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Experiment No. 5(a)

Aim: To measure spur gear tooth elements.

Instruments: Flange micrometer, Gear tooth vernier calliper.

Theory:- Gears are mainly used for transmission of power and motion. It is a round wheel that has teeth, which messes with another gear allowing force to be fully transferred without slippage. A brief overview of different types of gear has been documented herewith.

(i) Spur Gear: The edge of each tooth is straight and aligned parallel to the axis of rotation.

(ii) Helical Gear: The leading edges of the teeth are not parallel to the axis of rotation, but are set at an angle.

(iii) Bevel Gear: The angle between the shafts of mating gears can be anything except zero or 180 degrees. Bevel gears with equal numbers of teeth and shaft axes at 90 degrees are called miter gears.

(iv) Worm Gear: Type of helical gear, but its helix angle is usually something large and its body is usually fairly long in the axial direction; and it is these attributes which give it screw like qualities

Gear geometric nomenclature :-

The tooth thickness is generally measured at pitch circle shown in figure 1. The curve most commonly used for gear-tooth profile is the involute of a circle. It may be defined as the curve traced by a point on a taught (line BC in figure 2), inextensible string as it unwinds from another circle. The circle from which the involute is derived is called the base circle. The involute profile is shown in fig. 2. Pressure angle (Ψ) is defined as the angle between the line of action and the common tangent to the pitch circles. The base radius and the pitch radius are r_b and r_p respectively. Pitch circle radius is denoted by symbol R. The involute function (δ) is found from the fundamental principle of involute.

From fig. 2,

$$OB = OC\cos\Psi = r_b \qquad \text{Arc } BD = r_b\Psi \text{ (radians)}$$

$$BC = \text{arc } AB = r_b\tan\Psi \qquad r_b\delta = r_b\tan\Psi - r_b\Psi$$

$$\delta = \tan\Psi - \Psi \text{ (radians)}$$

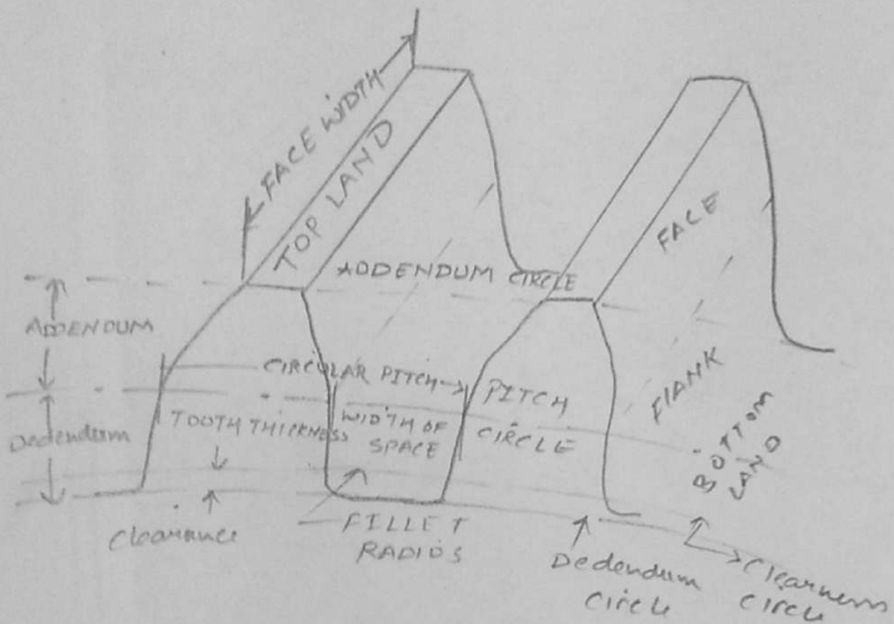

FIG 1:- GEAR NOMENCLATURE

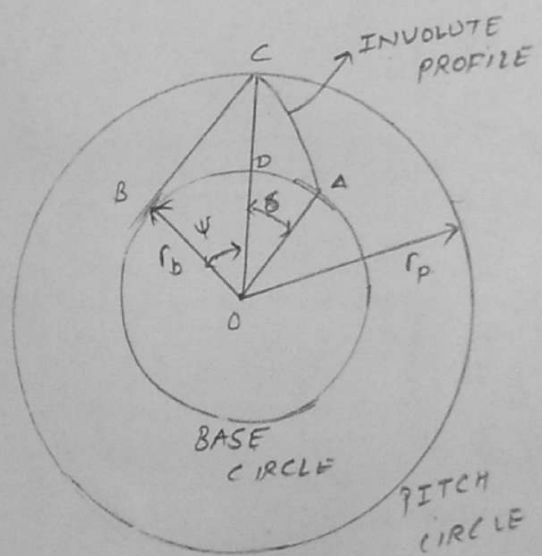

FIG 2:- INVOLUTE PROFILE

The following gear tooth elements are measured using vernier.

- Outside diameter
- Diameteral, pitch
- Pitch circle diameter
- Module
- Addendum
- Dedendum
- Tooth thickness of all teeth

→ Diametral pitch (D_p) :-

Diametral pitch = (N+2)/Outside diameter

where, N = Number of teeth

→ Pitch circle diameter (P.C.D) :-

Pitch circle diameter = N/Diametral pitch

→ Module (m) :-

Module = 1 / Diametral pitch

→ Addendum (a) :- Addendum = Module

→ Dedendum (d) :- Dedendum = 1.157 × Addendum

→ Tooth thickness (t) :-

Tooth thickness is measured by the gear tooth vernier. The vernier consists of two vernier calipers set at 90° to each other. Since the gear tooth thickness varies from the root to the tip, the vernier must be capable of measuring the tooth thickness at a specified position on the tooth. The tooth thickness is measured at the pitch circle as shown in fig. 3. The thickness of the tooth at pitch line and the addendum is measured by an adjustable tongue, each of which is adjusted independently by adjustable screws on the graduated bars. The gear tooth vernier is set with its vertical scale at a distance equal to chordal addendum so that the thin slit will be at a height 'm' from the tip of the jaw. Hence the gear tooth slit will sit on the top land and the tip of the jaws will measure the chordal thickness, t.

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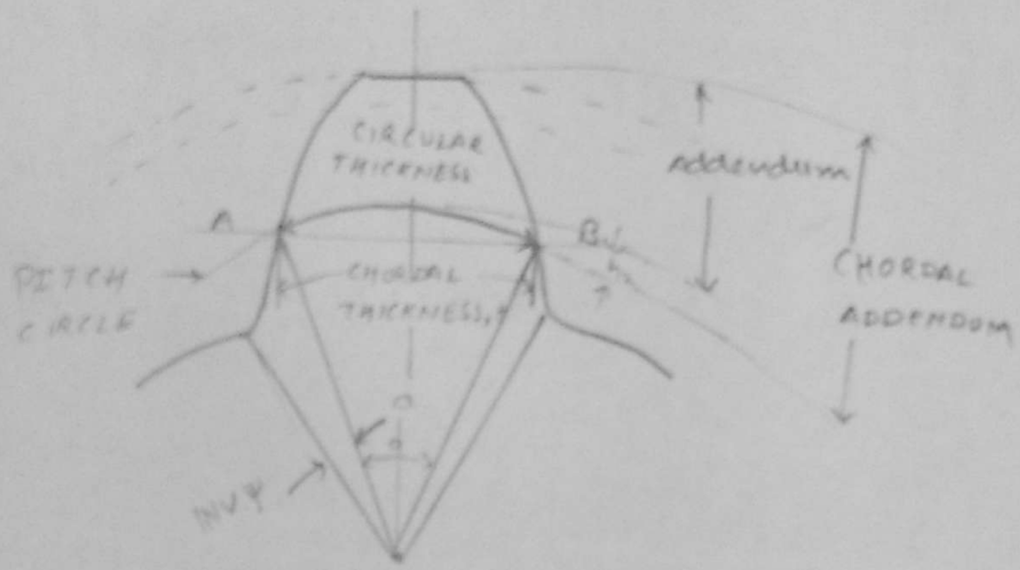

FIG 3: GEAR TOOTH GEOMETRY

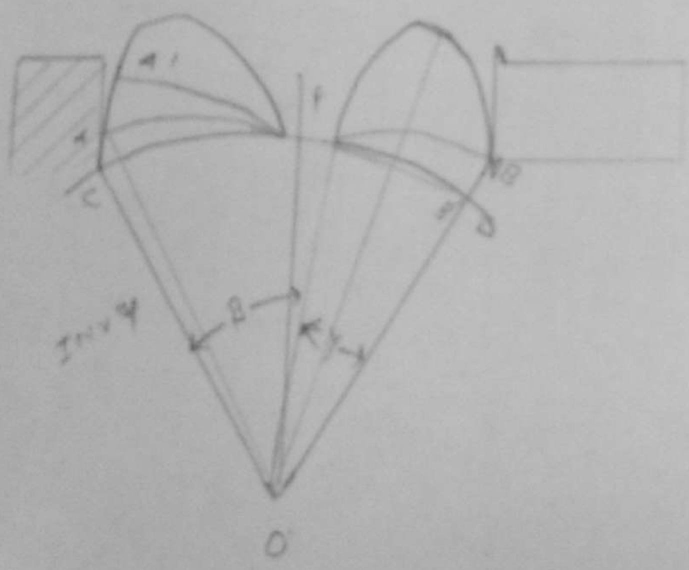

FIG 4:- MEASURMENT OF TOOTH THICKNESS ERROR

$$h = (m + h_2)$$

$$T = AB = 2AD$$

$$\angle AOD = \alpha/2 = 2\pi/4N = \pi/2N$$

where, R = Pitch Circle Radius $= Nm/2$

$$T = 2AO \sin(\alpha/2) = 2R \sin(\pi/2N)$$

$$T = Nm \sin(\pi/2N)$$

$$h_2 = DE = R(1-\cos(\alpha/2))$$

$$= \frac{Nm}{2}(1-\cos \pi/2N)$$

"f" is the chord ADB while tooth thickness is the arc AEB. Therefore the tooth thickness thus measured is called "Chordal tooth thickness."

Procedure to measure tooth thickness: Start from any one tooth by marking it and measure its thickness as t_1. Leaving one tooth measure the next one as t_2. Leaving another tooth measure the next one as t_3. Follow the procedu[re] till all the 30 teeth are measured.

Observation	t_1 (inch)	t_2 (inch)	t_3 (inch)	Mean t	T (mm)	V (mm)
1	0.244	0.245	0.244	0.244	6.28	0.057
2	0.243	0.243	0.246	0.244	6.28	0.057
3	0.244	0.244	0.244	0.244	6.28	0.057
4	0.245	0.245	0.243	0.244	6.28	0.057
5	0.246	0.245	0.244	0.245	6.28	0.057
6	0.243	0.243	0.244	0.243	6.28	0.057
7	0.243	0.245	0.243	0.244	6.28	0.057
8	0.242	0.243	0.243	0.243	6.28	0.057
9	0.245	0.244	0.244	0.244	6.28	0.057
10	0.244	0.254	0.250	0.250	6.28	0.057

Maximum variation of chordal tooth thickness

$= (\text{Max mean } t - \text{Min mean } t)$

$= 0.250 - 0.243$

$= 0.007$ inch

Chordal tooth thickness from formula $T = Nm \sin(\pi/2N)$

$= 30 \times 4 \times \sin(\pi/60)$

$= 6.28$ mm

Variation between the observed and theoretical value

$$V = t - T$$

$$= \left|(0.245 \text{ inch}) \times 25.4 \frac{mm}{inch} - 6.28\,mm\right|$$

$$= 6.223\,mm - 6.28\,mm$$

$$= \underline{\underline{0.057\,mm}}$$

Checking the tooth thickness error with Flange Micrometer [Span measurement / Base tangent measurement]

From the principle of the involute profile the sum of the generators.

AF + FB = A`F + FB` = arc length CD along the base circle as shown in figure 4. Hence the measurement of the span AB can be taken in any position with the Flange Micrometer touching tooth flange. Any tooth thickness error will show a corresponding error in the value of AB.

Let the number of teeth in the span of AB be "n"

Then $\beta = \frac{(n-1)2\pi}{N}$

$$OD = \frac{Nm\cos(\gamma/2)}{2}$$

$$\gamma = \alpha + 2\,\mathrm{inv}\,\psi$$

where

$$\mathrm{inv}\,\psi = \tan\psi - \psi \text{ (radians)}$$

$$CD = (\beta+\gamma)\,OD$$

$$AB = CD = A'B'$$

$$AB = \frac{(\beta+\gamma)}{2} Nm\cos(\gamma/2)$$

$$\alpha = \pi/N$$

$$\beta = (n-1)2\pi/N$$

$$\gamma = \alpha + 2\,\mathrm{inv}\,\psi$$

The optimum number of teeth "n" for the measurement of the span can be found by taking the contact points near the pitch points.

$$AB = AF + FB = CD = 2OF(\psi + inv\,\psi)$$

n = nearest integer to $\frac{AB \times N}{\pi N m \cos\psi} = \frac{N(\psi + inv\,\psi)}{\pi}$

$n = \frac{N\tan\psi}{\pi}$ here $\psi = 20^\circ$

$= \frac{30 \times \tan 20}{3.14}$

$= 3.48$

Nearest integer = $\underline{\underline{3}}$

Range of micrometer = 0.01 mm.

Observation no.	Span 1	Span 2	Mean Value S, mm
1	31.94	31.95	31.95
2	31.98	31.94	31.96
3	31.92	31.93	31.93
4	31.90	31.99	31.95

Maximum variation in values of span measured:

Theoretically the value of the span is given by

$$AB = \frac{(\beta + \gamma)\, Nm\cos(\gamma/2)}{2}$$

$\alpha = \pi/N = 0.105$ $\qquad$ $inv\,\psi = \tan\psi - \psi$

$\beta = (n-1)2\pi/N = 0.52$ $\qquad$ $= \tan 20^\circ - 20 \times \frac{\pi}{180}$

$\gamma = \alpha + 2\,inv\,\psi = 0.105 - 0.015 \times 2$ $\qquad$ $= 0.015$

$= 0.075$

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$$AB = \frac{(0.52 + 0.075) \times 30 \times 4 \times \cos\left(\frac{0.075}{2} \times \frac{180}{17}\right)}{2}$$

$= 35.675$ mm

~~So~~ 1
So Difference between the theoretical and observed values: AB − S

$$= 35.675 - \frac{(31.95 + 31.96 + 31.93 + 31.95)}{4}$$

$= \boxed{3.73}$ mm Ans

Discussion :-

Q. Discuss the results, especially the tooth thickness variation.

Ans → When measured with flange micrometer the thickness Variation was less as compared to the results we have gotten by using vernier callipers.

The variation in tooth thickness may be due to the following reasons:-

(i) There may be manufacturing defect.

(ii) The properties of material may be different at different location (heterogenity), thus there may be variation in thickness.

(iii) The human error due bad instruments.

EXPERIMENT No. 5B

MEASUREMENT OF GEAR TOOTH PROFILE USING COORDINATE MEASURING MACHINE

- **Objective:** To find out the profile error of an involute gear using 'optical CMM'

- **Equipment Required:** 1) Involute gear
  2) Coordinate measuring machine (having continuous contact or optical measuring capability)

- **Theory:** Gear is used for power transmission, specially when high power is required to transmit. Pressure angle of a gear plays very important role in power transmission, since it is the angle at which the driving gear applies normal force on the driven gear. The tangential component of this normal force contributes to the torque transmission, and the radial component loads the shaft and bearings. For more power transmission and lesser pressure on the bearings, pressure angle must be kept small standard pressure angles are 20° and 25°, gears with 14.5° pressure angle have become almost obsolete. The pressure angle depends on gear tooth profile. If there are errors in gear tooth profile then it will affect the pressure angle and hence direction of power transmission will get affected; which will result in failure of either gear, shaft or bearings. So inspection of gear tooth profile is necessary at periodic interval.

- **Procedure:** Following are few gear tooth profile measuring techniques.

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1.) Using Toolmaker's microscope connected with profile projector.
2.) Using Involute tester
3.) Using coordinate measuring machine (which has either continuous contact or optical inspection capability)

- **Coordinate Measuring Machine (CMM):** Coordinate measuring machine of continuous contact type or optical inspection type can also be used for the gear tooth profile measurement. The machine comes with different hardware configuration like 'rotary table', 'indexing probe' etc. apart from different software (e.g. 'PCDMIS', 'CALYPSO', etc.) which contains options for measuring gears, turbine blades, profile elements, torus, general surfaces, general curves, free form surfaces etc. Yet for measuring gears, turbine blades etc., another software (e.g. 'Gear pro' etc.) is required to be used with the CMM software. So this is the ideal method for gear measurement using CMM. But in the absence of these specific software (e.g. 'Gear pro') gear profile can also be measured using 2D and 3D curves inspection techniques of the CMM software. For that gear must properly be cleaned of any dust, and then it is placed on worktable of the CMM. After part alignment, 'VISCAN' is turned on. Now selecting proper illumination setting and suitable camera zoom, gear's teeth images are seen in 'camera window'. Then for gear tooth profile scanning, following steps can be followed:

- Go to Menu bar, and select 2D curve option under 'features' menu. Now we can see one 2D curve in the measurement plan area under 'features' tab.
- Double click on that 2D curve.
- In features window, under the 'Nominal data' drop down menu select 'additional' and then 'Digitization on'. Now put check mark on 'Stylus correction.'
- Open 'strategy window' and click on 'unknown cut'. Set suitable 'Clearance data'
- Double click on 'unknown cut' and specify suitable values for 'expected tolerance', 'speed', 'step width' etc. Also specify the 'start point' and 'End point'
- Specify 'End criterion' and 'space axis' and then check the direction of travel of stylus for curve scanning. If the direction is opposite, then change it.
- Click on 'Execute'. Keep full controls on CMM speed using speed regulating knob.
- Once curve scanning will complete, click on 'OK'.
- Go to 'Form and location' and select 'Curve form'.
- Double click on 'curve form' and select the scanned curve. Now click on 'OK'.
- Specify the nominal value for the curve and click on the 'Plot' icon. If required, 'custom printout' can also be taken. For that go to 'View' and select 'Custom printout'.
- If it is required to look the profile error of a particular

tooth face, then create a theoretical curve and pick features point using 'Recall feature points', of a particular tooth face from the complete curve

Results:

Sr. No.	CURVE FORM	NOMINAL	ACTUAL	DEVIATION
1.	INVOLUTE	0	0.4631	-0.2969

Conclusion:

From the measured gear tooth profile it can be seen that, the wear is maximum at the place where one tooth starts touching the mating gear's tooth. This is because of slightly impact loading (due to backlash in gear) on the tooth at that zone. This wear goes on decreasing towards pitch point. At the pitch point wear is zero and after that again it goes on increasing towards the addendum.

Advantages:

- It is less time consuming method.
- It gives very accurate (accuracy ≈ 1nm) and reliable results.
- Depending upon the workplace and load bearing capability of the machine's worktable, big size gears can also be measured.
- All dimensional elements of a gear (e.g. tooth thickness, pitch, space width etc.) can be measured.
- Using 'gear pro' software with the existing CMM software

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any types of gear (e.g. helical, herringbone, bevel, worm, spiral, hypoid etc.) can be measured, if the CMM has sufficient hardware configuration

- limitations:
  - The machine and software are very costly.
  - Skilled operator is required.