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Design of Mechanical Drives

Course Code: 23BTMEL403

B. Tech - VII Semester

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Teaching and Evaluation Scheme

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<table>
<tr><td colspan="11">Course Title: Design of Mechanical Drives</td></tr>
<tr><td rowspan="2">Semester</td><td rowspan="2">VII</td><td colspan="4" rowspan="2">Teaching Scheme</td><td colspan="5">Evaluation Scheme</td></tr>
<tr><td colspan="3">Theory</td><td colspan="2">Practical</td></tr>
<tr><td>Term</td><td>Odd</td><td>Th</td><td>Tu</td><td>Pr</td><td>Credits</td><td>TAE</td><td>CAE</td><td>ESE</td><td>INT</td><td>EXT</td></tr>
<tr><td>Course Category</td><td>PCC 14</td><td rowspan="2">2 Hrs.</td><td rowspan="2">-</td><td rowspan="2">2 Hrs.</td><td rowspan="2">3</td><td rowspan="2">10</td><td rowspan="2">15</td><td rowspan="2">50</td><td rowspan="2">25</td><td rowspan="2">-</td></tr>
<tr><td>Course Code</td><td>23BTMEL403
23BTMEP403</td></tr>
<tr><td>Teaching Mode</td><td>Offline</td><td colspan="3" rowspan="2">4 Hrs.</td><td rowspan="2">Total</td><td colspan="3">75</td><td colspan="2">25</td></tr>
<tr><td>Duration of ESE</td><td>3 Hrs.</td><td colspan="5">100</td></tr>
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Course Objectives and Outcomes

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Course Objectives	1. To develop competency in designing coupling, flywheel and bearing. 2. To understand the design of belt and chain drives. 3. To build the concepts of gear drives.
Course Outcomes	Upon successful completion of this course, student shall be able to:
	CO1. Evaluate use of couplings and flywheels for engineering applications. CO2. Analyze the appropriate bearing for real time application. CO3. Apply & choose belt and chain drives for various applications. CO4. Understand Design the spur and helical gears for power transmission. CO5. Understand worm and bevel gears for various industrial applications.

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Mapping of Course Outcomes with Program Outcomes and Program Specific Outcomes:

Course Outcomes	Program Outcomes and Program Specific Outcomes														
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	2	2	3	2	-	2	-	-	-	-	2	3	2	2
CO2	3	2	3	2	2	-	3	-	-	-	-	2	3	2	2
CO3	3	3	3	2	2	-	3	-	-	-	-	2	3	2	2
CO4	3	3	3	2	2	3	3	-	-	-	-	2	2	2	2
CO5	3	3	3	2	2	-	-	-	-	2	3	2	3	2	2

Syllabus

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Unit	Contents
Unit 1	Coupling and Flywheel: Types of shaft coupling, design of rigid and flexible coupling. Coefficient of fluctuation of energy and coefficient of fluctuation of speed, energy stored in flywheel, stresses in flywheel, design of flywheel.
Unit 2	Design of Bearings: Design of journal bearings for radial and thrust loads, selection of ball and roller bearing for radial and thrust loads, failures of antifriction bearing, design of hydrostatic pocket type thrust bearing such as circular step thrust bearing, bearing housing.
Unit 3	Design of Belt and Chain Drives: Types of belts and belt material, analysis of belt tension, condition for transmitting maximum power, design of flat belt, flat belt pulley, Types of V-belt, analysis of V-belt tension, design of V belt pulley. Design of chain and sprocket, Velocity ratio and length of chain, design of chain, dimensions of tooth profile, sprocket. Design of wire rope, sheaves and drums.

Syllabus

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Unit	Contents
Unit 4	Design of Spur and Helical Gears: Interference, tooth profiles, formative number of teeth etc., Buckingham equation, design of spur gear drive, helical gear drive.
Unit 5	Worm and Bevel Gear Drives: Types and proportion of worm and worm gear, force analysis, beam strength of worm gear teeth, dynamic tooth load, wear load, design of worm and worm gear. Bevel gear types and design . Advanced Topic:

Study Material

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Text Books	1. Design of Machine Elements by V. B. Bhandari, Tata McGraw-Hill Education, Third edition, First Reprint 2010. 2. "Mechanical Engg. Design", J. E. Shigley, Charles R. Mischke, Richard G. Budynas, McGraw-Hill, Tenth Edition, 2014. 3. Design Data for Machine elements, B.D. Shiwalkar, Benett& Co Publishing Division, revised edition, 2015.
E-Books	1. Fundamentals of Machine component design by Robert C. Juvinall, Kurt M. Marshek, John Wiley & Sons. 2. Mechanical Design of Machine elements and Machines by. A failure prevention perspective by Jack A Collins, Henry Busby, George Stab
Reference Books	1. Mechanical Engineering Design by Richard Budynas, Keith Nisbett, 2012. 2. Design of Machinery. An introduction to the synthesis and analysis of machanisms and machines by Robert L. Norton, McGraw Hill, 2013. 3. Machine Elements in Mechanical Design by Robert L. Mott, Edward M. Wavrek, Jyhwen Wang, Sixth edition, Pearson, 2014.
Online Material	1. Understanding Design Prof. Nina Sabnani IIT, B (mooc) https.//www.iitbombayx.in/courses/understanding-design 2. Basic 3D animation using Blender Sameer S Sahasrabudhe IIT, B (mooc) https.//www.iitbombayx.in/courses/basic-3d-animation-using-blender-1 3. Engineering Design Process with Autodesk Fusion 360 Autodesk Coursera, https.//www.coursera.org/learn/engineering-design-process-fusion-360

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Unit 1

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Introduction to Mechanical Drives

A mechanical drive system transmits power from a prime mover (motor/engine) to a driven machine.
Power transmission occurs in the form of torque and rotational motion.
Main elements:

- Shaft → transmits torque
- Coupling → connects shafts
- Flywheel → stores energy

Design objectives:

- Efficient transmission
- Minimum vibration
- Safe operation

Shaft Coupling – Definition

A coupling is a mechanical device used to connect two shafts for transmitting torque.
It ensures continuity of power transmission without interruption.
In practical systems, perfect alignment is not possible → coupling compensates for:

- Angular misalignment
- Parallel misalignment
- Axial displacement

Functions of coupling:

- Transmit torque
- Absorb shock and vibration
- Protect system from overload



Types of Couplings

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Rigid Coupling:

- Used when shafts are perfectly aligned
- No flexibility
- Examples: Muff coupling, Flange coupling

Flexible Coupling:

- Allows misalignment
- Absorbs shock and vibration
- Examples: Bushed pin coupling, Oldham coupling

Selection criteria:

- Torque capacity
- Speed
- Alignment accuracy
- Maintenance requirement

Muff Coupling – Working Principle

Muff coupling consists of:

- Sleeve (muff)
- Key
- Two shafts

Torque is transmitted from one shaft to another through the key and sleeve.
It is a rigid coupling → no misalignment allowed.



Advantages:

- Simple design
- Low cost

Limitations:

- Difficult assembly
- Cannot handle misalignment

Torque Transmission in Shaft (Derivation – Step 1)

Consider a circular shaft subjected to torque (T).

Shear stress distribution:

- Zero at center
- Maximum at outer surface



Torsion equation:

$$\tau / R = T / J$$

Where:

- τ = shear stress
- R = radius of shaft
- T = applied torque
- J = polar moment of inertia

Torque Equation (Final Derivation)

For solid shaft:

$J = (\pi d^4) / 32$

Substituting in torsion equation:

$T = (\pi / 16) \tau d^3$

Notation:

T = Torque (N·mm)

τ = Shear stress (MPa)

d = Shaft diameter (mm)

Design Insight:

Torque $\propto d^3$

Small increase in diameter → large increase in strength

Muff Coupling – Design Procedure

Step 1: Calculate torque:

$T = (P \times 60) / (2\pi N)$

Step 2: Shaft design:

$T = (\pi / 16)\ \tau\ d^3$

Step 3: Sleeve dimensions:

Outer diameter ≈ 2d

Length ≈ 3.5d

Step 4: Key design:

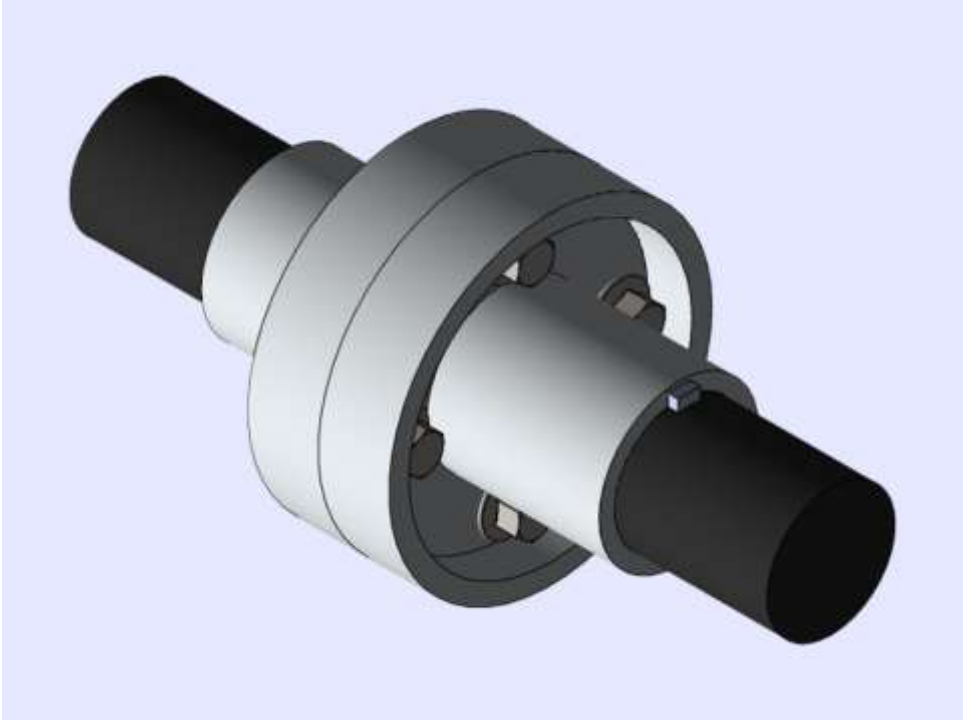
Check shear failure

Check crushing failure

Flange Coupling – Working & Design

Flange coupling consists of:

- Two flanges
- Bolts
- Key



Working:

- Torque transmitted through bolts on pitch circle

Torque equation:

$$T = n \times F \times r$$

Notation:

- n = number of bolts
- F = force per bolt
- r = pitch circle radius

Critical failure:

- Bolt shear failure

Numerical

Given:

Power = 20 kW

Speed = 200 rpm

Allowable stress = 40 MPa

Step 1: Torque calculation:

$T = (P \times 60) / (2\pi N)$

$T \approx 955$ N·m

Step 2: Shaft diameter:

$T = (\pi / 16)\ \tau\ d^3$

$d \approx 50$ mm

Final Answer:

Shaft diameter = 50 mm

Flywheel – Definition

A flywheel is a rotating mechanical device used to store energy in the form of kinetic energy.
It smooths fluctuations in speed where torque is not constant.
It absorbs excess energy and releases it when required.



Key purpose:

- Maintain uniform angular velocity
- Reduce speed fluctuations

Need of Flywheel

In many machines, energy supply is non-uniform:

- Internal combustion engines
- Punching machines

This causes:

- Speed fluctuations
- Vibrations
- Poor performance

Flywheel role:

- Stores excess energy
- Supplies energy during deficit
- Maintains steady motion

Important:

- Flywheel does NOT increase energy
- It only stores and redistributes energy

Kinetic Energy of Rotation (Step 1)

Consider a small mass element (dm) at radius (r).
Velocity of element:

$$v = \omega r$$

Kinetic energy of element:

$$dE = (1/2)\, dm\, v^2$$

Substituting:

$$dE = (1/2)\, dm\, (\omega r)^2$$

$$dE = (1/2)\, \omega^2\, r^2\, dm$$

Kinetic Energy (Step 2)

Total energy is obtained by integration:

$$E = \int dE$$

Substituting:

$$E = (1/2)\, \omega^2 \int r^2\, dm$$

Define:

$$I = \int r^2\, dm$$

Final equation:

$$E = (1/2)\, I\, \omega^2$$

Notation:

E = Energy

I = Moment of inertia

ω = Angular velocity

Moment of Inertia of Flywheel

Moment of inertia depends on mass distribution.
Flywheel mass is concentrated at rim.

For rim-type flywheel:

$I = mR^2$

Design insight:

Increasing radius is more effective than mass

Energy storage $\propto R^2$

Coefficient of Fluctuation of Speed

Coefficient of speed fluctuation:

$$C_s = (N_{max} - N_{min}) / N$$

Notation:

C_s = coefficient of fluctuation

N_{max} = maximum speed

N_{min} = minimum speed

N = mean speed

Interpretation:

Smaller C_s → smoother operation

L-02

Energy Fluctuation in Flywheel

Energy fluctuation:

$\Delta E = I \omega^2 Cs$

Also:

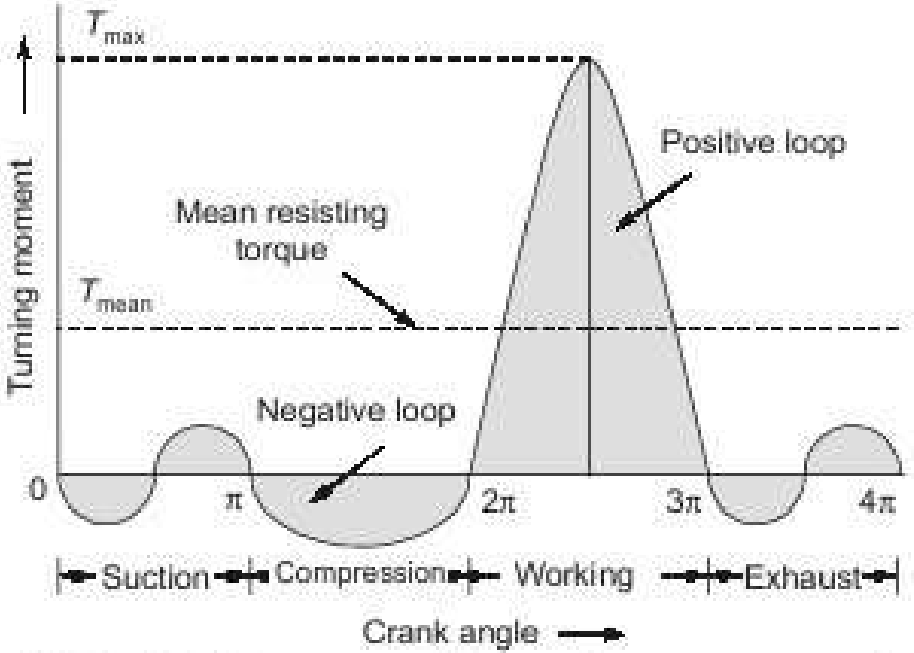
$\Delta E = Emax - Emin$

Explanation:

Flywheel stores energy between max and min values

Design importance:

Determines required flywheel size



S.No.	Stroke	Properties
1.	Suction	$P_{cyl} < P_{atm}$
2.	Compression	work is done an the gases
3.	Expansion/working	Work is done by the gases
4.	Exhaust	Work is done on the gases

Stress in Flywheel Rim

When flywheel rotates, centrifugal force acts outward.
This produces tensile stress in the rim.

Assumption:

- Rim behaves like a thin ring

Stress depends on:

- Density
- Velocity

Stress Equation (Derivation)

Considering a small rim element:
Centrifugal force produces tensile stress.

Stress equation:

$$\sigma = \rho v^2$$

Notation:

- σ = tensile stress
- ρ = density
- v = velocity

Key insight:

- Stress $\propto v^2$
- Small increase in speed → large stress

Numerical – Flywheel Design

Given:

$I = 10\ kg \cdot m^2$

$\omega = 20\ rad/s$

$Cs = 0.02$

Step 1: Energy stored:

$E = (1/2)\ I\ \omega^2 = 2000\ J$

Step 2: Energy fluctuation:

$\Delta E = I\ \omega^2\ Cs = 80\ J$

Final Answer:

Total energy = 2000 J

Fluctuation = 80 J

Flywheel Design – Overview

Flywheel design is based on:

- Energy storage requirement
- Allowable stress
- Speed fluctuation limits

Design objectives:

- Store required energy
- Maintain uniform speed
- Ensure safe stress levels

Key parameters:

- Moment of inertia
- Rim velocity
- Material strength

Flywheel Design Procedure

Step 1: Energy fluctuation:

$\Delta E = I \omega^2 Cs$

Step 2: Moment of inertia:

$I = \Delta E / (\omega^2 Cs)$

Step 3: Assume rim dimensions:

Radius (R)

Width (b)

Thickness (t)

Step 4: Mass calculation:

$m = I / R^2$

Rim Design of Flywheel

Rim stores 90–95% of total energy.
Design mainly focuses on rim.

Rim dimensions:

- Thickness (t)
- Width (b)

Empirical relation:

$b = 1.5\ t$

Condition:

- Stress must be within safe limits

Arm and Hub Design

Arms:

- Connect rim to hub
- Usually 4 to 8 arms
- Designed for bending stress

Hub:

- Mounted on shaft
- Transmits torque

Design checks:

- Bending stress in arms
- Shear stress in hub

IS Standards (Important for Exam)

Relevant IS codes:

- IS 2693 → Flywheel design
- IS 210 → Cast iron
- IS 2292 → Shaft & coupling

Design considerations:

- Factor of safety
- Material properties
- Allowable stress

Typical values:

- Cast iron ≈ 6–10 MPa
- Steel ≈ 15–30 MPa

Advanced Numerical – Flywheel

Given:

$\Delta E = 5000$ J

$N = 300$ rpm

$C_s = 0.02$

Step 1: Angular speed:

$\omega = (2\pi N) / 60$

$\omega = 31.4$ rad/s

Numerical Solution (Continue)

Step 2: Moment of inertia:

$I = \Delta E / (\omega^2 Cs)$

$I \approx 253\ kg \cdot m^2$

Step 3: Mass:

$m = I / R^2$

Assume $R = 1\ m$

$m = 253\ kg$

Flywheel vs Governor

Flywheel:

- Stores energy
- Works on energy fluctuation
- Used in engines & presses

Governor:

- Controls speed
- Works on speed variation
- Used in engines

Key insight:

- Flywheel → smoothens speed
- Governor → controls speed

Common Design Mistakes

Mistakes:

- Ignoring rim stress
- Incorrect material selection
- Overdesign (excess weight)
- Underestimating speed fluctuation

Consequences:

- Flywheel failure
- Excess vibration
- Reduced efficiency

Coupling – Detailed Introduction

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- Definition:
  - Mechanical device used to connect two shafts
  - Transmits torque and rotational motion
  - Ensures continuous power transmission without slip
- Working Principle:
  - Driving shaft generates torque
  - Torque transmitted through coupling elements
  - Driven shaft receives motion
- Engineering Importance:
  - Used in motors, pumps, compressors and turbines
  - Improves efficiency and reduces vibration

Functions of Couplings

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- Primary Functions:
  - Transmit torque between shafts
  - Maintain alignment
- Secondary Functions:
  - Absorb shock and vibration
  - Reduce mechanical stress
- Flexible Coupling Role:
  - Compensate angular misalignment
  - Compensate parallel misalignment
- Engineering Insight:
  - Increases machine life and reliability

Classification of Couplings

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- Rigid Couplings:
  - No relative motion between shafts
  - Used for perfectly aligned shafts
- Types:
  - Sleeve (Muff) coupling
  - Clamp coupling
  - Flange coupling
- Flexible Couplings:
  - Allow misalignment and absorb shock
- Types:
  - Bushed pin coupling
  - Oldham coupling
  - Universal coupling

Applications of Couplings

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- Industrial Applications:
  - Used in pumps, compressors and conveyors
  - Used in power transmission systems
- Automobile Applications:
  - Used in drive shafts and transmission systems
- Power Plants:
  - Used in turbines and generators
- Engineering Insight:
  - Essential wherever rotational power transfer is required

Design Requirements of Couplings

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- Mechanical Requirements:
  - Must transmit required torque safely
  - Must resist shear and bending stresses
- Operational Requirements:
  - Should accommodate misalignment
  - Should reduce vibration and noise
- Material Requirements:
  - High strength and fatigue resistance
- Engineering Insight:
  - Ensures durability and safe operation

Design Criteria of Couplings

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- Strength Criteria:
  - Shaft and key must resist shear stress
- Stiffness Criteria:
  - Deformation should be minimum
- Alignment Criteria:
  - Misalignment within permissible limits
- Engineering Insight:
  - Design based on torque and allowable stress

Torque Calculation

- Basic Equation:
  - $T = (P \times 60) / (2\pi N)$
- Where:
  - T = Torque (N·m)
  - P = Power (W)
  - N = Speed (RPM)
- Engineering Insight:
  - Fundamental equation in coupling design

Shaft Design Equation

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- Torsion Equation:
  - $T = (\pi/16) \times \tau \times d^3$
- Where:
  - τ = Allowable shear stress
  - d = Shaft diameter
- Engineering Insight:
  - Used to determine shaft size

Design Procedure of Coupling

- Step 1:
  - Determine power and speed
- Step 2:
  - Calculate torque
- Step 3:
  - Select material and allowable stress
- Step 4:
  - Design shaft, key and coupling
- Engineering Insight:
  - Systematic design ensures safety

Sleeve (Muff) Coupling Design

- Construction:
  - Hollow cylindrical sleeve connects shafts
- Working:
  - Torque transmitted through key
- Design Considerations:
  - Shaft diameter and key dimensions
- Engineering Insight:
  - Simple and economical coupling

Clamp Coupling Design

- Construction:
  - Two halves bolted around shaft
- Working:
  - Torque transmitted by friction and key
- Advantages:
  - Easy assembly and maintenance
- Engineering Insight:
  - Used where frequent disassembly required

Flange Coupling Design

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- Construction:
  - Two flanges connected by bolts
- Working:
  - Torque transmitted through bolts
- Types:
  - Protected and unprotected flange coupling
- Engineering Insight:
  - Used for heavy load applications

Design of Flange Coupling

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- Design Steps:
  - Determine shaft diameter
  - Select flange dimensions
  - Design bolts for shear
- Engineering Insight:
  - Most widely used coupling in industry

Failure Modes in Coupling

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- Shaft Failure:
  - Due to excessive shear stress
- Key Failure:
  - Due to shear and crushing
- Bolt Failure:
  - Due to shear stress
- Engineering Insight:
  - Proper design prevents failure

Advantages and Limitations of Couplings

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- Advantages:
  - Efficient power transmission
  - Reduces vibration
- Limitations:
  - Requires proper alignment
  - May fail under overload
- Engineering Insight:
  - Selection and design are critical

Flexible Couplings – Introduction

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- Definition:
  - Couplings that allow misalignment between shafts
  - Absorb shock and vibration during operation
- Types:
  - Bushed pin coupling
  - Oldham coupling
  - Universal coupling
- Engineering Insight:
  - Used in dynamic and misaligned systems

Types of Misalignment

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- Angular Misalignment:
  - Axes of shafts intersect at an angle
- Parallel Misalignment:
  - Axes are parallel but not collinear
- Axial Misalignment:
  - Relative axial movement of shafts
- Engineering Insight:
  - Flexible couplings accommodate these misalignments

Bushed Pin Coupling – Construction

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- Construction:
  - Flanges connected by pins with rubber bushes
- Working:
  - Torque transmitted through pins and bushes
- Advantages:
  - Absorbs vibration and shock loads
- Application:
  - Used in motor drives

Design of Bushed Pin Coupling

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- Design Considerations:
  - Torque transmitted by pins in shear
  - Bush material absorbs shock
- Important Parameters:
  - Number of pins
  - Diameter of pins
- Engineering Insight:
  - Combination of strength and flexibility

Oldham Coupling – Construction

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- Construction:
  - Three discs: two hubs and one intermediate disc
- Working:
  - Middle disc slides to accommodate misalignment
- Application:
  - Used in machine tools
- Engineering Insight:
  - Handles parallel misalignment effectively

Universal Coupling

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- Definition:
  - Connects shafts at an angle
- Working:
  - Transmits motion through cross joint
- Application:
  - Used in automobiles (propeller shaft)
- Engineering Insight:
  - Allows angular motion transmission

Torque in Flexible Couplings

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- Torque Equation:
  - $T = (P \times 60) / (2\pi N)$
- Design Consideration:
  - Flexible elements must withstand torque
- Engineering Insight:
  - Design ensures both strength and flexibility

Numerical Example 1

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- Given:
  - Power = 10 kW, Speed = 300 RPM
- Find:
  - Torque transmitted
- Solution:
  - $T = (P \times 60) / (2\pi N)$
  - $T = (10000 \times 60) / (2\pi \times 300)$
- Engineering Insight:
  - Basic torque calculation

Numerical Example 2

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- Given:
  - Torque and allowable stress
- Find:
  - Shaft diameter
- Formula:
  - $T = (\pi/16) \times \tau \times d^3$
- Engineering Insight:
  - Used in shaft design

Design of Pins in Coupling

- Shear Stress:
  - τ = Force / Area
- Force Calculation:
  - Based on transmitted torque
- Engineering Insight:
  - Pins must resist shear failure

Key Design in Coupling

- Function:
  - Connects shaft and hub
- Stresses:
  - Shear stress and crushing stress
- Engineering Insight:
  - Key failure affects entire system

Advantages of Flexible Couplings

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- Advantages:
  - Absorb shock and vibration
  - Allow misalignment
- Engineering Insight:
  - Improve machine life

Limitations of Flexible Couplings

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- Limitations:
  - Lower torque capacity than rigid couplings
  - Wear of flexible elements
- Engineering Insight:
  - Requires maintenance

Comparison: Rigid vs Flexible Coupling

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- Rigid Coupling:
  - No flexibility, high torque capacity
- Flexible Coupling:
  - Allows misalignment and absorbs shock
- Engineering Insight:
  - Selection depends on application

Summary of Coupling Design

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- Key Points:
  - Torque calculation is first step
  - Material selection is important
  - Design for safety and durability
- Engineering Insight:
  - Proper design ensures efficient power transmission

Introduction to Flywheel

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- Definition:
  - Flywheel is a rotating mechanical device used to store energy
  - Stores kinetic energy when excess energy is available
- Purpose:
  - To smooth out fluctuations in speed
  - To maintain uniform rotational motion
- Engineering Insight:
  - Used in engines, presses and machines

Function of Flywheel

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- Primary Function:
  - Stores excess energy during power stroke
  - Releases energy during non-power stroke
- Secondary Function:
  - Reduces speed fluctuation
  - Maintains uniform motion
- Engineering Insight:
  - Improves performance of cyclic machines

Energy Storage in Flywheel

- Kinetic Energy:
  - $E = (1/2) \times I \times \omega^2$
- Where:
  - I = Mass moment of inertia
  - ω = Angular velocity
- Engineering Insight:
  - Energy stored depends on mass and speed

Coefficient of Fluctuation of Energy

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- Definition:
  - Ratio of maximum fluctuation of energy to mean energy
- Formula:
  - $C_E = (E_{max} - E_{min}) / E_{mean}$
- Engineering Insight:
  - Indicates energy variation in system

Coefficient of Fluctuation of Speed

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- Definition:
  - Ratio of maximum fluctuation of speed to mean speed
- Formula:
  - $C_S = (N_{max} - N_{min}) / N_{mean}$
- Engineering Insight:
  - Indicates speed variation in machine

Relation Between Energy and Speed

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- Relationship:
  - Energy fluctuation depends on speed variation
- Important Concept:
  - Higher inertia reduces speed fluctuation
- Engineering Insight:
  - Flywheel design ensures stable speed

Maximum Fluctuation of Energy

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- Definition:
  - Difference between maximum and minimum energy
- Formula:
  - $\Delta E = E_{max} - E_{min}$
- Engineering Insight:
  - Used to design flywheel size

Mean Energy of Flywheel

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- Definition:
  - Average energy stored in flywheel
- Formula:
  - Emean = (Emax + Emin)/2
- Engineering Insight:
  - Used in energy fluctuation calculation

Turning Moment Diagram

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- Definition:
  - Graph showing variation of torque with crank angle
- Purpose:
  - Used to determine energy fluctuation
- Engineering Insight:
  - Area under curve represents energy

Flywheel Working Principle

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- Working:
  - Accelerates when energy input is high
  - Decelerates when energy demand is high
- Engineering Insight:
  - Balances energy supply and demand

Mass Moment of Inertia

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- Definition:
  - Resistance of body to change in rotational motion
- Formula:
  - $I = m \times r^2$
- Engineering Insight:
  - Higher inertia reduces speed fluctuation

Energy Stored in Rim

- Concept:
  - Most energy stored in rim of flywheel
- Reason:
  - Rim has maximum radius
- Engineering Insight:
  - Flywheel designed with heavy rim

Speed Fluctuation Control

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- Method:
  - Increase flywheel mass
  - Increase radius of gyration
- Engineering Insight:
  - Reduces variation in speed

Applications of Flywheel

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- Applications:
  - IC engines
  - Punch presses
  - Rolling mills
- Engineering Insight:
  - Used where load varies cyclically

Flywheel vs Governor

- Flywheel:
  - Controls speed fluctuation within cycle
- Governor:
  - Controls mean speed over time
- Engineering Insight:
  - Both are used together in engines

Advantages of Flywheel

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- Advantages:
  - Smooth operation
  - Reduces vibration
  - Stores energy efficiently
- Engineering Insight:
  - Improves machine performance

Limitations of Flywheel

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- Limitations:
  - Heavy and bulky
  - Initial cost is high
- Engineering Insight:
  - Requires proper balancing

Energy Balance in Flywheel

- Concept:
  - Energy stored = energy released
- Engineering Insight:
  - Maintains constant output power

Design Parameters of Flywheel

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- Parameters:
  - Mass of flywheel
  - Radius of gyration
  - Speed of rotation
- Engineering Insight:
  - Affects energy storage capacity

Summary of Flywheel Theory

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- Key Points:
  - Stores and releases energy
  - Controls speed fluctuation
  - Design based on energy variation
- Engineering Insight:
  - Critical for cyclic machines

Introduction to Flywheel (Detailed)

- Definition:
  - Flywheel is a rotating energy storage device
  - Stores kinetic energy in rotating mass
  - Used to smooth cyclic fluctuations in machines
- Purpose:
  - Maintains uniform angular velocity
  - Balances energy during different strokes
- Working Concept:
  - Energy stored when torque > load
  - Energy released when torque < load
- Engineering Insight:
  - Critical component in IC engines and presses

Functions of Flywheel (Expanded)

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- Primary Functions:
  - Stores excess energy during power stroke
  - Releases energy during idle stroke
- Secondary Functions:
  - Reduces speed fluctuations
  - Improves mechanical efficiency
  - Ensures smooth operation
- Dynamic Role:
  - Maintains constant output torque
- Engineering Insight:
  - Essential for cyclic load systems

Energy Storage in Flywheel

- Kinetic Energy Equation:
  - $E = (1/2) \times I \times \omega^2$
- Parameters:
  - I = Mass moment of inertia
  - ω = Angular velocity (rad/s)
- Observations:
  - Energy $\propto$ square of speed
  - Energy increases with radius
- Engineering Insight:
  - High-speed flywheels store more energy

Coefficient of Fluctuation of Energy

- Definition:
  - Ratio of maximum fluctuation of energy to mean energy
- Formula:
  - $C_E = (E_{max} - E_{min}) / E_{mean}$
- Interpretation:
  - Indicates variation in energy supply
  - Higher value → more fluctuation
- Engineering Insight:
  - Used to design flywheel capacity

Coefficient of Fluctuation of Speed

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- Definition:
  - Ratio of speed variation to mean speed
- Formula:
  - $C_S = (N_{max} – N_{min}) / N_{mean}$
- Important Note:
  - Lower value means smoother operation
- Engineering Insight:
  - Used to limit speed variation

Relation Between Energy and Speed

- Concept:
  - Energy fluctuation directly related to speed fluctuation
- Key Relation:
  - $\Delta E = I \times \omega^2 \times C_S$
- Observation:
  - Higher inertia reduces speed variation
- Engineering Insight:
  - Flywheel design balances energy and speed

Maximum Fluctuation of Energy

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- Definition:
  - Difference between maximum and minimum energy
- Formula:
  - $\Delta E = E_{max} - E_{min}$
- Use:
  - Determines required flywheel size
- Engineering Insight:
  - Higher $\Delta E \rightarrow$ larger flywheel required

Mean Energy of Flywheel

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- Definition:
  - Average value of stored energy
- Formula:
  - Emean = (Emax + Emin)/2
- Importance:
  - Used in fluctuation calculations
- Engineering Insight:
  - Helps in flywheel design

Turning Moment Diagram

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- Definition:
  - Graph showing torque variation vs crank angle
- Features:
  - Area under curve represents energy
  - Above mean line → energy surplus
  - Below mean line → energy deficit
- Engineering Insight:
  - Used to calculate fluctuation of energy

Flywheel Working Principle (Detailed)

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- Working:
  - Accelerates when input energy exceeds demand
  - Decelerates when demand exceeds input
- Energy Balance:
  - Stores excess energy
  - Releases stored energy when needed
- Engineering Insight:
  - Maintains uniform rotational motion

Mass Moment of Inertia (Detailed)

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- Definition:
  - Measure of resistance to change in rotational motion
  - Analogous to mass in linear motion
- Formula:
  - $I = m \times r^2$
  - For rim-type flywheel: $I \approx mR^2$
- Parameters:
  - m = Mass of flywheel
  - r = Radius of gyration
- Observations:
  - Higher radius increases inertia significantly
  - Mass concentrated at rim increases energy storage
- Engineering Insight:
  - Higher inertia → lower speed fluctuation

Energy Stored in Flywheel Rim

- Concept:
  - Most energy stored in outer rim of flywheel
- Reason:
  - Energy $\propto r^2$, so outer mass contributes more
- Design Feature:
  - Flywheel designed with heavy rim
  - Hub and arms kept lighter
- Engineering Insight:
  - Maximizes energy storage with minimum material

Radius of Gyration

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- Definition:
  - Distance at which entire mass assumed concentrated
- Formula:
  - $k = \sqrt{(I/m)}$
- Importance:
  - Determines energy storage capacity
- Observation:
  - Larger k → more energy stored
- Engineering Insight:
  - Used in flywheel design calculations

Speed Fluctuation Control Methods

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- Methods:
  - Increase flywheel mass
  - Increase radius of gyration
  - Improve system balancing
- Design Strategy:
  - Use heavy rim construction
- Engineering Insight:
  - Reduces speed variation in cyclic systems

Flywheel vs Governor (Detailed)

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- Flywheel Function:
  - Controls speed fluctuation within one cycle
  - Stores and releases energy
- Governor Function:
  - Controls mean speed over long duration
  - Regulates fuel supply
- Key Difference:
  - Flywheel → energy storage
  - Governor → speed regulation
- Engineering Insight:
  - Both used together in engines

Applications of Flywheel (Expanded)

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- Mechanical Systems:
  - Used in IC engines
  - Used in punching and shearing machines
- Industrial Systems:
  - Used in rolling mills
  - Used in power plants
- Modern Applications:
  - Energy storage systems
  - Hybrid vehicles
- Engineering Insight:
  - Used where load varies cyclically

Advantages of Flywheel (Detailed)

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- Advantages:
  - Smoothens power output
  - Reduces vibration and shock
  - Stores excess energy efficiently
- Operational Benefits:
  - Improves machine performance
  - Enhances system stability
- Engineering Insight:
  - Essential for cyclic load systems

Limitations of Flywheel (Detailed)

- Limitations:
  - Heavy and bulky structure
  - High initial cost
- Operational Issues:
  - Requires balancing
  - May cause stress due to centrifugal force
- Engineering Insight:
  - Proper design required to avoid failure

Energy Balance in Flywheel

- Concept:
  - Energy stored = Energy released
- During Cycle:
  - Excess energy stored in flywheel
  - Deficit energy supplied by flywheel
- Mathematical View:
  - ΔE = Work input – Work output
- Engineering Insight:
  - Maintains constant output power

Summary of Flywheel Theory (Expanded)

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- Key Concepts:
  - Flywheel stores and releases energy
  - Controls speed fluctuation
  - Energy stored depends on inertia and speed
- Important Parameters:
  - Mass, radius, speed
  - Coefficient of fluctuation
- Engineering Insight:
  - Critical for stable machine operation

L-07

Introduction to Flywheel Design

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- Objective:
  - Design flywheel to store required energy
  - Control speed fluctuation within limits
- Design Inputs:
  - Power transmitted
  - Speed of rotation
  - Coefficient of fluctuation of speed
- Engineering Insight:
  - Design based on energy variation

Energy Equation for Flywheel Design

- Energy Stored:
  - $\Delta E = I \times \omega^2 \times C_S$
- Where:
  - I = Mass moment of inertia
  - ω = Angular velocity
  - C_S = Coefficient of speed fluctuation
- Engineering Insight:
  - Used to determine flywheel size

Mass of Flywheel Rim

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- Formula:
  - $m = \Delta E / (v^2 \times C_S)$
- Where:
  - v = Tangential velocity
- Observation:
  - Higher velocity reduces required mass
- Engineering Insight:
  - Important design parameter

Tangential Velocity of Flywheel

- Formula:
  - $v = \pi DN / 60$
- Where:
  - D = Diameter of flywheel
  - N = Speed (RPM)
- Engineering Insight:
  - Velocity affects energy storage capacity

Design of Flywheel Rim

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- Rim Functions:
  - Stores majority of energy
  - Provides rotational inertia
- Design Considerations:
  - Rim thickness and width
  - Material strength
- Engineering Insight:
  - Rim carries maximum stress

Centrifugal Stress in Rim

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- Formula:
  - $\sigma = \rho \times v^2$
- Where:
  - ρ = Density of material
  - v = Velocity
- Engineering Insight:
  - Major stress acting on flywheel

Tensile Stress in Rim

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- Cause:
  - Due to centrifugal force
- Formula:
  - $\sigma = \rho \times v^2$
- Engineering Insight:
  - Must be within allowable stress limit

Design of Flywheel Arms

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- Function:
  - Connect rim to hub
- Forces:
  - Subjected to tensile and bending stress
- Design:
  - Arms designed as elliptical sections
- Engineering Insight:
  - Ensures structural stability

Design of Flywheel Hub

- Function:
  - Connects flywheel to shaft
- Design Considerations:
  - Hub diameter and length
  - Keyway strength
- Engineering Insight:
  - Must withstand transmitted torque

Stress Analysis in Flywheel

- Types of Stress:
  - Centrifugal stress
  - Tensile stress
  - Bending stress in arms
- Engineering Insight:
  - Design must ensure safety against all stresses

Numerical Problem 1: Energy Stored

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- Problem Statement:
  - A flywheel has moment of inertia 100 kg·m² and rotates at 300 RPM.
  - Coefficient of fluctuation of speed is 0.02.
  - Find the maximum fluctuation of energy.
- Solution:
  - Step 1: Convert speed into angular velocity
    - $\omega = (2\pi N)/60 = (2\pi \times 300)/60 = 31.42$ rad/s
  - Step 2: Use energy equation
    - $\Delta E = I \times \omega^2 \times C_S$
  - Step 3: Substitute values
    - $\Delta E = 100 \times (31.42)^2 \times 0.02$
  - Step 4: Calculate
    - $\Delta E = 100 \times 986 \times 0.02 = 1972$ J
- Final Answer:
  - Maximum fluctuation of energy = 1972 Joules

Numerical Problem 2: Tangential Velocity

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- Problem Statement:
  - A flywheel has diameter 1.5 m and rotates at 400 RPM.
  - Find the tangential velocity at the rim.
- Solution:
  - Step 1: Use velocity formula
    - $v = (\pi DN)/60$
  - Step 2: Substitute values
    - $v = (\pi \times 1.5 \times 400)/60$
  - Step 3: Calculate
    - $v = (3.14 \times 1.5 \times 400)/60$
    - $v = 31.4$ m/s
- Final Answer:
  - Tangential velocity = 31.4 m/s

Numerical Problem 3: Mass of Flywheel

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- Problem Statement:
  - A flywheel must store 5000 J of energy.
  - Coefficient of fluctuation of speed = 0.02.
  - Rim velocity = 25 m/s.
  - Find the mass of flywheel.
- Solution:
  - Step 1: Use mass equation
    - $m = \Delta E / (v^2 \times C_S)$
  - Step 2: Substitute values
    - $m = 5000 / (25^2 \times 0.02)$
  - Step 3: Calculate denominator
    - $25^2 = 625$
    - $625 \times 0.02 = 12.5$
  - Step 4: Final calculation
    - $m = 5000 / 12.5 = 400$ kg
- Final Answer:
  - Mass of flywheel = 400 kg

Material Selection for Flywheel

- Materials Used:
  - Cast iron
  - Steel
- Requirements:
  - High strength
  - Good fatigue resistance
- Engineering Insight:
  - Material affects safety and cost

Factors Affecting Flywheel Design

- Factors:
  - Speed of rotation
  - Energy fluctuation
  - Material properties
- Engineering Insight:
  - Design must satisfy all constraints

Advantages of Proper Flywheel Design

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- Advantages:
  - Smooth operation
  - Reduced vibration
  - Improved efficiency
- Engineering Insight:
  - Enhances machine performance

Limitations in Flywheel Design

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- Limitations:
  - High weight
  - Space requirement
- Engineering Insight:
  - Design trade-off required

Safety Considerations

- Safety Measures:
  - Stress within allowable limits
  - Proper balancing
- Engineering Insight:
  - Prevents catastrophic failure

Design Summary

- Steps:
  - Calculate energy fluctuation
  - Determine mass and dimensions
  - Check stresses
- Engineering Insight:
  - Systematic approach ensures safe design

Final Conclusion

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- Key Points:
  - Couplings transmit power
  - Flywheel stores energy
  - Design ensures efficiency and safety
- Engineering Insight:
  - Essential for mechanical systems

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Unit 2

L-08

Introduction to Bearings

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- Definition:
  - A bearing is a mechanical element that supports a rotating shaft and allows relative motion between moving parts with minimum friction.
  - It ensures smooth rotation and prevents direct metal-to-metal contact.
- Functions:
  - Supports radial and axial (thrust) loads acting on the shaft.
  - Reduces friction and wear between moving surfaces using lubrication.
  - Maintains proper alignment of shaft and machine components.
- Engineering Insight:
  - Bearings are essential in machines like motors, turbines, pumps and gearboxes.

Types of Bearings

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- Sliding Contact Bearings:
  - In these bearings, sliding motion occurs between shaft and bearing surface.
  - Examples include journal bearings and thrust bearings.
- Rolling Contact Bearings:
  - Use rolling elements like balls or rollers to reduce friction.
  - Examples include ball bearings and roller bearings.
- Engineering Insight:
  - Selection depends on load, speed, maintenance and efficiency requirements.

L-08

Journal Bearings

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- Definition:
  - Journal bearings are sliding contact bearings designed to support radial loads.
- Working Principle:
  - A thin film of lubricant separates shaft and bearing surface.
  - Hydrodynamic pressure is developed due to shaft rotation.
- Applications:
  - Used in turbines, engines and high-speed rotating machinery.
- Engineering Insight:
  - Suitable for heavy loads and continuous operation.

L-08

Hydrodynamic Lubrication

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- Concept:
  - Lubricating oil film is generated automatically by shaft motion.
- Working:
  - Relative motion creates pressure that lifts the shaft away from bearing surface.
  - No external pressure source is required.
- Advantages:
  - Reduces friction significantly and increases bearing life.
- Engineering Insight:
  - Widely used in high-speed machines.

L-08

Hydrostatic Lubrication

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- Concept:
  - Lubricant is supplied under pressure using an external pump.
- Working:
  - Oil film is maintained even when shaft is stationary.
  - Ensures zero metal contact at start-up.
- Applications:
  - Used in heavy load and precision machines.
- Engineering Insight:
  - Provides high load carrying capacity.

L-08

Rolling Contact Bearings

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- Definition:
  - Bearings that use rolling elements to reduce friction between moving parts.
- Types:
  - Ball bearings for light loads and high speed.
  - Roller bearings for heavy loads.
- Advantages:
  - Low friction, easy maintenance and high efficiency.
- Engineering Insight:
  - Commonly used in automobiles and electric motors.

L-08

Types of Loads on Bearings

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- Radial Load:
  - Load acting perpendicular to shaft axis, common in rotating shafts.
- Thrust Load:
  - Load acting parallel to shaft axis, common in propeller shafts.
- Combined Load:
  - Combination of radial and axial loads in practical applications.
- Engineering Insight:
  - Bearing selection depends on type of load.

Bearing Materials

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- Common Materials:
  - Babbitt metal used for good conformability and embeddability.
  - Bronze used for strength and durability.
  - Steel used in rolling element bearings.
- Properties Required:
  - Low friction, wear resistance and good thermal conductivity.
- Engineering Insight:
  - Material selection affects performance and life.

Factors Affecting Bearing Design

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- Operating Conditions:
  - Load, speed and temperature influence design.
- Design Parameters:
  - Clearance between shaft and bearing.
  - Type of lubrication used.
- Engineering Insight:
  - Improper design leads to overheating and failure.

Basic Design Parameters

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- Important Parameters:
  - Bearing pressure determines load capacity.
  - Coefficient of friction affects efficiency.
  - Heat generation must be controlled using lubrication.
- Engineering Insight:
  - All parameters must be balanced for safe design.

Journal Bearing Design – Overview

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- Objective:
  - To design bearing that supports radial load safely with minimum friction.
- Design Considerations:
  - Load acting on bearing, shaft speed and lubrication type.
  - Heat generated due to friction must be dissipated.
- Engineering Insight:
  - Proper design ensures long life and efficient operation.

Bearing Pressure

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- Definition:
  - Pressure acting on projected area of bearing surface.
- Formula:
  - $P = W / (L \times d)$
- Where:
  - W = Load on bearing, L = length, d = diameter.
- Engineering Insight:
  - Pressure must be within allowable limit to avoid failure.

Coefficient of Friction

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- Definition:
  - Ratio of frictional force to normal force between surfaces.
- Empirical Relation:
  - μ = (constant depending on lubrication conditions)
- Effect:
  - Higher μ increases heat generation and reduces efficiency.
- Engineering Insight:
  - Lubrication reduces coefficient of friction.

Heat Generated in Bearing

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- Concept:
  - Heat is generated due to friction between shaft and bearing.
- Formula:
  - Heat generated = $\mu \times W \times v$
- Where:
  - v = velocity of shaft surface.
- Engineering Insight:
  - Excess heat leads to failure of bearing.

Heat Dissipation

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- Concept:
  - Heat must be dissipated to surroundings.
- Methods:
  - Natural cooling and forced cooling.
- Engineering Insight:
  - Heat generated = Heat dissipated for safe design.

Sommerfeld Number

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- Definition:
  - Dimensionless parameter used in journal bearing design.
- Formula:
  - $S = (\mu \times N \times (r/c)^2) / P$
- Where:
  - μ = viscosity, N = speed, r = radius, c = clearance.
- Engineering Insight:
  - Indicates performance of bearing.

Design Steps of Journal Bearing

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- Step 1:
  - Determine load and speed of shaft.
- Step 2:
  - Select bearing dimensions (L and d).
- Step 3:
  - Calculate pressure and friction.
- Step 4:
  - Check heat generation and dissipation.
- Engineering Insight:
  - Ensures safe and efficient design.

Numerical 1: Bearing Pressure

- Problem:
  - Load = 5000 N, diameter = 50 mm, length = 100 mm.
  - Find bearing pressure.
- Solution:
  - $P = W / (L \times d)$
  - $P = 5000 / (0.1 \times 0.05)$
  - $P = 1{,}000{,}000\ N/m^2$
- Answer:
  - Bearing pressure = 1 MPa

Numerical 2: Velocity

- Problem:
  - Diameter = 50 mm, speed = 300 RPM.
  - Find surface velocity.
- Solution:
  - $v = \pi DN / 60$
  - $v = (3.14 \times 0.05 \times 300)/60$
  - $v = 0.785$ m/s
- Answer:
  - Velocity = 0.785 m/s

Numerical 3: Heat Generation

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- Problem:
  - $\mu = 0.02$, Load = 5000 N, velocity = 1 m/s.
- Solution:
  - Heat = $\mu \times W \times v$
  - Heat = $0.02 \times 5000 \times 1$
  - Heat = 100 W
- Answer:
  - Heat generated = 100 Watts

Numerical 4: Sommerfeld Number

- Problem:
  - $\mu = 0.02$, N = 300 RPM, r/c = 100, P = 1 MPa.
- Solution:
  - $S = (\mu \times N \times (r/c)^2) / P$
  - $S = (0.02 \times 300 \times 100^2) / 1 \times 10^6$
  - $S \approx 0.06$
- Answer:
  - Sommerfeld number ≈ 0.06

Numerical 5: Bearing Length

- Problem:
  - Load = 4000 N, pressure = 1 MPa, diameter = 40 mm.
- Solution:
  - $L = W / (P \times d)$
  - $L = 4000 / (1 \times 10^6 \times 0.04)$
  - $L = 0.1$ m = 100 mm
- Answer:
  - Length = 100 mm

Advantages of Journal Bearings

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- Advantages:
  - High load carrying capacity.
  - Simple construction and low cost.
  - Smooth and quiet operation.
- Engineering Insight:
  - Suitable for heavy duty machines.

Limitations of Journal Bearings

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- Limitations:
  - Requires continuous lubrication.
  - High starting friction.
- Engineering Insight:
  - Failure occurs without proper lubrication.

Summary of Journal Bearing Design

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- Key Points:
  - Pressure, friction and heat are key factors.
  - Proper lubrication is essential.
- Engineering Insight:
  - Design ensures efficiency and long life.

Introduction to Antifriction Bearings

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- Definition:
  - Antifriction bearings use rolling elements like balls or rollers to reduce friction.
  - They replace sliding friction with rolling friction.
- Advantages:
  - Low friction, high efficiency and easy maintenance.
- Engineering Insight:
  - Widely used in automobiles, motors and machinery.

Types of Rolling Contact Bearings

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- Ball Bearings:
  - Used for light loads and high-speed applications.
- Roller Bearings:
  - Used for heavy loads and moderate speed.
- Special Types:
  - Tapered, needle and spherical bearings.
- Engineering Insight:
  - Selection depends on load and application.

Load Carrying Capacity

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- Static Load Capacity:
  - Maximum load without permanent deformation.
- Dynamic Load Capacity:
  - Load that bearing can withstand for specified life.
- Engineering Insight:
  - Important for selecting bearing size.

Equivalent Dynamic Load

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- Definition:
  - Equivalent load acting on bearing considering radial and thrust loads.
- Formula:
  - $P = XFr + YFa$
- Where:
  - Fr = radial load, Fa = thrust load
- Engineering Insight:
  - Used in bearing life calculations.

Bearing Life (L10 Life)

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- Definition:
  - Number of revolutions before 10% bearings fail.
- Formula:
  - L10 = (C/P)^p
- Where:
  - C = dynamic load capacity, P = equivalent load
  - p = 3 (ball bearing), 10/3 (roller bearing)
- Engineering Insight:
  - Most important parameter in design.

Bearing Life in Hours

- Formula:
  - Life (hours) = $(L10 \times 10^6) / (60 \times N)$
- Where:
  - N = speed in RPM
- Engineering Insight:
  - Used for practical bearing selection.

Selection of Bearings

- Steps:
  - Determine load and speed.
  - Calculate equivalent load.
  - Select bearing from catalogue.
- Engineering Insight:
  - Selection ensures long life and reliability.

Failure of Antifriction Bearings

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- Causes:
  - Fatigue failure due to repeated loading.
  - Wear due to improper lubrication.
  - Overloading and misalignment.
- Engineering Insight:
  - Proper design prevents failure.

Numerical 1: Equivalent Load

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- Problem:
  - Fr = 1000 N, Fa = 500 N, X = 1, Y = 1.5.
- Solution:
  - P = XFr + YFa
  - P = (1 × 1000) + (1.5 × 500)
  - P = 1000 + 750 = 1750 N
- Answer:
  - Equivalent load = 1750 N

Numerical 2: Bearing Life

- Problem:
  - C = 5000 N, P = 2000 N (ball bearing).
- Solution:
  - L10 = (C/P)^3
  - L10 = (5000/2000)^3
  - L10 = (2.5)^3 = 15.625 million revolutions
- Answer:
  - Bearing life = 15.625×10^6 rev

Numerical 3: Life in Hours

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- Problem:
  - L10 = 15.625×10^6 rev, speed = 300 RPM.
- Solution:
  - Life = $(L10 \times 10^6)/(60 \times N)$
  - Life = $(15.625 \times 10^6)/(60 \times 300)$
  - Life ≈ 868 hours
- Answer:
  - Life ≈ 868 hours

Numerical 4: Dynamic Load Capacity

- Problem:
  - P = 2000 N, life = 10×10^6 rev.
- Solution:
  - C = P × (L10)^(1/3)
  - C = 2000 × (10)^(1/3)
  - C ≈ 2000 × 2.15 = 4300 N
- Answer:
  - Dynamic load capacity ≈ 4300 N

Numerical 5: Roller Bearing Life

- Problem:
  - C = 6000 N, P = 3000 N.
- Solution:
  - L10 = (C/P)^(10/3)
  - L10 = (6000/3000)^(10/3)
  - L10 = (2)^(3.33) ≈ 10 million rev
- Answer:
  - Life ≈ 10×10^6 rev

Advantages of Rolling Bearings

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- Advantages:
  - Low friction and high efficiency.
  - Easy replacement and maintenance.
  - No need of continuous lubrication.
- Engineering Insight:
  - Preferred in modern machines.

Limitations of Rolling Bearings

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- Limitations:
  - Lower load capacity compared to journal bearings.
  - Sensitive to shock loads.
- Engineering Insight:
  - Proper selection required for long life.

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Introduction to Hydrostatic Bearings

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- Definition:
  - Hydrostatic bearings use externally pressurized lubricant to support load.
  - Lubrication film exists even when shaft is stationary.
- Working Principle:
  - High-pressure oil is supplied through pump into bearing pocket.
  - This pressure creates a load-carrying oil film.
- Engineering Insight:
  - Used in precision and heavy load applications.

Advantages of Hydrostatic Bearings

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- Advantages:
  - No metal-to-metal contact even at start-up.
  - High load carrying capacity.
  - Very low friction and wear.
  - Excellent stiffness and accuracy.
- Engineering Insight:
  - Preferred in machine tools and turbines.

Limitations of Hydrostatic Bearings

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- Limitations:
  - Requires external pump system.
  - High initial cost and maintenance.
  - Energy required to maintain oil pressure.
- Engineering Insight:
  - Used only in critical applications.

Hydrostatic Thrust Bearing

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- Definition:
  - Supports axial (thrust) load using pressurized lubricant.
- Working:
  - Oil enters pocket and creates pressure under thrust surface.
  - Pressure balances axial load.
- Engineering Insight:
  - Used in vertical shafts and turbines.

Circular Step Thrust Bearing

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- Definition:
  - Type of hydrostatic bearing with stepped circular surface.
- Construction:
  - Consists of recess (pocket) and land region.
  - Oil supplied into central pocket.
- Engineering Insight:
  - Most common hydrostatic thrust bearing design.

Pressure Distribution

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- Concept:
  - Maximum pressure at oil inlet (pocket).
  - Pressure decreases towards edge.
- Graph:
  - Pressure vs radius curve shows gradual drop.
- Engineering Insight:
  - Used to calculate load carrying capacity.

Load Carrying Capacity

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- Formula:
  - $W = p \times A$
- Where:
  - p = oil pressure, A = bearing area.
- For circular bearing:
  - $A = \pi(R^2 - r^2)$
- Engineering Insight:
  - Higher pressure → higher load capacity.

Oil Flow Rate

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- Concept:
  - Oil flow required to maintain pressure.
- Formula:
  - $Q \propto (p \times \text{clearance}^3) / \text{viscosity}$
- Engineering Insight:
  - Important for pump design.

Power Loss in Bearing

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- Concept:
  - Power loss due to viscous friction of oil.
- Formula:
  - Power loss = Force × velocity
- Engineering Insight:
  - Should be minimized for efficiency.

Design Steps of Hydrostatic Bearing

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- Step 1:
  - Determine load and pressure required.
- Step 2:
  - Select bearing dimensions.
- Step 3:
  - Calculate flow rate and power loss.
- Engineering Insight:
  - Ensures stable and efficient design.

Numerical 1: Load Capacity

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- Problem:
  - Pressure = 2 MPa, outer radius = 0.1 m, inner radius = 0.05 m.
- Solution:
  - $A = \pi(R^2 - r^2)$
  - $A = 3.14(0.1^2 - 0.05^2)$
  - $A = 3.14(0.01 - 0.0025) = 0.0236\ m^2$
  - $W = p \times A = 2 \times 10^6 \times 0.0236$
  - $W = 47200\ N$
- Answer:
  - Load capacity = 47.2 kN

Numerical 2: Pressure Required

- Problem:
  - Load = 50 kN, area = 0.025 m^2.
- Solution:
  - p = W/A
  - p = 50000 / 0.025
  - p = 2×10^6 N/m^2 = 2 MPa
- Answer:
  - Required pressure = 2 MPa

Numerical 3: Oil Flow Concept

- Problem:
  - Explain effect of clearance on oil flow.
- Solution:
  - Flow rate $\propto$ clearance^3
  - Small increase in clearance increases flow significantly.
- Engineering Insight:
  - Clearance must be controlled carefully.

Numerical 4: Power Loss

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- Problem:
  - Force = 1000 N, velocity = 2 m/s.
- Solution:
  - Power = Force × velocity
  - Power = 1000 × 2 = 2000 W
- Answer:
  - Power loss = 2 kW

Summary of Hydrostatic Bearings

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- Key Points:
  - Uses external pressure lubrication.
  - Provides high load capacity and accuracy.
  - Used in critical engineering applications.
- Engineering Insight:
  - Important for precision machines.

Failures of Antifriction Bearings – Overview

- Definition:
  - Failure occurs when bearing cannot perform its function properly.
- Major Causes:
  - Fatigue, wear, corrosion and lubrication failure.
- Engineering Insight:
  - Failure analysis is essential for improving bearing life.

Fatigue Failure

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- Cause:
  - Repeated cyclic stresses cause cracks in bearing material.
- Effect:
  - Surface pitting and spalling occurs.
- Engineering Insight:
  - Most common failure in rolling bearings.

Wear Failure

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- Cause:
  - Insufficient lubrication or contamination.
- Effect:
  - Material loss and increase in clearance.
- Engineering Insight:
  - Proper lubrication prevents wear.

Corrosion Failure

- Cause:
  - Moisture or chemical reaction with lubricant.
- Effect:
  - Rust formation and surface damage.
- Engineering Insight:
  - Use corrosion-resistant materials.

Overloading Failure

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- Cause:
  - Load exceeding bearing capacity.
- Effect:
  - Permanent deformation of rolling elements.
- Engineering Insight:
  - Proper load selection is critical.

Bearing Housing – Introduction

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- Definition:
  - Housing supports and encloses the bearing.
- Functions:
  - Maintains alignment and protects bearing.
- Engineering Insight:
  - Important for stability and safety.

Types of Bearing Housing

- Types:
  - Plummer block (split housing).
  - Solid housing.
- Applications:
  - Used in shafts and heavy machinery.

Design Considerations for Housing

- Factors:
  - Load and vibration.
  - Material strength.
  - Ease of maintenance.
- Engineering Insight:
  - Proper housing design improves bearing life.

Numerical 1: Bearing Life (Advanced)

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- Problem:
  - C = 8000 N, P = 2000 N, speed = 600 RPM (ball bearing).
- Solution:
  - L10 = (C/P)^3 = (8000/2000)^3 = 4^3 = 64 million rev
- Life in hours:
  - Life = $(64\times10^6)/(60\times600) \approx 1777$ hours
- Answer:
  - Bearing life ≈ 1777 hours

Numerical 2: Equivalent Load (Advanced)

- Problem:
  - Fr = 2000 N, Fa = 1000 N, X = 0.56, Y = 1.6.
- Solution:
  - P = XFr + YFa
  - P = (0.56×2000) + (1.6×1000)
  - P = 1120 + 1600 = 2720 N
- Answer:
  - Equivalent load = 2720 N

Numerical 3: Dynamic Load Capacity

- Problem:
  - Required life = 20 million rev, load = 2500 N.
- Solution:
  - C = P × (L10)^(1/3)
  - C = 2500 × (20)^(1/3)
  - C ≈ 2500 × 2.71 = 6775 N
- Answer:
  - Dynamic load capacity ≈ 6775 N

Numerical 4: Hydrostatic Bearing

- Problem:
  - Pressure = 1.5 MPa, area = 0.02 m^2.
- Solution:
  - $W = p \times A = 1.5 \times 10^6 \times 0.02$
  - $W = 30000$ N
- Answer:
  - Load capacity = 30 kN

Numerical 5: Heat Generation

- Problem:
  - $\mu = 0.03$, load = 4000 N, velocity = 2 m/s.
- Solution:
  - Heat = $\mu \times W \times v$
  - Heat = $0.03 \times 4000 \times 2 = 240$ W
- Answer:
  - Heat generated = 240 W

Case Study: Bearing Failure

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- Observation:
  - Bearing failed due to overheating.
- Cause:
  - Insufficient lubrication and high load.
- Solution:
  - Improve lubrication system.
  - Reduce load and ensure alignment.
- Engineering Insight:
  - Proper maintenance prevents failure.

Final Summary of Bearing Design

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- Key Points:
  - Journal bearings handle heavy loads.
  - Rolling bearings provide low friction.
  - Hydrostatic bearings provide high precision.
- Design Considerations:
  - Load, speed, lubrication and material.
- Engineering Insight:
  - Proper design ensures efficiency and long life.

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Unit 3

L-13

Introduction to Belt Drives

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- Definition:
  - Belt drive is a power transmission system using flexible belt connecting two pulleys.
  - Power is transmitted through friction between belt and pulley.
- Applications:
  - Used in machines, conveyors, fans and compressors.
- Engineering Insight:
  - Simple, economical and suitable for moderate power transmission.

Types of Belt Drives

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- Open Belt Drive:
  - Used when shafts rotate in same direction.
- Cross Belt Drive:
  - Used when shafts rotate in opposite direction.
- Compound Drive:
  - Used for large speed reduction.
- Engineering Insight:
  - Selection depends on speed ratio and layout.

Types of Belts

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- Flat Belt:
  - Used for moderate power and long distances.
- V-Belt:
  - Used for high power transmission.
- Circular Belt:
  - Used for light power applications.
- Engineering Insight:
  - V-belt provides better grip due to wedge action.

Belt Materials

- Common Materials:
  - Leather, rubber, fabric and synthetic materials.
- Properties Required:
  - High strength, flexibility and wear resistance.
- Engineering Insight:
  - Material selection affects efficiency and life.

Working Principle of Belt Drive

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- Concept:
  - Power transmitted by friction between belt and pulley.
- Working:
  - Driving pulley pulls belt causing motion in driven pulley.
- Engineering Insight:
  - Slip reduces efficiency and must be minimized.

L-13

Velocity Ratio of Belt Drive

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- Definition:
  - Ratio of speed of driver to driven pulley.
- Formula:
  - $N1/N2 = D2/D1$
- Engineering Insight:
  - Slip affects actual velocity ratio.

Advantages of Belt Drives

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- Advantages:
  - Simple and low cost.
  - No lubrication required.
  - Smooth and quiet operation.
- Engineering Insight:
  - Widely used in industries.

Limitations of Belt Drives

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- Limitations:
  - Slip and creep occur.
  - Limited power transmission.
- Engineering Insight:
  - Not suitable for precise motion.

Applications of Belt Drives

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- Applications:
  - Used in textile machines, conveyors and machine tools.
  - Used in automobile engines.
- Engineering Insight:
  - Suitable for long distance power transmission.

Design Considerations

- Factors:
  - Power transmitted, speed, distance between shafts.
  - Type of belt and material.
- Engineering Insight:
  - Proper design ensures efficiency and durability.

Belt Tension – Introduction

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- Concept:
  - When belt transmits power, two different tensions are developed in the belt.
  - The tight side has higher tension (T1) and slack side has lower tension (T2).
- Reason:
  - Driving pulley pulls belt creating tension difference.
  - This tension difference is responsible for power transmission.
- Engineering Insight:
  - Higher difference between T1 and T2 increases transmitted power.

Types of Belt Tension

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- Tight Side Tension (T1):
  - Tension in the belt on the driving side of pulley.
  - Always greater because it transmits power.
- Slack Side Tension (T2):
  - Tension in the returning side of belt.
  - Always smaller due to loss of energy.
- Engineering Insight:
  - Power transmitted depends on difference (T1 - T2).

Ratio of Belt Tensions (Concept)

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- Concept:
  - Ratio of tensions depends on friction and angle of contact.
- Important Relation:
  - $T1/T2 = e^{(\mu\theta)}$
- Where:
  - μ = coefficient of friction between belt and pulley.
  - θ = angle of contact in radians.
- Engineering Insight:
  - Higher friction and contact angle increase power transmission.

Derivation of Tension Ratio

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- Assumption:
  - Consider small belt element on pulley surface.
- Forces Acting:
  - Tension, normal reaction and friction force.
- Mathematical Relation:
  - $dT/T = \mu\, d\theta$
- Integration:
  - $\int dT/T = \mu \int d\theta \rightarrow \ln(T1/T2) = \mu\theta$
- Final Equation:
  - $T1/T2 = e^{(\mu\theta)}$
- Engineering Insight:
  - This equation is fundamental in belt design.

Power Transmitted by Belt

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- Formula:
  - Power (P) = (T1 – T2) × v
- Where:
  - v = velocity of belt.
- Explanation:
  - Difference in tension produces effective driving force.
  - Velocity converts force into power.
- Engineering Insight:
  - Higher belt speed increases power transmission.

Condition for Maximum Power

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- Concept:
  - Maximum power is transmitted when belt tension is optimally distributed.
- Condition:
  - $T1 = 3T2$
- Explanation:
  - At this condition, power transmission is maximum without excessive stress.
- Engineering Insight:
  - Used in practical belt design.

Centrifugal Tension

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- Concept:
  - At high speed, belt experiences centrifugal force.
- Formula:
  - $Tc = m \times v^2$
- Where:
  - m = mass per unit length of belt.
- Effect:
  - Reduces effective tension available for power transmission.
- Engineering Insight:
  - Important for high-speed belt design.

Numerical 1: Belt Tension Ratio

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- Problem Statement:
  - Coefficient of friction = 0.3 and angle of contact = 180°.
  - Find ratio of tensions (T1/T2).
- Solution:
  - Step 1: Convert angle to radians → $\theta = \pi$ rad
  - Step 2: Use formula $T1/T2 = e^{(\mu\theta)}$
    - $T1/T2 = e^{(0.3 \times \pi)}$
  - Step 3: Calculate
    - $T1/T2 \approx e^{(0.942)} \approx 2.56$
- Final Answer:
  - T1/T2 = 2.56

Numerical 2: Power Transmitted

- Problem Statement:
  - T1 = 1000 N, T2 = 400 N, velocity = 10 m/s.
  - Find power transmitted.
- Solution:
  - Step 1: Use formula $P = (T1 – T2) \times v$
  - Step 2: Substitute values
    - $P = (1000 – 400) \times 10$
  - Step 3: Calculate
    - $P = 600 \times 10 = 6000$ W
- Final Answer:
  - Power = 6 kW

Numerical 3: Centrifugal Tension

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- Problem Statement:
  - Mass = 2 kg/m, velocity = 15 m/s.
  - Find centrifugal tension.
- Solution:
  - Step 1: Use formula $Tc = m \times v^2$
  - Step 2: Substitute values
    - $Tc = 2 \times (15)^2$
  - Step 3: Calculate
    - $Tc = 2 \times 225 = 450$ N
- Final Answer:
  - Centrifugal tension = 450 N

Flat Belt – Introduction

- Definition:
  - Flat belt is a flexible belt used to transmit power between two pulleys.
  - It operates on friction between belt surface and pulley.
- Characteristics:
  - Suitable for long distance power transmission.
  - Can run at high speeds with moderate loads.
- Engineering Insight:
  - Widely used in industries due to simplicity and low cost.

Design Parameters of Flat Belt

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- Important Parameters:
  - Power to be transmitted.
  - Speed of belt.
  - Coefficient of friction and angle of contact.
- Material Consideration:
  - Strength and flexibility of belt material.
- Engineering Insight:
  - Proper parameter selection ensures efficient design.

Velocity of Belt

- Formula:
  - $v = \pi DN / 60$
- Where:
  - D = diameter of pulley, N = speed in RPM.
- Explanation:
  - Velocity determines rate of power transmission.
- Engineering Insight:
  - Higher velocity increases power capacity.

Power Transmission in Flat Belt

- Formula:
  - $P = (T1 – T2) \times v$
- Explanation:
  - Difference in belt tension produces effective driving force.
  - Velocity converts force into power output.
- Engineering Insight:
  - Both tension and speed affect power transmission.

Design of Belt Width

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- Concept:
  - Belt width is determined based on allowable stress.
- Formula:
  - $T1 = \sigma \times b \times t$
- Where:
  - σ = allowable stress, b = width, t = thickness.
- Engineering Insight:
  - Higher width increases load carrying capacity.

Centrifugal Effect in Belt

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- Concept:
  - At high speeds, centrifugal force acts on belt.
- Formula:
  - $Tc = m \times v^2$
- Effect:
  - Reduces effective tension available for power transmission.
- Engineering Insight:
  - Must be considered in high-speed design.

Angle of Contact

- Definition:
  - Angle of contact is the angle subtended by belt on pulley.
- Importance:
  - Higher angle increases frictional grip.
- Engineering Insight:
  - Used in tension ratio calculation.

Numerical 1: Belt Velocity

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- Problem Statement:
  - Pulley diameter = 0.5 m, speed = 300 RPM.
  - Find velocity of belt.
- Solution:
  - Step 1: Use formula $v = \pi DN / 60$
  - Step 2: Substitute values
    - $v = (3.14 \times 0.5 \times 300)/60$
  - Step 3: Calculate
    - $v = 7.85$ m/s
- Final Answer:
  - Velocity = 7.85 m/s

Numerical 2: Power Transmission

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- Problem Statement:
  - T1 = 1200 N, T2 = 500 N, velocity = 8 m/s.
  - Find power transmitted.
- Solution:
  - Step 1: Use formula $P = (T1 – T2) \times v$
  - Step 2: Substitute values
    - $P = (1200 – 500) \times 8$
  - Step 3: Calculate
    - $P = 700 \times 8 = 5600$ W
- Final Answer:
  - Power = 5.6 kW

Numerical 3: Belt Width

- Problem Statement:
  - Allowable stress = 2 MPa, thickness = 5 mm, T1 = 2000 N.
  - Find belt width.
- Solution:
  - Step 1: Use formula $T1 = \sigma \times b \times t$
  - Step 2: Rearrange $\rightarrow b = T1 / (\sigma \times t)$
  - Step 3: Substitute values
    - $b = 2000 / (2 \times 10^6 \times 0.005)$
  - Step 4: Calculate
    - $b = 0.2$ m = 200 mm
- Final Answer:
  - Belt width = 200 mm

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Introduction to V-Belt

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- Definition:
  - V-belt is a trapezoidal cross-section belt used for high power transmission.
  - It runs in grooved pulleys providing better grip than flat belts.
- Working Principle:
  - Power transmitted by friction and wedge action in pulley groove.
- Engineering Insight:
  - Widely used in automobile engines and industrial drives.

Types of V-Belts

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- Classical V-Belts:
  - Used in general industrial applications.
- Narrow V-Belts:
  - Used for high power transmission in compact design.
- Special V-Belts:
  - Used for variable speed drives.
- Engineering Insight:
  - Selection depends on power and space availability.

Wedge Action in V-Belt

- Concept:
  - Belt fits into V-shaped groove of pulley.
  - Normal reaction increases due to wedge effect.
- Effect:
  - Increases frictional grip between belt and pulley.
  - Reduces slip significantly.
- Engineering Insight:
  - Main advantage over flat belt.

L-16

Tension Ratio in V-Belt

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- Formula:
  - $T1/T2 = e^{(\mu\theta \operatorname{cosec} \alpha)}$
- Where:
  - α = half angle of groove.
  - μ = coefficient of friction.
- Explanation:
  - cosec α increases frictional effect.
- Engineering Insight:
  - Higher grip compared to flat belt.

L-16

Power Transmission in V-Belt

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- Formula:
  - $P = (T1 – T2) \times v$
- Explanation:
  - Difference in tension produces driving force.
  - Velocity converts force into power.
- Engineering Insight:
  - V-belt transmits more power than flat belt.

Design of V-Belt Pulley

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- Design Considerations:
  - Pulley diameter based on belt type.
  - Groove angle must match belt angle.
- Important Factors:
  - Material strength and wear resistance.
- Engineering Insight:
  - Incorrect groove angle reduces efficiency.

Advantages of V-Belt

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- Advantages:
  - Higher power transmission capacity.
  - Reduced slip due to wedge action.
  - Compact design.
- Engineering Insight:
  - Preferred over flat belts in modern machines.

Numerical 1: Tension Ratio

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- Problem Statement:
  - $\mu = 0.3$, $\theta = 180°$, $\alpha = 20°$.
  - Find tension ratio T1/T2.
- Solution:
  - Step 1: Convert $\theta = \pi$ rad
  - Step 2: Use formula $T1/T2 = e^{(\mu\theta \operatorname{cosec} \alpha)}$
  - Step 3: $\operatorname{cosec} 20° \approx 2.92$
    - $T1/T2 = e^{(0.3 \times \pi \times 2.92)}$
  - Step 4: Calculate
    - $T1/T2 \approx e^{(2.75)} \approx 15.6$
- Final Answer:
  - Tension ratio ≈ 15.6

Numerical 2: Power Transmission

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- Problem Statement:
  - T1 = 1500 N, T2 = 300 N, velocity = 12 m/s.
  - Find power transmitted.
- Solution:
  - Step 1: Use formula $P = (T1 – T2) \times v$
  - Step 2: Substitute values
    - $P = (1500 – 300) \times 12$
  - Step 3: Calculate
    - $P = 1200 \times 12 = 14400$ W
- Final Answer:
  - Power = 14.4 kW

Numerical 3: Belt Velocity

- Problem Statement:
  - Pulley diameter = 0.4 m, speed = 400 RPM.
  - Find belt velocity.
- Solution:
  - Step 1: Use formula $v = \pi DN / 60$
  - Step 2: Substitute values
    - $v = (3.14 \times 0.4 \times 400)/60$
  - Step 3: Calculate
    - $v = 8.38$ m/s
- Final Answer:
  - Velocity = 8.38 m/s

Introduction to Chain Drive

- Definition:
  - Chain drive is a power transmission system using chain and sprockets.
  - It transmits power without slip unlike belt drives.
- Applications:
  - Used in bicycles, motorcycles and conveyors.
- Engineering Insight:
  - Provides constant velocity ratio.

Types of Chains

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- Roller Chain:
  - Used for power transmission.
- Silent Chain:
  - Used for smooth and noiseless operation.
- Leaf Chain:
  - Used in lifting applications.
- Engineering Insight:
  - Selection depends on application.

Working of Chain Drive

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- Concept:
  - Chain engages with sprocket teeth.
  - Motion transmitted by direct engagement.
- Advantages:
  - No slip, high efficiency.
- Engineering Insight:
  - Suitable for precise motion transmission.

Velocity Ratio of Chain Drive

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- Formula:
  - Velocity ratio = T2 / T1
- Where:
  - T1 = teeth on driver sprocket.
  - T2 = teeth on driven sprocket.
- Engineering Insight:
  - Constant velocity ratio without slip.

Length of Chain

- Formula:
  - $L = (T1 + T2)/2 + 2x/p + ((T2 - T1)^2) / (4\pi^2 \times x/p)$
- Where:
  - x = center distance, p = pitch.
- Explanation:
  - Determines number of chain links required.
- Engineering Insight:
  - Important for proper chain fitting.

Pitch of Chain

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- Definition:
  - Distance between centers of adjacent chain pins.
- Importance:
  - Determines size and strength of chain.
- Engineering Insight:
  - Standard pitch values are used.

Tooth Profile of Sprocket

- Concept:
  - Teeth designed to fit chain links properly.
- Features:
  - Curved profile to reduce wear.
- Engineering Insight:
  - Improper profile causes noise and wear.

Design of Chain Drive

- Steps:
  - Determine power and speed.
  - Select type of chain.
  - Calculate pitch and number of teeth.
  - Check strength and wear.
- Engineering Insight:
  - Ensures safe and efficient operation.

Numerical 1: Velocity Ratio

- Problem Statement:
  - Driver sprocket = 20 teeth, driven sprocket = 40 teeth.
  - Find velocity ratio.
- Solution:
  - Velocity ratio = T2/T1
  - = 40/20 = 2
- Final Answer:
  - Velocity ratio = 2

Numerical 2: Chain Length

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- Problem Statement:
  - T1 = 20, T2 = 40, center distance = 1 m, pitch = 0.02 m.
- Solution:
  - Step 1: Use chain length formula
    - Substitute values in formula.
  - Step 2: Calculate approximate value
    - L ≈ 120 links (approx)
- Final Answer:
  - Chain length ≈ 120 links

Numerical 3: Pitch Calculation

- Problem Statement:
  - Power = 5 kW, speed = 300 RPM.
- Solution:
  - Select standard pitch based on power and speed tables.
- Engineering Insight:
  - Pitch selection depends on design charts.

Advantages of Chain Drive

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- Advantages:
  - No slip and constant velocity ratio.
  - High efficiency.
  - Suitable for heavy loads.
- Engineering Insight:
  - Preferred for precise motion.

Limitations of Chain Drive

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- Limitations:
  - Requires lubrication.
  - Noise at high speed.
- Engineering Insight:
  - Not suitable for very high speeds.

Applications of Chain Drive

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- Applications:
  - Used in bicycles and motorcycles.
  - Used in conveyors and industrial machines.
- Engineering Insight:
  - Suitable for short-distance transmission.

Summary of Chain Drive

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- Key Points:
  - No slip and constant velocity ratio.
  - Requires lubrication and maintenance.
- Engineering Insight:
  - Important for precise power transmission.

Introduction to Wire Rope

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- Definition:
  - Wire rope is a flexible machine element used for lifting and transmitting tensile loads.
  - It consists of several strands of wire twisted together around a core.
- Applications:
  - Used in cranes, elevators, hoists and cableways.
- Engineering Insight:
  - Provides high strength with flexibility.

Construction of Wire Rope

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- Components:
  - Individual wires twisted into strands.
  - Strands twisted around a central core.
- Types of Core:
  - Fiber core and steel core.
- Engineering Insight:
  - Construction affects strength and flexibility.

Types of Wire Ropes

- Classification:
  - Based on number of strands and wires.
- Examples:
  - 6×7, 6×19, 6×37 constructions.
- Engineering Insight:
  - More wires → more flexibility, less wear resistance.

Stresses in Wire Rope

- Types of Stress:
  - Direct tensile stress due to load.
  - Bending stress over sheaves and drums.
- Effect:
  - Repeated bending leads to fatigue failure.
- Engineering Insight:
  - Proper design reduces stress concentration.

Strength of Wire Rope

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- Formula:
  - Strength = A × σ
- Where:
  - A = cross-sectional area.
  - σ = allowable stress.
- Engineering Insight:
  - Factor of safety must be considered.

Design of Wire Rope

- Steps:
  - Determine load to be lifted.
  - Select suitable rope type.
  - Calculate required diameter.
  - Check stresses and safety factor.
- Engineering Insight:
  - Ensures safe lifting operation.

Sheaves (Pulleys)

- Definition:
  - Sheaves are pulleys over which wire rope passes.
- Function:
  - Change direction of rope and reduce friction.
- Engineering Insight:
  - Proper diameter reduces bending stress.

Design of Sheaves

- Design Consideration:
  - Diameter of sheave = 20–30 times rope diameter.
- Reason:
  - Larger diameter reduces bending stress.
- Engineering Insight:
  - Improves life of wire rope.

Drums in Wire Rope System

- Definition:
  - Drum is used to wind or unwind wire rope.
- Function:
  - Stores rope and transmits motion.
- Engineering Insight:
  - Design affects rope life and efficiency.

Design of Drum

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- Design Considerations:
  - Diameter of drum depends on rope diameter.
  - Material strength and load capacity.
- Engineering Insight:
  - Proper design prevents excessive bending stress.

Numerical 1: Rope Strength

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- Problem Statement:
  - Area = 200 mm^2, allowable stress = 400 MPa.
  - Find strength of rope.
- Solution:
  - Step 1: Use formula Strength = $A \times \sigma$
  - Step 2: Convert units
    - $A = 200 \times 10^{-6}\ m^2$
  - Step 3: Substitute values
    - Strength = $200 \times 10^{-6} \times 400 \times 10^{6}$
  - Step 4: Calculate
    - Strength = 80,000 N
- Final Answer:
  - Strength = 80 kN

Numerical 2: Factor of Safety

- Problem Statement:
  - Breaking load = 100 kN, working load = 20 kN.
  - Find factor of safety.
- Solution:
  - FOS = Breaking load / Working load
  - Step 2: Substitute values
    - FOS = 100 / 20 = 5
- Final Answer:
  - Factor of safety = 5

Numerical 3: Sheave Diameter

- Problem Statement:
  - Rope diameter = 10 mm.
  - Find minimum sheave diameter.
- Solution:
  - D = 20 × rope diameter
  - Step 2: Substitute values
    - D = 20 × 10 = 200 mm
- Final Answer:
  - Sheave diameter = 200 mm

Numerical 4: Load Calculation

- Problem Statement:
  - Rope supports 5000 N load.
  - Find stress if area = 100 mm^2.
- Solution:
  - Stress = Load / Area
  - Step 2: Convert area
    - $A = 100 \times 10^{-6}\ m^2$
  - Step 3: Calculate
    - Stress = $5000 / (100 \times 10^{-6})$
    - Stress = 50 MPa
- Final Answer:
  - Stress = 50 MPa

Final Summary of Chapter

- Key Topics Covered:
  - Belt drives, chain drives and wire ropes.
  - Design formulas and working principles.
- Engineering Insight:
  - Selection depends on load, speed and application.
  - Proper design ensures safety and efficiency.

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Unit 4

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Introduction to Gears (Detailed)

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- Definition:
  - Gears are mechanical components used to transmit power and motion between rotating shafts through direct contact of teeth.
  - Unlike belts and chains, gears provide positive drive without slip ensuring exact velocity ratio.
- Working Principle:
  - Power transmission occurs due to meshing of gear teeth.
  - Force is transmitted along the line of action between mating teeth.
- Engineering Importance:
  - Used where precise speed control is required such as gearboxes and robotics.

Types of Gears (Detailed)

- Spur Gears:
  - Have straight teeth parallel to shaft axis.
  - Used for transmitting power between parallel shafts.
- Helical Gears:
  - Teeth are inclined to shaft axis forming a helix.
  - Provide smoother and quieter operation than spur gears.
- Other Types:
  - Bevel gears for intersecting shafts.
  - Worm gears for large speed reduction.
- Engineering Insight:
  - Selection depends on shaft arrangement and load condition.

Spur Gear – Detailed Explanation

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- Construction:
  - Consists of cylindrical wheels with straight teeth.
- Working:
  - Teeth engage suddenly resulting in impact load.
  - Power transmitted through line contact.
- Advantages:
  - Simple design and easy manufacturing.
- Limitations:
  - Produces noise and vibration at high speeds.
- Engineering Insight:
  - Best suited for moderate speeds.

Helical Gear – Detailed Explanation

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- Construction:
  - Teeth cut at an angle forming a helix.
- Working:
  - Gradual engagement of teeth reduces shock and noise.
  - Multiple teeth share load simultaneously.
- Advantages:
  - Higher load capacity and smooth operation.
- Limitation:
  - Generates axial thrust requiring bearings.
- Engineering Insight:
  - Used in high-speed gear systems.

Gear Terminology (Detailed)

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- Pitch Circle:
  - Imaginary circle that determines size and motion of gear.
  - All calculations are based on pitch circle.
- Module (m):
  - Ratio of pitch diameter to number of teeth.
  - Standard parameter for gear size selection.
- Pressure Angle:
  - Angle between line of action and tangent to pitch circle.
  - Common values: 20° and 14.5°.

Addendum and Dedendum (Detailed)

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- Addendum:
  - Distance from pitch circle to top of tooth.
  - Determines tooth height above pitch circle.
- Dedendum:
  - Distance from pitch circle to bottom of tooth.
  - Provides clearance for mating gear.
- Engineering Insight:
  - Proper values prevent interference and ensure smooth motion.

Circular Pitch and Module (Detailed)

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- Circular Pitch:
  - Distance between corresponding points on adjacent teeth along pitch circle.
- Relation:
  - $p = \pi m$ where m is module.
- Importance:
  - Determines spacing between teeth.
- Engineering Insight:
  - Used in gear manufacturing and design calculations.

Gear Ratio (Detailed)

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- Definition:
  - Ratio of angular speed of driving gear to driven gear.
- Formula:
  - $i = T2 / T1$
- Explanation:
  - Higher gear ratio reduces speed and increases torque.
- Engineering Insight:
  - Used in gearboxes to control speed.

Advantages of Gear Drive (Detailed)

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- Advantages:
  - Provides exact velocity ratio without slip.
  - High efficiency compared to belt drives.
  - Compact and reliable system.
- Engineering Insight:
  - Used in precision machines and automotive systems.

Limitations of Gear Drive (Detailed)

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- Limitations:
  - Manufacturing is complex and costly.
  - Requires proper lubrication to reduce wear.
  - Noise and vibration in spur gears.
- Engineering Insight:
  - Proper design and lubrication reduce limitations.

Tooth Profiles – Introduction

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- Concept:
  - Gear tooth profile defines the shape of teeth that ensures smooth transmission of motion.
  - Proper tooth profile maintains constant velocity ratio between gears.
- Types of Tooth Profiles:
  - Involute profile and cycloidal profile are commonly used.
- Engineering Insight:
  - Involute profile is most widely used due to ease of manufacturing.

Involute Tooth Profile (Detailed)

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- Definition:
  - Involute profile is generated by unwinding a string from a base circle.
- Working Principle:
  - Contact between teeth occurs along a straight line called line of action.
  - Maintains constant velocity ratio even with small alignment errors.
- Advantages:
  - Insensitive to center distance variations.
  - Easy to manufacture using standard tools.
- Engineering Insight:
  - Most commonly used profile in modern gear design.

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Cycloidal Tooth Profile (Detailed)

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- Definition:
  - Cycloidal profile is generated by rolling a circle on another circle.
- Working:
  - Teeth contact occurs along curved surfaces.
- Advantages:
  - No interference occurs.
- Limitations:
  - Sensitive to center distance changes.
  - Difficult to manufacture.
- Engineering Insight:
  - Used in clocks and light machinery.

Comparison: Involute vs Cycloidal

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- Involute Profile:
  - Constant velocity ratio even with slight misalignment.
  - Easy to manufacture and widely used.
- Cycloidal Profile:
  - No interference but sensitive to errors.
  - Used in low-load applications.
- Engineering Insight:
  - Involute is preferred in engineering practice.

Interference in Gears (Concept)

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- Definition:
  - Interference occurs when non-conjugate portions of teeth come in contact.
- Cause:
  - When number of teeth is too small.
  - Contact occurs below base circle.
- Effect:
  - Produces noise, vibration and damage to teeth.
- Engineering Insight:
  - Must be avoided in gear design.

Conditions for Interference

- Condition:
  - Occurs when addendum of one gear is too large.
  - Occurs when number of teeth is too small.
- Geometric Reason:
  - Contact extends below base circle region.
- Engineering Insight:
  - Design must ensure contact occurs only in involute region.

Minimum Number of Teeth (Concept)

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- Definition:
  - Minimum number of teeth required to avoid interference.
- Formula:
  - $Z_{min} = 2 / (\sin^2 \varphi)$
- Where:
  - φ = pressure angle.
- Engineering Insight:
  - For 20° pressure angle, minimum teeth ≈ 18.

Numerical 1: Minimum Teeth

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- Problem Statement:
  - Find minimum number of teeth for pressure angle = 20°.
- Solution:
  - Step 1: Use formula $Z_{min} = 2 / (\sin^2 \varphi)$
  - Step 2: $\sin 20° \approx 0.342$
  - Step 3: Substitute values
    - $Z_{min} = 2 / (0.342^2)$
  - Step 4: Calculate
    - $Z_{min} \approx 2 / 0.117 \approx 17.1 \approx 18$ teeth
- Final Answer:
  - Minimum number of teeth = 18

Numerical 2: Interference Check

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- Problem Statement:
  - A gear has 16 teeth with 20° pressure angle.
  - Check whether interference occurs.
- Solution:
  - Step 1: Minimum teeth required = 18
  - Step 2: Given teeth = 16 < 18
- Conclusion:
  - Gear will experience interference.
- Engineering Insight:
  - Design must increase number of teeth.

Methods to Avoid Interference

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- Methods:
  - Increase number of teeth.
  - Use higher pressure angle.
  - Use profile shifting.
- Engineering Insight:
  - Proper design ensures smooth and noise-free operation.

Forces Acting on Gear Teeth

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- Concept:
  - When gears mesh, forces are transmitted through contact of teeth.
  - These forces act along the line of action and can be resolved into components.
- Types of Forces:
  - Tangential force (Ft) responsible for power transmission.
  - Radial force (Fr) acts towards center of gear.
- Engineering Insight:
  - Proper analysis of forces is essential for gear design.

Tangential Force (Ft)

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- Definition:
  - Tangential force is the component responsible for transmitting torque.
- Formula:
  - $Ft = (2T) / d$
- Where:
  - T = torque, d = pitch diameter.
- Explanation:
  - Higher Ft means higher power transmission.
- Engineering Insight:
  - Primary design parameter for gear strength.

Radial Force (Fr)

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- Definition:
  - Radial force acts perpendicular to tangential force.
- Formula:
  - $Fr = Ft \times \tan \varphi$
- Where:
  - φ = pressure angle.
- Effect:
  - Causes separating force between gears.
- Engineering Insight:
  - Requires proper bearing support.

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Resultant Force on Gear Tooth

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- Concept:
  - Resultant force acts along line of action.
- Relation:
  - Resultant force is vector sum of Ft and Fr.
- Explanation:
  - This force causes bending and stress in gear tooth.
- Engineering Insight:
  - Design must consider both components.

Beam Strength of Gear Tooth

- Concept:
  - Gear tooth behaves like a cantilever beam.
- Failure Mode:
  - Tooth may fail due to bending stress at root.
- Engineering Insight:
  - Lewis equation is used to calculate beam strength.

Lewis Equation (Theory)

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- Formula:
  - $Ft = \sigma \times b \times m \times Y$
- Where:
  - σ = allowable stress, b = face width.
  - m = module, Y = Lewis form factor.
- Explanation:
  - Equation estimates bending strength of gear tooth.
- Engineering Insight:
  - Used for safe gear design.

Lewis Form Factor (Y)

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- Definition:
  - Factor representing tooth shape and strength.
- Dependence:
  - Depends on number of teeth.
- Observation:
  - Higher number of teeth → stronger tooth.
- Engineering Insight:
  - Important parameter in Lewis equation.

Formative Number of Teeth

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- Definition:
  - Equivalent number of teeth used in helical gear design.
- Formula:
  - $Zv = Z / \cos^3 \beta$
- Where:
  - β = helix angle.
- Explanation:
  - Helical gear behaves like spur gear with more teeth.
- Engineering Insight:
  - Used in Lewis equation for helical gears.

Numerical 1: Tangential Force

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- Problem Statement:
  - Torque = 500 Nm, pitch diameter = 0.2 m.
  - Find tangential force.
- Solution:
  - Step 1: Use formula Ft = (2T)/d
  - Step 2: Substitute values
    - Ft = (2 × 500) / 0.2
  - Step 3: Calculate
    - Ft = 1000 / 0.2 = 5000 N
- Final Answer:
  - Tangential force = 5000 N

Numerical 2: Lewis Equation

- Problem Statement:
  - $\sigma = 100$ MPa, $b = 50$ mm, $m = 5$ mm, $Y = 0.3$.
  - Find beam strength (Ft).
- Solution:
  - Step 1: Convert units (mm to m)
  - Step 2: Use $Ft = \sigma \times b \times m \times Y$
  - Step 3: Substitute values
    - $Ft = 100 \times 10^6 \times 0.05 \times 0.005 \times 0.3$
  - Step 4: Calculate
    - $Ft = 7500$ N
- Final Answer:
  - Beam strength = 7500 N

Spur Gear Design – Overview

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- Objective:
  - To design gear that can safely transmit power without failure.
  - Ensure gear tooth withstands bending and wear stresses.
- Design Considerations:
  - Power transmitted, speed, material and loading conditions.
- Engineering Insight:
  - Design must satisfy strength and wear conditions.

Design Procedure of Spur Gear

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- Step 1:
  - Determine power and speed of gears.
- Step 2:
  - Select material and allowable stress.
- Step 3:
  - Calculate module using Lewis equation.
- Step 4:
  - Check dynamic load using Buckingham equation.
- Step 5:
  - Check wear load.
- Engineering Insight:
  - Final design must satisfy all conditions.

Beam Strength Condition

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- Concept:
  - Gear tooth must resist bending failure.
- Condition:
  - $Ft \leq \sigma \times b \times m \times Y$
- Explanation:
  - If Ft exceeds beam strength → tooth failure occurs.
- Engineering Insight:
  - First condition checked in gear design.

Dynamic Load in Gears

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- Concept:
  - Actual load on gear teeth is higher than theoretical load.
- Reason:
  - Manufacturing errors, vibration and misalignment.
- Effect:
  - Increases stress and may cause failure.
- Engineering Insight:
  - Dynamic load must be considered for safe design.

Buckingham Equation (Theory)

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- Formula:
  - $Fd = Ft + (21v(bC + Ft)) / (21v + \sqrt{(bC + Ft)})$
- Where:
  - Fd = dynamic load, Ft = tangential load.
  - v = pitch line velocity, b = face width.
  - C = deformation factor.
- Engineering Insight:
  - Used to calculate actual load on gear tooth.

Pitch Line Velocity

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- Formula:
  - $v = \pi DN / 60$
- Where:
  - D = pitch diameter, N = speed.
- Explanation:
  - Higher velocity increases dynamic effects.
- Engineering Insight:
  - Important parameter in Buckingham equation.

Wear Load in Gears

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- Concept:
  - Gear tooth may fail due to surface wear.
- Formula:
  - $Fw = d \times b \times Q \times K$
- Where:
  - Q = ratio factor, K = material factor.
- Engineering Insight:
  - Wear condition must be satisfied.

Wear Condition

- Condition:
  - $F_w \geq F_d$
- Explanation:
  - Wear strength must be greater than dynamic load.
- Engineering Insight:
  - Ensures surface durability of gear.

Numerical 1: Tangential Load

- Problem Statement:
  - Power = 5 kW, speed = 300 RPM, diameter = 0.2 m.
  - Find tangential force.
- Solution:
  - Step 1: Torque $T = (P \times 60)/(2\pi N)$
    - $T = (5000 \times 60)/(2\pi \times 300) = 159.2$ Nm
  - Step 2: $Ft = (2T)/d$
    - $Ft = (2 \times 159.2)/0.2 = 1592$ N
- Final Answer:
  - Tangential force = 1592 N

Numerical 2: Pitch Line Velocity

- Problem Statement:
  - Diameter = 0.25 m, speed = 400 RPM.
  - Find velocity.
- Solution:
  - $v = \pi DN/60$
    - $v = (3.14 \times 0.25 \times 400)/60$
    - $v = 5.23$ m/s
- Final Answer:
  - Velocity = 5.23 m/s

Numerical 3: Beam Strength

- Problem Statement:
  - $\sigma = 120$ MPa, $b = 40$ mm, $m = 5$ mm, $Y = 0.3$.
- Solution:
  - $Ft = \sigma \times b \times m \times Y$
    - $Ft = 120 \times 10^6 \times 0.04 \times 0.005 \times 0.3$
    - $Ft = 7200$ N
- Final Answer:
  - Beam strength = 7200 N

Numerical 4: Dynamic Load (Buckingham)

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- Problem Statement:
  - Ft = 1500 N, v = 6 m/s, bC = 2000.
- Solution:
  - Fd = Ft + (21v(bC + Ft))/(21v + √(bC + Ft))
  - Step 2: Substitute values
    - Fd ≈ 1500 + additional dynamic term
- Engineering Insight:
  - Dynamic load > static load.

Numerical 5: Wear Load

- Problem Statement:
  - d = 0.2 m, b = 0.04 m, Q = 2, K = 1.2×10^6.
- Solution:
  - Fw = d × b × Q × K
    - Fw = $0.2 \times 0.04 \times 2 \times 1.2\times10^6$
    - Fw = 19200 N
- Final Answer:
  - Wear load = 19200 N

Design Check Summary

- Conditions:
  - Ft ≤ beam strength
  - Fd ≤ beam strength
  - Fw ≥ Fd
- Engineering Insight:
  - All conditions must be satisfied for safe design.

Conclusion of Spur Gear Design

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- Key Points:
  - Lewis equation ensures bending strength.
  - Buckingham equation accounts for dynamic load.
  - Wear load ensures durability.
- Engineering Insight:
  - Comprehensive design prevents failure.

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Introduction to Helical Gears

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- Definition:
  - Helical gears have teeth inclined at an angle to the shaft axis.
  - They transmit power between parallel shafts smoothly.
- Working Principle:
  - Teeth engage gradually resulting in smooth and quiet operation.
  - More than one tooth is in contact at a time.
- Engineering Insight:
  - Used in high-speed and heavy load applications.

Helix Angle (β)

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- Definition:
  - Angle between gear tooth and axis of rotation.
- Effect:
  - Higher helix angle increases smoothness of operation.
  - Also increases axial thrust.
- Engineering Insight:
  - Typical range: 15° to 30°.

Forces in Helical Gear

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- Types of Forces:
  - Tangential force (Ft) – transmits power.
  - Radial force (Fr) – acts towards center.
  - Axial force (Fa) – acts along shaft.
- Engineering Insight:
  - Axial force requires thrust bearings.

Tangential Force (Ft)

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- Formula:
  - Ft = (2T) / d
- Explanation:
  - Same as spur gear, responsible for power transmission.
- Engineering Insight:
  - Primary force for design calculations.

Axial Force (Fa)

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- Formula:
  - $Fa = Ft \times \tan \beta$
- Explanation:
  - Due to inclined teeth, force acts along shaft.
- Engineering Insight:
  - Requires thrust bearings to balance load.

Radial Force (Fr)

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- Formula:
  - $Fr = Ft \times \tan \varphi / \cos \beta$
- Explanation:
  - Acts perpendicular to tangential force.
- Engineering Insight:
  - Affects bearing design.

Formative Number of Teeth

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- Concept:
  - Helical gear behaves like spur gear with more teeth.
- Formula:
  - $Zv = Z / \cos^3 \beta$
- Explanation:
  - Used to calculate Lewis form factor.
- Engineering Insight:
  - Important for strength calculation.

Lewis Equation for Helical Gear

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- Modified Formula:
  - $Ft = \sigma \times b \times m \times Y$
- Note:
  - Y is based on formative number of teeth.
- Explanation:
  - Helical gear strength calculated using equivalent spur gear.
- Engineering Insight:
  - Ensures safe design.

Advantages of Helical Gear

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- Advantages:
  - Smooth and quiet operation.
  - Higher load carrying capacity.
  - Less vibration.
- Engineering Insight:
  - Preferred in high-speed systems.

Limitations of Helical Gear

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- Limitations:
  - Produces axial thrust.
  - More complex manufacturing.
- Engineering Insight:
  - Requires additional bearing support.

Numerical 1: Axial Force

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- Problem Statement:
  - Ft = 2000 N, helix angle = 20°.
  - Find axial force.
- Solution:
  - Fa = Ft × tan β
    - Fa = 2000 × tan20°
  - Step 2: Calculate
    - Fa = 2000 × 0.364 = 728 N
- Final Answer:
  - Axial force = 728 N

Numerical 2: Formative Teeth

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- Problem Statement:
  - $Z = 20$ teeth, $\beta = 25°$.
  - Find formative number of teeth.
- Solution:
  - $Zv = Z / \cos^3 \beta$
  - Step 2: $\cos 25° \approx 0.906$
    - $Zv = 20 / (0.906^3)$
  - Step 3: Calculate
    - $Zv \approx 20 / 0.744 \approx 26.9$
- Final Answer:
  - Formative teeth ≈ 27

Numerical 3: Tangential Force

- Problem Statement:
  - Torque = 600 Nm, diameter = 0.3 m.
- Solution:
  - Ft = (2T)/d
    - Ft = (2×600)/0.3
    - Ft = 4000 N
- Final Answer:
  - Tangential force = 4000 N

Numerical 4: Radial Force

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- Problem Statement:
  - Ft = 3000 N, φ = 20°, β = 25°.
- Solution:
  - Fr = Ft × tan φ / cos β
  - Step 2: Substitute values
    - Fr = 3000 × tan20° / cos25°
  - Step 3: Calculate
    - Fr ≈ 3000 × 0.364 / 0.906 ≈ 1205 N
- Final Answer:
  - Radial force ≈ 1205 N

Summary of Helical Gear Design

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- Key Points:
  - Helical gears provide smooth operation.
  - Axial thrust is major design consideration.
  - Formative teeth used in strength calculations.
- Engineering Insight:
  - Used in high-speed and heavy-duty applications.

Advanced Numerical 1: Spur Gear Design

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- Problem Statement:
  - Power = 10 kW, speed = 300 RPM, pitch diameter = 0.3 m.
  - Find tangential force acting on gear.
- Solution:
  - Step 1: Calculate torque $T = (P \times 60)/(2\pi N)$
    - $T = (10000 \times 60)/(2\pi \times 300) = 318.3$ Nm
  - Step 2: Calculate $Ft = (2T)/d$
    - $Ft = (2 \times 318.3)/0.3 = 2122$ N
- Final Answer:
  - Tangential force = 2122 N

Advanced Numerical 2: Beam Strength Check

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- Problem Statement:
  - $\sigma = 120$ MPa, $b = 50$ mm, $m = 6$ mm, $Y = 0.3$.
  - Check beam strength.
- Solution:
  - $Ft = \sigma \times b \times m \times Y$
    - $Ft = 120 \times 10^6 \times 0.05 \times 0.006 \times 0.3$
    - $Ft = 10800$ N
- Final Answer:
  - Beam strength = 10800 N

Advanced Numerical 3: Wear Load

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- Problem Statement:
  - d = 0.25 m, b = 0.05 m, Q = 2, K = 1.5×10^{6}.
- Solution:
  - Fw = d × b × Q × K
    - Fw = $0.25 \times 0.05 \times 2 \times 1.5\times10^{6}$
    - Fw = 37500 N
- Final Answer:
  - Wear load = 37500 N

Advanced Numerical 4: Helical Gear Forces

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- Problem Statement:
  - Ft = 2500 N, β = 20°, φ = 20°.
  - Find axial and radial forces.
- Solution:
  - Fa = Ft × tanβ = 2500×tan20° = 910 N
  - Fr = Ft × tanφ / cosβ
    - Fr = 2500×0.364/0.94 ≈ 968 N
- Final Answer:
  - Fa = 910 N, Fr = 968 N

Advanced Numerical 5: Formative Teeth

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- Problem Statement:
  - $Z = 25$, $\beta = 30°$.
  - Find formative number of teeth.
- Solution:
  - $Zv = Z / \cos^3\beta$
  - $\cos 30° = 0.866$
    - $Zv = 25 / (0.866^3)$
    - $Zv \approx 25 / 0.65 \approx 38.4$
- Final Answer:
  - Formative teeth ≈ 38

Design Case Study: Spur Gear

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- Given:
  - Ft = 2000 N, beam strength = 2500 N.
- Check:
  - Ft < beam strength → Safe design.
- Engineering Insight:
  - Always ensure load is less than strength.

Design Case Study: Dynamic Load

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- Observation:
  - Dynamic load is always greater than tangential load.
- Conclusion:
  - Design must consider dynamic effects.
- Engineering Insight:
  - Buckingham equation is essential.

Comparison: Spur vs Helical Gear

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- Spur Gear:
  - Simple, noisy at high speed.
- Helical Gear:
  - Smooth, high load capacity.
- Engineering Insight:
  - Helical gears preferred for modern machines.

Final Design Procedure Summary

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- Steps:
  - Calculate forces acting on gear.
  - Check beam strength using Lewis equation.
  - Calculate dynamic load using Buckingham equation.
  - Check wear load condition.
- Engineering Insight:
  - All conditions must be satisfied.

Final Conclusion of Chapter

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- Key Learnings:
  - Spur gears are simple but noisy.
  - Helical gears provide smooth operation.
  - Proper design ensures strength and durability.
- Engineering Insight:
  - Gear design is critical in mechanical systems.

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Unit 5

Introduction to Worm Gear Drive

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- Definition:
  - Worm gear drive consists of a worm (screw-like gear) and a worm wheel.
  - Used to transmit motion between non-parallel, non-intersecting shafts.
- Working Principle:
  - Power is transmitted through sliding contact between worm and gear teeth.
- Engineering Insight:
  - Provides very high speed reduction in compact space.

Applications of Worm Gear

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- Applications:
  - Used in elevators, conveyors and hoists.
  - Used in machine tools and automobile steering systems.
- Engineering Insight:
  - Preferred where high torque and low speed are required.

Types of Worm Gear

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- Based on Shape:
  - Cylindrical worm and globoidal worm.
- Based on Thread:
  - Single start and multi-start worms.
- Engineering Insight:
  - Multi-start worms increase speed ratio efficiency.

Terminology of Worm Gear

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- Lead:
  - Distance moved by worm in one revolution.
- Pitch:
  - Distance between threads.
- Lead Angle:
  - Angle between helix and plane perpendicular to axis.
- Engineering Insight:
  - Lead angle affects efficiency and friction.

Velocity Ratio of Worm Gear

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- Formula:
  - Velocity ratio = Zg / Zw
- Where:
  - Zg = number of teeth on gear.
  - Zw = number of starts on worm.
- Engineering Insight:
  - High velocity ratio achievable.

Advantages of Worm Gear

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- Advantages:
  - High speed reduction in single stage.
  - Smooth and silent operation.
  - Self-locking property possible.
- Engineering Insight:
  - Used where reverse motion must be prevented.

Limitations of Worm Gear

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- Limitations:
  - High friction due to sliding contact.
  - Lower efficiency compared to spur gears.
- Engineering Insight:
  - Requires good lubrication.

Materials for Worm Gear

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- Worm:
  - Made of hardened steel.
- Worm Wheel:
  - Made of bronze or phosphor bronze.
- Engineering Insight:
  - Different materials reduce wear.

Proportions of Worm Gear

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- Parameters:
  - Module, diameter and face width.
- Standard Practice:
  - Face width = 10m to 12m.
- Engineering Insight:
  - Proper proportion ensures strength.

Efficiency of Worm Gear

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- Concept:
  - Efficiency depends on lead angle and friction.
- Formula:
  - $\eta = \tan\gamma / (\tan\gamma + \mu)$
- Engineering Insight:
  - Higher lead angle increases efficiency.

Forces Acting on Worm Gear – Overview

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- Concept:
  - When worm and worm wheel mesh, forces are transmitted through sliding contact.
  - These forces act along the helical surface of worm thread.
- Types of Forces:
  - Tangential force (Ft) – responsible for power transmission.
  - Axial force (Fa) – acts along the axis of worm.
  - Radial force (Fr) – acts perpendicular to shaft axis.
- Engineering Insight:
  - All three forces must be considered for proper design.

Tangential Force (Ft) – Detailed

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- Definition:
  - Tangential force is the main force that transmits torque from worm to worm wheel.
- Formula:
  - $Ft = (2T) / d$
- Where:
  - T = torque transmitted, d = pitch diameter of gear.
- Explanation:
  - This force produces rotation of the driven gear.
- Engineering Insight:
  - Primary force used in strength calculations.

Axial Force (Fa) – Detailed

- Definition:
  - Axial force acts along the axis of worm due to helical thread.
- Formula:
  - $Fa = Ft / \tan \gamma$
- Where:
  - γ = lead angle of worm.
- Explanation:
  - As worm rotates, it pushes the gear along axial direction.
- Engineering Insight:
  - Requires thrust bearings to balance load.

Radial Force (Fr) – Detailed

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- Definition:
  - Radial force acts perpendicular to tangential force.
- Formula:
  - $Fr = Ft \times \tan \varphi$
- Where:
  - φ = pressure angle.
- Explanation:
  - This force tends to separate worm and gear.
- Engineering Insight:
  - Must be supported by bearings.

Resultant Force on Tooth

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- Concept:
  - Actual force acting on gear tooth is resultant of Ft, Fa and Fr.
- Explanation:
  - This force acts along contact surface causing stress and wear.
- Engineering Insight:
  - Important for strength and wear analysis.

Friction in Worm Gear

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- Concept:
  - Worm gear operates on sliding contact unlike spur gears.
- Effect:
  - High friction leads to heat generation and energy loss.
- Formula:
  - Friction force $\propto$ coefficient of friction $\times$ normal force.
- Engineering Insight:
  - Lubrication is essential to reduce friction.

Efficiency of Worm Gear (Detailed)

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- Formula:
  - $\eta = \tan\gamma / (\tan\gamma + \mu)$
- Where:
  - γ = lead angle, μ = coefficient of friction.
- Explanation:
  - Higher lead angle reduces friction effect.
  - Higher friction reduces efficiency.
- Engineering Insight:
  - Efficiency is generally lower than spur gears.

Condition for Self-Locking

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- Concept:
  - Worm gear becomes self-locking when gear cannot drive worm.
- Condition:
  - $\tan\gamma < \mu$
- Explanation:
  - Friction prevents reverse motion.
- Engineering Insight:
  - Used in hoists and lifts for safety.

Numerical 1: Tangential Force

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- Problem Statement:
  - Torque = 400 Nm, pitch diameter = 0.2 m.
  - Find tangential force.
- Solution:
  - Step 1: Ft = (2T)/d
  - Step 2: Substitute values
    - Ft = (2×400)/0.2
  - Step 3: Calculate
    - Ft = 800 / 0.2 = 4000 N
- Final Answer:
  - Tangential force = 4000 N

Numerical 2: Efficiency

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- Problem Statement:
  - Lead angle = 20°, coefficient of friction = 0.05.
  - Find efficiency.
- Solution:
  - Step 1: $\eta = \tan\gamma / (\tan\gamma + \mu)$
  - Step 2: $\tan 20° \approx 0.364$
  - Step 3: Substitute values
    - $\eta = 0.364 / (0.364 + 0.05)$
  - Step 4: Calculate
    - $\eta \approx 0.879 = 87.9\%$
- Final Answer:
  - Efficiency ≈ 88%

Worm Gear Design – Overview

- Objective:
  - To design worm and worm wheel that can safely transmit power.
  - Ensure gear teeth withstand bending, dynamic and wear stresses.
- Design Considerations:
  - Load, speed, material and lubrication.
- Engineering Insight:
  - All failure modes must be checked.

Design Procedure of Worm Gear

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- Step 1:
  - Determine power and speed.
- Step 2:
  - Select materials for worm and gear.
- Step 3:
  - Calculate tangential force.
- Step 4:
  - Check beam strength.
- Step 5:
  - Check wear load and efficiency.
- Engineering Insight:
  - Final design must satisfy all conditions.

Beam Strength of Worm Gear Tooth

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- Concept:
  - Gear tooth behaves like cantilever beam under load.
- Formula:
  - $Ft = \sigma \times b \times m \times Y$
- Explanation:
  - Used to calculate maximum load tooth can withstand.
- Engineering Insight:
  - Prevents bending failure.

Lewis Equation for Worm Gear

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- Formula:
  - $Ft = \sigma \times b \times m \times Y$
- Where:
  - σ = allowable stress, b = face width.
  - m = module, Y = form factor.
- Engineering Insight:
  - Fundamental design equation.

Dynamic Load in Worm Gear

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- Concept:
  - Actual load is higher due to vibration and errors.
- Effect:
  - Increases stress on gear teeth.
- Engineering Insight:
  - Dynamic effects must be included in design.

Wear Load in Worm Gear

- Concept:
  - Failure may occur due to surface wear.
- Formula:
  - $Fw = d \times b \times Q \times K$
- Explanation:
  - Determines load capacity against wear.
- Engineering Insight:
  - Critical for long-term operation.

Condition for Safe Design

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- Conditions:
  - Ft ≤ beam strength
  - Dynamic load ≤ beam strength
  - Wear load ≥ dynamic load
- Engineering Insight:
  - All conditions must be satisfied.

Efficiency Consideration

- Concept:
  - Efficiency affects power transmission.
- Factors:
  - Lead angle, friction and lubrication.
- Engineering Insight:
  - Higher efficiency improves performance.

Numerical 1: Tangential Load

- Problem Statement:
  - Power = 8 kW, speed = 200 RPM, diameter = 0.25 m.
- Solution:
  - $T = (P \times 60)/(2\pi N)$
    - $T = (8000 \times 60)/(2\pi \times 200) = 382$ Nm
  - $Ft = (2T)/d$
    - $Ft = (2 \times 382)/0.25 = 3056$ N
- Final Answer:
  - Tangential force = 3056 N

Numerical 2: Beam Strength

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- Problem Statement:
  - $\sigma = 100$ MPa, $b = 60$ mm, $m = 6$ mm, $Y = 0.3$.
- Solution:
  - $Ft = \sigma \times b \times m \times Y$
    - $Ft = 100 \times 10^6 \times 0.06 \times 0.006 \times 0.3$
    - $Ft = 10800$ N
- Final Answer:
  - Beam strength = 10800 N

Numerical 3: Wear Load

- Problem Statement:
  - d = 0.3 m, b = 0.05 m, Q = 2, K = 1.2×10^{6}.
- Solution:
  - Fw = d × b × Q × K
    - Fw = $0.3 \times 0.05 \times 2 \times 1.2\times10^{6}$
    - Fw = 36000 N
- Final Answer:
  - Wear load = 36000 N

Numerical 4: Efficiency

- Problem Statement:
  - Lead angle = 25°, μ = 0.04.
- Solution:
  - $\eta = \tan\gamma / (\tan\gamma + \mu)$
  - $\tan 25° \approx 0.466$
    - $\eta = 0.466/(0.466+0.04) \approx 0.92$
- Final Answer:
  - Efficiency ≈ 92%

Numerical 5: Safety Check

- Given:
  - Ft = 3000 N, beam strength = 5000 N.
- Check:
  - Ft < beam strength → Safe.
- Engineering Insight:
  - Design satisfies bending condition.

Design Case Study

- Given:
  - Dynamic load = 4000 N, wear load = 8000 N.
- Check:
  - Wear load > dynamic load → Safe.
- Engineering Insight:
  - Surface durability ensured.

Material Selection Impact

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- Observation:
  - Hard worm and soft gear reduce wear.
- Engineering Insight:
  - Material selection affects life and efficiency.

Heat Generation in Worm Gear

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- Concept:
  - High friction generates heat.
- Engineering Insight:
  - Lubrication required to reduce heat.

Lubrication in Worm Gear

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- Importance:
  - Reduces friction and wear.
- Engineering Insight:
  - Improves efficiency and life.

Advantages of Proper Design

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- Benefits:
  - Smooth operation.
  - High durability.
- Engineering Insight:
  - Ensures safe and efficient performance.

Limitations in Design

- Limitations:
  - High friction losses.
  - Complex manufacturing.
- Engineering Insight:
  - Trade-off required.

Summary of Worm Gear Design

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- Key Points:
  - Check beam strength, wear and efficiency.
  - Proper lubrication is essential.
- Engineering Insight:
  - Design ensures long life and safety.

Introduction to Bevel Gears

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- Definition:
  - Bevel gears are used to transmit power between intersecting shafts.
  - The axes of shafts typically intersect at 90°.
- Construction:
  - Teeth are cut on conical surfaces.
- Engineering Insight:
  - Used where direction of power transmission must change.

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Working of Bevel Gears

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- Concept:
  - Power is transmitted through meshing of conical gear teeth.
- Working:
  - Rotation of one gear causes rotation of another at an angle.
- Engineering Insight:
  - Used in differential systems of automobiles.

Types of Bevel Gears

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- Straight Bevel Gear:
  - Teeth are straight and radial.
- Spiral Bevel Gear:
  - Teeth are curved for smooth operation.
- Hypoid Gear:
  - Shafts do not intersect but are offset.
- Engineering Insight:
  - Spiral gears are smoother than straight bevel gears.

Straight Bevel Gear (Detailed)

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- Characteristics:
  - Teeth are straight and converge at apex.
- Advantages:
  - Simple design and easy manufacturing.
- Limitations:
  - Noisy at high speeds.
- Engineering Insight:
  - Used in moderate speed applications.

Spiral Bevel Gear (Detailed)

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- Characteristics:
  - Teeth are curved and inclined.
- Advantages:
  - Smooth and quiet operation.
  - Higher load carrying capacity.
- Engineering Insight:
  - Used in high-speed gear systems.

Pitch Cone Concept

- Definition:
  - Pitch cone is imaginary cone that rolls without slipping.
- Explanation:
  - Equivalent to pitch circle in spur gears.
- Engineering Insight:
  - All design calculations are based on pitch cone.

Cone Angles

- Pitch Cone Angle:
  - Angle between gear axis and pitch cone surface.
- Addendum Angle:
  - Angle for tooth height above pitch cone.
- Engineering Insight:
  - Angles determine geometry of gear teeth.

Gear Ratio in Bevel Gear

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- Formula:
  - i = Z2 / Z1
- Explanation:
  - Same as spur gear but applied to conical gears.
- Engineering Insight:
  - Used to control speed and torque.

Forces in Bevel Gears

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- Types:
  - Tangential force – transmits power.
  - Radial force – acts towards center.
  - Axial force – acts along shaft.
- Engineering Insight:
  - All forces must be considered in design.

Applications of Bevel Gears

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- Applications:
  - Automobile differential system.
  - Machine tools and gearboxes.
- Engineering Insight:
  - Used where direction of motion changes.

Bevel Gear Design – Overview

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- Objective:
  - To design bevel gears that can safely transmit power between intersecting shafts.
  - Ensure teeth withstand bending and wear stresses.
- Design Considerations:
  - Power, speed, material and loading conditions.
- Engineering Insight:
  - Design must ensure smooth and reliable operation.

Design Procedure of Bevel Gear

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- Step 1:
  - Determine power and speed of gears.
- Step 2:
  - Select material and allowable stress.
- Step 3:
  - Calculate tangential force.
- Step 4:
  - Check beam strength using Lewis equation.
- Step 5:
  - Check wear condition.
- Engineering Insight:
  - All conditions must be satisfied.

Tangential Force in Bevel Gear

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- Formula:
  - Ft = (2T) / d
- Explanation:
  - This force transmits torque between gears.
- Engineering Insight:
  - Primary force for design calculations.

Beam Strength of Bevel Gear Tooth

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- Concept:
  - Tooth behaves like a cantilever beam.
- Modified Lewis Equation:
  - $Ft = \sigma \times b \times m \times Y \times (R - b)/R$
- Explanation:
  - Accounts for tapering shape of bevel gear tooth.
- Engineering Insight:
  - Ensures bending safety.

Cone Distance (R)

- Definition:
  - Distance from apex to pitch circle.
- Formula:
  - $R = \sqrt{(r_1^2 + r_2^2)}$
- Explanation:
  - Used in strength calculations.
- Engineering Insight:
  - Important geometric parameter.

Dynamic Load in Bevel Gear

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- Concept:
  - Actual load is higher due to dynamic effects.
- Causes:
  - Manufacturing errors and vibration.
- Engineering Insight:
  - Dynamic load must be considered in design.

Wear Load in Bevel Gear

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- Concept:
  - Failure may occur due to surface wear.
- Formula:
  - $Fw = d \times b \times Q \times K$
- Engineering Insight:
  - Ensures durability of gear teeth.

Condition for Safe Design

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- Conditions:
  - Ft ≤ beam strength
  - Wear load ≥ dynamic load
- Engineering Insight:
  - All conditions must be satisfied.

Numerical 1: Tangential Force

- Problem Statement:
  - Power = 6 kW, speed = 250 RPM, diameter = 0.3 m.
- Solution:
  - $T = (P \times 60)/(2\pi N)$
    - $T = (6000 \times 60)/(2\pi \times 250) = 229$ Nm
  - $Ft = (2T)/d$
    - $Ft = (2 \times 229)/0.3 = 1526$ N
- Final Answer:
  - Tangential force = 1526 N

Numerical 2: Beam Strength

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- Problem Statement:
  - $\sigma = 120$ MPa, $b = 50$ mm, $m = 5$ mm, $Y = 0.3$, $R = 200$ mm.
- Solution:
  - $Ft = \sigma \times b \times m \times Y \times (R - b)/R$
    - $Ft = 120 \times 10^6 \times 0.05 \times 0.005 \times 0.3 \times (200-50)/200$
    - $Ft \approx 6750$ N
- Final Answer:
  - Beam strength ≈ 6750 N

Numerical 3: Cone Distance

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- Problem Statement:
  - r1 = 100 mm, r2 = 150 mm.
- Solution:
  - $R = \sqrt{(r1^2 + r2^2)}$
    - $R = \sqrt{(100^2 + 150^2)}$
    - $R = \sqrt{(10000 + 22500)}$
    - $R = \sqrt{32500} \approx 180.3$ mm
- Final Answer:
  - Cone distance ≈ 180 mm

Numerical 4: Wear Load

- Problem Statement:
  - $d = 0.25$ m, $b = 0.04$ m, $Q = 2$, $K = 1 \times 10^6$.
- Solution:
  - $Fw = d \times b \times Q \times K$
    - $Fw = 0.25 \times 0.04 \times 2 \times 1 \times 10^6$
    - $Fw = 20000$ N
- Final Answer:
  - Wear load = 20000 N

Numerical 5: Safety Check

- Given:
  - Ft = 1500 N, beam strength = 3000 N.
- Check:
  - Ft < beam strength → Safe design.
- Engineering Insight:
  - Gear is safe against bending failure.

Design Case Study

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- Given:
  - Dynamic load = 2500 N, wear load = 5000 N.
- Check:
  - Wear load > dynamic load → Safe.
- Engineering Insight:
  - Surface durability ensured.

Summary of Bevel Gear Design

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- Key Points:
  - Check beam strength, wear and dynamic load.
  - Proper geometry ensures smooth operation.
- Engineering Insight:
  - Design ensures reliability and long life.

Advanced Numerical 1: Worm Gear Design

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- Problem Statement:
  - Power = 10 kW, speed = 150 RPM, pitch diameter = 0.3 m.
  - Find tangential force.
- Solution:
  - Step 1: Calculate torque $T = (P \times 60)/(2\pi N)$
    - $T = (10000 \times 60)/(2\pi \times 150) = 636.6$ Nm
  - Step 2: Calculate $Ft = (2T)/d$
    - $Ft = (2 \times 636.6)/0.3 = 4244$ N
- Final Answer:
  - Tangential force ≈ 4244 N

Advanced Numerical 2: Worm Gear Efficiency

- Problem Statement:
  - Lead angle = 25°, coefficient of friction = 0.05.
  - Find efficiency.
- Solution:
  - $\eta = \tan\gamma / (\tan\gamma + \mu)$
  - Step 2: $\tan 25° \approx 0.466$
    - $\eta = 0.466/(0.466 + 0.05)$
  - Step 3: Calculate
    - $\eta \approx 0.903 = 90.3\%$
- Final Answer:
  - Efficiency ≈ 90%

Advanced Numerical 3: Bevel Gear Strength

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- Problem Statement:
  - $\sigma = 120$ MPa, $b = 60$ mm, $m = 6$ mm, $Y = 0.3$, $R = 250$ mm.
- Solution:
  - $Ft = \sigma \times b \times m \times Y \times (R - b)/R$
  - Step 2: Substitute values
    - $Ft = 120 \times 10^6 \times 0.06 \times 0.006 \times 0.3 \times (250-60)/250$
  - Step 3: Calculate
    - $Ft \approx 9840$ N
- Final Answer:
  - Beam strength ≈ 9840 N

Combined Design Check (Worm + Bevel)

- Concept:
  - Both worm and bevel gears must satisfy design conditions.
- Conditions:
  - Tangential load ≤ beam strength.
  - Wear load ≥ dynamic load.
- Engineering Insight:
  - Ensures safe and reliable operation.

Final Revision of Chapter

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- Worm Gear:
  - Used for high speed reduction and self-locking.
- Bevel Gear:
  - Used for intersecting shafts and direction change.
- Key Design Checks:
  - Beam strength, dynamic load and wear load.
- Engineering Insight:
  - Proper design ensures efficiency, durability and safety.

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Thank You