

Module-01

Introduction to Gear and Gear unit Design

Lecture-01

Introduction- Motivation and Theme of the Course



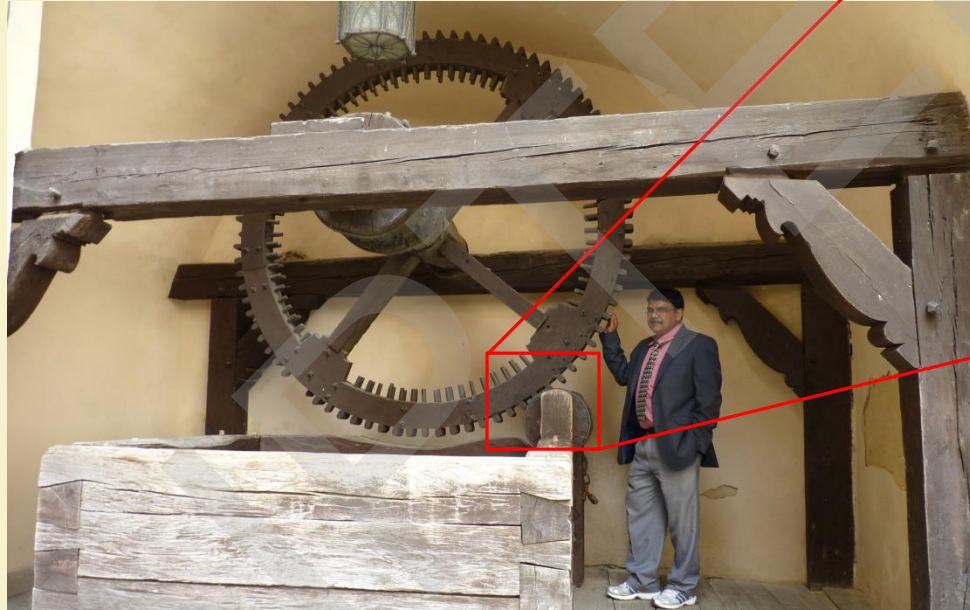
Outline of the Lecture

- **History of Toothed Gear Invention and Development**
 - **Gear Train**
 - **Special Sophisticated Gearing**
 - **Some Important [Information](#)**

History of Toothed Gear Invention and Development :

Early examples of toothed gears date back to the 4th. Century BC in China.

Hand lever driven Pinion and Gear with winch drum to lift water from below ground level to First floor in a Castle in Poland (Built in around 15th. Century).

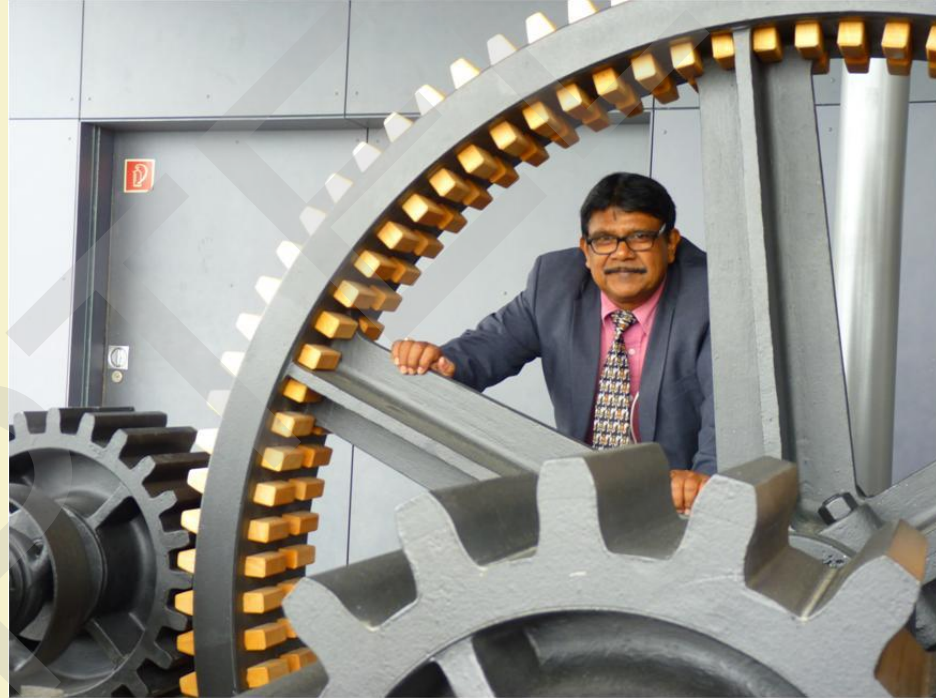


History of Toothed Gear Invention and Development (cont...) :

This is probably the first set of gear unit (Now discarded) to drive the cable car in Luzern.

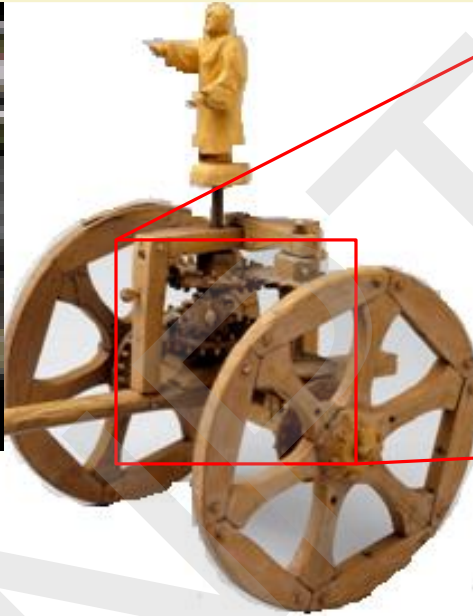
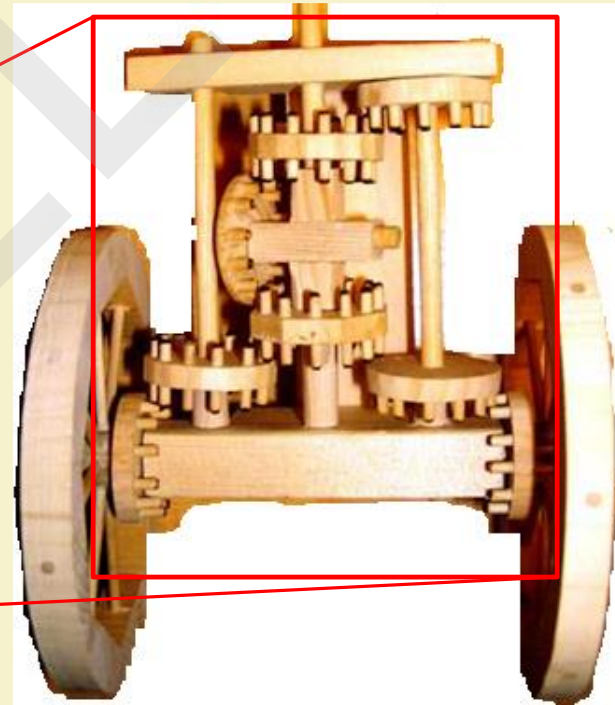
Tooth profile, particularly of gear, looks close to involute.

Those are cast and milled gear.

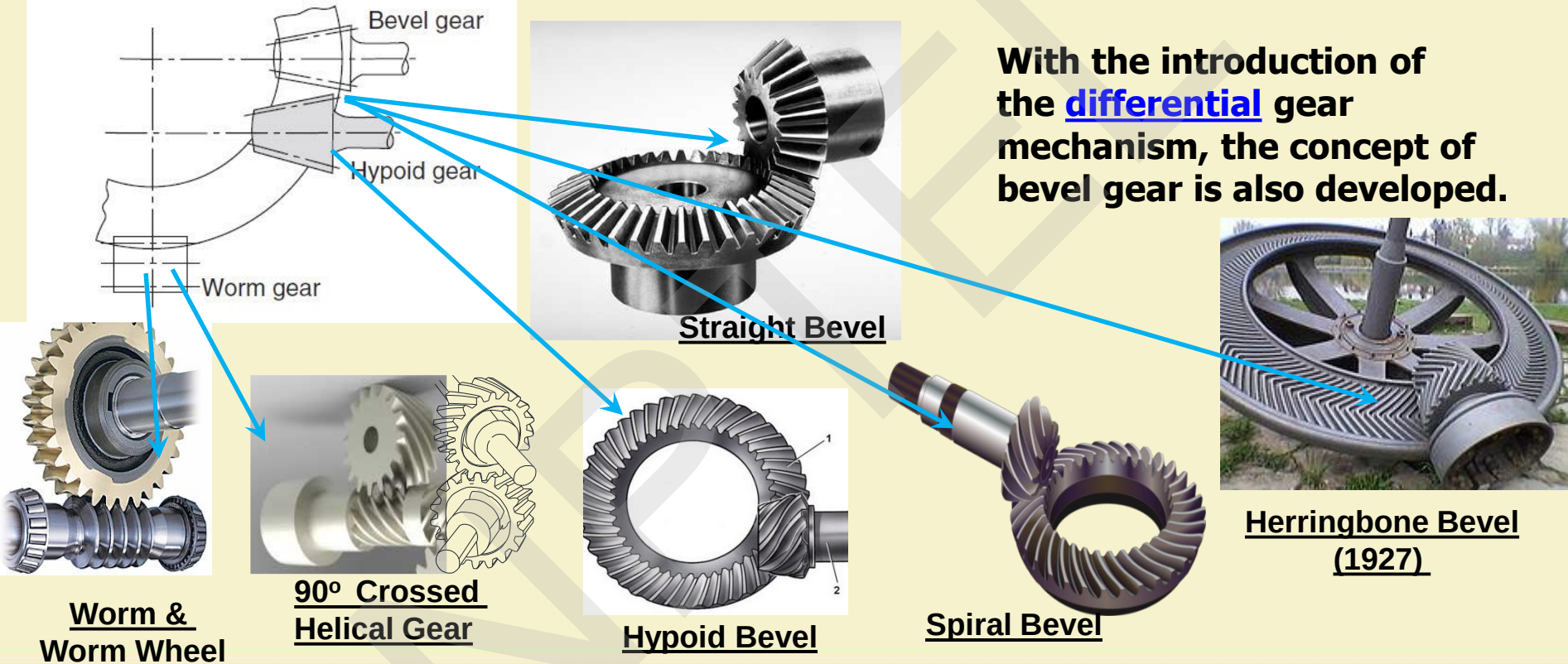


History of Toothed Gear Invention and Development (cont...) :

The differential gear mechanism also first found in the Chinese developed south-pointing chariot, dated to the first millennium BC.



History of Toothed Gear Invention and Development (cont...) :



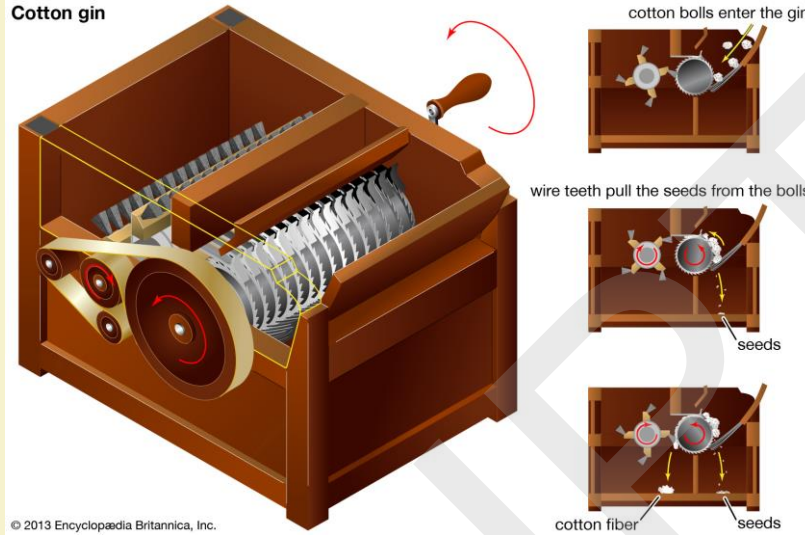
History of Toothed Gear Invention and Development (cont...) :

Classification of Bevel gears according to geometry, arrangement & kinematics:

- **Straight bevel gears** have conical pitch surface / Teeth are tapered but straight / Cone tapering towards vertex.
- **Spiral bevel gears** have curved teeth at an angle -
Resulting in tooth contact to be gradual and smooth like helical spur gears.
- **Hypoid bevel gears** are similar to spiral bevel but the pitch surfaces are hyperbolic and not conical. Pinion can be placed offset.
- **Zerol bevel gears** have similar features bevel gears except the teeth are curved.
- **Mitre gears**, used mostly for motion transmission, are 1:1 ratio of bevel gears .

History of Toothed Gear Invention and Development (cont...) :

The worm gear was invented in the Indian subcontinent, for use in roller cotton gins, some time during the 13th–14th centuries.



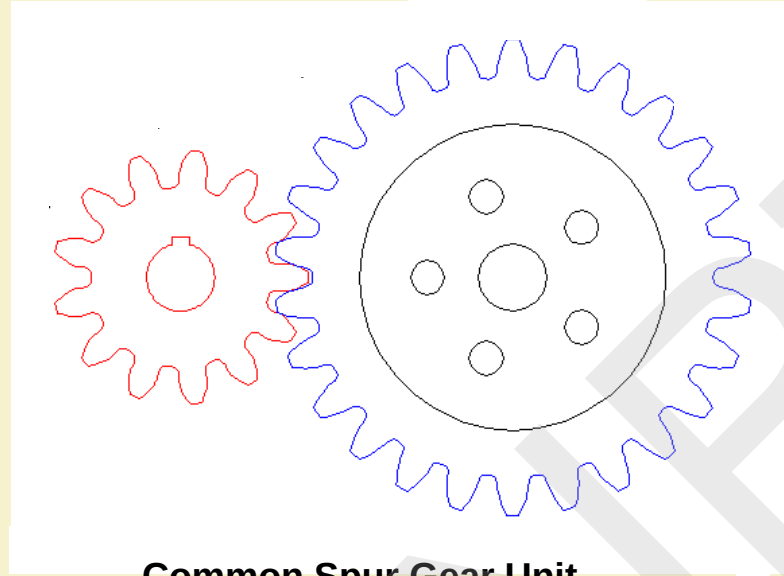
A diagram of a cotton gin shows how the machine separates the seeds from the cotton fiber.
Encyclopædia Britannica, Inc.



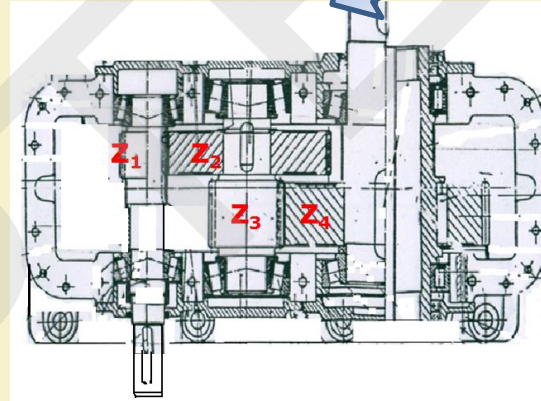
<https://en.wikipedia.org/wiki/Gear#History>

History of Toothed Gear Invention and Development (cont...) :

Most commonly used Gears are Straight and Helical Gears. Which are again of involute toothed.



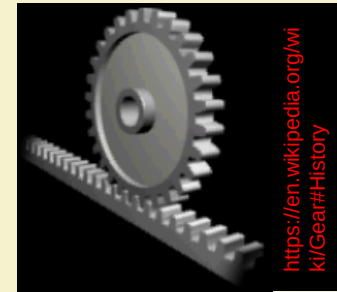
Common Spur Gear Unit
Simple Gear Train



Helical Gear Reduction Unit
(Top Open Plan View)
Compound Gear Train



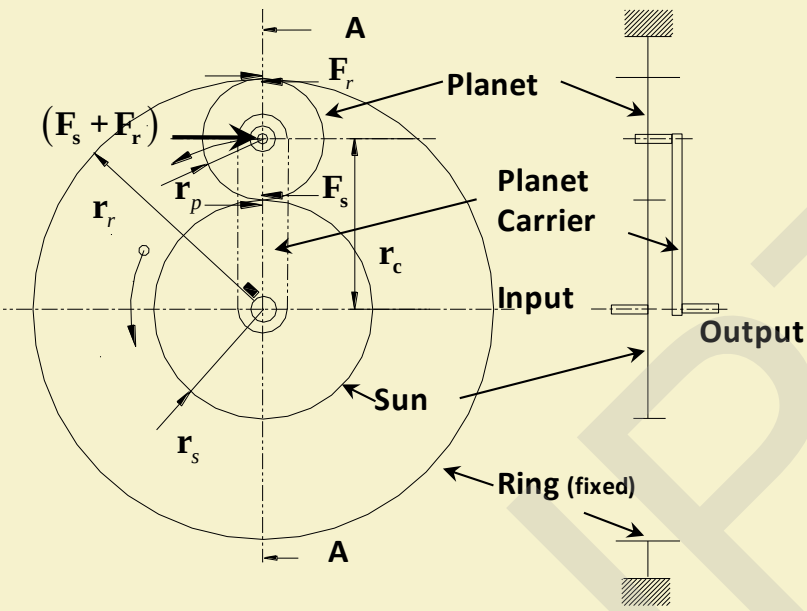
General Purpose Helical
Gear Reduction Unit



Rack and Pinion

History of Toothed Gear Invention and Development (cont...) :

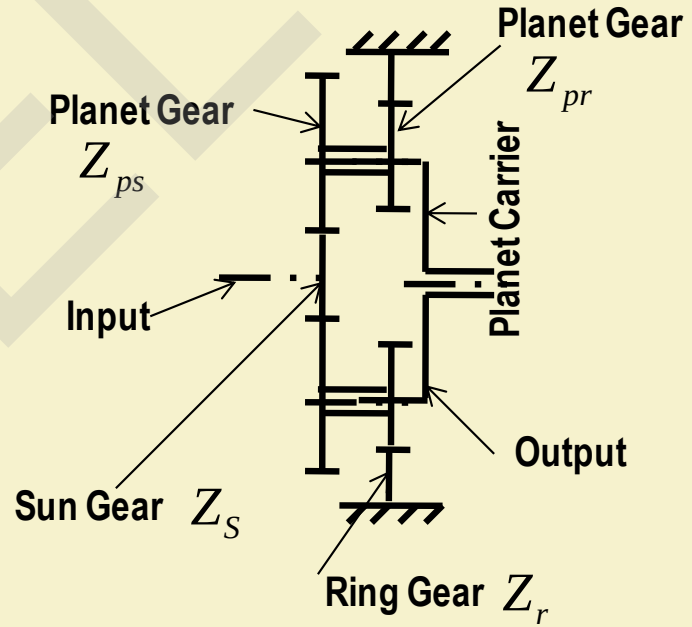
Epicyclic or Planetary Gearing



Simple Epicyclic Gearing - Schematic View- AA



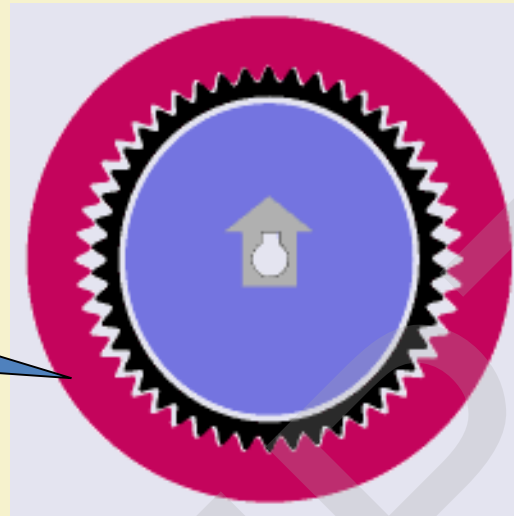
Internal Gearing



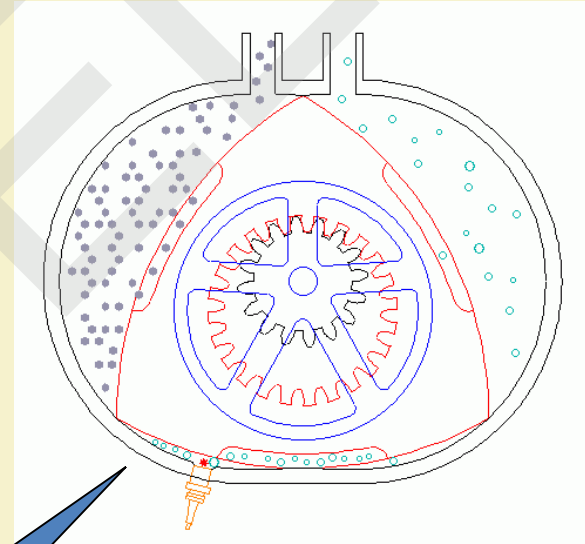
Compound Epicyclic Gearing (Side view)

History of Toothed Gear Invention and Development (cont...) :

Epicyclic or Planetary Gearing (Contd...)



Harmonic Drive



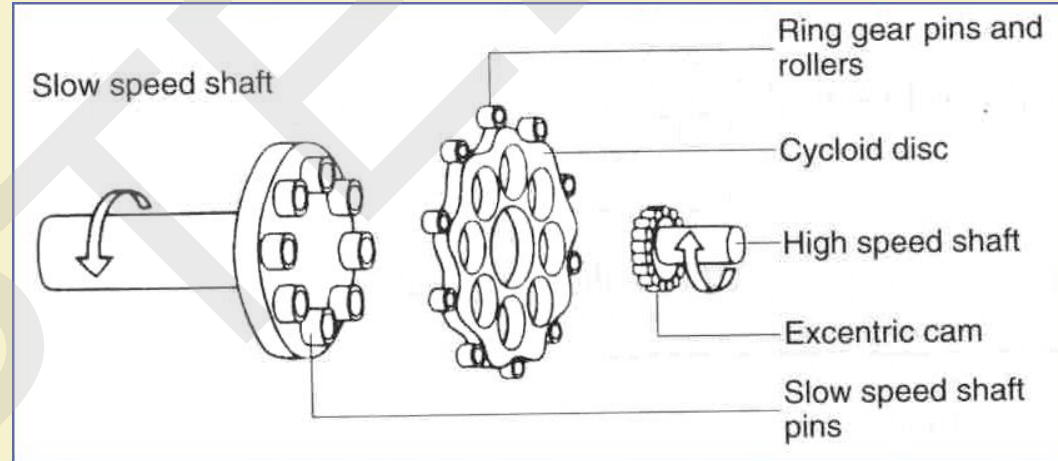
Wankel Engine

History of Toothed Gear Invention and Development (cont...) :

Epicyclic or Planetary Gearing (Contd...)



**Star - Ring of
ORBIT / GEROTOR
HST Units**

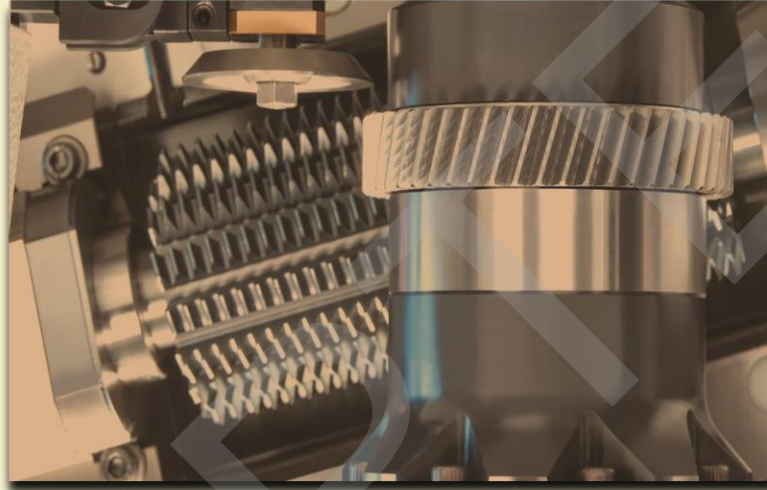


Cycloid Speed Reducer

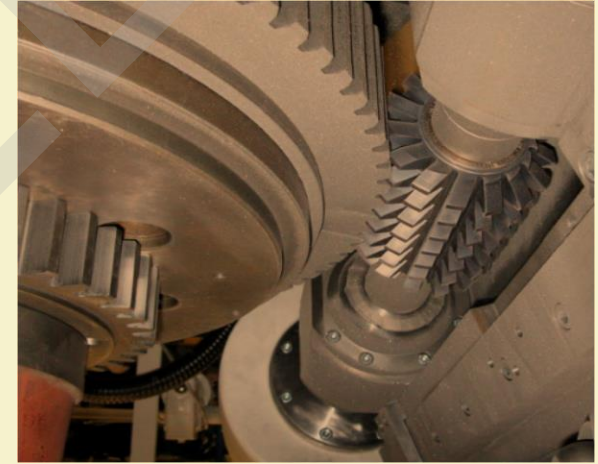
Manufacturing of Gears :

- Hobbing
- Shaping
- Grinding

- Forming
- Casting
- Milling

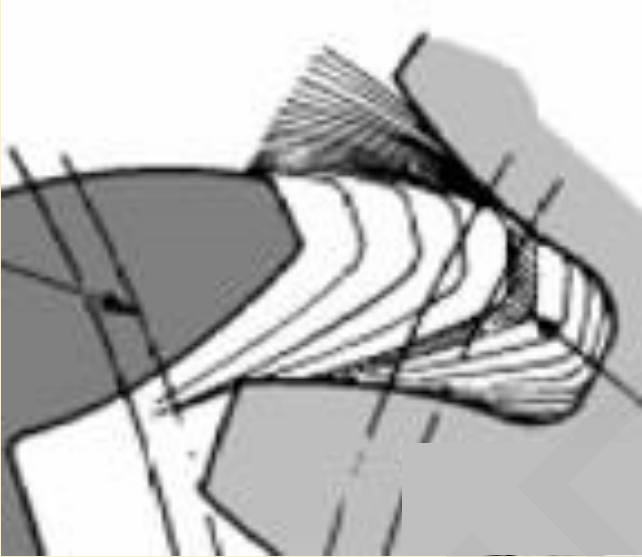


Hobbing- Helical Spur

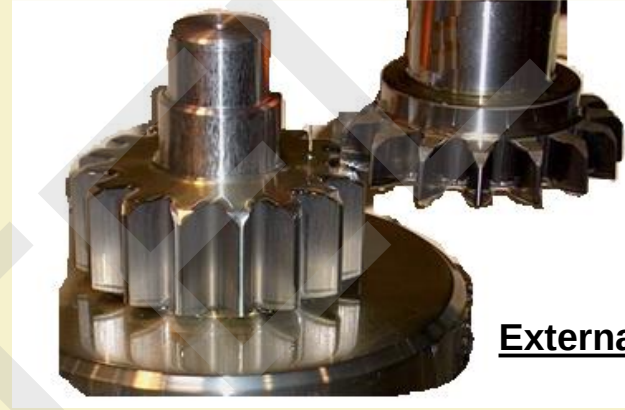


Hobbing-Straight Spur

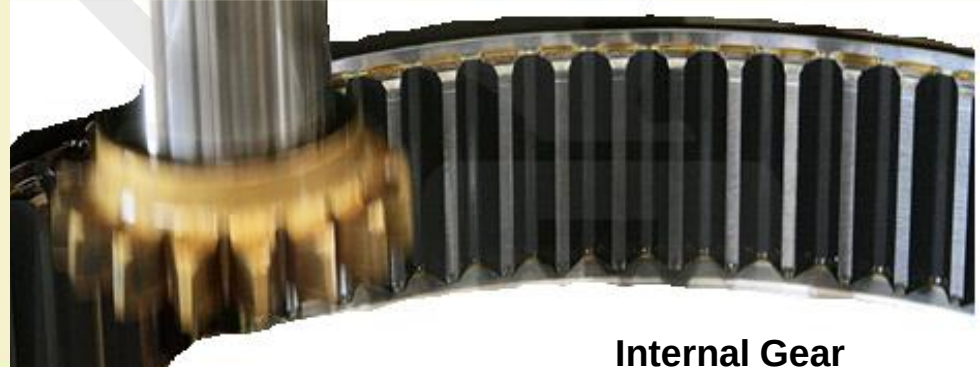
Manufacturing of Gears (contd..) :



Gear Shaping



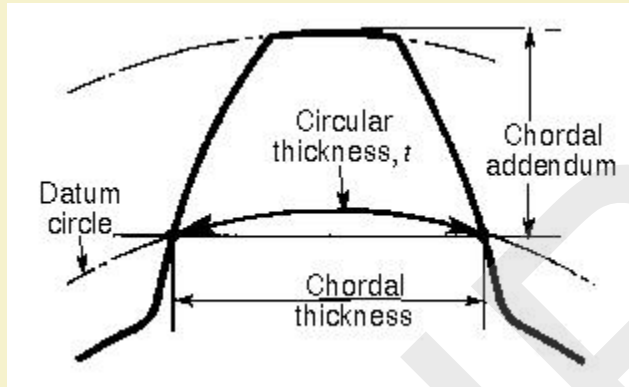
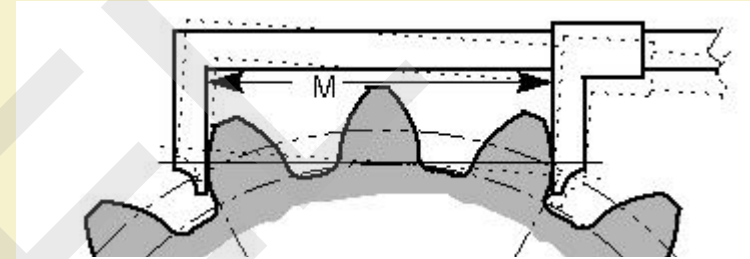
External Gear



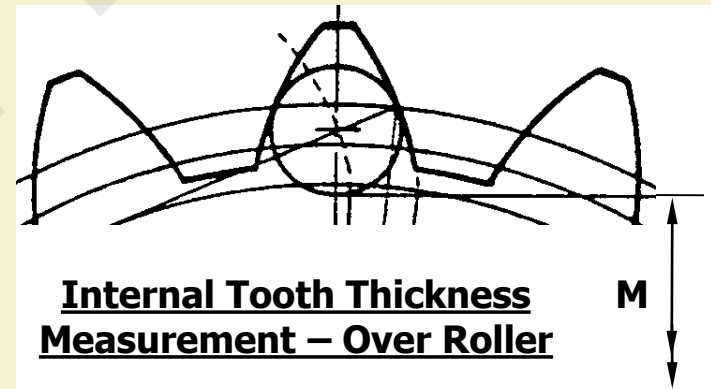
Internal Gear

Involute Gear Tooth :

Involute Tooth Thickness and its Measurement



External Tooth Chordal Thickness Measurement



Internal Tooth Thickness Measurement – Over Roller

The Course :
(8 Week)

Gear and Gear Unit Design : Theory and Practice

- Module-01 : Introduction to Gear and Gear unit Design**
- Module-02 : Design of Spur (Straight and Helical), Bevel and Worm gears**
- Module-03 : Design of a General Purpose Industrial Helical Gear Reduction Unit- Part I**
[Gear Design & Lay out (AutoCAD Drawing)]
- Module-04 : Design of a General Purpose Industrial Helical Gear Reduction Unit- Part II**
[Bearing Selection, Loads on shaft (SFD, BMD etc.) 1st. Layout of Shafts & Bearings (AutoCAD Drawing)]
- Module-05 : Design of a General Purpose Industrial Helical Gear Reduction Unit- Part III**
[Finalizing design (including housing), (AutoCAD Drawing)
Labeling components, Bill of materials]
- Module-06 : Design of a General Purpose Industrial Helical Gear Reduction Unit- Part IV**
[Detail drawing of components (Considering manufacturing aspects and Fits and Tolerances) (AutoCAD Drawing)]
- Module-07 : Introduction to Involute Gear Tooth Correction**
- Module-08 : Internal, Epicyclic and Other Special Gearing**

Bibliography (Whole Course)

1. Spotts M. F., Design of Machine Elements, Prentice Hall of India.
2. Shigley's Mechanical Engineering Design (McGraw-Hill Series in Mechanical Engineering) Hardcover – January 27, 2014 by Richard Budynas (Author), Keith Nisbett (Author).
3. PSG Design Data Book, or any other Machine Design Data Book.
4. G. M. Maitra, Handbook of Gear Design. (2nd. edn., 1989 ISBN 0-07- 460237-3), McGraw-Hill pub co ltd India.
5. J. E. Shigley, 'Theory of Machines', Mc Graw Hill, 1961.
6. E. Buckingham, 'Analytical Mechanics of Gears', Dover Publications, Inc.1963, (ISBN 0-486-65712-4).
7. F. L. Litvin & A. Fuentes, Gear Geometry and applied Theory (2nd. Edn., 2004), Cambridge University press, ISBN 0-521-81517-7.
8. Gisbert Lechner, Harald Naunheimer (In Collaboration with Joachim Ryborz) : Automotive Transmissions- *Fundamentals, Selection, Design and Application. Springer 1999. ISBN 3-540-65903-X.*
9. *Extract from Different Standards on Gear Geometry, Manufacturing, Measurement etc.*

Note: Some reference books / papers will be suggested during the course work.

Thank You



Module-01

Introduction to Gear and Gear unit Design

Lecture-02

Laws of Gearing, Kinematics and Geometry

Part-I



Outline of the Lecture

➤ Fundamentals of Gear Tooth Profiles

(i) Involute, Cycloidal and others tooth profiles

➤ Gearing Laws

(i) Constant seed ratio

(ii) Comparison between Involute and Cycloidal Profiles

(iii) Involute Gear Tooth Terminology

Concept of Toothed Gear and Tooth Profile :

Involute profile

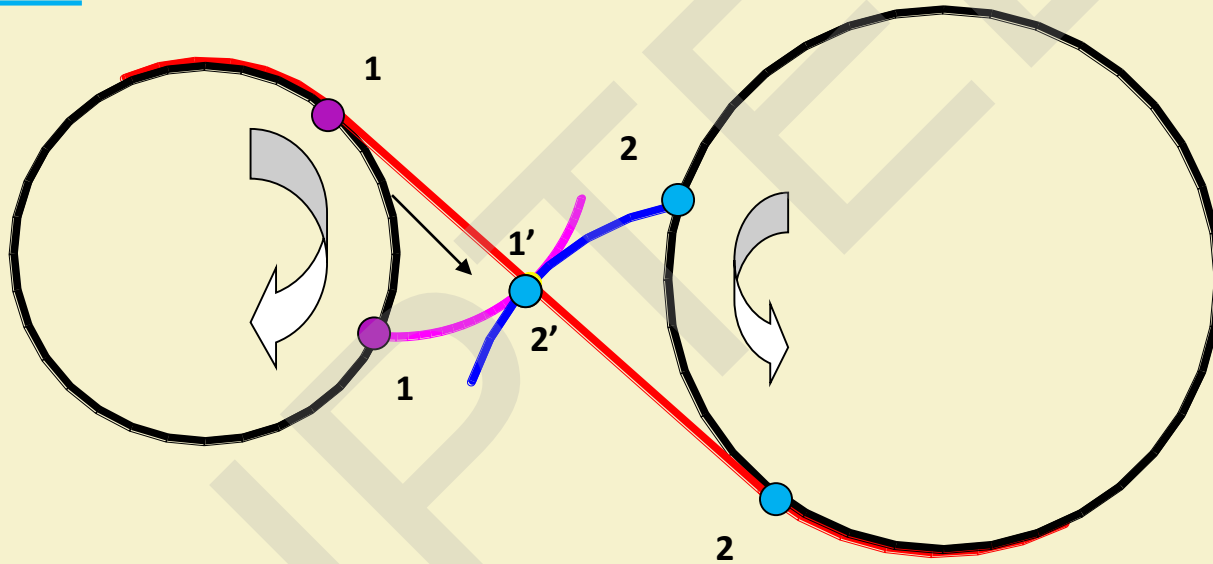


Fig.- 1. A cross belt drive and it's replacement by conjugate profiles.

Cycloidal profile:

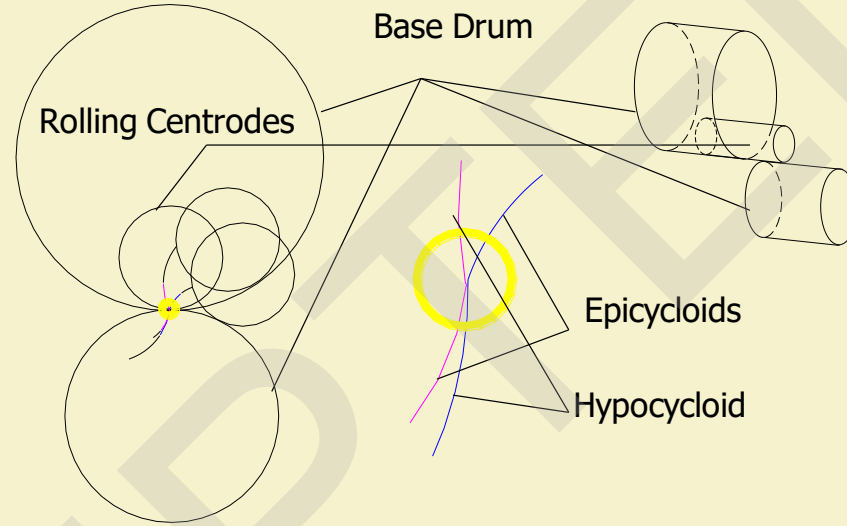
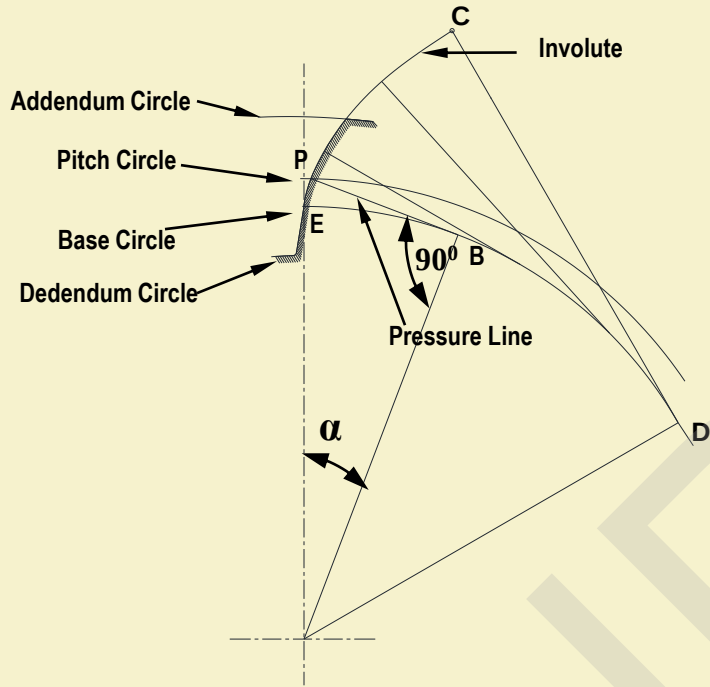
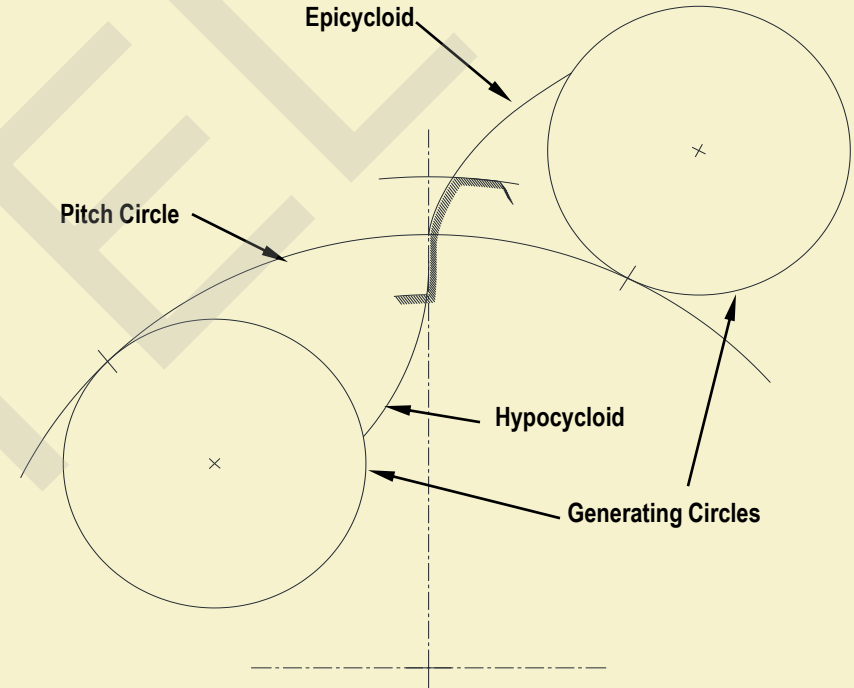


Fig.- 2. Generation of Cycloidal Profile

Profiles to Shape Gear Tooth



(a) Involute



(b) Cycloidal

Fig.- 3.

Fundamental Law of Toothed Gearing

Gearing laws of Constant Velocity can be derived as follows:

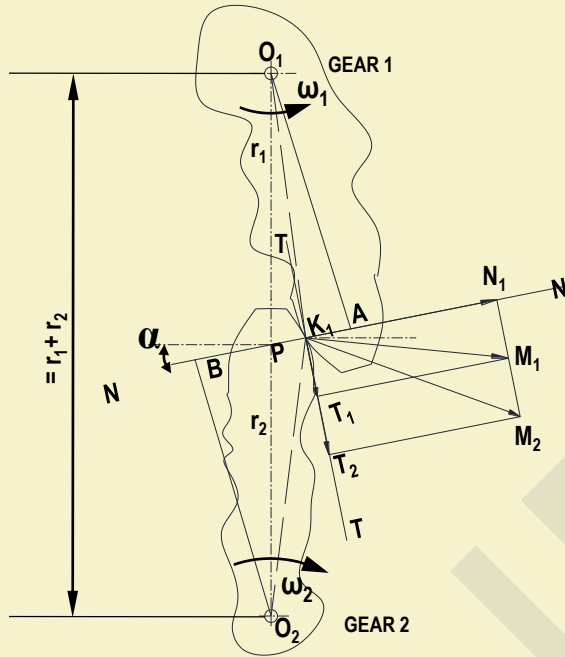


Fig.- 4. Gearing laws of Constant Velocity.

As $\Delta O_1 K_1 A \equiv \Delta K_1 N_1 M_1$

$$K_1 M_1 = \omega_1 \times O_1 K_1$$

$$K_1 M_2 = \omega_2 \times O_2 K_1$$

$$\therefore \frac{\omega_2}{\omega_1} = \frac{K_1 M_2}{O_2 K_1} \times \frac{O_1 K_1}{K_1 M_1}$$

$$\therefore \frac{O_1 K_1}{K_1 M_1} = \frac{O_1 A}{K_1 N_1}$$

$$\frac{K_1 M_2}{O_2 K_1} = \frac{K_1 N_1}{O_2 B}$$

$$\frac{\omega_2}{\omega_1} = \frac{O_1 A}{O_2 B} = \frac{O_1 P}{O_2 P} = \text{Constant}$$

Comparison with Involute & Cycloidal profiles wrt gear tooth:

	<u>Involute</u>	<u>Cycloidal</u>
1. Line of action	Straight	Curved
2. Radial component of Normal load	Constant	Vary
3. Effect due to change in centre distance	Gearing law remain Unaffected	Gearing law is violated
4. Beam strength of tooth	-	Cycloidal tooth has better strength capacity.
5. Tooth generation	Involute tooth generation is easy and less expensive	Relatively Expensive
6. Interchangeability	Possible	Not Possible
7. Interference & Undercut	Occur	Do not occur

(Ideal) Properties of Gear Tooth Profiles:

- I) Constant velocity ratio,
- II) Relative motion- Rolling in Nature,
- III) More than one pair to be in contact, &
- IV) Cantilever beam of uniform strength.

Profile other than Involute

Profile may be anything, provided it has a realistic conjugate profile.

However, from manufacturing point of view very, few are feasible.

Tooth profiles Cycloidal, Novikov etc. are special cases.

Among all Involute is the best.

Involute Gear Tooth - Terminology

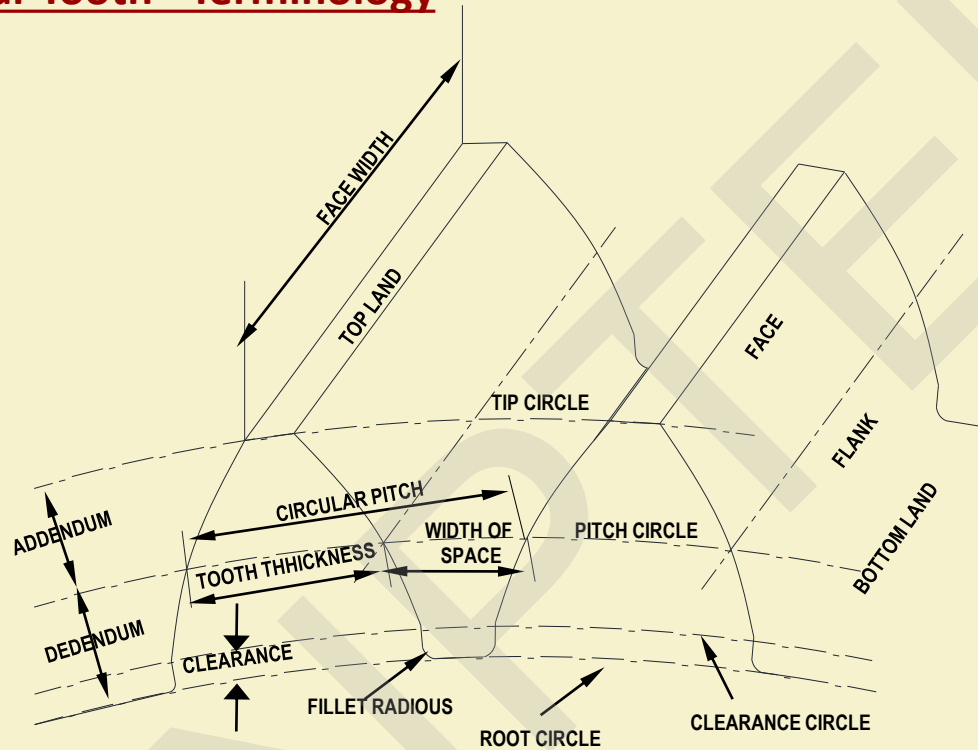
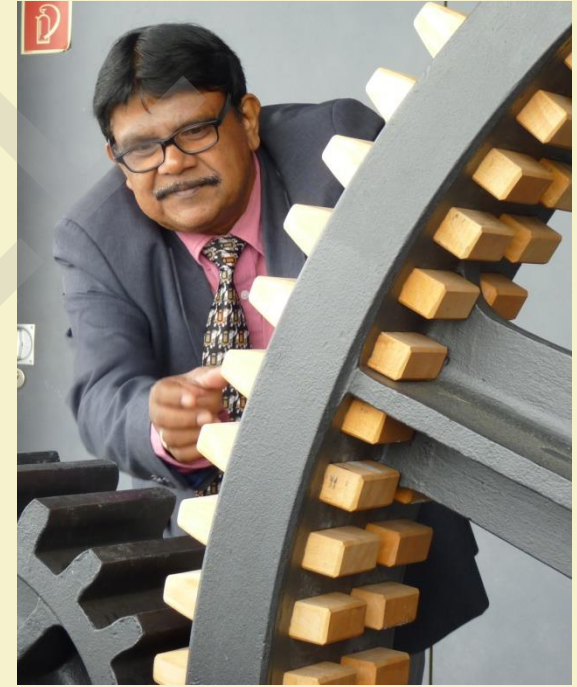


Fig.- 5.



Thank You



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CERTIFICATION COURSES

Prof. Rathindranath Maiti
Mechanical Engineering Department

Module-01

Introduction to Gear and Gear unit Design

Lecture-03

Laws of Gearing, Kinematics and Geometry Part-II



Outline of the Lecture

- **Involute Toothed Gear-
Some Basic Properties and Relations**
- **(i) Involutometry**
- **(ii) Backlash**
- **(iii) Tooth thickness at any radius
(With workout example)**
- **(iv) Minimum number of teeth to avoid undercut.**

Involutometry

It is an important Trigonometric relation in gear geometry.

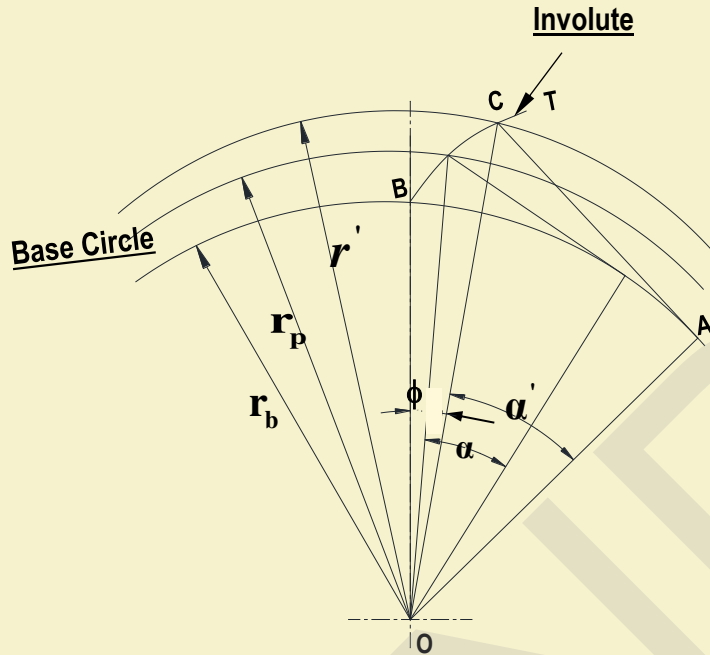


Fig.- 1. Involutometry

$$AC = \text{arc } AB$$

$$arc\ AB = r_b (\phi + \alpha')$$

$$AC = r_b \tan \alpha'$$

$$\tan \alpha' = \varphi + \alpha'$$

$$\phi = \tan \alpha' - \alpha'$$

$$\text{inv } \alpha' = \tan \alpha' - \alpha'$$

Where,

$$r' = r_b / \cos \alpha' = r_p \cos \alpha / \cos \alpha'$$

$$\alpha' = \cos^{-1} \frac{r_p}{r} \cos \alpha$$

Tooth Thickness at any radius

External Gear

$$\frac{\hat{t}'}{2r'} + \text{inv } \alpha' = \frac{\hat{t}}{2r} + \text{inv } \alpha$$

$$\hat{t}' = 2r' \left(\frac{\hat{t}}{2r} + \text{inv } \alpha - \text{inv } \alpha' \right)$$

Internal Gear

$$\hat{t}'' = \frac{2\pi r'}{Z} - \hat{t}'$$

Where $\hat{t}'$ is the thickness of the gap at radius r' of the internal gear. It is calculated using the same formula for external gear.

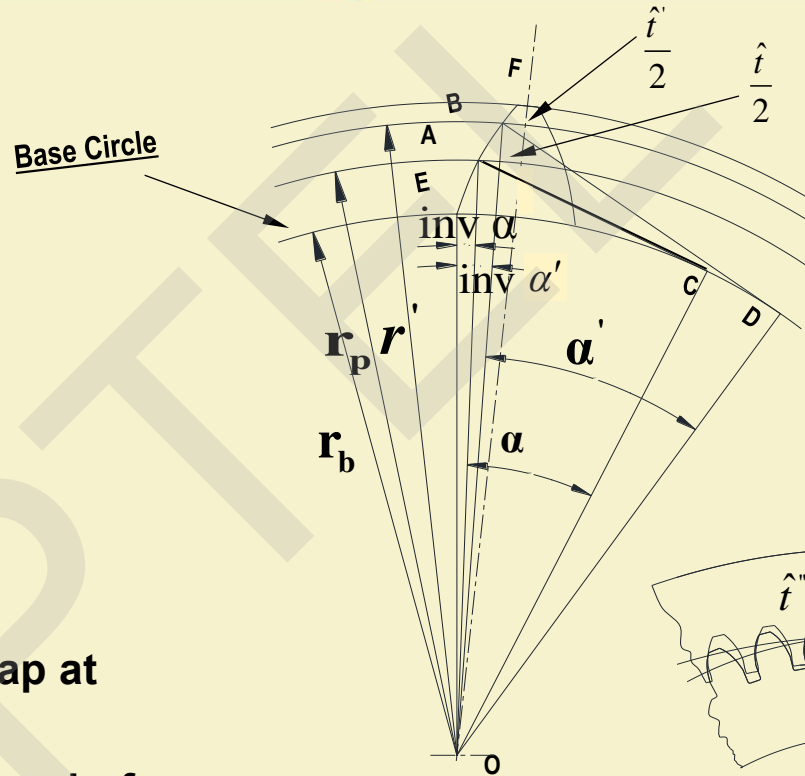


Fig.- 2 (a). External Gear

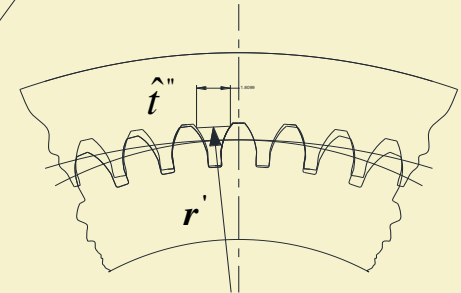


Fig.- 2 (b). Internal gear

An Workout Example on Gear tooth Thickness

Calculate the tooth tip thickness of a 80 teeth 20 degree full depth, 2.5 module involute standard cut straight tooth spur external gear.

Concept of Module

Module (m) / Normal module (m_n) : Pitch circle diameter (d_p) / Number of teeth (Z).

It is standardized and expressed in mm.

Tooth thickness at pitch circle $\hat{t} = \frac{\pi m}{2} = \frac{\pi \times 2.5}{2} = 3.926990$

Tip circle radius $r' = \frac{(Z+2) \times m}{2} = \frac{(80+2) \times 2.5}{2} = 102.5 \text{ mm}$

$$\hat{t}' = 2r' \left(\frac{\hat{t}}{2r} + \text{inv } \alpha - \text{inv } \alpha' \right)$$

$$\hat{t}' = 2 \times 102.5 \times \left(\frac{3.926990}{200} - 0.024795 + 0.0149 \right)$$

$$\hat{t}' = 1.9967 \text{ mm}$$

$$\text{inv } \alpha' = \tan \alpha' - \alpha'$$

[Note: In calculation a numerical figure of 5 decimal places is to be considered for accuracy].

Minimum Number of Teeth in a Gear, Interference and Undercut, &

Concept of Gear Tooth Correction :

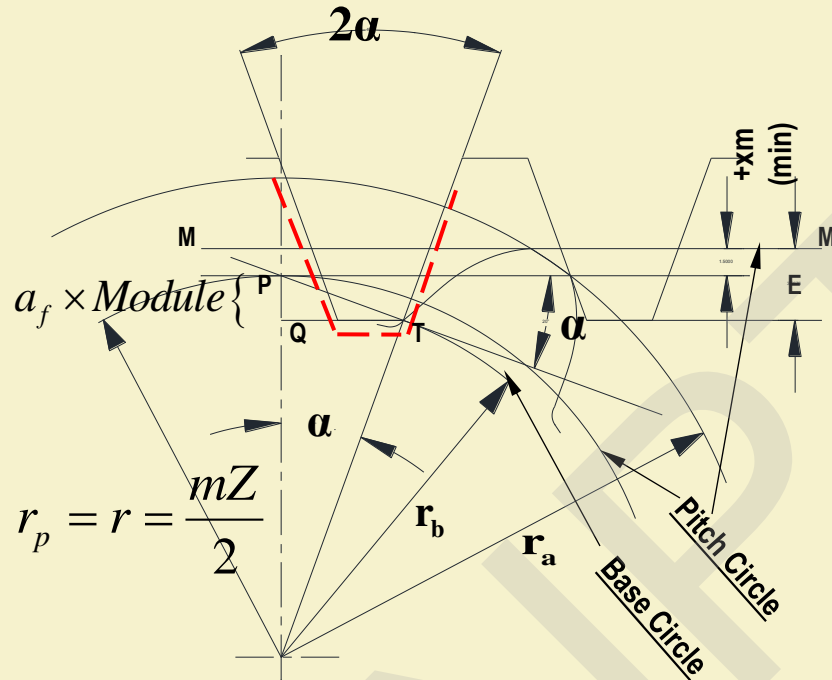


Fig.- 11. (b)

Minimum (Critical) Number of Teeth:

$$PQ = a_f \times m = r - r_b \cos \alpha$$

$$= r(1 - \cos^2 \alpha) = r \sin^2 \alpha$$

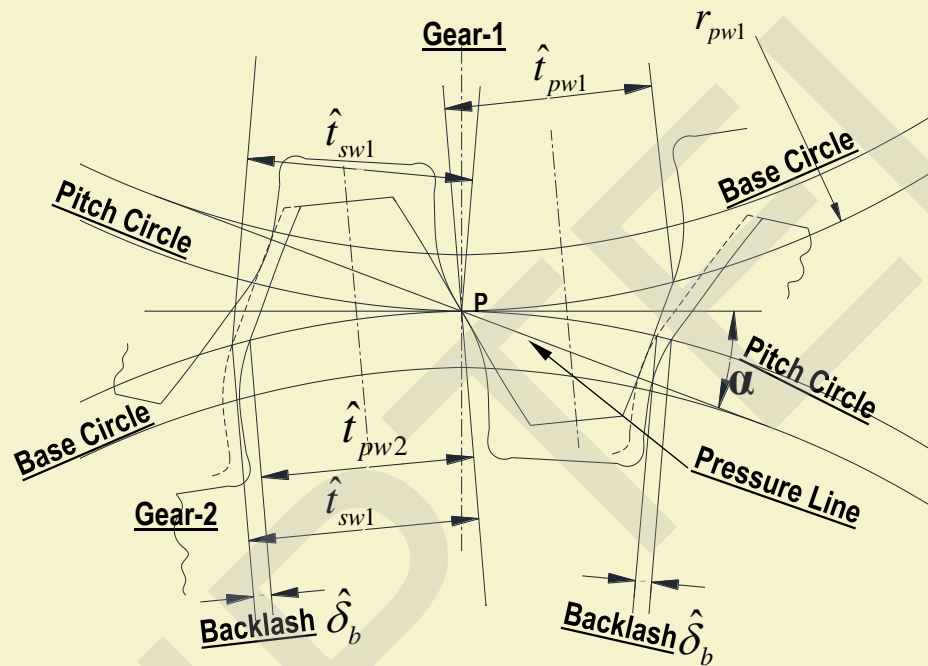
$$\text{or, } a_f \times m = r \sin^2 \alpha = \frac{Z_c \times m}{2} \sin^2 \alpha$$

$$Z_c = \frac{2a_f}{\sin^2 \alpha}$$

Where, $a_f \times \text{Module}$ [PQ in Fig. (b), a_f being a factor) is the addendum height (active) of basic rack.

Further discussion in Module-7.

Backlash



$$\hat{t}_{sw1} = 2\pi r_{pw1} / Z_1 - \hat{t}_{pw1}$$

$$\hat{\delta}_b = \hat{t}_{sw1} - \hat{t}_{pw2}$$

Fig.- 8. Backlash in External Toothed Gears

Thank You



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Mechanical Engineering Department

Module-01

Introduction to Gear and Gear unit Design

Lecture-04

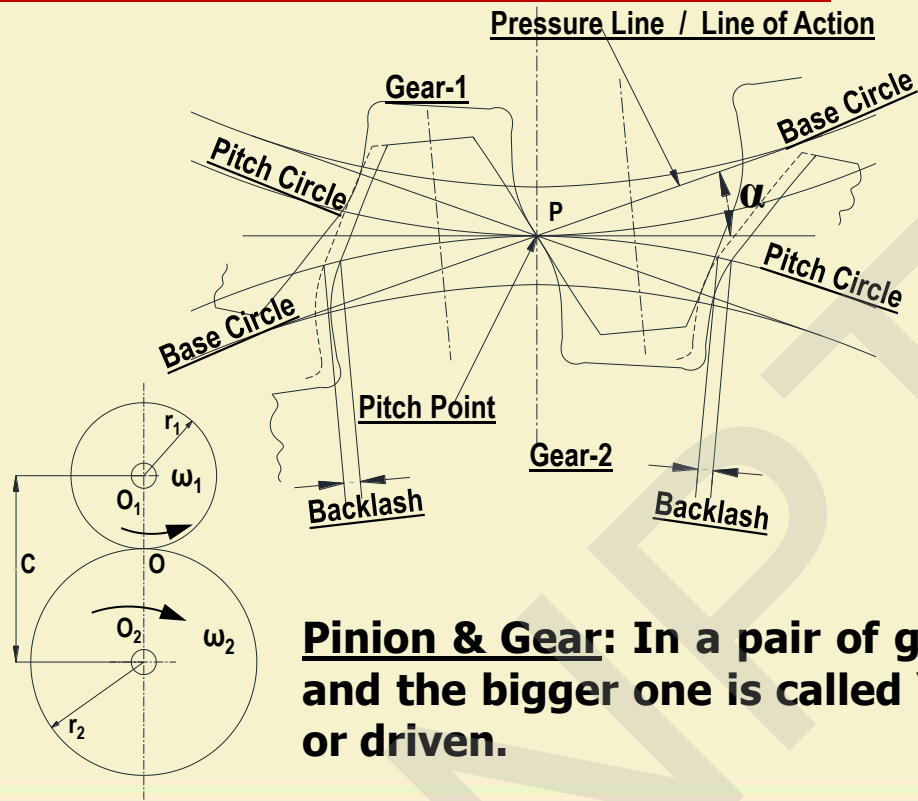
Involute Toothed Gear- Properties & Terminology



Outline of today's Lecture

- **Gear and Gear Tooth Terminology**
 - **Concept of Module**
 - **Concept of Diametral Pitch**
 - **Gear size and tooth- Fundamental Relations**
 - **Rack cutter**
 - **Concept of contact ratio**

Gear & Gear Tooth Terminology



Base Circle: It is an auxiliary circle used in involute gearing to generate tooth profiles.

Line of action : It is a common tangent, which passes through the pitch point, both base circles.

[Note: *For a particular generated involute gear the base circle remains fixed and can be considered as reference.*]

Pinion & Gear: In a pair of gears in mesh smaller one is called 'Pinion' and the bigger one is called 'Gear' irrespective of any of them is driver or driven.

Gear and Gear Tooth Terminology (Contd.)

Concept of Module

Module (m) / Normal module (m_n) : Pitch circle diameter (d_p) / Number of teeth (Z).

It is standardized and expressed in mm.

**[Note: In case of helical teeth 'normal module' m_n
(i.e., module in normal direction is standard one).]**

It is followed in Metric and SI unit system.

Standard Module (m) / (m_n) :

1, (1.25), 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 6, 7, 8, 10, 12, 15, 17, 20, 25 mm



Gear Tooth Terminology (Contd.)

Diametral Pitch (DP) :

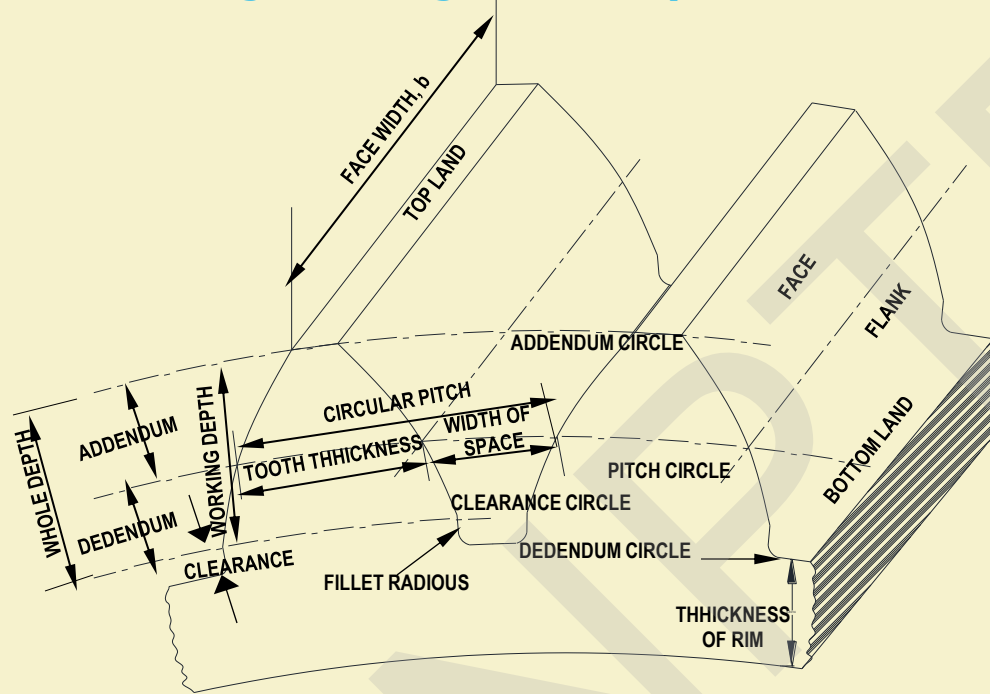
Average number of teeth per unit length (inch) of pitch circle diameter.

To compare with module system $1''/\text{DP}$ i.e., $25.4/\text{DP}$ gives a value close to a standard module.

Standard DP : 1, 2, 3, 4, 25 (It is a number)

Involute Toothed Gear : Fundamental Relations :

Referring to straight tooth spur Gear:



Pitch diameter

$$d_p = 2r_p = Z \times m$$

Circular pitch (arc)

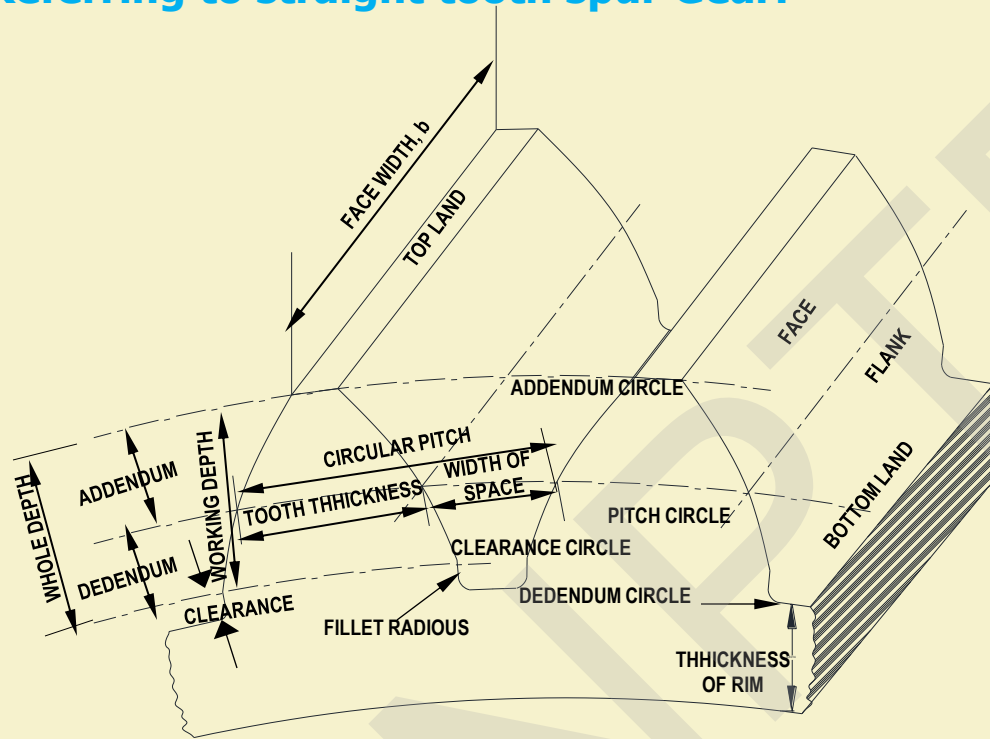
$$\hat{p}_c = 2\pi r_p / Z = \pi m$$

Base circle radius

$$r_b = r_p \cos \alpha$$

Involute Toothed Gear : Fundamental Relations (Contd.):

Referring to straight tooth spur Gear:



Tip or Addendum circle radius

$$r_a = \left(\frac{Z}{2} \pm a_f \right) \times m$$

('-' for internal toothed gear)

a_f **Addendum factor**

Root or Dedendum circle radius

$$r_d = \left(\frac{Z}{2} \pm d_f \right) \times m$$

d_f **Dedendum factor**

('+' for internal toothed gear)

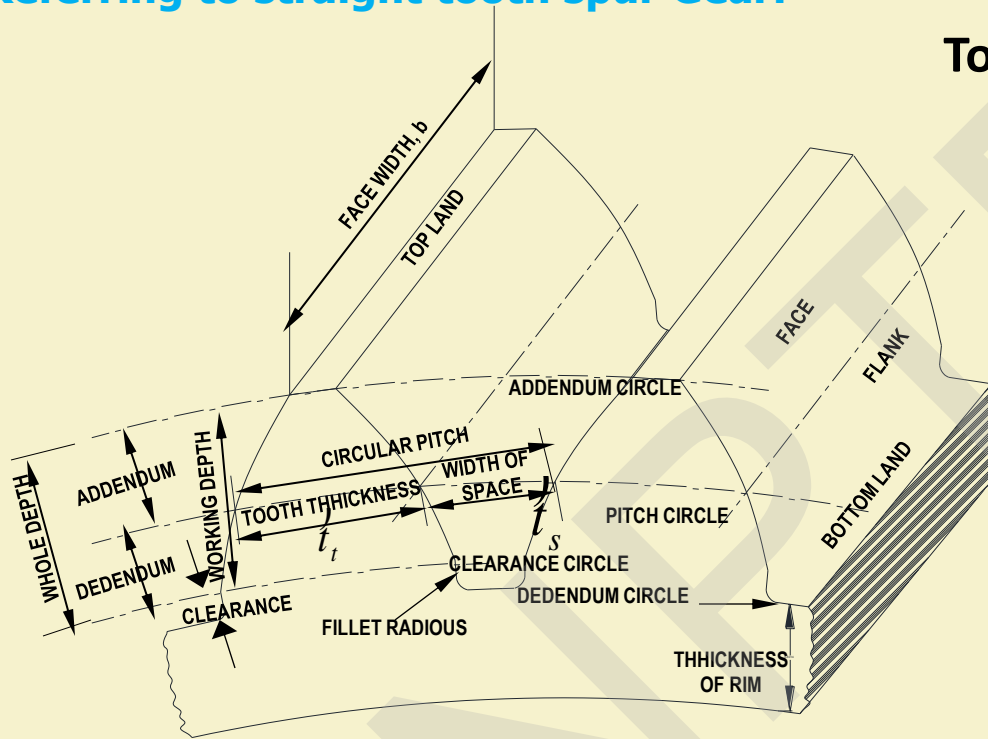
Involute Toothed Gear : Fundamental Relations (Contd.): Referring to straight tooth spur Gear:

Recapitulation :

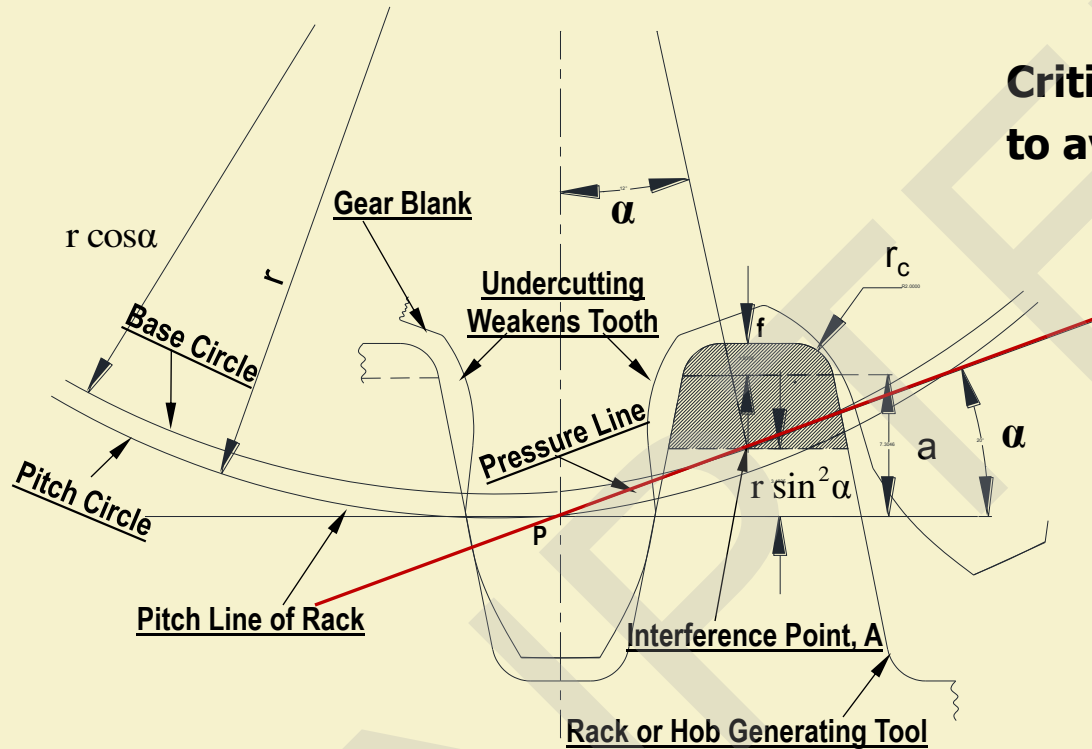
Tooth thickness ($\hat{t}_t$) and space ($\hat{t}_s$)
at standard pitch circle of
uncorrected (standard) gear
they are equal (arc).

$$\hat{t}_t = \hat{t}_s$$

$$= \hat{p}_c / 2 = \pi m / 2$$



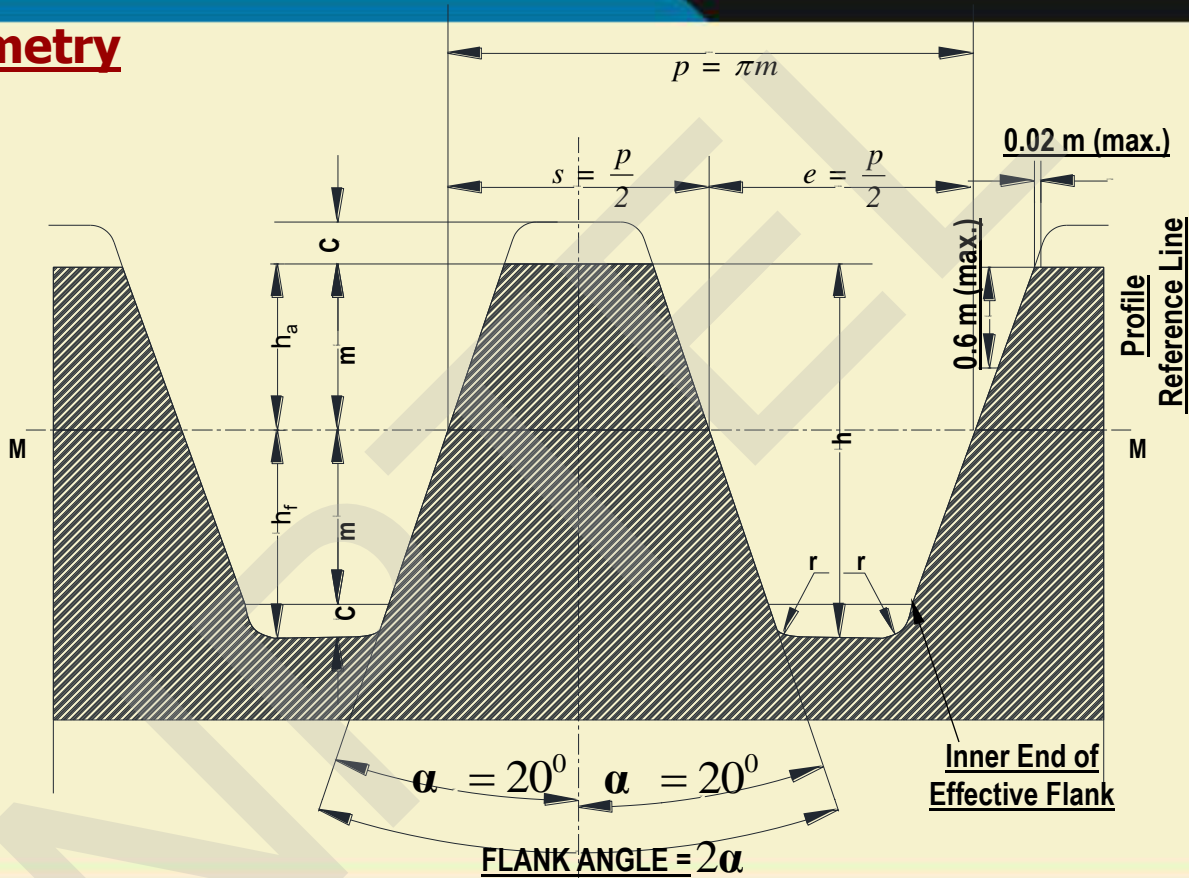
Minimum Number of Teeth in a Gear, Interference and Undercut



Critical (Minimum) number of teeth to avoid undercut.

$$Z_c = \frac{2a_f}{\sin^2 \alpha}$$

Rack Cutter Geometry



Contact ratio

External Gearing

$$C_{re} = \frac{AP + PB}{p_b}$$

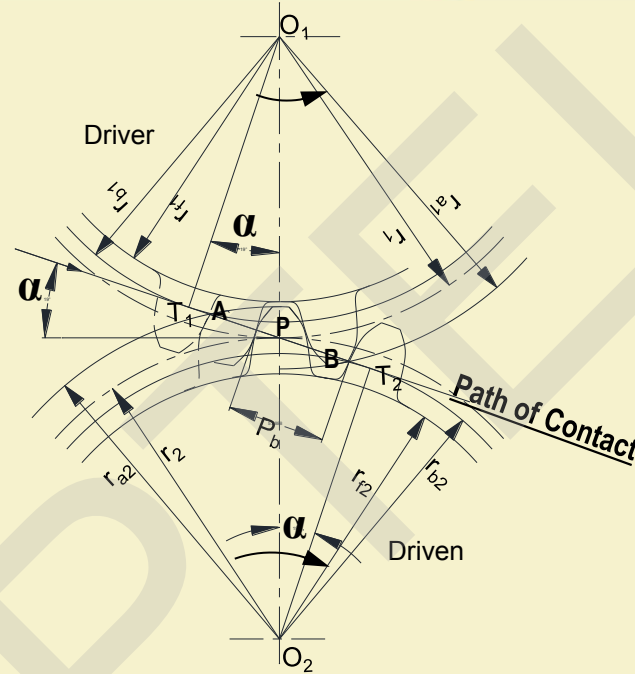
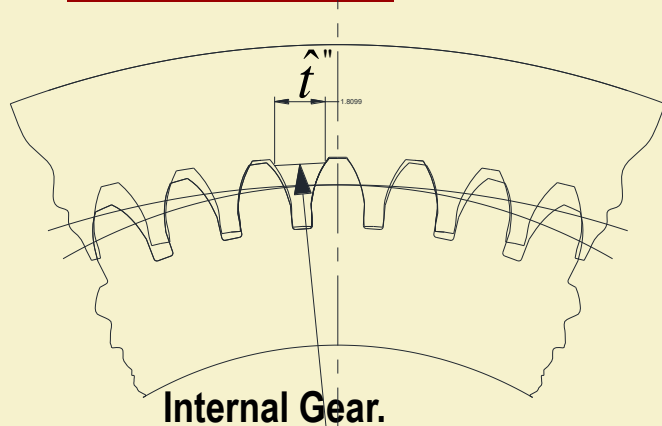
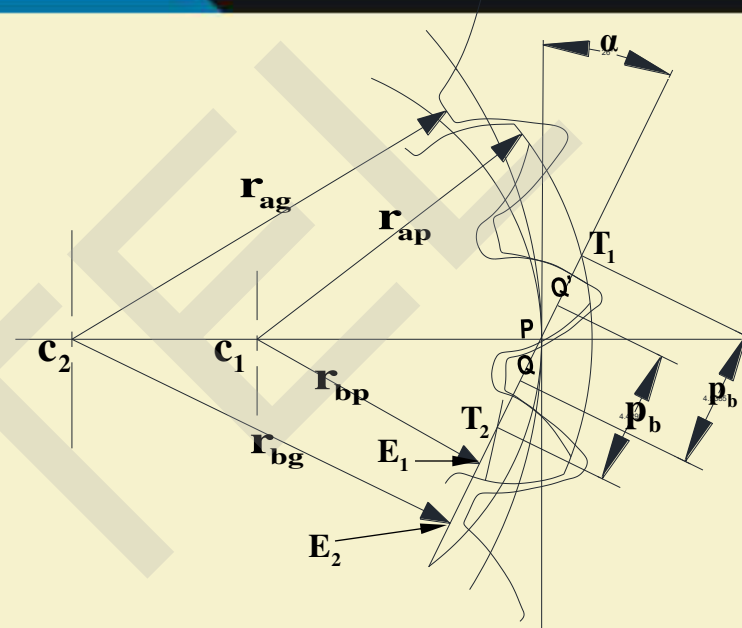


Fig.- 5. (a) External Gear.

$$C_{re} = \frac{\sqrt{(r_{ag}^2 - r_{bg}^2)} - r_{bg} \tan \alpha + \sqrt{(r_{ap}^2 - r_{bp}^2)} - r_{bp} \tan \alpha}{\pi m \cos \alpha_o}$$

Where, α is working and α_o is standard pressure angle.

Contact ratio Internal Gearing



Similarly for Internal Gearing

The **Contact Ratio** is expressed as:
$$C_{ri} = \frac{r_{bg} \tan \alpha - \sqrt{(r_{ag}^2 - r_{bg}^2)} + \sqrt{(r_{ap}^2 - r_{bp}^2)} - r_{bp} \tan \alpha}{\pi m \cos \alpha_o}$$

Note: Contact ratio is independent of module.

Thank You



Module-01

Introduction to Gear and Gear unit Design

Lecture-05

Tutorial



Outline of the Lecture

- **Problems and Solutions on Fundamentals of Involute Toothed Gearing**

Solution of GATE Questions on Gear of Previous Years

- Q1.** A gear set has a driving pinion of 20 teeth and a driven gear of 40 teeth. The pinion runs at 30 rev/s and transmits a power of 20 kW. The teeth are on the 20° full – depth system and have a module of 5 mm. The length of the line of action is 19 mm.

(i) The Input Torque in Nm is -

Options = (A) 212.2 (B) 106.1 (C) 10.61 (D) 1061

Soln.-

Torque Transmitted by the Pinion,
$$T_i = \frac{\text{Power(watt)}}{2\pi \times \text{Revolution/sec}(\text{rad / sec})}$$

ANS. (B) 106.1

Solution of GATE Questions on Gear of Previous Years (Contd..)

- Q1.** A gear set has a driving pinion of 20 teeth and a driven gear of 40 teeth. The pinion runs at 30 rev/s and transmits a power of 20 kW. The teeth are on the 20° full – depth system and have a module of 5 mm. The length of the line of action is 19 mm.

(ii) The contact ratio is-

Options = (A) 1.21 (B) 1.25 (C) 1.29 (D) 1.33

Soln.-

Contact Ratio :
$$C_r = \frac{\text{Length of Contact Along the Line of Action}}{\text{Base Pitch } [= \pi \times \text{module} \times \cos(\text{Std. pressure angle})]}$$

ANS. (C) 1.29

Solution of GATE Questions on Gear of Previous Years ([Contd..](#))

- Q1.** A gear set has a driving pinion of 20 teeth and a driven gear of 40 teeth. The pinion runs at 30 rev/s and transmits a power of 20 kW. The teeth are on the 20° full – depth system and have a module of 5 mm. The length of the line of action is 19 mm.

(iii) The center distance for the above gear set in mm is-

Options= (A) 140 (B) 150 (C) 160 (D) 170

Soln.-

Centre Distance
(Involute Straight Tooth Spur Gear)

$$A = \frac{(\text{No. of Tooth, Pinion} + \text{No. of Tooth, Gear}) \times \text{Module}}{2}$$

ANS. (B) 150

Solution of GATE Questions on Gear of Previous Years ([Contd..](#))

Q2. One tooth of a gear having 4 module and 32 teeth is shown in the figure. Assume that the gear tooth and the corresponding tooth space make equal intercepts on the pitch circumference.

(i) The dimensions (mm) ' a ' and ' b ', respectively, are closed to-

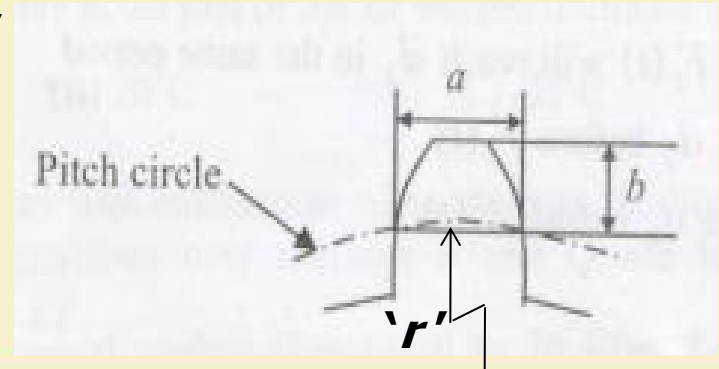
Options= (A) 6.08, 4 (B) 6.48, 4.2 (C) 6.28, 4.3 (D) 6.28, 4.1

Soln.- Tooth thickness (Chord) at pitch circle,

$$a = 2 \times (Z \times m / 2) \sin(360^\circ / (2 \times 2 \times Z))$$

$$b = (1 \times m) + (Z \times m / 2) \times (1 - \cos(360^\circ / (2 \times 2 \times Z)))$$

ANS- (D) 6.28 mm, 4.1 mm



Solution of GATE Questions on Gear of Previous Years ([Contd..](#))

Q3. Match the type of gears with their most appropriate description.

	Type of gear		Description
P	Helical	1	Axes non parallel and non intersection
Q	Spiral Bevel	2	Axes parallel and teeth are inclined to the axis
R	Hypoid	3	Axes are parallel and teeth are parallel to the axis
S	Rack and pinion	4	Axes are perpendicular and intersecting, and teeth are inclined to the axis
		5	Axes are perpendicular and used for large speed reduction
		6	Axes parallel and one of the gears has infinite radius

Options = (A) P-2, Q-4, R-1, S-6

(B) P-2, Q-4, R-5, S-6

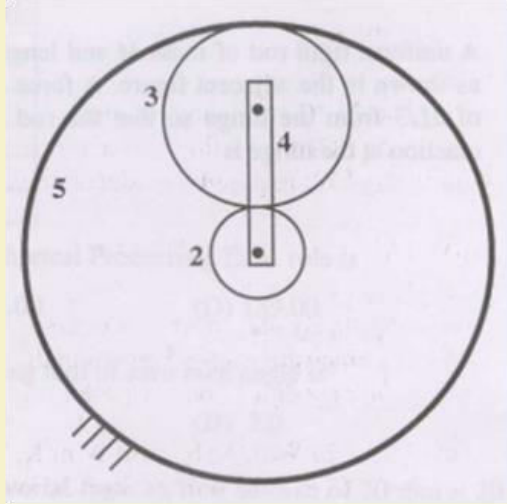
(C) P-2, Q-6, R-4, S-2

(D) P-6, Q-3, R-1, S-5

ANS- (A) P-2, Q-4, R-1, S-6

Solution of GATE Questions on Gear of Previous Years ([Contd..](#))

Q4. An epicyclic gear train is shown schematically in the adjacent figure.



The sun gear 2 on the input shaft is a 20 teeth external gear.

The planet gear 3 is a 40 teeth external gear.

The ring gear 5 is a 100 teeth internal gear.

The ring gear 5 is fixed and the gear 2 is rotating at 60 rpm ccw (ccw=counterclockwise and cw=clockwise).

The arm 4 attached to the output shaft will rotate at:

Options = (A) 10 rpm ccw (B) 10 rpm cw (C) 12 rpm cw (D) 12 rpm ccw

ANS- (A) 10 rpm ccw

Solution of GATE Questions on Gear of Previous Years ([Contd..](#))

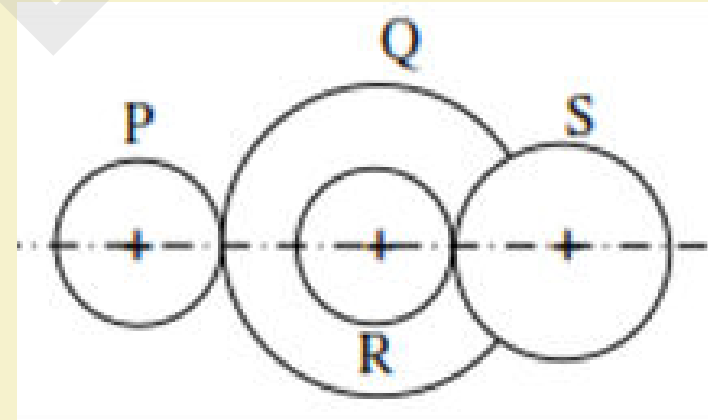
Q5. A compound gear train with gears P, Q, R and S has number of teeth 20, 40, 15 and 20, respectively.

**Gears Q and R are mounted on the same shaft as shown in the figure below.
The diameter of the gear Q is twice that of the gear R.**

If the module of the gear R is 2 mm, the center distance in mm between gears P and S is :

Options = (A) 40 (B) 80
(C) 120 (D) 160

ANS- (B) 80



Solution of GATE Questions on Gear of Previous Years ([Contd..](#))

Q6. Which one of the following is used to convert a rotational motion into a translational motion?

Options = (A) Bevel gears

(B) Double helical gears

(C) Worm gears

(D) Rack and pinion gears

ANS- (D) Rack and Pinion gears

Solution of GATE Questions on Gear of Previous Years (Contd..)

Q7. Gear 2 rotates at 1200 rpm in counter clockwise direction and engages with Gear 3.

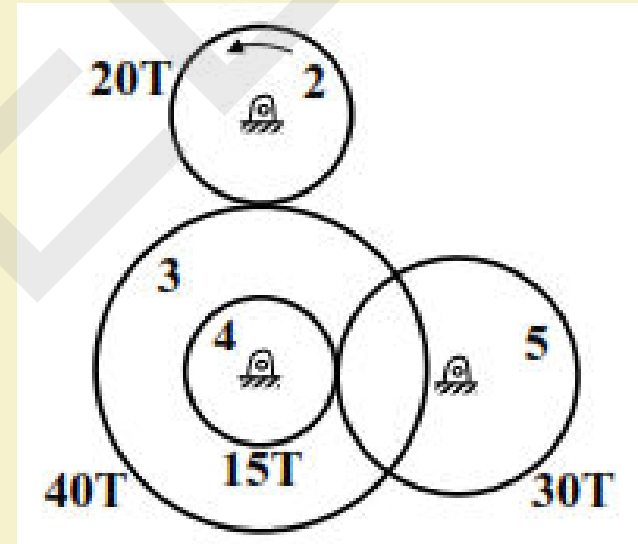
Gear 3 and Gear 4 are mounted on the same shaft.

Gear 5 engages with Gear 4.

The numbers of teeth on Gears 2, 3, 4 and 5 are 20, 40, 15 and 30, respectively.

The angular speed (in rpm) of Gear 5 is :

**Options = (A) 300 ccw (B) 300 cw
(C) 4800 ccw (C) 4800 cw**



ANS- (A) 300 ccw

Solution of GATE Questions on Gear of Previous Years ([Contd..](#))

Q8. A pair of spur gears with module 5 mm and a center distance of 450 mm is used for a speed reduction of 5:1.

The number of teeth on pinion is _____.

Range- 29 to 31

Ans.- 30

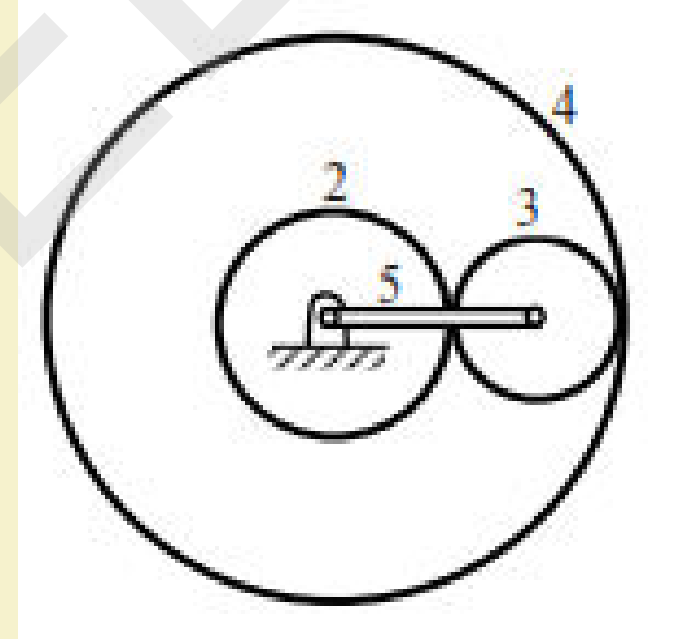
Solution of GATE Questions on Gear of Previous Years (Contd..)

Q9. In the gear train shown, gear 3 is carried on arm 5. Gear 3 meshes with gear 2 and gear 4. The number of teeth on gear 2, 3, and 4 are 60, 20, and 100, respectively.

If gear 2 is fixed and gear 4 rotates with an angular velocity of 100 rpm in the counterclockwise direction, the angular speed of arm 5 (in rpm) is:

Options = (A) 166.7 ccw (B) 166.7 cw
(C) 62.5 ccw (D) 62.5 cw

ANS- (C) 62.5 ccw



Thank You



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