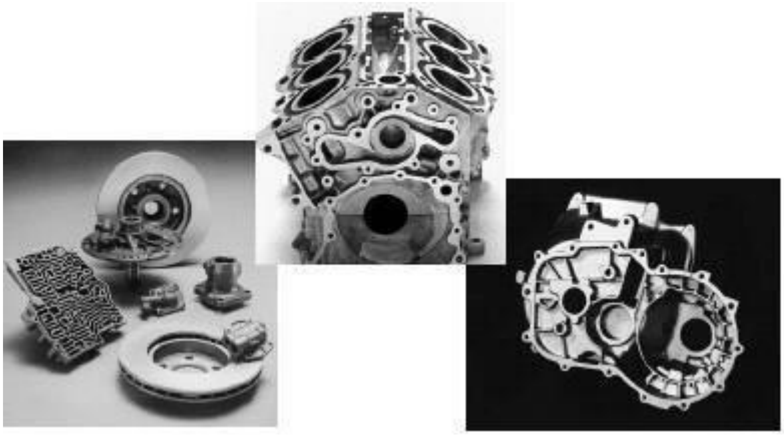


Fig. 1: Metal Cast parts

Advantages

The metal casting process is extensively used in manufacturing because of its many advantages.

1. Molten material can flow into very small sections so that intricate shapes can be made by this process. As a result, many other operations, such as machining, forging, and welding, can be minimized or eliminated.
2. It is possible to cast practically any material that is ferrous or non-ferrous.
3. As the metal can be placed exactly where it is required, large saving in weight can be achieved.
4. The necessary tools required for casting molds are very simple and inexpensive. As a result, for production of a small lot, it is the ideal process.
5. There are certain parts made from metals and alloys that can only be processed this way.
6. Size and weight of the product is not a limitation for the casting process.

Limitations

1. Dimensional accuracy and surface finish of the castings made by sand casting processes area limitation to this technique. Many new casting processes have been developed which cantake into consideration the aspects of dimensional accuracy and surface finish. Some of these processes are die casting process, investment casting process, vacuum-sealed molding process, and shell molding process.

2. The metal casting process is a labor intensive process.

The details can also be seen in the Fig. 2 below**:**

- Initially a suitable size of molding box for creating suitable wall thickness is selected for a two piece pattern. Sufficient care should also be taken in such that sense that the molding box must adjust mold cavity, riser and the gating system (sprue, runner and gates etc.).
- Next, place the drag portion of the pattern with the parting surface down on the bottom (ram- up) board as shown in Fig. 2 (a).
- The facing sand is then sprinkled carefully all around the pattern so that the pattern doesnot stick with molding sand during withdrawn of the pattern.
- The drag is then filled with loose prepared molding sand and ramming of the molding sand is done uniformly in the molding box around the pattern. Fill the molding sand once again and then perform ramming. Repeat the process three four times,
- The excess amount of sand is then removed using strike off bar to bring molding sand atthe same level of the molding flask height to completes the drag.
- The drag is then rolled over and the parting sand is sprinkled over on the top of the drag[Fig. 2(b)].
- Now the cope pattern is placed on the drag pattern and alignment is done using dowel pins.
- Then cope (flask) is placed over the rammed drag and the parting sand is sprinkled all around the cope pattern.
- Sprue and riser pins are placed in vertically position at suitable locations using support of molding sand. It will help to form suitable sized cavities for pouring molten metal etc. [Fig. 2 (c)].
- The gaggers in the cope are set at suitable locations if necessary. They should not be located too close to the pattern or mold cavity otherwise they may chill the casting and fill the cope with molding sand and ram uniformly.
- Strike off the excess sand from the top of the cope.
- Remove sprue and riser pins and create vent holes in the cope with a vent wire. The basic purpose of vent creating vent holes in cope is to permit the escape of gases generated during pouring and solidification of the casting.
- Sprinkle parting sand over the top of the cope surface and roll over the cope on the bottom board.
- Rap and remove both the cope and drag patterns and repair the mold suitably if needed and dressing is applied
- The gate is then cut connecting the lower base of sprue basin with runner and then the mold cavity.
- Apply mold coating with a swab and bake the mold in case of a dry sand mold.
- Set the cores in the mold, if needed and close the mold by inverting cope over drag.
- The cope is then clamped with drag and the mold is ready for pouring, [Fig. 2 (d)].

1. **Flask:** A metal or wood frame, without fixed top or bottom, in which the mold is formed. Depending upon the position of the flask in the molding structure, it is referred to by various names such as drag – lower molding flask, cope – upper molding flask, cheek – intermediate molding flask used in three piece molding.

2. **Pattern:** It is the replica of the final object to be made. The mold cavity is made with the help of pattern.

3. **Parting line:** This is the dividing line between the two molding flasks that makes up the mold.

4. **Molding sand:** Sand, which binds strongly without losing its permeability to air or gases. Itis a mixture of silica sand, clay, and moisture in appropriate proportions.

5. **Facing sand:** The small amount of carbonaceous material sprinkled on the inner surfaceof the mold cavity to give a better surface finish to the castings.

6. **Core:** A separate part of the mold, made of sand and generally baked, which is used to create openings and various shaped cavities in the castings.

7. **Pouring basin:** A small funnel shaped cavity at the top of the mold into which the molten metal is poured.

8. **Sprue:** The passage through which the molten metal, from the pouring basin, reaches the mold cavity. In many cases it controls the flow of metal into the mold.

9. **Runner:** The channel through which the molten metal is carried from the sprue to thegate.

10. **Gate:** A channel through which the molten metal enters the mold cavity.

11. **Chaplets:** Chaplets are used to support the cores inside the mold cavity to take care of its own weight and overcome the metallostatic force.

12. **Riser**: A column of molten metal placed in the mold to feed the castings as it shrinks and solidifies. Also known as "feed head".

13. **Vent:** Small opening in the mold to facilitate escape of air and gases.

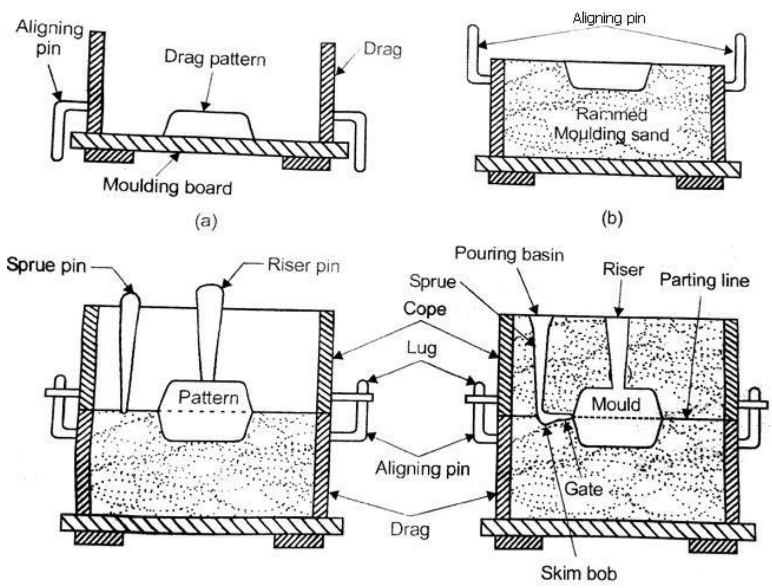


Fig. 2: Steps for making a mould cavity

PATTERN

A pattern is a model or the replica of the object (to be casted). It is embedded in molding sand and suitable ramming of molding sand around the pattern is made. The pattern is then withdrawn for generating cavity (known as mold) in molding sand. Thus it is a mould forming tool. Pattern can be said as a model or the replica of the object to be cast except for the various al1owances a pattern exactly resembles the casting to be made. It may be defined as a model or form around which sand ispacked to give rise to a cavity known as mold cavity in which when molten metal is poured, the resultis the cast object. When this mould/cavity is filled with molten metal, molten metal solidifies and produces a casting (product). So the pattern is the replica of the casting.

OBJECTIVES OF A PATTERN

1. Pattern prepares a mould cavity for the purpose of making a casting.
2. Pattern possesses core prints which produces seats in form of extra recess for core placementin the mould.
3. It establishes the parting line and parting surfaces in the mould.
4. Runner, gates and riser may form a part of the pattern.
5. Properly constructed patterns minimize overall cost of the casting.
6. Pattern may help in establishing locating pins on the mould and therefore on the casting witha purpose to check the casting dimensions.
7. Properly made pattern having finished and smooth surface reduce casting defects.

Patterns are generally made in pattern making shop. Proper construction of pattern and its material may reduce overal1 cost of the castings.

COMMON PATTERN MATERIALS

The common materials used for making patterns are wood, metal, plastic, plaster, wax or mercury. The some important pattern materials are discussed as under.

1. *Wood*

Wood is the most popular and commonly used material for pattern making. It is cheap, easily availablein abundance, repairable and easily fabricated in various forms using resin and glues. It is very light and can produce highly smooth surface. Wood can preserve its surface by application of a shellac coating for longer life of the pattern. But, in spite of its above qualities, it is susceptible to shrinkage and warpage and its life is short because of the reasons that it is highly affected by moisture of the molding sand. After some use it warps and wears out quickly as it is having less resistance to sand abrasion.

It can not withstand rough handily andis weak in comparison to metal. In the light of above qualities,wooden patterns are preferred only when the numbers of castings to be produced are less. The mainvarieties of woods used in pattern-making are shisham, kail, deodar, teak and mahogany.

Shisham

It is dark brown in color having golden and dark brown stripes. It is very hard to work and blunts the cutting tool very soon during cutting. It is very strong and durable. Besides making pattern, it is also used for making good variety of furniture, tool handles, beds, cabinets, bridge piles, plywood etc.

Kail

It has too many knots. It is available in Himalayas and yields a close grained, moderately hard anddurable wood. It can be very well painted. Besides making pattern, it is also utilized for making wooden doors, packing case, cheap furniture etc.

Deodar

It is white in color when soft but when hard, its color turns toward light yellow. It is strong and durable. It gives fragrance when smelled. It has some quantity of oil and therefore it is not easily attacked by insects. It is available in Himalayas at a height from 1500 to 3000 meters. It is used for making pattern, manufacturing of doors, furniture, patterns, railway sleepers etc. It is a soft wood having a close grain structure unlikely to warp. It is easily workable and its cost is also low. It is preferred for making pattern for production of small size castings in small quantities.

Teak Wood

It is hard, very costly and available in golden yellow or dark brown color. Special stripes on it add to its beauty. In India, it is found in M.P. It is very strong and durable and has wide applications. It can maintain good polish. Besides making pattern, it is used for making good quality furniture, plywood, ships etc. It is a straight-grained light wood. It is easily workable and has little tendency to warp. Its cost is moderate.

Mahogany

This is a hard and strong wood. Patterns made of this wood are more durable than those of above mentioned woods and they are less likely to warp. It has got a uniform straight grain structure and it can be easily fabricated in various shapes. It is costlier than teak and pine wood, It is generally not preferred for high accuracy for making complicated pattern. It is also preferred for production of small size castings in small quantities. The other Indian woods which may also be used for pattern making are deodar, walnllt, kail, maple, birch, cherry and shisham.

Advantages of wooden patterns

1. Wood can be easily worked.
2. It is light in weight.
3. It is easily available.
4. It is very cheap.
5. It is easy to join.
6. It is easy to obtain good surface finish.
7. Wooden laminated patterns are strong.
8. It can be easily repaired.

Disadvantages

1. It is susceptible to moisture.
2. It tends to warp.
3. It wears out quickly due to sand abrasion.
4. It is weaker than metallic patterns.

2. *Metal*

Metallic patterns are preferred when the number of castings required is large enough to justify their use. These patterns are not much affected by moisture as wooden pattern. The wear and tear of this pattern is very less and hence posses longer life. Moreover, metal is easier to shape the pattern with good precision, surface finish and intricacy in shapes. It can withstand against corrosion and handling for longer period. It possesses excellent strength to weight ratio. The main disadvantages of metallic patterns are higher cost, higher weight and tendency of rusting. It is preferred for production of castings in large quantities with same pattern. The metals commonly used for pattern making are

cast iron, brass and bronzes and aluminum alloys.

Cast Iron

It is cheaper, stronger, tough, and durable and can produce a smooth surface finish. It also possesses good resistance to sand abrasion. The drawbacks of cast iron patterns are that they are hard, heavy, brittle and get rusted easily in presence of moisture.

Advantages

1. It is cheap
2. It is easy to file and fit
3. It is strong
4. It has good resistance against sand abrasion
5. Good surface finish

Disadvantages

1 It is heavy

2 It is brittle and hence it can be easily broken

3 It may rust

Brasses and Bronzes

These are heavier and expensive than cast iron and hence are preferred for manufacturing small castings. They possess good strength, machinability and resistance to corrosion and wear. They can produce a better surface finish. Brass and bronze pattern is finding application in making match plate pattern

Advantages

1. Better surface finish than cast iron.
2. Very thin sections can be easily casted.

Disadvantages

1. It is costly
2. It is heavier than cast iron.

Aluminum Alloys

Aluminum alloy patterns are more popular and best among all the metallic patterns because of their high light ness, good surface finish, low melting point and good strength. They also possesses good resistance to corrosion and abrasion by sand and there by enhancing longer life of pattern. These materials do not withstand against rough handling. These have poor repair ability and are preferred for making large castings.

Advantages

1. Aluminum alloys pattern does not rust.
2. They are easy to cast.
3. They are light in weight.
4. They can be easily machined.

Disadvantages

1. They can be damaged by sharp edges.
2. They are softer than brass and cast iron.
3. Their storing and transportation needs proper care.

White Metal (Alloy of Antimony, Copper and Lead)

Advantages

1. It is best material for lining and stripping plates.
2. It has low melting point around 260°C
3. It can be cast into narrow cavities.

Disadvantages

1. It is too soft.
2. Its storing and transportation needs proper care
3. It wears away by sand or sharp edges.

3. Plastic

Plastics are getting more popularity now a days because the patterns made of these materials are lighter, stronger, moisture and wear resistant, non sticky to molding sand, durable and they are notaffected by the moisture of the molding sand. Moreover they impart very smooth surface finish on the pattern surface. These materials are somewhat fragile, less resistant to sudden loading and theirsection may need metal reinforcement. The plastics used for this purpose are thermosetting resins. Phenolic resin plastics are commonly used. These are originally in liquid form and get solidified whenheated to a specified temperature. To prepare a plastic pattern, a mould in two halves is prepared inplaster of paris with the help of a wooden pattern known as a master pattern. The phenolic resin is poured into the mould and the mould is subjected to heat. The resin solidifies giving the plastic pattern. Recently a new material has stepped into the field of plastic which is known as foam plastic.Foam plastic is now being produced in several forms and the most common is the expandable polystyrene plastic category. It is made from benzene and ethyl benzene.

4. Plaster

This material belongs to gypsum family which can be easily cast and worked with wooden tools andpreferable for producing highly intricate casting. The main advantages of plaster are that it has highcompressive strength and is of high expansion setting type which compensate for the shrinkage allowance of the casting metal. Plaster of paris pattern can be prepared either by directly pouring the slurry of plaster and water in moulds prepared earlier from a master pattern or by sweeping it into desired shape or form by the sweep and strickle method. It is also preferred for production of small size intricate castings and making core boxes.

5. Wax

Patterns made from wax are excellent for investment casting process. The materials used are blends of several types of waxes, and other additives which act as polymerizing agents, stabilizers, etc. Thecommonly used waxes are paraffin wax, shellac wax, bees-wax, cerasin wax, and micro-crystalline wax. The properties desired in a good wax pattern include low ash content up to 0.05 per cent, resistant to the primary coat material used for investment, high tensile strength and hardness, and substantial weld strength. The general practice of making wax pattern is to inject liquid or semi- liquid wax into a split die. Solid injection is also used to avoid shrinkage and for better strength. Waxes use helps in imparting a high degree of surface finish and dimensional accuracy castings. Waxpatterns are prepared by pouring heated wax into split moulds or a pair of dies. The dies after havingbeen cooled down are parted off. Now the wax pattern is taken out and used for molding. Such patterns need not to be drawn out solid from the mould. After the mould is ready, the wax is pouredout by heating the mould and keeping it upside down. Such patterns are generally used in the process of investment casting where accuracy is linked with intricacy of the cast object.

Advantages of wooden patterns

1 Wood can be easily worked.

2 It is light in weight.

3 It is easily available.

4 It is very cheap.

5 It is easy to join.

6 It is easy to obtain good surface finish.

7 Wooden laminated patterns are strong.

8 It can be easily repaired.

Disadvantages

5 It is susceptible to moisture.

6 It tends to warp.

7 It wears out quickly due to sand abrasion.

8 It is weaker than metallic patterns.

TYPES OF PATTERN

The types of the pattern and the description of each are given as under.

1. One piece or solid pattern
2. Two piece or split pattern
3. Cope and drag pattern
4. Three-piece or multi- piece pattern
5. Loose piece pattern
6. Match plate pattern
7. Follow board pattern
8. Gated pattern
9. Sweep pattern
10. Skeleton pattern
11. Segmental or part pattern

Single-piece or solid pattern

Solid pattern is made of single piece without joints, partings lines or loose pieces. It is the simplest form of the pattern. Typical single piece pattern is shown in **Fig. 3**.

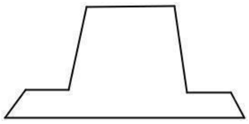


Fig. 3: Single piece pattern

Two-piece or split pattern

When solid pattern is difficult forwithdrawal from the mold cavity, then solid pattern is splited in twoparts. Split pattern is made in two pieces which are joined at the parting line by means of dowel pins.The splitting at the parting line is done to facilitate the withdrawal of the pattern. A typical example is shown in **Fig. 4.**

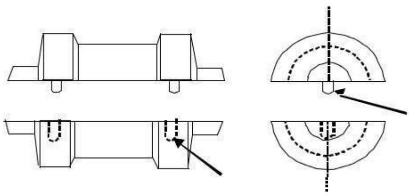
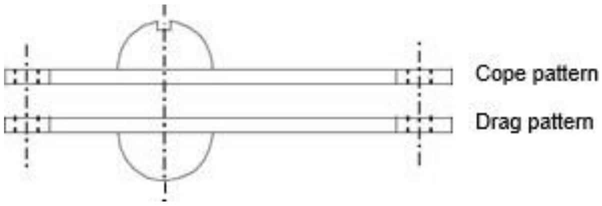


Fig. 4: Two-piece or split pattern

Cope and drag pattern

In this case, cope and drag part of the mould are prepared separately. This is done when the completemould is too heavy to be handled by one operator. The pattern is made up of two halves,which are mounted on different plates. A typical example of match plate pattern is



shown in **Fig. 5.**

Fig. 5: Cope and drag pattern

Three-piece or multi-piece pattern

Some patterns are of complicated kind in shape and hence cannot be made in one or two pieces
because of difficulty in withdrawing the pattern. Therefore these patterns are made in either three pieces or in multi- pieces. Multi molding flasks are needed to make mold from these patterns. The pattern can also be seen from the **Fig. 6.**

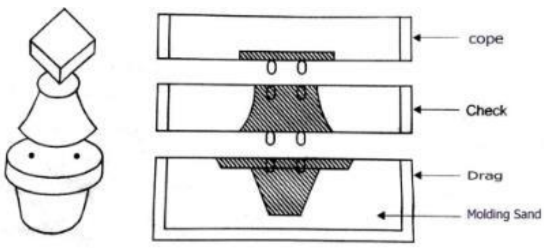


Fig. 6: Three-piece or multi-piece pattern

Loose-piece pattern

A single piece are made to have loose piece in easy to allow withdrawal from the mold the molding process are completed, after the main pattern is withdrawn leaving from that piece in the sand. Afterthe withdrawal of piece from mold, it cavity separately formed by the pattern. It loose piece pattern is highly skilled job and expensive. The pattern can also be seen from the **Fig. 7.**

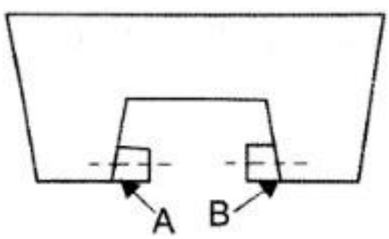


Fig. 7: Loose-piece pattern

Match plate pattern

The match plate pattern types is having two parts, one for one side and another one for another side of pattern. It is called match plate pattern. The sand casting pattern making in two pieces. It also having gates and runner attached with pattern. The molding process completed after that match plate removed together, the gating is obtained for joining the cope and drag. It pattern is mainly used for casting of metal, usually aluminum are machined in this method with light weight and machinability. It should be possible for mass production of small casting with high dimensional accuracy. They are also used for machine molding. The cost will be high of molding but it is easily compensated by high rate of production and more accuracy. The pattern can also be seen from the **Fig. 8.**

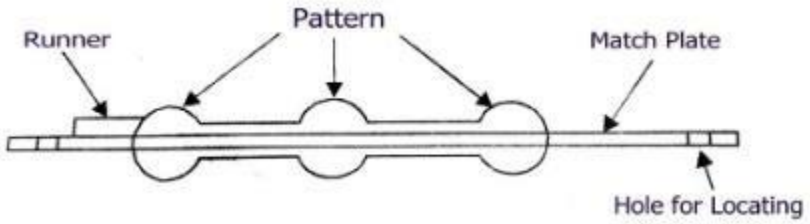


Fig. 8: Match plate pattern

Follow board type pattern

In casting process some portions are structurally weak. It is not supported properly and may be breakunder the force of ramming. In this stage the special pattern to allow the mold may be such as woodenmaterial. The pattern can also be seen from the **Fig. 9.**

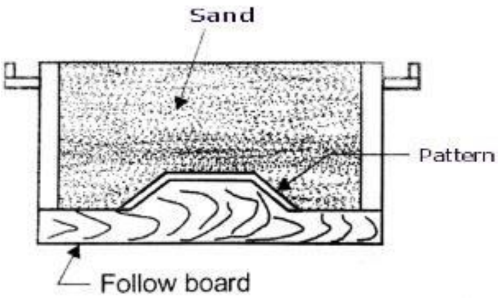


Fig. 9: Follow board type pattern

Gated Pattern

In the mass production of casings, multi cavity moulds are used. Such moulds are formed by joining anumber of patterns and gates and providing a common runner for the molten metal, as shown in **Fig.**

10. These patterns are made of metals, and metallic pieces to form gates and runners are attached tothe pattern.

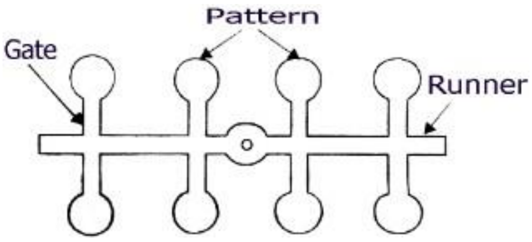


Fig. 10: Gated Pattern

Sweep Pattern

Sweep patterns are used for forming large circular moulds of symmetric kind by revolving a sweep attached to a spindle as shown in **Fig. 11.** Actually a sweep is a template of wood or metal and is attached to the spindle at one edge and the other edge has a contour depending upon the desired shape of the mould. The pivot end is attached to a stake of metal in the center of the mould.

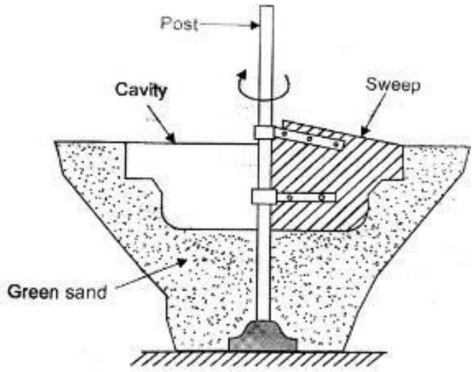


Fig. 11: Sweep Pattern

Skeleton Pattern

When only a small number of large and heavy castings are to be made, it is not economical to make asolid pattern. In such cases, however, a skeleton pattern may be used. This is a ribbed construction ofwood which forms an outline of the pattern to be made. This frame work is filled with loam sand andrammed. The surplus sand is removed by strickle board. For round shapes, the pattern is made in twohalves which are joined with glue or by means of screws etc. A typical skeleton pattern is shown in **Fig.12.**

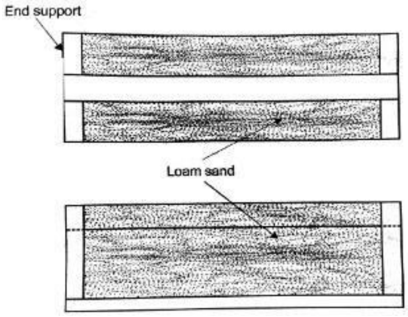


Fig. 12: Skeleton Pattern

Segmental pattern

The segmental pattern is used to prepare the mold of larger circular casting to avoid the use of solid pattern of exact size. It is similar to sweep pattern, but the difference from Sweep pattern, the sweeppattern is give a continuous revolve motion to generate the part, the segmental pattern itself and mold is prepared. In this segmental pattern construction should be save the material for pattern makeand easy carried. The segmental pattern is mounted on the central pivot and mold in one position forafter prepare of mold the segment is moved for next position. That is repeat together the complete mold is done. A typical segmental pattern is shown in **Fig. 13.**

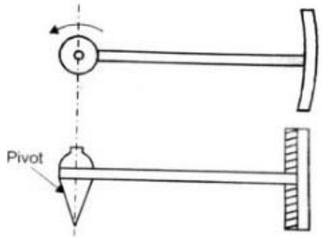


Fig. 13: Segmental pattern

Pattern Allowances

Pattern may be made from wood or metal and its color may not be same as that of the casting. Thematerial of the pattern is not necessarily same as that of the casting. Pattern carries an additional allowance to compensate for metal shrinkage. It carries additional allowance for machining. It carries the necessary draft to enable its easy removal from the sand mass. It carries distortions allowance also. Due to distortion allowance, the shape of casting is opposite to pattern. Pattern maycarry additional projections, called core prints to produce seats or extra recess in mold for setting or adjustment or location for cores in mold cavity. It may be in pieces (more than one piece) whereascasting is in one piece. Sharp changes are not provided on the patterns. These are provided on the casting with the help of machining. Surface finish may not be same as that of casting.

The size of a pattern is never kept the same as that of the desired casting because of the fact that during cooling the casting is subjected to various effects and hence to compensate for these effects,corresponding allowances are given in the pattern. These various allowances given to pattern can be enumerated as, allowance for shrinkage, allowance for machining, allowance for draft, allowancefor rapping or shake, allowance for distortion and allowance for mould wall movement. These allowances are discussed asunder.

Shrinkage Allowance

In practice it is found that all common cast metals shrink a significant amount when they are cooledfrom the molten state. The total contraction in volume is divided into the following parts:

1. Liquid contraction, i.e. the contraction during the period in which the temperature of the liquid metal or alloy falls from the pouring temperature to the liquidus temperature.
2. Contraction on cooling from the liquidus to the solidus temperature, i.e. solidifying contraction.
3. Contraction that results there after until the temperature reaches the room temperature. Thisis known as solid contraction.

The first two of the above are taken care of by proper gating and risering. Only the last one, i.e. thesolid contraction is taken care by the pattern makers by giving a positive shrinkage allowance. This contraction allowance is different for different metals. The contraction allowances for different metals and alloys such as Cast Iron 10 mm/mt.. Brass 16 mm/mt., Aluminium Alloys. 15 mm/mt., Steel 21 mm/mt., Lead 24 mm/mt. In fact, there is a special rule known as the pattern marks contraction rule in which the shrinkage of the casting metals is added. It is similar in shape as that of a common rule but is slightly bigger than the latter depending upon the metal for which it is intended. A typical shrinkage allowance can be shown in the **Fig. 14.**

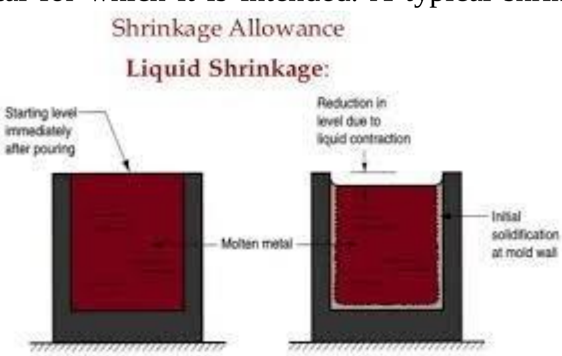


Fig. 14: Shrinkage Allowance

Machining Allowance

It is a positive allowance given to compensate for the amount of material that is lost in machining or finishing the casting. If this allowance is not given, the casting will become undersize after machining.

The amount of this allowance depends on the size of casting, methods of machining and the degree of finish. In general, however, the value varies from 3 mm. to 18 mm. A typical machining allowance can be shown in the **Fig. 15.**

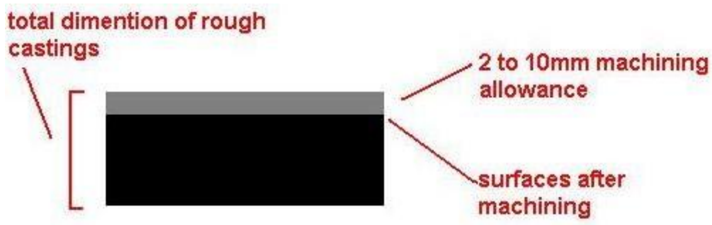


Fig. 15: Machining Allowance

Draft or Taper Allowance

Taper allowance (Fig. 1.1.11) is also a positive allowance and is given on all the vertical surfaces of pattern so that its withdrawal becomes easier. The normal amount of taper on the external surfaces varies from 10 mm to 20 mm/mt. On interior holes and recesses which are smaller in size, the taper should be around 60 mm/mt. These values are greatly affected by the size of the pattern and the molding method. In machine molding its, value varies from 10 mm to 50 mm/mt. A typical taper allowance can be shown in the **Fig. 16.**

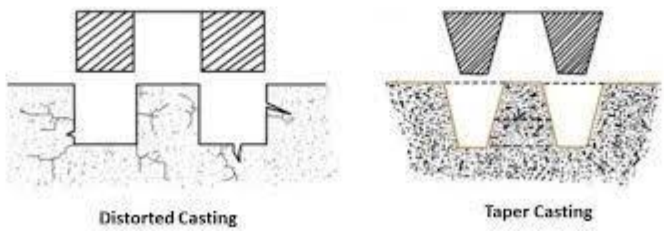


Fig. 16: Machining Allowance

Rapping or Shake Allowance

Before withdrawing the pattern it is rapped and thereby the size of the mould cavity increases. Actually by rapping, the external sections move outwards increasing the size and internal sections move inwards decreasing the size. This movement may be insignificant in the case of small and medium size castings, but it is significant in the case of large castings. This allowance is kept negative and hence the pattern is made slightly smaller in dimensions 0.5-1.0 mm.

Distortion Allowance

This allowance is applied to the castings which have the tendency to distort during cooling due to thermal stresses developed. For example a casting in the form of U shape will contract at the closed end on cooling, while the open end will remain fixed in position. Therefore, to avoid the distortion, the legs of U pattern must converge slightly so that the sides will remain parallel after cooling.

Mold wall Movement Allowance

Mold wall movement in sand moulds occurs as a result of heat and static pressure on the surface layer of sand at the mold metal interface. In ferrous castings, it is also due to expansion due to graphitisation. This enlargement in the mold cavity depends upon the mold density and mould composition. This effect becomes more pronounced with increase in moisture content and temperature.

Gating system refers to all those elements which are connected with the flow of molten metal fromthe ladle to the mould cavity. The various elements that are connected with the gating system are:Pouring Basin

- *Sprue*
  - **Sprue- base**
- *Well*
  Runner
  - **Runner**
- *Extension In-gate*
  - **Riser**

Pouring Basin: In order to avoid mould erosion, molten metal is poured into a pouring basin, which acts as a reservoir from which it moves smoothly into the sprue. The pouring basin is also able to stop the slag from entering the mould cavity by means of a skimmer or skim core.

Sprue: It is the channel through which the molten metal is brought into the parting plane, where it enters the runners and gates to ultimately reach the mould cavity. If the sprue were to be straight- cylindrical then the meatl flow would not be full at the bottom to avoid this problem the sprue is designed tapper.

Sprue Base Well: This is a reservoir for metal at the bottom of the sprue, to reduce the momentum ofthe molten metal.

Runner: The runner takes the molten metal from sprue to the casting. Ingate: This is the final stage where the molten metal moves from the runner to the mold cavity.

Riser: Riser is a source of extra metal which flows from riser to mold cavity to compensate for shrinkage which takes place in the casting when it starts solidifying. Without a riser heavier parts of thecasting will have shrinkage defects, either on the surface or internally.

Types of Gating Systems:

The gating system also depends on the direction of the parting plane, which contains the sprue, runner and the ingate. They are as follows:

Horizontal Gating System : This is used most widely. This type is normally applied in ferrous metal'ssand casting and gravity die-casting of non-ferrous metals. They are used for flat casting, which are filled under gravity.

Vertical Gating System : This is applied in tall castings were high-pressure sand mold, shell mold anddie-casting processes are done. Top Gating System : this is applied in places where the hot metal is poured form the top of the casting. It helps directional solidification of the casting from top to bottom. It suits only flat castings to limit the damage of the metal during the initial filling.

Bottom Gating System : it is used in tall castings where the molten metal enters the casting through the bottom.

Middle Gating System : It has the characteristics of both the top and bottom.

Physical Properties of Various Materials at Room Temperature

Material	Density (kg/m³)	Melting point (°C)	Specific heat (J/kg K)	Thermal conductivity (W/m K)	Coefficient of thermal expansion (µm/m°C)
Metallic					
Aluminum	2700	660	900	222	23.6
Aluminum alloys	2630–2820	476–654	880–920	121–239	23.0–23.6
Beryllium	1854	1278	1884	146	8.5
Columbium (niobium)	8580	2468	272	52	7.1
Copper	8970	1082	385	393	16.5
Copper alloys	7470–8940	885–1260	337–435	29–234	16.5–20
Gold	19300	1063	129	317	19.3
Iron	7860	1537	460	74	11.5
Steels	6920–9130	1371–1532	448–502	15–52	11.7–17.3
Lead	11350	327	130	35	29.4
Lead alloys	8850–11350	182–326	126–188	24–46	27.1–31.1
Magnesium	1745	650	1025	154	26.0
Magnesium alloys	1770–1780	610–621	1046	75–138	26.0
Molybdenum alloys	10210	2610	276	142	5.1
Nickel	8910	1453	440	92	13.3
Nickel alloys	7750–8850	1110–1454	381–544	12–63	12.7–18.4
Silicon	2330	1423	712	148	7.63
Silver	10500	961	235	429	19.3
Tantalum alloys	16600	2996	142	54	6.5
Titanium	4510	1668	519	17	8.35
Titanium alloys	4430–4700	1549–1649	502–544	8–12	8.1–9.5
Tungsten	19290	3410	138	166	4.5
Nonmetallic					
Ceramics	2300–5500	–	750–950	10–17	5.5–13.5
Glasses	2400–2700	580–1540	500–850	0.6–1.7	4.6–70
Graphite	1900–2200	–	840	5–10	7.86
Plastics	900–2000	110–330	1000–2000	0.1–0.4	72–200
Wood	400–700	–	2400–2800	0.1–0.4	2–60

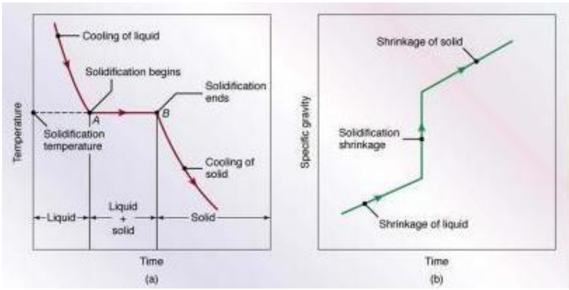


Fig. 17: Temperature as a function of time for the solidification of pure metals. Note that the **freezing takes place at a constant temperature. (b) Density as a function of time.**

In order to provide defect-free casting the gating system should make certain provisions whiledesigning the gating system.

1. The mould should be completely filled in the smallest time possible without having to raise the metal temperature or use high metal heads.
2. The metal should flow smoothly into the mould without any turbulence. A turbulence metal flow tends to form dross in the mould.
3. Unwanted material such as slag, dross and other mould material should not be allowed to enter the mould cavity
4. The metal entry into the mould cavity should be properly controlled in such a way that aspiration of the atmospheric air is prevented.
5. A proper thermal gradient be maintained so that the casting is cooled without any shrinkage cavities or distortions.
6. Metal flow should be maintained in such a way that no gating or mould erosion takes place.
7. The gating system should ensure that enough molten metal reaches the mould cavity
8. The gating system design should be economical and easy to implement and remove after casting solidification.
9. Ultimately, the casting yield should be maximized.

Solidification of Metals

After pouring molten metal into a mold, a series of events takes place during the solidification of themetal and cooling to room temperature. These events greatly influence the size, shape uniformity, and chemical composition of the grains formed throughout the casting, which in turn influence its over all properties.

Solidification of Pure Metals: A pure metal solidifies at a constant temperature. It has a clearly defined melting (or freezing) point (see table above and **Fig. 17**). After the temperature of the moltenmetal drops to its freezing point, its temperature remains constant while the latent heat of fusion is given off. The solidification front (solid-liquid interface) moves through the molten metal, solidifyingfrom the mold walls in toward the center.

The grain structure of a pure metal cast in a square mold is shown in Fig. 17 a: 9At the mold walls (usually at room temp), the metal cools rapidly and produces a solidified skin (or shell) of fine

equiaxed grains (approx. equal dims. in all dirs.) 9The grains grow in a direction opposite to that of the heat transfer out through the mold. Those grains that have favorable orientations grow preferentially away from the surface of the mold producing columnar grains (Fig. 10.3). 9As the driving force of the heat transfer is reduced away from the mold walls, the grains become equiaxedand coarse. Those grains that have substantially different orientations are blocked from further growth. Such grains development is known as homogeneous nucleation, meaning that the grains grow upon themselves, starting at the mold wall.
When the heat is abstracted rapidly, however, solidification it leads to fine structures due to a decrease in diffusion rates.

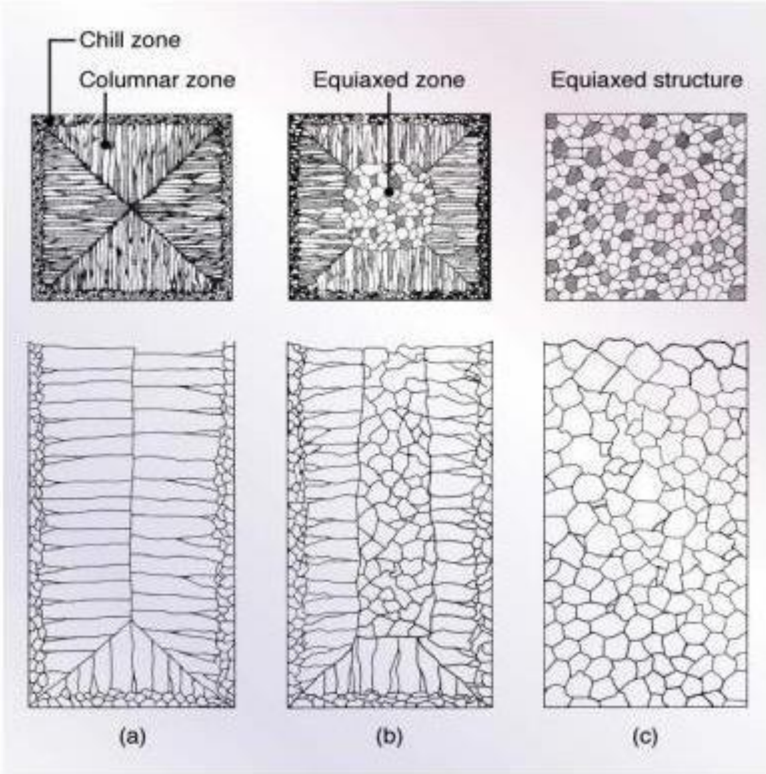


Fig. 18: Schematic illustration of three cast structures of metals solidified in a square mold: (a)Pure metals (b) Solid-solutions alloys and (C) Structure obtained by using nucleating agents.

Solidification of Alloys

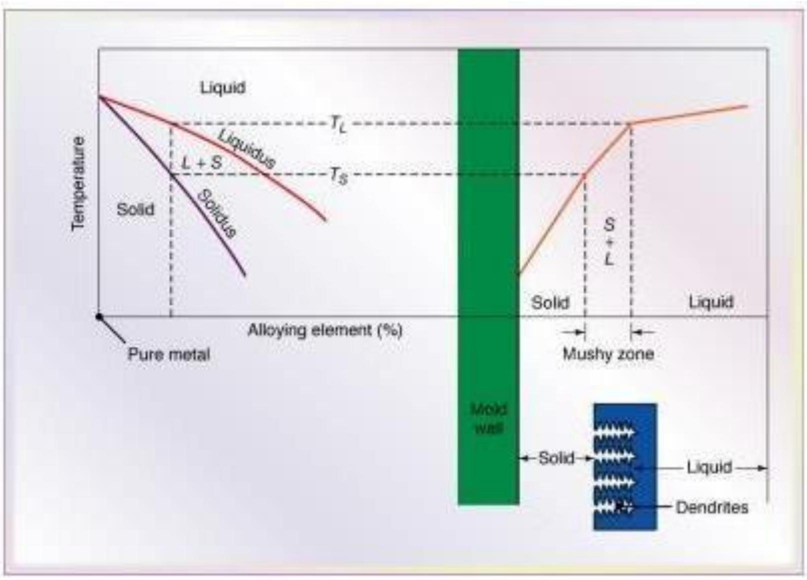


Fig. 19: Schematic illustration of alloy solidification and temperature distribution in the solidifying metal. Note the formation of dendrites in the mushy zone.

Solidification begins when the temperature drops below the liquidus, TL, and is complete when it reaches the solidus, TS (Fig.19). Within this temperature range, the alloy is in a mushy or pasty state with columnar dendrites (close to tree). Note the liquid metal present between the dendrite arms.

Dendrites have 3-D arms and branches (secondary arms) which eventually interlock, as can be seenin Fig.20.
(L & S) is an important factor during solidification. It is described by the freezing range as: 5Freezing range = TL - TS (Fig. 17) .

It can be seen in Figure 10.1 that pure metals have no freezing range, and that the solidification frontmoves as a plane front without forming a mushy zone. In alloys with a nearly symmetrical phase diagram, the structure is generally lamellar, with two or more solid phases present, depending on thealloy system. When the volume fraction of the minor phase of the alloy is less than about 25%, the structure generally becomes fibrous. These conditions are particularly important for cast irons. For alloys, a short freezing range generally involves a temperature difference < 50o C, and a long freezingrange > 110o C.

Ferrous castings generally have narrow mushy zones, whereas aluminum and magnesium alloys havewide mushy zones.

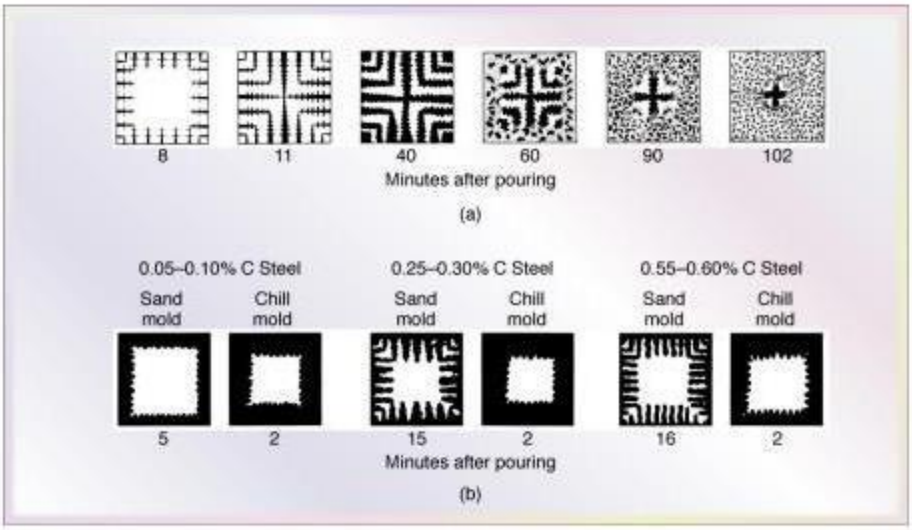


Fig. 20: (a) Solidification patterns for grey cast iron in a 180mm square casting. Note that after 11 minutes of cooling, dendrites reach each other, but the casting is still mushy throughout. It takes about two hours for this casting to solidify completely. (b)Solidification of carbon steels in sand and chill (metal) molds. Note the difference in solidification patterns as the carbon content increases.

Riser

Riser is a source of extra metal which flows from riser to mold cavity to compensate for shrinkage which takes place in the casting when it starts solidifying. Without a riser heavier parts of the castingwill have shrinkage defects, either on the surface or internally.
Risers are known by different names as metal reservoir, feeders, or headers. Shrinkagein a mold, from the time of pouring to final casting, occurs in three stages.

1. during the liquid state
2. during the transformation from liquid to solid
3. during the solid state

First type of shrinkage is being compensated by the feeders or the gating system. For the second type of shrinkage risers are required. Risers are normally placed at that portion of the casting which is last to freeze. A riser must stay in liquid state at least as long as the casting and must be able to feed the casting during this time.

Functions of Risers

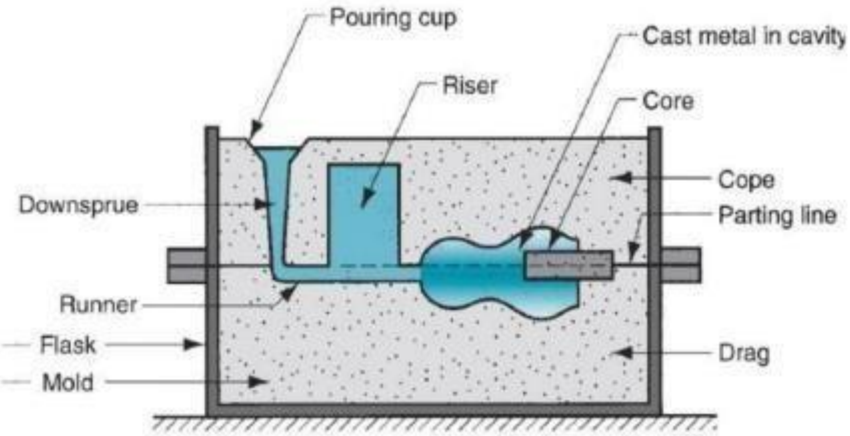
- Provide extra metal to compensate for the volumetric shrinkage
- Allow mold gases to escape
- Provide extra metal pressure on the solidifying mold to reproduce mold details more exact

Design Requirements of Risers

1. Riser size: For a sound casting riser must be last to freeze. The ratio of (volume / surface area)^2 of the riser must be greater than that of the casting. However, when this condition does not meet the metal in the riser can be kept in liquid state by heating it externally or using exothermic materials in the risers.
2. Riser placement: the spacing of risers in the casting must be considered by effectively calculating the feeding distance of the risers.
3. Riser shape: cylindrical risers are recommended for most of the castings as spherical risers, although considers as best, are difficult to cast. To increase volume/surface area ratio the bottom of the riser can be shaped as hemisphere.

Riser Design

The riser is a reservoir in the mold that serves as a source of liquid metal for the casting to compensate for shrinkage during solidification. The riser must be designed to freeze after the maincasting in order to satisfy its function Riser Function As described earlier, a riser is used in a sand- casting mold to feed liquid metal to the casting during freezing in order to compensate for solidification shrinkage. To function, the riser must remain molten until after the casting solidifies. Chvorinov's rule can be used to compute the size of a riser that will satisfy this requirement. The following example illustrates the calculation. The riser represents waste metal that will be separated from the cast part and re-melted to make subsequent castings. It is desirable for the volume of metal in the riser to be a minimum. Since the geometry of the riser is normally selected to maximizethe V/A ratio, this tends to reduce the riser volume as much as possible Risers can be designed in different forms. The design shown in Figure below is a side riser. It is attached to the side of the casting by means of a small channel. A top riser is one that is connected to the top surface of the casting. Risers can be open or blind. An open riser is exposed to the outside at the top surface of the cope. This has the disadvantage of allowing more heat to escape, promoting faster solidification. A blind riser is entirely enclosed within the mold, as in Figure below.



(b)

This process was patent in 20 century to make higher standards hollow castings. The first centrifugal casting machine was invented by a British, A.G. Eckhardt in 1807. This process is widely used forcasting hollow pipes, tubes and other symmetrical parts.

Core and Core Box:

Cores are compact mass of core sand that when placed in mould cavity at required location with proper alignment does not allow the molten metal to occupy space for solidification in that portion and hence help to produce hollowness in the casting. The environment in which the core is placed is much different from that of the mold. In fact the core (Fig. 22) has to withstand the severe action of hot metal which completely surrounds it. Cores are classified according to shape and position in the mold. There are various types of cores such as horizontal core, vertical core, balanced core, drop core and hanging core are shown in the Fig. 22 below.

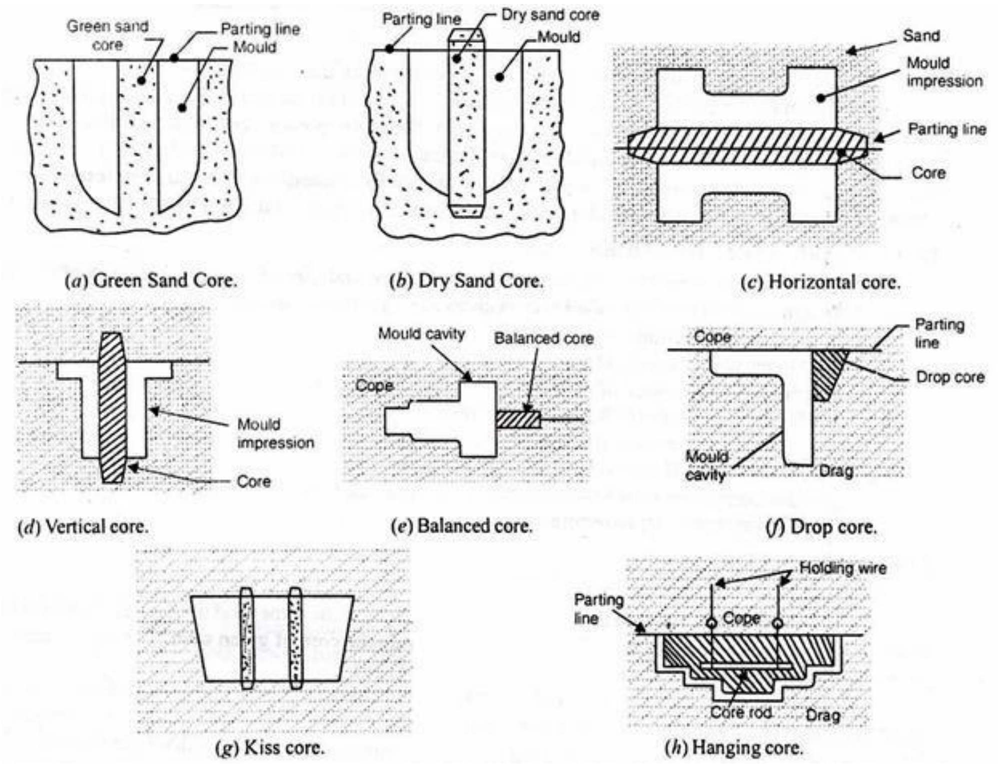


Fig. 22: Types of Core

There are various functions of cores which are given below
Core is used to produce hollowness in castings in form of internal

cavities. It may form a part of green sand mold

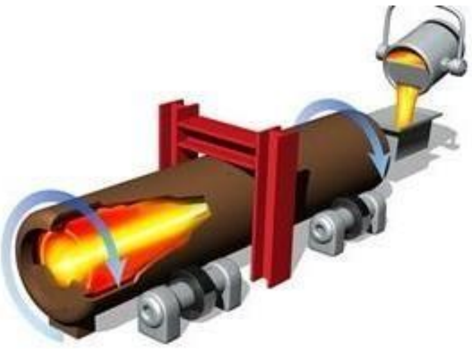
1. It may be deployed to improve mold surface.
2. It may provide external undercut features in casting.
3. It may be used to strengthen the mold.
4. It may be used to form gating system of large size mold
5. It may be inserted to achieve deep recesses in the casting

Special Casting processes:

This process was patent in 20 century to make higher standards hollow castings. The first centrifugal casting machine was invented by a British, A.G. Eckhardt in 1807. This process is widely used for casting hollow pipes, tubes and other symmetrical parts.

Centrifugal Casting:

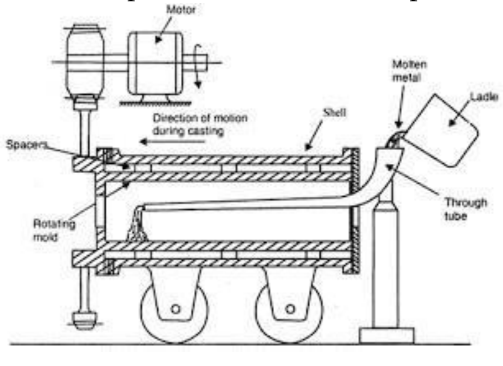
Working Principle: It works on basic principle of centrifugal force on a rotating Component. In this process, a mould is rotated about its central axis when the molten metal is poured into it. A centrifugal force acts on molten metal due to this rotation, which forces the metal at outer wall of mould. The mould rotates until the whole casting solidifies. The slag oxide and other inclusion being lighter, gets separated from metal and segregate towards the center.



Types

True Centrifugal Casting:

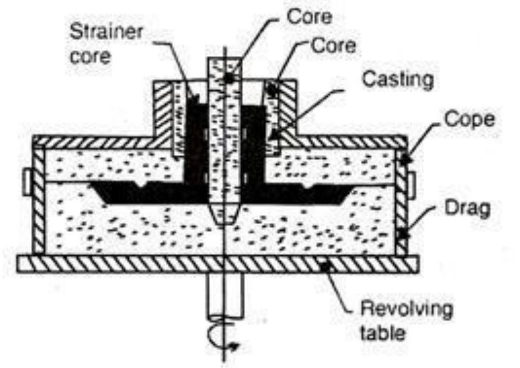
True centrifugal casting is sometime known as centrifugal casting is a process of making symmetrical round hollow sections. This process uses no **cores** and the symmetrical hollow section is created by pure centrifugal action. In this process, the mould rotates about horizontal or vertical axis. Mostly the mould is rotated about horizontal axis and the molten metal introduce from an external source. The centrifugal force acts on the molten metal which forces it at the outer wall of mould. The mould rotates until the whole casting solidifies. The slag particles are lighter than metal thus separated at the central part of the casting and removed by machining or other suita



used to make hollow pipes, tubes, hollow bushes etc. which are axi symmetrical with a concentric hole.

Semi Centrifugal Casting:

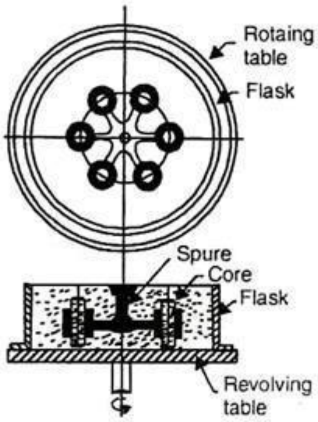
This process is used to cast large size axi symmetrical object. In this process mould is placed horizontally and rotated along the vertical axis. A core is inserted at the center which is used to cast hollow section. When the mould rotates, the outer portion of the mould fill by purely centrifugal action and as the liquid metal approaches toward the center, the centrifugal component decreases



and gravity component increase. Thus a core is inserted at center to make hollow cavity at the centerwithout centrifugal force. In this process centrifugal force is used for uniform filling of axi symmetricalparts. Gear blanks, flywheel etc. are made by this process.

Centrifuging:

In this process there are several mould cavities connected with a central sprue with radial gates. Thisprocess uses higher metal pressure during solidification. It is used to cast shapes which are not axi symmetrical. This is only suitable for small objects.



Application:

- It is widely used in aircraft industries to cast rings, flanges and compressor
- casting.It is used for cast Steam turbine bearing shell.
- Roller for steel rolling mill is another example of centrifugal casting.
- It is used in automobile industries to cast gear blank, cylindrical liners, piston
- rings etc.It is used to cast bearings.
- This process used to cast switch gear components used in electronic industries.

Advantages and Disadvantages:

- It provides dense metal and high mechanical properties.
- Unidirectional solidification can obtain up to a certain
- thickness.It can use for mass production.
- No cores are required for cast hollow shapes like tubes
-

etc.Gating system and runner are totally eliminated.

- All the impurity like oxide or other slag particles, segregated at center from where it can easilyremove.
- It required lower pouring temperature thus save energy.
- Lower casting defects due to uniform solidification.
- Disadvantages:Limited design can be cast. It can cast only
- symmetrical shapes.
- High equipment or setup cost.
- It is not suitable for every
- metal.Higher maintenance
- required.

High skill operator required.

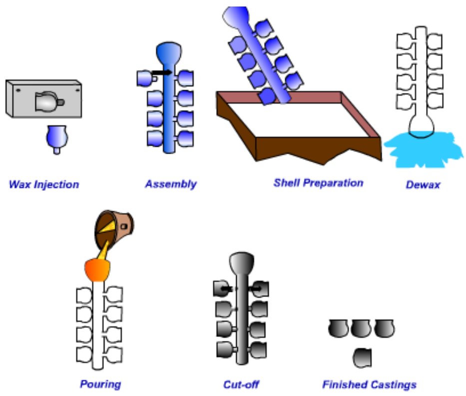
In this casting process, solidification time and temperature distribution is difficult to determine.

Investment Casting Process

The root of the investment casting process, the cire perdue or "lost wax" method dates back to at least the fourth millennium B.C. The artists and sculptors of ancient Egypt and Mesopotamia used therudiments of the investment casting process to create intricately detailed jewelry, pectorals and idols.The investment casting process alos called lost wax process begins with the production of wax replicas or patterns of the desired shape of the castings. A pattern is needed for every casting to beproduced. The patterns are prepared by injecting wax or polystyrene in a metal dies. A number of patterns are attached to a central wax sprue to form a assembly. The mold is prepared by surrounding the pattern with refractory slurry that can set at room temperature. The mold is then heated so that pattern melts and flows out, leaving a clean cavity behind. The mould is further hardened by heating and the molten metal is poured while it is still hot. When the casting is solidified,the mold is broken and the casting taken out.

The basic steps of the investment casting process are (Figure 11) :

1. Production of heat-disposable wax, plastic, or polystyrene patterns
2. Assembly of these patterns onto a gating system
3. "Investing," or covering the pattern assembly with refractory slurry
4. Melting the pattern assembly to remove the pattern material
5. Firing the mold to remove the last traces of the pattern material
6. Pouring
7. Knockout, cutoff and finishing.



The basic Steps of Investment Casting

Advantages

- Formation of hollow interiors in cylinders without cores

- Less material required for gate
- Fine grained structure at the outer surface of the casting free of gas and shrinkage cavities and porosity

Disadvantages

- More segregation of alloy component during pouring under the forces of rotation
- Contamination of internal surface of castings with non-metallic inclusions
- Inaccurate internal diameter

Ceramic Shell Investment Casting Process

The basic difference in investment casting is that in the investment casting the wax pattern is immersed in a refractory aggregate before dewaxing whereas, in ceramic shell investment casting a ceramic shell is built around a tree assembly by repeatedly dipping a pattern into a slurry (refractory material such as zircon with binder). After each dipping and stuccoing is completed, the assembly is allowed to thoroughly dry before the next coating is applied. Thus, a shell is built up around the assembly. The thickness of this shell is dependent on the size of the castings and temperature of the metal to be poured.

After the ceramic shell is completed, the entire assembly is placed into an autoclave or flash fire furnace at a high temperature. The shell is heated to about 982 o C to burn out any residual wax andto develop a high-temperature bond in the shell. The shell molds can then be stored for future use ormolten metal can be poured into them immediately. If the shell molds are stored, they have to be preheated before molten metal is poured into them.

Advantages

- excellent surface finish
- tight dimensional tolerances
- machining can be reduced or completely eliminated

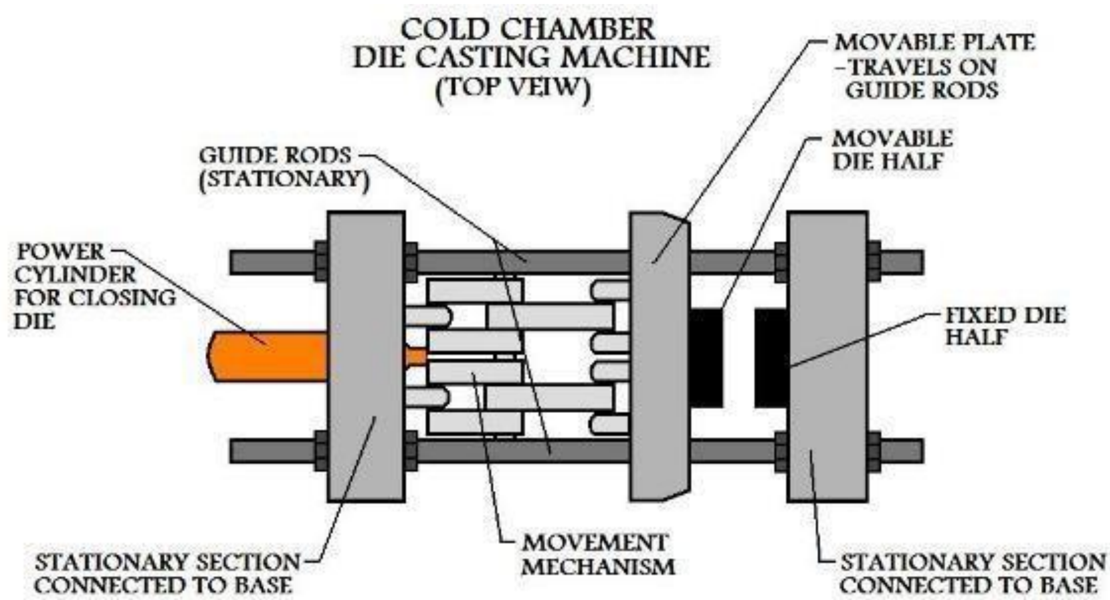
The Process

The Mold: Like in all permanent mold manufacturing processes, the first step in die casting is the production of the mold. The mold must be accurately created as two halves that can be opened and closed for removal of the metal casting, similar to the basic permanent mold casting process. The mold for die casting is commonly machined from steel and contains all the components of the gatingsystem. *Multi-cavity die* are employed in manufacturing industry to produce several castings with eachcycle. *Unit dies* which are a combination of smaller dies are also used to manufacture metal castings in industry.

In a die casting production setup, the mold, (or die), is designed so that its mass is far greater than thatof the casting. Typically the mold will have 1000 times the mass of the metal casting. So a 2 pound part will require a mold weighing a ton! Due to the extreme pressures and the continuous exposure to thermal gradients from the molten metal, wearing of the die can be a problem. However in a well maintained manufacturing process, a die can last hundreds of thousands of cycles before needing to be replaced.

Die Casting Machines

In addition to the opening and closing of the mold to prepare for and remove castings, it is very important that there is enough force that can be applied to hold the two halves of the mold togetherduring the injection of the molten metal. Flow of molten metal under such pressures will create a tremendous force acting to separate the die halves during the process. Die casting machines are largeand strong, designed to hold the mold together against such forces.



In manufacturing industry, die casting machines are rated on the force with which they can hold themold closed. Clamping forces for these machines vary from around 25 to 3000 tons.

Melting Practices

Melting is an equally important parameter for obtaining a quality castings. A number of furnaces canbe used for melting the metal, to be used, to make a metal casting. The choice of furnace depends on the type of metal to be melted. Some of the furnaces used in metal casting are as following:

- Crucible furnaces
- Cupola
- Induction furnace
- Reverberatory furnace

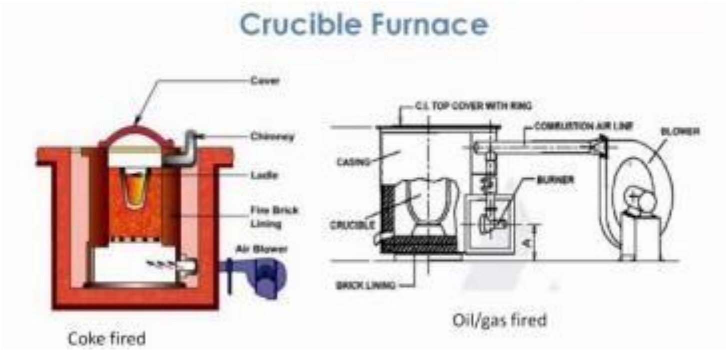
The crucible furnace as you see in the image below is how a crucible furnace looks. So, in this basicallyyou have a crucible, which is normally made of clay or graphite and then this crucible will be kept andthere will be heating source, and through this heating source this crucible is heated and the molten metal which is kept in the crucible normally that is melted. So, normally it is used for very you know smaller quantity of material can be normally is a held, but you can have the larger crucible, you havethe crucible numbers, sometimes you have different numbers and that is basically specifies by amountof copper which can be melted into that particular number of crucible.

So, kgs of copper which can be melted like that so, if this is a large crucible certainly you need a largeand that it has to be put in you will have the refractory, which is rammed from the other sides and then you will have the heat source, and then using that heat source you can heat the liquid metal which will be melted. So, as you see you will have a ladle you have the fire brick lining and then this isa chimney this is the covers, you can take the cover out and this is a air blower. So, that will be blownand then this way the heating will be done, and due to the heat the metal is melted here.

So, it is normally convenient for a smaller foundries. So, that you know for handling these smaller quantities you have to take this crucible out. So, for a smaller foundries when you have to melt in small quantities, this crucible furnace are basically important.

Now there may be basically coke fired or the oil or gas fired. So, basically when you have to use thesenormally for nonferrous melting, nonferrous metal these coke fired furnaces are used, and because you have the low installation cost in that low fuel cost and ease in operation. So, because of these reasons these coke fired furnaces are used for nonferrous metal. Now you have also the oil and gas fired furnace. So, as the name indicts you have oil or gas, which are used as the heating source in suchfurnaces. So, basically they are cylindrical in shape and then the flame is produced by heating of this atomised fuel.

So, they will combine with air and then they will be heated, and then they will be sweeping around the crucible. So, that way it will have the enveloped in enveloped in the crucible and then uniformly heat the crucible. So, this way you have the combustion products will be coming into the contact withthe charge, then they will be heating it and then they that way you can melt them by tilting you can take the you know metal out and pour it into the mould. So, you have certain advantages of this oil or gas fired furnace like you do not have any wastage of fuel. So, that is one of the. So, here if this is the oil or gas fired furnace you do not have much of the wastage of the fuel. So, you have more thermal efficiency in the case of oil or you know gas fired furnace, you have better temperature control by controlling the flow of this gases by controlling through a knob, you can have accurate control of the temperature, air contamination will be less in the case of this oil or gas fired furnaces. So, it will also save the floor space and you have also the low labour cost because here you need oneperson just simply to regulate these burners or so. So, this way you have these crucible furnaces andthey are the different types normally you will have this used by the smaller foundries.



Cupola Furnace:

Cupola Furnace is a melting device used to melt cast iron, Ni-resist iron, and some bronzes and It is used in Foundries. The cupola can be made of any size and the size of the cupola is measured in diameters which range from 1.5 to 13 feet. The shape of the cupola is cylindrical and the equipment is arranged in the vertical fitted with doors which swings down and Out to drop bottom.

The top is open or fitted with a cap to escapes gases or rain entering. The cupola may be fitted with acap to control emission of gases and to Pull the gases into the device to cool the gases and remove allthe Particulate Matter.

The cupola shell is made of steel and has a refractory brick and plastic refractory Patching material lining. The clay and sand mixture is used as a bottom line and the lining is temporary. The coal can bemixed with the clay lining so when it heats up the coal decomposes and the bond becomes friable. This makes opening up of the two holes easy. The bottom of the cupola lining is compressed against the bottom doors. Cooling jackets are also fitted with some of the cupola's to keep the sides cool andwith oxygen injection to make the coke fire burn hotter.

Principal:

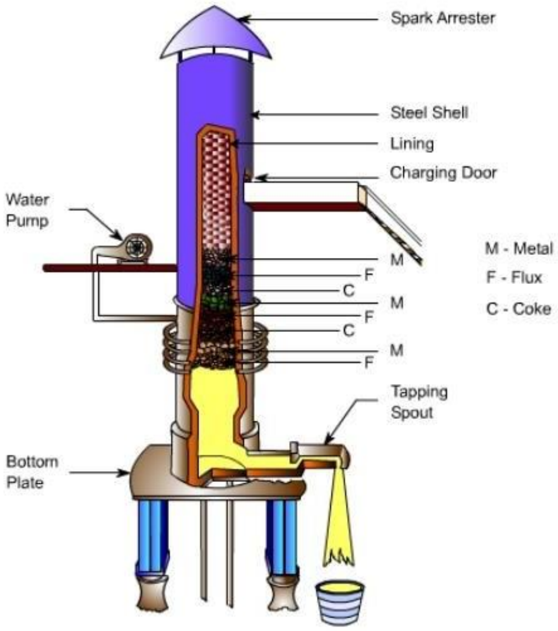
The cupola furnace works on a simple principal that combustion of coke generates carbon dioxide andheat and this causes the iron to melt. The iron drains downward when get melted.

Afterwards, the carbon dioxide is reduced partly, reduced again by consuming energy and coke with carbon monoxide, carbon dioxide and supplied coke is present in the reaction equilibrium so it is possible to show a defined combustion ratio for the utilization of thermal energy for the coke combustion.

Finally, high concentration of carbon monoxide is present in the exhaust gas and it can be extracted from the furnace.

Construction:

Cupola furnace constructed in the form of a hollow cylindrical vertical steel shell and it is lined from inside with a refractory material. This furnace is generally supported on four cast iron lags mounted on a concrete base.



Cupola Furnace

The bottom of the furnace is closed by two cast iron doors hinged to the bed plate of the furnace. A wind box cast iron encircles to the outside of the furnace bottom. This box is connected to the furnaceblower pipe known as the blast pipe. Air which supplies the oxygen necessary to burn the fuels forcedthrough the cupola by a blower. The top of the furnace is shielded by a mesh screen and topped witha cone-shaped spark arrester, which permits the free vent of the waste gas and deflects spark and dust back into the furnace.

Working:

Basically, the operation of cupola furnace consists of following steps:

After building the cupola make sure it is dried completely before getting it to fire. Any slag around thetuyeres from previous runs needs to be cleaned properly.

Also, A broken part is repaired with the mixture of the silica sand and fire clay. Over the Brunt area, alayer of refractory material is applied To about thickness 6 inches or more is rammed on the bottom sloping toward the tap hole to ensure better flow of molten metal.

A hole opening of about 30 mm diameter and a tap hole of about 25 mm diameter is being provided there. A fire of wood is ignited. When the wood burns well coke is dumped on the bed well from the top. Make sure that the coke gets burned too. A bed of coke about 40 inches is placed next to the sand.

Firstly The air blast is turned on At a lower blowing rate than as normal for provoking the coke. A measuring rod is also used which indicates the height of the coke bed. For about 3 hours firing is donebefore the molten metal required.

Now the charge is fed into the cupola. Many factors like charge composition, affect the final structureof the gray cast iron obtained. It composed of 10% steel,50% grey cast iron scrap, and 3% limestone as a flux.

Alternate layers are formed by these constituents. Besides limestone, fluorspar and soda ash are alsoused as flux material. The main function of flux is to remove the impurities in the iron and protect theiron from oxidation.

After the fully charged furnace, it is allowed to remain as such for about 1 hour. As this process goes in charge slowly gets heated up as the air blast is kept shut this time and because of this, the iron getssoaked up.

At the end of the soaking period, the air blast is opened. The topmost opening is kept closed till the metal melts. The sufficient amount of metal is collected. The contents of the charge move downwardsas the melting proceeds.

The rate of charging is equal to the rate of melting. The furnace is kept full throughout the heat. Closing feeding of charge and air blast is stopped when no more melting is required. The bottom plateswings to open when the prop is removed. The deposited slag is being removed. The cupola runs continuously and the melting period does not exceed 4 hours in most of the time. But can be operatedfor more than 10 hours.

Advantages:

- Low cost of construction.
- Low cost of maintenance.
- Low cost of operation.
- Very skilled operators are not required.
- Simple in construction
- Simple in operations.
- Melting composition can be controlled.
- Small floor area is required.

Disadvantages:

- With a long list of advantages, cupola furnace also comes with few of limitations or disadvantages and they are listed below:
- It is sometimes difficult to maintain the temperature in a cupola furnace.
- Metal elements are converted to their oxides which are not suitable for casting.

Application:

Cupola furnace is a used widely as a melting unit for cast iron. Some of the characteristic that makesthe cupola furnace a primary method used in melting irons in the foundries. Some of them are:

- Cupola furnace is the only method which is continuous while operations.
- The melting rate of cupola furnace is high.

It is easy to operate. Operating costs in use of cupola furnace is comparability very low to othermethods for this purpose.

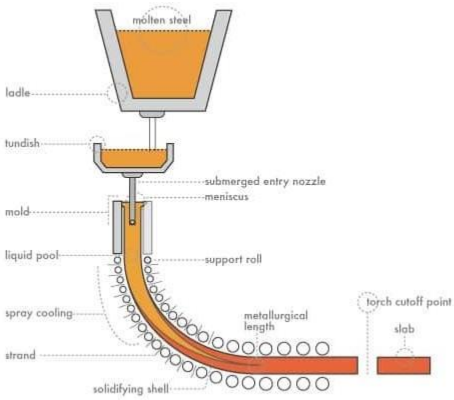
Advanced Casting Processes:

Continuous Casting:

In this process, the molten metal is continuously supplied to the mold. The mold has an indeterminate length. When the molten metal is cast through a mold, it keeps travelling downward increasing in itslength as the time passes by. The molten metal is continuously passed through the mold, at the samerate to match the solidifying casting. This results in casting of long strands of metal. The whole processof continuous casting is a precisely deliberated process that can produce astounding results.

Benefits of continuous casting

Unlike other processes of casting, the time line of steps in continuous casting is entirely different. While in other casting processes, each step of casting heating of the metal, poring of the molten liquid into casts, solidification and cast removal are a sequential process, in continuous casting all steps occur congruently and hence it saves a lot of processing time.



Continuous Casting of Steel

The process

Continuous casting has several advantages but it is also a process that needs distinct resources. This is the reason why this process is employed only in industries that require high yield of steel cast. Themetal is first liquefied and poured into a tundish, which is a container that leads to the mold that willcast the steel. The tundish is placed about 80-90 feet above the ground level and the whole process of casting sues gravity to operate. The tundish is constantly supplied with molten steel to keep the process going. The whole process is controlled to ensure there is smooth flow of molten steel throughtundish. Further, the impurities and slag are filtered in tundish before they move into the mold. The entrance of the mold is filled with inert gases to prevent reaction of molten steel with the gases in theenvironment like oxygen. The molten metal moves swiftly through the mold and it does not completely solidify in it.The entire mold is cooled with water that flows along the outer surface. Typically, steel casting solidifies along the walls of the casting and then gradually moves to the interiorof the steel casting. The metal casting moves outside the mold with the help of different sets of rollers.

While one set of rollers bend the metal cast, another set will straighten it. This helps to change the direction of flow of the steel slab from vertical to horizontal.

Squeeze Casting

Squeeze casting is a combination of casting and forging process. The process can result in the highestmechanical properties attainable in a cast product. The development of squeeze casting process, canusher in tremendous possibility for manufacturing of components of aluminium alloys, which are notproperly commercialized as yet. It can also be effective in for import substitution of critical components.

The process starts when the molten metal is poured into the bottom half of a pre-heated die. As soonas the metal starts solidifying, the upper half of the die closes and starts applying pressure during thesolidification process. The extent of pressure applied is significantly less than that in forging. Parts of great detail can be produced. Coring can be used in tandem with the process to form holes and recesses. The high pressure and the close contact of molten alloy with the metal die surface results inminimum porosity and improvised mechanical properties. This process can be used for both ferrous and non-ferrous metals. This technique is very much suited for making fiber-reinforced castings fromfiber cake preform.

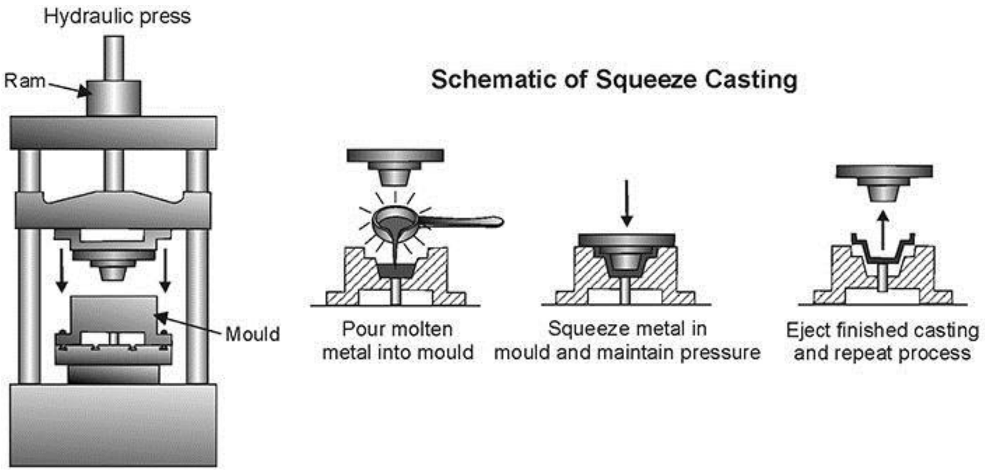
Squeeze Casting Process (or squeeze forming) are of two types:

Direct (liquid metal forging)

This is done in equipment which closely resemble the forging process. Liquid metal is poured into lower die segment, contained in a hydraulic press. Upper die segment is closed. A very high pressureof 100 Mpa or more is applied to the whole cavity until the part gets solidified.

Indirect Squeeze Casting

This process is very much similar to die casting. It takes place in a die casting equipment. This equipment van be vertical or horizontal. The melt which is cleaned and grain -refined is poured in to the shot sleeve of a horizontal or vertical casting machine. The melt is then injected into the die through relatively large gates. This is accomplished through relatively slow velocity (less than 0.5m/sec). The melt in the die cavity is then solidified under pressures, ranging from 55MPa to 300MPa. In this process the parts displays good tensile strength.



Squeeze Casting

Application of Squeeze Casting:

Squeeze casting is an economical, simple and convenient process. It has found extensive application in automotive industry in producing aluminium front steering knuckles, chassis frames, brackets or nodes. High capacity propellers for boat-engine.

Vacuum Mould Casting:

V-process or vacuum molding which was developed by Japanese using unbonded sand and vacuum isa perfect substitute for permanent mold and die casting process. Now the process is employed worldwide as an effective method to cast quality products in start up and low to medium job. The most highlighted feature of vacuum molding is that the flow of molten metal can be controlled.

Process: Patterns are mounted on plates and boards, which are perforated, and each board is connected with a vacuum chamber. Unbonded sand is used for the molding purpose. Permeability isnot a concern in this casting process, therefore sand of the finest structure can be used. The vented, plated pattern is coated with a layer of flexible plastic, which expand when the vacuum is applied in the mold. Enabling, the pattern to be stripped easily from the mold. Patterns should be perfectly smooth since in vacuum molding, every small intricate design gets imprinted on the cast. The patternare not damaged during the process so they can be uses repeatedly.

In the vacuum molding process the mold are made is two parts (cope & drag) with each parts attachedwith its vacuum chamber. The pattern is kept and a metal or wooden flask place around it. Unbondedsand is poured over the molding box, and the tables is shaken vibrantly, by which the sand particle become tight and compact. Another layer of plastic sheet is draped over the molding box. The two halves are joined. Now the vacuum is formed through the patter. The vacuum makes the sand strongand the pattern coating expands, which makes it easy to strip the pattern from the mold.

The mold in kept in a housing and placed above a furnace of molten metal. Using sprue or gating the mold is connected inside the molten metal. When the vacuum from the mold is evacuated the moltenmetal gets forces into the mold, because of the difference in pressure that is created between the outer atmosphere and the mold. The plastic sheet melts and the mold is filled with the molten metal.After the metal solidifies and cools, the vacuum is released. The sand mold starts to fall apart as the solidification process completes. This sand can be cooled and reused for further casting process.

The power of vacuum: In mid 1600,Otto von Guericke a German mayor and scientist conducted the first experiment to prove the power of vacuum. He joined two large copper hemispheres and evacuated the air out of it. Now, eight horses were hooked on opposite side of the hemispheres. Thehorse pulled the hemisphere is two different direction, but the ball could not be torn apart. Guerickethen let in air and the hemisphere came apart. In this way he proved the power and possibilities of vacuum.

Application: Vacuum molding process can be used to cast industrial components from both ferrous and non-ferrous metals.

Application:

- Casted products have high dimensional accuracy and surface finish.
- The process is economical, environment friendly and clean
- No moisture related defects for the castings
- Provides consistent thickness for wall that give the casting an aesthetic appeal
- Low cost operations.

Evaporative casting

Consumable or eva-foam casting is a sand casting process where the foam pattern evaporates into thesand mold. A process similar to investment casting, this expendable casting process is predicted to beused for 29% of aluminum and 14% of ferrous casting in 2010. There are two main **evaporative casting** process lost-foam casting and full moldcasting which are widely used because intricate designcan be cast with relative ease and with reasonable expense. The main difference between the two is that in the lost-foam casting unbonded sand is used and in the full-mold casting green sand or bondedsand is used.

Process: In the first step of **evaporative casting**, a foam pattern is shaped using material like polystyrene. The pattern is attached with sprues, and gates using adhesives and brushed with refractory substances so that the molds are strong and resistant to high temperature. Refractory covered pattern assembly is then surrounded by a sand mixture to form a mold. In some instances thepattern assembly is mixed in ceramic slurry which forms a shell round the pattern when it dries.

In both cases, the mold in kept at a specific temperature to allow the metal to flow smoothly and enterinto every designs and cuts made by the pattern. Molten metal is poured into the mold and the pattern-forming material disappears into the mold. The molten metal takes the shape of the mold andsolidifies. When the metal solidifies it is removed from the mold to form the casting.

Unlike in the traditional sand casting method, in evaporative sand casting, the pattern does not have to be removed from the mold which reduces the need for draft provisions. Some of the parameter that are used to determine the quality of a eva-foam casting are grain fineness number, time of vibration, degree of vacuum and pouring temperature on surface roughness etc.

Applications: **Evaporative castings** is used for steel-casting cast iron parts like water pipe and pump parts, aluminum castings etc.

Advantages:

- High dimensional accuracy and superior casting surface smoothness
- Reduced work process unlike other casting methods
- Light weight casting are be done
- Casting have improved heat resistance and also abrasion resistance and other cast steel properties.
- Complicated shapes can be cast without using cores or drafts.

Ceramic Shell Casting:

Introduction: A process that can be fully automated, ceramic shell molding is the most rapidly used technique for mold and core making. Also known a croning process, this casting technique was invented and patented by J.Croning during World War II. Also known as the process, shell molding technique is used for making thin sections and for acquiring surface finish and dimensional accuracy.

Process: In the first stage of ceramic shell molding, a metal pattern is made which is resistant to high temperature and can withstand abrasion due to contact with sand. The sand and resin mixture for theshell mold is brought in contact with the pattern. The mold is placed in an oven where the resin is cured. This process causes the formation of a thin shell around the pattern.

The thickness of the moldcan be 10-20mm as compared to the heavy mold made for sand castings. When fully cured the skin isremoved from the pattern, which is the shell mold.

For each **ceramic shell molds** there are two halves know as the cope and drag section. The two sections are joined by resin to form a complete shell mold. If an interior design is required, the cores are placed inside the mold before sealing the two parts.

For heavy castings, ceramic shell molds are held together by metals or other materials. Now, the molten metal is poured into the mold, and once it solidifies, the shell is broken to remove the casting.This process is highly useful for near net shape castings. Another advantage is that shell molding can be automated.

Automated Ceramic Shell Molding Machines and Robots: Shell molding machines like the cold shell molding machines helps in making castings with little molding material. In a cold shell molding machine the molds are made using cold binding materials. In it patterns made of wood, metal or plaster can be used. And the greatest benefit is that the mold can be kept horizontally or vertically.

Robotizing: Using robots for ceramic shell molding is a milestone for the old molding technology. Robots which are multi functional and re programmable are used in some foundries. Robots are usedfor a number of activities like robotic gate and sprue removal, robotic cutting of wedges for gate valves, robotic core setting, etc. The robots are reliable, consistent, more productive, provides bettersurface finish, and less machining etc.

Applications: A sizable amount of the casting in the steel industry are made by shell molding process,that ensures better profitability. Carbon steel, alloy steel, stainless steel, low alloys, aluminum alloys,copper, are all cast using shell molding process. Casting that require thin section and excellent dimensional accuracy are cast using this process. Body panes, truck hoods, small size boats, bath tubs,shells of drums, connecting rods, gear housings, lever arms, etc. are cast using croning process.

Advantages:

- Thin sections, complex parts and intricate designs can be cast
- Excellent surface finish and good size tolerances
- Less machining required for the castings
- Near net shape castings, almost 'as cast' quality
- Simplified process that can be handled by semi skilled operators
- Full mechanized and automated casting process
- Less foundry space required.

Casting Defects:

The following are the major defects, which are likely to occur in sand castings

- Gas defects
- Shrinkage cavities
- Molding material defects
- Pouring metal defects
- Mold shift

Gas Defects

A condition existing in a casting caused by the trapping of gas in the molten metal or by mold gases evolved during the pouring of the casting. The defects in this category can be classified into blowholesand pinhole porosity. Blowholes are spherical or elongated cavities present in the casting on the surface or inside the casting. Pinhole porosity occurs due to the dissolution of hydrogen gas, which gets entrapped during heating of molten metal.

Causes

The lower gas-passing tendency of the mold, which may be due to lower venting, lower permeabilityof the mold or improper design of the casting. The lower permeability is caused by finer grain size of the sand, high percentage of clay in mold mixture, and excessive moisture present in the mold.

- Metal contains gas
- Mold is too hot
- Poor mold burnout

Shrinkage Cavities

These are caused by liquid shrinkage occurring during the solidification of the casting. To compensatefor this, proper feeding of liquid metal is required. For this reason risers are placed at the appropriateplaces in the mold. Sprues may be too thin, too long or not attached in the proper location, causing shrinkage cavities. It is recommended to use thick sprues to avoid shrinkage cavities.

Molding Material Defects

The defects in this category are cuts and washes, metal penetration, fusion, and swell.

Cut and washes

These appear as rough spots and areas of excess metal, and are caused by erosion of molding sand bythe flowing metal. This is caused by the molding sand not having enough strength and the molten metal flowing at high velocity. The former can be taken care of by the proper choice of molding sandand the latter can be overcome by the proper design of the gating system.

Metal penetration

When molten metal enters into the gaps between sand grains, the result is a rough castingsurface. This occurs because the sand is coarse or no mold wash was applied on the surface of the mold. The coarser the sand grains more the metal penetration.

Fusion

This is caused by the fusion of the sand grains with the molten metal, giving a brittle, glassy appearance on the casting surface. The main reason for this is that the clay or the sand particles are of lower refractoriness or that the pouring temperature is too high.

Swell

Under the influence of metallostatic forces, the mold wall may move back causing a swell in thedimension of the casting. A proper ramming of the mold will correct this defect.

Inclusions

Particles of slag, refractory materials, sand or deoxidation products are trapped in the casting duringpouring solidification. The provision of choke in the gating system and the pouring basin at the top ofthe mold can prevent this defect.

Pouring Metal Defects

The likely defects in this category are

- Mis-runs and

- Cold shuts.

A mis-run is caused when the metal is unable to fill the mold cavity completely and thus leaves unfilledcavities. A mis-run results when the metal is too cold to flow to theextremities of the mold cavity before freezing. Long, thin sections are subject to this defect and should be avoided in casting design.

A cold shut is caused when two streams while meeting in the mold cavity, do not fuse together properly thus forming a discontinuity in the casting. When the molten metal is poured into the mold cavity through more-than-one gate, multiple liquid fronts will have to flow together and become onesolid. If the flowing metal fronts are too cool, they may not flow together, but will leave a seam in thepart. Such a seam is called a cold shut, and can be prevented by assuring sufficient superheat in the poured metal and thick enough walls in the casting design.

The mis-run and cold shut defects are caused either by a lower fluidity of the mold or when the section thickness of the casting is very small. Fluidity can be improved by changing the composition of the metal and by increasing the pouring temperature of the metal.

Mold Shift

The mold shift defect occurs when cope and drag or molding boxes have not been properly aligned. of weld beads if welded from both sides in butt welds.

Casting Defects

Manufacturing Processes- WELDING

Welding which is the process of joining two metallic components for the desired purpose, can be defined as the process of joining two similar or dissimilar metallic components with the application of heat, with orwithout the application of pressure and with or without the use of filler metal. Heat may be obtained by chemical reaction, electric arc, electrical resistance, frictional heat, sound and light energy. If no filter metal is used during welding then it is termed as ‘Autogenous Welding Process'.

During ‘Bronze Age' parts were joined by forge welding to produce tools, weapons and ornaments etc, however, present day welding processes have been developed within a period of about a century. First application of welding with carbon electrode was developed in 1885 while metal arc welding with bare electrode was patented in 1890. However, these developments were more of experimental value and applicable only for repair welding but proved to be the important base for present day manual metal arc (MMAW) welding and other arc welding processes.

In the mean time resistance butt welding was invented in USA in the year 1886. Other resistance welding processes such as spot and flash welding with manual application of load were developed around 1905. With the production of cheap oxygen in 1902, oxy – acetylene welding became feasible in Europe in 1903.

When the coated electrodes were developed in 1907, the manual metal arc welding process become viable for production/fabrication of components and assemblies in the industries on large scale.

Subsequently other developments are as follows:

- Thermit Welding (1903)
- Cellulosic Electrodes (1918)
- Arc Stud Welding (1918)
- Seam Welding of Tubes (1922)
- Mechanical Flash Welder for Joining Rails (1924)
- Extruded Coating for MMAW Electrodes (1926)
- Submerged Arc Welding (1935)
- Air Arc Gouging (1939)
- Inert Gas Tungsten Arc (TIG) Welding (1941)
- Iron Powder Electrodes with High Recovery (1944)
- Inert Gas Metal Arc (MIG) Welding (1948)
- Electro Slag Welding (1951)
- Flux Cored Wire with CO 2 Shielding (1954)
- Electron Beam Welding (1954)
- Constricted Arc (Plasma) for Cutting (1955)
- Friction Welding (1956)
- Plasma Arc Welding (1957)
- Electro Gas Welding (1957)
- Short Circuit Transfer for Low Current, Low Voltage Welding with CO 2 Shielding (1957)
- Vacuum Diffusion Welding (1959)
- Explosive Welding (1960)

Applications:

Although most of the welding processes at the time of their developments could not get their place in the production except for repair welding, however, at the later stage these found proper place in manufacturing/production. Presently welding is widely being used in fabrication of pressure vessels, bridges, building structures, aircraft and space crafts, railway coaches and general applications. It is also being used in shipbuilding, automobile, electrical, electronic and defense industries, laying of pipe lines and railway tracks and nuclear installations etc.

General Applications:

Welding is vastly being used for construction of transport tankers for transporting oil, water, milk and fabrication of welded tubes and pipes, chains, LPG cylinders and other items. Steel furniture, gates, doors and door frames, body and other parts of white goods items such as refrigerators, washing machines, microwave ovens and many other items of general applications are fabricated by welding.

Pressure Vessels:

One of the first major use of welding was in the fabrication of pressure vessels. Welding made considerable increases in the operating temperatures and pressures possible as compared to riveted pressure vessels.

Bridges:

Early use of welding in bridge construction took place in Australia. This was due to problems in transporting complete riveted spans or heavy riveting machines necessary for fabrication on site to remote areas. The first all welded bridge was erected in UK in 1934. Since then all welded bridges are erected very commonly and successfully.

Ship Building:

Ships were produced earlier by riveting. Over ten million rivets were used in ‘Queen Mary' ship which required skills and massive organization for riveting but welding would have allowed the semiskilled/ unskilled labor and the principle of pre-fabrication. Welding found its place in ship building around 1920 and presently all welded ships are widely used. Similarly submarines are also produced by welding.

Building Structures:

Arc welding is used for construction of steel building leading to considerable savings in steel and money. In addition to building, huge structures such as steel towers etc also require welding for fabrication.

Aircraft and Spacecraft:

Similar to ships, aircrafts were produced by riveting in early days but with the introduction of jet engines welding is widely used for aircraft structure and for joining of skin sheet to body.

Space vehicles which have to encounter frictional heat as well as low temperatures require outer skin and other parts of special materials. These materials are welded with full success achieving safety and reliability.

Railways:

Railways use welding extensively for fabrication of coaches and wagons, wheel tyres laying of new railwaytracks by mobile flash butt welding machines and repair of cracked/damaged tracks by thermit welding. **Automobiles:**

Production of automobile components like chassis, body and its structure, fuel tanks and joining of doorhinges require welding.

Electrical Industry:

Turbine blades and cooling fins are also joined by welding.

Electronic Industry:

Electronic industry uses welding to limited extent such as for joining leads of special transistors but otherjoining processes such as brazing and soldering are widely being used. Soldering is used for joining electronic components to printed circuit boards. Robotic soldering is very commonfor joining of parts to printed circuit boards of computers, television, communication equipment and other control equipment etc.

Nuclear Installations:

Spheres for nuclear reactor, pipe line bends joining two pipes carrying heavy water and other componentsrequire welding for safe and reliable operations.

Defence Industry:

Defence industry requires welding for joining of many components of war equipment. Tank bodies fabrication, joining of turret mounting to main body of tanks are typical examples of applications of welding.

Micro-Joining:

It employs the processes such as micro-plasma, ultrasonic, laser and electron beam welding, for joining of thin wire to wire, foil to foil and foil to wire, such as producing junctions of thermocouples, strain gaugesto wire leads etc.

Apart from above applications welding is also used for joining of pipes, during laying of crude oil and gas pipelines, construction of tankers for their storage and transportation. Offshore structures, dockyards, loading and unloading cranes are also produced by welding.

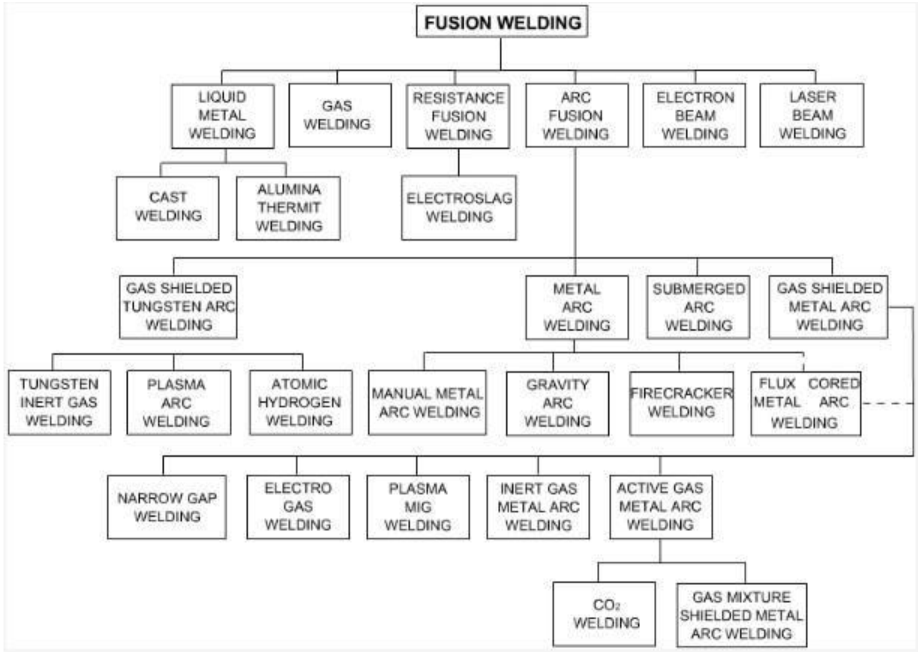
Classification of Welding Processes:

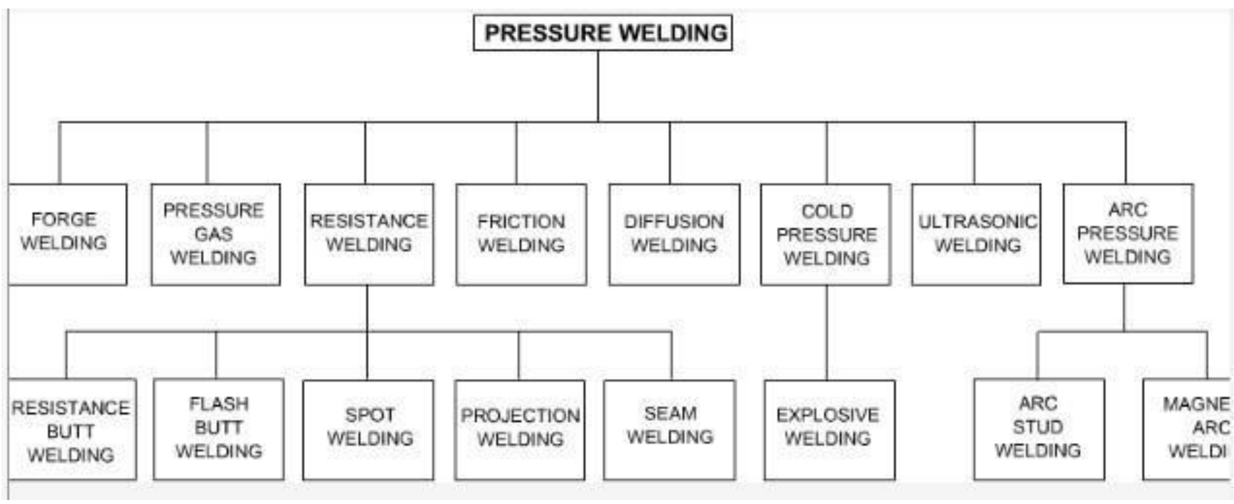
Welding processes can be classified based on following criteria;

1. Welding with or without filler material.
2. Source of energy of welding.
3. Arc and Non-arc welding.
4. Fusion and Pressure welding.

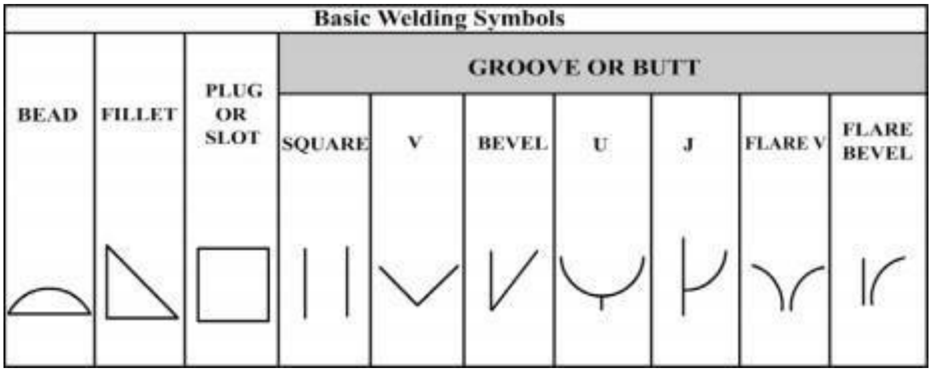
1. Welding can be carried out with or without the application of filler material. Earlier only gas welding was the fusion process in which joining could be achieved with or without filler material. When welding was done without filler material it was called 'autogenous welding'. However, with the development of TIG, electron beam and other welding processes such classification created confusion as many processes shall be falling in both the categories.
2. Various sources of energies are used such as chemical, electrical, light, sound, mechanical energies, but except for chemical energy all other forms of energies are generated from electricalenergy for welding. So this criterion does not justify proper classification.
3. Arc and Non-arc welding processes classification embraces all the arc welding processes in one class and all other processes in other class. In such classification it is difficult to assign either of the class to processes such as electroslag welding and flash butt welding, as in electroslag weldingthe process starts with arcing and with the melting of sufficient flux the arc extinguishes while inflash butt welding tiny arcs i.e. sparks are established during the process and then components are pressed against each other. Therefore, such classification is also not perfect.
4. Fusion welding and pressure welding is most widely used classification as it covers all processes in both the categories irrespective of heat source and welding with or without filler material. In fusion welding all those processes are included where molten metal solidifies freely while in pressure welding molten metal if any is retained in confined space under pressure (as may be in case of resistance spot welding or arc stud welding) solidifies under pressure or semisolid metal cools under pressure. This type of classification poses no problems so it is considered as the best criterion.

Processes falling under the categories of fusion and pressure welding are shown in Figures 2.1 and 2.2.





Need of welding symbols It is important to communicate information about welding procedure without any ambiguity to all those who are involved in various steps of fabrication of successful weld joints rangingfrom edge preparation to final inspection and testing of welds. To assist in this regard, standard symbols and methodology for representing the welding procedure and other conditions have been developed. Symbols used for showing the type of weld to be made are called weld symbols. Some common weld symbols are shown below.

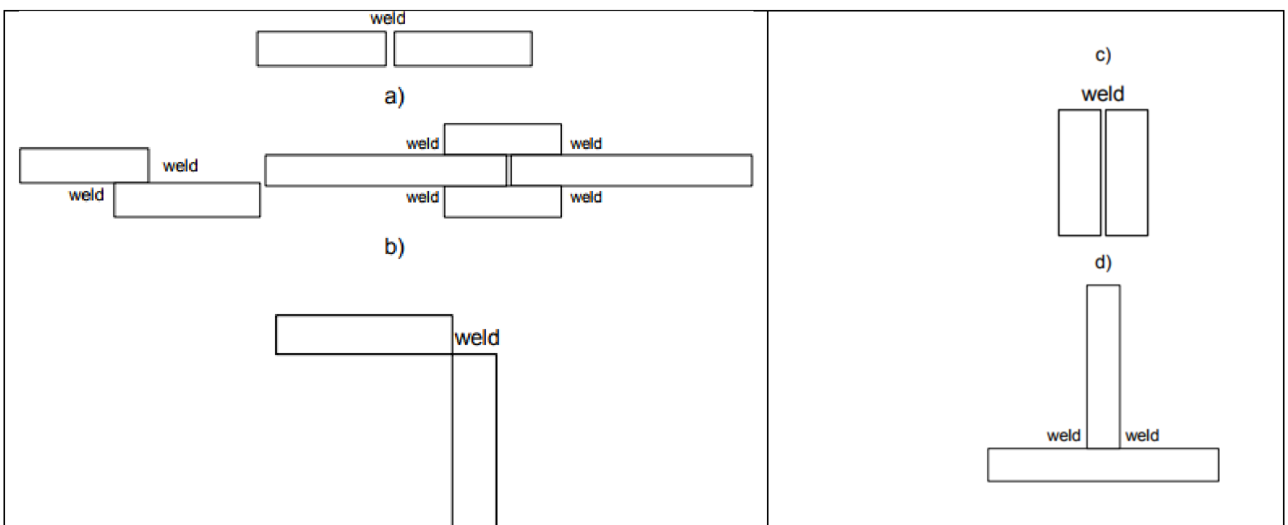


Basic Weld Symbols

Symbols which are used to show not only the type of weld but all relevant aspects related with welding like size & location of weld, welding process, edge preparation, bead geometry and weld inspection process and location of the weld to be fabricated and method of weld testing etc. are called welding symbols. Following sections present standard terminologies and joints used in field of welding engineering.

22.7 Types of weld Joints the classification of weld joints is based on the orientation of plates/members to be welded. Common types of weld joints and their schematics are shown in Fig. 22.2 (a-e). Butt joint: plates are in same horizontal plane and aligned with maximum deviation of 50. Lap joint: plates overlapping each other and the overlap can just one side or both the sides of plates being welded Cornerjoint: joint is made by melting corners of two plates being welded and therefore plates are approximatelyperpendicular (750 - 900) to each other at one side of the plates being welded Edge joint: joint is made bymelting the edges of twoplates to be welded and therefore the plates are almost parallel (00 - 50)

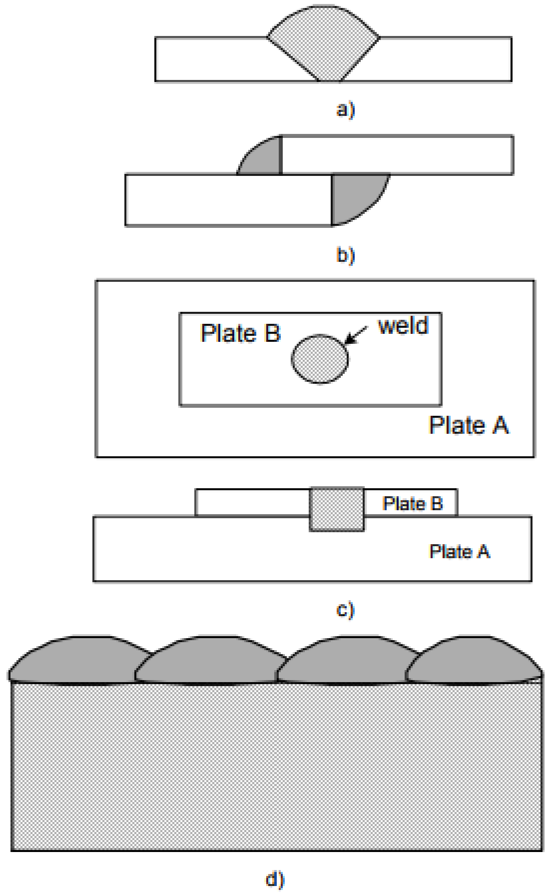
T joint: one plate is approximately perpendicular to another plate (850 - 900).



Schematic of different types of weld joints a) Butt b) Lap c) Corner d) Edge and e) T- Joint

Types of weld:

This classification in based on the combined factors like “how weld is made” and “orientation of plates" to be welded. Common types of weld joints and their schematics are shown in Figure shown below.



Schematic of different types of welds a) Groove b) Fillet c) Plug and d) Bead on Plate

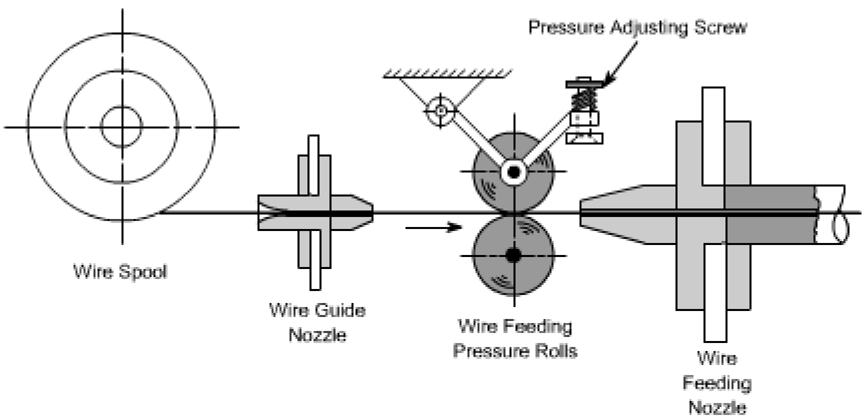
Gas Metal Arc Welding

Gas metal arc welding (GMAW) is the process in which arc is struck between bare wireelectrode and workpiece. The arc is shielded by a shielding gas and if this is inert gas such as argon or helium then it is termed as metal inert gas (MIG) and if shielding gas is active gas such as CO_2 or mixture of inert and active gases then process is termed as metal active gas (MAG) welding. Figure 9.1 illustrates the process of GMA welding.

Schematic Diagram of GMA

Direct current flat characteristic power source is the requirement of GMAW process. The electrode wire passing through the contact tube is to be connected to positive terminal of power source so that stable arc is achieved. If the electrode wire is connected to negative terminal then it shall result into unstable spattery arc leading to poor weld bead. Flat characteristic leads to self adjusting or self regulating arc leading to constant arc length due to relatively thinner electrode wires.

GMA welding requires consumables such as filler wire electrode and shielding gas. Solid filler electrode wires are normally employed and are available in sizes 0.8, 1.0, 1.2 and 1.6 mm diameter. Similar to submerged arc welding electrode wires of mild steel and low alloyed steel, are coated with copper to avoid atmospheric corrosion, increase current carrying capacity and for smooth movement through contact tube. The electrode wire feeding system is shown in Figure 9.2.



Electrode Wire Feeding System

Pressure adjusting screw is used to apply required pressure on the electrode wire during its feeding to avoidany slip. Depending on the size and material of the wire, different pressures are required for the smoothfeeding of wire with minimum deformation of the wire. Further, wire feeding rolls have grooves of different sizes and are to be changed for a particular wire size.

The range of welding current and voltage vary and is dependent on material to be welded, electrode sizeand mode of metal transfer i.e. mode of molten drop formed at the tip of electrode and its transfer to theweld pool. This process exhibits most of the metal transfer modes depending on welding parameters.

The range of current and voltage for a particular size of electrode wire, shall change if materialof electrodewire is changed. With lower currents normally lower voltages are employed while higher voltages are associated with higher currents during welding. Thin sheets and plates in all positions or root runs in medium plates are welded with low currents while medium and heavy plates in flat position are welded with high currents and high voltages. Welding of medium thickness plates in horizontal and vertical positions are welded with medium current and voltage levels.

Table 9.1 gives the total range of currents and voltages for different sizes of structural steel i.e. mild steelelectrodes of different sizes.

Table 9.1: Welding Current and Voltage Ranges for Mild Steel Electrodes

Electrode Wire Diameter (mm)	**Current Range (A)**	**Voltage Range (V)**
0.8	50-180	14-24
1.0	70-250	16-26

1.2	120-320	17-30

1.6	150-380	18-34

Both inert gases like argon and helium and active gases like CO_2 and N_2 are being used for shielding depending upon the metal to be welded. Mixtures of inert and active gases like CO_2 and O_2 are also beingused in GMA welding process. For mild steel carbon dioxide is normally used which gives high quality, lowcurrent out of position welding i.e. also in welding positions other than flat position. Low alloyed and stainless steels require argon plus oxygen mixtures for better fluidity of molten metal and improved arc stability. The percentage of oxygen varies from 1-5% and remaining is argon in argon and oxygen mixtures.However, low alloy steels are also welded with 80% argon and 20% CO_2 mixture.

Nickel, monel, inconel, aluminum alloys, magnesium, titanium, aluminum bronze and silicon bronze are welded with pure argon. Nickel and nickel alloys may sometimes be welded with mixture of argon and hydrogen (upto 5%). Copper and aluminum are also welded with 75% helium and 25% argon mixture to encounter their thermal conductivity. Nitrogen may be used for welding of copper and some of its alloys,but nitrogen and argon mixtures are preferred over pure nitrogen for relatively improved arc stability.

The process is extremely versatile over a wide range of thicknesses and all welding positions for both ferrous and nonferrous metals, provided suitable welding parameters and shielding gases are selected. High quality welds are produced without the problem of slag removal. The process can be easily mechanized / automated as continuous welding is possible. However, process is costly and less portable than manual metal arc welding. Further, arc shall be disturbed and poor quality of weld shall be producedif air draught exists in working area.

GMA welding has high deposition rate and is indispensable for welding of ferrous and specially for nonferrous metals like aluminum and copper based alloys in shipbuilding, chemical plants, automobile and electrical industries. It is also used for building structures.

This chapter presents the basic principle of arc welding processes with focus on shielded metal arc welding.Further, the influence of welding parameters on performance of weld joint and the role of coating on electrode have been described. Keywords: Arc welding, shielded metal arc welding, shielding in SMAW, electrode coating, welding current, electrode size

Arc Welding Process All arc welding processes apply heat generated by an electric arc for melting the faying surfaces of the base metal to develop a weld joint (Fig. 11.1). Common arc welding processes are manual metal or shielded metal arc welding (MMA or SMA), metal inert gas arc (MIG), tungsten inert gas(TIG), submerged arc (SA), plasma arc (PA), carbon arc (CA) selding etc.

Schematic diagram showing various elements of SMA welding system

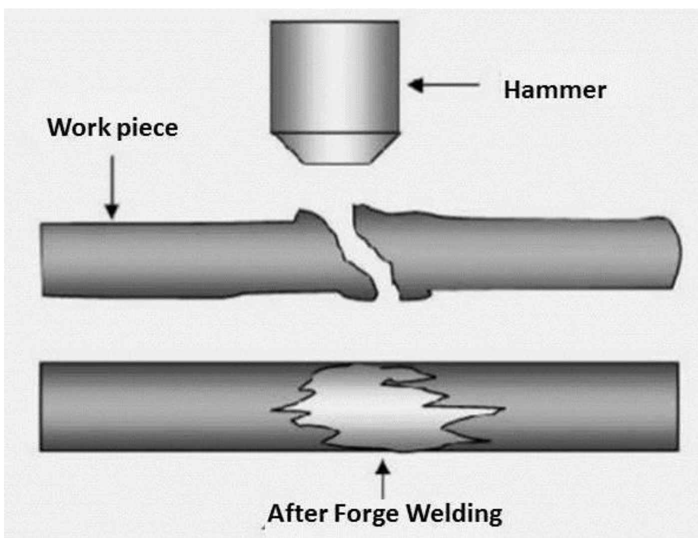
Arc Welding

Forge
Welding
Principle

As we discussed, forge welding is a solid state welding process in which both the plates are heated quite below its melting temperature. This heating deforms the work pieces plastically. Now a repeated hammering or high pressurize load is applied on these plates together. Due to this high pressure and temperature, inter-molecular diffusion takes place at the interface surface of the plates which make a strong weld joint. This is basic principle of forge welding. One of the basic requirement of this **types of welding**, is clean interface surface which should be free from oxide or other contaminant particles. To prevent the welding surface from oxidation, flux is used which mixes with the oxide and lower down its melting temperature and viscosity. This allow to flow out the oxide layer during heating and hammering process.

Working

Forge welding was one of the most applied welding method in ancient time. This is a fundamental welding process of all solid state welding. Its working can be summarized as follow.



- First both the work plates heated together. The heating temperature is about 50 to 90% of its melting temperature. Both the plates are coated with flux.
- Now manual hammering is done by a blacksmith **hammer** for making a joint. This process is repeated until a proper joint is created.
- For welding large work pieces, mechanical hammering is used which is either driven by electric motor or by using hydraulic mean. Sometime dies are used which provides finished surface.

Application

- It is used to join steel or iron.
- It is used to manufacture gates, prison cells etc.
- It was used to weld weapon like sword
- etc.

- It is widely used in cookware.
- It was used to join boiler plates before introduction of other welding process.

- It was used to weld weapon like sword
- etc.

Advantages

- It is simple and easy.
- It does not require any costly equipment for weld small pieces.
- It can weld both similar and dissimilar metals.
- Properties of weld joint is similar to base material.
- No filler material required.

Disadvantages

- Only small objects can be weld. Larger objects required large press and heating furnaces, which are not economical.
- High skill required because excessive hammering can damage the welding plates.
- High **Welding defects** involve.
- It cannot use as mass production.
- Mostly suitable for iron and steel.
- It is a slow welding process.

Resistance Welding

Resistance welding processes are pressure welding processes in which heavy current is passed for short time through the area of interface of metals to be joined. These processes differ from other welding processes in the respect that no fluxes are used, and filler metal rarely used. All resistance welding operations are automatic and, therefore, all process variables are preset and maintained constant. Heat is generated in localized area which is enough to heat the metal to sufficient temperature, so that the parts can be joined with the application of pressure. Pressure is applied through the electrodes.

The heat generated during resistance welding is given by following expression:

$$\mathbf{H = I^2 R T}$$

Where, **H** is heat generated

I is current in amperes

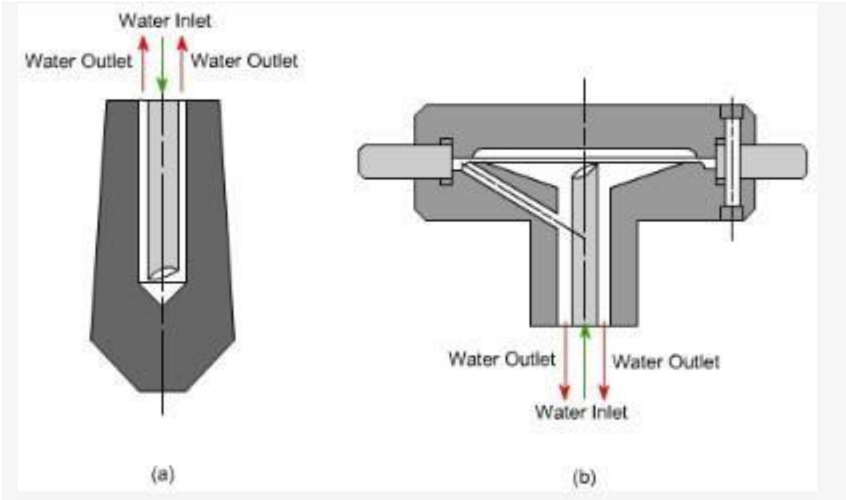
R is resistance of area being welded

T is time for the flow of current

The process employs currents of the order of few KA, voltages range from 2 to 12 volts and times vary from few ms to few seconds. Force is normally applied before, during and after the flow of current to avoid arcing between the surfaces and to forge the weld metal during post heating. The necessary pressure shall vary from 30 to 60 N mm^{-2} depending upon material to be welded and other welding conditions. For good quality welds these parameters may be properly selected which shall depend mainly on material of components, their thicknesses, type and size of electrodes. Apart from proper setting of welding parameters, component should be properly cleaned so that surfaces to be welded are free from rust, dust, oil and grease. For this purpose components may be given pickling treatment i.e. dipping in diluted acid bath and then washing in hot water bath and then in the cold water bath. After that components may be dried through the jet of compressed air. If surfaces are rust free then pickling is not required but surface cleaning can be done through some solvent such as acetone to remove oil and grease.

The current may be obtained from a single phase step down transformer supplying alternating current.

to sustain high pressure at elevated temperatures. Commonly used electrode materials are pure copper and copper base alloys. Copper base alloys may consist of copper as base and alloying elements such as cadmium or silver or chromium or nickel or beryllium or cobalt or zirconium or tungsten. Pure tungsten or tungsten-silver or tungsten-copper or pure molybdenum may also be used as electrode material. To reduce wear, tear and deformation of electrodes, cooling through water circulation is required. Figure
11.1 shows the water cooling system of electrodes.

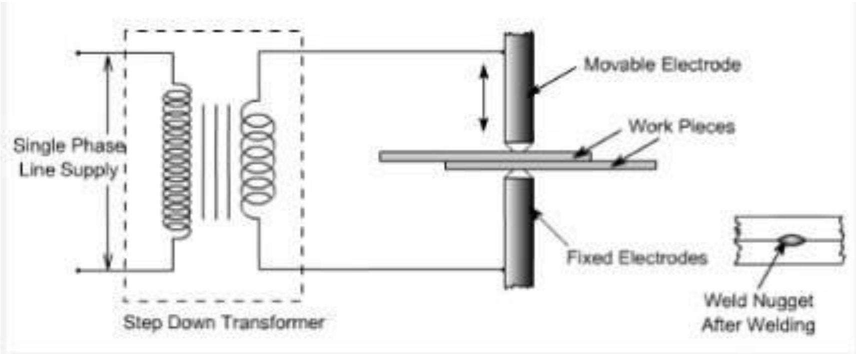


Water Cooling Electrodes a)Spot Welding b) Seam Welding

Commonly used resistance welding processes are spot, seam and projection welding which produce lap joints except in case of production of welded tubes by seam welding where edges are in butting position.In butt and flash welding, components are in butting position and butt joints are produced.

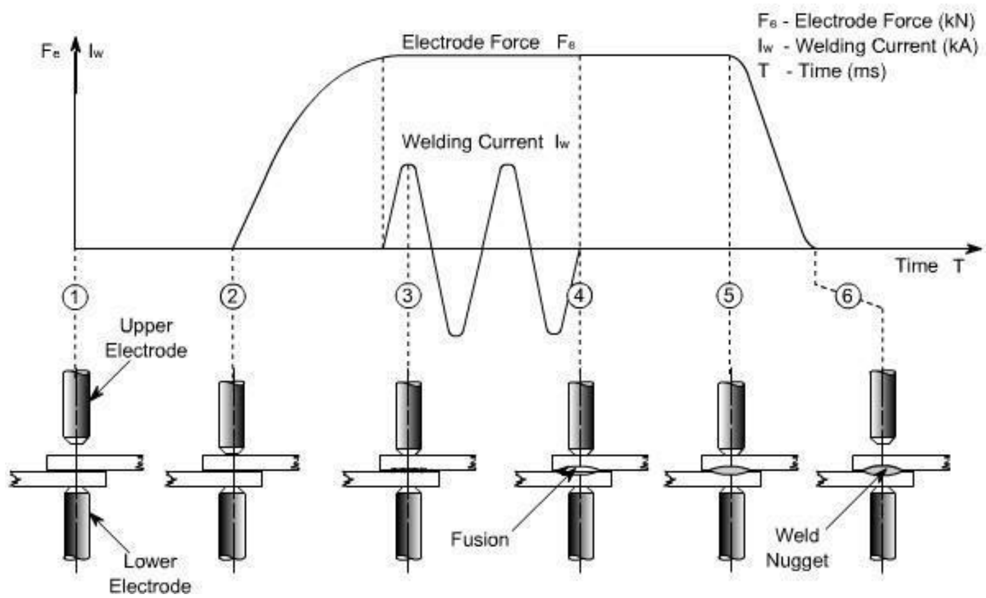
Spot Welding

In resistance spot welding, two or more sheets of metal are held between electrodes through which welding current is supplied for a definite time and also force is exerted on work pieces. The principle is illustrated in Figure 11.2.

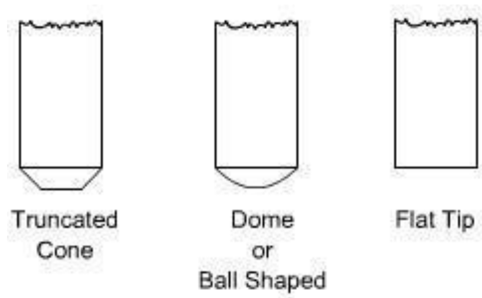


Spot Welding

The welding cycle starts with the upper electrode moving and contacting the work pieces resting on lowerelectrode which is stationary. The work pieces are held under pressure and only then heavy current is passed between the electrodes for preset time. The area of metals in contact shall be rapidly raised to welding temperature, due to the flow of current through the contacting surfaces of work pieces. The pressure between electrodes, squeezes the hot metal together thus completing the weld. The weld nuggetformed is allowed to cool under pressure and then pressure is released. This total cycle is known as resistance spot welding cycle and illustrated in Figure 11.3



Spot welding electrodes of different shapes are used. Pointed tip or truncated cones with an angle of 120°
- 140° are used for ferrous metal but with continuous use they may wear at the tip. Domed electrodes arecapable of withstanding heavier loads and severe heating without damage and are normally useful for welding of nonferrous metals. The radius of dome generally varies from 50- 100 mm. A flat tip electrode is used where minimum indentation or invisible welds are desired.

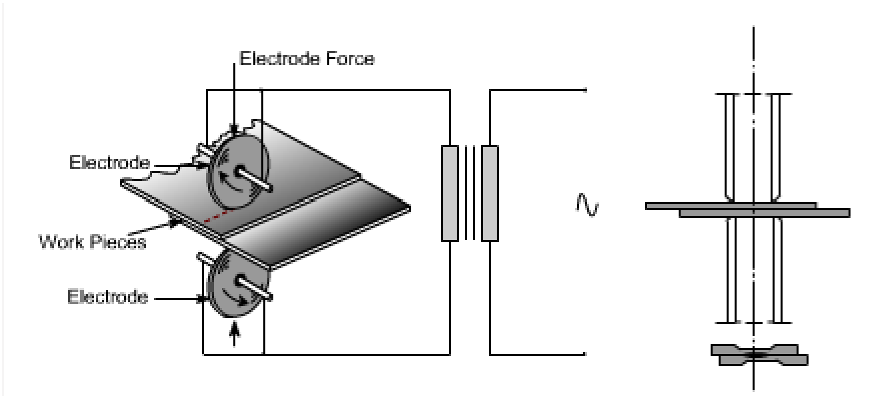


Electrode Shapes for Spot Welding

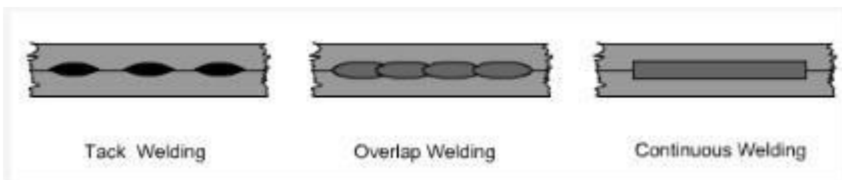
Most of the industrial metal can be welded by spot welding, however, it is applicable only for limited thickness of components. Ease of mechanism, high speed of operation and dissimilar metal combination welding, has made is widely applicable and acceptable process. It is widely being used in electronic, electrical, aircraft, automobile and home appliances industries.

Seam Welding:

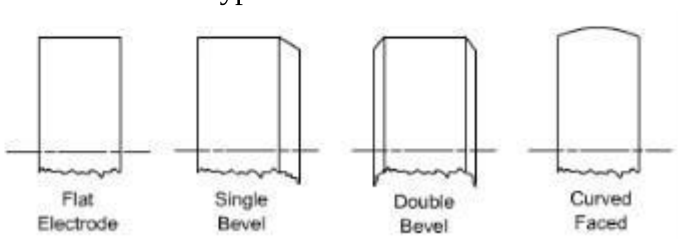
In seam welding overlapping sheets are gripped between two wheels or roller disc electrodes and currentis passed to obtain either the continuous seam i.e. overlapping weld nuggets or intermittent seam i.e. weldnuggets are equally spaced. Welding current may be continuous or in pulses. The process of welding is illustrated in Figure 11.5.



Process of Seam Welding



Types of Seam Welds

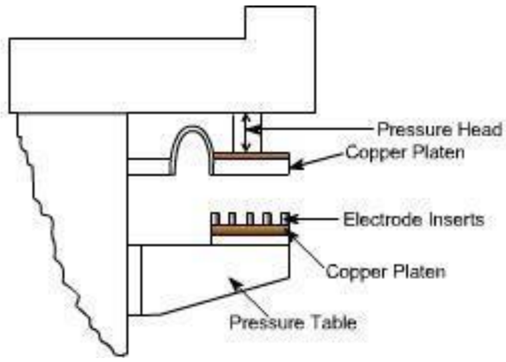


Electrodes shapes of Seam Welding

Overlapping of weld nuggets may vary from 10 to 50 %. When it is approaching around 50 % then it is termed as continuous weld. Overlap welds are used for air or water tightness.
It is the method of welding which is completely mechanized and used for making petrol tanks for automobiles, seam welded tubes, drums and other components of domestic applications. Seam welding is relatively fast method of welding producing quality welds. However, equipment is costly and maintenance is expensive. Further, the process is limited to components ofthickness less than 3 mm.

Projection Welding:

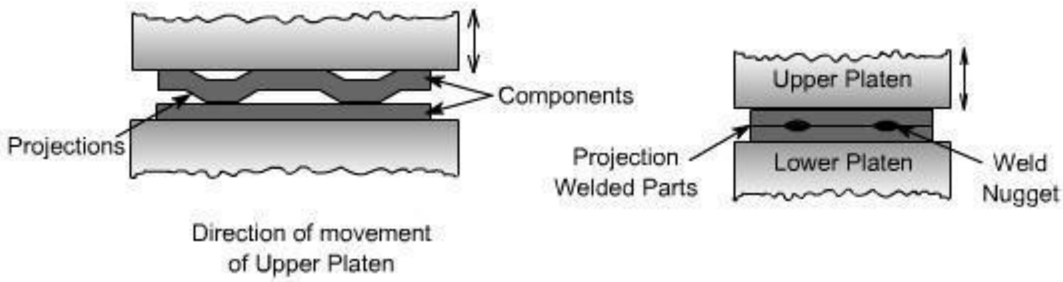
Projections are little projected raised points which offer resistance during passage of current and thus generating heat at those points. These projections collapse under heated conditions and pressure leadingto the welding of two parts on cooling. The operation is performed on a press welding machine and components are put between water cooled copper platens under pressure. Figures 11.8 and 11.9 illustratethe principle of resistance projection welding.



Resistance Projection welding Machine

These projections can be generated by press working or machining on one part or by putting some externalmember between two parts. Members such as wire, wire ring, washer or nut can be put between two parts to generate natural projection. Insert electrodes are used on copper platen so that with continuoususe only insert electrodes are damaged and copper platen is safe. Relatively cheaper electrode inserts canbe easily replaced whenever these are damaged.

Formation of Welds from Projections on Components



Projection welding may be carried out with one projection or more than one projections simultaneously. No consumables are required in projection welding. It is widely being used for fastening attachments likebrackets and nuts etc to sheet metal which may be required in electronic, electrical and domestic equipment.

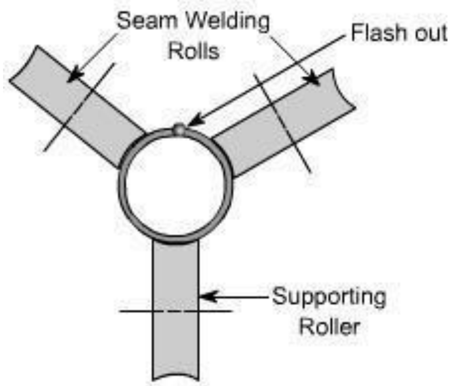
Production of seam welded Tubes:

Welded tubes are produced by resistance seam welding. Tubes are produced from strips which are wrapped on spool with trimmed edges. The width of strip should be slightly bigger than the periphery of

Thermit Welding

The tube to be produced to take care for the loss of metal in flashout. The strip is fed through set of forming rollers to form first the shape of the tube and then it is passed under the seam welding rolls. Under seam welding rolls the edges are butt welded with some flash out on the joint. This flash out is trimmed and then tubes are cut to required size. The process is shown in Figures 11.10 & 11.11.

Forming of Tube from Strip



Seam Welding of Tube

Thermit Welding:

After reading this article you will learn about:- 1. Process of Thermit Welding 2. Operation of ThermitWelding 3. Application and Uses 4. Advantages 5. Disadvantages.

Process of Thermit Welding:

Thermit welding is a chemical welding process in which an exothermic chemical reaction is used to supplythe essential heat energy. That reaction involves the burning of Thermit, which is a mixture of fine aluminum powder and iron oxide in the ratio of about 1:3 by weight.

Although a temperature of 3000°C may be attained as a result of the reaction, preheating of the Thermitmixture up to about 1300°C is essential in order to start the reaction.

The mixture reacts according to the chemical reaction:

$8\,Al + 3\,Fe_3O_4 \rightarrow 9\,Fe + 4\,Al_2O_3$ + heat (3000˚C, 35 kJ/kg of mixture).

Aluminum has greater affinity to react with oxygen; it reacts with ferric oxide to liberate pure iron and slagof aluminum oxide. Aluminum oxide floats on top of molten metal pool in the form of slag and pure iron (steel) settled below, because of large difference in densities.

The various steps involved in Thermit welding

Operation of Thermit Welding:

ADVERTISEMENTS:

Thermit welding process is essentially a casting and foundry process, where the metal obtained by the

The various steps involved in Thermit welding

1. The two pieces of metal to be joined are properly cleaned and the edge is prepared.
2. Then the wax is poured into the joint so that a wax pattern is formed where the weld is to be obtained.
3. A moulding box is kept around the joint and refractory sand is packed carefully around the wax pattern as shown in Fig. 7.40, providing the necessary pouring basin, sprue, and riser and gating system.
4. A bottom opening is provided to run off the molten wax. The wax is melted through this opening which is also used to preheat the joint. This makes it ready for welding.
5. The Thermit is mixed in a crucible which is made of refractory material that can withstand the extreme high heat and pressure, produced during the chemical reaction.
6. The igniter (normally barium peroxide or magnesium) is placed on top of the mixture and is lighted with a red hot metal rod or magnesium ribbon.
7. The reaction takes about 30 seconds and highly super-heated molten iron is allowed to flow into the prepared mould cavity around the part to be welded.
8. The super-heated molten metal fuses the parent metal and solidifies into a strong homogeneous weld.
9. The weld joint is allowed to cool slowly.

There are different Thermit mixtures available for welding different metals, such as copper and chromium.They use different metal oxides in place of ferrous oxide. Some typical Thermit mixture reactions with their temperature obtained are given below:

$3\,CuO + 2\,Al \rightarrow 3Cu + Al_2O_3$ + Heat (4860°C, 275 Kcal) $Cr_2O_3 + 2Al$
$\rightarrow 2Cr + Al_2O_3$ + Heat (3000°C, 540 Kcal)

Application and Uses of Thermit Welding:

Thermit welding is a very old process and now-a-days, in most cases, it is replaced by electro-slagwelding. However, this process is still in use.

Some applications are:

- Thermit welding is traditionally used for the welding of very thick and heavy plates.
- Thermit welding is used in joining rail roads, pipes and thick steel sections.
- Thermit welding is also used in repairing heavy castings and gears.
- Thermit welding is suitable to weld large sections such as locomotive rails, ship hulls etc.
- Thermit welding is used for welding cables made of copper.

Advantages of Thermit Welding:

- This process is cheap, as no costly power supply is required.
- This process can be used at the places where power supply is not available.

Disadvantages of Thermit Welding:

- Thermit welding is essentially used for ferrous metal parts of heavy sections.

Plasma Arc Welding

Introduction The plasma arc welding (PAW) can be considered as an advanced version of TIG welding. LikeTIGW, PAW also uses the tungsten electrode and inert gases for shielding of the molten metal. Low velocity plasma and diffused arc is generated in the TIG welding while in case of PAW very high velocity and coherent plasma is generated. Large surface area of the arc exposed to ambient air and base metal incase of TIG welding causes greater heat losses than PAW and lowers the energy density. Therefore, TIG arcburns at temperature lower than plasma arc.

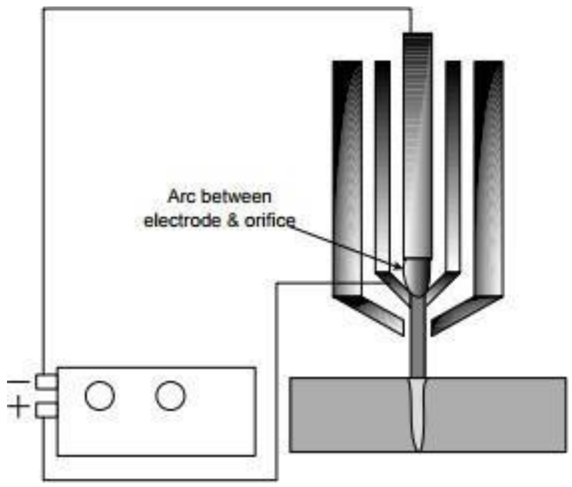
Principle of PAW

In plasma arc welding, arc is forced to pass through nozzle (water cooled copper) which causes the constriction of the arc (Fig. 16.5). Constriction of arc results in (a) reduction in cross-sectional area of arc,

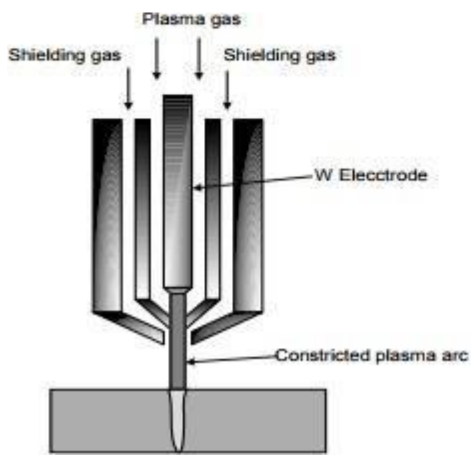
(b) increases (d) increases energy density and (c) increases to velocity of plasma approaching to the sound velocity and temperature to about 25000 0 C. these factors together make PAW, a high energy density and low heat input welding process therefore; it poses fewer which in turn reduces problems associated with weld thermal cycle.

Constriction of arc increases the penetration and reduces the width of weld bead. Energy associated with plasma depends on plasma current, size of nozzle, plasma gas (Fig. 16.6). A coherent, calumniated and stiff plasma is formed due to constriction therefore it doesn't get deflected and diffused. Hence, heat is transferred to the base metal over a very small area which in turns results in high energy density and deepof penetration and small width of the weld pool / key hole / cut. Further, stiff and coherent plasma makesit possible to work having stable arc with very low current levels (<15A) which inturn has led to micro- plasma system.

Energy density and penetration capability of plasma jet is determined by the various process parametersnamely plasma current, nozzle orifice diameter and shape, plasma forming gas (Air, He, Ar) and flow rateof plasma carrying. Increasing plasma current, flow rate, thermal conductivity of plasma forming gas andreducing nozzle orifice diameter increases togetherresult in the energy density and penetration capabilityof plasma jet. In general, the plasma cutting uses high energy density in combination with high plasma velocity and high flow rate of high thermal conductivity plasma forming gas. A combination of such characteristics for plasma cutting is achieved by controlling above process parameters. Further, thermal conductivity of plasma forming gas must be high enough for cutting operation so that heat can be effectively transferred rapidly to the base metal. Plasma welding needs comparatively low energy densityand low velocity plasma to avoid melt through or blowing away tendency of molten metal.



Schematic of plasma arc welding system showing important components



Schematic of constriction of arc in PAW

High energy density associated with plasma arc produces a temperature of order of 25,000 0 C. This process uses the heat transferred by plasma (high temperature charged gas column) produced by a gas (Ar, Ar-H2 mixture) passing through an electric arc, for melting of faying surfaces. Inert gas (Ar, He) is usedto protect the molten weld pool from the atmospheric gases. Charged particles (electrons and ions) formedas a result of ionization of plasma gas tends to reunite when they strike to the surface of work piece. Recombination of charged particles liberates heat which is also used in melting of base metal. Electric arccan be produced between nonconsumable electrode and work-piece or non-consumable electrode and nozzle. As discussed above, plasma arc welding uses two types of gases one is called plasma gas and otheris inert gas primarily for shielding the weld pool from the contamination by atmospheric gases. Plasma gasis primarily used to develop plasma by passing through arc zone and transfer the heat to the weld pool.

PAW uses the constant current type power source with DCEN polarity. The DCEN polarity is invariable used in PAW because tungsten electrode is used for developing the arc through which plasma forming gasis passed. Tungsten electrode has good electron emitting capability therefore it is made cathode. Further, DCEN polarity causes less thermal damage to the electrode during welding as about one third of total heatis generated at the cathode and balance two-third of arc heat is generated at the anode side i.e. workpiece. DCEP polarity does not help the process in either way. Current can vary from 2-200 A. The plasma arc in PAW is not initiated by the conventional touch start method but it heavily depend on use of high frequency unit. Plasma is generated using two cycles approach a) producing very small high- intensity spark (pilot arc) within the torch body by imposing pulses of high voltage, high frequency and low current about 50A (from HF unit) between the electrode and nozzle which in turn generates a small pocket of plasma gas and then as soon as torch approaches the work-piece main current starts flowing between electrode and job leading to the ignition of the transferred arc. At this stage pilot is extinguished and taken off the circuit.

Types of PAW Plasma generated due to the arc between the non-consumable electrode and workpiece is called transferred plasma whereas that due to arc between non-consumable electrode and nozzle is called non-transferred plasma. Non-transferred plasma system to a large extent becomes independent of nozzle to work piece distance.
Transferred plasma offers higher energy density than non-transferred plasma and therefore it is preferred for welding and cutting of high speed steel, ceramic, aluminium etc. Non-transferred plasma is usually applied for welding and thermal spray application of steel and other common metals. Depending upon the current, plasma gas flow rate, and the orifice diameter following variants of PAW has been developed such as:

- Micro-plasma (< 15 Amperes)
- Melt-in mode (15–400 Amperes) plasma arc
- Keyhole mode (>400 Amperes) plasma arc

Micro-plasma welding systems work with very low plasma forming current (generally lower than 15 A) which in turn results in comparatively low energy density and low plasma velocity. These conditions become good enough to melt thin sheet for plasma welding.

Plasma for melt-in mode uses somewhat higher current and greater plasma velocity than micro-plasma system for welding applications. This is generally used up to 2.4 mm thickness sheet. For thickness of sheet greater than 2.5 mm normally welding is performed using key-hole technique. The key hole technique uses high current and high pressure plasma gas to ensure key-hole formation. High energy density of plasma melts the faying surfaces of base metal and high pressure plasma jet pushes the molten metal against vertical wall created by melting of base metal and developing key-hole. Plasma velocity should be such that it doesn't push molten metal out of the hole. The key is formed under certain combination of plasma current, orifice gas flow rate and velocity of plasma welding torch and any disturbance to above parameters will cause loss of key-hole. For key-holing, flow rate is very crucial and therefore is controlled accurately + 0.14 liter/min. Nozzles are specified with current and flow rate.

Advantage of PAW

With regard to energy density, PAW stands between GTAW/GMAW and EBW/LBW accordingly it can be used using melt-in mode and key-hole mode. Melt-in mode results in greater heat input and higher width to depth of weld ratio than key-hole mode. Higher energy density associated with PAW than GTAW produces narrow heat affected zone and lowers residual stress and distortion related problems. High depth to width ratio of weld produced by PAW reduces the angular distortion. It generally uses about one tenth of welding current as compared to GTAW for same thickness therefore it can be effectively applied for joining of the thin sheets. Further, non-transferred plasma offers flexibility of variation in standoff distance between nozzle and work- piece without extinction of the arc.

Limitation of PAW

Infrared and ultra-violet rays generated during the PA welding are found harmful to human being. High noise (100dB) associated with PAW is another undesirable factor. PAW is a more complex, costlier, difficultto operate than GTAW besides generating high noise level during welding. Narrow width of the PAW weldcan be problematic from alignment and fit-up point of view. Productivity of the PAW in respect of weldingspeed is found lower than LBW.

Oxy-Fuel Gas Cutting:

This is the most frequently employed thermal cutting process used for low carbon and low alloy steelplates and often referred to as ‘flame cutting’ or ‘gas cutting’. It can be used to cut steel upto 2 m thick. Oxy-fuel gas process involves preheating a small zone, wherefrom the cut is to be started, to the kindlingtemperature of the material. Compressed oxygen is then made to impinge upon the hot metal resultingin very high rate of oxidation which is often accompanied by evolution of heat due to exothermic natureof the reaction.

The fuel gas employed is generally acetylene but propane, LPG (liquefied petroleum gas),natural gas, or methylacetylene propadiene stabilised (MAPP or MPS) may also be employed depending upon availabilityand cost considerations.

The torch employed for oxy-acetylene cutting is shown in Fig. 19.2. It has a mixing chamber for oxygen and acetylene as in a welding torch. But after mixing the gas mixture flows out of the torch nozzle througha number of small holes placed in a circle around the central hole through whicha stream of high pressurepure oxygen can be made to flow by pressing a lever on the torch handle. The diameter of these holes vary and increases with increase in thickness of the material to be cut.

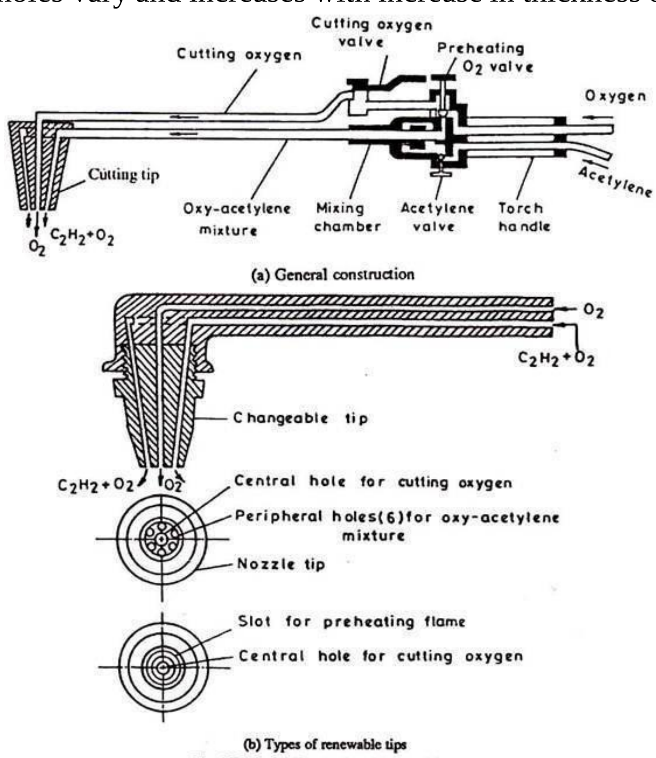


Fig. 19.2 Gas cutting torch and types of tips.

When the material to be cut is raised to its kindling temperature* (which is 870 to 950°C for low carbon steels, depending upon the carbon content) and high pressure pure oxygen reacts with it, the following reactions are possible in the case of ferrous materials.

1. $Fe + O \rightarrow FeO$ + heat (267 KJ)…....................(1)
2. $2Fe + 1.5O_2 \rightarrow Fe_2O_3$+heat (825 KJ)… ....(2)
3. $3Fe + 2O_2 \rightarrow Fe_3O_4$ + heat (1120KJ)..............(3)

Mainly third reaction takes place with tremendous release of heat. Second reaction occurs to some extentin cutting of heavier sections only. Theoretically 0.29 m^3 of O_2 will oxidise 1 kg of iron to form Fe_3O_4. However, in practice the consumption of oxygen is higher than this value for plate thickness less than 40 mm and it is lower for higher thicknesses, being the least for the thickness range of 100 to 125 mm.

The exothermic reaction between O_2 and Fe generates enough heat to continue the thermal cutting process without the use of preheating flame using only oxygen but in practice it is not possible because alot of heat is used up in burning dirt, paint, scale, etc., and a considerable amount is lost by radiation. Also,the high speed jet impinging upon the surface causes cooling action which needs to be compensated by preheating.

The chemical reaction between ferrous and oxygen is rarely complete and the analysis of the blown out material (or slag) often indicates that 30% to 40% of the slag is parent material.

Steel and some other metals can be cut by oxy-acetylene flame if they fulfill the following conditions:

- The melting point of the metal should be higher than its kindling temperature.
- The metal oxide formed by reaction with oxygen should have lower melting point than the melting point of the parent material and it should be fluid in molten state so as to blow out easily.
- It should have low thermal conductivity so that the material can be rapidly raised to its kindling temperature.

When a workpiece is cut by a thermal cutting process, the width of the cut is referred to as KERF, which inoxy-fuel gas process is a function of oxygen hole size in the nozzle tip, flowrate of oxygen and preheatinggases, speed of cutting and the nature of the material being cut.

Cutting of Ferrous and Non-Ferrous Metals:

Metal Powder Cutting:

It is an oxygen cutting process in which metal powder (iron or aluminum) is employed to facilitate cutting.This process is used for cutting cast iron, chromium-nickel, stainless steel and some high alloy steels. Theworking principle of powder cutting is lite injection of metal powder into the oxygen stream well before it strikes the metal to be cut.

The powder is heated by its passage through the oxy-acetylene preheat flames and almost immediately ignites in the stream of cutting oxygen. The powder from a powder dispenser is carried to the lip of the cutting torch by the use of compressed air or nitrogen as shown in Fig. 19.7.

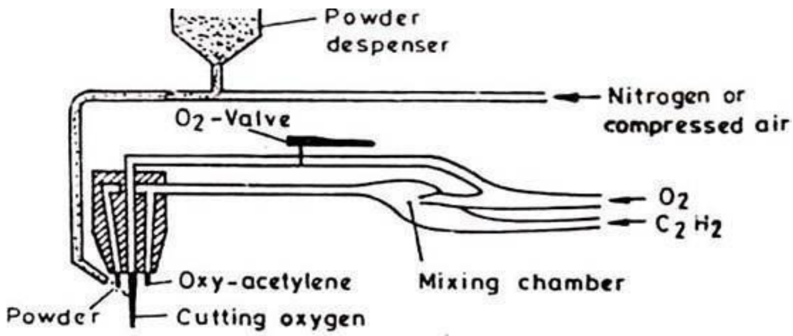


Fig. 19.7 Cutting torch for metal powder cutting.

The ignited powder provides much higher temperature in the stream and that helps in culling the metal in almost the same manner as cutting of low carbon steel. Preheating is not essential for powder cutting.

Cutting speeds and cutting oxygen pressures are similar to those for cutting mild steel; however for cuttingmaterial thicker than 25 mm a nozzle one size larger should be used. Flow rates are generally kept at 010to 0-25 kg of iron powder per minute of cutting. Powder cutting usually leaves a scale on the cut surface which can be easily removed on cooling.

Metal powder culling was initially introduced for cutting stainless steel but has been successfully used forcutting alloy steels, cast iron, bronze, nickel, aluminium, steel mill ladle spills, certain refractories, and concrete. The same basic process can also be used for gouging and scarfing to condition billets, blooms, and slabs in steel mills.

Powder cutting is also useful for stack cutting wherein preheat from an ordinary flame culling is not sufficient on the lower plate(s) either due to large depth or separation between plates. By means of the metal powder and its reaction in the oxygen the cut is completed even across separations. However, powder cutting generates quite a bit of smoke that needs to be removed to safeguard the health of the operator and to avoid interference with other operations in the area.

Process # 3. Chemical Flux Cutting:

In the oxygen-cutting process a chemical flux is injected into the oxygen stream as metal powder is injected in powder cutting. The flux combines with the refractory oxides and makes them a soluble compound. The chemical fluxes may be salts of sodium such as sodium carbonate.

Fig. 19.8 shows one of the setups used for flux cutting. In this method oxygen sucks flux from a hopper atthe rate of 0 06 to 0-30 kg per minute and flows through the jet of cutting oxygen.

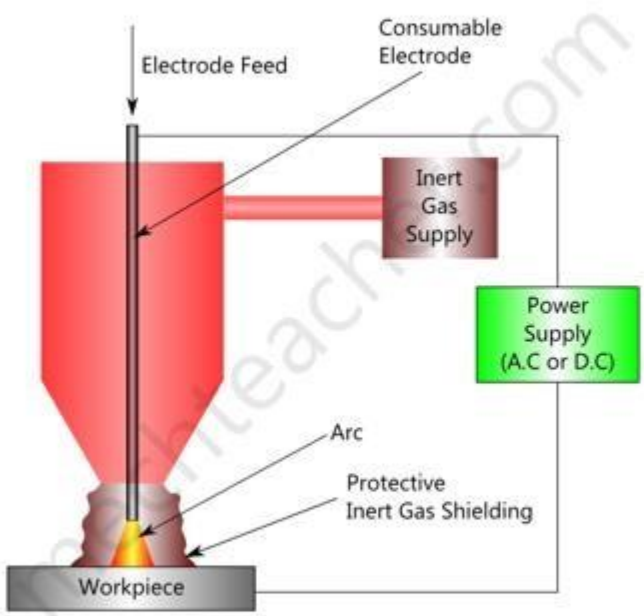
The procedure for flux cutting involves heating the initiating point of cut to white heat, the cutting oxygen valve is then opened half-turn and the flux in oxygen stream is led to the torch. As the molten metal reaches the lower edge of the work, the torch is made to move along the line of the cut and the cutting oxygen valve is fully opened. To halt the operation first flux-supply valve is closed and then the other torchvalves are shut-off.

It is advisable to position the flux-supply 10 m away from the cutting area. It should also be ensured that thehoses through which the flux-oxygen mixture is passed have no sharp bends otherwise it may lead to clogging.

This process can be used for cutting cast iron, chromium-steel, chromium-nickel steel, copper, brass and bronze. However, it is not recommended for cutting steels of high-nickel type, for example, 15 Cr 35Ni steel. Chemical flux cutting, however, is slowly losing its industrial importance because of the development of more efficient methods like plasma cutting.

Metal Inert Gas (MIG) welding (also known as Gas Metal Arc Welding [GMAW])

MIG is an arc welding technique in which a consumable electrode is used to weld two or more work pieces. A diagrammatic representation of metal inert gas welding is shown below:



Components used in Metal Inert Gas Welding (MIG

Welding): Metal Inert Gas Welding (MIG Welding) makes use of the

following components:

1. Consumable Electrode
2. Inert Gas Supply
3. Welding Head
4. A.C or D.C Power Supply
5. Electrode Feeding Mechanism Working:

The workpiece to be welded and the consumable electrode (in the form of wire) are connected to the Power Supply (D.C or A.C). Whenever the consumable electrode is brought near the workpiece (with a smallair gap), an arc is produced. This arc melts the electrode. The melted electrode fills uniformly over the required regions of the workpiece.

An inert gas supply is provided around the electrode (hence the name ‘Metal Inert Gas Welding’) during the welding process. It forms a gas shield around the arc and the weld (See the diagram above). This is intended to protect the weld from the external atmosphere. The type of electrode used and the shieldinggas used primary depends on the material to be welded. In many cases the shielding gas used is a mixtureof many gases.

If many workpieces are to be welded continuously an electrode spool (in the form of coil) is used. Consumable electrode is continuously supplied from this spool by a suitable feeding mechanism. Commonly, servo mechanisms are used for feeding long electrodes. In MIG Welding, consumable electrode itself acts as filler metal. So, no seperate filler rod or filler wire is needed.

Advantages of Metal Inert Gas Welding (MIG Welding):

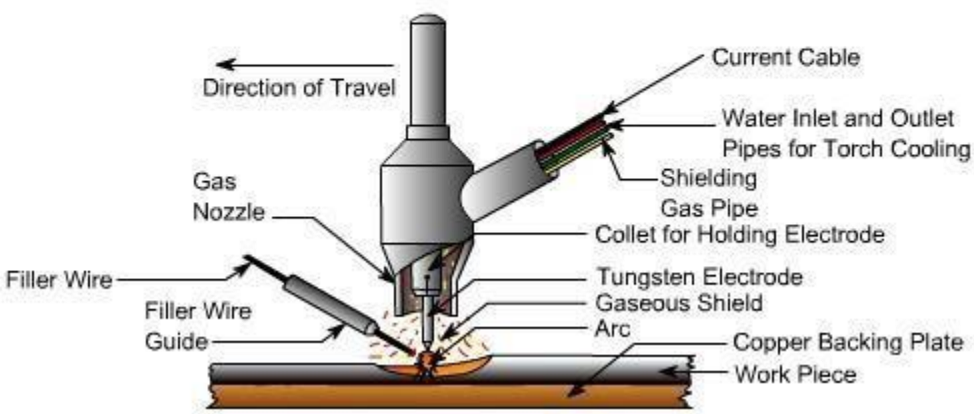
1. Consumable electrodes are easy to feed.
2. No filler rod is needed.
3. Welding is simple.
4. Inert gas shield protects the weld automatically.

Disadvantages of Metal Inert Gas Welding (MIG Welding):

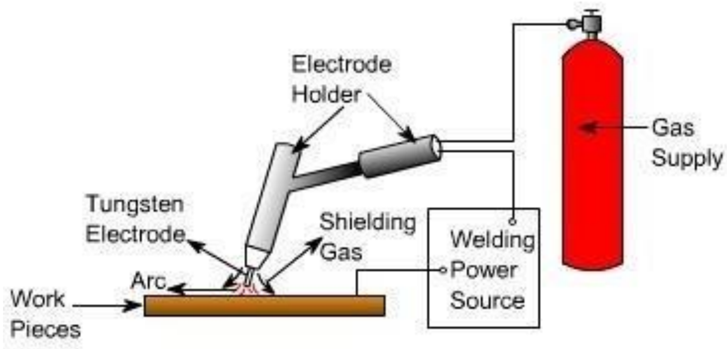
1. Improper welding may lead to the floating of solid impurities over the liquid weld.
2. If not handled properly, weld may become porous.
3. MIG Welding exposes welders to hazardous gases.
4. Care must be taken to avoid the formation of less ductile welds.
5. Work pieces and Electrodes should be kept clean before welding.

TIG Welding

Tungsten Inert Gas (TIG) or Gas Tungsten Arc (GTA) welding is the arc welding process in which arc is generated between non-consumable tungsten electrode and work piece. Thetungsten electrode and theweld pool are shielded by an inert gas normally argon and helium. Figures 10.1 & 10.2 show the principleof tungsten inert gas welding process.



Principle of TIG Welding.



Schematic Diagram of TIG Welding System.

The tungsten arc process is being employed widely for the precision joining of critical components whichrequire controlled heat input. The small intense heat source provided by the tungsten arc is ideally suitedto the controlled melting of the material. Since the electrode is not consumed during the process, as withthe MIG or MMA welding processes, welding without filler material can be done without the need for continual compromise between the heat input fromthe arc and the melting of the filler metal. As the fillermetal, when required, can be added directly to the weld pool from a separate wire feed system or manually, all aspects of the process can be precisely and independently controlled i.e. the degree of melting of the parent metal is determined by the welding current with respect to the welding speed, whilst the degree of weld bead reinforcement is determined by the rate at which the filler wire is addedto the weld pool.

In TIG torch the electrode is extended beyond the shielding gas nozzle. The arc is ignited by high voltage, high frequency (HF) pulses, or by touching the electrode to the workpiece and withdrawing to initiate the arc at a preset level of current. Selection of electrode composition and size is not completely independent and must be considered in relation to the operating mode and the current level. Electrodesfor DC welding are pure tungsten or tungsten with 1 or 2% thoria, the thoria being added to improve electron emission which facilitates easy arc ignition. In AC welding, where the electrode must operate ata higher temperature, a pure tungsten or tungsten-zirconia electrode is preferred as the rate of tungstenloss is somewhat lesser than with thoriated electrodes and the zirconia aids retention of the ‘balled' tip.Table below indicates the chemical composition of tungsten electrodes as per American Welding Society(AWS) classification.

Chemical Composition of TIG Electrodes

AWS Classification	**Tungsten, min. percent**	**Thoria, percent**	**Zirconia ,percent**	**Total other elements, max. percent**
EWP	99.5	-	-	0.5
EWTh-1	98.5	0.8 to 1.2	-	0.5
EWTh-2	97.5	1.7 to 2.2	-	0.5
EWZr	99.2	-	0.15 to 0.40	0.5

Tungsten electrodes are commonly available from 0.5 mm to 6.4 mm diameter and 150 - 200 mm length.

positive terminal of DC power source. AC is used only in case of welding of aluminum and magnesium and their alloys. Table 10.2 gives typical current ranges for TIG electrodes when electrode is connected to negative terminal (DCEN) or to positive terminal (DCEP).

Typical Current Ranges for TIG Electrodes

Electrode Dia. (mm)	**DCEN**	**DCEP**
	Pure and Thoriated Tungsten	**Pure and Thoriated Tungsten**
0.5	5-20	-
1.0	15-80	-
1.6	70-150	10-20
2.4	150-250	15-30
3.2	250-400	25-40
4.0	400-500	40-55
4.8	500-750	55-80
6.4	750-1000	80-125

The power source required to maintain the TIG arc has a drooping or constant current characteristic which provides an essentially constant current output when the arc length is varied over several millimeters. Hence, the natural variations in the arc length which occur in manual welding have little effect on welding current. The capacity to limit the current to the set value is equally crucial when the electrode is short circuited to the workpiece, otherwise excessively high current shall flow, damaging theelectrode. Open circuit voltage of power source ranges from 60 to 80 V. Argon or helium may be used successfully for most applications, with the possible exception of the welding of extremely thin materialfor which argon is essential. Argon generally provides an arc which operates more smoothly and quietly,is handled more easily and is less penetrating than the arc obtained by the use of helium. For these reasons argon is usually preferred for most applications, except where the higher heat and penetration characteristic of helium is required for welding metals of high heat conductivity in larger thicknesses. Aluminum and copper are metals of high heat conductivity and are examples of the type of material forwhich helium is advantageous in welding relatively thick sections.

Pure argon can be used for welding of structural steels, low alloyed steels, stainless steels, aluminum, copper, titanium and magnesium. Argon hydrogen mixture is used for welding of some grades of stainlesssteels and nickel alloys. Pure helium may be used for aluminum and copper. Helium argon mixtures maybe used for low alloy steels, aluminum and copper.

TIG welding can be used in all positions. It is normally used for root pass(es) during welding of thick pipesbut is widely being used for welding of thin walled pipes and tubes. This process can be

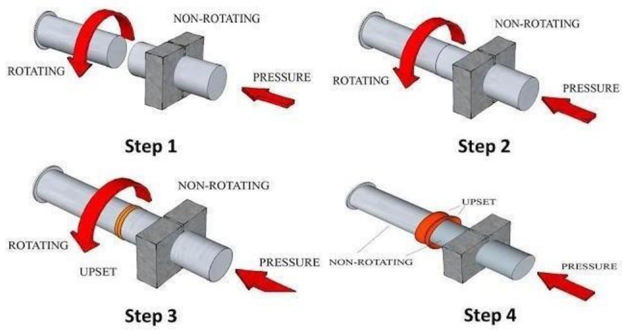
easily mechanised
i.e. movement of torch and feeding of filler wire, so it can be used for precision welding in nuclear, aircraft, chemical, petroleum, automobile and space craft industries. Aircraft frames and its skin, rocketbody and engine casing are few examples where TIG welding is very popular.

Friction

Friction welding works on basic principle of friction. In this welding process, the friction is used to generate heat at the interference surface. This heat is further used to join two work pieces by applying external pressure at the surface of work piece. In this welding process, the friction is applied until the plastic forming temperature is achieved. It is normally 900-1300 degree centigrade for steel. After this heating phase, a uniformly increasing pressure force applied until the both metal work pieces makes a permanent joint. This joint is created due to thermo mechanical treatment at the contact surface.

Working:

There are many types of friction welding processes which works differently. But all different these processes involves common a working principle which can be summarize as follow.



Friction Welding

- First both the work pieces are prepared for smooth square surface. One of them is mounted on a rotor driven chuck and other one remains stationary.
- The rotor allows rotating at high speed thus it makes rotate mounted work piece. A little pressure force is applied on the stationary work piece which permits cleaning the surface by burnishing action.
- Now a high pressure force applied to the stationary work piece which forces it toward rotating work piece and generates a high friction force. This friction generates heat at the contact surface. It is applied until the plastic forming temperature is achieved.
- When the temperature is reached the desire limit, the rotor is stopped and the pressure force is applied increasingly until the whole weld is formed.

This welding is used to weld those metals and alloys which cannot be welded by other method

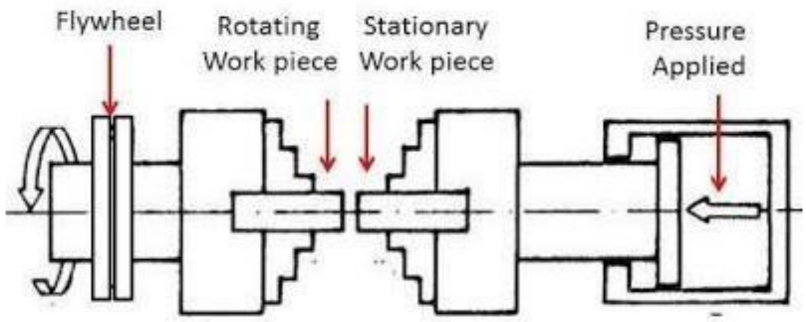
Types:

Continuous induce friction welding:

This welding is same as we discussed above. In this welding process, the rotor is connected with a band **brake**. When the friction crosses the limit of plastic temperature, the band brake comes into action which stops the rotor but the pressure applied on the work piece increasingly until the weld is formed.

Inertia friction

In this type of friction welding the band brake is replaced by the **engine** flywheel and shaft flywheel. These flywheels connect chuck to the motor. In the starting of the welding, both flywheels are connected with one another. When the speed or friction reaches its limit, the engine flywheel separated from the shaft flywheel. Shaft flywheel has low moment of inertia which stops



without brake. The pressure force is continuously applied to the work piece until the weld is formed.

Application:

- For welding tubes and shafts.
- It is mostly used in aerospace, **automobile**, marine and oil industries.
- Gears, axle tube, valves, **drive line** etc. components are friction welded.
- It is used to replace **forging** or **casting** assembly.
- Hydraulic piston rod, truck rollers bushes etc. are join by friction welding.
- Used in electrical industries for welding copper and aluminum equipment's.
- Used in pump for welding pump shaft (stainless steel to carbon steels).
- Gear levers, drill bits, connecting rod etc. are welded by friction welding.

Advantages and Disadvantages:

Advantages:

- It is environment friendly process without generation smoke etc.
- Narrow heat affected zone so no change in properties of heat sensitive material.
- No filler metal required.
- Welding strength is strong in most cases.
- Easily automated.
- High welding speed.
- High efficiency of weld.
- Wide variety of metal can be weld by this process.

Disadvantages:

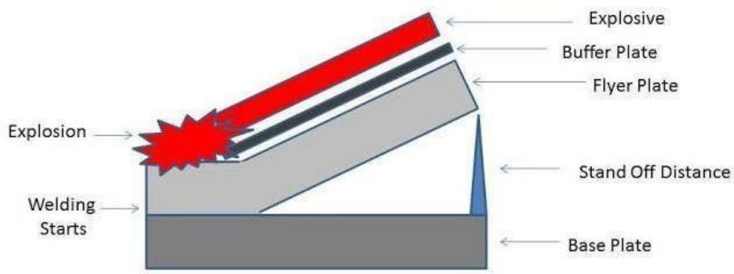
- This is mostly used only for round bars of same cross section.
- Non-forgeable material cannot be weld.
- Preparation of work piece is more critical
- High setup cost.

- Joint design is limited.This is all about friction welding principle, working, types, application, advantages and disadvantages. If you have any query regarding this article, ask by commenting. If you like this article, don't forget to shareit on your social networks. Subscribe our website for more interesting articles.

Explosive Welding:

Principle:

This welding process works on basic principle of metallurgical bonding. In this process, a controlled detonation of explosive is used on the welding surface. This explosion generates a high pressure force, whichdeform the work plates plastically at the interface. This deformation forms a metallurgical bond between these plates. This metallurgical bond is stronger than the parent materials. The detonation process occurs for a very short period of time which cannot damage the parent material. This is basic principle of explosionwelding. This welding is highly depend on welding parameters like standoff distance, velocity of detonation, surface preparation, explosive etc. This welding is capable to join large area due to high energy available inexplosive.



Explosion Welding

Basic terminology:

Base Plate: This is one of the welding plate which is kept stationary on a avail. It involves a backer which supports the base plate and minimizes the distortion during the explosion.

Flyer Plate: This is another welding plate which is going to be weld on base plate. It has lowest density andtensile yield strength compare to base plate. It is situated parallel or at an angle onthe base plate.

Buffer Plate: Buffer plate is situated on the flyer plate. This plate is used to minimize the effect or explosionon upper surface of flyer plate. This protects the flyer plate from any damage due to explosion.

Standoff distance: Stand-off distance plays a vital role in explosion welding. It is distance between flyer plate and base plate. Generally it is taken double of thickness of flyer plate for thin plates and equal to thickness of flyer plate for thick plates.

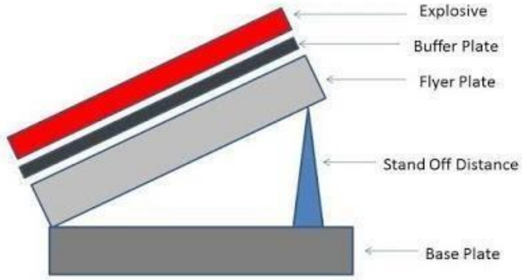
Explosive: Explosive is placed over the flyer plate. This explosive is situated in a box structure. This box placed on the flyer plate. Mostly RDX, TNT, Lead azide, PETN etc. used as explosive.

Velocity of detonation: It is the rate at which the explosive detonate. This velocity should be kept lessthan 120% of sonic velocity. It is directly proportional to explosive type and its density.

Types:
This welding can be classified into two types according to the setup configuration.

Oblique Explosion Welding:

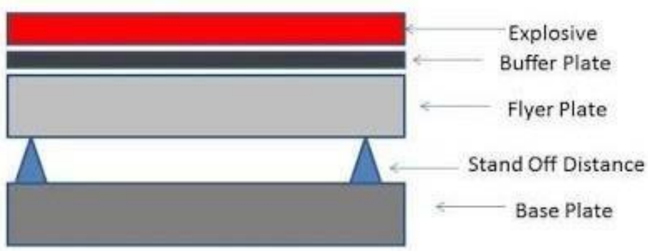
In this type of welding process base plate is fixed on an anvil and filler plate makes an angle with the baseplate. This welding configuration is used to join thin and small plates.



Oblique Explosion Welding

Parallel Explosion Welding:

As the name implies, in this welding configuration filler plate is parallel to the base plate. There is some standoff distance between base plate and flyer plate. This configuration is used to weld thick and large plates.



Parallel Explosion Welding

Working:

We have discussed about working principle of explosion welding. Its working can be summarized asfollow.

- First both the flyer plate and the base plate interface surface are cleaned and prepared for good weld.
- Now the base plate fixed on the avail and the flyer plate place at the top surface of it at a pre- define distance (stand-off distance). The flyer plate may be inclined or parallel according to the welding configuration.
- The buffer plate is set over the flyer plate. This plate protects the upper surface of flyer place from damage due to high impact force of explosion.
- The prepared explosive is place into a box of same size of welding surface. This box is placed over buffer plate. There is a detonator at one side of the explosive. This is used to start explosion.

- Now the detonator ignited the explosive which create a high pressure wave. These waves deforms the interface surface plastically and form a metallurgical bond between base plate and flyer plate. This bond is stronger than parent material.

Application:

- Used to weld large structure sheets of aluminum to stainless steel.
- It is used to weld cylindrical component like pipe, concentric cylinder, tube etc.
- Weld clad sheet with steel in a heat exchanger.
- Join dissimilar metals which cannot be weld by other welding process.
- For joining cooling fan etc.

Advantages and Disadvantages:

Advantages:

- It can join both similar and dissimilar material.
- Simple in operation and handling.
- Large surface can be weld in single pass.
- High metal joining rate. Mostly time is used in preparation of the welding.
- It does not effect on properties of welding material.
- It is solid state process so does not involve any filler material, flux etc.

Disadvantages:

- It can weld only ductile metal with high toughness.
- It creates a large noise which produces noise Pollution.
- Welding is highly depends on process parameters.
- Higher safety precautions involved due to explosive.
- Designs of joints are limited.

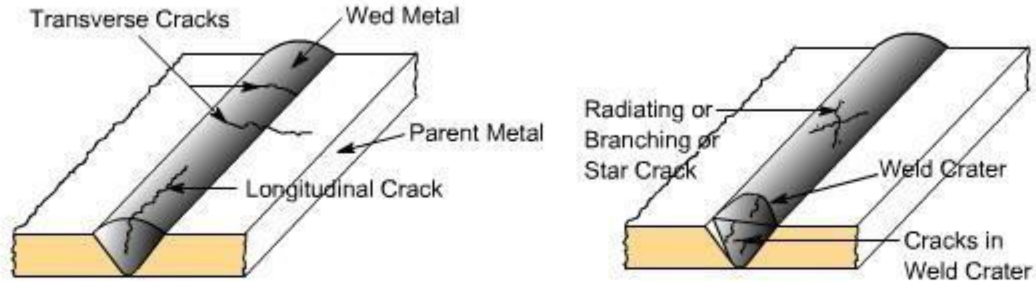
This is all about explosion welding principle, working, types, application, advantages and disadvantages. If you have any query regarding this article, ask by commenting. If you like this article, don't forget to share it on your social networks. Subscribe our website for more interesting articles.

Welding Defects

The defects in the weld can be defined as irregularities in the weld metal produced due to incorrect welding parameters or wrong welding procedures or wrong combination of filler metal and parent metal. Weld defect may be in the form of variations from the intended weld bead shape, size and desired quality. Defects may be on the surface or inside the weld metal. Certain defects such as cracks are never tolerated but other defects may be acceptable within permissible limits. Welding defects may result into the failure of components under service condition, leading to serious accidents and causing the loss of property and sometimes also life. Various welding defects can be classified into groups such as cracks, porosity, solid inclusions, lack of fusion and inadequate penetration, imperfect shape and miscellaneous defects.

Cracks

Cracks may be of micro or macro size and may appear in the weld metal or base metal or base metal and weld metal boundary. Different categories of cracks are longitudinal cracks, transverse cracks or radiating/star cracks and cracks in the weld crater. Cracks occur when localized stresses exceed the ultimate tensile strength of material. These stresses are developed due to shrinkage during solidification of weld metal.

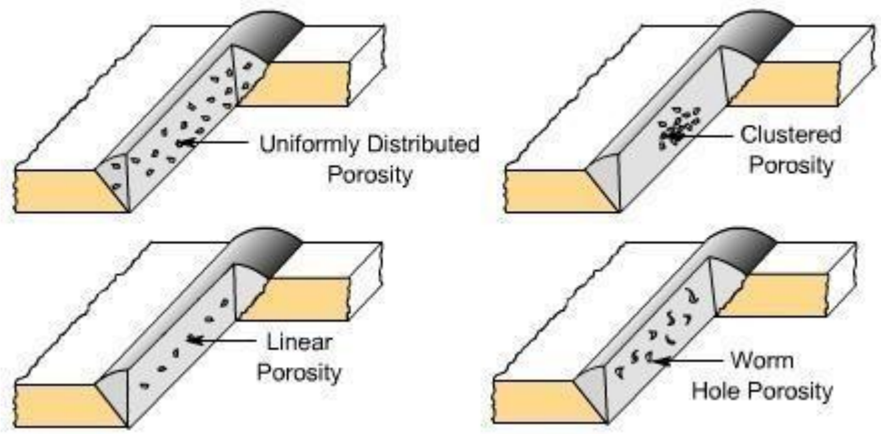


Various Types of Cracks in Welds

Cracks may be developed due to poor ductility of base metal, high sulpher and carbon contents, high arctravel speeds i.e. fast cooling rates, too concave or convex weld bead and high hydrogen contents in theweld metal.

Porosity

Porosity results when the gases are entrapped in the solidifying weld metal. These gases are generated from the flux or coating constituents of the electrode or shielding gases used during welding or from absorbed moisture in the coating. Rust, dust, oil and grease present on the surface of work pieces or on electrodes are also source of gases during welding. Porosity may be easily prevented if work pieces are properly cleaned from rust, dust, oil and grease.Futher, porosity can also be controlled if excessively highwelding currents, faster welding speeds and long arc lengths are avoided flux and coated electrodes are properly baked.

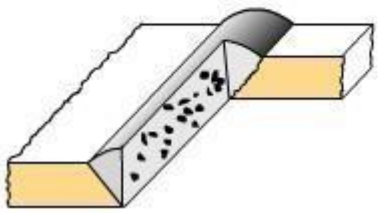


Different Forms of Porosities

Solid Inclusion

Solid inclusions may be in the form of slag or any other nonmetallic material entrapped in the weld metal as these may not able to float on the surface of the solidifying weld metal. During arc welding flux either in the form of granules or coating after melting, reacts with the molten weld metal removing oxides and other impurities in the form of slag and it floats on the surface of weld metal due to its low density. However, if the molten weld metal has high viscosity or too low temperature or cools rapidly then the slag may not be released from the weld pool and may cause inclusion.

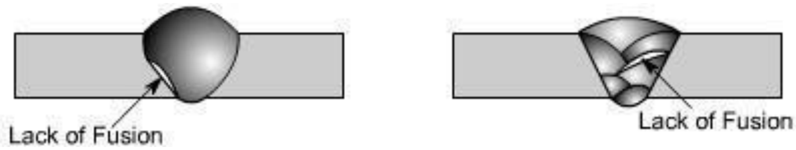
Slag inclusion can be prevented if proper groove is selected, all the slag from the previously deposited bead is removed, too high or too low welding currents and long arcs are avoided.



Slag Inclusion in Weldments

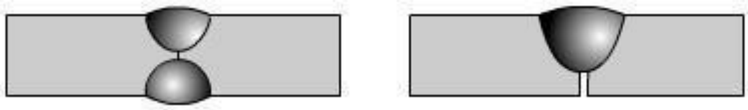
Lack of Fusion and Inadequate or incomplete penetration:

Lack of fusion is the failure to fuse together either the base metal and weld metal or subsequent beads in multipass welding because of failure to raise the temperature of base metal or previously deposited weld layer to melting point during welding. Lack of fusion can be avoided by properly cleaning of surfaces to be welded, selecting proper current, proper welding technique and correct size of electrode.



Types of Lack of Fusion

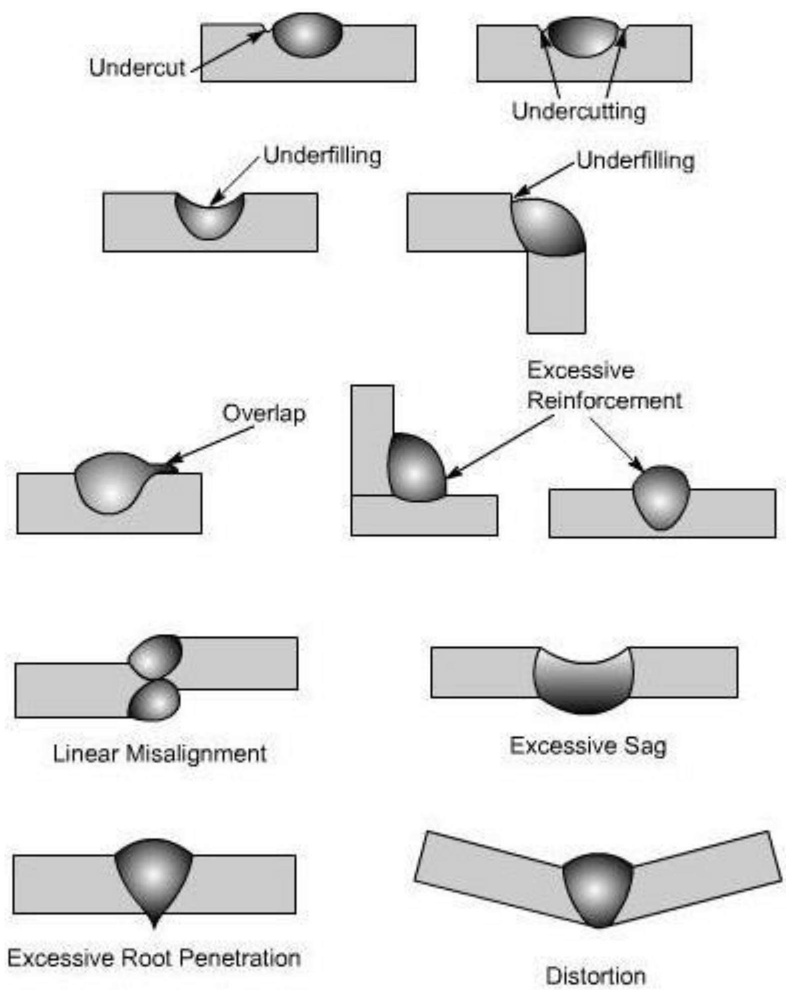
Incomplete penetration means that the weld depth is not upto the desired level or root faces have not reached to melting point in a groove joint. If either low currents or larger arc lengths or large root face or small root gap or too narrow groove angles are used then it results into poor penetration.



Examples of Inadequate Penetration

Imperfect shape means the variation from the desired shape and size of the weld bead. During undercutting a notch is formed either on one side of the weld bead or both sides in which stresses tend to concentrate and it can result in the early failure of the joint. Main reasons for undercutting are the excessive welding currents, long arc lengths and fast travel speeds.

Underfilling may be due to low currents, fast travel speeds and small size of electrodes. Overlap may occur due to low currents, longer arc lengths and slower welding speeds.



Various Imperfect Shapes of Welds

Excessive reinforcement is formed if high currents, low voltages, slow travel speeds and large size electrodes are used. Excessive root penetration and sag occur if excessive high currents and slow travel speeds are used for relatively thinner members. Distortion is caused because of shrinkage occurring due to large heat input during welding.

Miscellaneous Defects

Various miscellaneous defects may be multiple arc strikes i.e. several arc strikes are one behind the other, spatter, grinding and chipping marks, tack weld defects, oxidized surface in the region of weld, unremoved slag and misalignment

Manufacturing processes METAL FORMING

Metal forming is also known as mechanical working of metals. Metal forming operations are frequently desirable either to produce a new shape or to improve the properties of the metal. Shaping in the solid state may be divided into non-cutting shaping such as forging, rolling, pressing, etc., and cutting shaping such as the machining operations performed on various machine tools. Non-cutting or non-machining shaping processes are referred to as mechanical working processes. It means an intentional and permanent deformation of metals plastically beyond the elastic range of the material. The main objectives of metal working processes are toprovide the desired shape and size, under the action of externally applied forces in metals. Such processes are used to achieve optimum mechanical properties in the metal and reduce any internal voids or cavities present and thus make the metal dense.

Metals are commonly worked by plastic deformation because of the beneficial effect that is imparted to the mechanical properties by it. The necessary deformation in a metal can be achieved by application of mechanical force only or by heating the metal and then applying a small force. The impurities present in the metal are thus get elongated with the grains and in the process get broken and dispersed throughout the metal. This also decreases the harmful effect of the impurities and improves the mechanical strength. This plastic deformation of a metal takesplace when the stress caused in the metal, due to the applied forces reaches the yield point. Thetwo common phenomena governing this plastic deformation of a metal are (*a*) deformation by slip and (*b*) deformation by twin formation. In the former case it is considered that each grain ofa metal is made of a number of unit cells arranged in a number of planes, and the slip or deformation of metal takes place along that slip plane which is subjected to the greatest shearingstress on account of the applied forces. In the latter case, deformation occurs along two parallel planes, which move diagonally across the unit cells. These parallel planes are called twinning planes and the portion of the grains covered between them is known as twinned region. On the macroscopic scale, when plastic deformation occurs, the metal appears to flow in the solid statealong specific directions, which are dependent on the processing and the direction of applied forces. The crystals or grains of the metal get elongated in the direction of metal flow. Howeverthis flow of metal can be easily be seen under microscope after polishing and suitable etching ofthe metal surface. The visible lines are called fibre flow lines. The above deformations may be carried out at room temperature or higher temperatures. At higher temperatures the deformation is faster because the bond between atoms of the metal grains is reduced. Plasticity,ductility and malleability are the properties of a material, which retains the deformation produced under applied forces permanently and hence these metal properties are important formetal working processes.

Plasticity is the ability of material to undergo some degree of permanent deformation without rupture or failure. Plastic deformation will take place only after the elastic range has been exceeded. Such property of material is important in forming, shaping, extruding and many otherhot and cold working processes. Materials such as clay, lead, etc. are plastic at room temperature and steel is plastic at forging temperature. This property generally increases with increase in temperature.

Ductility is the property of a material enabling it to be drawn into wire with the application

of tensile force. A ductile material must be both strong and plastic. The ductility is usually measuredby the terms percentage elongation and percent reduction in area often used as empirical measures of ductility. The ductile material commonly used in engineering practice in order of
diminishing ductility are mild steel, copper, aluminum, nickel, zinc, tin and lead.

Malleability is the ability of the material to be flattened into thin sheets without cracking by hotor cold working. A malleable material should be plastic but it is not essential to be so strong. Themalleable materials commonly used in engineering practice in order of diminishing malleability are lead, soft steel, wrought iron, copper and aluminum. Aluminum, copper, tin, lead, steel, etc.are recognized as highly malleable metals.

STRAIN HARDENING

Strain hardening (also called work-hardening or cold-working) is the process of making a metal harder and stronger through plastic deformation. When a metal is plastically deformed, dislocationsmove and additional dislocations are generated. The more dislocations within a material, the more they will interact and become pinned or tangled. This will result in a decrease in the mobility of the dislocations and a strengthening of the material. This type of strengthening is commonly called cold-working. It is called cold-working because the plastic deformation must occurs at a temperature lowenough that atoms cannot rearrange themselves. When a metal is worked at higher temperatures (hot-working) the dislocations can rearrange and little strengthening is achieved.

Strain hardening can be easily demonstrated with piece of wire or a paper clip. Bend a straight section back and forth several times. Notice that it is more difficult to bend the metal at the same place. In the strain hardened area dislocations have formed and become tangled, increasing the strength of the material. Continued bending will eventually cause the wire to break at the bend dueto fatigue cracking. (After a large number of bending cycles, dislocations form structures called Persistent Slip Bands (PSB). PSBs are basically tiny areas where the dislocations have piled up and moved the material surface out leave steps in the surface that act as stress risers or crack initiation points.).

Effects of Elevated Temperature on Strain Hardened Materials

When strain hardened materials are exposed to elevated:
Temperatures, the strengthening that resulted from the plastic deformation can be lost. This can be a bad thing if the strengthening is needed to support a load. However, strengthening dueto strain hardening is not always desirable, especially if the material is being heavily formed sinceductility will be lowered.
Heat treatment can be used to remove the effects of strain hardening. Three things can occur during heat treatment:

1. Recovery
2. Recrystallization
3. Grain growth

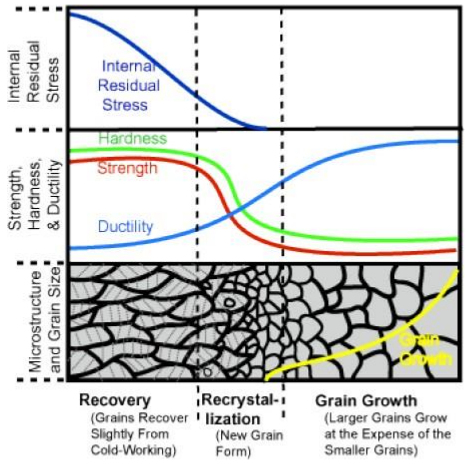
RECOVERY

When a stain hardened material is held at an elevated temperature an increase in atomic diffusion occurs that relieves some of the internal strain energy. Remember that atoms are not fixed in position but can move around when they have enough energy to break their bonds. Diffusion increases rapidly with rising temperature and this allows atoms in severely strained regions to move to unstrained positions. In other words, atoms are freer to move around and recover a normal position in the lattice structure. This is known as the recovery phase and it results in an adjustment of strain on a microscopic scale. Internal residual stresses are lowered due to a reduction in the dislocation density

and a movement of dislocation to lower-energy positions. The tangles of dislocations condense into sharp two-dimensional boundaries and the dislocation density within these areas decrease. These areas are called subgrains. There is no appreciable reduction in the strength and hardness of the material but corrosion resistance often improves.

RECRYSTALLIZATION

At a higher temperature, new, strain-free grains nucleate and grow inside the old distorted grains and at the grain boundaries. These new grains grow to replace the deformed grains produced by the strain hardening. With recrystallization, the mechanical properties return to their original weaker and more ductile states. Recrystallization depends on the temperature, the amount of time at this temperature and also the amount of strain hardening that the material experienced. The more strain hardening, the lower the temperature will be at which recrystallization occurs. Also, a minimum amount (typically 2-20%) of cold work is necessary for any amount of recrystallization to occur. The size the new grains is also partially dependant on the amount of strain hardening. The greater the stain hardening, the more nuclei for the new grains, and the



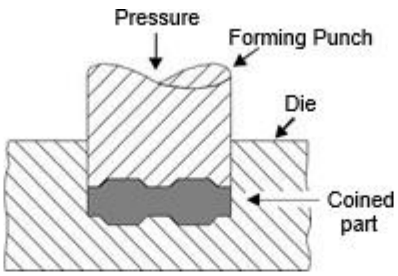
resulting grain size will be smaller (at least initially).

GRAIN GROWTH

If a specimen is left at the high temperature beyond the time needed for complete recrystallization, the grains begin to grow in size. This occurs because diffusion occurs across the grain boundaries and larger grains have less grain boundary surface area per unit of volume. Therefore, the larger grains lose fewer atoms and grow at the expense of the smaller grains. Larger grains will reduce the strength and toughness of the material. Comparison between hot working and cold working processes can be done in aspects like carried out temperature, stress set up, tolerances, hardening, deformation, surface finish, improved properties, and cracks formation.

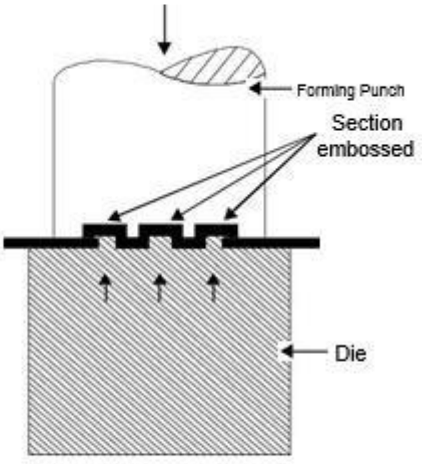
EMBOSSING

The below Figure shows the embossing process. It is a process through which blanks of sheet metal are stretched to shape under pressure by means of a punch and a die. Punch operates at a low speed to allow time for proper stretching. The operation gives a stiffening effect to the metal being embossed. Stress in the material may be reduced by producing deep parallel ridges. A large number of ornamental wares, such as plates in sheet metal are produced. A simple form of this process, called open embossing, consists of producing simple shallow shapes by the punch only.



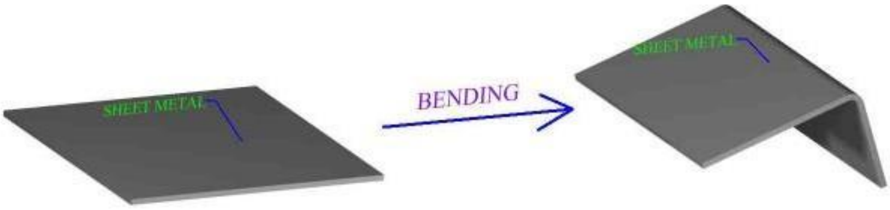
COINING

The below figure shows the coining process used in cold working operations. It is basically a cold working operation, which is performed in dies where the metal blank is confined and its lateral flow is restricted. It is mainly used for production of important articles such as medals, coins, stickers and other similar articles, which possess shallow configurations on their surfaces. The operation involves placing a metal slug in the die and applying heavy pressure by the punch. The metal flows plastically and is squeezed to the shape between punch and the die. The process, on account of the very high pressures required, can be employed only for soft metals with high plasticity.



BENDING

Bending of sheet metal is a common and vital process in manufacturing industry. **Sheet metal bending** is the plastic deformation of the work over an axis, creating a change in the part's geometry. Similar to other metal forming processes, bending changes the shape of the work piece, while the volume of material will remain the same. In some cases bending may produce a small change in sheet thickness. For most operations, however, bending will produce essentially no change in the thickness of the sheet metal. In addition to creating a desired geometric form, bending is also used to impart strength and stiffness to sheet metal, to change a part's moment of inertia, for cosmetic appearance and to eliminate sharp edges.



HOT WORKING

Mechanical working processes which are done above recrystallization temperature of the metal are known as hot working processes. Some metals, such as lead and tin, have a low recrystallization temperature and can be hot-worked even at room temperature, but most commercial metals requiresome heating. However, this temperature should not be too high to reach the solidus temperature; otherwise the metal will burn and become unsuitable for use. In hot working, the temperature of completion of metal working is important since any extra heat left after working aid in grain growth. This increase in size of the grains occurs by a process of coalescence of adjoining grains and is a function of time and temperature. Grain growth results in poor mechanical properties. If the hot working is completed just above the recrystallization temperature then the resultant grain size wouldbe fine. Thus for any hot working process the metal should be heated to such a temperature below its solidus temperature, that after completion of the hot working its temperature will remain a little higher than and as close as possible to its recrystallization temperature

EFFECT OF HOT WORKING ON MECHANICAL PROPERTIES OF METALS

1. This process is generally performed on a metal held at such a temperature that the metal does not work-harden. A few metals e.g., Pb and Sn (since they possess low crystallization temperature) can be hot worked at room temperature.
2. Raising the metal temperature lowers the stresses required to produce deformations and increases the possible amount of deformation before excessive work hardening takes place.
3. Hot working is preferred where large deformations have to be performed that do not havethe primary purpose of causing work hardening.
4. Hot working produces the same net results on a metal as cold working and annealing. It does not strain harden the metal.
5. In hot working processes, compositional irregularities are ironed out and non-metallic impurities are broken up into small, relatively harmless fragments, which are uniformly dispersed throughout the metal instead of being concentrated in large stress-raising metal working masses.
6. Hot working such as rolling process refines grain structure. The coarse columnar dendrites of cast metal are refined to smaller equiaxed grains with corresponding improvement in mechanical properties of the component.
7. Surface finish of hot worked metal is not nearly as good as with cold working, because of oxidation and scaling.
8. One has to be very careful as regards the temperatures at which to start hot work and at which to stop because this affects the properties to be introduced in the hot worked metal.
9. Too high a temperature may cause phase change and overheat the steel whereas too low temperature may result in excessive work hardening.
10. Defects in the metal such as blowholes, internal porosity and cracks get removed or welded up during hot working.
11. During hot working, self-annealing occurs and recrystallization takes place immediately following plastic deformation. This self-annealing action prevents hardening and loss of ductility.

MERITS OF HOT WORKING

1. As the material is above the recrystallisation temperature, any amount of working can be imparted since there is no strain hardening taking place.
2. At a high temperature, the material would have higher amount of ductility and therefore there is no limit on the amount of hot working that can be done on a material. Even brittle materials can be hot worked.
3. In hot working process, the grain structure of the metal is refined and thus mechanical properties improved.
4. Porosity of the metal is considerably minimized.
5. If process is properly carried out, hot work does not affect tensile strength, hardness, corrosion resistance, etc.
6. Since the shear stress gets reduced at higher temperatures, this process requires much less force to achieve the necessary deformation.
7. It is possible to continuously reform the grains in metal working and if the temperature and rate of working are properly controlled, a very favorable grain size could be achievedgiving rise to better mechanical properties.
8. Larger deformation can be accomplished more rapidly as the metal is in plastic state.
9. No residual stresses are introduced in the metal due to hot working.
10. Concentrated impurities, if any in the metal are disintegrated and distributed throughout the metal.
11. Mechanical properties, especially elongation, reduction of area and izod values are improved, but fibre and directional properties are produced.
12. Hot work promotes uniformity of material by facilitating diffusion of alloy constituents and breaks up brittle films of hard constituents or impurity namely cementite in steel.

DEMERITS OF HOT WORKING

1. Due to high temperature in hot working, rapid oxidation or scale formation and surface de-carburization take place on the metal surface leading to poor surface finish and loss of metal.
2. On account of the loss of carbon from the surface of the steel piece being worked the surface layer loses its strength. This is a major disadvantage when the part is put to service.
3. The weakening of the surface layer may give rise to a fatigue crack which may ultimately result in fatigue failure of the component.
4. Some metals cannot be hot worked because of their brittleness at high temperatures.
5. Because of the thermal expansion of metals, the dimensional accuracy in hot working is difficult to achieve.
6. The process involves excessive expenditure on account of high cost of tooling. This however is compensated by the high production rate and better quality of components.
7. Handling and maintaining of hot working setups is difficult and troublesome.

COLD WORKING

Cold working of a metal is carried out below its recrystallization temperature. Although normal roomtemperatures are ordinarily used for cold working of various types of steel, temperatures up to the recrystallization range are sometimes used. In cold working, recovery processes are not effective.

PURPOSE OF COLD WORKING

The common purpose of cold working is given as under

1. Cold working is employed to obtain better surface finish on parts.
2. It is commonly applied to obtain increased mechanical properties.
3. It is widely applied as a forming process of making steel products using pressing and spinning.
4. It is used to obtain thinner material.

LIMITATIONS OF COLD WORKING

1. The cold worked process possesses less ductility.
2. Imparted directional properties may be detrimental
3. Strain hardening occurs.
4. Metal surfaces must be clean and scale free before cold working.
5. Hot worked metal has to be pickled in acid to remove scale, etc.
6. Higher forces are required for deformation than those in hot working.
7. More powerful and heavier equipments are required for cold working.

ADVANTAGES OF COLD WORKING

1. In cold working processes, smooth surface finish can be easily produced.
2. Accurate dimensions of parts can be maintained.
3. Strength and hardness of the metal are increased but ductility decreased.
4. Since the working is done in cold state, no oxide would form on the surface and consequently good surface finish is obtained.
5. Cold working increases the strength and hardness of the material due to the strain hardening which would be beneficial in some situations.
6. There is no possibility of decarburization of the surface
7. Better dimensional accuracy is achieved.
8. It is far easier to handle cold parts and it is also economical for smaller sizes.

DISADVANTAGES OF COLD WORKING

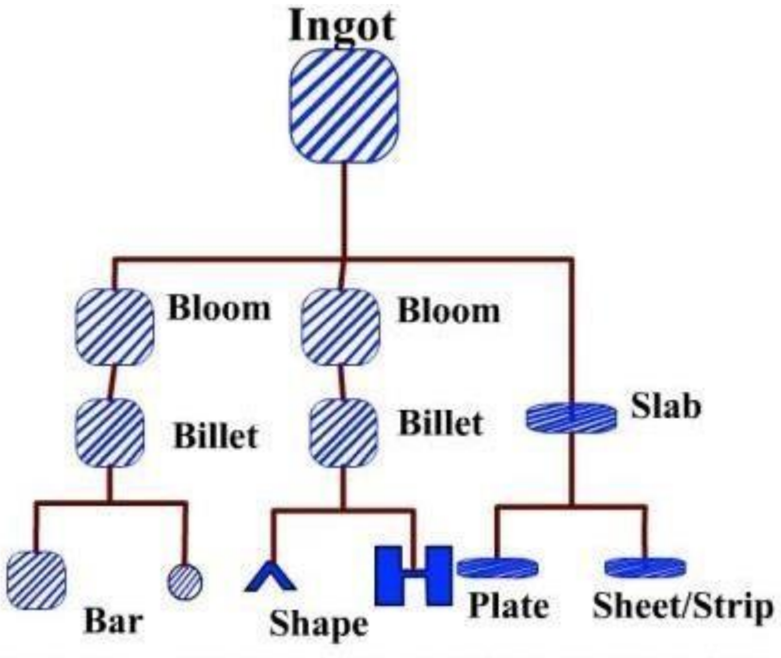
1. Some materials, which are brittle, cannot be cold worked easily.
2. Since the material has higher yield strength at lower temperatures, the amount of deformation that can be given to is limited by the capability of the presses or hammers used.
3. A distortion of the grain structure is created.
4. Since the material gets strain hardened, the maximum amount of deformation that can be given is limited. Any further deformation can be given after annealing.
5. Internal stresses are set up which remain in the metal unless they are removed by proper heat- treatment.

ROLLING

Introduction Rolling is one of the most important industrial metal forming operations. Hot Rolling is employed for breaking the ingots down into wrought products such as into blooms and billets, whichare subsequently rolled to other products like plates, sheets etc. Rolling is the plastic deformation of materials caused by compressive force applied through a set of rolls. The cross section of the work piece is reduced by the process. The material gets squeezed between a pair of rolls, as a result of which the thickness gets reduced and the length gets increased.

Mostly, rolling is done at high temperature, called hot rolling because of requirement of large deformations. Hot rolling results in residual stress-free product. However, scaling is a major problem, due to which dimensional accuracy is not maintained. Cold rolling of sheets, foils etc is gaining importance, due to high accuracy and lack of oxide scaling. Cold rolling also strengthens the product due to work hardening

Steel ingot is the cast metal with porosity and blowholes. The ingot is soaked at the hot rolling temperature of 1200o C and then rolled into blooms or billets or slabs**.**



Plates have thickness greater than 6 mm whereas strips and sheets have less than 6 mm thickness. Sheets have greater width and strip has lower width – less than 600 mm.

Rolling mills:

Today we will learn about rolling process types, working, terminology and application with its diagram. Rolling is a major manufacturing process of sheets and other cross sections of large length like I beam, railroads etc. It is one of a metal forming process in which the metal work piece is compressed between a set of rolls where it reduces its cross section area and increases its length. This process gives high production rate, surface finish and grain structure which make it a most suitable metal forming process for large length same cross section work pieces but high set up cost of rolling machinemakes it as an alternative process.

Rolling Process:

Terminology:

The most common terminologies used in rolling process are given below.

Ingot:

It is casted structure with porosity and blowholes. Ignot is same as used in forging. This ingot is rolledout at hot temperature of about 1200 degree centigrade into blooms. This ingot may have any size according to the rolling requirement.

Blooms:

It is first rolled product making by rolling ingot at high temperature. It has cross section area more than or equal to 230 square centimeters. This bloom is further rolled to make I section, billet, channel, railroad etc.

Slab:

Slab is made by hot rolling of ingot. It has cross section area greater than or equal to 100 centimeterssquare and its width is greater than or equal to three times of its thickness. Slabs are used to form plates, sheets, strips etc.

Billets:

Billets are product of hot rolling of blooms. It has greater than or equal to 40 square centimeters crosssection area. Billets are used to roll into pipes, bars, wire etc.

Plate:

Plate is product of further rolling of slab. It has greater than 6 mm thickness.

Sheet:

Sheet has less than 6 mm thickness and width greater than 60 cm.

Strip:

Strip is same as sheet but have width less than 60 cm.

Two high reversing mill:

In two high reversing rolling mills the rolls rotate ist in one direction and then in the other, so that rolled metal may pass back and forth through the rolls several times. This type is used in pluming andslabing mills and for roughing work in plate , rail , structural and other mills.
These are more expensive compared to the non reversing rolling mills. Because of the reversible driveneeded.

Two high non reversing mill:

In two high non reversing mills as two rolls which revolve continuously in same direction therefore smaller and less costly motive power can be used. However every time material is to be carried back over the top of the mill for again passing in through the rolls. Such an arrangement is used in mills through which the bar passes once and in open train plate mill.

Three high rolling mill:

It consists of a roll stand with three parallel rolls one above the other. Adjacent rolls rotates in oppositedirection. So that the material may be passed between the top and the middle roll in one direction and the bottom and middle rolls in opposite one.
In three high rolling mills the work piece is rolled on both the forward and return passes. First of all the work piece passes through the bottom and middle rolls and the returning between the middle andthe top rolls.

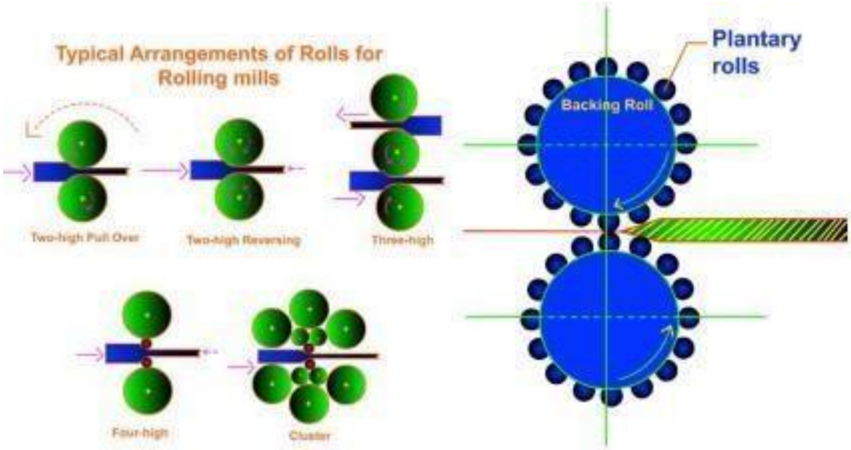
So that thickness is reduced at each pass. Mechanically operated lifted tables are used which move vertically or either side of the stand. So that the work piece fed automatically into the roll gap. Since the rolls run in one direction only a much less powerful motor and transmission system is required. The rolls of a three high rolling mills may be either plain or grooved to produce plate or sections respectively.
A four high rolling mill is used for the hot rolling of armor and other plates as well as cold

rolling of plates, sheets and strips.

Tandem rolling mills:It is a set of two or three stands of roll set in parallel alignment. So that a continuous pass may be made through each one successively with change the direction of material.

Cluster rolling mills:

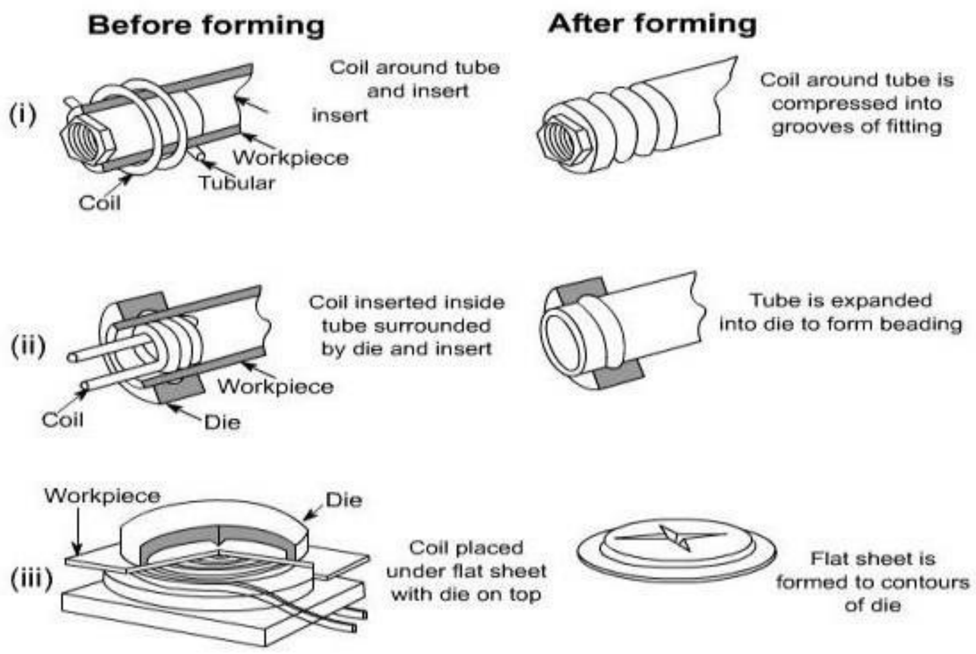
It is a special type of four high rolling mill in which each of the two working rolls is backup by two or more of the larger backup rolls for rolling hard in materials. It may be necessary to employ work rollsof a very small diameter but of considerable length. In such cases adequate of the working rolls can be obtained by using a cluster mill.



Electro Magnetic Forming

The process is also called magnetic pulse forming and is mainly used for swaging type operations, suchas fastening fittings on the ends of tubes and crimping terminal ends of cables. Other applications areblanking, forming, embossing, and drawing. The work coils needed for different applications vary although the same power source may be used.

To illustrate the principle of electromagnetic forming, consider a tubular work piece. This work piece is placed in or near a coil, in the figure below, A high charging voltage is supplied for a short time to abank of capacitors connected in parallel. (The amount of electrical energy stored in the bank can be increased either by adding capacitors to the bank or by increasing the voltage). When the charging is complete, which takes very little time, a high voltage switch triggers the stored electrical energy through the coil. A high – intensity magnetic field is established which induces eddy currents into the conductive work piece, resulting in the establishment of another magnetic field. The forces producedby the two magnetic fields oppose each other with the consequence that there is a repelling force between the coil and the tubular work piece that causes permanent deformation of the work piece.



Various applications of magnetic forming process. (i) Swaging, (ii) Expanding, and (iii) Embossing orBlanking

Either permanent or expandable coils may be used. Since the repelling force acts on the coil as well the work, the coil itself and the insulation on it must be capable of withstanding the force, or else theywill be destroyed. The expandable coils are less costly and are also preferred when high energy level is needed.

Magnetic forming can be accomplished in any of the following three ways, depending upon the requirements.

Coil surrounding work piece. When a tube – like part x is to fit over another part y (shown as insert inIn Figure above (i), coil is designed to surround x so that when energized, would force the material ofx tightly around y to obtain necessary fit.

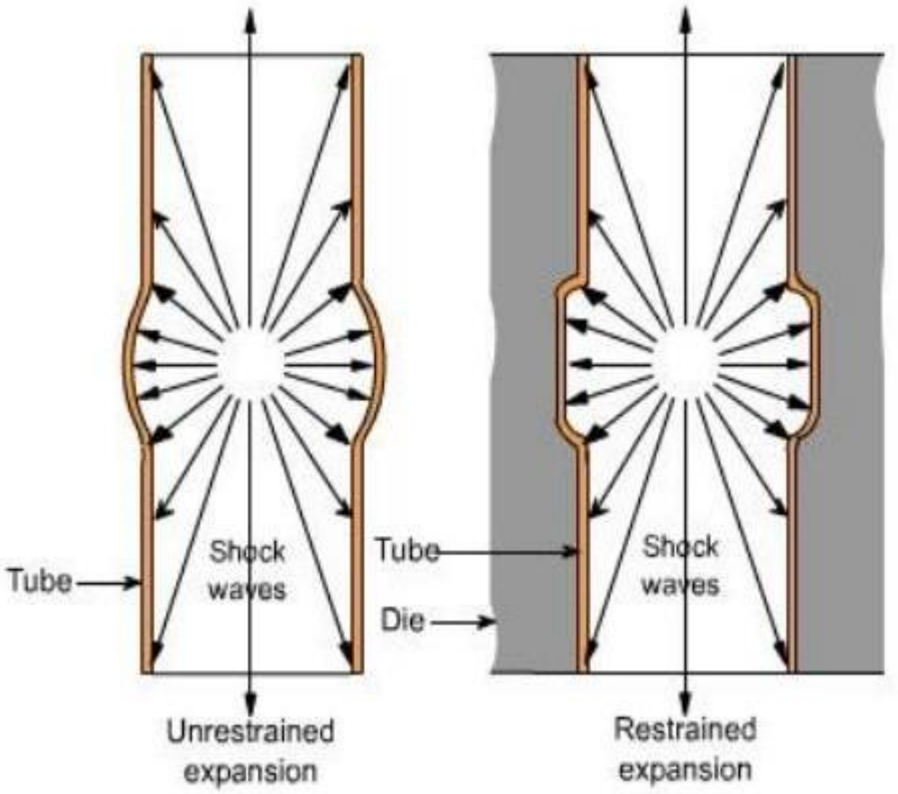
Coil inside work piece. Consider fixing of a collar on a tube – like part, as shown in above figure (ii). The magnetic coil is placed inside the tube – like part, so that when energized would expand the material of the part into the collar.

Coil on flat surface. Flat coil having spiral shaped winding can also be designed to be placed either above or below a flat work piece, as shown in above figure (iii).These coils are used in conjunction with a die to form, emboss, blank, or dimple the work piece.

In electromagnetic forming, the initial gap between the work piece and the die surface, called the fly distance, must be sufficient to permit the material to deform plastically. From energy considerations,the ideal pressure pulse should be of just enough magnitude that accelerates the part material to some maximum velocity and then let the part come to zero velocity by the time it covers the full fly distance. All forming coils fail, expendable coils fail sooner than durable coils, and because extremelyhigh voltages and currents are involved, it is essential that proper safety precautions are observed bythe production and maintenance personnel.

Electro Hydraulic Forming

Electro hydraulic forming (EHF), also known as electro spark forming, is a process in which electrical energy is converted into mechanical energy for the forming of metallic parts. A bank of capacitors is first charged to a high voltage and then discharged across a gap between two electrodes, causing explosions inside the hollow work piece, which is filled with some suitable medium, generally water.These explosions produce shock waves that travel radially in all directions at high velocity until they meet some obstruction. If the discharge energy is sufficiently high, the hollow work piece is deformed.The deformation can be controlled by



applying external restraints in the form of die or by varying theamount of energy released,

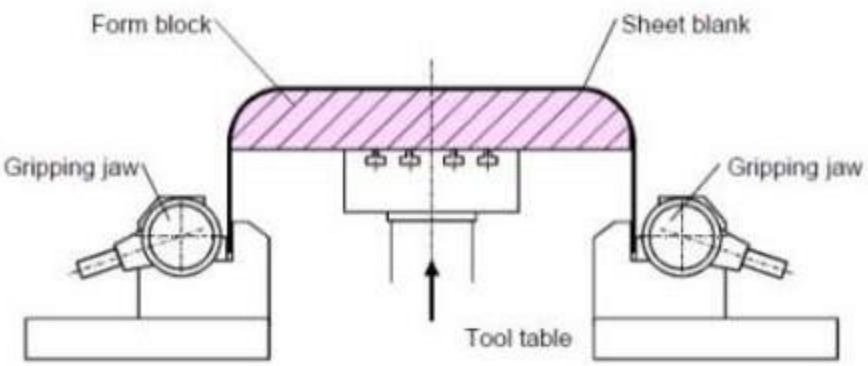
Unrestrained and Restrained Electro-hydraulic forming

Advantages

1. EHF can form hollow shapes with much ease and at less cost compared to other forming techniques.
2. EHF is more adaptable to automatic production compared to other high energy rate forming techniques.
3. EHF can produce small – to intermediate sized parts that don't have excessive energy requirements.

Stretch forming

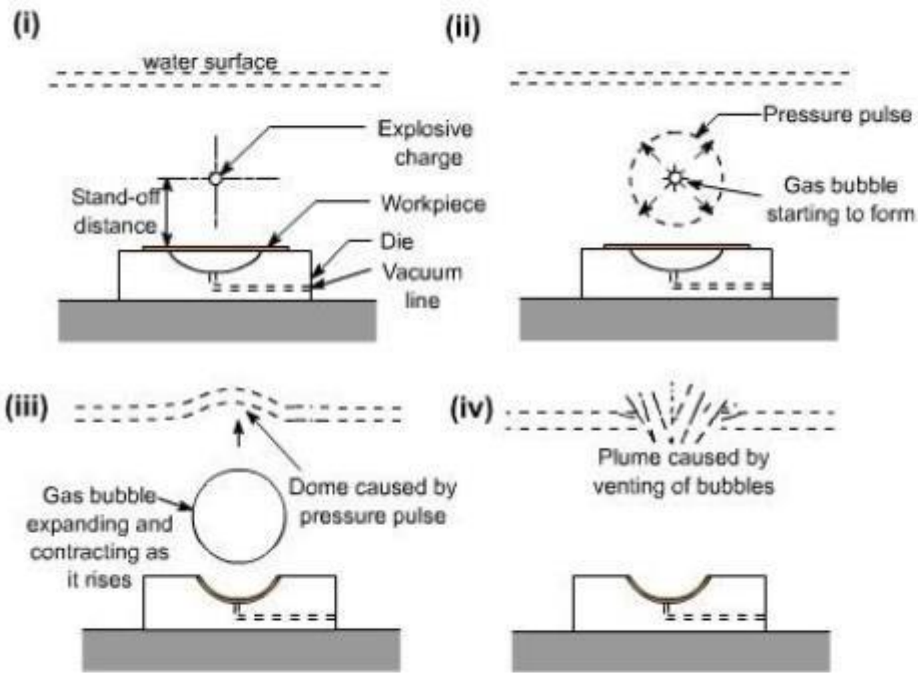
Stretch forming is a metal forming process in which a piece of sheet metal is stretched and bent simultaneously over a die in order to form large contoured parts. Stretch forming is performed on a stretch press, in which a piece of sheet metal is securely gripped along its edges by gripping jaws. Thegripping jaws are each attached to a carriage that is pulled by pneumatic or hydraulic force to stretchthe sheet. The tooling used in this process is a stretch form block, called a form die, which is a solid contoured piece against which the sheet metal will be pressed. The most common stretch presses areoriented vertically, in which the form die rests on a press table that can be raised into the sheet by a hydraulic ram. As the form die is driven into the sheet, which is gripped tightly at its edges, the tensileforces increase and the sheet plastically deforms into a new shape. Horizontal stretch presses mountthe form die sideways on a stationary press table, while the gripping jaws pull the sheet horizontally around the form die.



Stretch Forming

Explosive forming is distinguished from conventional forming in that the punch or diaphragm is replaced by an explosive charge. The explosives used are generally high – explosive chemicals, gaseous mixtures, or propellants. There are two techniques of high – explosive forming: stand – off technique and the contact technique.

Standoff Technique The sheet metal work piece blank is clamped over a die and the assembly is lowered into a tank filled with water. The air in the die is pumped out. The explosive charge is placed at some predetermined distance from the work piece. On detonation of the explosive, a pressure pulse of very high intensity is produced. A gas bubble is also produced which expands spherically and then collapses. When the pressure pulse impinges against the work piece, the metal is deformed into the die with as high velocity as 120 m/s.



Explosive Forming

SWARRNIM START UP AND INNOVATION UNIVERSITY

NAME OF INSTITUTE: - SWARRNIM INSTITUTE OF TECHNOLOGY, GANDHINAGAR
NAME OF COURSE:-

Science and Humanity

Introduction to Vedic Mathematics

1. **Introduction to Vedic Mathematics**

- The Origins and History
- Significance and Relevance Today
- Overview of Vedic Sutras

The Origins and History

Vedic Mathematics traces its roots back to ancient India, a civilization renowned for its contributions to science, astronomy, and mathematics. The term "Vedic" refers to the Vedas, the oldest sacred texts of India, dating back to around 1500-1000 BCE. These texts, written in Sanskrit, contain vast knowledge, including mathematical concepts that were not just abstract ideas but practical tools for solving real-world problems.

The system of Vedic Mathematics as we know it today was rediscovered in the early 20th century by the Indian scholar Jagadguru Swami Bharati Krishna Tirthaji Maharaja (1884-1960). He found references to mathematical sutras (aphorisms) in the Vedas, particularly the Atharva Veda, and compiled them into a coherent system. Tirthaji's work, documented in his seminal book "Vedic Mathematics," unveiled 16 main sutras and 13 sub-sutras, providing methods for solving a wide range of mathematical problems with simplicity and speed.

Historically, Vedic Mathematics was not just about numerical computation but encompassed a broad understanding of numbers and their applications in various fields, such as geometry, algebra, and calculus. The ancient scholars and sages utilized these techniques in their astronomical calculations, architectural designs, and philosophical discourses. The rediscovery of Vedic Mathematics brought these age-old techniques back to the forefront, highlighting their elegance and efficiency.

Significance and Relevance Today

In today's fast-paced world, where competitive exams and quick mental calculations are highly valued, Vedic Mathematics offers a unique advantage. The techniques derived from the sutras enable students and professionals to perform complex calculations mentally, often in just a few seconds. This not only saves time but also boosts confidence and reduces the dependency on calculators and computers.

Vedic Mathematics is not just about speed; it also enhances cognitive abilities. By understanding and applying these sutras, one develops a deeper insight into the number system and mathematical relationships. This holistic approach to mathematics fosters creativity and logical thinking, which are essential skills in problem-solving across various disciplines.

Moreover, the simplicity of Vedic Mathematics makes it accessible to people of all ages. It breaks down complex mathematical problems into easy-to-understand steps, making learning an enjoyable experience. This has led to its inclusion in school curricula in various countries, where it complements traditional mathematical teaching methods.

In the digital age, Vedic Mathematics has found applications beyond the classroom. The principles underlying these ancient techniques are being explored in fields such as computer science, cryptography, and artificial intelligence, where efficient algorithms and quick computations are critical. Thus, Vedic Mathematics not only bridges the past with the present but also paves the way for future innovations.

Overview of Vedic Sutras

The core of Vedic Mathematics lies in its 16 sutras and 13 sub-sutras, each offering a unique method to solve specific types of mathematical problems. These sutras are concise and can be translated as aphorisms or guiding principles. For example:

Ekadhikena Purvena ("By One More than the Previous One") - Used in various multiplication techniques.

Nikhilam Navatashcaramam Dashatah ("All from 9 and the Last from 10") - Aids in simplifying multiplication and division problems.

Urdhva-Tiryagbhyam ("Vertically and Crosswise") - A versatile sutra used for multiplication of numbers of any size.

Each sutra is accompanied by one or more sub-sutras, which provide additional strategies or clarify specific applications. The power of these sutras lies in their ability to reduce large, complex problems into smaller, manageable steps, often revealing patterns and shortcuts that are not immediately apparent through conventional methods.

For instance, the Urdhva-Tiryagbhyam sutra can be applied to multiply two numbers of any size without the need for long multiplication tables. This technique is not only faster but also reduces the cognitive load, allowing the practitioner to focus on the logic rather than the mechanics of calculation.

The flexibility of Vedic Mathematics also allows for multiple approaches to the same problem, fostering a deeper understanding of mathematical concepts. This adaptability makes it a valuable tool for both students learning the basics and professionals looking for efficient solutions to advanced problems.

In the following chapters, we will delve deeper into each of these sutras, exploring their derivations, applications, and practical examples. By the end of this journey, you will not only have a thorough understanding of Vedic Mathematics but also the skills to apply these ancient techniques to modern mathematical challenges.

Nikhilam Navatashcaramam Dashatah: All from 9 and the Last from 10

2. **Nikhilam Navatashcaramam Dashatah: All from 9 and the Last from 10**

- Concept and Derivation
- Applications in Multiplication
- Division Using Nikhilam Method

The sutra Nikhilam Navatashcaramam Dashatah, which translates to "All from 9 and the Last from 10," is one of the most powerful and widely applicable sutras in Vedic Mathematics. This sutra provides a method for simplifying arithmetic operations, especially when dealing with large numbers close to powers of 10 (like 10, 100, 1000, etc.).

The concept behind this sutra is straightforward: for any number, subtract each digit from 9, except for the last digit, which you subtract from 10. This simple rule can be applied to a variety of arithmetic operations, including multiplication and division, making calculations faster and easier.

Derivation: To understand the derivation, let's consider a number

x close to a base B (such as 10, 100, 1000, etc.). The sutra suggests transforming the number by subtracting each digit from 9 and the last digit from 10.

For example, let's apply the sutra to the number 87:

Subtract each digit from 9: 9 - 8 = 1.

Subtract the last digit from 10: 10 - 7 = 3. Thus, the transformed number is 13.

This transformation simplifies many calculations, particularly when multiplying numbers close to the base, as it reduces the problem to a simpler arithmetic operation.

Applications in Multiplication

One of the most common applications of the Nikhilam sutra is in multiplication, especially when multiplying numbers close to a base like 10, 100, or 1000. The method transforms the multiplication process into a simple and quick calculation.

Example 1: Multiplying numbers close to 10

Consider multiplying 7 × 8:

Find the base, which is 10.

Subtract each number from 10: 10 - 7 = 3 and 10 - 8 = 2.

Subtract diagonally: 7 - 2 = 5 or 8 - 3 = 5.

Multiply the differences: 3 × 2 = 6.

Combine the results: 56.

Example 2: Multiplying numbers close to 100

Consider multiplying 97 × 96:

Base is 100.

Subtract from the base: 100 - 97 = 3 and 100 - 96 = 4.

Subtract diagonally: 97 - 4 = 93 or 96 - 3 = 93.

Multiply the differences: 3 × 4 = 12.

Combine the results: 9312.

This technique not only simplifies the multiplication process but also enables it to be performed mentally in many cases, making it a valuable tool for quick calculations.

Division Using Nikhilam Method

The Nikhilam sutra can also be applied to division, particularly when dividing numbers close to a power of 10. The method simplifies the division process by transforming the divisor and dividend into simpler forms.

Example: Dividing 987 by 9

Subtract the divisor (9) from 10: 10 - 9 = 1.

Start with the first digit of the dividend (9):

9 divided by 9 is 1, with a remainder of 0.

Bring down the next digit (8): 8 divided by 9 gives 0, remainder 8.

Combine the remainder (8) with the last digit (7), making 87: 87 divided by 9 is 9, remainder 6.

The quotient is 109 with a remainder of 6.

The Nikhilam method reduces complex division problems to simple arithmetic steps, making it easier to solve mentally or with minimal written work.

Introduction to the 16 Sutras

The foundation of Vedic Mathematics is built upon 16 primary sutras, or aphorisms, which are concise, easy-to-remember formulas that can be applied to various mathematical problems. These sutras encapsulate the wisdom of ancient Indian sages and offer methods to simplify and solve complex calculations with ease. The sutras cover a wide range of topics, including arithmetic, algebra, geometry, and calculus, providing versatile tools for both basic and advanced mathematical operations.

The 16 sutras are:

Ekadhikena Purvena ("By One More than the Previous One")

Nikhilam Navatashcaramam Dashatah ("All from 9 and the Last from 10")

Urdhva-Tiryagbhyam ("Vertically and Crosswise")

Paravartya Yojayet ("Transpose and Apply")

Sankalana-Vyavakalanabhyam ("By Addition and by Subtraction")

Puranapuranabhyam ("By the Completion or Non-Completion")

Sunyam Samyasamuccaye ("When the Sum is the Same that Sum is Zero")

Anurupye Shunyamanyat ("If One is in Ratio, the Other is Zero")

Shesanyankena Charamena ("The Remainder by the Last Digit")

Sopantyadvayamantyam ("The Ultimate and Twice the Penultimate")

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Gunitasamuchyah ("The Product of the Sum")

Gunakasamuchyah ("The Factors of the Sum")

Antyayordashake’pi ("Last Totals Last")

Yavadunam ("Whatever the Deficiency")

Vyastisamastih ("Individual and Collective")

Each of these sutras is designed to address specific types of mathematical problems, making calculations faster and more intuitive. The beauty of these sutras lies in their flexibility—they can be adapted to solve a wide range of problems, from simple arithmetic to more complex algebraic equations.

Understanding Upa-Sutras

In addition to the 16 main sutras, Vedic Mathematics also includes 13 sub-sutras, known as Upa-Sutras. These sub-sutras serve as auxiliary tools that provide further guidance or alternative methods for solving problems when the main sutras alone are not sufficient. The Upa-Sutras enhance the applicability of the main sutras and offer additional insights that make problem-solving even more efficient.

Some examples of Upa-Sutras include:

Anurupyena ("Proportionately")

Shunyam Saamyasamuccaye ("If the Transpose is the Same, the Whole is Zero")

Sankalana Vyavakalanabhyam ("By Addition and by Subtraction")

These sub-sutras provide alternate routes to solutions, enabling practitioners to approach problems from different angles. For instance, while the main sutra might suggest a direct method for solving an equation, the Upa-Sutra might reveal a shortcut or a more elegant approach that simplifies the process even further.

Together, the 16 sutras and 13 Upa-Sutras form a comprehensive system that is both versatile and powerful. This system is capable of addressing a broad spectrum of mathematical challenges, making it a valuable tool for students, educators, and professionals alike.

Application of Sutras in Modern Mathematics

While Vedic Mathematics is rooted in ancient traditions, its principles are surprisingly applicable to modern mathematics. The sutras can be used to solve problems more efficiently, often reducing complex calculations to simple, mental arithmetic.

In modern educational settings, Vedic Mathematics is increasingly being recognized for its potential to enhance mathematical understanding and performance. For example, students preparing for competitive exams can use these techniques to solve problems quickly and accurately, giving them an edge in time-constrained tests.

Beyond the classroom, the principles of Vedic Mathematics are finding applications in fields such as computer science, where algorithms based on these sutras can optimize calculations. For instance, the "Vertically and Crosswise" sutra has been used in the development of algorithms that perform multiplication more efficiently in computer systems.

Moreover, the conceptual understanding fostered by Vedic Mathematics encourages a deeper engagement with mathematical concepts, promoting creativity and logical thinking. This makes it a valuable tool not just for solving problems, but for developing a holistic understanding of mathematics as a discipline.

Python for Differential Equations

- **Differential Equations**: Equations involving derivatives.

Solving Ordinary Differential Equations (ODEs)

Python code

```
from scipy.integrate import solve_ivp

def odefunc(t, y):
    return -0.5 * y
```

```
sol = solve_ivp(odefunc, [0, 5], [1])
print("Solution:", sol.y[0])
```

Numerical Methods for ODEs

- **Euler's Method**: Basic numerical method for ODEs.
- **Runge-Kutta Method**: More accurate numerical method.

Partial Differential Equations (PDEs)

- **Finite Difference Method**: Discretize and solve PDEs numerically.

Applications

- **Physics and Engineering**: Model physical systems and processes using differential equations.

Python in Mathematical Logic and Set Theory

- **Logic**: Study of formal reasoning.

Set Operations and Theory

Python code

```
set1 = {1, 2, 3}
set2 = {3, 4, 5}

union = set1 | set2
difference = set1 - set2

print("Union:", union)
print("Difference:", difference)
```

Propositional Logic and Predicate Logic

- **Propositional Logic**: Logical statements that are either true or false.
- **Predicate Logic**: Extends propositional logic by dealing with predicates and quantifiers.

Formal Proofs and Symbolic Manipulation

python

Copy code

```
import sympy as sp

p, q = sp.symbols('p q')
logical_expr = sp.Implies(p, q)
print("Logical expression:", logical_expr)
print("Simplified:", sp.simplify(logical_expr))
```

Applications

- **Computer Science**: Use logic for algorithm design and verification.

Python for Algebraic Structures

- **Algebraic Structures**: Groups, rings, and fields.

Algebraic Computation with SymPy

python code

```
import sympy as sp

x = sp.symbols('x')
poly = x**3 + 2*x**2 + 1
roots = sp.solve(poly, x)
print("Roots:", roots)
```

Polynomials and Their Properties

- **Polynomials**: Algebraic expressions involving sums of powers of variables.

Applications in Cryptography and Error Detection

- **Cryptography**: Use algebraic structures for secure communication.

Error Detection: Use polynomials for error-checking codes.

Impact on Modern Mathematics and Education

Introduction

Vedic Mathematics is an ancient system of mathematics that originates from the Vedas, the oldest scriptures of Indian wisdom. It offers a set of 16 sutras (aphorisms) and 13 upa-sutras (sub-aphorisms) that simplify various mathematical operations, providing alternative and often faster methods for arithmetic, algebra, geometry, calculus, and more. This system, rediscovered by Bharati Krishna Tirthaji in the early 20th century, is not only rooted in deep mathematical principles but also reflects a holistic approach to learning, where intuition and creativity are emphasized alongside logic and calculation.

The essence of Vedic Mathematics lies in its ability to simplify complex calculations, making them accessible even for those who struggle with traditional mathematical methods. The sutras are easy to understand and apply, making them valuable tools for both students and professionals.

The Origins and History

Vedic Mathematics traces its roots to the Vedic period, a time in ancient India when the Vedas were composed. The techniques found in Vedic Mathematics are believed to be derived from the Atharva Veda, one of the four Vedas, which deals with the knowledge of everyday life and sciences.

Despite its ancient origins, the system was largely forgotten until Bharati Krishna Tirthaji, a scholar and spiritual leader, revived it in the 20th century. He studied the ancient texts and synthesized the mathematical principles into 16 main sutras and 13 upa-sutras. His work was published posthumously in the 1960s, and since then, Vedic Mathematics has gained popularity worldwide for its simplicity and effectiveness.

Significance and Relevance Today

In today’s fast-paced world, where time is of the essence, Vedic Mathematics offers tools that can significantly reduce the time required for calculations. This is particularly relevant in competitive exams and academic contexts, where speed and accuracy are crucial.

Moreover, Vedic Mathematics fosters mental calculation skills, promoting cognitive development and enhancing problem-solving abilities. It encourages a flexible approach to mathematical problems, allowing for multiple methods of arriving at the same solution. This adaptability is especially useful in a world that increasingly values innovation and out-of-the-box thinking.

Vedic Mathematics is also gaining recognition in educational institutions as a supplementary tool to traditional mathematical methods. It not only aids in faster calculations but also builds a strong foundational understanding of numbers and operations, making it easier for students to grasp more advanced concepts.

Overview of Vedic Sutras

The 16 sutras and 13 upa-sutras of Vedic Mathematics cover a wide range of mathematical operations. Each sutra is a short phrase, often in Sanskrit, that encapsulates a specific mathematical principle or technique.

For example, the sutra **Ekadhikena Purvena**, meaning "One more than the previous one," is used for specific types of multiplication and finding the reciprocals of numbers. Another powerful sutra, **Nikhilam Navatashcaramam Dashatah**, which translates to "All from 9 and the last from 10," is used to simplify multiplication, division, and other operations involving large numbers.

These sutras are not limited to arithmetic; they can also be applied to algebra, geometry, calculus, and other branches of mathematics. The flexibility and universality of these techniques are what make Vedic Mathematics a unique and valuable tool for learners of all levels.

Key Sutras and Their Applications

Ekadhikena Purvena: The Power of One More

This sutra is primarily used in multiplication, especially when multiplying numbers near a base, such as 10, 100, or 1000. It simplifies the multiplication process by transforming the numbers into easier forms, allowing for quick and accurate calculations.

For example, to multiply 9 by 9, one would use the base 10:

- Subtract 1 from 9 (the base minus 1), resulting in 8.
- Multiply 8 by 9 (the previous digit), giving 72.
- Add 1 to the last digit, resulting in 81.

This method illustrates the power of Vedic Mathematics in making complex operations straightforward and intuitive.

Nikhilam Navatashcaramam Dashatah: All from 9 and the Last from 10

This sutra is especially useful for performing multiplication and division with large numbers. The method involves subtracting each digit of the number from 9, except for the last digit, which is subtracted from 10. This simplification allows for rapid calculations, even with numbers that would traditionally require lengthy processes.

For example, to multiply 98 by 97 using this sutra:

- Subtract 98 from 100 and 97 from 100, resulting in 2 and 3.
- Subtract 3 from 98 or 2 from 97, giving 95.
- Multiply the remainders (2 and 3), resulting in 6.
- Combine the results to get 9506.

This technique reduces multiplication to a few simple steps, demonstrating the efficiency of Vedic methods.

Urdhva-Tiryagbhyam: Vertical and Crosswise

This sutra is perhaps the most versatile in Vedic Mathematics, applicable to multiplication of numbers of any size. The principle involves multiplying digits vertically and crosswise, then summing the results to obtain the final product. This method can be visualized as a grid, where each cell represents a part of the multiplication process.

For example, to multiply 23 by 45 using Urdhva-Tiryagbhyam:

- Multiply the digits vertically: $3 \times 5 = 15$ (write down 5, carry over 1).
- Multiply crosswise: $(2 \times 5) + (3 \times 4) = 10 + 12 = 22$ (add the carryover, write down 2, carry over 2).
- Multiply the leftmost digits vertically: $2 \times 4 = 8$ (add the carryover to get 10).
- Combine the results to get 1035.

This method, when practiced, becomes second nature, allowing for rapid mental calculations without the need for written work.

Paravartya Yojayet: Transpose and Apply

This sutra is particularly useful in solving equations and division. It involves transposing terms and applying the resulting simplified equation to find the solution. This technique is especially effective in dealing with equations that involve fractions or ratios.

For example, in dividing polynomials, this sutra allows for the terms to be rearranged and simplified, making the division process much more straightforward.

Sankalana-Vyavakalanabhyam: By Addition and Subtraction

This sutra is a versatile tool for simplifying algebraic expressions and solving equations. It emphasizes the use of addition and subtraction as fundamental operations to reduce complexity. This technique is particularly effective in symmetric equations, where terms can be strategically added or subtracted to reach a solution.

For example, to solve x2−4x+4=0x^2 - 4x + 4 = 0x2−4x+4=0, one could factor the equation by adding and subtracting terms, resulting in (x−2)2=0(x - 2)^2 = 0(x−2)2=0, giving x=2x = 2x=2.

Impact on Modern Mathematics and Education

Vedic Mathematics has a profound impact on modern mathematics and education. It offers a different perspective on problem-solving, one that emphasizes creativity, intuition, and mental agility. As an alternative to traditional methods, Vedic Mathematics provides tools that can make learning more engaging and less intimidating for students.

In education, Vedic Mathematics is being integrated into curricula around the world as a supplementary tool. It helps students develop a strong number sense, improve mental calculation skills, and build confidence in their mathematical abilities. Teachers and educators recognize the value of these ancient techniques in making mathematics more accessible and enjoyable.

Moreover, Vedic Mathematics has found applications in various fields, including computer science, engineering, and economics, where rapid and accurate calculations are essential. Its techniques are also being explored in research, with scholars investigating the potential of Vedic methods to address complex mathematical problems.

Conclusion

Vedic Mathematics is more than just a system of calculation; it is a holistic approach to understanding mathematics that integrates logic, creativity, and intuition. The 16 sutras and 13 upa-sutras offer powerful tools that simplify mathematical operations, making them accessible to everyone.

As we continue to explore and apply these ancient techniques, Vedic Mathematics will likely play an increasingly important role in education and beyond. Its relevance in today's world is a testament to the timeless wisdom of the Vedas, proving that even the oldest knowledge can have profound implications for the future.

This summary provides a comprehensive overview of Vedic Mathematics, highlighting its origins, key sutras, applications, and impact on modern mathematics and education. Through its unique methods, Vedic Mathematics offers a powerful alternative to traditional mathematical approaches, making complex calculations simple and intuitive.

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The Sutras of Vedic Mathematics

Introduction to the 16 Sutras

The foundation of Vedic Mathematics is built upon 16 primary sutras, or aphorisms, which are concise, easy-to-remember formulas that can be applied to various mathematical problems. These sutras encapsulate the wisdom of ancient Indian sages and offer methods to simplify and solve complex calculations with ease. The sutras cover a wide range of topics, including arithmetic, algebra, geometry, and calculus, providing versatile tools for both basic and advanced mathematical operations.

The 16 sutras are:

Ekadhikena Purvena ("By One More than the Previous One")
Nikhilam Navatashcaramam Dashatah ("All from 9 and the Last from 10")
Urdhva-Tiryagbhyam ("Vertically and Crosswise")
Paravartya Yojayet ("Transpose and Apply")
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Vyastisamastih ("Individual and Collective")

Each of these sutras is designed to address specific types of mathematical problems, making calculations faster and more intuitive. The beauty of these sutras lies in their flexibility—they can be adapted to solve a wide range of problems, from simple arithmetic to more complex algebraic equations.

Understanding Upa-Sutras

In addition to the 16 main sutras, Vedic Mathematics also includes 13 sub-sutras, known as Upa-Sutras. These sub-sutras serve as auxiliary tools that provide further guidance or alternative methods for solving problems when the main sutras alone are not sufficient. The Upa-Sutras enhance the applicability of the main sutras and offer additional insights that make problem-solving even more efficient.

Some examples of Upa-Sutras include:

Anurupyena ("Proportionately")
Shunyam Saamyasamuccaye ("If the Transpose is the Same, the Whole is Zero")
Sankalana Vyavakalanabhyam ("By Addition and by Subtraction")

These sub-sutras provide alternate routes to solutions, enabling practitioners to approach problems from different angles. For instance, while the main sutra might suggest a direct method for solving an equation, the Upa-Sutra might reveal a shortcut or a more elegant approach that simplifies the process even further.

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Application of Sutras in Modern Mathematics

While Vedic Mathematics is rooted in ancient traditions, its principles are surprisingly applicable to modern mathematics. The sutras can be used to solve problems more efficiently, often reducing complex calculations to simple, mental arithmetic.

In modern educational settings, Vedic Mathematics is increasingly being recognized for its potential to enhance mathematical understanding and performance. For example, students preparing for competitive exams can use these techniques to solve problems quickly and accurately, giving them an edge in time-constrained tests.

Beyond the classroom, the principles of Vedic Mathematics are finding applications in fields such as computer science, where algorithms based on these sutras can optimize calculations. For instance, the "Vertically and Crosswise" sutra has been used in the development of algorithms that perform multiplication more efficiently in computer systems.

Moreover, the conceptual understanding fostered by Vedic Mathematics encourages a deeper engagement with mathematical concepts, promoting creativity and logical thinking. This makes it a valuable tool not just for solving problems, but for developing a holistic understanding of mathematics as a discipline.