DI04019031: Engineering Costing and Plant Maintenance

GTU Course Presentation

July 25, 2026

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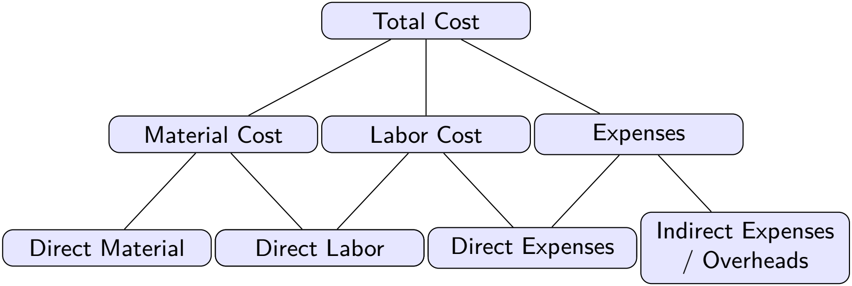
Agenda I

- Introduction to Engineering Costing
- Elements of Cost: Material, Labor, and Expenses
- Direct vs. Indirect Costs (Prime Cost)
- Overhead Cost Classification
- Cost Behavior: Fixed, Variable, and Semi-Variable Costs
- Cost Concepts for Engineering Decisions
- Relevance of Costing in Plant Maintenance and Design

Introduction to Costing in Engineering I

- Costing represents the systematic determination of expenses incurred in manufacturing a product or rendering a service.
- In mechanical systems, thermodynamic efficiency must be balanced against economic feasibility to achieve optimal engineering design.
- Capital Expenditure (CAPEX) vs. Operational Expenditure (OPEX) governs critical plant design and lifecycle decisions.
- Understanding cost elements helps engineers optimize the lifecycle costs of thermal power plants and process equipment.

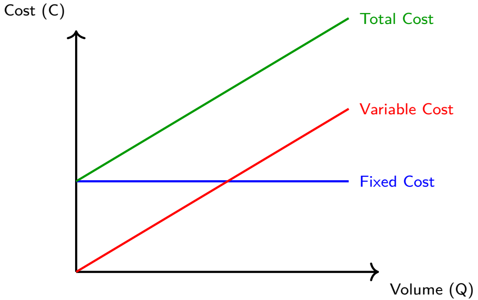
Classification of Cost Elements I



Direct vs. Indirect Costs I

- Direct Costs are easily traceable to a specific cost object, such as raw materials for a turbine blade.
- Indirect Costs cannot be directly attributed to a single product or process (e.g., factory rent, maintenance lubricants).
- Prime Cost is the summation of all direct costs: Direct Material + Direct Labor + Direct Expenses.
- In plant maintenance, direct labor represents technicians repairing a boiler, while indirect labor is the plant supervisor.

Cost Behavior: Fixed vs. Variable I



Overhead Cost Classification I

- Overheads represent the aggregate of indirect materials, indirect labor, and indirect expenses.
- Factory or Works Overheads: Expenses incurred on the factory floor (e.g., power consumption, depreciation of plant machinery).
- Administration Overheads: Expenses related to general management and policy formulation (e.g., office staff salaries).
- Selling and Distribution Overheads: Costs to secure orders and deliver goods (e.g., marketing, warehouse expenses).

Cost Concepts for Engineering Decisions I

- Sunk Costs: Historical costs already incurred that cannot be recovered (e.g., research and development of a retired reactor design).
- Opportunity Cost: The benefit foregone by choosing one alternative over another (e.g., using factory space for inventory instead of production).
- Incremental Cost: The change in total cost resulting from a specific design choice or capacity expansion.
- Marginal Cost: The cost of producing one additional unit of output.

Costing in Plant Maintenance I

- Maintenance costing involves tracking preventative, predictive, and breakdown maintenance expenses.
- Preventative Maintenance (PM) Cost: Scheduled servicing of pumps, valves, and compressors to avoid failure.
- Breakdown Maintenance Cost: Expenses due to unexpected downtime, emergency repairs, and lost production capacity.
- Optimum Maintenance Level: The point where the sum of PM cost and breakdown cost is minimized.

Summary & Conclusion I

- Engineering Thermodynamics and Costing are intrinsically linked through efficiency-cost trade-offs.
- All cost elements are classified into Material, Labor, and Expenses, further subdivided into Direct and Indirect.
- Cost behavior (Fixed, Variable, Semi-variable) is critical for break-even analysis of engineering projects.
- Strategic plant maintenance planning minimizes total operational cost and maximizes machine uptime.

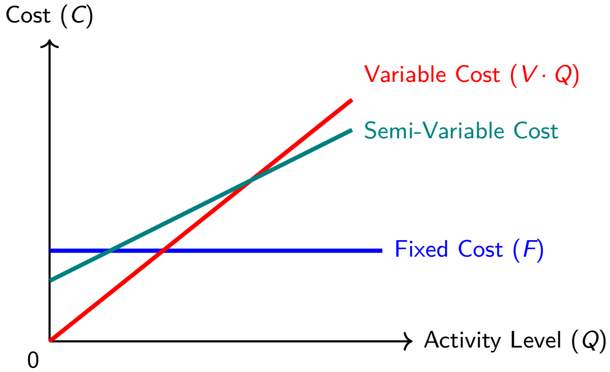
Agenda & Learning Objectives I

- 1. Introduction to Engineering Costing: Core terminology and significance in plant operations.
- 2. Elements of Cost: Breakdown into Materials, Labor, and Expenses.
- 3. Cost Classification by Traceability: Direct vs. Indirect Costs.
- 4. Cost Classification by Behavior: Fixed, Variable, and Semi-variable Costs.
- 5. Cost Structure Hierarchy: From Prime Cost to Total Cost of Production.
- 6. Decision-Making Cost Concepts: Sunk costs, Opportunity costs, and Marginal costing.

The Three Elements of Cost I

- Cost is the amount of expenditure incurred on, or attributable to, a given product, service, or engineering activity.
- Material Cost: The cost of physical substances from which the product is made, or which are consumed in the manufacturing process (e.g., raw steel, cutting oils, welding electrodes).
- Labor Cost: The cost of human effort expended in converting raw materials into a finished product, including wages, salaries, bonuses, and social security contributions.
- Expenses: The cost of services provided to an undertaking and the hire of assets (e.g., equipment rental, power usage, software licensing, sub-contractor fees).

Cost Behavior: Fixed, Variable, and Semi-Variable Costs I



Understanding Cost Behavior Models I

- Fixed Costs: Costs that remain constant in total amount over a wide range of activity for a specified period (e.g., factory rent, executive salaries, straight-line depreciation of machinery).
- Variable Costs: Costs that vary in direct proportion to changes in the activity level or production volume (e.g., raw material consumption, direct labor wages on a piece-rate system).
- Semi-Variable (Mixed) Costs: Costs containing both a fixed and a variable component; they change with activity but not in direct proportion (e.g., factory electricity bills with a basic fixed charge plus usage charges).
- Mathematical Model: Total Cost $C_T = F + V \times Q$, where F is Fixed Cost, V is unit variable cost, and Q is production quantity.

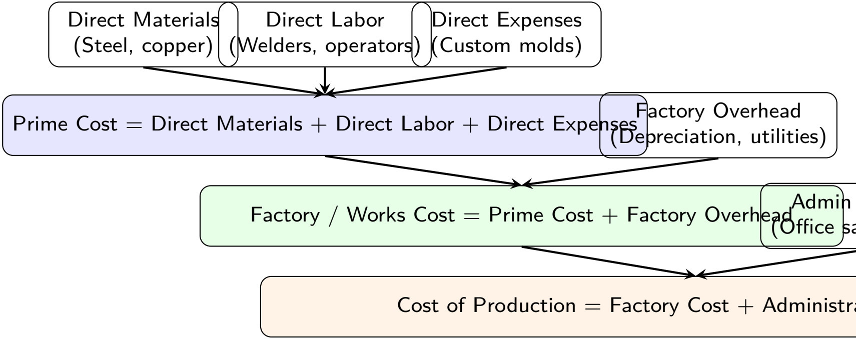
Traceability: Direct vs. Indirect Costs I

- Direct Costs: Costs that can be easily and cost-effectively traced to a specific cost object (e.g., a specific engine, machine component, or batch).
- Examples of Direct Costs: Steel sheets for manufacturing pressure vessels, direct wages paid to CNC machine operators.
- Indirect Costs: Costs that cannot be easily or cost-effectively traced to a single cost object; they must be allocated or apportioned using logical bases (known as Overheads).
- Examples of Indirect Costs: Lubricating oils for all factory machines, salary of the factory supervisor, depreciation of the plant building.

Direct Material, Direct Labor, and Direct Expenses I

- Direct Materials: Materials entering into and becoming a constituent part of the finished product (e.g., pig iron in a foundry, timber in furniture fabrication).
- Direct Labor: Labor cost directly involved in the manufacture of a product (e.g., machinists operating lathes, assembly line technicians).
- Direct Expenses: Any expenses (other than direct material and direct labor) directly incurred for a specific cost center or product (e.g., cost of hiring special machinery for a particular project, cost of custom blueprints).

The Engineering Cost Hierarchy I



Decision-Making Costs: Sunk, Opportunity, and Marginal I

- Sunk Costs: Past costs that have already been incurred and cannot be recovered by any future decision; they should be ignored in future decision-making (e.g., past R&D costs for a design that is now obsolete).
- Opportunity Costs: The potential benefit or revenue foregone by choosing one course of action over another (e.g., using a company-owned warehouse for a new project instead of renting it out to a third party).
- Marginal Cost: The additional cost incurred by producing one additional unit of output. It is essentially equivalent to the variable cost per unit.
- Differential Cost: The difference in total cost between two alternative decisions or engineering designs.

Summary & Key Takeaways I

- Classification of costs is essential for accurate product pricing, cost control, budget preparation, and engineering economic analysis.
- Prime Cost represents the sum of all direct elements, while Overheads represent indirect materials, labor, and expenses.
- Understanding cost behavior (Fixed vs. Variable) is critical for Break-Even Analysis ($Q_{BE} = F/(P - V)$) and capacity planning.
- For engineering design choices, sunk costs are irrelevant, whereas opportunity costs and differential costs must guide selection.

Agenda I

- Introduction to Overheads and Key Costing Terminology
- Functional, Behavioral, and Element-wise Classification of Overheads
- Methods of Allocation and Apportionment of Overhead Costs
- Primary and Secondary Distribution of Service Department Costs
- Overhead Absorption and its Significance in Plant Maintenance

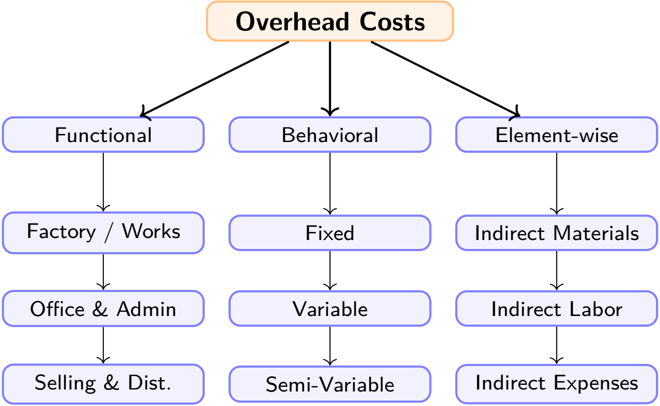
Introduction to Overheads and Terminology I

- Direct Costs vs. Indirect Costs: Direct costs (materials, labor) can be traced directly to a cost object, whereas indirect costs cannot.
- Definition of Overheads: Overheads represent the aggregate of indirect materials, indirect labor, and indirect expenses.
- Cost Center: A location, person, or item of equipment for which costs may be ascertained and used for purposes of cost control.
- Cost Unit: A unit of product or service in relation to which costs are ascertained (e.g., kilowatt-hour in power generation, ton-mile in transport).
- Significance in Plant Maintenance: Maintenance overheads include lubricating oils, spare parts, and salaries of maintenance crews which cannot be directly traced to a single output unit.

Functional Classification of Overheads I

- Factory / Works Overheads: All indirect costs incurred inside the factory walls (e.g., factory rent, depreciation of machinery, power and fuel, factory supervisor salaries).
- Office and Administration Overheads: Costs incurred in formulating policies, directing the organization, and controlling operations (e.g., office rent, salaries of executives, legal expenses).
- Selling Overheads: Costs incurred to secure orders and create demand (e.g., advertisement, sales commission, showroom expenses).
- Distribution Overheads: Costs incurred from the time the product is completed in the factory until it reaches the consumer (e.g., warehouse rent, carriage outwards, delivery van maintenance).

Classification of Overheads I



Classification by Behavior / Variability I

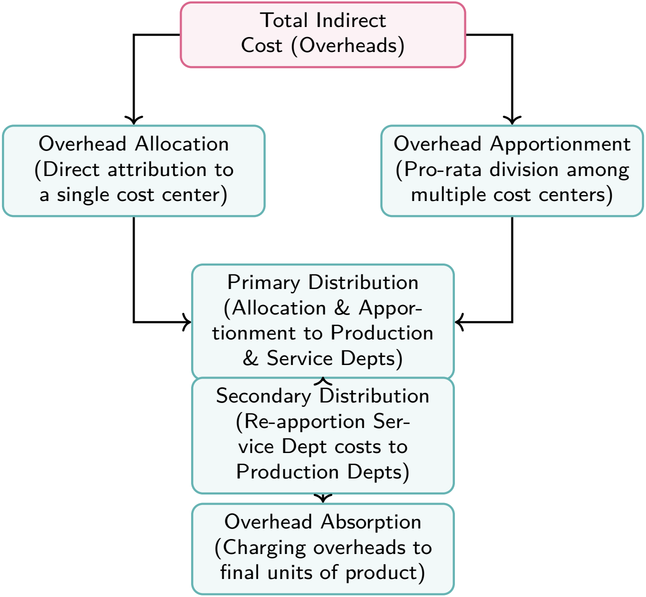
- Fixed Overheads: Costs that remain constant in total amount irrespective of changes in the volume of production (e.g., rent, taxes, depreciation, salaries of permanent staff). Cost per unit decreases as production increases.
- Variable Overheads: Costs that vary in direct proportion to the volume of output (e.g., indirect materials, lubricants, small tools). Cost per unit remains constant.
- Semi-Variable Overheads: Costs that contain both fixed and variable elements; they vary with output but not in direct proportion (e.g., electricity, telephone expenses, maintenance costs).
- Methods of Segregation: Techniques like High-Low Method, Least Squares Regression, or Scatter Diagram are used to split semi-variable costs into fixed and variable components.

Overhead Allocation vs. Apportionment I

- Overhead Allocation: The process of identifying and charging the whole item of overhead cost directly to a specific department or cost center (e.g., salary of a factory manager allocated to the admin department).
- Overhead Apportionment: The distribution of overhead costs that cannot be directly linked to a single cost center, divided among multiple departments on an equitable basis.
- Common Bases of Apportionment:
- - Floor Area: Rent, rates, heating, and lighting.
- - Number of Employees: Canteen expenses, welfare services, timekeeping cost.
- - Capital Value of Assets: Depreciation, insurance of plant and machinery.
- - Horse Power of Machine / KWh: Electric power and steam generation.

Process Flow of Overhead Cost Distribution I

Process Flow of Overhead Cost Distribution II



Primary vs. Secondary Overhead Distribution I

- Primary Distribution: The process of allocating and apportioning overhead costs of both production and service departments to all departments (e.g., Production Dept A, Production Dept B, and Maintenance Dept).
- Secondary Distribution: The process of re-distributing the cost of service departments (like Plant Maintenance, Powerhouse, Canteen) to the production departments.
- Why Secondary Distribution is Necessary: Service departments do not directly manufacture products, so their costs must be shared by the production departments that benefit from their services.
- Methods of Secondary Distribution:
- - Direct Redistribution Method: Service dept costs are allocated directly to production depts only, ignoring inter-service dept services.

Primary vs. Secondary Overhead Distribution II

- - Step-Ladder Method: Costs are allocated in a step-down sequence starting with the department that serves the largest number of other service departments.
- - Reciprocal Services Method: Recognizes mutual services rendered among service departments (using Simultaneous Equations or Repeated Distribution).

Overhead Absorption & Cost Control I

- Definition of Absorption: The process of charging overhead costs of production departments to cost units (products or services) using an appropriate rate.
- Common Overhead Absorption Rates (OAR):
- - Direct Material Cost Percentage Rate
- - Direct Labor Cost Percentage Rate
- - Direct Labor Hour Rate
- - Machine Hour Rate (most suitable for highly automated plants)
- Under-absorption and Over-absorption: Occurs when actual overheads differ from absorbed overheads due to variations in production volume or actual expenditure.

- Plant Maintenance Context: Accurate allocation and absorption of maintenance overheads ensures that equipment downtime, spare parts inventory, and preventive maintenance labor costs are correctly factored into the product's final cost.

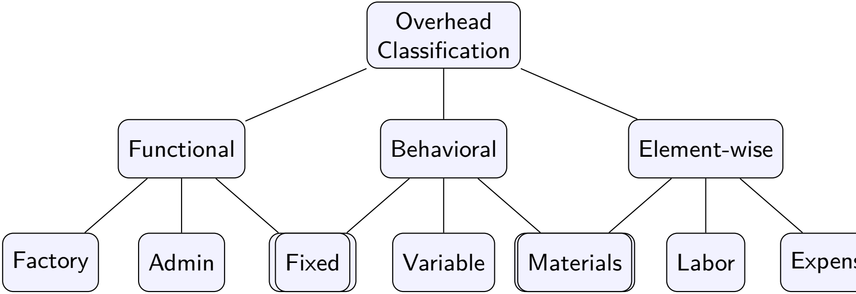
Agenda I

- Introduction to Overhead Cost Terminology
- Classification of Overheads (Functional, Behavioral, and Element-wise)
- Overhead Allocation vs. Overhead Apportionment
- Principles and Bases of Apportioning Common Expenses
- Methods of Overhead Absorption in Production environments
- Practical Application to Plant Maintenance & Machine Hour Rates

Terminology of Overheads I

- Overhead represents the aggregate of indirect materials, indirect labor, and indirect expenses.
- Indirect Materials: Consumables and parts not directly traceable to a specific unit of output (e.g., lubricants, coolants, wiping rags, and cleaning solvents used in machine maintenance).
- Indirect Labor: Wages paid to employees who do not directly fabricate the product but support the production process (e.g., maintenance technicians, storekeepers, supervisors, and quality inspectors).
- Indirect Expenses: Operational expenditures that cannot be directly charged to a single cost center, such as factory rent, building insurance, depreciation of plant equipment, and steam/power utilities.

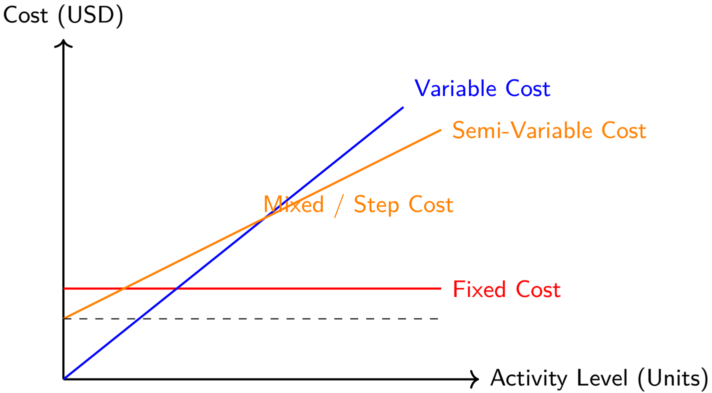
Classification Hierarchy of Overheads I



Functional Classification of Overheads I

- Factory / Production Overheads: All indirect costs incurred within the factory gate, including factory rent, power, lighting, depreciation of plant, and wages of factory supervisors.
- Office / Administration Overheads: Expenses incurred in formulating policy, directing the organization, and controlling operations, such as office staff salaries, office rent, and audit fees.
- Selling Overheads: Expenses incurred to secure orders and promote sales, including advertising, sales commissions, showroom expenses, and catalog printing.
- Distribution Overheads: Expenses incurred from the time the product is finished in the factory until it reaches the customer, e.g., warehouse rent, packing cost, and delivery vehicle upkeep.

Behavioral Classification: Cost Dynamics I



Overhead Allocation vs. Apportionment I

- Overhead Allocation is the process of identifying and charging the entire amount of an overhead cost directly to a specific cost center or department.
- Example of Allocation: The salary of a supervisor dedicated solely to the Machine Shop is allocated entirely to the Machine Shop's cost center.
- Overhead Apportionment is the distribution of common overhead expenses across multiple departments on an equitable, proportionate basis.
- Example of Apportionment: Total factory rent is apportioned to the Machining, Assembly, and Maintenance departments based on the floor area each occupies.

Bases for Apportioning Common Overheads I

- Floor Area Occupied: Used to apportion rent, rates, heating, cooling, fire insurance, and general factory lighting.
- Capital Value of Assets: Used to apportion machinery depreciation, fire insurance on assets, and maintenance expenditures.
- Number of Employees / Labor Hours: Used to apportion welfare services, canteen expenses, payroll administration, and personnel department costs.
- Technical Estimates / Kilowatt Hours: Used to apportion high-voltage electric power, steam consumption, and process water costs.

Overhead Absorption Methods I

- Overhead Absorption: The final step in costing where the accumulated factory overheads from both production and service departments are charged to individual products or cost units.
- Direct Labor Hour Rate: Factory Overheads divided by Direct Labor Hours. Best suited for labor-intensive, manual manufacturing environments.
- Machine Hour Rate (MHR): Factory Overheads divided by Machine Hours. Ideal for highly automated, capital-intensive engineering plants.
- Percentage of Direct Material Cost: (Factory Overheads / Direct Material Cost) x 100. Used when material cost constitutes a significant and stable portion of total costs.

Overhead Absorption Methods II

- Under-absorption and Over-absorption occur when actual overheads differ from the predetermined overhead absorption rates applied to production.

Engineering Applications: Overheads in Plant Maintenance I

- Plant Maintenance is typically a Service Cost Center whose overheads must be redistributed to Production Cost Centers (e.g., Machining, Casting).
- Maintenance labor hours and spares consumed are tracked per machine using computerized maintenance management systems (CMMS).
- Correct apportionment of maintenance overheads ensures accurate calculation of Machine Hour Rates (MHR) for production planning.
- Accurate overhead tracking is vital for Life Cycle Cost (LCC) analysis of industrial assets and for making Repair vs. Replace decisions.

Agenda I

- Introduction to Pricing Terminology: Catalogue/List Price vs. Selling Price
- Components of Cost and the Price Ladder Structure
- Mathematical Models for Calculating Selling Price from Total Cost
- Determining Catalogue Price based on Trade Discounts
- Visualizing Cost-Price Components (TikZ Diagram)
- Impact of Overheads, Administrative, and Distribution Costs
- Pricing Strategies: Cost-Plus Pricing vs. Market-Driven Pricing
- Break-Even Analysis in Pricing Decisions (TikZ Diagram)
- Illustrative Engineering Costing Numerical Problems
- Summary and Core Takeaways

Understanding Catalogue Price and Selling Price I

- Catalogue Price (List Price): The published or printed price of an item in a manufacturer's catalog or price list, representing the maximum price before discounts.
- Selling Price: The actual price paid by the customer or distributor after subtracting any applicable trade discounts or promotional allowances from the catalogue price.
- Relationship: Selling Price = Catalogue Price - Discount (or Selling Price = Catalogue Price * (1 - Discount Rate)).
- Trade Discount: A reduction in list price allowed by manufacturers to wholesalers or retailers to cover their operating expenses and profit margins.

Visual Structure of Selling and Catalogue Price I

Selling Price + Trade Discount = Catalogue (List) Price

Total Cost + Desired Profit = Selling Price

Cost of Production + Selling & Distribution Overheads = Total Cost (Cost of Sa

Factory Cost + Office & Administrative Overheads = Cost of Production

Prime Cost + Factory/Works Overheads = Factory or Works Cost

Direct Material + Direct Labor + Direct Expenses = Prime Cost

Mathematical Formulation of Price Components I

- Prime Cost (PC) = Direct Material Cost (DMC) + Direct Labor Cost (DLC) + Direct Expenses (DE).
- Factory Cost (FC) = Prime Cost (PC) + Factory Overheads (FO) [including indirect materials, indirect labor, depreciation, power].
- Production Cost (COPs) = Factory Cost (FC) + Office and Administrative Overheads (AO).
- Total Cost or Cost of Sales (TC) = Production Cost (COPs) + Selling and Distribution Overheads (SDO).
- Selling Price (SP) = Total Cost (TC) + Net Profit (P) [where profit can be expressed as a % of cost or a % of selling price].
- Catalogue Price (CP) = Selling Price (SP) / (1 - d), where d is the trade discount fraction.

Profit Margin vs. Cost Markup in Pricing I

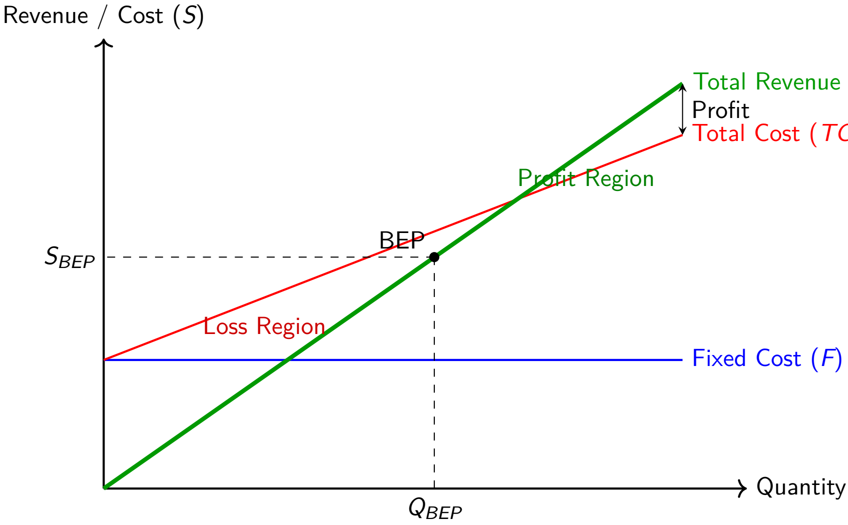
- Markup: The percentage added to the Total Cost to determine the Selling Price. Formula: Markup % = (Profit / Total Cost) * 100.
- Margin: The percentage of the Selling Price that is profit. Formula: Margin % = (Profit / Selling Price) * 100.
- Mathematical Conversion: If markup is m, margin is $g = m / (1 + m)$. If margin is g, markup is $m = g / (1 - g)$.
- Example: A 25% markup on cost ($m = 0.25$) corresponds to a 20% profit margin on sales ($g = 0.25 / 1.25 = 0.20$). Knowing this distinction is critical for setting catalogue prices without eroding profits.

Trade Discounts and Catalogue Pricing Strategies I

- Why Use Catalogue Prices? Catalogues are printed in advance and distributed widely. Using a list price allows stable pricing while adjusting actual selling prices via flexible trade discounts.
- Trade discounts encourage bulk purchases (quantity discounts) and reward loyal distribution channels (wholesalers vs. retailers).
- Chain Discounts: Sometimes multiple discounts are applied (e.g., 20% trade discount plus a 5% cash discount for prompt payment).
- Net Selling Price calculation with chain discounts: $SP = CP * (1 - d_1) * (1 - d_2)$.

Break-Even Analysis in Pricing Decisions I

Break-Even Analysis in Pricing Decisions II



Numerical Illustration of Pricing Calculations I

- Problem Statement: A manufacturing firm produces an industrial valve with Direct Material = \$150, Direct Labor = \$100. Factory overhead is 60% of Labor, Administrative overhead is 20% of Factory Cost, and Selling/Distribution overhead is 10% of Production Cost. If the firm desires a 20% profit on the selling price and offers a 15% trade discount, find the Selling Price and Catalogue Price.
- Step 1: Prime Cost = \$150 + \$100 = \$250. Factory Overhead = 0.60 * \$100 = \$60. Factory Cost = \$250 + \$60 = \$310.
- Step 2: Admin Overhead = 0.20 * \$310 = \$62. Cost of Production = \$310 + \$62 = \$372. Selling & Distribution Overhead = 0.10 * \$372 = \$37.20. Total Cost = \$372 + \$37.20 = \$409.20.

Numerical Illustration of Pricing Calculations II

- Step 3: Profit is 20% of Selling Price, so Margin = 20%. Markup = 0.20 / (1 - 0.20) = 25%. Profit = 0.25 * $409.20 = $102.30. Selling Price = $409.20 + $102.30 = $511.50.
- Step 4: Trade Discount is 15%. Catalogue Price = Selling Price / (1 - 0.15) = $511.50 / 0.85 = $601.76.

Summary and Key Takeaways I

- Engineering costing requires systematic tracing of costs from raw materials through production, administration, and distribution to prevent underpricing.
- Selling price must cover all components of the total cost (prime cost + all overheads) plus an adequate return on investment (profit).
- Catalogue price is a strategic tool enabling price stability in catalog distribution, using discounts to adjust to market demands and channel tiers.
- Incorrect application of margin vs. markup rules or failure to account for all overhead categories can lead to severe operating losses, even with high sales volumes.

Agenda I

- Understanding Cost Accumulation in Thermal Systems Engineering
- Components of Total Cost: Prime Cost, Factory Overheads, and Office Overheads
- Definitions: Selling Price versus Catalogue (List) Price
- Calculations of Profit Margin and Mark-up for Power Plant Components
- Trade Discounts and Distributor Margins in Industrial Piping & Valves
- Diagram: Flowchart of Pricing Hierarchy from Raw Materials to Retail
- Diagram: Formulaic Flow of Selling Price and Catalogue Price
- Numerical Example: Pricing a Shell and Tube Heat Exchanger
- Key Summary and Review Questions for Plant Design Projects

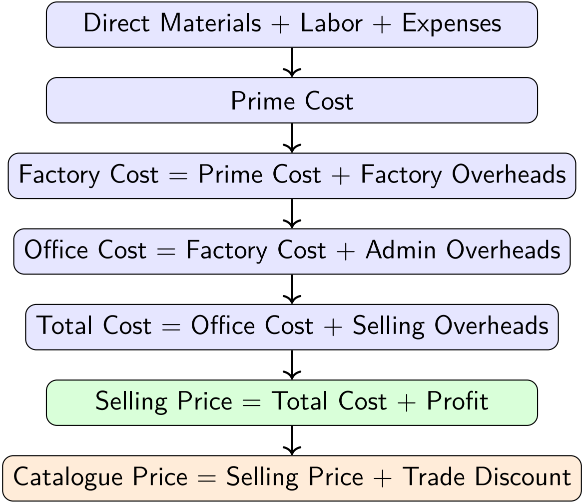
Structure of Industrial Product Costing I

- Industrial costing for thermodynamic systems begins with raw material costing (e.g., alloy steel tubes, copper sheets, insulations).
- Prime Cost is the sum of Direct Material, Direct Labor (e.g., welders, machining technicians), and Direct Expenses.
- Factory Overheads encompass manufacturing costs not directly traceable, such as electricity for casting furnaces, rent of the fabrication yard, and depreciation of hydraulic presses.
- Office/Administrative Overheads include engineering design office expenses, CAD software licenses, and administrative salaries.
- Selling and Distribution Overheads include logistics for shipping heavy equipment, marketing of industrial boilers, and commissioning engineers' travel expenses.

Defining Selling Price and Catalogue Price I

- Selling Price (SP) is the net amount the manufacturing firm receives after all discounts: SP = Total Cost (TC) + Profit.
- The selling price must cover the cost of thermodynamic design, manufacturing, and distribution while generating a sustainable return on capital.
- Catalogue Price (CP), or List Price, is the retail/market price published in the product catalogue or engineering procurement databases.
- Manufacturers offer a Trade Discount (TD) to distributors or EPC (Engineering, Procurement, and Construction) contractors to incentivize bulk purchasing.
- Distributor Net Purchase Price is the manufacturer's Selling Price: SP = CP - TD.

Cost to Selling Price Hierarchy I



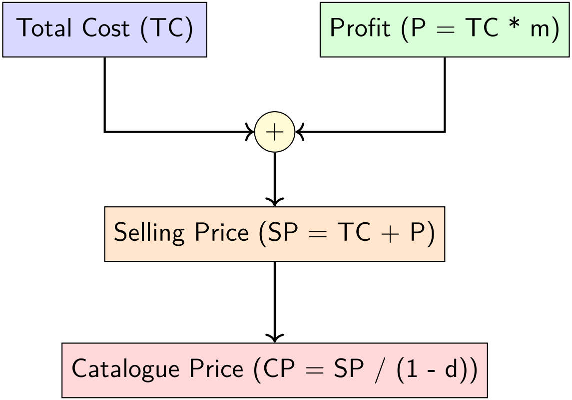
Profit Margin vs. Mark-up I

- Profit Mark-up is the profit expressed as a percentage of the Total Cost: Mark-up % = (Profit / Total Cost) * 100.
- Profit Margin is the profit expressed as a percentage of the Selling Price: Margin % = (Profit / Selling Price) * 100.
- Under-pricing risk: If an engineering manager mistakes a 25% mark-up for a 25% margin, they will underestimate the necessary selling price.
- Equivalence relation: Margin % = (Mark-up %) / (1 + Mark-up %/100).
- Equivalence relation: Mark-up % = (Margin %) / (1 - Margin %/100).
- For a 20% desired profit margin on a gas turbine, the mark-up on cost must be set to 25%.

Calculation of Catalogue Price I

- Let 'd' represent the trade discount rate offered to industrial distributors (expressed as a decimal).
- The relationship between Selling Price (SP) and Catalogue Price (CP) is given by: SP = CP * (1 - d).
- To find the required Catalogue Price to publish: CP = SP / (1 - d).
- Substituting the cost equation: CP = (Total Cost + Desired Profit) / (1 - d).
- This formulation ensures that even after the distributor takes their discount 'd', the manufacturer secures the exact Selling Price needed to cover costs and profit.

Pricing Calculation Flowchart I



Numerical Example: Pricing a Shell and Tube Heat Exchanger I

- Case Study: Pricing a Shell and Tube Heat Exchanger.
- Direct Material Cost = \$12,000; Direct Labor Cost = \$8,000; Factory Overheads = 60% of Direct Labor.
- Prime Cost = Direct Material + Direct Labor = \$12,000 + \$8,000 = \$20,000.
- Factory Cost = Prime Cost + Factory Overheads = \$20,000 + (0.60 * \$8,000) = \$24,800.
- Office Overheads = 20% of Factory Cost = 0.20 * \$24,800 = \$4,960. Office Cost = \$24,800 + \$4,960 = \$29,760.
- Selling Overheads = 10% of Office Cost = \$2,976. Total Cost = Office Cost + Selling Overheads = \$32,736.

Numerical Example: Pricing a Shell and Tube Heat Exchanger II

- If the manufacturer wants a 20% profit margin on the Selling Price: SP = Total Cost / (1 - 0.20) = $32,736 / 0.80 = $40,920. Desired Profit = $8,184.
- If a 15% trade discount is to be offered to the contractor: CP = SP / (1 - 0.15) = $40,920 / 0.85 = $48,141.18.

Summary & Key Takeaways I

- A clear distinction between Prime Cost, Factory Cost, Office Cost, and Total Cost is essential for accurate project estimation.
- Selling Price must account for all hidden overheads, including engineering design and administrative support.
- Catalogue prices must be strategically inflated to accommodate trade discounts while preserving the manufacturer's target selling price.
- Formulas to remember: SP = Total Cost + Profit; CP = SP / (1 - d); Markup = Margin / (1 - Margin).
- Homework: Calculate the catalogue price for a 50 kW steam turbine generator where Total Cost is $150,000, desired profit margin is 25%, and trade discount is 12%.

Agenda I

- Core Concepts of Asset Value Loss over Time
- Understanding Depreciation and Obsolescence in Engineering Systems
- Physical vs. Functional vs. Accidental Depreciation
- Factors Influencing Technical and Market Obsolescence
- Mathematical and Accounting Methods for Depreciation Calculation
- Straight Line Method (SLM) & Sinking Fund Method (SFM)
- Declining Balance Method (DBM) & Double Declining Balance Method (DDBM)
- Sum-of-the-Years'-Digits (SYD) & Service Output Methods
- Strategic Engineering Replacement and Maintenance Decisions

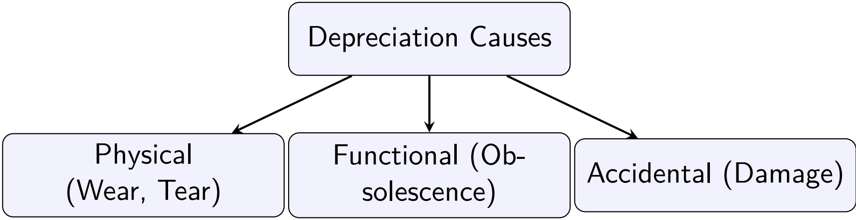
Introduction to Depreciation & Obsolescence I

- Depreciation is the continuous, gradual decrease in the utility and value of a physical engineering asset due to wear, tear, age, and decay.
- Obsolescence represents a sudden loss of value caused by external technological progress or market changes, rather than physical deterioration.
- Engineering economics relies on depreciation calculations to determine the true net cost of production and make informed capital replacement plans.
- Initial Cost (V0) represents the total capitalized cost of purchasing, transporting, and installing the plant machinery or equipment.
- Salvage Value (Vs) is the estimated market value of the asset at the end of its useful life, often equivalent to scrap value.

Introduction to Depreciation & Obsolescence II

- Useful Life (N) is the period over which the asset can be economically and safely operated for production purposes.

Classification of Depreciation Causes I



Detailed Types of Depreciation I

- Physical Depreciation: Caused by chemical action, mechanical friction, material fatigue, and environmental corrosion during operational cycles.
- Functional Depreciation: Occurs when an asset is physically intact but cannot meet production demands due to inadequacy or design limitations.
- Obsolescence (Technological): Driven by the emergence of superior, more energy-efficient, or highly automated alternative equipment.
- Obsolescence (Economic): Driven by structural shifts in market demand, new environmental laws, or safety regulations that render the output obsolete.
- Accidental Depreciation: Results from sudden, unpredictable failures or disasters (e.g., fires, floods, major mechanical wreckage) not covered by standard wear.

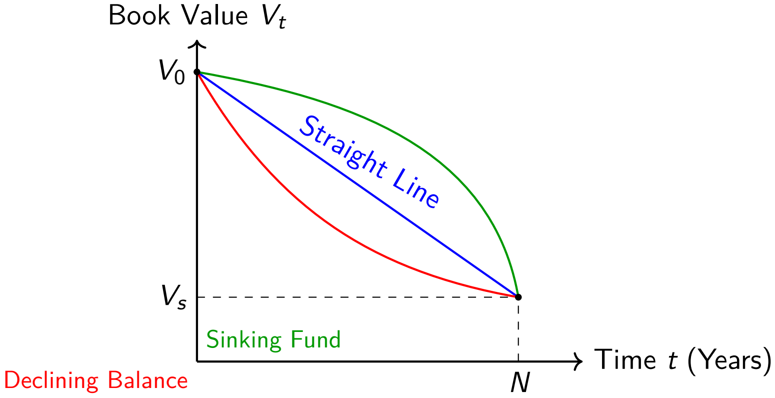
Industrial Impact of Obsolescence I

- A machine may be in peak physical condition but still suffer 100% obsolescence if its operating cost exceeds that of newer tech.
- Example: Mechanical pneumatic controllers replaced by digital PLC systems, drastically reducing plant operating expenses.
- Capacity-based inadequacy occurs when a plant expands and a machine becomes too small to handle the required throughput efficiently.
- Life Cycle Cost (LCC) analysis helps engineers decide whether to perform retrofitting/refurbishing or opt for complete asset replacement.
- Accounting for obsolescence prevents industries from retaining obsolete machinery that yields uncompetitive production costs.

Straight Line and Sinking Fund Methods I

- Straight Line Method (SLM): Assumes that the asset depreciates by a uniform amount every year throughout its useful life.
- SLM Annual Depreciation Formula: D = (V0 - Vs) / N. This is the simplest method but neglects the time value of money.
- Sinking Fund Method (SFM): Assumes that the depreciation fund is reinvested and accumulates compound interest at a rate 'i'.
- SFM Annual Depreciation Formula: D = (V0 - Vs) * [i / ((1 + i)^N - 1)]. Here, the annual deposit remains constant.
- Under SFM, the book value of the asset decreases slowly in the early years and faster as compound interest accumulates.

Visualizing Depreciation Trajectories I



Declining Balance and Double Declining Balance Methods I

- Declining Balance Method (DBM): Assumes the asset depreciates by a constant annual percentage 'k' of its remaining book value.
- DBM Annual Depreciation for year t: Dt = k * V_t-1. The book value at year t is given by Vt = V0 * (1 - k)^t.
- The DBM depreciation factor can be calculated directly using: k = 1 - (Vs / V0)^(1/N).
- Double Declining Balance Method (DDBM): An accelerated method where the depreciation rate is set to k = 2 / N.
- Under DDBM, salvage value is not used to calculate the annual rate, but the asset is never depreciated below its estimated salvage value.
- Accelerated depreciation methods are ideal for assets that lose utility rapidly or have high maintenance costs in later years.

Method Comparison and Engineering Decisions I

- Straight Line Method is preferred for simple assets with stable, predictable wear profiles (e.g., structures, pipelines).
- Accelerated methods (DBM, DDBM) write off costs quickly, matching high initial depreciation against high initial productivity.
- Sinking Fund Method is used in public utilities and heavy infrastructure, where capital is recouped along with interest returns.
- Sum-of-the-Years'-Digits (SYD) calculates depreciation using a decreasing fraction: Remaining Life / Sum of Year Digits.
- Selecting the correct depreciation method minimizes tax burdens, helps fund future equipment purchases, and ensures accurate plant costing.

Agenda I

- Definition of Depreciation and Obsolescence
- Key Differences Between Depreciation and Obsolescence
- Physical, Functional, and Technological Depreciation Types
- Methods of Calculating Depreciation: Straight Line Method
- Accelerated Depreciation: Declining Balance & Sum-of-the-Years'-Digits
- Sinking Fund Method and Engineering Economic Decision Analysis

Definition of Depreciation I

- Depreciation is the systematic reduction in the recorded cost of a physical asset over its useful life.
- It accounts for the consumption of the asset's economic benefits due to physical wear and tear, age, and decay.
- Engineering factors such as operating hours, corrosion, thermal fatigue, and maintenance quality directly affect the depreciation rate.
- Accounting purpose: Distributes the initial acquisition cost (P) minus salvage value (S) over the asset's useful life (N) for tax and replacement funding.

Concept of Obsolescence I

- Obsolescence refers to the loss in an asset's value due to external technological advancements or shifts in market demand.
- Unlike physical depreciation, obsolescence occurs even if the asset remains in perfect working condition.
- Example: Introduction of high-efficiency combined cycle gas turbines rendering standard coal units economically unviable.
- Key causes: Technological innovation, changing environmental or safety regulations, and permanent changes in production scale requirements.

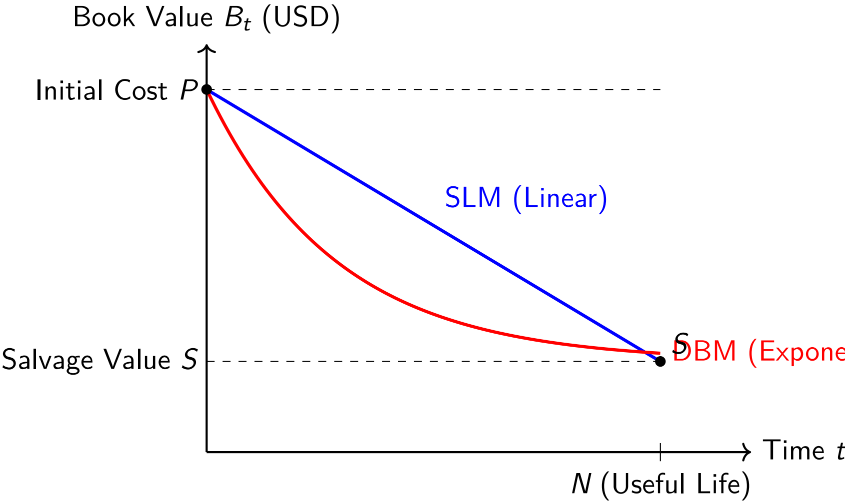
Types of Depreciation I

- Physical Depreciation: Direct deterioration of physical components due to operation (e.g., boiler tube erosion, pump cavitation).
- Functional Depreciation: Loss of usefulness because the asset cannot meet current capacity or product specification demands.
- Accidental / Contingent Depreciation: Sudden loss of value due to uninsurable accidents, natural events, or operational disasters.
- Technological Depreciation (Obsolescence): Value loss driven by new inventions that produce similar output at a lower operating cost.

Straight-Line and Declining Balance Methods I

- Straight-Line Method (SLM): Assumes uniform value loss. Annual Depreciation D = (P - S) / N.
- Book Value in year t: B_t = P - t * D. Simple, standard for buildings and pipelines.
- Declining Balance Method (DBM): Accelerated method. Depreciation in year t: D_t = d * B_t-1.
- Depreciation rate d is a constant fraction. For Double Declining Balance (DDBM), d = 2 / N.
- Book Value in year t: B_t = P * (1 - d)^t. Salvage value S is not subtracted initially but acts as a floor.

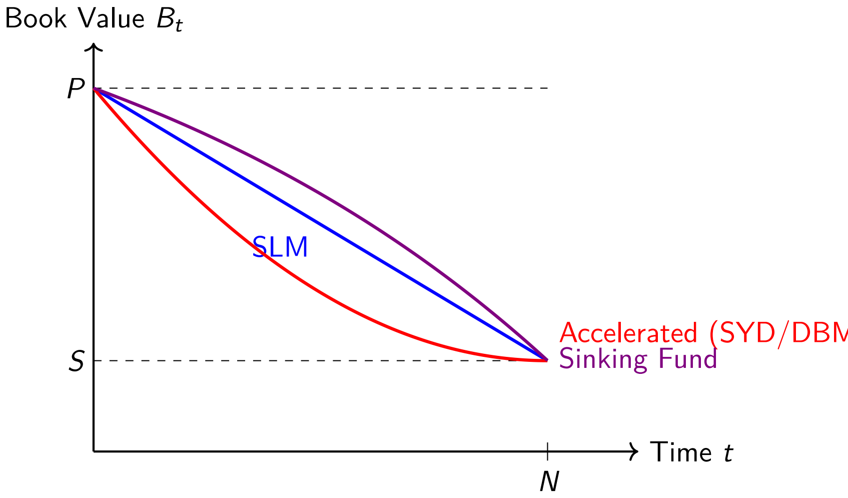
Book Value Decay Curve (SLM vs. DBM) I



Sum-of-the-Years'-Digits and Sinking Fund Methods I

- Sum-of-the-Years'-Digits (SYD): Accelerated depreciation based on remaining life fraction. Sum of digits S_D = N * (N + 1) / 2.
- Depreciation in year t: D_t = (N - t + 1) / S_D * (P - S). Book Value decreases faster in early years.
- Sinking Fund Method (SFM): Assumes depreciation fund accumulates interest. Annual uniform deposit A = (P - S) * [i / ((1 + i)^N - 1)].
- Depreciation increases annually as interest accumulates. D_t = A * (1 + i)^t-1.
- Book Value at year t: B_t = P - A * [((1 + i)^t - 1) / i]. Ideal for public utilities with dedicated replacement funds.

Comparison of Depreciation Profiles I



Engineering Decision-Making and Summary I

- Selecting a method depends on asset characteristics, tax laws, and cash flow preferences.
- Accelerated methods (DBM, SYD) reduce taxes in early years, offset high initial maintenance costs, and hedge against technological obsolescence.
- Sinking Fund Method (SFM) is economically sound but rarely used for tax purposes due to slow early write-offs.
- Engineering managers must evaluate the time value of money, regulatory frameworks (e.g., MACRS), and replacement cycles to maximize plant ROI.

Agenda I

- Closed System Boundary Work & Heat Transfer Calculations
- First Law Analysis of Steady-State Control Volumes (SSSF)
- Second Law Analysis: Carnot Cycles & Entropy Generation Rates
- Ideal Rankine Cycle Efficiency Calculations for Power Plants
- Vapor Compression Refrigeration Cycle Performance Analysis

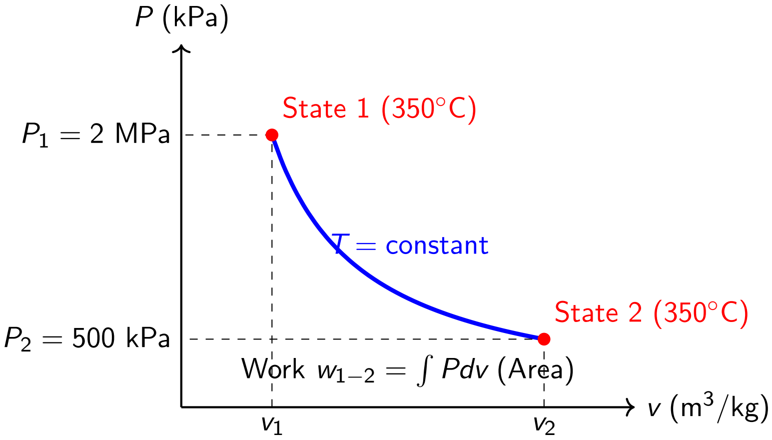
Closed System Boundary Work Calculation I

- Problem Statement: Air expands isothermally from 2 MPa and 350°C to 500 kPa in a piston-cylinder device.
- Goal: Calculate the boundary work done and heat transfer per unit mass (assuming air behaves as an ideal gas with R = 0.287 kJ/kg · K).
- Boundary Work Formula: $w = \int P dv$. Since PV = mRT is constant for isothermal process, $w = RT \ln(P_1/P_2)$.
- Temperature Conversion: T = 350 + 273.15 = 623.15 K.
- Work Calculation: $w = (0.287 \text{ kJ/kg} \cdot \text{K}) \times (623.15 \text{ K}) \times \ln(2000 \text{ kPa}/500 \text{ kPa}) =$ 247.93 kJ/kg.
- First Law of Thermodynamics: $q - w = \Delta u$. For an ideal gas undergoing isothermal process, internal energy change $\Delta u = c_v \Delta T = 0$.

Closed System Boundary Work Calculation II

- Result: Heat transfer q = w = 247.93 kJ/kg. The system requires 247.93 kJ/kg of heat input to maintain constant temperature during expansion.

P-v Diagram for Isothermal Process I



First Law Analysis: Steam Turbine I

- Problem Statement: Steam enters an adiabatic turbine at 10 MPa, 450°C, and 80 m/s, and exits at 10 kPa with 92% quality and 50 m/s.
- Goal: Calculate the work output per unit mass, and determine the power output for a mass flow rate of 12 kg/s.
- Steam Table Lookup: Inlet enthalpy h_1 = 3242.4 kJ/kg. Saturated mixture exit enthalpies: h_f = 191.81 kJ/kg, h_fg = 2392.1 kJ/kg.
- Exit Enthalpy Calculation: h_2 = h_f + x_2 * h_fg = 191.81 + 0.92 * 2392.1 = 2392.5 kJ/kg.
- Kinetic Energy Change: $\Delta ke = (V_2^2 - V_1^2)/2000 = (50^2 - 80^2)/2000 = -1.95$ kJ/kg.
- Energy Balance: $w_{out} = -(h_2 - h_1 + \Delta ke) = -(2392.5 - 3242.4 - 1.95) = 847.95$ kJ/kg.

First Law Analysis: Steam Turbine II

- Power Output Calculation: $\dot{W}_{out} = \dot{m} * w_{out} = 12 \text{ kg/s} * 847.95 \text{ kJ/kg} = 10,175.4 \text{ kW} = 10.18 \text{ MW}$.

Carnot Engine & Entropy Generation I

- Problem Statement: A heat engine operates between a thermal reservoir at 1000 K and a low-temperature sink at 300 K. It produces 400 kJ of work while absorbing 1000 kJ of heat.
- Goal: Determine the thermal efficiency, compare it with the maximum theoretical Carnot efficiency, and calculate the entropy generated.
- Thermal Efficiency: $\eta_{th} = W_{net}/Q_H = 400 \text{ kJ}/1000 \text{ kJ} = 40\%$.
- Carnot (Maximum) Efficiency: $\eta_{max} = 1 - T_L/T_H = 1 - 300/1000 = 70\%$. Since $\eta_{th} < \eta_{max}$, the engine is physically possible.
- Heat Rejected Calculation: Q_L = Q_H - W_net = 1000 - 400 = 600 kJ.
- Entropy Generation (ΔS_{gen}): $\Delta S_{gen} = \Delta S_{sys} + \Delta S_{surr} = 0 + (Q_L/T_L - Q_H/T_H)$.

Carnot Engine & Entropy Generation II

- Calculation: $\Delta S_{gen} = (600\text{ kJ}/300\text{ K}) - (1000\text{ kJ}/1000\text{ K}) = 2.0 - 1.0 = 1.0\text{ kJ/K}$. Since $\Delta S_{gen} > 0$, the engine is irreversible but possible.

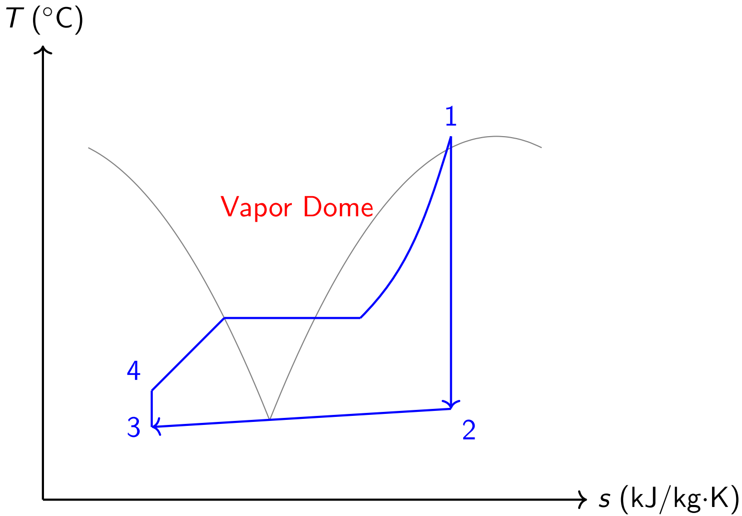
Ideal Rankine Cycle Analysis I

- Problem Statement: A steam power plant operates on the ideal Rankine cycle. Steam enters the turbine at 3 MPa, 350°C and condenses at 75 kPa.
- Goal: Calculate the thermal efficiency of the cycle.
- State 1 (Turbine Inlet): $P_1 = 3$ MPa, $T_1 = 350$°C -> $h_1 = 3116.1$ kJ/kg, $s_1 = 6.7450$ kJ/kg · K.
- State 2 (Condenser Inlet): $s_2 = s_1 = 6.7450$. Quality $x_2 = (6.7450 - 1.2132) / 6.2426 = 0.886$. Enthalpy $h_2 = h_f + x_2 * h_{fg} = 384.44 + 0.886 * 2278.0 = 2402.7$ kJ/kg.
- State 3 (Pump Inlet): Saturated liquid at 75 kPa -> $h_3 = 384.44$ kJ/kg, specific volume $v_3 = 0.001037$ m^3/kg.
- Pump Work & State 4: $w_{pump} = v_3(P_4 - P_3) = 0.001037 * (3000 - 75) = 3.03$ kJ/kg. Enthalpy $h_4 = h_3 + w_{pump} = 387.47$ kJ/kg.

Ideal Rankine Cycle Analysis II

- Thermal Efficiency:
  $\eta_{th} = (w_{turb} - w_{pump})/q_{in} = [(h_1 - h_2) - w_{pump}]/(h_1 - h_4) = [713.4 - 3.03]/2728.6 = 26.0\%$.

T-s Diagram of the Ideal Rankine Cycle I



Vapor Compression Refrigeration Cycle I

- Problem Statement: An ideal vapor-compression refrigeration cycle operates with R-134a as the refrigerant between evaporator pressure of 0.14 MPa and condenser pressure of 0.8 MPa. The mass flow rate is 0.05 kg/s.
- Goal: Calculate the cooling capacity, compressor power input, and coefficient of performance (COP).
- State 1 (Evaporator Exit): Saturated vapor at 0.14 MPa -> $h_1 = h_g = 239.16$ kJ/kg, $s_1 = 0.94467$ kJ/kg $\cdot$ K.
- State 2 (Compressor Exit): Superheated vapor at 0.8 MPa, $s_2 = s_1 = 0.94467$ kJ/kg $\cdot$ K -> $h_2 = 275.40$ kJ/kg.
- State 3 (Condenser Exit): Saturated liquid at 0.8 MPa -> $h_3 = h_f = 95.47$ kJ/kg.
- State 4 (Throttling Valve Exit): Isenthalpic expansion -> $h_4 = h_3 = 95.47$ kJ/kg.

- Calculations: Cooling capacity $\dot{Q}_L = \dot{m}(h_1 - h_4) = 0.05 * (239.16 - 95.47) = 7.18$ kW. Power input $\dot{W}_{in} = \dot{m}(h_2 - h_1) = 0.05 * (275.40 - 239.16) = 1.81$ kW. $extCOP = \dot{Q}_L / \dot{W}_{in} = 3.97$.

Thermodynamics Problem Solving Checklist I

- Define the System Boundary: Categorize as Closed System (mass is constant) or Control Volume (steady flow mass rate).
- Identify Key States: Determine independent properties (e.g., pressure, temperature, quality) to retrieve parameters from steam/refrigerant tables.
- Apply Mass and Energy Balances: Always start with the general form of the First Law and eliminate terms logically (adiabatic, negligible kinetic energy, etc.).
- Enforce Second Law Limitations: Verify that thermal efficiency does not exceed the Carnot limit and check that entropy generation is positive ($\Delta S_{gen} \geq 0$).
- Units Check: Ensure pressures are converted to kPa when working with specific volumes to yield output values in kJ/kg.

Agenda I

- Introduction to Engineering Costing in Plant Operations
- Concept of Fixed Costs (FC) and standard examples
- Concept of Variable Costs (VC) and engineering drivers
- Semi-Variable and Step Costs in industrial setups
- Mathematical relationship between Total Cost (TC) and Quantity of Production (Q)
- Marginal Costing and average cost behaviors
- Break-Even Analysis and Cost-Volume-Profit (CVP) diagram
- Unit Cost Dynamics vs. Production Scale
- Practical applications in Plant Maintenance and Operations

Introduction to Cost Classification I

- Cost classification is the process of grouping costs according to their common characteristics to aid managerial decision-making.
- In engineering plant operations, costs are analyzed to optimize production quantity and maintenance schedules.
- The behavior of costs in response to changes in the volume of activity (quantity of production, Q) is critical for budgeting and pricing.
- Costs can be classified by behavior: Fixed Costs (FC), Variable Costs (VC), and Semi-variable/Mixed Costs.
- Understanding these behaviors allows engineers to calculate break-even points, execute cost-benefit analysis, and optimize plant capacity utilization.

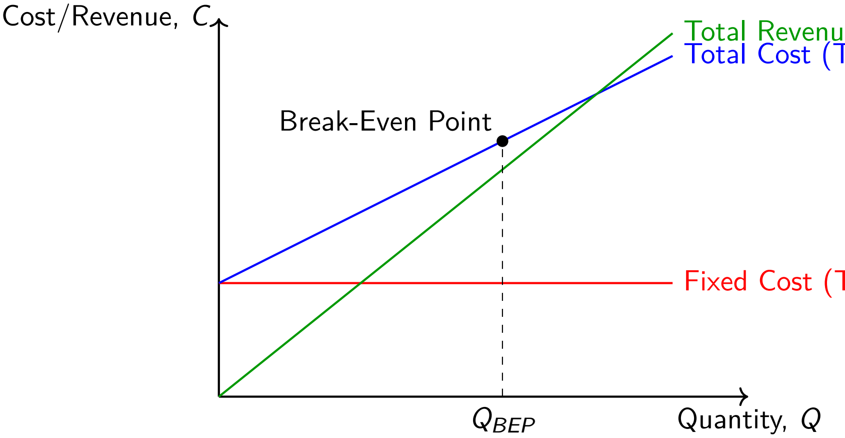
Fixed Costs (FC) in Engineering I

- Fixed costs are costs that remain constant in total amount over a defined period, regardless of the quantity of production (Q) within a relevant range.
- Key engineering examples: Depreciation of machinery (using straight-line method), factory building rent, salaries of permanent plant engineers, property taxes, and insurance.
- Formula: Total Fixed Cost (TFC) = Constant.
- Unit Fixed Cost behavior: Average Fixed Cost per unit (AFC = TFC / Q) decreases asymptotically as production volume (Q) increases.
- This dilution of fixed costs per unit is known as 'spreading overheads' and is a primary driver of economies of scale.

Variable Costs (VC) in Production I

- Variable costs are costs that vary in direct proportion to changes in the quantity of production (Q).
- Key engineering examples: Direct raw materials, direct labor wages (hourly workers), electrical power consumed by production machinery, and packaging materials.
- Formula: Total Variable Cost (TVC) = Unit Variable Cost (UVC) * Q, where UVC is assumed constant in the short run.
- Unit Variable Cost behavior: Average Variable Cost per unit (AVC = TVC / Q = UVC) remains constant regardless of the production quantity.
- In real systems, non-linearities can occur due to bulk discounts on raw materials (degressive variable costs) or overtime labor premiums (progressive variable costs).

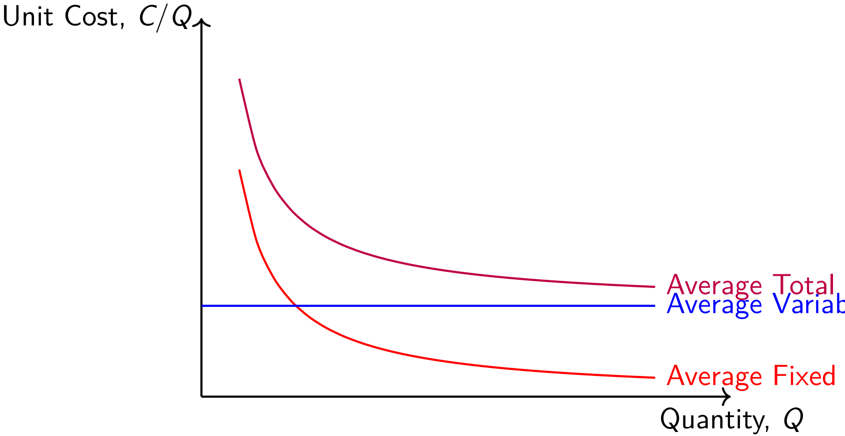
Cost-Volume-Profit (CVP) Relationship Diagram I



Semi-Variable and Step Costs I

- Semi-variable costs (mixed costs) contain both a fixed and a variable component.
- Example: Utilities (electricity bills with a fixed connection charge plus a charge per kilowatt-hour consumed), telephone plans.
- Step costs are constant over a specific range of production but increase by a discrete jump once capacity limits are exceeded.
- Example: Hiring an additional supervisor for a new production shift, adding another boiler or generator unit to meet high load requirements.
- Formula for mixed costs: $Y = a + b*X$, where Y is total cost, a is fixed cost, b is unit variable cost, and X is activity level (Q).
- High-Low Method: An engineering-accounting tool to separate fixed and variable components from historical mixed cost data.

Unit Cost Behavior vs. Quantity of Production I



Mathematical Models of Cost Functions I

- Linear Cost Model: TC(Q) = TFC + (UVC * Q), where UVC is constant. This is standard in short-run breakeven analysis.
- Non-linear Cost Model: TC(Q) = a + b*Q - c*Q^2 + d*Q^3. This model captures diminishing returns and cubic cost behaviors.
- Marginal Cost (MC): The change in total cost resulting from producing one additional unit, MC = d(TC)/dQ.
- For a linear model, Marginal Cost is constant and equal to the Unit Variable Cost (MC = UVC).
- For non-linear models, MC is the slope of the TC curve and intersects ATC and AVC at their minimum points.

Engineering Decision Making and Summary I

- Plant maintenance managers use cost classification to make 'Make or Buy' decisions for spare parts and servicing.
- Operating below the break-even quantity (Q_BEP) leads to financial losses, requiring capacity optimization or cost reduction.
- Fixed costs must be controlled during plant shutdowns, while variable costs must be minimized during peak production cycles.
- Economies of scale are realized by maximizing Q to minimize the average fixed cost component per unit.
- Understanding the relationship between production volume and costs is fundamental to plant feasibility studies and life-cycle costing.

Agenda I

- Introduction to Cost Classifications in Engineering Systems
- Concept and Behavior of Fixed Costs (FC)
- Concept and Behavior of Variable Costs (VC)
- Diagrammatic Representation of Total Cost Components
- Semi-Variable and Step Costs in Manufacturing
- Mathematical Relationships: Cost vs. Production Quantity (Q)
- Diagrammatic Representation of Unit Cost Curves (ATC, AFC, AVC)
- Application to Thermodynamic Power Plant Operations & Maintenance
- Managerial Decisions and Economies of Scale
- Summary and Preview of the Break-Even Point (BEP)

Concept and Behavior of Fixed Costs (FC) I

- Fixed costs are expenditures that remain constant in total amount regardless of variations in the level of production or output volume (Q) within a relevant capacity range.
- Key attribute: These costs are time-dependent (incurred periodically) rather than directly driven by production activity.
- Engineering examples: Depreciation of power plant machinery (computed via straight-line or MACRS methods), licensing fees, plant facility lease, property taxes, and salaries of supervisory staff.
- Unit cost behavior: As the quantity of production (Q) increases, the average fixed cost per unit ($AFC = FC/Q$) decreases hyperbolically, leading to the phenomenon of spreading the overhead.

Concept and Behavior of Fixed Costs (FC) II

- Capacity constraint: Fixed costs are only static within a 'relevant range'. If production capacity must be expanded, fixed costs will step up to a new baseline level.

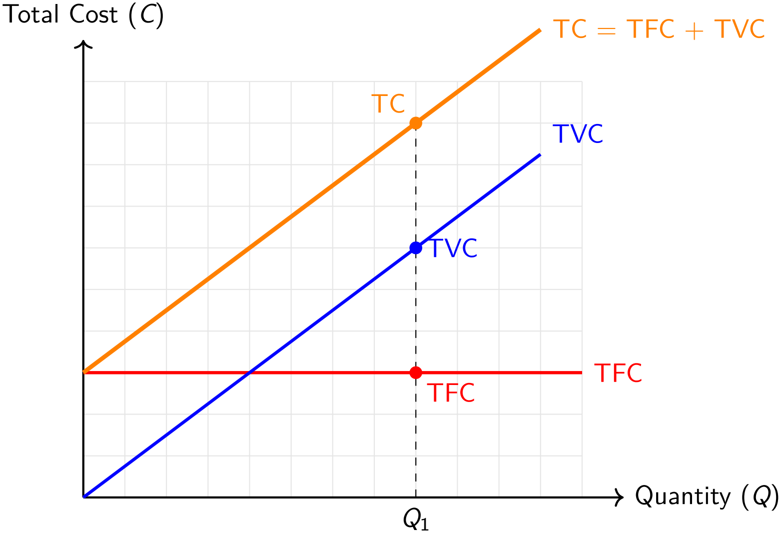
Concept and Behavior of Variable Costs (VC) I

- Variable costs are operational expenses that vary in direct proportion to the volume or quantity of production (Q) of the engineering plant.
- Key attribute: They are activity-dependent; if production is completely halted ($Q = 0$), total variable cost is zero. Total variable cost is represented as $TVC = v \cdot Q$.
- Engineering examples: Raw material costs (coal/gas for power plants, process water, working fluids), direct hourly labor wages, packaging materials, and electrical utilities consumed during machinery operation.
- Unit cost behavior: The average variable cost per unit ($AVC = v$) is theoretically constant within the relevant operating range.

Concept and Behavior of Variable Costs (VC) II

- Real-world deviations: In practical systems, the unit variable cost may experience slight non-linearities due to bulk raw material discounts or machinery efficiency variation at off-design conditions.

Diagram: Breakdown of Total Cost Components I



Semi-Variable and Step-Variable Costs I

- Semi-Variable (Mixed) Costs: Consist of both a fixed component and a variable component. The total cost changes with output, but not in a direct 1:1 proportion.
- Example: Plant electricity utility. There is a fixed charge for maintaining service connection and a variable charge based on active kilowatt-hours consumed.
- Step-Variable Costs: Remain constant over a narrow range of production output, then jump to a higher level once capacity limits are exceeded.
- Example: Supervisory labor. A single plant supervisor can manage up to 12 operators. Adding the 13th operator requires hiring a second supervisor, causing a step increase in supervisory cost.

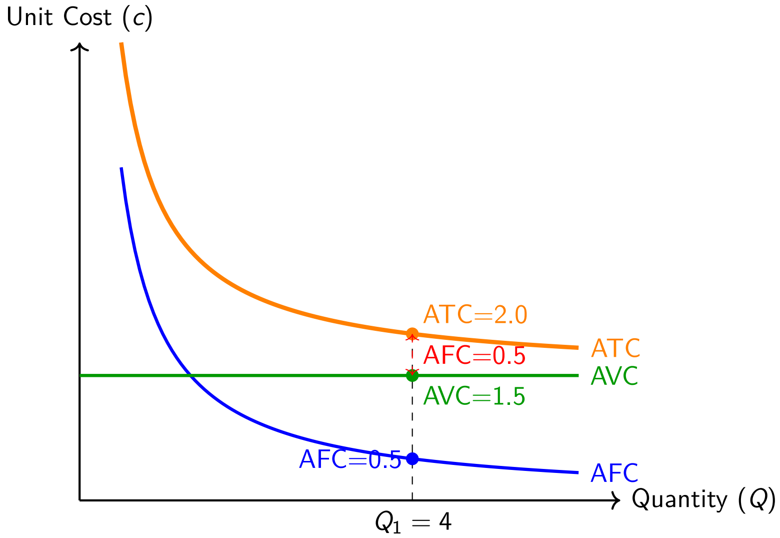
Semi-Variable and Step-Variable Costs II

- Decomposition techniques: The High-Low method and least-squares linear regression are standard engineering tools used to separate mixed costs into pure fixed and variable elements.

Mathematical Relationship: Cost vs. Quantity of Production I

- Total Cost Equation: $TC(Q) = TFC + TVC(Q) = FC + (v \cdot Q)$, where FC is the total fixed cost and v is the unit variable cost.
- Average Total Cost (ATC): The unit cost of production. $ATC(Q) = \frac{TC(Q)}{Q} = \frac{FC}{Q} + v = AFC(Q) + AVC$.
- Average Fixed Cost ($AFC(Q) = FC/Q$): Exhibits a hyperbolic decrease as production volume (Q) increases, driving the financial incentive for maximizing plant capacity factor.
- Average Variable Cost ($AVC(Q)$): Equals the unit variable cost v under linear assumptions.
- Marginal Cost (MC): The increment in total cost resulting from producing one additional unit, mathematically defined as $MC = \frac{d(TC)}{dQ} = v$.

Diagram: Unit Cost Behavior (ATC, AFC, AVC) I



Cost-Volume Relationships in Plant Maintenance I

- Maintenance classification is crucial: Plant maintenance costs exhibit both fixed and variable features depending on the maintenance scheme.
- Fixed maintenance costs: Salaries of the permanent maintenance engineering team, annual servicing contracts for steam turbines, and periodic inspections.
- Variable maintenance costs: Consumable materials (lubricants, seals, replacement filters) and utility power consumed during repair operations.
- Wear-and-tear correlation: Higher production rates (Q) lead to greater mechanical and thermal stress, accelerating component fatigue and increasing variable maintenance frequency.

Cost-Volume Relationships in Plant Maintenance II

- Optimizing cost trade-offs: Engineering managers must determine the optimal frequency of preventive maintenance (fixed overhead) to minimize downtime losses (variable operational costs).

Summary and Break-Even Point Preview I

- Classification is fundamental: Separating expenditures into fixed and variable categories is essential for plant design, operating budget forecasting, and pricing models.
- Fixed costs (FC) are static in total but decrease per unit (AFC) as production volume (Q) increases, highlighting the benefits of economies of scale.
- Variable costs (VC) scale proportionally with total output volume (Q) but remain constant per unit (v) within the relevant range.
- Total Cost (TC) model: Serves as the mathematical backbone for industrial engineering decision-making, where $TC = FC + v \cdot Q$.
- Preview of Break-Even Point (BEP): The volume where total revenue equals total cost, calculated as $Q_{\text{BEP}} = FC/(p - v)$, which is the subject of the next lecture.

Lecture Agenda I

- Fixed and Variable Cost Structures
- Mathematical Formulation of BEP
- Graphical BEP Representation
- The Concept of Margin of Safety
- Need of BEP in Equipment Selection
- Product Planning & Pricing Strategy
- Sensitivity Analysis: BEP under Changing Conditions
- Practical Limitations of BEP Analysis
- Interplay between BEP and Plant Maintenance
- Summary and Engineering Takeaways

Fixed vs. Variable Costs in Engineering Costing I

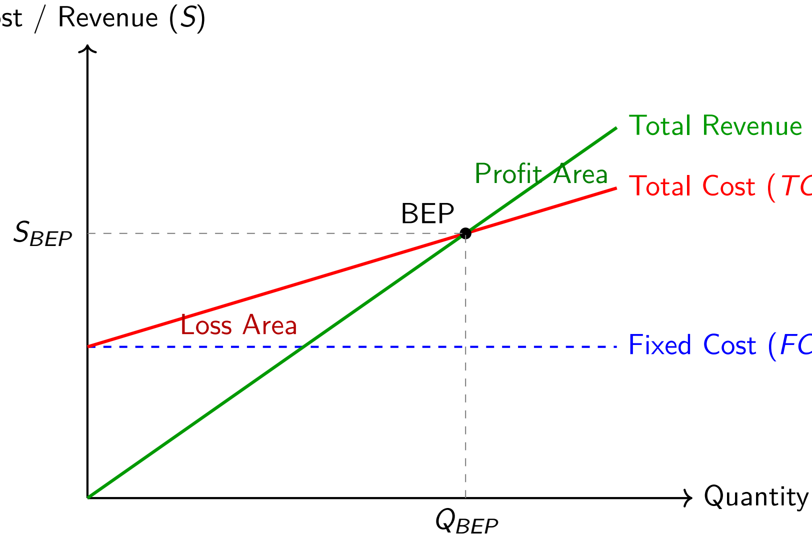
- Fixed Costs (FC): Capital-intensive expenses that do not vary with production quantity (e.g., machinery depreciation, building lease, salaries of permanent engineers, plant insurance).
- Variable Costs (VC): Operational expenses directly proportional to output volume (e.g., raw material consumption, electrical power for manufacturing units, direct hourly labor, consumable tooling).
- Semi-Variable Costs: Costs containing both static and dynamic components (e.g., utility bills with base connection charges plus usage rates).
- Total Cost Equation: $TC = FC + (UVC * Q)$, where UVC is Unit Variable Cost and Q is the production quantity.

Mathematical Derivation of Break-Even Point (BEP) I

- Break-Even Condition: The operational state where Total Revenue (TR) equals Total Cost (TC). Net profit or loss equals exactly zero.
- Revenue Equation: TR = P * Q, where P is the unit selling price and Q is the volume sold.
- BEP (Units): Derived by setting TR = TC, yielding Q_BEP = FC / (P - UVC), where (P - UVC) is defined as the Unit Contribution Margin.
- PV Ratio: Profit-Volume Ratio, calculated as (P - UVC) / P, representing the fraction of sales revenue contributing to covering fixed costs.
- BEP (Sales Value): Calculated as FC / PV_Ratio, determining the minimum sales revenue required to avoid operating losses.

Graphical Representation of BEP I

Graphical Representation of BEP II



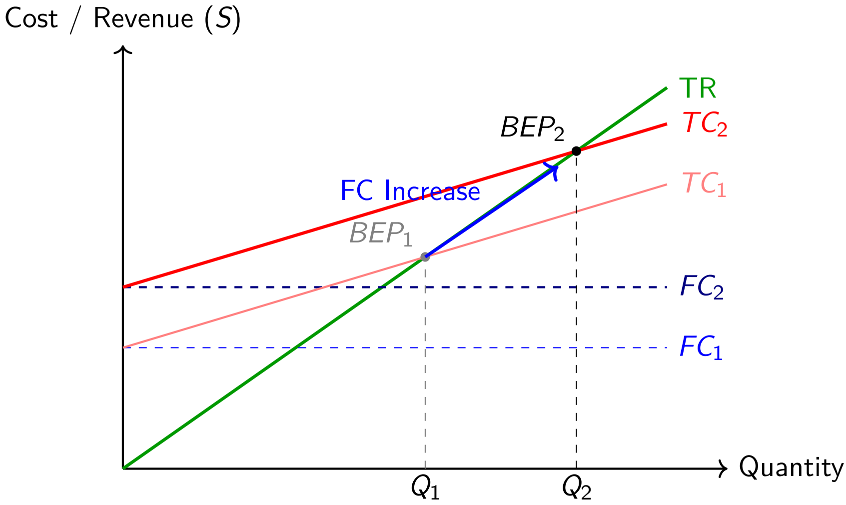
The Concept of Margin of Safety (MoS) I

- Margin of Safety (MoS): The excess of actual or budgeted sales volume over the break-even sales volume.
- Operational Buffer: Indicates how much sales can drop before the manufacturing plant begins to operate at a loss.
- MoS Equation (Units): MoS = Q_Actual - Q_BEP, showing the physical safety margin in manufactured units.
- MoS Equation (Percentage): MoS (%) = [(Sales_Actual - Sales_BEP) / Sales_Actual] * 100.
- Risk Mitigation: A higher MoS percentage signals a resilient plant operation capable of withstanding market volatility and downtime.

Industrial Needs for Break-Even Analysis I

- Product Planning & Viability: Assessing if a proposed engineering design can be commercialized profitably at anticipated production scales.
- Equipment and Technology Selection: Deciding between low-fixed/high-variable cost methods (manual) and high-fixed/low-variable cost systems (automation).
- Make-or-Buy Decisions: Comparing internal manufacturing costs against external supplier quotes using break-even thresholds.
- Pricing Optimization: Simulating how price reductions, volume expansions, or marketing campaigns impact overall corporate profitability.
- Budgetary Target Setting: Establishing clear minimum production quotas for plant floor supervisors and operations managers.

BEP Sensitivity: Impact of Fixed Cost Changes I



Key Engineering Limitations of BEP Analysis I

- Linearity Assumption: Assumes unit price and unit variable cost are constant, ignoring quantity discounts, learning curves, and step-variable costs.
- Static Nature: Reflects a single point in time, failing to capture fast-moving dynamic market trends or macroeconomic shifts.
- Production-Sales Equivalence: Assumes all items produced are sold immediately, ignoring inventory carrying costs and supply-chain delays.
- Multi-Product Complexities: Direct allocation of shared fixed costs (e.g., building heat, management salaries) across multiple product lines is difficult and arbitrary.
- Cost Division Subjectivity: Hard to strictly classify complex industrial costs as purely fixed or purely variable.

BEP Interplay with Plant Maintenance Strategies I

- Preventive Maintenance (PM): PM increases fixed overheads (dedicated technicians, diagnostic software) but decreases variable unit costs by optimizing machinery efficiency.
- Corrective Maintenance (CM): High CM rates lead to unpredictable variable costs (emergency repairs, scrap materials) and raise the operational BEP.
- Plant Utilization Pressures: A high BEP forces the plant to run continuously, compressing the time windows available for scheduled maintenance.
- Modernization Justification: BEP analysis helps plant engineers prove that investing in reliable machinery (higher FC) will reduce variable costs enough to lower the overall BEP.

Agenda I

- Fundamentals of Cost Classification: Fixed vs. Variable Costs
- Definition & Mathematical Formulation of Break-Even Point (BEP)
- Graphical Representation of BEP (The Break-Even Chart)
- Margin of Safety (MoS) and Angle of Incidence
- Economic Interpretation of BEP in Decision Making
- Industrial Applications: Manual vs. Automated Systems Crossover
- Plant Maintenance Applications: Repair vs. Replace Decisions
- Limitations and Sensitivity Analysis of BEP in Real-World Operations

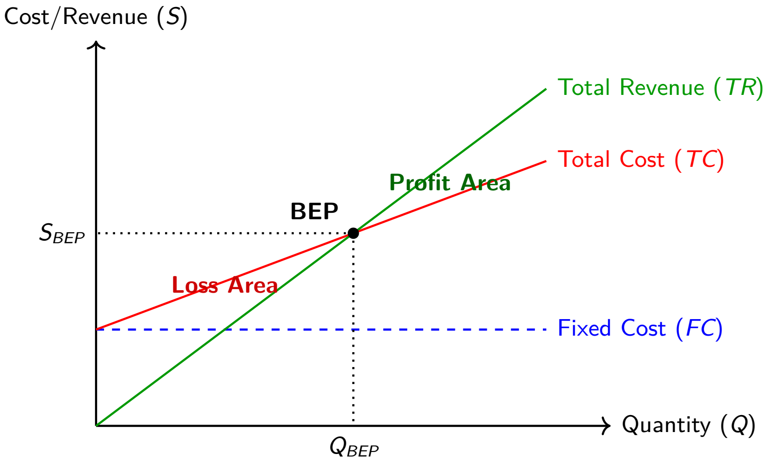
Core Cost Components in Engineering Production I

- Fixed Costs (FC): Expenses that remain constant regardless of production volume within a relevant range (e.g., rent, depreciation, administrative salaries, insurance).
- Variable Costs (VC): Expenses that vary directly in proportion to the level of production output (e.g., raw materials, direct labor, production utilities).
- Total Cost (TC): The sum of Fixed Costs and Total Variable Costs: $TC = FC + (VC\_unit * Q)$, where Q is the quantity of units produced.
- Semi-Variable Costs: Costs containing both fixed and variable elements (e.g., maintenance costs with a basic monthly fee plus hourly service charges) that require step-cost modeling.

Mathematical Derivation of Break-Even Point I

- Definition: The Break-Even Point is the level of production/sales where Total Revenue (TR) equals Total Cost (TC), resulting in zero profit and zero loss.
- Total Revenue Equation: TR = P * Q, where P is the unit selling price and Q is the production/sales quantity.
- Total Cost Equation: TC = FC + (V * Q), where V is the unit variable cost.
- At BEP: TR = TC => P * Q_BEP = FC + V * Q_BEP
- BEP in Units: Q_BEP = FC / (P - V). The term (P - V) is called the Unit Contribution Margin (UCM).
- BEP in Sales Value: S_BEP = FC / PV_Ratio, where PV_Ratio (Profit-Volume Ratio) = (P - V) / P.

Graphical Representation: The Break-Even Chart I

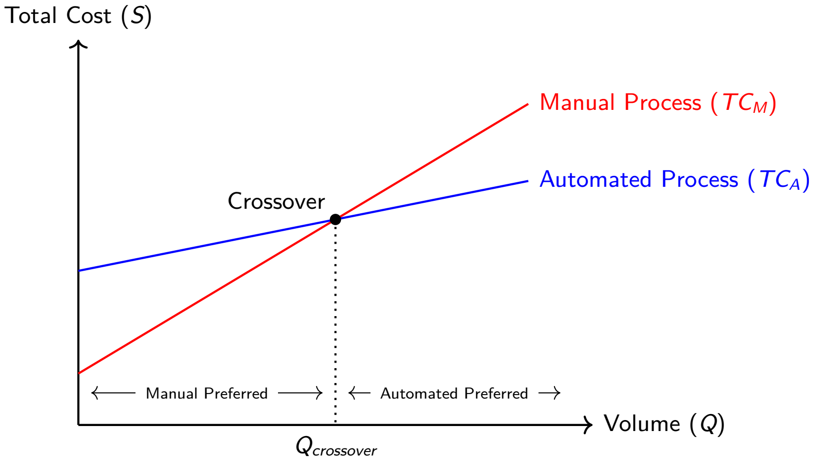


Margin of Safety and Angle of Incidence I

- Margin of Safety (MoS): The difference between the actual or projected sales volume and the break-even sales volume: MoS = Q_Actual - Q_BEP.
- Significance of MoS: Indicates the strength of the business. A high MoS means the company can withstand a significant drop in sales before incurring a loss.
- Angle of Incidence: The angle between the Total Revenue line and the Total Cost line at the Break-Even Point.
- Significance of Angle of Incidence: A large angle indicates a high rate of profit generation once the break-even point is passed, while a small angle indicates slow profit growth and higher operational risk.
- Industrial Strategy: Companies strive to maximize both MoS and the Angle of Incidence by reducing fixed costs, lowering variable costs, or optimizing product prices.

Industrial Significance & Needs of BEP Analysis I

- Pricing Decisions: Helps determine the minimum selling price of a product to avoid losses and evaluate the feasibility of discount offers.
- Sales Volume Target Setting: Provides the exact sales volume needed to achieve a target profit: Q_Target = (FC + Profit_Target) / (P - V).
- Expansion and Investment Feasibility: Used to assess if new product lines or plant expansions can generate enough sales to cover their incremental fixed costs.
- Cost Control & Budgeting: Highlights the impact of changes in cost structures (e.g., raw material price hikes or rent changes) on corporate profitability.
- Risk Assessment: Enables sensitivity analysis ('what-if' scenarios) to evaluate business vulnerability to economic downturns.


Total Cost (S)
Manual Process (TC_M)
Automated Process (TC_A)
Crossover
Manual Preferred
Automated Preferred
Volume (Q)
$Q_{crossover}$

BEP in Plant Maintenance Decisions I

- Repair vs. Replacement Decision: When a machine breaks down or deteriorates, maintenance engineers use cost crossover analysis to decide whether to repair or replace it.
- Repair Cost Structure: Typically involves low initial cost (fixed component) but high operating/maintenance costs (variable component, e.g., parts and downtime).
- Replacement Cost Structure: Involves high capital expenditure (high fixed cost) but significantly lower operating/maintenance costs (low variable cost).
- Break-Even Running Hours: The threshold operating hours where the total cost of keeping the repaired machine equals the total cost of purchasing and running the new machine.
- Predictive Maintenance Scheduling: Using break-even models to time maintenance cycles such that the maintenance cost is justified by the savings in production downtime.

Limitations of BEP Analysis and Summary I

- Assumption of Constant Prices: BEP assumes selling price and variable cost per unit remain constant, ignoring bulk discounts or economies of scale.
- Linear Cost-Revenue Assumption: Real-world cost and revenue functions are often non-linear due to worker efficiency gains or market supply-demand curves.
- Static Nature: BEP is a static tool that represents a snapshot in time; it does not account for time value of money (inflation or interest rates).
- Summary: Despite these limitations, BEP analysis is an essential tool for managers and engineers to understand risk, justify automation, and schedule maintenance.
- Key Formula Reference: Q_BEP = Fixed Cost / Contribution Margin; Margin of Safety (MoS) = Actual Sales - BEP Sales.

Agenda I

- Introduction to Break-Even Analysis in Engineering Economics
- Core Assumptions in Constructing a Break-Even Chart
- Step-by-Step Procedure for Graphical Construction
- Visualizing the Break-Even Chart (TikZ Diagram)
- Analytical Calculation of Break-Even Point (BEP)
- Mathematical Derivation of BEP and Margin of Safety
- Graphical Determination and Key Chart Features (TikZ Diagram)
- Engineering Thermodynamics Context: Costing in Thermal Plants
- Limitations and Practical Applications of Break-Even Charts

Introduction to Break-Even Analysis I

- Break-even analysis is a critical tool in Engineering Costing used to determine the activity level where total revenue equals total cost.
- At the Break-Even Point (BEP), the engineering venture or plant operates with zero profit and zero loss.
- Fixed Costs (FC): Expenses that remain constant regardless of production volume (e.g., land, building rent, salaries of permanent staff, depreciation of machinery).
- Variable Costs (VC): Expenses that vary directly in proportion to the volume of production (e.g., raw materials, direct labor, fuel, power, utility consumption).
- Total Cost (TC) is the sum of Fixed Cost and Variable Cost: $TC = FC + VC$.
- Total Revenue (TR) is the total sales value generated: TR = Price per unit (p) * Quantity sold (q).

Assumptions Made in Break-Even Charts I

- Linearity of Costs: All costs (fixed and variable) can be separated and behave in a linear manner over the relevant range of production.
- Constant Selling Price: The selling price per unit remains constant regardless of the volume of sales or market fluctuations.
- Constant Variable Cost: Variable cost per unit remains constant, meaning total variable cost changes in direct proportion to output.
- Stable Fixed Costs: Total fixed costs remain completely unchanged across the entire range of output being analyzed.
- Single Product or Constant Sales Mix: The organization sells a single product, or if multiple products are sold, the proportion (sales mix) remains constant.

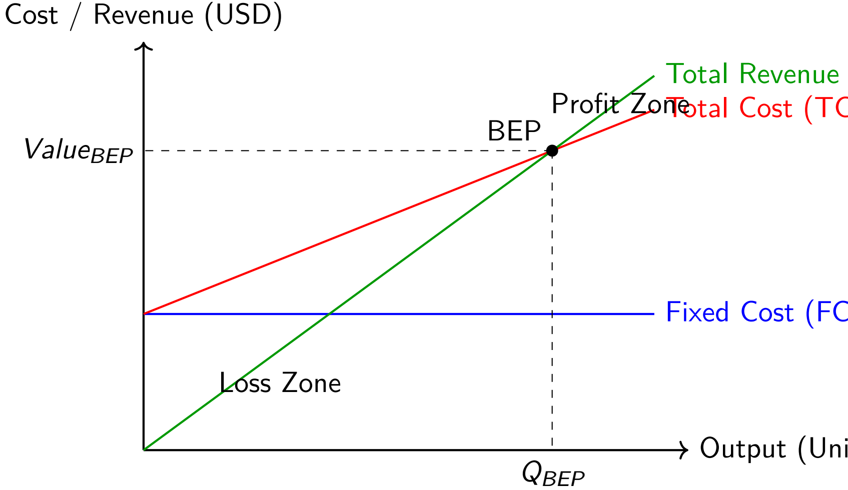
Assumptions Made in Break-Even Charts II

- Inventory Levels: Production and sales volumes are equal, meaning there is no change in opening and closing inventory levels.

Procedure of Construction of Break-Even Chart I

- Step 1: Set up the axes. Plot the volume of production (units) or capacity utilization (%) on the horizontal X-axis.
- Step 2: Plot the costs and revenues (in monetary value, e.g., USD or local currency) on the vertical Y-axis.
- Step 3: Draw the Fixed Cost (FC) line. This is a horizontal line parallel to the X-axis starting from the Y-axis value equal to FC.
- Step 4: Draw the Total Cost (TC) line. This line starts from the intersection of the FC line on the Y-axis and slopes upwards, with a slope equal to the unit variable cost (v).
- Step 5: Draw the Total Revenue (TR) line. This line starts from the origin (0,0) and slopes upwards, with a slope equal to the unit selling price (p).
- Step 6: Identify the intersection. The point where the TR line and TC line intersect is the Break-Even Point (BEP).

Graphical Layout of Break-Even Chart I

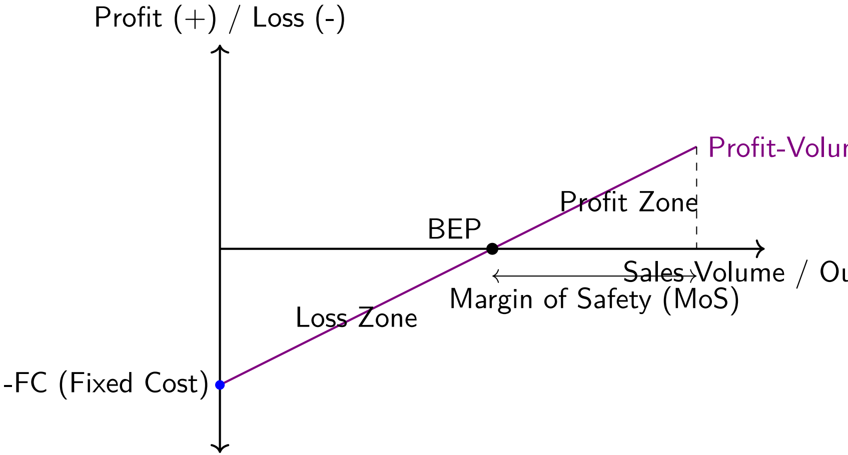


Analytical Calculation of BEP I

- The Break-Even Point can be calculated mathematically in terms of units or monetary value.
- Let: p = selling price per unit, v = variable cost per unit, F = total fixed cost, Q = quantity produced and sold.
- Total Revenue (TR) = p * Q
- Total Cost (TC) = F + (v * Q)
- At BEP: TR = TC => p * Q = F + v * Q => Q * (p - v) = F
- Break-Even Quantity (Q_{BEP}): $Q_{BEP} = \frac{F}{p-v}$ units.
- The term (p - v) is called the Contribution Margin per Unit (CM), which contributes towards recovering fixed costs.
- Break-Even Sales Value (S_{BEP}): $S_{BEP} = Q_{BEP} * p = \frac{F*p}{p-v} = \frac{F}{1-\frac{v}{p}} = \frac{F}{P/V\,\text{Ratio}}$.
- P/V Ratio (Profit-Volume Ratio) is the ratio of contribution to sales: $\frac{p-v}{p}$.

Key Parameters: Margin of Safety and Angle of Incidence I

- Margin of Safety (MoS): The difference between actual or projected sales volume and the break-even sales volume.
- MoS indicates the extent to which sales can drop before the company incurs a loss:
  $\text{MoS} = \text{Actual Sales} - \text{Break-Even Sales}$.
- MoS Percentage: $\text{MoS\%} = \frac{\text{Actual Sales} - \text{Break-Even Sales}}{\text{Actual Sales}} \times 100$.
- Angle of Incidence: The angle at which the Total Revenue line cuts the Total Cost line on the chart.
- A large angle of incidence indicates that profits are being earned at a high rate once the BEP is crossed, reflecting high profitability.
- A small angle of incidence indicates low contribution margin and high vulnerability to changes in volume.


Profit (+) / Loss (-)
Profit-Volur
Profit Zone
BEP
Sales Volume / Ou
Margin of Safety (MoS)
Loss Zone
-FC (Fixed Cost)

Thermodynamic Systems Application and Summary I

- In thermal power plants, break-even analysis helps optimize the operational hours needed to cover capital equipment costs vs fuel cost.
- Fixed costs include initial turbine, boiler installations and financing, while variable costs are dominated by coal/natural gas consumption.
- Determining BEP helps engineers evaluate the financial feasibility of upgrading to high-efficiency combined cycle gas turbines (CCGT).
- A higher initial investment (high FC) in advanced thermodynamic cycles must be justified by a lower fuel cost per MWh (lower VC).
- Break-even charts serve as a visual bridge between thermodynamic efficiency improvements and corporate financial performance.

Thermodynamic Systems Application and Summary II

- Key Takeaways: BEP is where Revenue = Costs. It can be found analytically ($Q_{BEP} = F/(p - v)$) or graphically at the intersection of TR and TC lines.

Lecture Agenda I

- 1. Core concepts of Break-Even Analysis in engineering economics
- 2. Fundamental assumptions in Break-Even Chart construction
- 3. Step-by-step graphical construction procedure
- 4. Analytical formulas for Break-Even Point (BEP) in units and currency
- 5. Graphical interpretation of BEP and Margin of Safety
- 6. Understanding the Profit-Volume (P/V) Ratio and Angle of Incidence

Introduction to Break-Even Analysis I

- Break-Even Analysis is a decision-making tool used to determine the level of activity where total cost equals total revenue.
- Fixed Costs (FC): Expenses that remain constant regardless of production level (e.g., building rent, salaries of permanent staff, depreciation).
- Variable Costs (VC): Expenses that vary directly in proportion to the volume of production (e.g., raw materials, direct labor, power consumption).
- Total Cost (TC) = Fixed Costs (FC) + Variable Costs (VC). Variable cost is expressed as v * Q, where v is the variable cost per unit and Q is quantity.
- Total Revenue (TR) = p * Q, where p is the selling price per unit.

Introduction to Break-Even Analysis II

- At the Break-Even Point (BEP), Profit = TR - TC = 0, meaning the organization operates at no profit and no loss.

Key Assumptions in Break-Even Chart Construction I

- All costs can be clearly categorized into two distinct groups: completely fixed costs and completely variable costs.
- Fixed costs remain constant over the entire range of output under consideration.
- Variable cost per unit remains constant; hence, total variable cost changes in direct proportion to the volume of production (linear relationship).
- Selling price per unit remains constant regardless of the volume of sales, which implies a linear total revenue line.
- There is no change in inventory levels; the volume of production equals the volume of sales (all manufactured units are sold).
- Productivity and operational efficiency remain constant throughout the analyzed production range.

Key Assumptions in Break-Even Chart Construction II

- In multi-product scenarios, the sales mix is assumed to remain constant over the period.

Graphical Construction Procedure I

- Step 1: Set up the coordinate axes. Plot the Volume of Production or Sales on the horizontal X-axis (in units or % capacity).
- Step 2: Plot the Costs and Revenues on the vertical Y-axis (in currency units).
- Step 3: Draw the Fixed Cost (FC) Line. This is a horizontal line parallel to the X-axis, starting at the fixed cost value on the Y-axis.
- Step 4: Draw the Total Cost (TC) Line. This line starts at the Y-intercept of the Fixed Cost line and slopes upward to represent $TC = FC + VC$.
- Step 5: Draw the Total Revenue (TR) Line. This line starts at the origin (0,0) and slopes upward with a slope equal to the selling price per unit.

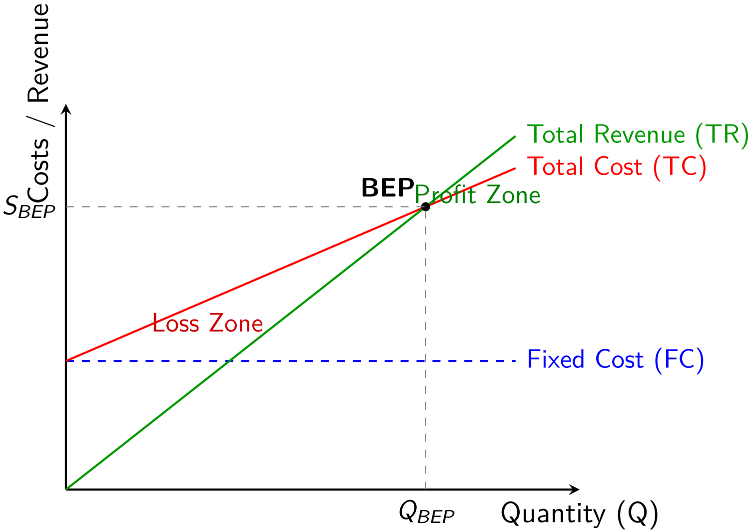
Graphical Construction Procedure II

- Step 6: Identify the intersection point of the TR and TC lines. This intersection is the Break-Even Point (BEP).

Analytical BEP Formulation I

- Let Q = Production/Sales quantity, F = Total Fixed Costs, v = Variable Cost per unit, p = Selling Price per unit.
- The profit equation is: Profit = Total Revenue (TR) - Total Cost (TC) = (p * Q) - (F + v * Q).
- Setting Profit = 0 defines the Break-Even Point: (p * Q_bep) - v * Q_bep = F.
- BEP in Units (Q_bep): Q_bep = F / (p - v) = Fixed Cost / Contribution Margin per Unit.
- Contribution Margin per Unit (C) = p - v. It represents the amount each unit contributes towards recovering fixed costs.
- BEP in Sales Value (S_bep): S_bep = p * Q_bep = F / [(p - v) / p] = F / (P/V Ratio).
- Profit-Volume (P/V) Ratio = (Contribution Margin / Sales) = (p - v) / p.

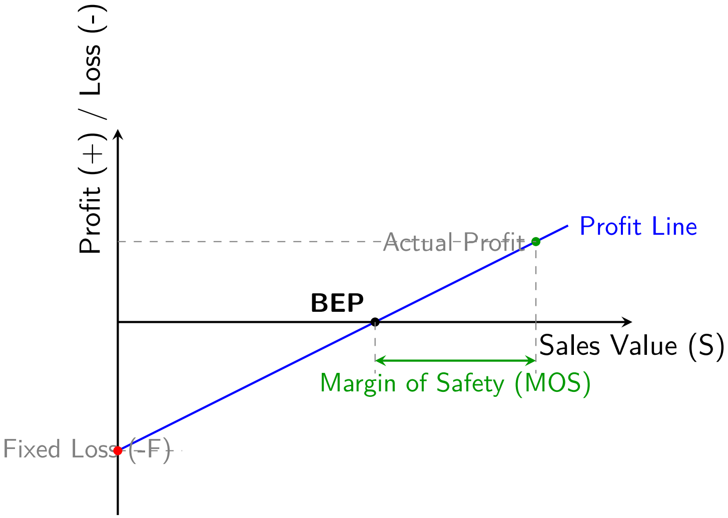
The Classical Break-Even Chart I



Margin of Safety and Angle of Incidence I

- Margin of Safety (MOS): The difference between the actual or projected sales volume and the break-even sales volume.
- MOS (in units) = Actual Sales (Q_act) - Break-Even Sales (Q_bep).
- MOS (in value) = Actual Sales Value (S_act) - Break-Even Sales Value (S_bep).
- MOS Ratio = (Actual Sales - Break-Even Sales) / Actual Sales = Profit / Contribution.
- Angle of Incidence (theta): The angle at which the Total Revenue line cuts the Total Cost line at the Break-Even Point.
- A large Angle of Incidence indicates a high rate of profit generation once the Break-Even Point is crossed.
- A small Angle of Incidence implies that profit accumulates slowly, and variable costs consume a larger portion of revenue.

Profit-Volume (P/V) Relationship I



Limitations and Plant Engineering Applications I

- Linearity Assumption: In real-world plant operations, selling prices and unit variable costs fluctuate due to discounts, efficiency changes, or scaling.
- Static Model: It assumes fixed costs do not change, but equipment upgrades or plant modifications shift the fixed cost line.
- Single-Product Simplification: A typical manufacturing plant produces multiple products; allocating overhead costs accurately to each product is complex.
- Inventory Adjustments: In practice, production does not always equal sales, creating inventory holding costs not captured in standard break-even charts.
- Ignores Time Value of Money: Break-even analysis assumes costs and revenues occur simultaneously, failing to account for capital investment dynamics.

Limitations and Plant Engineering Applications II

- Applications: Plant capacity selection, equipment replacement decisions, product mix optimization, and cost-control strategy formulation.

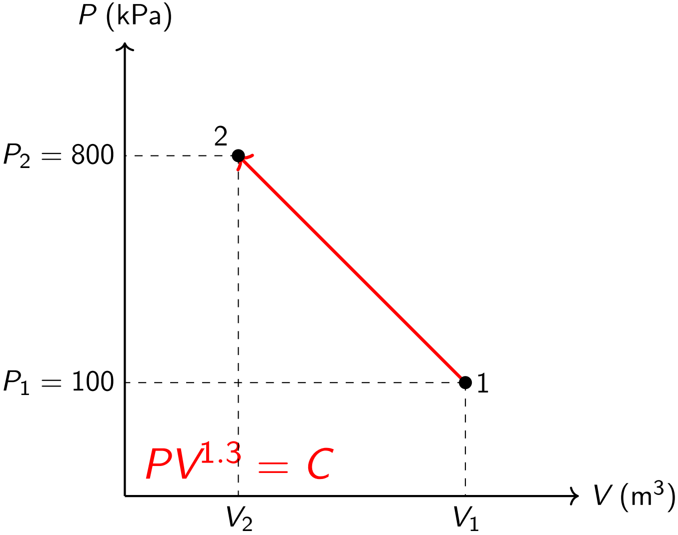
Agenda I

- Polytropic Process Analysis and Work/Heat Calculations
- Steady Flow Energy Equation (SFEE) applied to Steam Turbines
- Second Law of Thermodynamics: Carnot Efficiency and Entropy Changes
- Cost-Benefit and Economic Analysis in Thermal Power Plant Design

Problem 1: Closed System Polytropic Compression I

- System Definition: A closed system contains 0.5 kg of air behaving as an ideal gas.
- Initial State: Pressure P1 = 100 kPa, Temperature T1 = 300 K.
- Process: Polytropic compression following PV^1.3 = constant to a final pressure P2 = 800 kPa.
- Required: Calculate the final temperature T2, work done W, change in internal energy dU, and heat transfer Q.
- Properties of Air: Gas constant R = 0.287 kJ/kg-K, Constant-volume specific heat Cv = 0.718 kJ/kg-K.

P-V Diagram for Polytropic Compression I



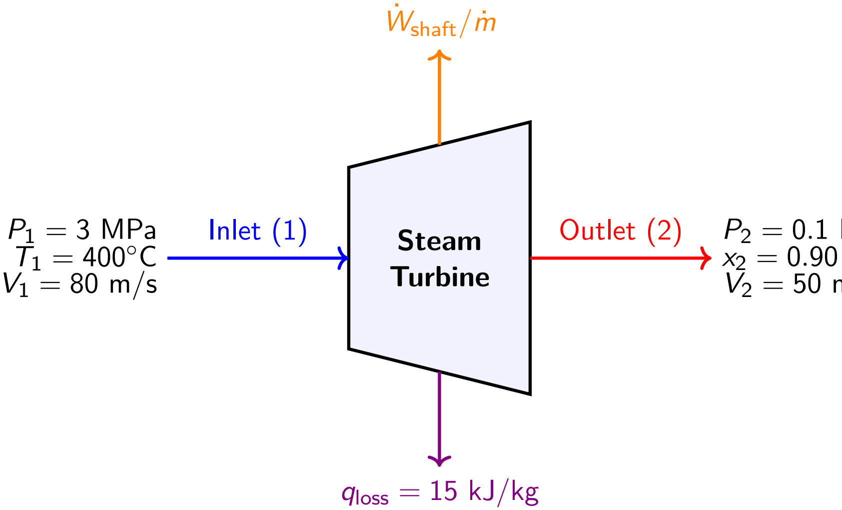
Problem 1 Solution: Step-by-Step Calculation I

- Step 1 (Final Temperature): Using T2 = T1 * (P2/P1)^((n-1)/n), T2 = 300 * (800/100)^((1.3-1)/1.3) = 300 * (8)^0.2308   484.5 K.
- Step 2 (Polytropic Work): W = m*R*(T1 - T2)/(n - 1) = 0.5 * 0.287 * (300 - 484.5)/(1.3 - 1) = 0.1435 * (-184.5)/0.3 = -88.25 kJ (Work is done ON the system).
- Step 3 (Internal Energy Change): dU = m*Cv*(T2 - T1) = 0.5 * 0.718 * (484.5 - 300) = 0.359 * 184.5 = 66.23 kJ.
- Step 4 (Heat Transfer): From the First Law (Q = dU + W), Q = 66.23 - 88.25 = -22.02 kJ (Heat is rejected from the system).

Problem 2: Steam Turbine Analysis (Open System) I

- System Definition: A steam turbine operating at steady state under control volume analysis.
- Inlet State (1): P1 = 3 MPa, T1 = 400°C (Enthalpy h1 = 3230.9 kJ/kg, Velocity V1 = 80 m/s).
- Exit State (2): P2 = 0.1 MPa, Quality x2 = 0.90 (Enthalpy h2 = 2443.3 kJ/kg, Velocity V2 = 50 m/s).
- Energy Loss: Heat loss from the turbine to surroundings is estimated at q = -15 kJ/kg.
- Goal: Calculate the specific work output (w) of the turbine in kJ/kg, accounting for kinetic energy changes.

Control Volume and Energy Flow in Turbine I



Problem 2 Solution: Steady Flow Energy Equation I

- Step 1 (Governing Equation): SFEE is written as: h1 + V1^2/2000 + q = h2 + V2^2/2000 + w.
- Step 2 (Rearranging for Work): w = (h1 - h2) + (V1^2 - V2^2)/2000 + q.
- Step 3 (Calculating Terms): Enthalpy drop = 3230.9 - 2443.3 = 787.6 kJ/kg. Kinetic energy change = (80^2 - 50^2)/2000 = (6400 - 2500)/2000 = 1.95 kJ/kg.
- Step 4 (Final Computation): w = 787.6 + 1.95 - 15 = 774.55 kJ/kg.
- Analysis: The kinetic energy change contributes positively but minimally (0.25%) to the overall power output.

Problem 3: Second Law Carnot Cycle Analysis I

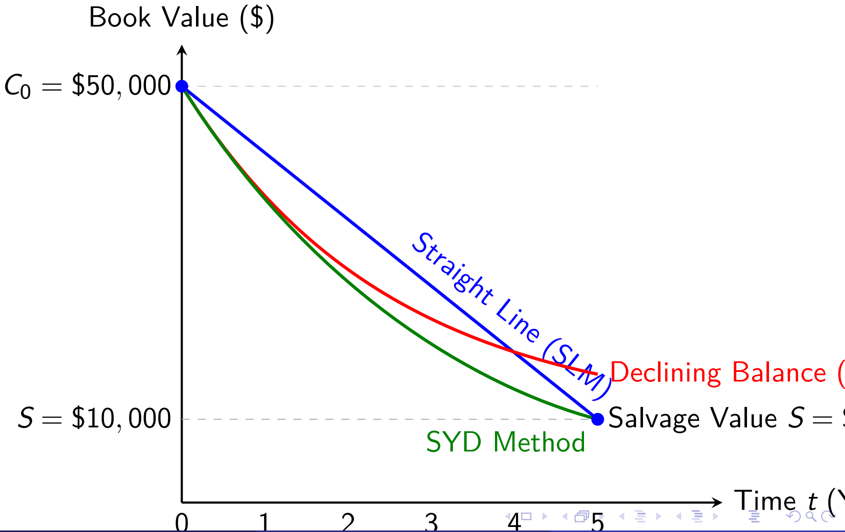
- Problem Statement: A heat engine operating on the Carnot cycle operates between thermal reservoirs at TH = 800°C and TL = 25°C.
- Input Energy: The engine receives QH = 500 kJ of heat from the high-temperature reservoir.
- Step 1 (Reservoir Temperatures in Kelvin): TH = 800 + 273.15 = 1073.15 K, TL = 25 + 273.15 = 298.15 K.
- Step 2 (Thermal Efficiency Calculation): _th,max = 1 - (TL / TH) = 1 - (298.15 / 1073.15) = 1 - 0.2778 = 0.7222 or 72.22%.
- Step 3 (Work and Heat Rejection): Work output W = * QH = 0.7222 * 500 = 361.1 kJ. Heat rejected QL = QH - W = 500 - 361.1 = 138.9 kJ.

Summary & Key Engineering Conclusions I

- First Law analysis shows energy is conserved: heat input is converted into work output, internal energy, and flow energy.
- Second Law analysis indicates that 100% conversion of heat to work is impossible, with efficiency limited by thermal reservoir temperatures.
- Polytropic exponent (n) determines the path of compression/expansion and directly influences boundary work.
- In steady-flow engineering devices (turbines), enthalpy changes dominate over kinetic and potential energy changes.
- Economic cost analysis in plant maintenance must balance thermodynamic efficiency improvements against the initial capital cost.

Comparative Asset Depreciation Curves & Book Value Decay I

Comparative Asset Depreciation Curves & Book Value Decay II

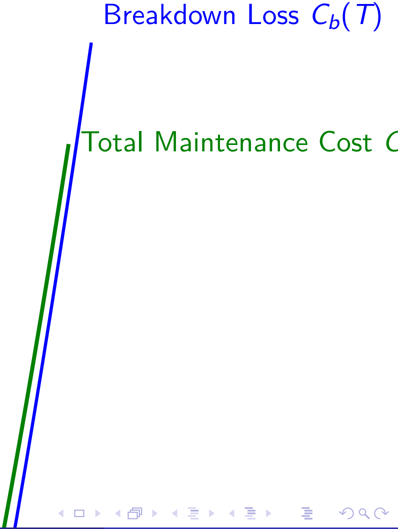


Numerical Problem 1: Asset Depreciation Schedule Matrix I

Year (t)	SLM Dep. ($)	SLM Book Value ($)	SYD Dep. (
0	-	80,000	-
1	14,400	65,600	24,000
2	14,400	51,200	19,200
3	14,400	36,800	14,400
4	14,400	22,400	9,600
5	14,400	8,000	4,800

Numerical Problem 2: Plant Maintenance Optimization & Total Cost Minimization I

Numerical Problem 2: Plant Maintenance Optimization & Total Cost Minimization II



Numerical Problem 3: Machine Hour Rate (MHR) Computation I

- Base Specifications: Purchase price $C = \$120,000$, installation cost $I = \$10,000$, salvage value $S = \$10,000$, working life = 10 years at 2,000 operating hrs/year.
- Annual Standing Charges: Factory rent = \$4,000, $lighting = \$1,200$, supervisory salary = \$6,800, $insurancepremium = \$2,000$. Total Standing = \$14,000/year.
- Hourly Standing Charge Rate = $\frac{\text{Total Standing Charges}}{\text{Annual Working Hours}} = \frac{\$14{,}000}{2{,}000\text{ hrs}} = \$7.00/hour$.
- Hourly Variable Running Charges: Hourly depreciation = $\frac{(\$120{,}000+\$10{,}000)-\$10{,}000}{10\times2{,}000} = \$6.00/hr$; Power = 15 kWh $\times$ \$0.12 $= \$1.80/hr$; Repairs = \$3.20/hr; $Consumables = \$1.00/hr$.

Numerical Problem 3: Machine Hour Rate (MHR) Computation II

- Comprehensive Machine Hour Rate (MHR) = Standing Charge (\$7.00) + Running Charges (\$6.00 + \$1.80 + \$3.20 + \$1.00) = \$19.00/hour\$.

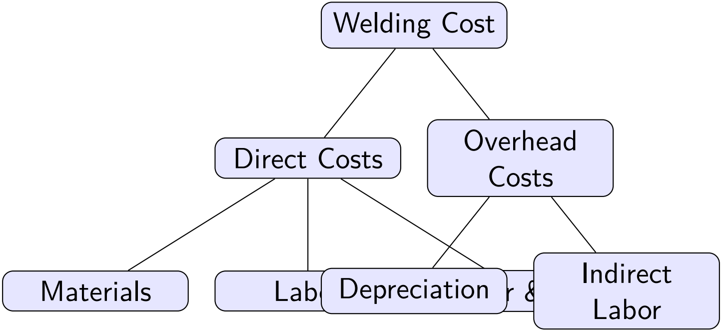
Agenda I

- Welding Shop Cost Terminology & Components
- Welding Cost Estimation Equations & Procedures
- Machining Shop Cost Terminology & Components
- Machining Time & Cost Calculations
- Tool Life and Machining Cost Optimization
- Comparative Analysis: Welding vs. Machining Costing

Cost Terminology in Welding Shop I

- Direct Material Costs: Expenses for parent metals, filler wires/electrodes, and shielding gases (e.g., Argon, CO_2) or flux materials used during welding.
- Direct Labor Costs: Wages paid to welders, helpers, and operators involved in joint preparation, tack welding, final welding, and post-weld cleaning.
- Power Costs: The cost of electricity consumed by the welding power source, determined by welding voltage, current, arc time, and power efficiency.
- Consumable Costs: Non-durable materials like contact tips, nozzles, grinding discs, and gas cups that wear out or are consumed during fabrication.
- Indirect Costs & Overheads: Indirect labor (supervision, quality inspectors), machinery depreciation, maintenance, rent, and safety equipment.

Welding Cost Component Breakdown I



Welding Cost Estimation Procedure I

- Step 1: Calculate the volume of weld metal required based on the joint geometry (e.g., V-groove, fillet, double-V) and weld length.
- Step 2: Estimate the weight of weld metal deposited, incorporating deposition efficiency (50-60% for SMAW, 80-90% for GMAW/MIG) to find total electrode/wire weight.
- Step 3: Calculate welding time using the deposition rate (kg/hr) of the welding process and the total weld metal weight.
- Step 4: Determine direct labor cost by multiplying welding time by labor hourly rates, accounting for operator duty cycle (arc-on time fraction).
- Step 5: Estimate electrical power cost using: Power (kWh) = (Voltage x Current x Arc Time) / (1000 x Machine Efficiency), multiplied by energy rate.

Welding Cost Estimation Procedure II

- Step 6: Compute shielding gas and flux costs based on flow rates (L/min or kg/hr) and total welding time.
- Step 7: Apply overhead rates to direct costs to determine the total fabrication cost.

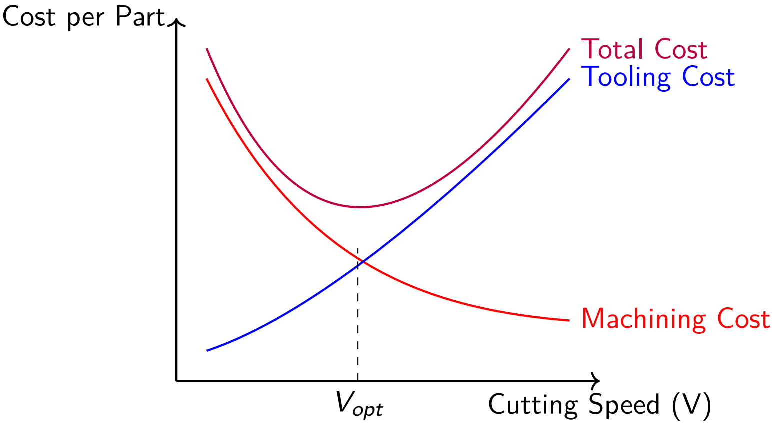
Cost Terminology in Machining Shop I

- Set-up Cost: The cost incurred in preparing the machine tool, jigs, fixtures, and program (CNC) before machining a batch of parts.
- Machining (Cutting) Cost: The cost of the direct labor and machine resources used during actual metal removal (cutting time).
- Material Handling Cost: The cost associated with loading the workpiece, tool indexing/changing, measuring dimensions, and unloading parts.
- Tooling Cost: The cost of purchasing and reconditioning/resharpening cutting tools or inserts, proportional to tool wear and tool life.
- Machining Overhead Costs: General expenses such as cutting fluids/coolants, electricity, machine maintenance, shop floor management, and machine tool depreciation.

Machining Time and Cost Calculations I

- Total Machining Time (T_m): Calculated using feed rate (f), spindle speed (N), and length of cut (L). For turning: $T_m = L/(f \cdot N)$ where Spindle Speed $N = (1000 \cdot V)/(\pi \cdot D)$.
- Direct Labor Cost: Product of labor rate per minute and total production time (including handling and setup time).
- Direct Material Cost: Calculated as the weight of raw material stock (bar stock, casting) multiplied by the unit cost, minus the salvage value of chips/scrap.
- Tooling Cost per Part: Calculated as the tool purchase/sharpening cost divided by the number of parts machined per tool lifetime.

Machining Cost Optimization Curve I



Step-by-Step Machining Cost Estimation Procedure I

- Step 1: Analyze the part drawing to identify required machining operations (turning, milling, drilling, grinding) and dimensions.
- Step 2: Select appropriate machine tools, jigs, fixtures, and cutting tools based on accuracy, material, and batch size.
- Step 3: Determine optimum cutting parameters (cutting speed, feed, depth of cut) using tool-material handbooks and optimization formulas.
- Step 4: Calculate setup time (T_s), handling time (T_h), actual machining time (T_m), and tool change time (T_{tc}) for each operation.
- Step 5: Compute direct labor cost and machine overhead cost based on hourly rates and total processing time.

Step-by-Step Machining Cost Estimation Procedure II

- Step 6: Compute tooling cost per part by estimating the tool life under selected cutting conditions.
- Step 7: Aggregate raw material cost, direct labor cost, tool cost, and overhead expenses to determine the final unit cost.

Comparison of Costing: Welding vs. Machining I

- Cost Driver Focus: Welding costs are highly sensitive to filler material deposition rate and operator duty cycle, whereas machining costs are sensitive to cutting speed and tool wear rates.
- Setup and Preparation: Machining involves significant setup time for fixtures and programming (CNC), while welding setup is relatively shorter but requires careful joint preparation (beveling, cleaning).
- Consumable Dynamics: Welding consumables (gas, electrodes) are calculated directly per unit volume of joint, whereas machining tools (inserts) are calculated using tool life equations based on time/speed.

Comparison of Costing: Welding vs. Machining II

- Waste and Salvage: Welding has minimal scrap salvage (mostly stub-ends/spatter), while machining generates substantial scrap chips which can have significant salvage/recycling value.

Agenda I

- Understand the major cost components of welding and thermal cutting operations.
- Formulate and calculate the consumption rates of gases (Oxygen & Acetylene) in gas cutting and welding.
- Determine electrode consumption based on joint volume, deposition efficiency, and wastage factors.
- Calculate electrical energy consumption and cost for Shielded Metal Arc Welding (SMAW).
- Apply costing equations to a practical production job to estimate total direct cost.

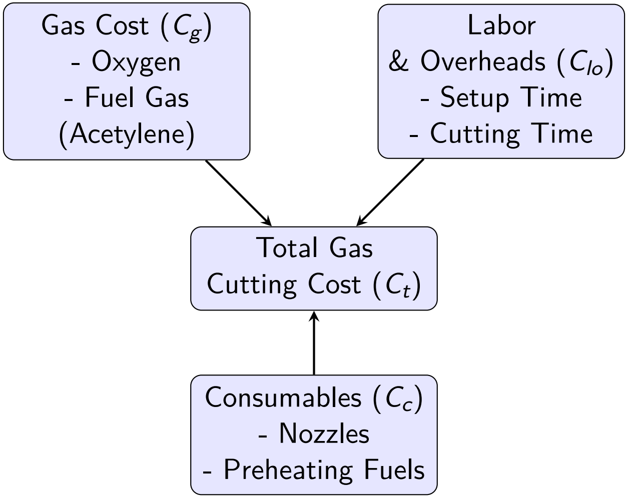
Introduction to Fabrication Costing I

- Accurate cost estimation is critical for bidding, production scheduling, and profitability in fabrication shops.
- Total fabrication cost consists of direct material cost (filler metal, shielding gases, flux), direct labor cost, direct power cost, and overhead expenses.
- Costing enables engineers to choose between alternative processes (e.g., GMAW vs. SMAW) based on economic viability.
- Consumables like electrodes, oxygen, acetylene, and shielding gases represent a major variable cost component that depends directly on the joint design.

Gas Welding & Cutting: Key Parameters & Consumables I

- Gas cutting uses oxygen and a fuel gas (commonly acetylene, LPG, or propane) to preheat and oxidize metal.
- Gas welding relies on the combustion of oxygen and acetylene to melt the base metal and filler rod.
- Consumption rate of oxygen and fuel gas depends on plate thickness, nozzle size, cutting speed, and cutting pressure.
- Cutting speed decreases non-linearly with plate thickness, requiring larger nozzle diameters and higher gas flow rates.
- Filler rod consumption in gas welding depends on joint volume, reinforcement height, and wastage factors (typically 10-15% losses).

Gas Cutting Cost Factors Breakdown I



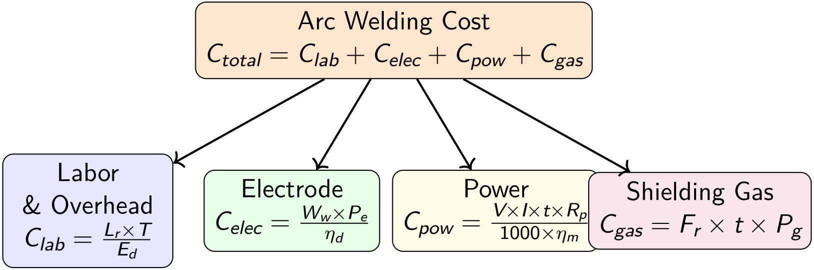
Mathematical Formulation for Gas Cutting Costs I

- Total cutting cost is expressed as: $C\_Total = C\_Oxygen + C\_Fuel + C\_Labor + C\_Overhead$.
- Oxygen consumed (liters): $V\_o = Q\_o * T\_c$, where Q_o is flow rate (L/min) and T_c is cutting time (min).
- Fuel gas consumed (liters): $V\_f = Q\_f * T\_c$, where Q_f is fuel flow rate (L/min) and T_c is cutting time (min).
- Cutting time: $T\_c = L / S$, where L is cutting length (mm) and S is cutting speed (mm/min).
- Labor cost: $C\_Labor = (T\_c + T\_s) * R\_l$, where T_s is setup time (min) and R_l is labor rate per minute.

Arc Welding: Electrode and Power Consumption I

- Electrode cost is a major variable expense, influenced by electrode diameter, deposition rate, and wastage.
- Weight of weld metal required (kg): $W_w = \rho * V_{weld}$, where ρ is density ($7.85 * 10^{-6}$ kg/mm^3 for steel) and V_{weld} is weld volume.
- Total electrode weight needed: $W_e = W_w/\eta_d$, where η_d is deposition efficiency (typically 55-65% for SMAW due to stub end loss and spatter).
- Power consumed (kWh): $E = (V * I * T_w)/(1000 * \eta_p)$, where V is voltage, I is current (Amps), T_w is arc time (hr), and η_p is power source efficiency.
- Duty cycle: D = T_w / T_total, where T_total is total production time including cleaning and fit-up.

Arc Welding Cost Components Breakdown I



Practical Cost Estimation: Case Study of a Butt Joint I

- Given Job: V-butt weld of two mild steel plates (length L = 1000 mm, thickness t = 10 mm, V-angle = 60 degrees, root face = 1.5 mm, root gap = 2 mm).
- Weld metal volume calculation: V_weld = Cross-Sectional Area (A) * Length (L) = 115,000 mm^3.
- Weld metal mass: W_w = V_weld * density = 115,000 * 7.85e-6 = 0.903 kg.
- Total electrode mass required (60% efficiency): W_e = 0.903 / 0.60 = 1.505 kg.
- Power cost estimation: Assuming V = 25V, I = 150A, speed = 150 mm/min, power cost = $0.15/kWh, efficiency = 80%. Total energy = 0.3125 kWh.

Summary & Optimization Strategies I

- Welding cost can be optimized by improving the operating factor (duty cycle) and minimizing electrode spatter and stub losses.
- Correct joint design (e.g., narrowing the groove angle) directly reduces the required weld metal volume and consumable cost.
- For gas cutting, optimizing cutting speed and gas pressures to match plate thickness prevents wasting oxygen and fuel gas.
- Labor and overheads typically dominate the total cost (often 70-80%), making automated welding/cutting highly cost-effective for large production runs.

Agenda I

- Fundamentals of Fabrication Costing
- Target Object Specifications: Air Receiver Tank
- Direct Material Cost Calculation
- Welding Consumables & Joint Design Costing
- Direct Labor and Machine Operation Costing
- Overheads & Non-Destructive Testing (NDT)
- Summary & Cost Optimization Strategies

Fundamentals of Fabrication Costing I

- Total fabrication cost is the sum of direct materials, direct labor, consumables, machine utilization, and factory overheads.
- Direct Materials: Primary stock plates, structural shapes, nozzle pipes, and standard connection flanges.
- Consumables: Welding electrodes, filler wire, shielding gases (CO_2/Argon), grinding wheels, and fuel gases for cutting.
- Direct Labor: Wages paid for physical operations including layout marking, plate cutting, rolling, fit-up assembly, welding, and post-weld inspection.
- Overheads: Allocation of power consumption, machine depreciation, facility rent, and administrative overheads.

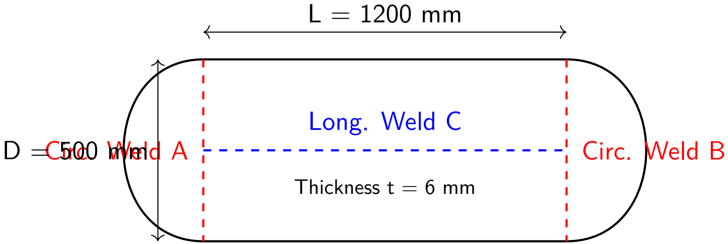
Case Study Object: Mild Steel Air Receiver Tank I

- Target Object: Industrial Air Receiver Tank (Class II Pressure Vessel as per ASME Section VIII Div 1).
- Specifications: Design pressure of 1.0 MPa, Volumetric capacity of 0.25 cubic meters.
- Shell Geometry: Cylinder with outer diameter $D = 500$ mm, length $L = 1200$ mm, plate thickness $t = 6$ mm.
- Dish Ends: Two torispherical heads, nominal thickness $t = 6$ mm, straight flange height $sf = 25$ mm.
- Material Selection: ASTM A516 Grade 70 carbon steel plate, selected for high weldability and tensile properties.

Direct Material Cost Estimation I

- Shell Plate Area: A_shell = pi * D * L = 3.1416 * 0.5 m * 1.2 m = 1.885 square meters.
- Dish Ends Area (approximate flat plate equivalent): A_dish = 2 * (1.2 * pi * D^2 / 4) = 0.471 square meters.
- Total Plate Area (with 10% scrap allowance): A_total = (1.885 + 0.471) * 1.1 = 2.592 square meters.
- Total Plate Mass: Mass = 2.592 m^2 * 0.006 m * 7850 kg/m^3 = 122.1 kg.
- Base Plate Cost: 122.1 kg * $1.20/kg = $146.52.
- Inlets & Flanges: 2x 2-inch scheduled pipe inlets (20.00) $+ 2x Class 150 weld - neck flanges$ (45.00) = $65.00.

Pressure Vessel Schematic and Weld Seams I

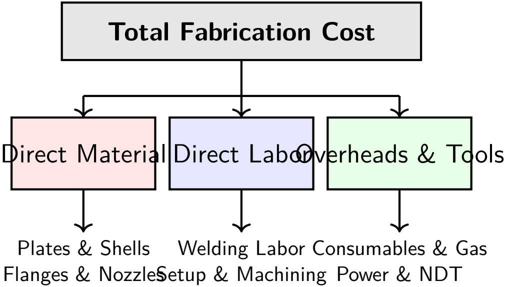


Air Receiver Vessel Layout

Welding Consumables and Power Costing I

- Joint Selection: Single V-groove weld with 60-degree included angle and 1.5 mm root face / root gap.
- Weld Cross-Section Area: A_w = t * root_gap + t^2 * tan(30) = 6 * 1.5 + 36 * 0.577 = 29.8 square millimeters.
- Total Weld Length: L_weld = Longitudinal (1.2 m) + 2x Circumferential (2 * 3.1416 * 0.5 m = 3.14 m) = 4.34 meters.
- Deposited Weld Metal Mass: Volume * Density = (29.8 mm^2 * 4.34 m) * 7.85 g/cm^3 = 1.015 kg.
- Required Electrode Mass (60% recovery rate): Mass_electrode = 1.015 kg / 0.6 = 1.69 kg.
- Consumables Expense: 1.69 kg E7018 electrodes (7.61) + *Shieldinggas*(10.85) + Power ($4.20) = $22.66.

Fabrication Cost Breakdown Flowchart I



Direct Labor and Machine Operation Costing I

- Welding Process: Shielded Metal Arc Welding (SMAW). Average welding speed v = 0.15 m/min.
- Total Arc-On Time: L_weld / v = 4.34 m / 0.15 m/min = 28.93 minutes.
- Operating Factor: 30% duty cycle for manual SMAW (includes cleaning, fit-up checks, and repositioning).
- Total Welder Time: Arc Time / Operating Factor = 28.93 / 0.3 = 96.4 minutes = 1.61 hours.
- Labor Charge: 1.61 hours * $25.00/hour welder wage rate = $40.25.
- Machine Rolling and Beveling Charges: 0.5 hours @ $30.00/hour machine utilization rate = $15.00.

Summary and Cost Optimization I

- Direct Materials Total: \$146.52 (Plates) + \$65.00 (Standard Components) = \$211.52
- Direct Labor and Machining Total: \$40.25 (Welding Labor) + \$15.00 (Rolling & Beveling) = \$55.25
- Consumables, Gas, and Power Total: \$22.66
- Factory Overheads (25% of Prime Cost): 0.25 * (\$211.52 + \$55.25 + \$22.66) = \$72.36
- Total Standard Fabrication Cost: \$211.52 + \$55.25 + \$22.66 + \$72.36 = \$361.79
- Cost Optimization: Transitioning from manual SMAW to automatic submerged arc welding (SAW) increases the operating factor from 30% to 60%, reducing direct labor costs by approximately \$20.00 per unit.

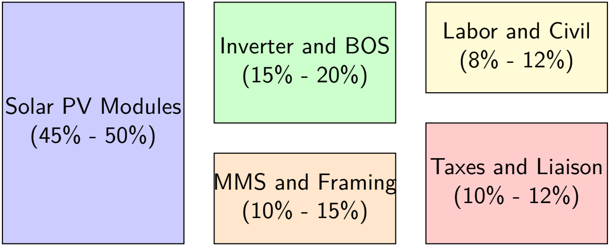
Agenda I

- Overview of Solar Rooftop System Components & Sizing
- Cost Breakdown Structure (CBS) of Solar Installation
- Fabrication & Framing Costs (Welding & Materials)
- Solar PV Panel & Balance of System (BOS) Pricing
- Installation, Civil Work, and Labor Estimation
- Taxation, Duties, and Subsidy Framework
- Comparative Cost Analysis (3kW, 10kW, 100kW capacities)
- Financial Feasibility (Payback Period & LCOE)

Solar Rooftop System Components & Sizing I

- Solar PV Modules: Monocrystalline or Polycrystalline silicon panels representing 45-50% of total hardware cost.
- Balance of System (BOS): Inverters (string or micro-inverters), charge controllers, AC/DC distribution boxes, and cabling (approx. 15-20% of cost).
- Module Mounting Structure (MMS): Hot-dip galvanized iron (GI) or aluminum framing designed to withstand wind loads up to 150 km/h.
- Civil & Installation: Foundation preparation, welding, grounding, lightning arrestors, and net-metering integration.

Cost Breakdown Structure (CBS) of Solar Rooftop Systems I



Cost Breakdown Structure

Framing & Welding Cost Calculation I

- Structural Material Selection: Structural steel (IS 2062) or galvanized steel sections (80 microns hot-dip) or AL6063-T6 aluminum rails.
- Weight Estimation: Typical MMS weight ranges from 25-35 kg per kW of solar capacity depending on wind zone class.
- Welding Cost Elements: Cost of electrodes (E6013), power consumption (kWh per meter of weld), welder labor rate per hour, and joint preparation.
- Welding Cost Formula: $C_w = (L * W_e * C_e) + (P * C_p * t_w) + (L_r * t_w)$, where L is length, W_e is electrode consumption rate, C_e is cost of electrode, P is power in kW, C_p is power cost/kWh, t_w is welding time, and L_r is labor rate.

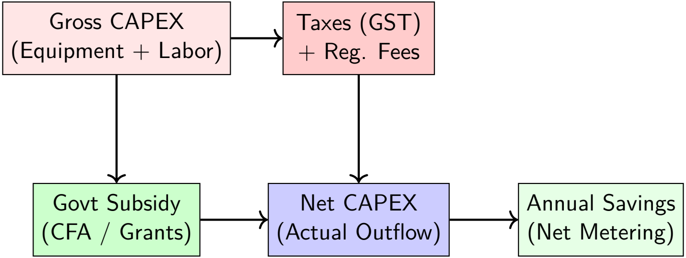
Solar Panel & Inverter Costing Details I

- Module Pricing (USD/Wp or INR/Wp): Varies based on technology (e.g., Bifacial Monoperc vs. Polycrystalline) and efficiency (18-22%).
- Inverter Selection: Grid-tied string inverters costing 10-15% of the total system cost, with typical life span of 10-12 years (requiring replacement budgeting).
- DC/AC Cabling & Switchgear: Copper/aluminum solar cables (XLPE insulation), MC4 connectors, surge protection devices (SPDs), and circuit breakers.
- Net Metering & Grid Interconnection: Regulatory application fee, utility inspection charges, bi-directional meter cost, and liaisoning charges.

Labor and Civil Work Cost Estimation I

- Civil Work Costs: Concrete ballast blocks (M25 grade) for non-penetrative roof anchoring, waterproofing chemical coating, and curing time.
- Labor Categorization: Skilled labor (welders, electricians for grid connection), semi-skilled labor (panel alignment, cabling), and unskilled labor (shifting, mixing concrete).
- Man-Hour Requirements: Typically 8-12 man-hours per kW for installation, scaling down for utility-scale or large commercial installations.
- Safety & Tools: Cost of safety harnesses, scaffolding, personal protective equipment (PPE), crane/hoist rentals for high-rise buildings.

Financial Flow: Subsidies, Taxes, and Net Cost I



Taxation and Subsidy Calculations I

- Goods and Services Tax (GST): Concessional GST rate of 12% (applies as 68% of contract value at 18% and 32% of contract value at 5% in certain regions, effectively 13.8%).
- Basic Customs Duty (BCD): 40% on solar modules and 25% on solar cells imported to promote domestic manufacturing.
- Central Financial Assistance (CFA) / Subsidies: Fixed government subsidy models (e.g., PM-Surya Ghar Muft Bijli Yojana) providing up to 60% subsidy for 2kW systems and 40% for additional capacity up to 3kW.
- Accelerated Depreciation (AD): Commercial and industrial (C&I) consumers can claim 40% AD in the first year, yielding significant income tax savings.

Comparative Analysis & Payback Estimation I

- Capacity Comparison: Sizing options analyzed: 3 kW (Residential), 10 kW (Large Residential/Small Commercial), 100 kW (Industrial/Institutional).
- Cost per kW Scale: Cost reduces from $800/kW (3 kW system) to $600/kW (10 kW system) and further to $450/kW (100 kW system) due to economies of scale.
- Levelized Cost of Energy (LCOE) Equation: LCOE = [Total Lifecycle Cost] / [Total Lifetime Energy Generation] in $/kWh or INR/kWh.
- Payback Period: Typically 3 to 4 years for commercial installations (high tariff offset) and 4 to 6 years for residential installations (subsidized cost).
- Expected Lifespan: Panels guaranteed for 25 years at 80% output, yielding high positive cashflows after the payback period.

Agenda I

- Elements of machining cost: setup, labor, tooling, and machine overhead.
- Equations and parameters for calculating machining cost in lathe turning.
- TikZ illustration of tool-workpiece interaction in lathe turning.
- Drilling cost variables: approach height, feed rate, and spindle speed.
- Milling costing structure: slab vs. face milling and multi-tooth table feed.
- TikZ illustration of peripheral (slab) milling cutter dynamics.
- Optimization of parameters using Taylor's tool life equation for minimum cost.

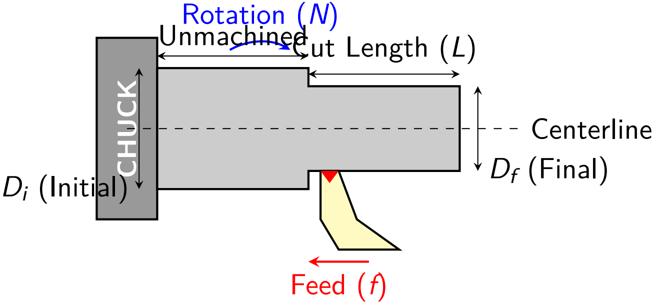
Components of Machining Cost I

- Machining cost is computed to determine the total economic expenditure required to transform raw material into a finished component via machining.
- Total cost per piece (C_m) is given by:
  $C_m = C_{setup} + C_{machining} + C_{tooling} + C_{overhead}$.
- Setup Cost (C_{setup}): Amortized cost of preparing the machine, jigs, fixtures, and tools for the production run ($T_{setup} \times R_l / N_{batch}$).
- Direct Machining Cost: The labor cost during active cutting ($T_m \times R_l$), where T_m is the actual machining time and R_l is the hourly labor rate.
- Machine Overhead ($C_{overhead}$): Covers electrical power, depreciation of the machine tool, floor space, and maintenance ($T_m \times R_o$, where R_o is overhead rate).

Lathe Turning Cost Analysis I

- Lathe turning involves rotating a cylindrical workpiece against a stationary single-point cutting tool.
- Machining Time (T_m) for a single turning pass: $T_m = \frac{L+L_c}{f \times N}$ minutes.
- Here, L is the length of workpiece to be turned (mm), L_c is tool clearance/run-out (mm), f is feed rate (mm/rev), and N is spindle speed (rpm).
- Spindle speed is computed using cutting speed (V_c, m/min) and diameter (D, mm): $N = \frac{1000 \times V_c}{\pi \times D}$.
- For multiple passes, total time $T_{m,total} = n_{passes} \times T_m$, where $n_{passes} = \frac{D_{initial} - D_{final}}{2 \times d}$ (with d being the depth of cut).

Lathe Turning Diagram I

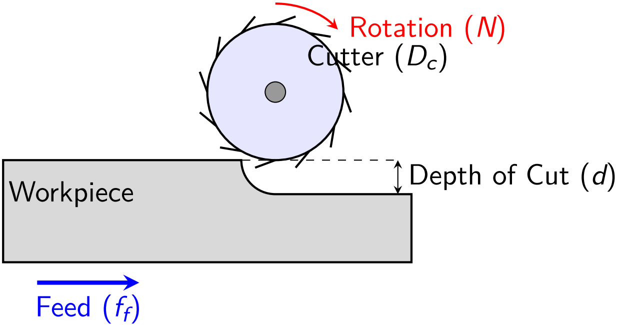


Drilling Process Costing I

- Drilling is a machining process that creates cylindrical holes in workpieces using a rotating multi-fluted tool.
- Machining Time (T_m) for a through-hole: $T_m = \frac{h+A+L_c}{f \times N}$ minutes.
- Where h is the workpiece thickness or hole depth (mm), A is the drill tip approach height (mm), and L_c is tool clearance (mm).
- The approach height (A) is critical because the drill has a conical tip. $A = \frac{D}{2 \times \tan(\theta)}$ where θ is half the point angle.
- For standard drills with a 118° point angle, $\theta = 59^\circ$ and $A \approx 0.3 \times D$ (where D is drill diameter).

Milling Machining Time and Feed Calculations I

- Milling uses rotating multi-tooth cutters. Time depends on feed rate per minute, which is a function of cutter speed and tooth count.
- Table Feed Rate (f_f, mm/min): $f_f = f_z \times z \times N$, where f_z is feed per tooth (mm/tooth) and z is the number of teeth.
- Machining Time (T_m) for a milling cut: $T_m = \frac{L+A+O}{f_f}$ minutes.
- Where L is workpiece length (mm), A is approach distance (mm), and O is over-travel distance (mm).
- For Peripheral (Slab) Milling: $A = \sqrt{d(D_c - d)}$, where d is depth of cut and D_c is cutter diameter.
- For Face Milling: If cutter is centered, $A = O = 0.5 \times (D_c - \sqrt{D_c^2 - W^2})$, where W is the width of cut.


Rotation (N)
Cutter (D_c)
Depth of Cut (d)
Workpiece
Feed (f_f)

Machining Cost Optimization & Taylor's Equation I

- Increasing cutting speed (V_c) reduces actual cutting time (T_m), thus reducing labor and machine overhead costs.
- However, tool wear accelerates with higher speed. This is modeled by Taylor's Tool Life Equation: $V_c T_L^n = C$, where n and C are material constants.
- Tool life (T_L) decreases dramatically at high speeds, increasing tooling cost per workpiece due to rapid replacement and downtime.
- The optimal tool life for minimum cost ($T_{L,opt}$) is given by: $T_{L,opt} = \left(\frac{1-n}{n}\right)\left(\frac{C_g + t_g \times R_l}{R_l + R_o}\right)$ minutes.
- Optimizing cutting speed ($V_{opt} = C/T_{L,opt}^n$) balances machining labor costs against tool consumption costs.

Case Study: Total Machining Cost Calculation I

- Problem: Estimate the machining cost to face-mill a plate of length 250 mm and width 80 mm.
- Parameters: Cutter diameter $D_c = 100$ mm (8 teeth), cutting speed $V_c = 60$ m/min, feed per tooth $f_z = 0.15$ mm/tooth.
- Rates: Labor rate $R_l = \$25$/hr, Overhead rate $R_o = \$35$/hr. Tool cost per insert edge = \$5, with tool life = 120 min.
- 1. Spindle Speed: $N = \frac{1000 \times 60}{\pi \times 100} \approx 191$ rpm. Table feed $f_f = 0.15 \times 8 \times 191 = 229.2$ mm/min.
- 2. Machining Time (T_m): With symmetric approach $A = 0.5(100 - \sqrt{100^2 - 80^2}) = 20$ mm. Total travel $L + 2A = 290$ mm. $T_m = \frac{290}{229.2} \approx 1.27$ min.
- 3. Cost calculation: Operating rate $R_{total} = R_l + R_o = \$60/\text{hr} = \$1.00/\text{min}$. Amortized tool cost per cut $\approx \frac{1.27}{120} \times \$5 = \$0.053$.

Case Study: Total Machining Cost Calculation II

- 4. Total Machining Cost per part:
  $1.27 \times \$1.00 + \$0.053 = \$1.323$ per piece.

Agenda I

- Estimation of welding cost (V-butt joint)
- Estimation of machining time and cost (lathe turning operation)
- Estimation of sheet metal fabrication cost
- Key equations and parametric influence on unit production cost

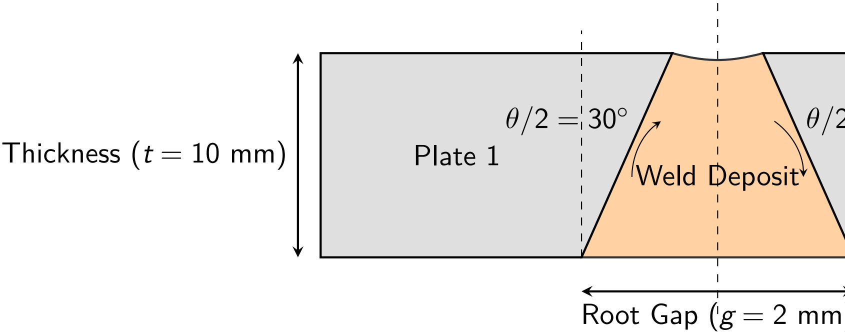
Problem 1: Arc Welding Costing I

- Problem: Calculate the total welding cost to join two steel plates of thickness t = 10 mm and length L = 1.5 m.
- Joint specification: V-butt joint with a groove angle of 60 degrees and root gap of 2 mm.
- Electrode diameter: 4 mm; Deposition efficiency: 65%.
- Density of weld metal (steel): 7.85 g/cm^3.
- Cost of electrodes: $3.50/kg; Labor rate: $15.00/hour.
- Welding speed: 5 m/hour.

Welding Cost Estimation Solution I

- Cross-sectional area of V-groove weld (A):
- A = (g * t) + t^2 * tan(theta/2) = (0.2 cm * 1.0 cm) + (1.0 cm)^2 * tan(30) = 0.2 + 0.577 = 0.777 cm^2.
- Volume of weld metal for 1.5 m (150 cm) length (V):
- V = A * L = 0.777 cm^2 * 150 cm = 116.55 cm^3.
- Weight of deposited metal (W):
- W = 116.55 cm^3 * 7.85 g/cm^3 = 914.9 g = 0.915 kg.
- Total mass of electrodes required (accounting for 65% efficiency):
- M = 0.915 kg / 0.65 = 1.408 kg.
- Electrode Material Cost = 1.408 kg * $3.50/kg = $4.93.
- Time required = 1.5 m / 5 m/hour = 0.3 hours.
- Labor Cost = 0.3 hours * $15.00/hour = $4.50.
- Total Direct Welding Cost = $4.93 + $4.50 = $9.43.

V-Groove Joint Cross-Section I



Problem 2: Lathe Turning Costing I

- Problem: A steel bar of 80 mm diameter is turned to 74 mm diameter over a length of 400 mm on a lathe.
- Cutting speed V = 90 m/min; Feed f = 0.25 mm/rev; Depth of cut d = 1.5 mm per pass.
- Number of passes: Total reduction = 80 - 74 = 6 mm. Since d = 1.5 mm (on radius), number of passes = (6/2) / 1.5 = 2 passes.
- Labor rate = $18.00/hour; Overhead rate = 150% of direct labor.
- Tool setup and loading time = 5 minutes per component.
- Tool cost per cutting edge = $4.50; Taylor tool life equation: $V * T^{\frown}0.2 = 120$.

Turning Cost Estimation Solution I

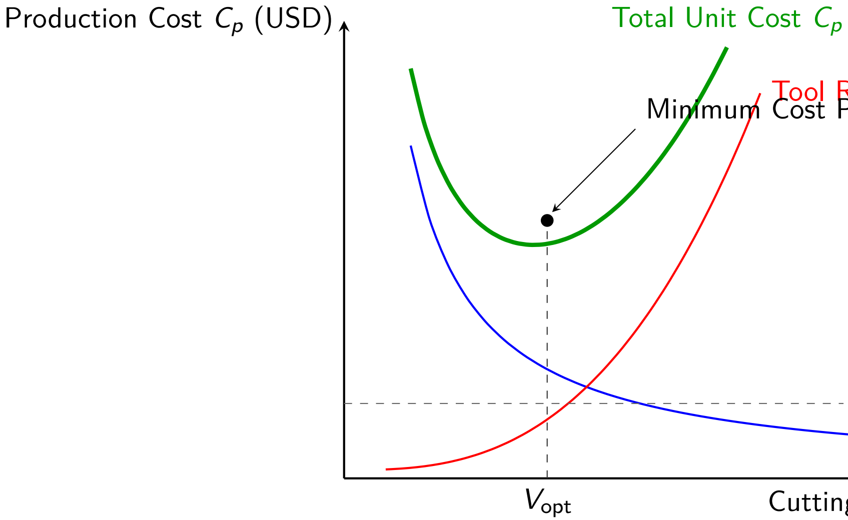
- Mean diameter of the workpiece (D) = (80 + 74) / 2 = 77 mm.
- Spindle rotational speed (N) = (1000 * V) / (pi * D) = (1000 * 90) / (pi * 77) = 372 RPM.
- Machining time per pass (t_p) = L / (f * N) = 400 / (0.25 * 372) = 4.3 minutes.
- Total machining time for 2 passes (T_m) = 2 * 4.3 = 8.6 minutes.
- Tool life (T) from V * T^0.2 = 120:
- T = (120 / 90)^5 = (1.333)^5 = 4.21 minutes.
- Number of cutting edges consumed per component = T_m / T = 8.6 / 4.21 = 2.04 edges.
- Tool Cost per component = 2.04 * $4.50 = $9.18.

Turning Cost Estimation Solution II

- Total time for cycle = Setup time + Machining time = 5.0 + 8.6 = 13.6 minutes = 0.227 hours.
- Direct Labor Cost = 0.227 hours * $18.00/hour = $4.09.
- Overhead Cost = 1.50 * $4.09 = $6.14.
- Total Machining Cost = Labor + Overhead + Tool Cost = $4.09 + $6.14 + $9.18 = $19.41.

Economics of Machining Speed vs Cost I

Economics of Machining Speed vs Cost II



Problem 3: Sheet Metal Fabrication Costing I

- Problem: Calculate the production cost for fabricating 50 units of mild steel brackets.
- Each bracket requires profile gas cutting (perimeter = 800 mm, thickness = 6 mm) followed by 2 bending operations on a press brake.
- Gas cutting speed = 400 mm/min; CNC gas cutting machine rate = $45.00/hour.
- Setup time for gas cutting = 20 minutes (for the entire batch).
- Bending cycle time = 0.5 minutes per bend; Press brake operating rate = $30.00/hour.
- Sheet metal blank material cost = $6.50 per bracket.
- Factory overhead overheads = 40% of the total fabrication processing cost.

Fabrication Cost Solution & Summary I

- Gas Cutting cost per batch of 50:
- Total perimeter = 50 * 800 mm = 40,000 mm = 40 m.
- Cutting run time = 40,000 mm / (400 mm/min) = 100 minutes.
- Total gas cutting time = 100 mins (running) + 20 mins (setup) = 120 mins = 2.0 hours.
- Total Gas Cutting Cost = 2.0 hours * $45.00/hour = $90.00.
- Press Brake Bending cost per batch of 50:
- Total bends = 50 pieces * 2 bends/piece = 100 bends.
- Bending time = 100 bends * 0.5 mins/bend = 50 minutes = 0.833 hours.
- Total Bending Cost = 0.833 hours * $30.00/hour = $25.00.
- Direct Processing Cost per unit = ($90.00 + $25.00) / 50 = $2.30.

Fabrication Cost Solution & Summary II

- Overheads per unit = 40% of processing cost = 0.40 * \$2.30 = \$0.92.
- Total Unit Cost = Material (6.50) + $Processing(2.30)$ + Overhead (\$0.92) = \$9.72 per bracket.
- Total Batch Cost = 50 * \$9.72 = \$486.00.

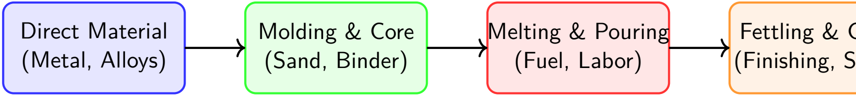
Agenda I

- Casting Cost Components: Material, Melting, and Scrap Credit
- Molding, Core-Making, and Fettling Charges
- Process Flow of Cost Accumulation in Casting Shop
- Forging Cost Components: Direct and Indirect Elements
- Material Losses in Forging (Scale, Flash, Tong Hold, Shear)
- Process Flow of Cost Accumulation in Forging Shop
- Step-by-Step Cost Estimation Procedure for Casting and Forging
- Comparative Analysis: Casting vs. Forging Shop Costs

Casting Cost Components: Material & Melting I

- Direct Material Cost: Primarily consists of the raw metal charge (pig iron, steel scrap, scrap casting) and alloying elements required to meet chemical specifications.
- Process Scrap Credit: A critical deduction computed by subtracting the scrap value of gates, risers, runners, and rejected castings that are recycled directly back into the furnace.
- Melting Cost: Includes fuel expenses (coke for cupola, electricity for induction furnace), fluxing agents (limestone), furnace labor, and refractory maintenance costs.
- Melting Loss: An unavoidable loss of metal due to oxidation, slag formation, and vaporization during melting, typically ranging from 5% to 10% of the total charge weight.

Casting Cost Flow Structure I



Casting Shop Cost Accumulation Flow

Molding, Core-making, and Fettling Charges I

- Molding Cost: Direct labor and material costs for preparing green sand or dry sand molds, setting up patterns, and using molding machines.
- Core-making Cost: Charges related to fabricating sand cores for internal cavities, including binders, reinforcements, baking energy, and specialized core-maker labor.
- Fettling & Cleaning Cost: Expenses incurred post-solidification, including knocking out molds, removing gates/risers (using sawing or oxy-fuel cutting), shot blasting, and grinding.
- Foundry Overhead Costs: Allocated indirect costs such as sand mixer maintenance, pattern shop depreciation, safety equipment, and general plant power.

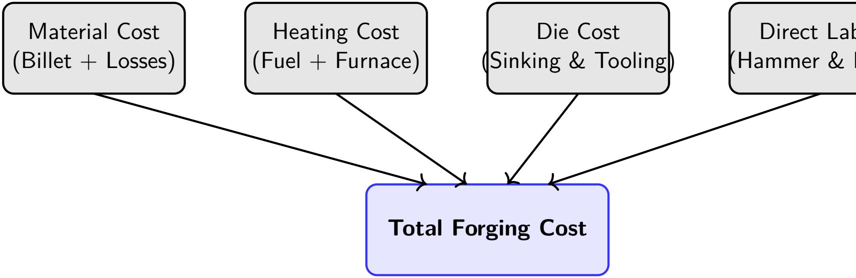
Forging Cost Components I

- Direct Material Cost: Derived from the starting stock (billet or bar) weight which must cover the final component weight plus all process-related scrap and material losses.
- Direct Labor Cost: Wages for skilled operators and crew running heating furnaces, forging hammers (gravity drop, power drop), mechanical presses, and trimming presses.
- Die Cost (Tooling Overhead): The cost of purchasing die blocks (die steel), machining cavity profiles (die sinking), and die maintenance/resinking amortized over the production run.
- Direct Operating Expenses: Power and fuel costs for heating furnaces (gas, oil, induction heating) and lubricants sprayed onto die cavities to prevent sticking.

Material Losses in Forging Shop I

- Shear Loss: Material wasted during the initial shearing of bar stock into individual billets, including kerf width and uneven end crops.
- Scale Loss: High-temperature oxidation forming scale on the surface of the billet during furnace heating, resulting in a 2% to 7% loss of gross metal weight.
- Flash Loss: In closed-die forging, excess metal squeezed into the flash gutter to ensure complete cavity filling; represents 5% to 20% of billet weight.
- Tong Hold Loss: An extension left on the billet so the operator's tongs can manipulate it under the hammer, which is sheared off during trimming.
- Sprue/Gatings Loss: The metal connecting the forging to the tong hold or joining multiple parts in multi-cavity dies, removed in post-forging trimming operations.

Forging Cost Structure I



Cost Estimation Procedure I

- Step 1: Calculate Net Weight: Estimate the volume of the finished part from engineering drawing dimensions and multiply by material density.
- Step 2: Compute Gross Weight: Add all process-specific material losses (melting and scrap for casting; scale, flash, shear, and tong hold for forging) to the net weight.
- Step 3: Calculate Material Cost: Multiply the gross weight by raw material cost per kg, and deduct credit for any recovered scrap material.
- Step 4: Determine Direct Labor and Overhead: Calculate operational hours for molding, melting, forging, trimming, and heat treatment; multiply by shop rates.
- Step 5: Aggregate Total Cost: Sum Direct Material Cost, Direct Labor, Direct Expenses, Tooling (pattern/die) depreciation, and administrative overheads.

Comparative Cost Analysis: Casting vs. Forging I

- Tooling Investment: Forging dies require high-alloy tool steels and complex machining, resulting in significantly higher tooling costs than casting patterns.
- Material Costs: Forging requires higher-grade wrought starting material and suffers non-recyclable scale loss, whereas casting scrap is directly remelted.
- Machining & Finishing: Castings often require more extensive machining due to lower dimensional accuracy, increasing final finishing costs.
- Break-Even Quantity: Forging has high fixed costs and low variable costs, making it economical only for high production volumes; casting is preferred for low/medium batches.

Agenda I

- Significance of Volume in Production Costing
- Volume Calculations for Prisms and Cylinders
- Volume of Cones, Pyramids, and Frustums
- Volume of Spheres, Spherical Caps, and Tori
- Estimation of Irregular Shapes via Simpson's Rule
- Application of Pappus-Guldinus Theorems
- Volume Allocations for Castings (Gates, Risers, Shrinkage)
- Volume Allocations for Forgings (Flash, Scale Loss, Sprue)

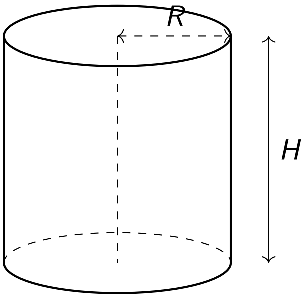
Significance of Volume in Production Costing I

- Material cost is typically the largest component of total product cost (50-70% in casting/forging).
- Estimating volume accurately allows calculation of component weight using material density ($M = \rho \times V$).
- Determines furnace/crucible capacity requirements and energy consumption during melting operations.
- Directly influences cooling rate, solidification time (Chvorinov's Rule: $t_s = B(V/A)^2$), and grain structure.
- Prevents costly material waste in forging operations and ensures adequate mold filling in casting operations.

Volume Calculations for Prisms and Cylinders I

- Prism: A solid object with two identical ends and flat sides. Volume is Cross-sectional Area (A) $\times$ Height (H).
- Rectangular Prism (Cuboid): $V = L \times W \times H$, used for rectangular blocks, plates, and casting flasks.
- Solid Cylinder: A cylinder with a circular cross-section. Volume is $V = \pi R^2 H = \frac{\pi}{4} D^2 H$.
- Hollow Cylinder: Common for bush bearings, sleeve castings, and pipes. Volume is $V = \frac{\pi}{4}(D_o^2 - D_i^2)H$.
- Hexagonal Prism: Common in bolt heads and nuts. Volume is $V = \frac{3\sqrt{3}}{2} s^2 H$, where s is the side length.

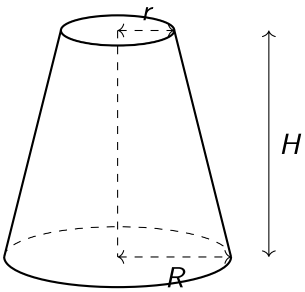
Cylinder Geometric Diagram I



Volume of Cones, Pyramids, and Frustums I

- Cones and Pyramids: Tapered shapes with volume $V = \frac{1}{3} A_{base} \times H$.
- Right Circular Cone: Volume is $V = \frac{1}{3}\pi R^2 H$, used to calculate weight of conical risers and sprue wells.
- Frustum of a Cone: A cone with the top cut off parallel to the base. Crucial for draft angles on casting patterns.
- Frustum Volume Formula: $V = \frac{\pi H}{3}(R^2 + Rr + r^2) = \frac{\pi H}{12}(D^2 + Dd + d^2)$.
- Pyramidal Frustum: Volume is $V = \frac{H}{3}(A_1 + A_2 + \sqrt{A_1 A_2})$, where A_1 and A_2 are bottom and top areas.

Conical Frustum Geometry I



Volume of Spheres, Spherical Caps, and Tori I

- Sphere: A perfectly round solid. Volume is $V = \frac{4}{3}\pi R^3 = \frac{\pi}{6} D^3$, representing ball bearings or spherical risers.
- Spherical Segment (Cap): A slice of a sphere cut by a plane. Volume is $V = \frac{\pi h}{6}(3r^2 + h^2) = \frac{\pi h^2}{3}(3R - h)$.
- Torus (Ring): Generated by revolving a circular section of radius r about an external axis. Volume is $V = 2\pi^2 R_{mean} r^2$.
- Fillets and Rounds: Fillets reduce stress concentration. The volume of a fillet chord is approximately $V_{fillet} \approx 0.2146 r^2 L$.
- Segment of Torus: Used to estimate the volume of curved pipe fittings, elbows, and rim flanges.

Estimation of Irregular Shapes via Simpson's Rule I

- Many complex engineering parts cannot be decomposed into simple standard geometric primitives.
- Simpson's 1/3 Rule: Approximates the volume of a body of length L divided into an even number of intervals n.
- Formula: $V = \frac{d}{3}[A_0 + 4(A_1 + A_3 + \cdots + A_{n-1}) + 2(A_2 + A_4 + \cdots + A_{n-2}) + A_n]$, where $d = L/n$.
- Requires equidistant cross-sectional areas $(A_0, A_1, \ldots, A_n)$ taken perpendicular to the longitudinal axis.
- Trapezoidal Rule: Alternatively used for volume estimation: $V = d[\frac{A_0 + A_n}{2} + A_1 + A_2 + \cdots + A_{n-1}]$.

Volume Allocations for Castings & Forgings I

- Net Volume vs. Gross Volume: Production cost must account for material lost during the manufacturing process.
- Casting Allowances: Gross casting volume includes gates, risers, and runner systems (adds 30-50% to net volume).
- Pattern Shrinkage: Pattern volume is enlarged by 1-2% depending on metal shrinkage (e.g., 1.3% for Cast Iron, 2.1% for Steel).
- Forging Flash: Excess metal squeezed out at the die parting line to ensure complete filling, adding 20-40% to volume.
- Scale Loss & Machining: Scale loss from hot oxidation adds 2-5%; machining allowance adds 1.5-3 mm to all surfaces.

Agenda I

- Fundamentals of Mass Estimation
- Density of Common Engineering Materials
- Geometry Deconstruction Principles
- Accounting for Material Losses
- Diagram: Component Deconstruction
- Sample Problem: Stepped Shaft Calculation
- Diagram: Stepped Shaft Dimensions
- Material Cost Calculations
- Final Assessment and Summary

Fundamentals of Mass Estimation I

- Mass estimation is the first critical step in engineering costing.
- The mass of a component directly determines its raw material cost.
- Formula: Mass (m) = Volume (V) * Density (rho).
- Volume must be calculated from engineering drawings by dividing the component into simple geometric shapes.
- Standard units used: Mass in kg, Volume in cubic meters (m3), Density in kg/m3.

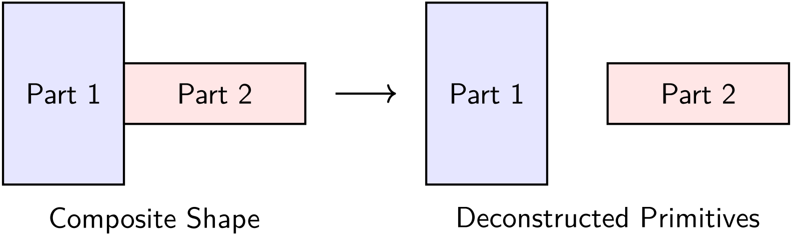
Density of Common Engineering Materials I

- Density is a physical property defined as mass per unit volume.
- Cast Iron: 7,200 kg/m3 to 7,800 kg/m3.
- Mild Steel: 7,850 kg/m3.
- Aluminum Alloys: 2,700 kg/m3.
- Brass/Copper Alloys: 8,400 kg/m3 to 8,900 kg/m3.
- Selecting the correct density is crucial for accuracy in mass calculation.

Geometry Deconstruction Principles I

- Most engineering components have complex, non-standard shapes.
- To calculate volume, we deconstruct the component into standard primitive shapes.
- Standard primitives: Cylinders, Rectangular Prisms, Cones, Spheres.
- Additive Volumes: Adding volumes of projections, flanges, and bosses.
- Subtractive Volumes: Subtracting volumes of holes, slots, keyways, and recesses.
- Total Volume = Sum of Additive Volumes - Sum of Subtractive Volumes.

Diagram: Component Deconstruction I



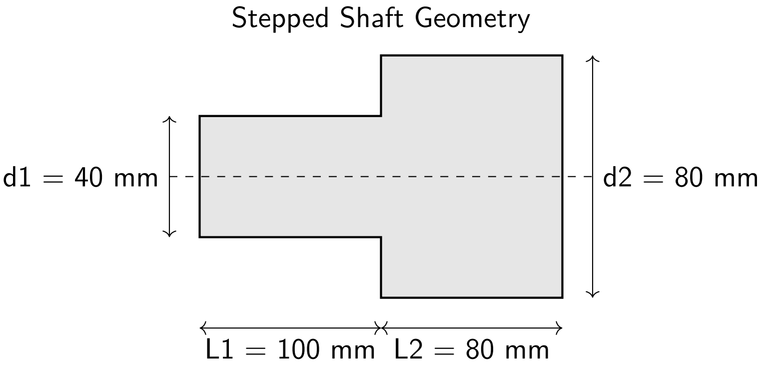
Accounting for Material Losses I

- Gross weight is always greater than net weight due to manufacturing losses.
- Forging losses include: scale loss (oxidation), flash loss, shear loss, and sprue loss.
- Casting losses include: gates, runners, risers, and melting losses.
- Machining allowance must be added if the component is to be finished by machining.
- Gross Mass = Net Mass + Process Losses + Machining Allowance.
- Material Cost is calculated based on the Gross Mass, not the Net Mass.

Sample Problem: Stepped Shaft Calculation I

- Problem Statement: Calculate the mass and material cost of a forged stepped shaft.
- Material: Mild Steel (density = 7,850 kg/m3).
- The shaft consists of two steps: Step 1 (Diameter d1 = 40 mm, Length L1 = 100 mm) and Step 2 (Diameter d2 = 80 mm, Length L2 = 80 mm).
- Unit material cost: $2.50 per kg.
- Process loss allowance: 10% of net volume.
- Let's first visualize the geometry and dimensioning of the shaft.

Diagram: Stepped Shaft Dimensions I



Material Cost Calculations I

- Step 1: Calculate Net Volume. V1 = (pi/4)*d1^2*L1 = (pi/4)*(0.04)^2*(0.10) = 0.0001257 m3.
- V2 = (pi/4)*d2^2*L2 = (pi/4)*(0.08)^2*(0.08) = 0.0004021 m3.
- Total Net Volume (V_net) = V1 + V2 = 0.0005278 m3.
- Step 2: Calculate Gross Volume (including 10% loss). V_gross = 1.10 * V_net = 0.0005806 m3.
- Step 3: Calculate Gross Mass. Mass = V_gross * density = 0.0005806 * 7850 = 4.56 kg.
- Step 4: Calculate Material Cost. Cost = Mass * Unit Cost = 4.56 kg * $2.50/kg = $11.40.

Agenda I

- Introduction to Forging Operations and Cost Elements
- Understanding Forging Losses: Shear, Scale, Flash, Sprue, and Tonghold
- Mathematical Formulation of Net vs. Gross Weight
- Material Cost Estimation and Forging Cost Components
- Step-by-Step Forging Cost Calculation Methodology
- Interactive TikZ Diagram: Mass Balance in Forging
- Interactive TikZ Diagram: Cost Breakdown Structure
- Numerical Problem: Data Specification
- Step-by-Step Solution of the Numerical Problem
- Summary and Key Takeaways

Understanding Forging Losses I

- Forging is a metalworking process involving the shaping of metal using localized compressive forces, resulting in material waste.
- Gross Weight: The total weight of the raw material (billet or bar stock) required to produce a forged component.
- Net Weight: The final weight of the forged and finished component after machining.
- Forging losses refer to the difference between the Gross Weight and Net Weight, which directly impact the material cost.
- Key losses include: Shear Loss, Scale Loss, Flash Loss, Sprue Loss, and Tonghold Loss.

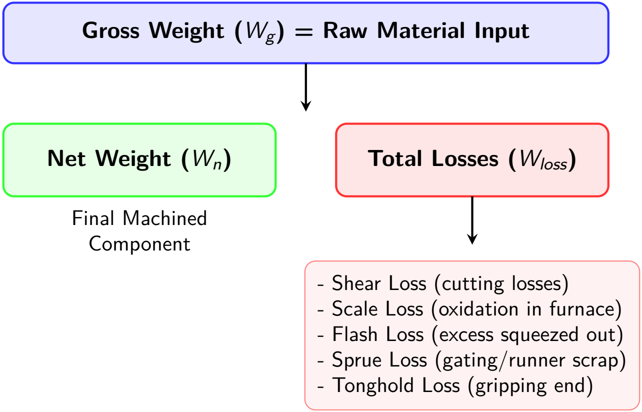
Classification of Forging Losses I

- Shear Loss: Material lost during the cutting (shearing) of bar stock into billets. Usually estimated as 2% to 5% of net weight.
- Scale Loss: Loss due to oxidation of metal when heated to high temperatures in a furnace. Typically ranges from 5% to 7.5% of net weight.
- Flash Loss: Excess metal that squeezes out of the die cavity to ensure complete filling of the die. Often ranges from 10% to 20% of net weight.
- Sprue Loss (or Gate Loss): The material left in the runner or gate channel that connects the forging to the bar stock. Usually about 5% to 10% of net weight.
- Tonghold Loss: The portion of the stock gripped by tongs during open die forging or manipulation. Typically 2.5% to 5% of net weight.

Formulas for Gross Weight & Material Cost I

- Gross Weight (W_g) = Net Weight (W_n) + Total Losses
- Total Losses = Shear Loss + Scale Loss + Flash Loss + Sprue Loss + Tonghold Loss
- Often, losses are expressed as a percentage of Net Weight (W_n) or previous steps. Standard practice: W_g = W_n * (1 + sum(loss percentages)) or calculated step-by-step.
- Material Cost = Gross Weight (W_g) * Rate of Material per Unit Weight (C_m)
- Net Material Cost = Material Cost - (Scrap Recovery Weight * Scrap Value per Unit Weight)

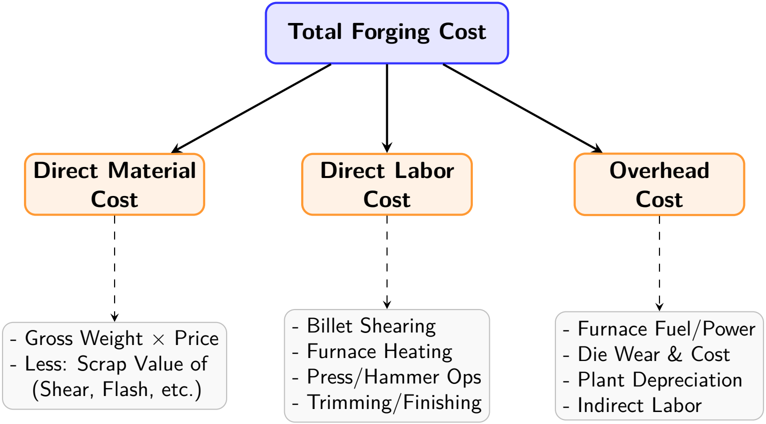
Diagram: Mass Balance of Material in Forging I



Components of Forging Cost I

- Direct Material Cost: Cost of raw material required (based on Gross Weight) minus scrap value.
- Direct Labor Cost: Cost of labor for heating, forging, trimming, and finishing operations (calculated as Time * Hourly Labor Rate).
- Overhead Costs: Indirect materials, power, fuel for furnace, maintenance, depreciation of hammers/presses, and factory overheads (expressed as a percentage of labor cost or machine hour rate).
- Cost of Forging = Direct Material Cost + Direct Labor Cost + Direct Overheads + Setup/Die Cost allocation.

Diagram: Forging Cost Breakdown Structure I



Numerical Problem Statement I

- A forged component has a net weight of 3.0 kg. Estimate the gross weight and cost of forging given the following data:
- Losses (percentage of net weight): Shear loss = 4%, Scale loss = 6%, Flash loss = 15%, Sprue loss = 7%, Tonghold loss = 3%
- Material cost rate: $2.50 per kg. Scrap recovery value: $0.60 per kg of scrap.
- Labor cost: $1.80 per piece. Factory overheads: 150% of labor cost.

Numerical Solution and Analysis I

- 1. Total Loss Percentage = 4% + 6% + 15% + 7% + 3% = 35% of Net Weight.
- 2. Gross Weight (W_g) = W_n * (1 + 0.35) = 3.0 * 1.35 = 4.05 kg.
- 3. Total Scrap Weight = W_g - W_n = 4.05 - 3.00 = 1.05 kg.
- 4. Direct Material Cost = (4.05 kg * $2.50/kg) - (1.05 kg * $0.60/kg) = $10.125 - $0.63 = $9.495.
- 5. Direct Labor Cost = $1.80. Factory Overheads = 1.5 * $1.80 = $2.70.
- 6. Total Forging Cost per Piece = Direct Material Cost (9.495) + *LaborCost*(1.80) + Overheads ($2.70) = $13.995 (approx. $14.00).

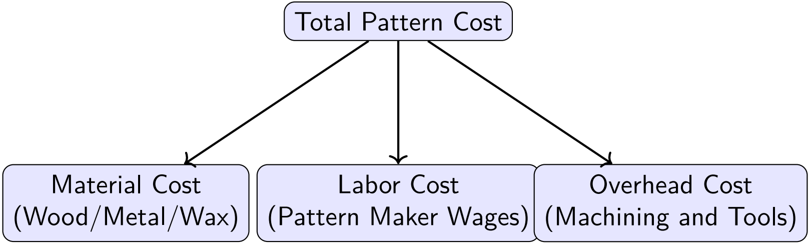
Agenda I

- Overview of Pattern Costing in Foundries
- Cost Structure: Direct Material, Direct Labor, and Overheads
- Foundry Allowances and Their Impact on Pattern Volume
- Mathematical Modeling of Pattern Cost Components
- Step-by-Step Computational Procedure
- Practical Numerical Analysis of a Wooden Flange Pattern
- Cost Optimization and Material Selection Criteria

Foundations of Pattern Making Cost I

- A pattern is a dimensional replica of the final casting, modified by metallurgical allowances to facilitate clean molding.
- Pattern making cost is treated as a tooling or initial setup cost in casting shops.
- Unlike consumable molds, a pattern is reused multiple times, meaning its cost is amortized over the total production batch size.
- Cost estimation must account for the pattern material (wood, aluminum, brass, or plastics), which determines pattern life and durability.
- Design complexity dictates the labor hours required for hand-carving, CNC routing, or precision machining.

Elements of Pattern Cost Structure I



Direct Material Cost & Foundry Allowances I

- Direct Material Cost (C_m) = Volume of Pattern (V_p) * Density (ρ) * Unit Cost per Mass (C_u)
- The pattern volume is always larger than the final casting volume to account for shrinkage and machining allowances.
- Shrinkage Allowance: Liquid and solid metal contraction requires linear dimensions to be scaled up by 1% to 2% (e.g., 1.3% for steel).
- Machining (Finish) Allowance: Added to surfaces requiring a clean finish, usually adding 1.5 mm to 3.0 mm of stock material.
- Draft (Taper) Allowance: A slight taper (0.5 to 2.0 degrees) added to vertical walls to allow clean withdrawal without damaging the sand mold.

Direct Labor and Overhead Allocation I

- Direct Labor Cost (C_l) = Total labor hours (T) * Hourly wage rate of the pattern maker (R_l).
- Pattern makers are highly skilled technicians, making labor hours the dominant cost component for custom wooden tooling.
- Overheads (C_o) encompass indirect factory expenses: machine depreciation, shop power, tooling wear, and supervisor salaries.
- Overheads are typically allocated as a percentage of direct labor cost (ranging from 80% to 150%) or as a machine-hour rate.

Cost Estimation Flowchart I

1. Calculate Nominal Volume from Engineering Drawing
2. Add Shrinkage and Machining Allowances
3. Calculate Material Weight (Volume $\times$ Density)
4. Compute Material Cost and Direct Labor Costs
5. Apply Factory Overheads to Find Total Cost

Numerical Problem: Given Data I

- Estimate the total cost to manufacture a teak wood pattern for a cast iron hollow cylinder flange.
- Flange Finished Dimensions: Outer Diameter = 400 mm, Inner Diameter = 200 mm, Thickness = 80 mm.
- Teak Wood Cost Rate = \$1,800 per cubic meter (\$/m^3).
- Pattern Making Time = 15 hours; Pattern Maker Labor Rate = \$25.00/hour.
- Factory Overhead Rate = 110% of direct labor cost.
- Foundry Parameter: Shrinkage allowance is 1.5% and must be added to all linear dimensions before cutting wood.

Numerical Solution: Calculations I

- Step 1: Compute dimensions with 1.5% shrinkage allowance:
- Scaled OD = 400 * 1.015 = 406 mm = 0.406 m
- Scaled ID = 200 * 1.015 = 203 mm = 0.203 m
- Scaled Thickness = 80 * 1.015 = 81.2 mm = 0.0812 m
- Step 2: Calculate pattern volume (V_p):
- $V_p = (\pi/4) * (OD^2 - ID^2) * \text{Thickness} = (\pi/4) * (0.406^2 - 0.203^2) * 0.0812 = 0.00788 \text{ m}^3$
- Step 3: Calculate direct material cost:
- Material Cost = 0.00788 m^3 * $1,800/m^3 = $14.18
- Step 4: Calculate labor cost and overheads:
- Labor Cost = 15 hours * $25.00/hour = $375.00
- Overheads = 1.10 * $375.00 = $412.50
- Step 5: Total Pattern Cost = $14.18 (Material) + $375.00 (Labor) + $412.50 (Overhead) = $801.68

Practical and Economic Considerations I

- Direct labor and overheads represent the major share of pattern costs, especially for wood and complex geometries.
- Material allowances are critical: neglecting shrinkage leads to out-of-tolerance castings, while ignoring draft ruins molds.
- Tooling selection is driven by volume: wooden patterns are cheap initially but wear out quickly; metal patterns cost more but lower unit cost over large batches.
- Accurate cost calculation ensures competitive bidding, appropriate tooling choices, and profitable foundry operations.

Agenda I

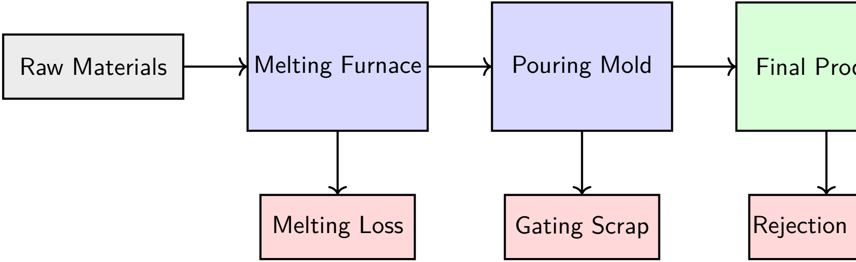
- Introduction to Casting Cost Estimation
- Key Cost Elements & Foundry Direct Materials
- Understanding Process Scrap (Gating & Riser System)
- Melting Losses and Rejection Rates in Sand Casting
- Material Flow and Losses Schematic (TikZ)
- Mathematical Formulations for Net Material Cost
- Calculating Total Metal Charge Weight
- Anatomy of a Casting Mold and Gating System (TikZ)
- Step-by-Step Numerical Example
- Industrial Strategies for Yield Optimization & Cost Reduction

Introduction to Casting Cost Estimation I

- Casting cost estimation is a critical practice used to determine the economic viability of a cast component before pattern making begins.
- Unlike subtractive processes, casting costs are heavily influenced by phase changes, volumetric shrinkage, and recycled scrap material.
- Direct material cost is not simply the mass of the final product multiplied by the raw metal rate per kilogram.
- Every cast component requires auxiliary channels (sprues, runners, gates) and reservoirs (risers) to ensure defect-free solidification.
- Accurate cost calculation must track the total weight of metal charged into the furnace, accounting for all metallurgical and process losses.

Key Cost Components & Material Losses I

- Direct Material Cost: The cost of virgin ingots, scrap metal, and ferroalloys charged into the melting furnace.
- Process Scrap: The runner-riser system that is cut off (fettled) from the final casting. This is recycled internally as scrap, offsetting some cost.
- Melting Loss: Metal lost due to high-temperature oxidation, vaporization, slag/dross removal, and spillage during pouring (typically 2% to 10%).
- Rejection Loss: Casting defects (e.g., shrinkage cavities, sand inclusions, gas porosity) discovered during inspection that render the part scrap.
- Fettling & Processing Cost: Energy and labor costs for sprue removal, shot blasting, grinding, heat treatment, and quality inspection.


Raw Materials
Melting Furnace
Pouring Mold
Final Proc
Melting Loss
Gating Scrap
Rejection

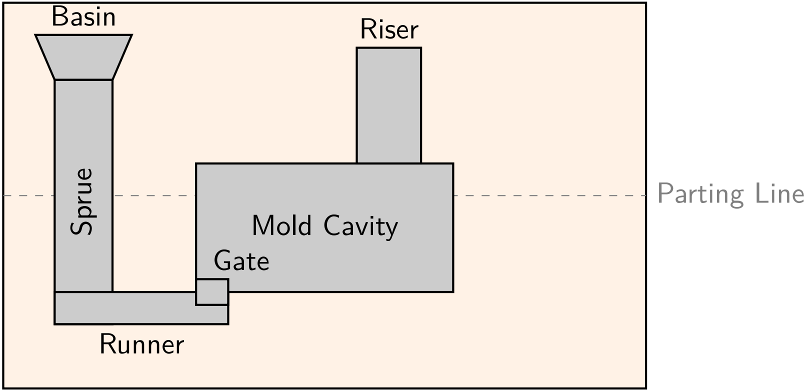
Mathematical Formulation of Casting Cost I

- Let W_c = Net weight of the finished clean casting (kg).
- Let W_g = Weight of the gating and riser system per casting (kg).
- Total poured weight (W_p) = W_c + W_g (kg). This represents the metal entering the mold cavity.
- Total charged weight (W_t) = W_p / (1 - L_m / 100), where L_m is the percentage melting loss.
- Let C_r = Cost of raw metal charge per kg, and C_s = Salvage/resale value of scrap returned to furnace per kg.
- Net Material Cost per Poured Mold = (W_t * C_r) - (W_g * C_s). The gating system is treated as returnable scrap.
- Total Manufacturing Cost = Molding cost + Core making cost + Melting energy cost + Fettling cost + Overhead expenses.

Accounting for Rejection (Scrap) Losses I

- In production, a fraction of castings is rejected. Let r = Rejection rate (expressed as a fraction, e.g., 0.05 for 5%).
- To produce N acceptable castings, the number of molds that must be poured is $N_p = N / (1 - r)$.
- Energy, labor, and mold sand consumed for rejected castings are entirely lost and must be amortized over the good castings.
- The rejected castings are fettled and returned to the furnace, generating a credit equivalent to their salvage value ($W_c * C_s$).
- Total Material Cost per Good Casting = $[(W_t * C_r) - (W_g * C_s) - r * (W_c * C_s)] / (1 - r)$.
- Reducing the rejection rate (r) directly decreases both material wastes and the average processing time per good unit.

Anatomy of a Casting Mold and Gating System I



Step-by-Step Numerical Example I

- Problem: Calculate cost of a 15 kg cast iron component. Runner-riser system weight = 5 kg. Melting loss = 6%. Rejection rate = 8%.
- Costs: Raw iron cost = $2.00/kg. Returned scrap value = $0.80/kg. Mold prep, pouring, and cleaning labor = $15.00 per mold poured.
- Step 1: Poured weight (W_p) = 15 + 5 = 20 kg. Total charged weight (W_t) = W_p / (1 - 0.06) = 20 / 0.94 = 21.28 kg per mold.
- Step 2: Material cost per poured mold = (21.28 * $2.00) - (5.00 * $0.80) = $42.56 - $4.00 = $38.56.
- Step 3: Total cost per poured mold = Material cost + Labor/energy = $38.56 + $15.00 = $53.56.

Step-by-Step Numerical Example II

- Step 4: Account for rejects. Cost per good casting = \$53.56 / (1 - 0.08) = \$53.56 / 0.92 = \$58.22.
- Step 5: Deduct salvage value of rejected casting scrap. Scrap credit = 15 kg * \$0.80 * (0.08 / 0.92) = \$1.04. Net Cost = \$57.18.

Industrial Cost Reduction Strategies I

- Optimize Casting Yield: Yield = (Weight of casting / Total poured weight). Higher yield reduces energy wasted remelting sprues.
- Computer-Aided Solidification Design: Use mold flow simulation to shrink riser size without creating shrinkage porosity.
- Strict Process Control: Monitor sand moisture, binders, and pouring temperatures to reduce rejection rates.
- Furnace Efficiency: Minimize melting times and use protective fluxes or inert gas blankets to reduce melting loss.
- Recycle and Reclaim Sand: Clean and reuse silica sand to cut down on waste disposal fees and raw sand logistics.

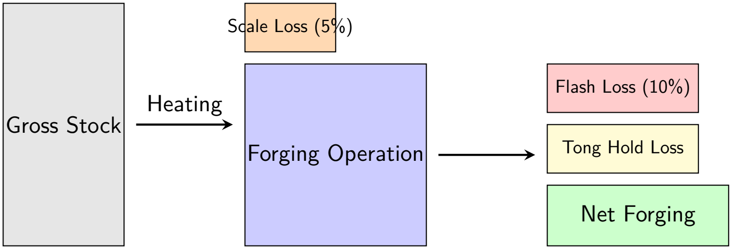
Lecture Agenda I

- Theoretical overview of forging and casting costing elements
- Step-by-step raw material weight calculation (Gross vs. Net Weight)
- Mathematical representation of scale, flash, shear, and tong hold losses
- Numerical Case Study 1: Complete Forging Cost Calculation
- Analysis of casting cost parameters: pattern, moulding, and melting scrap
- Numerical Case Study 2: Complete Casting Selling Price Estimation

Understanding Forging Losses & Material Calculations I

- Gross Weight equation: Gross Weight = Net Weight + Scale Loss + Flash Loss + Shear Loss + Tong Hold Loss
- Scale Loss: Caused by oxidation of surface metal during heating in the furnace (typically 5% to 7.5% of net weight)
- Flash Loss: Material that flows out into the parting line gutter; usually calculated as 10% to 15% of the net weight
- Shear Loss: The loss of material at the end of bar stock during shearing/cutting (about 4% to 5% of the gross weight)
- Tong Hold Loss: The length of stock gripped by tongs during forging; typically 2.0 to 2.5 cm of the bar stock diameter equivalent

Process Flow and Weight Breakdown in Forging I



Numerical Case Study 1: Forging Cost Estimation I

- Problem Statement: Determine the total cost for forging 1,000 steel connecting rods with a net weight of 1.8 kg each.
- Given loss metrics: Scale loss = 5% of net weight; Flash loss = 10% of net weight; Shear loss = 3% of net weight; Tong hold loss = 7% of net weight.
- Cost variables: Raw steel stock cost = $2.20 per kg; Direct forging labor cost = $3.50 per rod; Overhead costs = 120% of direct labor cost.
- Objective: Calculate the total production cost and the unit cost of each forged connecting rod.

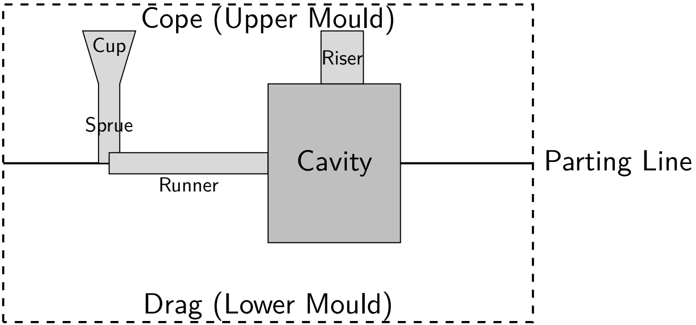
Solution to Numerical Case Study 1 I

- Step 1: Gross Weight = Net Weight * (1 + Scale% + Flash% + Shear% + TongHold%) = 1.8 kg * (1 + 0.05 + 0.10 + 0.03 + 0.07) = 1.8 * 1.25 = 2.25 kg.
- Step 2: Total raw material needed = 1,000 pieces * 2.25 kg/piece = 2,250 kg.
- Step 3: Total Material Cost = 2,250 kg * $2.20/kg = $4,950.00.
- Step 4: Direct Labor Cost = 1,000 pieces * $3.50/piece = $3,500.00.
- Step 5: Factory Overheads = 120% of Labor Cost = 1.2 * $3,500 = $4,200.00.
- Step 6: Total Forging Cost = Material Cost + Labor Cost + Overheads = $4,950.00 + $3,500.00 + $4,200.00 = $12,650.00.
- Unit Production Cost = $12,650.00 / 1,000 = $12.65 per rod.

Casting Cost Components and Process Scrap I

- Total Casting Cost = Material Cost + Moulding Labor + Fettling & Cleaning Labor + Melting Cost + Overhead Allocations.
- Molten Metal Cost: Includes the weight of the actual casting plus gating system components (sprue, runner, gates, and risers).
- Process Scrap: Remeltable scrap consisting of the gating system. It is credited back to the material cost at scrap metal value.
- Melting Loss: Non-recoverable metal oxidized during melting (usually 4% to 8% of total charged weight).
- Labor Cost elements: Moulding time is driven by pattern complexity, while fettling is driven by casting weight and gate removal effort.

Gating System and Sand Mould Configuration I



Numerical Case Study 2: Casting Selling Price I

- Problem Statement: Estimate the unit selling price of 500 grey cast iron motor housings weighing 12 kg each.
- Given Parameters: Process scrap (gating system) = 20% of net casting weight; Melting loss = 6% of total metal poured; Metal cost = \$1.90 per kg; Recycled scrap value = \$0.60 per kg.
- Time estimates: Moulding time = 30 minutes per mould; Moulding labor rate = \$8.00 per hour; Fettling & cleaning cost = \$0.50 per kg of net casting weight.
- Financial parameters: Factory overheads = 80% of moulding labor cost; Administrative overheads = 15% of factory cost; Desired profit margin = 20% of total cost.

Solution to Numerical Case Study 2 I

- Step 1: Metal poured per casting = Net weight + Process scrap = 12 kg + (0.20 * 12 kg) = 14.4 kg. Total charged metal (accounting for melting loss) = 14.4 kg / (1 - 0.06) = 15.32 kg.
- Step 2: Material Cost = (15.32 kg * $1.90) - (2.40 kg scrap * $0.60) = $29.11 - $1.44 = $27.67 per casting.
- Step 3: Direct Labor Cost = Moulding labor ((30/60) hr * $8.00) + Fettling (12 kg * $0.50) = $4.00 + $6.00 = $10.00.
- Step 4: Factory Overheads = 80% of Moulding Labor = 0.8 * $4.00 = $3.20. Factory Cost = Material + Labor + Overheads = $27.67 + $10.00 + $3.20 = $40.87.
- Step 5: Admin Overheads = 15% of Factory Cost = 0.15 * $40.87 = $6.13. Total Production Cost = $40.87 + $6.13 = $47.00.

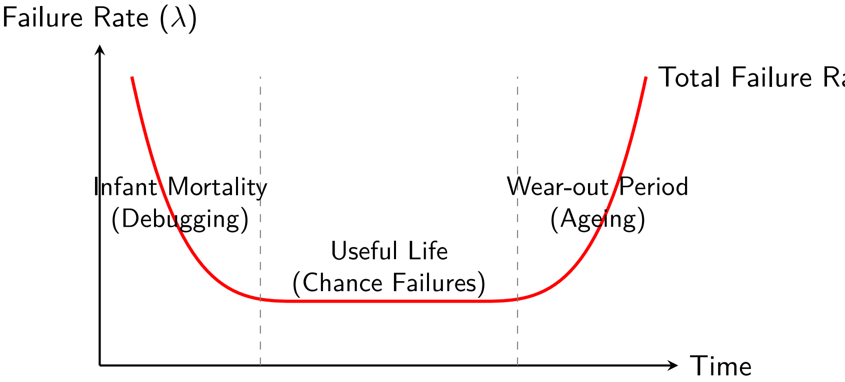
- Step 6: Selling Price (with 20% profit) = Total Cost * 1.20 = $47.00 * 1.20 = $56.40 per motor housing.

Agenda I

- Understanding the Need for Maintenance in Engineering Systems
- Primary Objectives of a Maintenance Program
- Overview of Maintenance Types: Breakdown vs. Preventive
- Predictive and Proactive Maintenance Strategies
- Comparing Maintenance Policies and Selecting the Optimal Mix

Definition and Fundamentals of Maintenance I

- Maintenance is the combination of all technical and administrative actions, including supervision, intended to retain an item in, or restore it to, a state in which it can perform its required function.
- It is not merely repairing broken equipment; it is a strategic function that ensures asset availability, reliability, and safety.
- From a thermodynamic perspective, maintenance counters the natural progression of entropy (degradation, wear, and tear) in engineering systems.
- Key performance indicators (KPIs) include Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR).


Failure Rate (λ)
Total Failure Ra
Infant Mortality
(Debugging)
Useful Life
(Chance Failures)
Wear-out Period
(Ageing)
Time

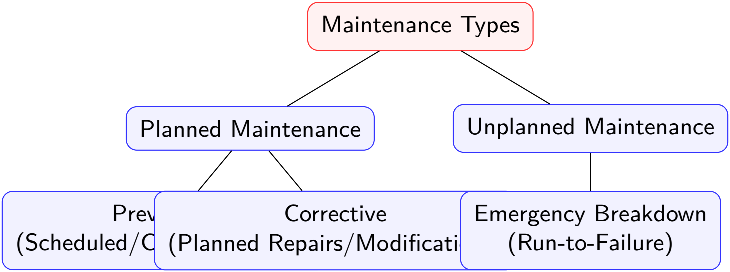
The Economic and Operational Need for Maintenance I

- Reduces operational downtime and avoids catastrophic breakdowns that disrupt production schedules.
- Protects capital investment by extending the useful lifespan of heavy machinery and plant facilities.
- Ensures safety of personnel by preventing catastrophic pressure vessel explosions, leakages, or electrical hazards.
- Improves thermodynamic efficiency of energy-conversion equipment (e.g., boilers, turbines, compressors) by reducing fouling and friction losses.

Core Objectives of Plant Maintenance I

- Maximize availability: Keep plant, machinery, and other assets available for production at optimal design capacity.
- Minimize total maintenance cost: Optimize the balance between preventive maintenance activities and breakdown repair costs.
- Enhance product quality: Properly maintained equipment produces parts within design tolerances, reducing scrap rates.
- Maintain safety and environmental standards: Meet statutory regulations regarding emissions, effluent discharge, and workspace hazards.

Classification of Maintenance Types I



Breakdown or Corrective Maintenance I

- Also known as run-to-failure or reactive maintenance, where repairs are done only after the equipment fails.
- Advantages: Low initial costs, minimal planning needed, and high utilization of components before replacement.
- Disadvantages: High risk of secondary damage, unpredictable production downtime, safety risks, and expensive emergency repairs.
- Best applied to: Non-critical equipment with low replacement cost, or systems where redundancy is built-in.

Preventive and Predictive Maintenance I

- Preventive Maintenance (PM): Performed at scheduled intervals (time-based or usage-based) to reduce failure probability.
- Examples of PM: Periodic lubrication, filter replacement, cleaning, and scheduled overhaul of turbines.
- Predictive Maintenance (PdM): Condition-based maintenance that monitors physical parameters (vibration, thermography, oil analysis).
- PdM targets maintenance actions exactly when indicators show imminent failure, minimizing unnecessary PM actions.

Summary: Selecting the Right Maintenance Mix I

- An optimal maintenance strategy uses a mix of preventive, predictive, and corrective approaches based on criticality.
- Thermodynamic components like high-pressure boilers and steam turbines require strict preventive and predictive monitoring.
- Low-criticality auxiliary pumps or lighting systems can be safely managed under breakdown maintenance.
- The final goal is to minimize the total lifecycle cost of plant assets while maintaining high reliability and safety standards.

Lecture Agenda I

- Introduction to Maintenance Strategies (Breakdown, Preventive, Predictive)
- Comparison of Maintenance Philosophies (Costs, Down-time, Reliability)
- Preventive Maintenance (PM) - Scheduling, Benefits, and Limitations
- Predictive Maintenance (PdM) - Principles and Technologies
- Condition-Based Maintenance (CBM) - Key Parameters
- Vibration Monitoring and Analysis
- Thermographic (Temperature) Analysis
- Lubricant Analysis and Tribology

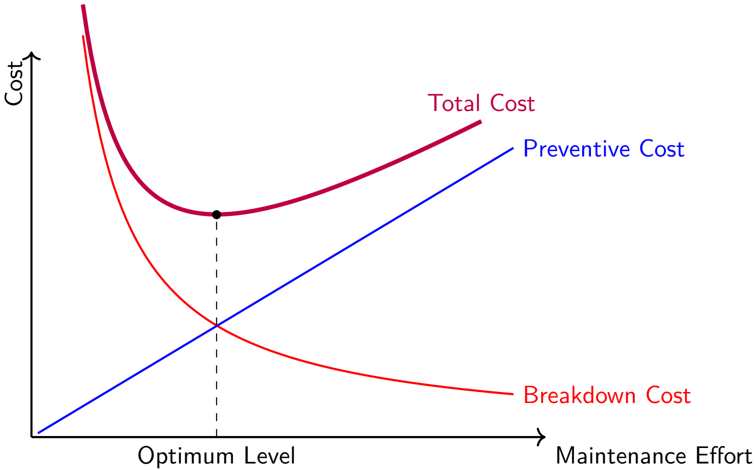
Breakdown (Reactive) Maintenance I

- Definition: Run-to-failure strategy where equipment is repaired or replaced only after it fails.
- Appropriate for: Low-cost, non-critical items whose failure does not affect safety, production, or cause secondary damage (e.g., standard light bulbs, hand tools).
- Advantages: Minimal planning required, zero cost spent on preventive measures, fully utilizes component lifetime.
- Disadvantages: High unplanned downtime costs, safety hazards from catastrophic failures, expensive emergency shipping and overtime labor, increased secondary damage to adjacent components.

Preventive (Time-Based) Maintenance I

- Definition: Maintenance performed at predetermined intervals (calendar time, operating hours, cycles) regardless of actual condition.
- Objective: To reduce the probability of failure or degradation of functioning of an item.
- Core Activities: Routine inspection, cleaning, lubrication, adjustments, and periodic replacement of wear-prone parts (e.g., changing engine oil every 5,000 miles).
- The PM Paradox: Risk of 'infant mortality' due to human error during maintenance, and potential waste of remaining useful life (RUL) of components.

Maintenance Cost Optimization Curve I



Predictive Maintenance (PdM) I

- Definition: Condition-based maintenance where the actual operational condition of the equipment is monitored to predict when failure will occur.
- Goal: To perform maintenance only when warranted, maximizing the lifetime of components while avoiding unexpected downtime.
- Key Steps: Data collection (sensors) -> State detection -> Health assessment -> Prognostics (Remaining Useful Life estimation) -> Decision support.
- Techniques: Vibration analysis, infrared thermography, oil/lubricant analysis, acoustic emissions, and motor current signature analysis (MCSA).

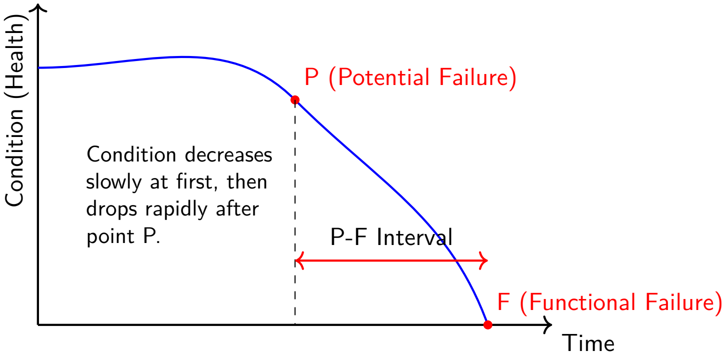
Condition Monitoring: Vibration Analysis I

- Principle: Rotating machinery produces distinct vibration signatures; changes in these signatures indicate underlying mechanical faults.
- Sensors: Accelerometers, velocity transducers, and proximity probes measure acceleration, velocity, and displacement.
- Fault Detection: High overall vibration levels indicate general distress, while frequency-domain analysis (FFT spectra) isolates specific defects.
- Signature Identification: 1x RPM suggests unbalance, 2x RPM suggests misalignment, and high-frequency sidebands indicate gear or rolling-element bearing defects.

Condition Monitoring: Thermography and Lubrication Checks I

- Infrared Thermography: Non-contact measurement of temperature distributions. Identifies hotspots in electrical connections, bearing friction, and insulation breakdown.
- Lubricant Analysis: Testing oil samples for physical properties (viscosity, water contamination, acidity) and wear debris.
- Spectrographic Analysis: Identifies specific metals in the oil (e.g., copper indicates brass cage wear, iron indicates gear/shaft wear).
- Ferrography: Separates magnetic wear particles using a magnetic field to analyze particle shape, size, and quantity under a microscope.

The P-F Curve and Warning Window I



Economic and Strategic Trade-offs I

- Cost Breakdown: Breakdown maintenance has low setup costs but high failure costs. Preventive maintenance has constant labor costs. Predictive maintenance has high initial sensor/hardware costs but lowest operating downtime costs.
- Implementation Strategy: Use Breakdown for non-critical/redundant assets. Use Preventive for assets with known age-related wear characteristics. Use Predictive/Condition-Based for highly critical assets with high failure costs.
- Key Performance Indicators (KPIs): MTBF (Mean Time Between Failures), MTTR (Mean Time To Repair), OEE (Overall Equipment Effectiveness), and Maintenance Cost per Unit Output.

Economic and Strategic Trade-offs II

- Conclusion: A mature maintenance program integrates all three strategies depending on criticality, cost-benefit analysis, and failure mode effects analysis (FMEA).

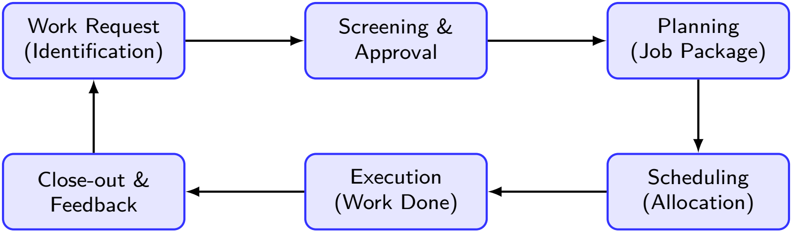
Agenda I

- Overview of Maintenance Planning
- Work Order Systems & Planning Workflows
- Maintenance Scheduling Principles
- Critical Path & Resource Allocation
- Maintenance Documentation & Record Keeping
- Computerized Maintenance Management Systems (CMMS)

What is Maintenance Planning? I

- Maintenance planning is the process of identifying, analyzing, and preparing all resources required to execute a maintenance task before it begins.
- Goal: Minimize idle time, reduce equipment downtime, and optimize maintenance costs.
- Planning answers the 'WHAT', 'HOW', 'WITH WHAT', and 'HOW LONG' questions of a job.
- Key components include defining the scope of work, step-by-step procedures, identifying safety hazards (HAZOP), and listing tools, parts, and materials.
- Effective planning can increase worker efficiency (Wrench Time) from a typical 25-35% in unplanned environments to over 50-60%.

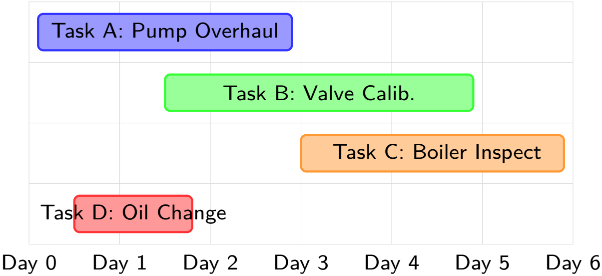
The Maintenance Planning Workflow I



Maintenance Scheduling Principles I

- Scheduling is the process of matching planned work with the appropriate resources (labor, tools, equipment availability) at a specific time.
- Unlike planning (which answers HOW), scheduling answers the 'WHEN' and 'WHO' of the maintenance cycle.
- Scheduling rules of thumb: 1. Schedule for a full 100% of the crew's available hours. 2. Prioritize jobs based on equipment criticality (e.g., using RIME - Relative Importance of Maintenance Economy).
- Schedule compliance (jobs completed vs. jobs scheduled) is a key performance metric for scheduling effectiveness.
- Coordination with operations is crucial to ensure equipment is shut down, depressurized, cooled, and ready for work.

Example of Weekly Maintenance Schedule (Gantt representation) I



Maintenance Documentation & Records I

- Documentation provides the historical record of asset performance, failure modes, parts replaced, and labor hours spent.
- Critical documents: Equipment History Logs, Standard Operating Procedures (SOPs), Safety Data Sheets (SDS), and Work Orders.
- A Work Order is the primary legal and operational document for authorizing and tracking maintenance activity.
- Failure data captured during close-out (using codes like Cause, Effect, and Remedy) fuels Reliability-Centered Maintenance (RCM) analysis.
- Accurate documentation ensures regulatory compliance (OSHA, EPA) and simplifies external audits.

Computerized Maintenance Management Systems (CMMS) I

- A CMMS is a software platform that centralizes maintenance information, automates workflows, and tracks assets.
- Core modules: Asset Registry, Work Order Management, Preventive Maintenance (PM) Scheduling, and Inventory/Spare Parts Control.
- Benefits of CMMS: 1. Automated PM generation based on calendar or runtime triggers. 2. Real-time spare parts tracking. 3. Historical breakdown analysis.
- Modern CMMS integrated with Enterprise Resource Planning (ERP) allows automatic purchase requisitions when spare parts reach reorder points.
- IoT-enabled CMMS supports Predictive Maintenance (PdM) by pulling real-time sensor data (vibration, temperature) to trigger work orders.

Key Performance Indicators (KPIs) I

- 1. Planned Maintenance Percentage (PMP): Target $>$ 85% of total maintenance hours should be planned.
- 2. Schedule Compliance: Target $>$ 90% of scheduled tasks completed within the scheduled window.
- 3. Backlog: Measured in weeks of work. Target is typically 2-4 weeks of ready-to-work backlog per technician.
- 4. Wrench Time: Percentage of a shift a technician spends actively executing maintenance (world-class is $>$ 65%).
- 5. Emergency/Reactive Work Percentage: Target $<$ 10% to prevent high cost and safety risks associated with unplanned events.

Summary: The Thermodynamic Context I

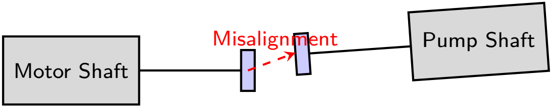
- Why does maintenance planning matter in Thermodynamics? Unplanned degradation increases entropy generation and reduces thermal efficiency.
- Fouled heat exchangers, worn turbine blades, and leaking steam traps directly degrade cycle performance (W_{net}, η_{th}).
- Rigorous scheduling of preventive cleaning and component replacements keeps operating parameters close to design thermodynamic cycles.
- Comprehensive documentation ensures that baseline efficiency metrics can be compared against current performance for trend analysis.
- In short: Systematic maintenance planning is the practical engineering method to combat the Second Law of Thermodynamics (entropy increase) in plant operations.

Agenda & Learning Objectives I

- Identify and classify hand, power, and torque-limiting maintenance tools.
- Describe precision diagnostic and alignment instruments used in mechanical plants.
- Review safe operations of lifting tackles, hoists, and heavy machinery jacks.
- Understand the workflow of maintenance records and the documentation lifecycle.
- Structure Equipment History Cards and design effective PM checklists.

Classification of Maintenance Tools I

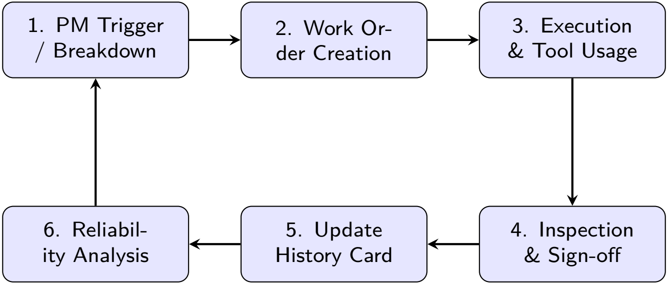
- Hand Tools: Hand spanners, adjustable wrenches, pipe wrenches, socket sets, heavy-duty pliers, and cold chisels.
- Power Tools: Electric drills, angle grinders, pneumatic impact wrenches, and high-performance hydraulic torque multipliers.
- Torque Control: Essential for seal integrity and preventing bolt fatigue in high-pressure steam lines and process piping.
- Pullers and Presses: Gear pullers, bearing splitters, and portable hydraulic jacks to extract components without mechanical damage.
- Safety Compliance: Tools must comply with ISO/OSHA standards, utilizing insulated grips for electrical isolation and spark-resistant alloys in hazardous zones.


Motor Shaft
Misalignment
Pump Shaft

Heavy Maintenance and Lifting Equipment I

- Material Handling: Overhead gantry cranes, mobile floor cranes, and diesel/electric forklifts for plant-wide asset relocation.
- Lifting Tackles: High-tensile wire ropes, synthetic web slings, rated shackles, eye bolts, and load-tested chain blocks.
- Positioning Hoists: Manual chain lever hoists (come-alongs) and pneumatic winches for micro-positioning heavy machinery.
- Jacking Systems: Low-profile hydraulic toe jacks, high-tonnage cylinder rams, and synchronized multi-point lifting jacks.
- Legal Inspections: Annual proof-load testing and magnetic particle inspection (MPI) on critical welds of lifting components are mandatory.

Workflow of Maintenance Records I



Maintenance Record Keeping Systems I

- Record Objectives: Provide regulatory compliance, verify safety standards, track costing, and build failure database.
- Core Documents: Daily operator logbooks, maintenance requests, formal work orders, and strict Permits to Work (PTW).
- Inventory Records: Spare parts logs, storage location maps, purchase requests, and safety stock level calculations.
- Calibration Logs: Traceable certificates of accuracy for plant pressure gauges, safety relief valves, and thermometers.
- Digital Transition: Computerized Maintenance Management Systems (CMMS) automate work scheduling and archival processes.

Equipment History Cards (EHC) I

- EHC Definition: A master record tracking the entire lifecycle of an asset from installation to decommission.
- Vital Statistics: Unique equipment tag ID, manufacturer details, installation coordinates, electrical ratings, and drawing numbers.
- Failure Classification: Recording standardized failure codes (e.g., fatigue wear, lubrication failure, overheating) for analytics.
- Key Performance Indicators (KPIs): Using history card data to compute Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR).
- Life-cycle Decisions: Serves as the primary evidence to support repair-versus-replace decisions for plant machinery.

Checklists: Structure and Execution I

- Role of Checklists: Standardize operating procedures, eliminate technician memory bias, and document quality checks.
- Preventive Checklists: Scheduled tasks such as fluid level verification, belt tension adjustments, and filter replacements.
- Pre-Start Checklists: Quick check routines by operators covering safety interlocks, guard placements, and critical level sensors.
- Turnaround Checklists: Detailed steps during major plant shutdowns, including line purges, blind insertions, and pressure tests.
- Design Principles: Must be clear, action-oriented, require binary sign-off (pass/fail), and hold signatures of executor and inspector.

Best Practices in Maintenance Documentation I

- Immediate Reporting: Technicians must record maintenance execution immediately post-repair to ensure accurate diagnostic data.
- Quality Traceability: Every work order should cross-reference used parts batch numbers and test tool calibration stamps.
- Root Cause Analysis (RCA): Documenting deep analyses (e.g., 5-Why method, Fishbone diagrams) directly into the equipment history database.
- Periodic Audit: Regularly reviewing records to refine preventive maintenance frequencies, preventing over-maintenance.
- Asset Tagging: Deploying QR/RFID codes on plant hardware to give field engineers immediate access to digital history cards.

Agenda I

- Introduction to Machine Diagnostics & Fault Analysis
- Evolution of Maintenance Strategies (Reactive, Preventive, Predictive)
- Key Objectives and Purposes of Diagnostics
- The Multistep Diagnostic Process Flowchart
- Economic and Operational Importance of Diagnostics
- Introduction to Core Monitoring Technologies
- The P-F Curve and the Diagnostic Window of Opportunity
- Application in Rotating and Thermal Plant Machinery
- Summary & Key Takeaways

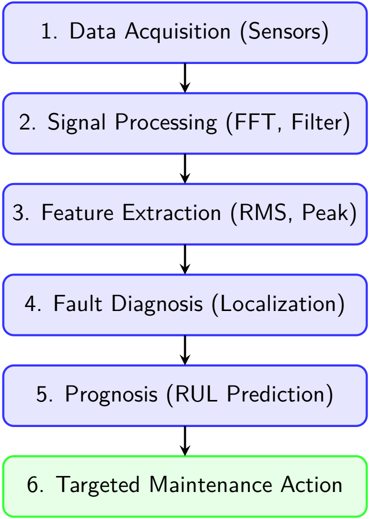
Introduction to Machine Diagnostics I

- Machine Diagnostics is the science and practice of identifying, localizing, and evaluating faults in engineering systems.
- It involves measuring physical parameters (vibration, temperature, pressure, wear debris) to assess health.
- Diagnostics answers three key questions: What is the fault? Where is it located? How severe is it?
- Unlike simple troubleshooting, diagnostics uses continuous or periodic condition monitoring data to detect degradation prior to functional failure.

Evolution of Maintenance Philosophies I

- Run-to-Failure (Reactive): Fix it when it breaks. High secondary damage risk and unpredictable downtime.
- Preventive Maintenance (Time-Based): Scheduled maintenance based on calendar time or operating hours. Risk of over-maintenance and introducing human-induced faults.
- Predictive Maintenance (Condition-Based): Maintenance performed only when diagnostics indicate a threshold of degradation has been crossed.
- Proactive Maintenance: Eliminating root causes (e.g., precision alignment, dynamic balancing, fluid cleanliness) to extend machine life indefinitely.

The Diagnostic Process Flowchart I



Key Purposes of Machine Diagnostics I

- Early Fault Detection: Identifying micro-cracks, bearing spalls, or thermal anomalies before they impact machine function.
- Fault Isolation and Localization: Identifying the exact component (e.g., inner race vs. outer race of a bearing, specific cylinder in an engine).
- Severity Assessment: Estimating the severity level (Good, Alert, Danger) to determine if immediate shutdown is required.
- Prognostics: Estimating the Remaining Useful Life (RUL) of the asset based on the current rate of fault degradation.

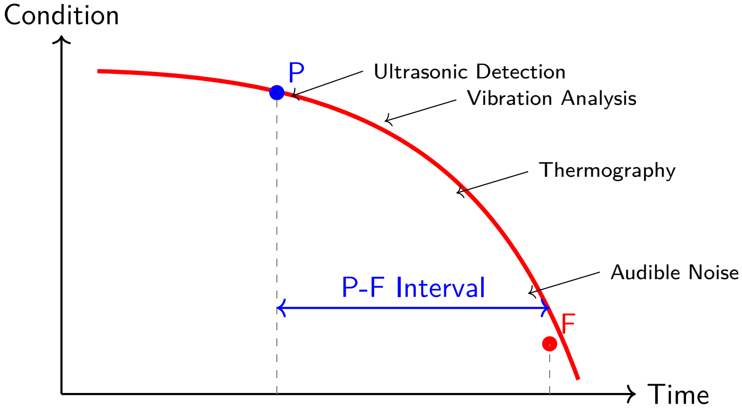
Economic and Operational Importance I

- Downtime Minimization: Unplanned outages in thermal power plants or process lines can cost thousands of dollars per minute.
- Avoiding Catastrophic Collateral Damage: Preventing a minor bearing failure from destroying a turbine rotor, casing, or shaft.
- Inventory Cost Control: Allowing spare parts to be ordered 'just-in-time' based on diagnostics, reducing warehouse holding costs.
- Safety and environmental protection: Preventing catastrophic failures that lead to hazardous fluid leaks, fires, or explosions.

Core Condition Monitoring Techniques I

- Vibration Analysis: The primary tool for rotating equipment. Detects imbalance, misalignment, gear wear, and rolling element bearing faults.
- Thermography: Monitors temperature distribution in machines, electrical cabinets, and heat exchangers to detect overheating or insulation breakdown.
- Oil and Wear Debris Analysis (Tribology): Analyzes wear particles, viscosity changes, and chemical degradation in lubricants.
- Acoustic Emission (AE): Detects high-frequency elastic waves released during active plastic deformation, micro-cracking, or high-pressure leaks.

The P-F Curve and Diagnostic Window I



Summary and Review Questions I

- Diagnostics is essential for shifting plant maintenance from reactive to cost-effective predictive and proactive strategies.
- The P-F curve illustrates that early detection methods (ultrasonic/vibration) provide a wider warning window than physical signs (noise/heat).
- Review Question 1: Distinguish between Point P (Potential Failure) and Point F (Functional Failure) on the P-F curve.
- Review Question 2: In a steam power plant, list three parameters you would monitor to diagnose turbine degradation.

Agenda I

- Characterizing Imbalance: Causes, Centrifugal Forces, and Phase Shifts
- Identifying Misalignment: Offset and Angular Types and Vibrational Signatures
- Analyzing Wear, Tribological Modes, and Bearing Degradation Stages
- Understanding Leakages, Noise Diagnostics, and Acoustic Emission Testing
- Vibration Analysis Foundations: Transducers, Frequency Spectrum, and Fault Interpretation

Mechanical Imbalance: Principles & Diagnostics I

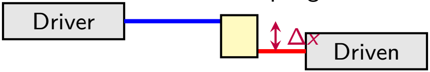
- Imbalance is the unequal distribution of mass about a rotating component's geometric axis of rotation, creating dynamic forces.
- The rotating heavy spot creates a centrifugal force: $F_c = m \cdot e \cdot \omega^2$, where m is the unbalance mass, e is the eccentricity, and ω is the angular velocity.
- Vibrational Signature: Extremely dominant at 1X rotational frequency (running speed) in the radial direction, where amplitude is proportional to the square of rotational speed.
- Phase Behavior: A consistent 90-degree phase shift is observed between radial-horizontal and radial-vertical vibration measurements, indicating a circular/elliptical orbit.

Shaft Misalignment: Classifications & Signatures I

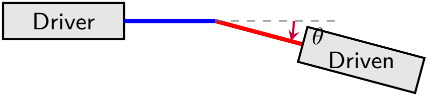
- Parallel (Offset) Misalignment occurs when the shaft centerlines are parallel but offset by a distance. Angular misalignment occurs when the shaft centerlines intersect at an angle.
- Sources of misalignment include dynamic thermal growth of components, piping stress/strain, foundation settling, or poor initial installation tolerances.
- Vibrational Signature: Characterized by strong 2X rotational frequency components in the radial direction (parallel misalignment) and dominant 1X and 2X axial vibration (angular misalignment).
- Phase Behavior: A 180-degree phase shift across the coupling in the axial direction is a classic indicator of angular misalignment.

Visual Representation of Shaft Misalignment I

Offset Coupling



Angular Coupling Deviation



Mechanical Wear and Tribological Faults I

- Wear is the progressive loss of material from the contacting surfaces of relative-moving components, categorized into adhesive, abrasive, fatigue, and corrosive wear.
- Rolling element bearing failure occurs in four distinct stages: Stage 1 starts in the ultrasonic range (250-350 kHz); Stage 2 excites natural frequencies of the bearing structure (500-2000 Hz).
- In Stage 3, bearing defect frequencies (BPFI, BPFO, BSF, FTF) emerge in the vibration spectrum. Stage 4 presents a broad band noise floor and major mechanical clearances.
- Journal bearing wear leads to increased radial clearances, which can cause fluid film instability, such as oil whirl or oil whip, occurring at 0.43X to 0.48X rotational speed.

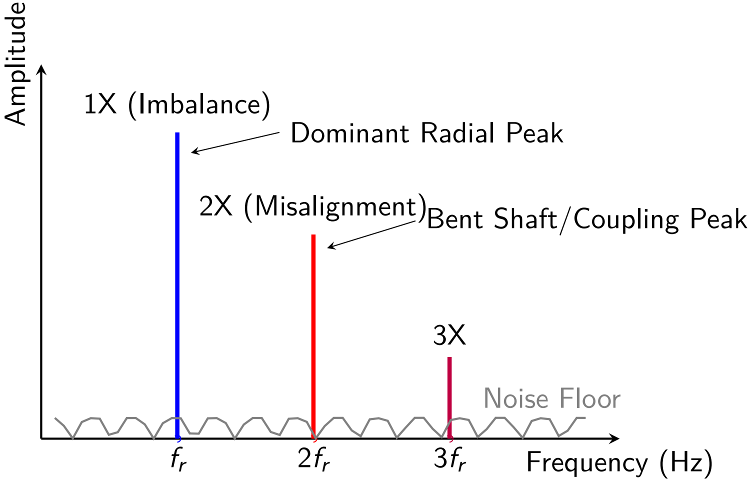
Fluid Leakage and Acoustic Noise Analysis I

- Internal leakages (e.g., across valve seats, hydraulic pistons) degrade thermodynamic efficiency and produce high-frequency turbulent noise.
- External leakages (e.g., flange gaskets, mechanical face seals) cause mass balance losses, pressure drops, and severe safety and environmental hazards.
- Noise Diagnostics: Distinguishes between mechanical noise (impacts, backlash, friction) and aerodynamic noise (turbulent flows, vortex shedding, pressure pulses).
- Acoustic Emission (AE) Testing detects high-frequency transient elastic waves (100 kHz - 1 MHz) from localized sources like micro-crack propagation or fluid leaks.

Vibration Analysis: Sensors & Transducers I

- Displacement Sensors (Eddy Current Probes): Measure relative shaft displacement; ideal for low frequencies ($<$10 Hz) and monitoring shaft orbit inside journal bearings.
- Velocity Transducers: Measure absolute velocity of casing vibration; ideal for intermediate frequencies (10 Hz - 1,000 Hz) using self-generating electromagnetic coils.
- Accelerometers (Piezoelectric): Measure absolute casing acceleration; best suited for high-frequency ranges ($>$1,000 Hz) to detect gear meshing and bearing defects.
- Vibration Severity: Evaluated using root-mean-square (RMS) velocity (mm/s or in/s) according to ISO 10816, which defines levels from 'Good' to 'Unacceptable' based on machine class.

Vibration Signal Interpretation & Spectral Signatures I



Diagnostic Summary & Plant Maintenance Decisions I

- Precision Shaft Alignment: Rectifies angular and parallel offsets using laser alignment tools to maximize bearing and coupling fatigue life.
- Dynamic Field Balancing: Corrects mass distribution faults by calculating and applying correction weights at designated angles on the rotor plane.
- Tribological and Leak Programs: Involves regular ferrography for wear particles and ultrasonic surveys for pneumatic/hydraulic leak detection.
- Predictive Maintenance (PdM) Integration: Combines periodic vibration analysis, acoustic emission tracking, and infrared thermography into a plant-wide monitoring strategy.

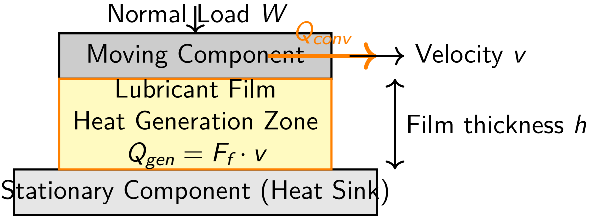
Agenda I

- Introduction to Thermal Diagnostics in Industrial Systems
- Mechanisms and Physics of Overheating in Machinery
- Tribological Fundamentals: Friction and Frictional Heat Generation
- Lubrication Regimes and Lubrication-Related Failure Modes
- Condition Monitoring: Infrared Thermography and Spot Temperature Detection
- Mitigation, Alarm Settings, and Maintenance Actions

Foundations of Thermal Diagnostics I

- Thermal analysis involves tracking the thermodynamic state of machinery using temperature profiles.
- Thermodynamic losses (frictional shear, magnetic hysteresis, windage, electrical resistance) manifest directly as heat energy.
- Diagnostic parameters include: Absolute temperature, differential temperature above ambient (dT), and rate of temperature change (dT/dt).
- Anomalous heat signatures reveal localized structural, electrical, or tribological degradation prior to catastrophic component failure.

Friction Heat Generation Model I



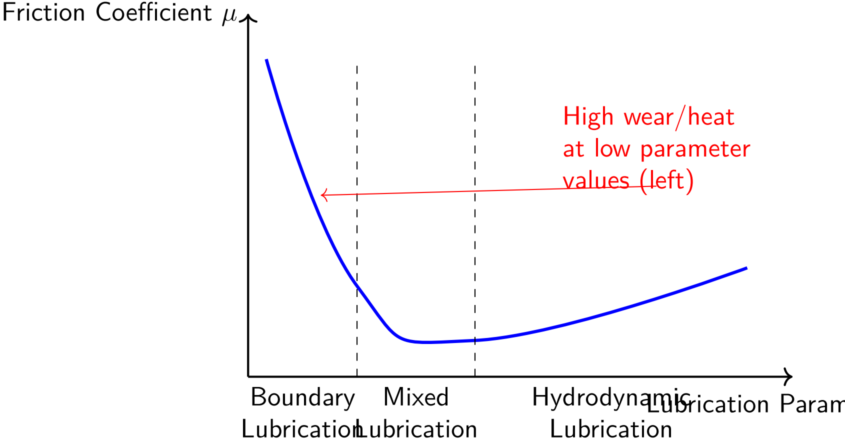
Mechanisms of Machine Overheating I

- Mechanical Overload: Operating machines past their rating raises shear rate, generating excess thermal energy in bearings.
- Misalignment & Unbalance: Misalignment exerts parasitic static/dynamic forces, resulting in high cyclic stresses and localized heat.
- Joule Heating (I^2 * R): Occurs in electrical subsystems due to loose connections, oxidized contacts, or winding insulation degradation.
- Cooling System Degradation: Caused by fouled heat exchanger tubes, clogged cooling fins, low coolant flow, or fan failures.

Tribological Fundamentals & Frictional Heat I

- Frictional Force Equation: $F_f = \mu \cdot N$, where μ is the coefficient of friction and N is the normal load.
- Frictional Power Dissipation: $Q_{gen} = F_f \cdot v = \mu \cdot N \cdot v$, which represents the conversion of mechanical work into heat.
- Contact Asperities: Load is carried by micro-peaks where plastic deformation occurs, creating transient flash temperatures exceeding 1000 degrees C.
- Thermal Runaway: Radial/axial thermal expansion reduces component clearances, increasing contact pressure, friction, and heat in a feedback loop.

Stribeck Curve & Lubrication Regimes I



Lubrication Failure Modes & Thermal Effects I

- Viscosity Thinning: Viscosity drops exponentially with temperature (Vogel's equation), causing film collapse and metal-to-metal contact.
- Lubricant Starvation: Lack of continuous oil/grease supply stops the creation of a fluid film, triggering boundary friction.
- Thermal Oxidation: High temperatures accelerate oil aging. The oxidation rate doubles for every 10 degrees C increase above 70 degrees C.
- Contaminant Entrainment: Hard particulates or water contamination decreases film strength, accelerating wear and heat generation.

Infrared Thermography & Thermal Monitoring I

- Infrared Thermography (IRT): Captured infrared radiation is processed to produce 2D thermal maps showing equipment heat distribution.
- Stefan-Boltzmann Law: $E = \epsilon \cdot \sigma \cdot T^4$. Knowing target emissivity (ϵ) is critical for accurate temperature calculation.
- Qualitative Thermography: Involves comparing identical equipment or symmetrical parts to find relative hot spots or heat anomalies.
- Quantitative Thermography: Employs absolute temperature calculations to assess severity against ISO standards (e.g., ISO 18434-1).

Mitigation & Corrective Actions I

- Lubricant Engineering: Use high Viscosity Index (VI) oils and synthetic formulations for high-temperature and variable environments.
- Precision Maintenance: Implement regular laser alignments and balancing to reduce parasitic forces and structural heating.
- Heat Dissipation Optimization: Clean dust from motor cooling fins, clear heat exchanger fouling, and verify cooling fan operation.
- Alarm Thresholds: Establish baseline temperature trends and set limits: advisory (+10C), warning (+20C), and critical (+30C) above normal.

Agenda I

- Introduction to Thermodynamic Fault Tracing
- Systematic Troubleshooting Procedures (Symptom-Cause-Action)
- Root Cause Analysis (RCA) Methodologies
- The 5-Whys and Fishbone Diagram for Thermal Systems
- Failure Mode and Effects Analysis (FMEA) in Plant Maintenance
- Fault Tree Analysis (FTA) & Diagrammatic Troubleshooting Loop
- Corrective and Preventive Actions (CAPA) Framework
- Case Study: Boiler Tube Failure Analysis & Cause-Effect Fishbone
- Diagnostics Tools: Infrared Thermography & Vibration Analysis
- Summary and Key Engineering Takeaways

Introduction to Thermodynamic Fault Tracing I

- Thermodynamic fault tracing involves identifying deviations from design-point performance (e.g., changes in temperature, pressure, and mass flow rate).
- Faults in thermal power plants can be categorized as structural (e.g., pipe leaks, fouling) or operational (e.g., control valve failure, incorrect fuel-to-air ratio).
- First Law of Thermodynamics (Energy Conservation) is used to track energy losses (enthalpy drops) across components like turbines and compressors.
- Second Law of Thermodynamics (Entropy Generation / Exergy Destruction) helps identify the exact location of irreversibilities and degradation.

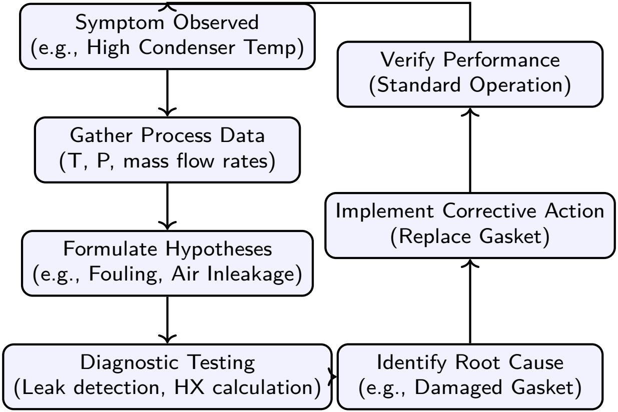
Systematic Troubleshooting Procedure I

- Step 1: Symptom Identification - Observe anomalies in process parameters (e.g., high condenser backpressure, low superheater exit temperature).
- Step 2: Information Gathering - Extract real-time sensor data from SCADA/DCS systems and check historical maintenance logs.
- Step 3: Hypothesis Generation - Formulate potential failure modes based on physical thermodynamic constraints.
- Step 4: Testing & Verification - Conduct non-destructive testing (NDT), isolate components, or vary boundary conditions to verify the hypothesis.
- Step 5: Corrective Action - Execute repairs, component replacement, or process recalibration.

Systematic Troubleshooting Procedure II

- Step 6: Follow-up & Documentation - Monitor system recovery and log the event in the Computerized Maintenance Management System (CMMS).

Troubleshooting Loop Flowchart I



Root Cause Analysis (RCA) Methodologies I

- Root Cause Analysis (RCA) is a structured problem-solving method targeting the initiating cause of a failure rather than just addressing symptoms.
- Physical Root Cause: Material or physical component degradation (e.g., fatigue failure of a turbine blade due to resonant vibration).
- Human Root Cause: Errors in operation or maintenance execution (e.g., overtightening a flange causing gasket failure).
- Latent/Organizational Root Cause: Failure of systems, procedures, or training (e.g., lack of periodic calibration schedules for temperature sensors).
- RCA Tools: Include Ishikawa (Fishbone) Diagrams, 5-Whys Technique, Barrier Analysis, and Change Analysis.

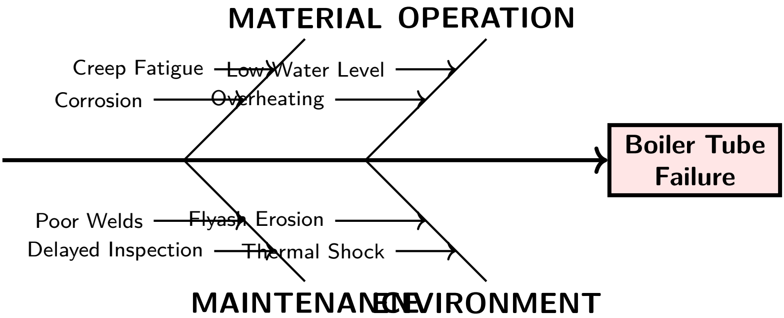
The 5-Whys and Ishikawa Methodologies I

- The 5-Whys technique involves repeatedly asking 'Why' to peel back layers of symptoms to expose the core systemic failure.
- Example: 1. Why did the turbine trip? High bearing temperature. 2. Why was it hot? Loss of lubrication. 3. Why did lube oil fail? Pump motor tripped. 4. Why did it trip? Overcurrent. 5. Why overcurrent? Oil filter was completely clogged (root cause).
- Ishikawa (Fishbone) Diagram categorizes potential causes into categories: People, Methods, Machines, Materials, Measurements, and Environment (the 6Ms).
- In thermal plants, 'Machines' focuses on valves, pumps, exchangers; 'Measurements' focus on thermocouple drift or pressure transmitter calibration.

Failure Mode and Effects Analysis (FMEA) I

- FMEA is a proactive, structured approach to identify potential failure modes and evaluate their causes and plant-wide impacts.
- Risk Priority Number (RPN) is calculated as: RPN = Severity (S) x Occurrence (O) x Detection (D).
- Severity (S) measures the impact of the failure on plant safety, performance, and revenue.
- Occurrence (O) estimates the probability or frequency of the failure mode occurring.
- Detection (D) rates the likelihood of identifying the fault before component or system failure occurs.
- High RPN items are prioritized for immediate corrective actions or preventive maintenance redesigns.

Boiler Tube Failure Fishbone Diagram I



Corrective and Preventive Actions (CAPA) I

- Corrective Actions target existing failures to prevent recurrence (e.g., redesigning boiler support structures to allow thermal expansion).
- Preventive Actions target potential failures before they happen (e.g., installing online sensor arrays to monitor real-time wall thickness).
- Verification of Effectiveness: Requires monitoring thermal efficiency, heat rate, and emissions to ensure post-remedy performance is restored.
- Feedback Loop: Updates must be integrated into standard operating procedures (SOPs) and training manuals to sustain reliability gains.

Agenda I

- Overview of Industrial Safety and Plant Maintenance Hazards
- Mechanical Hazards: Kinematics of Machinery, Pinch Points, and Guarding
- Electrical Hazards: Shock Mechanisms, Arc Flash, and Thermal Damage
- Chemical Hazards: Toxicity, Flammability, and Vapor Cloud Explosions
- Fire Hazards: Thermodynamics of Combustion, Fire Triangle, and Classification
- Risk Mitigation: The Hierarchy of Safety Controls

Mechanical Hazards: Kinematics of Machinery & Pinch Points I

- Point of Operation: The area where work is performed on the material, such as cutting, shaping, boring, or forming.
- Power Transmission Apparatus: Components of the mechanical system that transmit energy, including flywheels, pulleys, belts, connecting rods, couplings, cam mechanisms, and gears.
- In-Running Nip Points (Pinch Points): Created by rotating parts turning in opposite directions, or between rotating and tangentially moving parts (e.g., belt and pulley, chain and sprocket, gear mesh).
- Transverse Motions: Straight-line continuous motion where a worker may be struck or caught in a pinch or shear point between a moving part and a fixed structure.

Mechanical Hazards: Kinematics of Machinery & Pinch Points II

- Engineering Safeguards: Fixed guards, interlocked guards, adjustable guards, and self-adjusting guards, supplemented by presence-sensing devices (light curtains, pressure-sensitive mats).

Electrical Hazards: Shock, Arc Flash, and Thermal Energy I

- Electric Shock Physiology: Current pathways through the human body. As little as 10 mA can cause muscle contraction ('let-go' threshold); 50-100 mA can cause ventricular fibrillation; above 1 A causes cardiac arrest and severe internal burns.
- Ohm's Law in Safety: $I = V/R$. Dry skin resistance is 100,000 to 600,000 Ohms, while wet skin drops to 1,000 Ohms or less, dramatically increasing current for a given voltage.
- Arc Flash & Arc Blast: High-energy electric arcs vaporize conductors, causing explosive expansion (arc blast pressure wave) and extreme thermal radiation (up to 35,000 F / 19,400 C).

Electrical Hazards: Shock, Arc Flash, and Thermal Energy II

- Electrostatic Discharges (ESD): Spark ignition hazards in explosive atmospheres. Accumulation of static charge on non-conductive surfaces or isolated conductors can discharge with enough energy to ignite vapor-air mixtures.
- Mitigation Strategies: Lockout/Tagout (LOTO) protocols, Ground Fault Circuit Interrupters (GFCI), double-insulated tools, and National Electrical Code (NEC) compliance.

Chemical Hazards: Classification & Toxicological Action I

- Toxicity and Route of Entry: Chemical agents enter the body via inhalation, ingestion, dermal absorption, or injection. Quantified by LD50 (Lethal Dose 50%) and LC50 (Lethal Concentration 50%) metrics.
- Corrosives, Irritants, and Sensitizers: Acids/bases (pH < 2 or > 12.5) that destroy tissue, substances causing inflammation, and allergens that induce hyper-sensitivity reactions over time.
- Asphyxiants: Simple asphyxiants (nitrogen, helium) displace oxygen in air; chemical asphyxiants (carbon monoxide, hydrogen cyanide) interfere with cellular oxygen transport.
- Vapor Cloud Explosions (VCE) and BLEVE: Boiling Liquid Expanding Vapor Explosion (BLEVE) occurs when a pressurized vessel containing liquid above its atmospheric boiling point catastrophically ruptures.

Chemical Hazards: Classification & Toxicological Action II

- Safety Data Sheets (SDS): 16-section standardized documents detailing chemical properties, hazards, handling, storage, exposure controls, and emergency response.

Fire Hazards: Thermodynamics of Combustion I

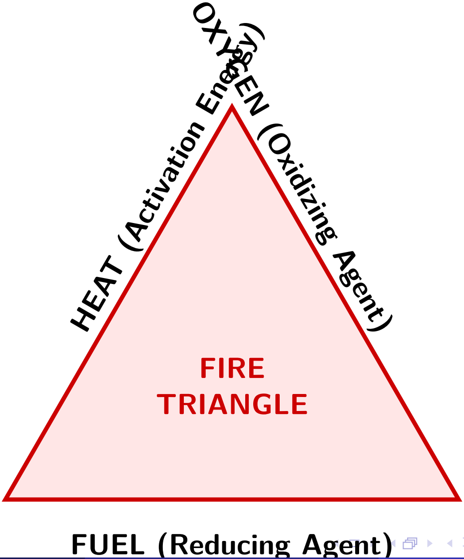
- Combustion Chemistry: Rapid exothermic oxidation of a fuel, releasing heat, light, and reaction products. Requires fuel, oxidizer, thermal energy, and self-sustained chemical chain reaction.
- Flash Point vs. Fire Point: Flash point is the lowest temperature at which a liquid produces sufficient vapor to form an ignitable mixture with air. Fire point is the temperature at which sustained combustion occurs.
- Autoignition Temperature: The minimum temperature required to initiate or cause self-sustained combustion in any substance without an external spark or flame.
- Flammability Limits: Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL) define the concentration range of flammable vapor in air within which combustion can occur.

Fire Hazards: Thermodynamics of Combustion II

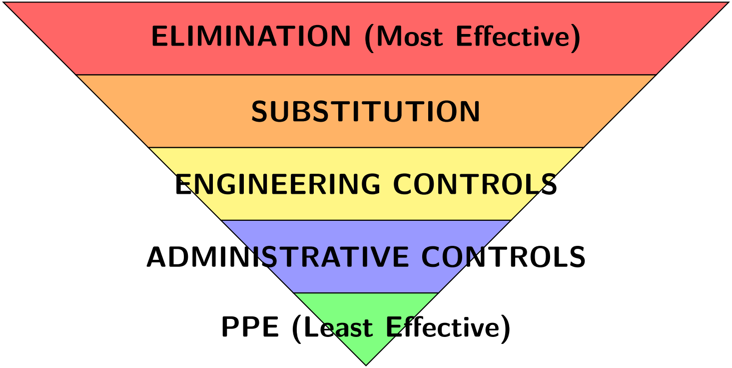
- Thermodynamic Heat Release Rate (HRR): Measured in kW or MW, HRR is the single most important variable in defining fire hazard, determining fire growth rate and time to flashover.

The Fire Triangle: Essential Components of Combustion I

The Fire Triangle: Essential Components of Combustion II



Risk Mitigation: The Hierarchy of Controls I



Fire Classification and Extinguishing Agents I

- Class A Fires: Common combustibles (wood, paper, trash). Extinguished by cooling with water or dry chemical agents.
- Class B Fires: Flammable liquids and gases (gasoline, propane, solvents). Extinguished by smothering (carbon dioxide, foam) or interrupting the chain reaction (dry chemicals).
- Class C Fires: Energized electrical equipment. Requires non-conductive extinguishing agents (CO2, halon alternatives, dry chemical) to prevent operator shock.
- Class D Fires: Combustible metals (magnesium, sodium, titanium). Requires dry powder agents (e.g., sodium chloride-based) that form a crust to exclude oxygen; water must NEVER be used.
- Class K Fires: Commercial cooking oils and fats. Extinguished using wet chemical agents that undergo saponification, creating a soapy foam layer that cools and smothers the fire.

Summary & Plant Maintenance Best Practices I

- Plant maintenance and hazard control are intrinsically linked; proper preventive maintenance reduces equipment failure risks.
- A multi-disciplinary approach addressing mechanical, electrical, chemical, and fire safety is essential for zero-accident cultures.
- Implementation of standard operating procedures, routine safety audits, and continuous worker training.
- Adherence to international standards: OSHA guidelines, NFPA codes, and local safety legislation.

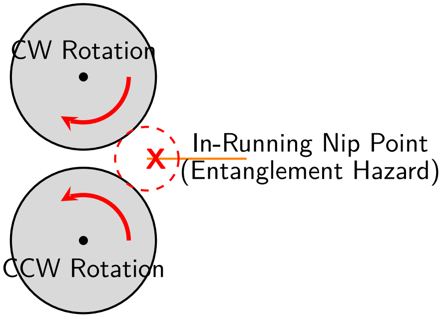
Agenda I

- Classification of industrial hazards and risk assessment frameworks
- Mechanical hazards: key danger zones, motion types, and physical safeguarding mechanisms
- Electrical hazards: physiological shock thresholds, arc flash phenomena, and grounding systems
- Chemical hazards: toxicological routes of exposure, Permissible Exposure Limits (PEL), and Safety Data Sheets (SDS)
- Fire hazards: the fire tetrahedron, classification of fires (Classes A, B, C, D, K), and suppression techniques

Mechanical Hazards: Motion and Mechanisms I

- Mechanical hazards are associated with relative motion between machine components, tools, or processed workpieces.
- Point of Operation: The specific area where work (cutting, shearing, shaping, drilling) is actively performed on materials.
- Power Transmission Apparatus: Components that transmit energy to the point of operation, including flywheels, pulleys, belts, shafts, and gears.
- Motion Types: Rotating (spindles, shafts), reciprocating (back-and-forth slides), transverse (moving belts in straight lines), and in-running nip points.
- Typical Injuries: Entanglement (loose clothing caught in rotating shafts), crushing (press rams), shearing (guillotine blades), and punctures.

Diagram: In-Running Nip Point Hazard I



Electrical Hazards: Shock and Arc Flash I

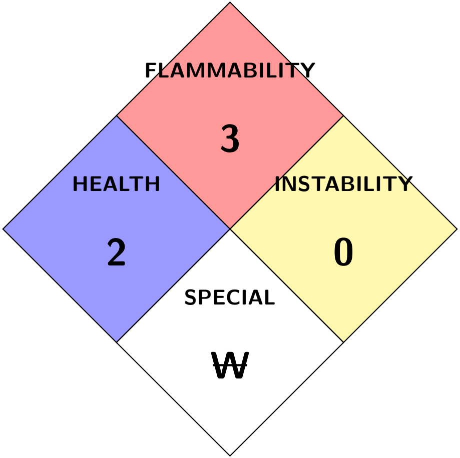
- Physiological Shock Thresholds (at 50/60 Hz AC): Current levels dictate severity. 1 mA is the threshold of perception; 10-20 mA is the 'let-go' threshold causing muscle contraction; 50-100 mA causes ventricular fibrillation and can be fatal; $>$1000 mA causes severe internal/external burns and cardiac arrest.
- Electrical Burns: Occur via Joule heating (current path through tissue) or external thermal energy from an arc blast.
- Arc Flash & Arc Blast: Explosive release of electrical energy across an air gap. Temperatures can reach 20,000 Kelvin, vaporizing metal, producing shockwaves, and causing severe radiation burns.

- Control Strategies: Use of Ground Fault Circuit Interrupters (GFCI) to detect current imbalances, double insulation on hand-held tools, and strict adherence to NFPA 70E work practices.

Chemical Hazards: Toxicology and Exposure Limits I

- Industrial chemicals are categorized by their hazardous properties: Corrosives (acids/alkalis), Toxins (systemic poisons), Flammables, Reactives (oxidizers, water-reactive), and Carcinogens.
- Routes of Exposure: Inhalation (respiratory entry of gases/vapors/dusts), dermal absorption (skin contact), ingestion (contaminants on food/hands), and injection.
- Dose-Response Metric: Threshold Limit Values (TLV) and Permissible Exposure Limits (PEL) define time-weighted averages (TWA) for safe worker exposure over an 8-hour shift.
- Safety Data Sheet (SDS): A standard 16-section document required under GHS (Globally Harmonized System) providing comprehensive data on chemical properties, hazards, handling, storage, and first-aid.

Diagram: NFPA 704 Hazard Classification System I



Fire Hazards: The Science of Combustion I

- The Fire Tetrahedron: Combustion is a rapid oxidation process requiring four concurrent components: Fuel (reducing agent), Oxygen (oxidizing agent), Heat (activation energy), and an Uninhibited Chemical Chain Reaction.
- Class A Fires: Wood, paper, textiles, and trash. Extinguished primarily by cooling with water.
- Class B Fires: Flammable liquids, oils, greases, tars, and gases. Extinguished by smothering (carbon dioxide, dry chemical, or foam).
- Class C Fires: Energized electrical equipment. Requires non-conductive extinguishing agents (CO2 or dry chemical).
- Class D & K Fires: Class D involves combustible metals (magnesium, sodium) requiring dry powder; Class K involves cooking media (fats/oils) requiring wet chemical agents.

- Hierarchy of Hazard Controls: 1. Elimination (redesign process to remove hazards), 2. Substitution (use less toxic chemicals), 3. Engineering Controls (physical barriers, local exhaust ventilation), 4. Administrative Controls (procedures, training, LOTO), 5. PPE (safety glasses, respirators, steel-toed boots).
- Lockout/Tagout (LOTO): A strict protocol (OSHA 1910.147) where energy isolation devices are locked and tagged during maintenance to prevent accidental machine start-up.
- Local Exhaust Ventilation (LEV): Engineering system designed to capture contaminants at the point of release before they enter the breathing zone of the operator.
- Industrial Fire Suppression: Sprinklers, deluge systems, carbon dioxide systems for electrical vaults, and clean agent systems (FM-200) that interrupt the chemical chain reaction without leaving residue.

Summary and Review Questions I

- Summary: Plant maintenance engineers must systematically identify, assess, and control mechanical, electrical, chemical, and fire hazards to ensure personnel safety and reduce downtime costs.
- Review Question 1: Describe the hierarchy of hazard controls and explain why Personal Protective Equipment (PPE) is considered the last line of defense.
- Review Question 2: In the context of industrial fire safety, explain how the extinguishing action of carbon dioxide differs from that of a clean agent suppressant on the fire tetrahedron.

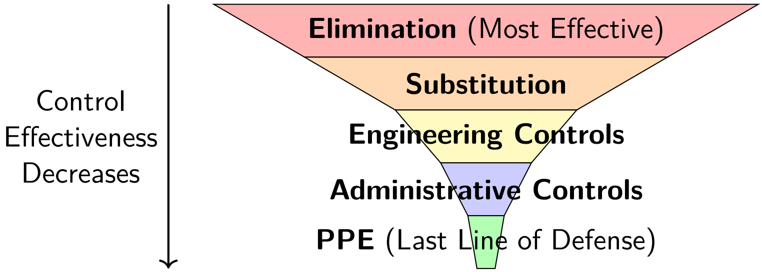
Agenda I

- Introduction to Industrial Safety and the Hierarchy of Hazard Controls
- Head, Eye, and Face Protection: Standards and Plant Hazards
- Hearing and Respiratory Protection: Noise Reduction Ratings and Filtration
- Hand, Foot, and Body Protection: Material Selection and Arc Flash Hazards
- Safe Working Practices: Lockout/Tagout (LOTO) Energy Isolation
- Permit to Work (PTW), Job Safety Analysis (JSA), and Confined Space Entry

Industrial Safety & Hierarchy of Controls I

- Industrial safety in mechanical plants protects human lives and maintains plant asset integrity.
- The Hierarchy of Hazard Controls specifies five tiers of safety measures sorted by effectiveness.
- 1. Elimination: Removing the hazard entirely from the workspace.
- 2. Substitution: Replacing hazardous materials or processes with safer alternatives.
- 3. Engineering Controls: Isolating personnel from hazards using guards, ventilation, or shields.
- 4. Administrative Controls: Modifying work schedules, policies, signage, and training protocols.
- 5. Personal Protective Equipment (PPE): Wearable protective barriers, considered the last line of defense.

Hierarchy of Controls Diagram I



Head, Eye, and Face Protection I

- Head Protection: ANSI Z89.1 standards categorize hard hats into Class G (General, up to 2,200V), Class E (Electrical, up to 20,000V), and Class C (Conductive, no electrical protection).
- Eye and Face Protection: ANSI Z87.1 standards cover safety glasses, splash-resistant goggles, and full-face shields.
- Plant applications: Goggles protect against chemical splashes during water treatment plant maintenance.
- Thermal protection: Face shields are critical when inspecting boiler furnace sight-glasses to protect against radiant heat and potential blowback.

Hearing & Respiratory Protection I

- Hearing protection is dictated by noise levels and exposure times. OSHA limits continuous exposure to 90 dBA over an 8-hour shift.
- Protective devices include earplugs and earmuffs, characterized by their Noise Reduction Rating (NRR). High-noise zones (compressor rooms, turbine halls) require double hearing protection.
- Respiratory protection prevents inhalation of toxic dusts, metal fumes, and hazardous gases.
- Types of respirators: Air-purifying respirators (using particulate filters like N95/P100 or chemical cartridges) and Atmosphere-supplying respirators (SCBA).

Hand, Foot & Body Protection I

- Hand Protection: Materials include leather (abrasion/heat), nitrile (chemicals/oils), Kevlar (cuts/punctures), and dielectric rubber (electrical safety).
- Foot Protection: ASTM F2413 standards define specifications for protective footwear. Safety boots must feature steel/composite toes, slip-resistant soles, and puncture-resistant plates.
- Body Protection: Heavy-duty cotton or Flame-Resistant (FR) clothing (Nomex) is required in electrical arc flash or flash fire risk areas.
- Plant Maintenance: When handling steam lines, thermal protective sleeves and insulated gloves prevent severe conductive heat transfer burns.

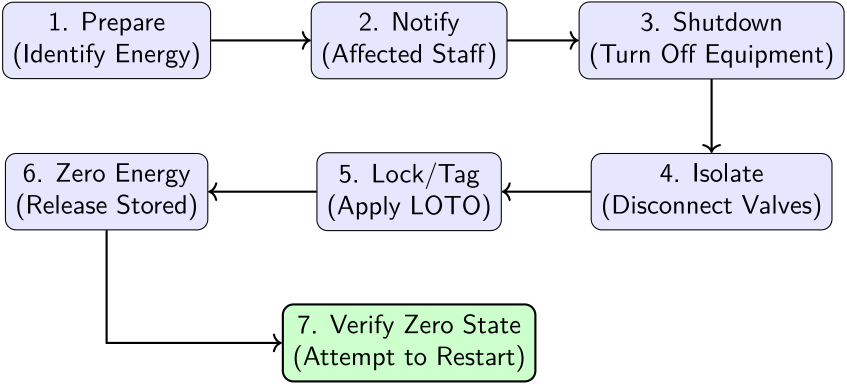
Lockout/Tagout (LOTO) Procedures I

- Lockout/Tagout (LOTO) is a standardized safety procedure under OSHA 1910.147 to prevent accidental machine startup during maintenance.
- LOTO isolates multiple energy sources: Electrical (breakers), Pneumatic/Hydraulic (valves), Thermal (steam/hot water lines), and Kinetic/Potential (springs, gravity).
- The 7 essential steps of LOTO:
- 1. Preparation: Identify all energy sources and isolation points.
- 2. Notification: Alert all affected employees of the shutdown.
- 3. Shutdown: Power down the system using standard procedures.
- 4. Isolation: De-energize and disconnect all energy sources.
- 5. LOTO Application: Apply personal padlocks and danger tags to each isolation device.

Lockout/Tagout (LOTO) Procedures II

- 6. Stored Energy Release: Bleed off pressure, drain lines, discharge capacitors, block gravity loads.
- 7. Verification: Attempt to restart the equipment locally to confirm a zero-energy state before starting work.

Lockout/Tagout (LOTO) Workflow I



Safe Working Practices & Permit to Work I

- Job Safety Analysis (JSA): A protocol to break down a maintenance task into steps, identify hazards at each step, and define preventive measures.
- Permit to Work (PTW): A formal, written authority used to control high-risk activities. Examples include Hot Work Permits, Confined Space Entry Permits, and Working at Heights Permits.
- Confined Space Safety: Requires atmospheric testing for oxygen levels (optimal 19.5% to 23.5%), flammability, and toxic gases before entry.
- Summary: Safety is built on rigorous adherence to LOTO, continuous atmosphere monitoring, proper tool selection, and wearing certified, well-maintained PPE.

Agenda I

- Introduction to Industrial Safety Signs & ISO 7010 Standards
- Geometric Shapes, Safety Colours, and Safety Meanings
- Industrial Safety Signals: Acoustic and Visual/Light Indicators
- ANSI/ASME A13.1 Piping Identification and Marker Layouts
- NFPA 704 Hazard Identification System (Fire Diamond)
- Operational Rules for Plant Signage Placement and Maintenance

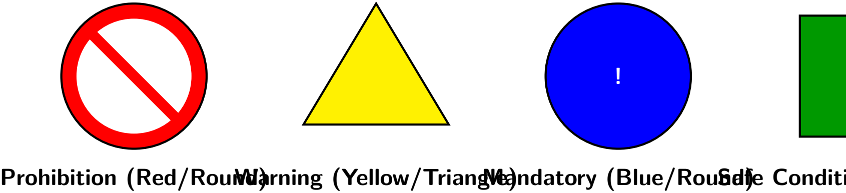
ISO 7010 Safety Sign Categorization I

- Prohibition Signs: Circular shape, red border and crossbar on a white background with a black pictogram. Indicates actions that must not be taken (e.g., No Smoking, Do Not Enter).
- Warning Signs: Triangular shape, black border on a yellow background with a black pictogram. Warns of hazards or dangerous conditions (e.g., High Voltage, Toxic Material, Hot Surface).
- Mandatory Action Signs: Circular shape, solid blue background with a white pictogram. Specifies actions required to avoid injury (e.g., Wear Safety Goggles, Eye Protection Required).
- Safe Condition Signs: Rectangular/square shape, solid green background with a white pictogram. Identifies safety routes, first aid, emergency equipment, or evacuation exits.

ISO 7010 Safety Sign Categorization II

- Fire Safety Signs: Rectangular/square shape, solid red background with a white pictogram. Locates fire-fighting equipment (e.g., Fire Extinguishers, Fire Hoses).

ISO 7010 Geometric Shapes and Color Code Standards I



Industrial Safety Signals: Acoustic & Visual I

- Acoustic Signals: Horns, sirens, and buzzers used for immediate evacuation, fire, or machine start warnings. Sound levels must be at least 15 dB above the ambient noise level, or 5 dB above any maximum noise level lasting for at least 30 seconds.
- Acoustic Signal Characteristics: Continuous tone indicates a stable safety alert or standby warning. Variable or intermittent tone indicates a high-level hazard or urgent action (e.g., immediate evacuation).
- Light Signals: Beacons or strobe lights. Must create a high contrast with the environment. Red flashing lights indicate extreme danger; amber/yellow indicates caution or system standby; green indicates normal operation.

Industrial Safety Signals: Acoustic & Visual II

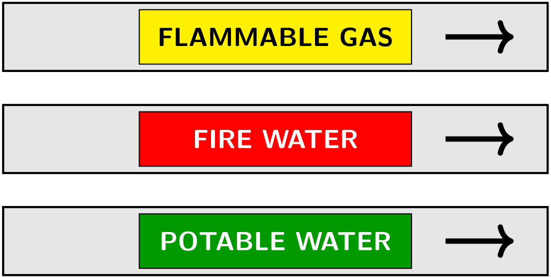
- Combination of Signals: Acoustic and light signals are synchronized to ensure perception by workers with hearing or visual impairments, and in high-noise or poor-visibility environments.

Piping System Identification (ANSI/ASME A13.1) I

- ANSI/ASME A13.1 is the standard for identifying piping systems in industrial facilities based on fluid hazards.
- Fire Quenching Fluids: Red background with white lettering. Applies to fire sprinkler systems, fire water lines, and standpipes.
- Toxic and Corrosive Fluids: Orange background with black lettering. Used for acids, bases, and highly toxic chemical piping.
- Flammable and Oxidizing Fluids: Yellow background with black lettering. Includes natural gas, fuel oils, butane, and high-pressure steam.
- Combustible Fluids: Brown background with white lettering. Typically used for low-risk combustible liquids like diesel fuel.

Piping System Identification (ANSI/ASME A13.1) II

- Water (Potable, cooling, boiler feed): Green background with white lettering. Used for non-hazardous water lines.
- Compressed Air: Blue background with white lettering. Used for instrument air and utility air systems.



Yellow: Flammable/Combu

Red: Fire Quenching Fluids

Green: Potable/Cooling Wa

NFPA 704 Hazard Identification (Fire Diamond) I

- NFPA 704 standard uses a color-coded diamond (commonly known as the 'safety square' or 'fire diamond') to quickly identify chemical hazards.
- Health Hazard (Blue - Left): Rating from 0 (normal material) to 4 (deadly). Indicates potential health risks from exposure.
- Flammability Hazard (Red - Top): Rating from 0 (will not burn) to 4 (highly flammable liquid or gas with flashpoint below 73 F / 23 C).
- Instability/Reactivity Hazard (Yellow - Right): Rating from 0 (stable) to 4 (capable of detonation or explosive decomposition at normal temperatures and pressures).
- Special Hazard (White - Bottom): Contains symbols for specific hazards. 'W' with a line through it indicates unusual reactivity with water; 'OX' indicates an oxidizer; 'SA' indicates simple asphyxiant gas.

Sign Installation & Maintenance Guidelines I

- Sign Placement: Safety signs must be placed at eye level and under good illumination at the entrance to hazardous areas or directly adjacent to hazards.
- Maintenance of Signage: Regulated by OSHA and industrial safety acts. Signs must be cleaned, replaced when faded, and kept free from obstruction.
- Training Requirements: Workers must be trained to recognize and interpret safety signs, acoustic warnings, and piping codes within the plant.
- Auditory System Testing: Plant emergency sirens must be tested regularly with pre-announced schedules to verify function and avoid worker panic.

Lecture Summary & Key Takeaways I

- Standardized shapes and colors (ISO 7010) eliminate language barriers, enabling quick hazard recognition and immediate emergency response.
- Piping codes (ANSI/ASME A13.1) and chemical labels (NFPA 704) provide plant operators and emergency responders with critical substance information.
- Effective plant maintenance relies on the visibility, durability, and systematic installation of safety signs and signals.
- Continuous auditing and safety training are mandatory to ensure that all plant personnel understand and adhere to safety codes.

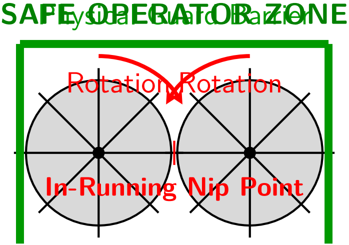
Agenda I

- Principles of Industrial Machine Guarding
- Classification of Safety Guards (Fixed, Interlocked, Adjustable)
- Diagram: Point of Hazard & Mechanical Protective Guarding
- Introduction to Lockout-Tagout (LOTO) Regulations (OSHA 1910.147)
- The Six Steps of LOTO Isolation Procedure
- Diagram: Sequential Process Flow of Lockout-Tagout Operations
- Energy Isolation Types (Electrical, Thermal, Fluid Power)
- Key Safety Rules and Plant Management Standards

Principles of Machine Guarding I

- Machine guarding is a safety feature on devices consisting of a shield or cover over hazardous areas.
- Its primary purpose is to protect operators from hazards created by point of operation, ingoing nip points, and rotating parts.
- Guards must prevent hand or body contact, be secured to prevent tampering, and create no new hazards.
- Common hazard points include shear points, cutting edges, drawing-in points, and rotating shafts.
- Guarding is the first line of physical defense in the hierarchy of hazard controls (Engineering Controls).

Point of Hazard & Guard Barrier I



Classification of Machine Guards I

- Fixed Guards: Permanent barriers that are a physical part of the machine, removable only with tools.
- Interlocked Guards: Barriers shut off or disengage power automatically when opened, preventing machine restart.
- Adjustable Guards: Barriers that can be adjusted to fit different sizes or shapes of workpieces.
- Self-Adjusting Guards: Moveable barriers pushed open by the stock, automatically returning to the closed position.
- Presence Sensing Devices: Photoelectric, radiofrequency, or electromechanical sensors that stop operation if tripped.

Lockout-Tagout (LOTO) Overview I

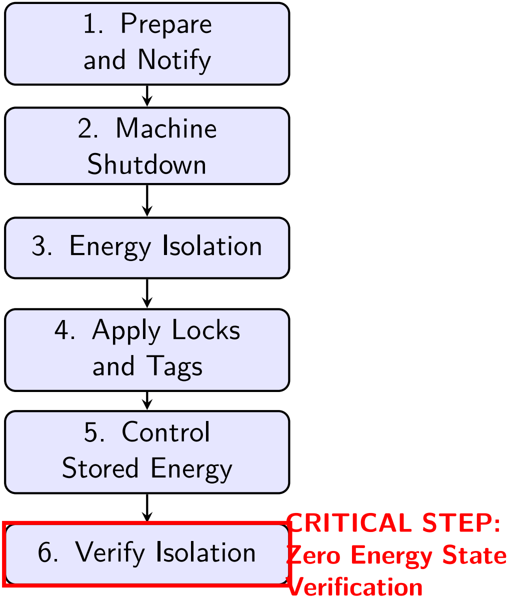
- Lockout-Tagout (LOTO) is a safety procedure used to ensure that machines are shut down and inoperable during maintenance.
- Governed by OSHA Standard 29 CFR 1910.147 for controlling hazardous energy sources.
- Protects service technicians from accidental startup or release of stored energy during inspections.
- Lockout involves placing a physical padlock on energy-isolating devices so energy cannot be restored.
- Tagout involves attaching a prominent warning label (tag) explaining why the machine is locked out.

The 6 Steps of LOTO Procedure I

- 1. Preparation: Identify all hazardous energy sources and notify all affected employees.
- 2. Shutdown: Turn off the machine using the manufacturer's normal operating procedures.
- 3. Isolation: Locate and operate all energy-isolating devices (e.g. circuit breakers, valves, switches) to shut off power.
- 4. Application: Apply authorized personal locks and tags to each energy-isolating device.
- 5. Stored Energy Control: Safely release or restrain stored/residual energy (vent air lines, drain hydraulics, block weights).
- 6. Verification: Attempt to turn on the machine using normal controls to confirm zero-energy state, then return to 'off'.

LOTO Sequential Flowchart I

LOTO Sequential Flowchart II



Thermodynamic and Fluid Energy Isolation I

- Thermal Energy: Isolation of steam, superheated fluids, or cryogenic lines requires block valves and cooling periods.
- Hydraulic Systems: Must discharge accumulators, vent high-pressure lines, and secure physical blocks on rams.
- Pneumatic Systems: Requires purging of receiver tanks, isolation of air supply, and blocking pneumatic actuators.
- Chemical/Process Systems: Flush and purge toxic/flammable fluids; implement double block and bleed configurations.
- Gravity/Stored Mechanical Energy: Securely pin, brace, block, or lower any raised loads or counterweights.

LOTO Rules and Plant Best Practices I

- Key Golden Rule: 'One person, one lock, one key' - every worker must place their own lock on the hasp.
- Never allow another worker to remove your lock, and never remove a lock that does not belong to you.
- Establish clear distinction between 'Authorized' employees (who perform LOTO) and 'Affected' employees (who use the machines).
- Perform regular, documented safety audits of LOTO procedures and equipment once per year.
- Design new systems for safety: incorporate easily accessible isolation points and built-in interlocks.

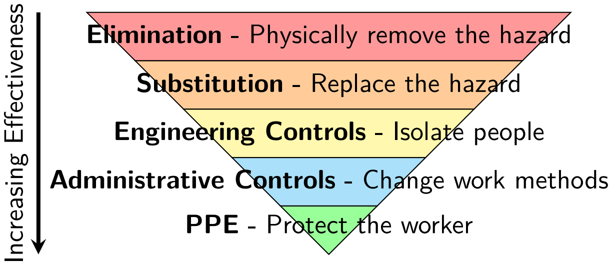
Agenda I

- Industrial Safety Standards & Regulations
- Hierarchy of Hazard Controls
- Lockout/Tagout (LOTO) Procedures
- Fire Hazards & Extinguisher Classes
- Chemical Hazard Label Components (GHS)
- Personal Protective Equipment (PPE)
- Emergency Action Plans & Response
- Safety Summary & Best Practices

Industrial Safety Standards & Regulations I

- OSHA (Occupational Safety and Health Administration) compliance represents the legally binding baseline for industrial environments.
- ISO 45001 specifies requirements for an Occupational Health and Safety (OH&S) management system to prevent work-related injury and ill health.
- Safety indicators are categorized into Leading Indicators (proactive measures like safety audits) and Lagging Indicators (reactive metrics like Lost Time Injury Frequency Rate - LTIFR).
- Employers must maintain OSHA 300 logs for recording occupational injuries and illnesses based on severity and work-relatedness.

Hierarchy of Hazard Controls I



Lockout/Tagout (LOTO) Procedures I

- Lockout/Tagout (LOTO) under OSHA 29 CFR 1910.147 prevents the unexpected energization or startup of machinery during maintenance.
- The process begins with preparation and notification of all affected employees regarding the shutdown.
- Energy isolation involves turning off circuit breakers, closing valves, and disconnecting lines.
- Locks and tags are applied to energy-isolating devices. Each lock must be uniquely keyed to an authorized employee.
- Residual energy (e.g., electrical charge in capacitors, hydraulic pressure, spring tension) must be safely dissipated or restrained.
- Verification of isolation is the critical final step: attempting to restart the equipment to confirm zero energy state before starting work.

Fire Hazards & Extinguisher Classes I

- Fire requires three elements: fuel, oxygen, and heat (the Fire Triangle), plus an uninhibited chain reaction (the Fire Tetrahedron).
- Class A Fires: Common combustibles (wood, paper, trash). Extinguished using water or multi-purpose dry chemical.
- Class B Fires: Flammable liquids and gases (gasoline, propane, oil-based paints). Extinguished by smothering oxygen (CO2, dry chemical).
- Class C Fires: Energized electrical equipment. Requires non-conductive extinguishing agents (CO2, clean agents).
- Class D Fires: Combustible metals (magnesium, titanium, sodium). Requires specialized dry powder agents.
- Class K Fires: Cooking media (vegetable oils, animal fats in commercial kitchens). Extinguished using wet chemical agents.

Chemical Hazard Label Components (GHS) I

Product Identifier: Hexane (UN 1208)

SIGNAL WORD: DANGER

Flame

Hazard Statements:

- Highly flammable liquid and vapor.
- Causes skin irritation.
- May cause drowsiness or dizziness.

Health

Precautionary Statements:

- Keep away from heat, sparks, open flames.
- Wear protective gloves/eye protection.
- IF ON SKIN: Wash with plenty of water.

Supplier: SafeChem Inc., Ph: 800-555-0199

Personal Protective Equipment (PPE) I

- PPE represents the final line of defense in the Hierarchy of Controls, utilized when hazards cannot be engineered out.
- Head Protection: ANSI Z89.1 Hard Hats (Class G for general, Class E for electrical up to 20,000V, Class C for conductive).
- Eye and Face Protection: ANSI Z87.1 certified safety glasses, goggles, or face shields selected based on impact, splash, or radiation hazard.
- Respiratory Protection: Selected based on the Assigned Protection Factor (APF). Requires qualitative or quantitative fit testing.
- Foot Protection: ASTM F2413 certified steel or composite toe boots, with specific ratings for electrical hazard (EH) or static dissipation.

Personal Protective Equipment (PPE) II

- Hand Protection: Chemical-resistant gloves (nitrile, neoprene) must be selected based on permeation rates and degradation times.

Emergency Action Plans & Response I

- An Emergency Action Plan (EAP) is required by OSHA under 29 CFR 1910.38 for facilitating organized employer and employee actions during emergencies.
- Escape Routes: Must be clearly marked, unobstructed, and lead directly to a designated safe assembly area outside the facility.
- Emergency Coordinator: A designated individual responsible for coordinating emergency actions, accounting for personnel, and contacting public services.
- Alarm Systems: Must incorporate both audible and visual signals to warn all employees, including those with hearing or visual impairments.
- Critical Plant Operations: Procedures must be defined for employees who remain behind to operate critical systems before evacuating.

Safety Summary & Best Practices I

- Maintaining a culture of safety requires constant training, regular safety audits, and a non-punitive system for reporting near-misses.
- Incident Investigation: Root Cause Analysis (RCA) must be performed for all accidents and near-misses to prevent recurrence.
- Safety Data Sheets (SDS): 16-section documents under GHS must be readily accessible to all workers handling chemicals.
- Continuous Improvement: Regular review of safety performance indicators (LTIFR, TRIR) to update emergency procedures and guidelines.

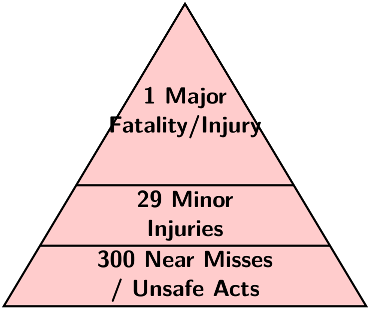
Agenda I

- Definition & Classification of Accidents
- Heinrich's Safety Triangle & Law
- Human Factors & Technical Causes
- Accident Reporting & Regulatory Frameworks
- Root Cause Analysis (RCA) Methodologies
- Prevention Techniques & Hierarchy of Controls

Definition & Classification of Accidents I

- Accident: An unplanned, undesired event that results in physical harm (injury/disease) to personnel, damage to property, or process disruption.
- Near Miss: An incident where no injury or damage occurred, but had the clear potential to do so under slightly different conditions.
- Classifications: Minor (first-aid cases), Reportable (resulting in lost workdays or restricted duty), and Fatal (resulting in loss of life).
- In industrial plants, accidents are evaluated using thermodynamic and physical energy release models (e.g., sudden release of pressure, kinetic energy, or chemical potential).

Heinrich's Safety Triangle I



Causes of Accidents: Unsafe Acts vs. Unsafe Conditions I

- Unsafe Acts: Work practices departing from standard operating procedures (SOPs), constituting approximately 88% of industrial accidents.
- Examples of Unsafe Acts: Bypassing safety interlocks on pressure vessels, operating machinery without authorization, or improper PPE usage.
- Unsafe Conditions: Physical hazards in the workplace (10% of accidents), with the remaining 2% attributed to acts of nature.
- Examples of Unsafe Conditions: Fatigue failure of boiler pipes, corrosion-induced stress cracking in heat exchangers, and faulty pressure relief valves.

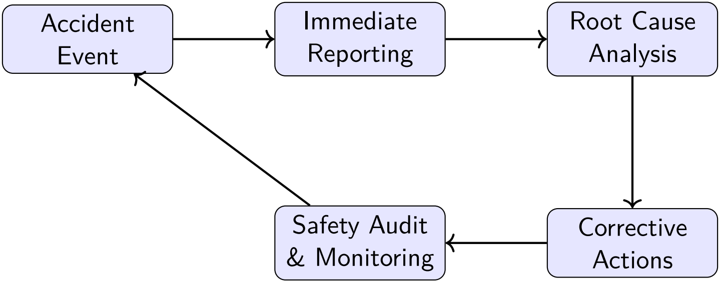
Accident Reporting & Regulatory Frameworks I

- Purpose: Reporting is critical to prevent recurrence, establish organizational accountability, and ensure compliance with statutory laws.
- OSHA compliance: Mandates the logging of all work-related injuries and illnesses using standard documentation (OSHA Form 300 and 301).
- Key Performance Indicators (KPIs): Lost Time Injury Frequency Rate (LTIFR) = (Number of LTIs * 1,000,000) / Total Man-Hours worked.
- Timeline constraints: Requires immediate verbal notification within 8 hours for fatalities or hospitalization of three or more employees.

Root Cause Analysis (RCA) Methodologies I

- RCA: A structured problem-solving approach focused on identifying the underlying systemic failure rather than merely treating symptoms.
- 5-Whys Technique: Repeatedly asking 'Why' (typically 5 iterations) to drill down through layers of causality to the systemic source.
- Fishbone (Ishikawa) Diagram: Categorizes potential causes into People, Process, Equipment, Materials, Environment, and Management.
- Failure Mode and Effects Analysis (FMEA): A proactive method used to evaluate potential failure modes and their impact on plant maintenance.

Process of Accident Investigation I



Prevention Techniques & Hierarchy of Controls I

- The Hierarchy of Controls establishes a priority ranking for risk mitigation methods, from most effective to least effective.
- Elimination & Substitution: Physically removing the hazard (e.g., replacing a toxic thermodynamic fluid with a non-toxic one) or substituting it.
- Engineering Controls: Isolating personnel from the hazard (e.g., installing machine guards, automated interlocks, soundproofing enclosures).
- Administrative Controls & PPE: Altering work procedures (SOPs, permit-to-work systems, job rotation) and providing protective gear (hard hats, safety glasses).

Summary & Key Takeaways I

- Industrial safety directly impacts plant maintenance economics, operational efficiency, and legal compliance.
- Accidents are multifactorial, combining human cognitive errors, mechanical component wear, and environmental stressors.
- Root Cause Analysis (RCA) must focus on system-level corrections rather than assigning individual blame.
- Applying the Hierarchy of Controls ensures that engineering-level solutions are prioritized over administrative procedures or PPE.