Design and Analysis of Six Speed Gear Box

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Abstract: A gearbox is a mechanical device that is used to provide Speed and Torque conversions from a rotating power source to output shaft. As the speed of the shaft increases, the torque transmitted decreases and vice versa. Multi-speed gearboxes are used in applications which require frequent changes to the speed/torque at the output shaft. Gearboxes work on the principle of meshing of teeth, which result in the transmission of motion and power from the input source to the output. A gearbox is formed by mounting different gears in appropriate speed ratios to obtain the desired variations in speed. Gearboxes usually have multiple sets of gears that are placed appropriately to obtain different speed reductions. The types of gearboxes are Sliding mesh gearbox, Constant mesh gearbox, synchromesh gearbox. In a sliding mesh gearbox, the two types of gears are sliding gears and stationary gears. The sliding gears are mounted on splined shafts to enable them to slide along the axis of the shaft to enable meshing with different pairs of gear.

Keywords: Six speed gear box

I. INTRODUCTION

A. General concept of a gearbox

The main purpose of a gearbox is to transmit power according to variable needs from an input power source to the desired output member. A Gearbox is a mechanical device that is used to provide Speed and Torque conversions from a rotating power source to output shaft. As the speed of the shaft increases, the torque transmitted decreases and vice versa. Multi-speed gearboxes are used in applications which require frequent changes to the speed/torque at the output shaft. Gearboxes work on the principle of meshing of teeth, which result in the transmission of motion and power from the input source to the output.

Transmission of a gearbox: A transmission or gearbox provides speed and torque conversions from a rotating power source to another device using gear ratios. The transmission reduces the higher engine speed to the slower wheel speed, increasing torque in the process. A transmission will have a multiple gear ratios, with the ability to switch between them as speed varies. This switching may be done manually, or automatically. Directional (forward and reverse) control may also be provided.

Most modern gear boxes are used to increase torque while reducing the speed of a prime mover output shaft, and this reduction in speed will produce a mechanical advantage, causing an increase in torque.

Uses of a gearbox:
Gearboxes are used for some or all of the following purposes, changing the Direction through which the power is transmitted. Changing the amount of force or torque that is transmitted. Changing the Revolutionary speed of the input relative to the output.

Fig. 1. Constant mesh gearbox

II. TYPES OF GEARBOX

1. Sliding mesh gearbox
2. Constant mesh gearbox
3. Synchromesh gearbox
4. Planetary gearbox

A. List of components used in a gearbox

Some of the primary components used in a Gearbox are listed below. Gears, Bearings, and Shafts.

B. Types of gearing

The following are the primary types of gearing in a Gearbox. These may be used individually or in unison with other types.

- Spur Gearing
- Helical Gearing
- Herringbone Gearing Epicyclic or Planetary Gearing.

C. Terms associated with a gearbox

The following are some of the terms associated with gearboxes and their working.

1. Gear Ratio
2. Power Transmitted
3. Type of Drive
4. Step Ratio
5. Number of Speeds

1. Gear Ratio: The Gear ratio is the ratio with which the speed varies from one gear pair to another. In a multi stage gearbox the product of the gear ratios of each stage gives the final gear ratio.
2. **Power Transmitted**: Power transmitted is the total power transmitted by the gearbox through its gears from the input shaft to the output shaft taking into account the losses due to efficiency and other factors. Generally the power transmitted at the output shaft is lower than the power received at the input shaft. In British English, the term transmission refers to the whole drive train. But in American English the term refers more specifically to the gearbox alone. A gearbox uses gears and gears trains to provide speed and torque conversions from a rotating power source to another device.

Conventional gear/belt transmissions are not the only mechanism for speed or torque adaptations. Alternative mechanisms include torque converters and power transmission (e.g. diesel-electric transmission and hydraulic drive system). Hybrid configurations also exit. Automatic transmissions use a valve body to shift gears using fluid pressures in conjunctions with an ECM.

3. **Type of Drive**: This is used to denote the type of gearing and the types of contact between the gears in a gearbox. Some types are Epicyclical Drive, Synchronmesh Drive, etc.

## III. Overview and Principles of Components Used

Gears are used to transmit power between shafts rotating at different speeds. Gears are widely used in applications which require high load carrying capacity, high efficiency and no slip between the meshing shafts.

Spur gears are gears which have vertical upright teeth perpendicular to the radial axis of the Gear wheel. The following figure illustrates the terms and notations associated with a spur gear.

Spur Gears are used to transmit power and motion between parallel axes or shafts. The gear types available for spur gear vary in terms of their module, metric gears, pinion gears, racks, internal and cluster gears etc. The Gears mesh or mate with teeth of very specific geometry. If the teeth are not cut to the required level of accuracy, the teeth may interfere with each other’s movements and cause jamming or locking.

### A. Some terms associated with spur gears

- **Module**: The ratio of pitch circle diameter in mm to the number of teeth in the same gear.
- **Pitch**: A measure of the tooth spacing and is expressed in several ways.
  - **Circular Pitch** $p_c$: It is a direct measure of the distance from one tooth center to the adjacent tooth center. It is one of the most widely used terms in gearing.
  - **Diameter Pitch** $p_d$: The ratio of number of teeth to the pitch circle diameter in inches is called the diameter pitch.

The angle between the line of force between meshing teeth and the tangent to the pitch circle at the point of mesh is the pressure angle.

Gears must have the same module and pressure angle to mesh without interference.

### B. Bearings

Bearings as the name suggests are components that are used to carry load and at the same time permit constrained relative motion of the loading member. There are a number of types of bearings. Some of them are listed below:

1. **Roller Bearings**
2. **Ball Bearings**

Ball bearings are used to provide smooth, low friction motion in rotary applications. Ball bearings include Radial ball bearings (Deep Groove and Angular Contact) and thrust ball bearings. Radial ball bearings are designed to carry both radial and axial loads, while thrust bearings are for axial loads only. Radial or Deep Groove Ball Bearings consist of an inner ring, an outer ring, balls and sometimes a cage to contain and separate the balls. These bearings are designed to permit rotational motion of one ring relative to other but do not allow axial movement. These bearings in order to function properly are assembled with a thrust load (Pre-loaded). Similar applications are used for roller bearings, where in place of a ball, rollers are used.

### C. Shafts

Shafts are the members of the gearbox that transmit the rotary motion of the gears to subsequent stages and also transmit power from one stage to the other. They are also the members on which the gears are mounted. The shafts are coupled to the bearings to enable the shafts to rotate without much friction. In a gearbox, two types of shafts are primarily used, keyed shafts and Splined shafts.

Splined Shaft are the shafts in which splines are cut to enable the gears which have an opposite mating spline cut into them to transmit rotational motion from the gear through the shaft without causing slip. The splines are cut to enable the axial movement of sliding of the gears on the shaft while executing rotational motion without slip.

### D. Keyway

They are the shafts in which a keyway is machined so as to enable a gear to be mounted to the said shaft rigidly with the help of a key. In the case of such shafts the gears are rigidly coupled with the shaft and cannot move relative to the shaft.

### E. Properties of shaft materials

- Should have high strength.
- Should have good machinability.
- Should have great heat treatment properties.
- Should have high wear resistant properties.

The material used for ordinary shaft is carbon steel of grades 40C8, 45C8, 50C4 and 50C12.

In this design we have selected the shafts of mild steel and we have kept the key way and spline for the required dimension.
IV. DESIGN AND ASSOCIATED CALCULATIONS

There are many ways of approaching the design of a multi speed gearbox. One of the methods is to consider each pair individually and design them accordingly and check if they meet the required design and operating criteria. This method of design is called the Lewis Buckingham method and the gears subjected to the highest loads/stresses/forces are designed since all the remaining gears, designed proportionally will satisfy the required safe operation criterion.

Initial specifications for the gearbox

- Power transmitted: 2KW
- Max. Speed: 1400 rpm
- Min. Speed: 460 rpm

A. Calculation of progression ratio

\[ R_n = \frac{1400}{460} = 3.043 \]  
(where \( R_n \) is speed ratio)

\[ Z = 6 \]  
(where \( Z \) is the number of spindle speeds)

\[ \Phi = \frac{(R_n)^{1/(Z-1)}}{3.043^{1/5}} = 1.2489 \]  

Therefore, The nearest standard value of \( \Phi = 1.25 \)

From G.P. series we can say that,

\[ 1400 = a (\Phi)^{Z-1} \]

Or, \( 1400 = a (1.25)^5 \)

\( a = 458 \approx 460 \) rpm (approx.)  
(where \( a \) is the minimum speed)

B. Calculation of pitch circle diameter

\[ D_n = \frac{1400}{460} \]  
(where \( D_n \) is pitch circle diameter)

\[ D = 6 \]  
(where \( D \) is the pitch circle diameter)

\[ \Phi = \frac{(D_n)^{1/(Z-1)}}{3.043^{1/5}} = 1.2489 \]  

Therefore, The nearest standard value of \( \Phi = 1.25 \)

By using the same process we can find the rest of the speeds,

2nd Speed = \( 460 \times 1.25 = 575 \) rpm

3rd Speed = \( 460 \times (1.25)^2 = 718.75 \approx 720 \) rpm (approx.)

4th Speed = \( 460 \times (1.25)^3 = 898.43 \approx 900 \) rpm (approx.)

5th Speed = \( 460 \times (1.25)^4 = 1123.04 \approx 1120 \) rpm (approx.)

6th Speed = \( 460 \times (1.25)^5 = 1403.8 \approx 1400 \) rpm (approx.)

Therefore, the following set of speeds are: 460, 575, 720, 900, 1120 and 1400.

V. RAY DIAGRAMS

There are different patterns of ray diagram for a six speed gearbox, they are of the following types:

1. open-type unilateral ray diagram
2. open-type bilateral ray diagram
3. cross-type unilateral ray diagram
4. cross-type bilateral ray diagram

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Or, 2T₁ = 20+ 38.9 = 58.9
Or, T₁ = 58.9/2 = 29.4
T₁ = 38.9 = 40 (approx.)
Or, T₂ = 30 (approx.), which is equal to T₃
Therefore,
T₁ = T₂ = 40.
Similarly, considering the intermediate and output shaft
Tₑ + T₁ = Tₑ + T₂ = Tₑ + T₃ (where Tₑ, T₁, T₂, T₃ are the
no of teeth in gears e, f, g, h, i, j respectively)
Tₑ/T₁ = Nₑ/N₁ = 720/720 = 1
Tₑ = T₁
Tₑ/Tₙ = Nₑ/Nₙ = 575/720 = 0.798 = 0.8 (approx)
Tₑ/T₁ = Nₑ/T₁ = 450/720 = 0.63
Assuming the smallest gear teeth Tₑ = 20
Therefore,
T₁ = 31.74 = 32 (approx.)
Tₑ = Tₙ = 26
1.8Tₑ = 52 or, Tₑ = 28.8 = 30
T₁ = 0.8Tₑ = 24
Therefore, the number of teeth of all the gears are
respectively as follows:
Tₑ = Tₑ = Tₑ = 30, T₁ = T₁ = 20, T₄ = 40, T₅ = T₅ = 26, T₆ = T₇ = 24, T₈ = 32

VI. CALCULATION OF MODULE
Now, to calculate the module we are equating Fₑ and Fₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑ euler}
Fₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑ euler}
Or, m = 1.44; -0.72; -0.72
We will consider the value of m to be 1.5mm = 1.5mm (approx.)
Therefore, b = 10*m = 10*1.5 = 15mm

VII. CALCULATION OF CENTER DISTANCE
aₑ¹ = (Tₑ + Tₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑ euler)}*m²/2
(aₑ¹ is the center distance between the shaft 1 and shaft 2) (3)

= (20+40)*1.5/2
= 45mm
aₑ² = (Tₑ + Tₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑ euler)}*m²/2
(aₑ² is the center distance between the shaft 2 and shaft 3) = (24 + 30)*1.5/2 = 40.5mm
(Here aₑ¹ and aₑ² are the centre distance between the 3 shafts respectively)
Fₑ = 2594.03/m (m = 1.5mm)
Fₑ = 1729.35N
Now, assuming the length of the shaft (L) = 265mm
Force acting along the pressure line, Fₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑ euler}
Therefore, Bending Moment of the shaft due to Fₑ = Fₑ*L/4
Or, Bending Moment (BM) = 1840.33*265/4
= 121922.249N-mm
Now, we are considering maximum permissible shear stress
to be 55N/mm²
Tₑ = (BM2 + Tₑₑₑₑₑₑ euler)}
where Tₑ = Torque acting on the gears
= (121922.249 + 41.512)/2
Tₑ = 6000N (Taking N=460rpm)
= 121.922*103 N-mm
Tₑₑₑₑₑₑₑₑₑₑₑₑ euler}
Tₑₑₑₑₑₑₑₑₑₑₑₑ euler}
Or, d₃ = (16* 121.922 + 103)/3.14*55
Or, d = 22.43 mm = 25mm (approx.)
(Where d is the bore diameter of the shaft)

VIII. SELECTION OF BEARING
Series 6305, Deep groove ball bearing, is used as it meets the
requirements for the loading capacity and service life. We can
get the values from the table given below,

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>DIMENSIONS AND STATIC LOAD CAPACITIES OF SINGLE ROW DEEP GROOVE BALL BEARINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
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<td>30</td>
<td>45</td>
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<tr>
<td>35</td>
<td>50</td>
</tr>
</tbody>
</table>

Specification for the above mentioned bearing are as follows:
1. Bore diameter= 25mm
2. Outside diameter= 62mm
3. Width=17mm
4. Basic static capacity= 11.4kN
5. Basic dynamic capacity= 22.56kN.
IX. RESULTS AND DISCUSSION

We have made an attempt to design a Six Speed Gearbox for Low Power applications. In this process we have designed Spur Gears, Shafts, and Bearings. We have designed the CAD model in SOLIDWORKS and proceeded with further analysis in ANSYS 14.5.

X. CONCLUSION

Lastly, we conclude that we have designed a gear box and as per the design criteria, the design made by us is safe and satisfactory and can be proceeded with production process. Here we also conclude that we have made the design along with its stress, strain and force analysis and the design is concluded safe.

REFERENCES