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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.

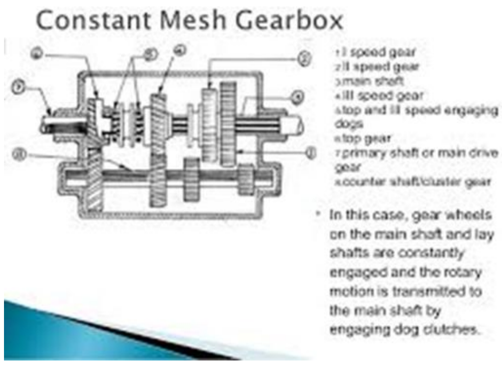

Fig. 1. Constant mesh gearbox

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.

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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 gear box 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 exits. 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, Synchromesh 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 is the ratio of pitch circle diameter in mm to the number of teeth in the same gear.

Pitch is a measure of the tooth spacing and is expressed in several ways.

Circular Pitch pc: 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 pd: The ratio of number of teeth to the pitch circle diameter in inches is called the diameter pitch.

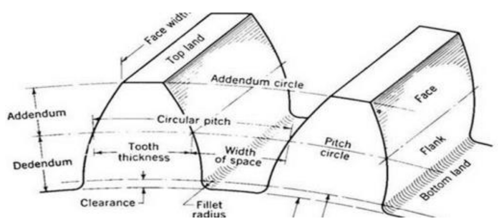

Fig. 2. Spur gear

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.

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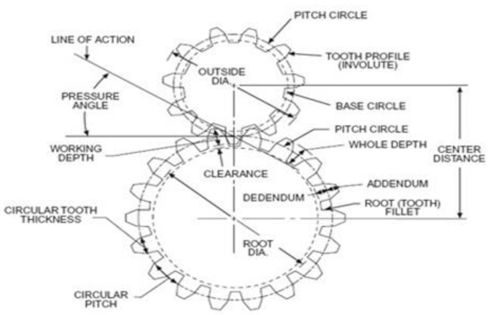

Fig. 3. Design

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

$R_n = 1400/460 = 3.043$
(where R_n is speed ratio)
Z= 6 (where Z is the number of spindle speeds)
$\Phi = (R_n)^{1/(z-1)}$ (where φ is the common ratio in GP series)
$\Phi = 3.043^{1/.5} = 1.2489$
Therefore, The nearest standard value of $\phi = 1.25$
From G.P. series we can say that,
$1400 = a\,(\phi)^{z-1}$
Or, $1400 = a\,(1.25)^5$
Or, a = 458 = 460 rpm (approx.) (where a= minimum speed)

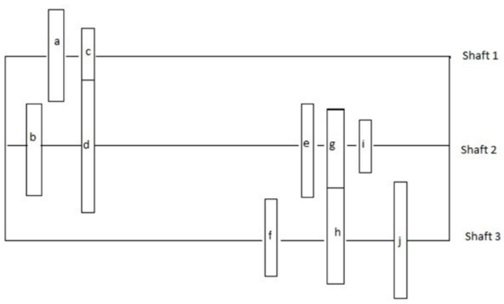

Fig. 4. Structural diagram of a six speed gear box

By using the same process we can find the rest of the speeds,
2^{nd} Speed = 460*φ =460*1.25 = 575 rpm
3^{rd} Speed = $460*(1.25)^2$ = 718.75 = 720 rpm (approx.)
4^{th} Speed = $460*(1.25)^3$= 898.43 = 900 rpm (approx.)
5^{th} Speed = $460*(1.25)^4$ =1123.04 = 1120 rpm (approx.)
6^{th} Speed = $460*(1.25)^5$ =1403.8 = 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

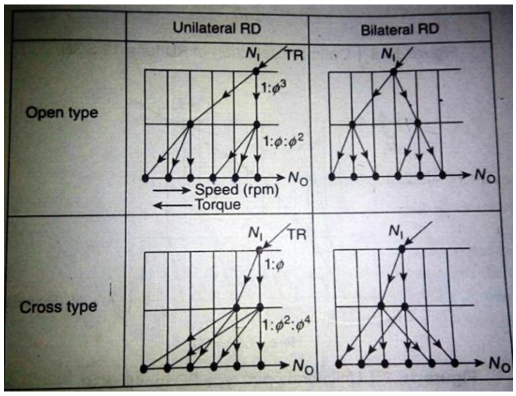

Fig. 5. Different patterns of ray diagrams

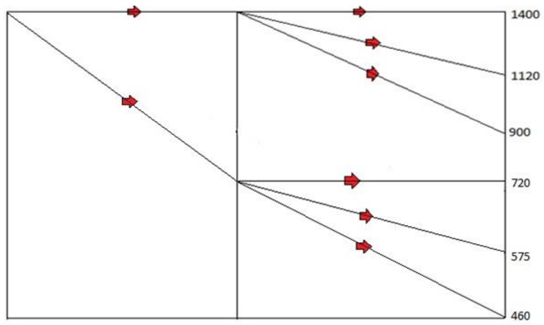

Fig. 6. Ray diagram of six speed gear box

Considering the input and intermediate shaft, as the centre distance of the gears is constant,
$T_a + T_b = T_c + T_d$………… (1)
(Where T_a, T_b, T_c, T_d, are the no of teeth in gears a,b,c,d respectively)
$N_a/N_b = T_b/T_a = 1400/1400 = 1$
So, $T_a = T_b$
Again,
$N_d/N_c = T_c/T_d = 720/1400 = 0.514$…….. (2)
Or, $T_d = T_c/ 0.514$
Since we are considering 20^o full depth involutes system, therefore minimum number of teeth = 17
Assuming minimum number of teeth used= 20.
$T_c = 20$;
Therefore,
$T_a + T_b = 20 + T_d$
Or, $2T_a = 20 + (20/0.514)$

Or, $2T_a$ = 20+ 38.9 = 58.9

Or, T_a = 58.9/2 =29.4

T_d=38.9 = 40 (approx.)

Or, T_a=30 (approx.), which is equal to T_b

Therefore,

T_a=30; T_b=30; T_c=20; T_d=40.

Similarly, considering the intermediate and output shaft

$T_e + T_f = T_g + T_h = T_i + T_j$ (where T_e, T_f, T_g, T_h, T_i , T_j , are the no of teeth in gears e,f,g,h,i,j respectively)

$T_e/T_f = N_f/N_e$ = 720/720 = 1

$T_e = T_f$

$T_g/T_h = N_h/N_g$ = 575/720 = 0.798 = 0.8(approx)

$T_i/T_j = N_j/N_I$= 450/720 = 0.63

Assuming the smallest gear teeth T_i = 20

Therefore,

T_j = 31.74 = 32 (approx.)

$T_e=T_f$=26

$1.8T_h$=52 or, T_h=28.8=30

$T_g=0.8T_h$=24

Therefore, the number of teeth of all the gears are respectively as follows:

$T_a=T_h=T_b=30$, $T_c=T_i=20$, $T_d=40$, $T_e=T_f=26$, $T_g=24$, $T_j=32$

VI. CALCULATION OF MODULE

Now, to calculate the module we are equating F_t and F_{db}, Tangential force acting at the point where two gear teeth are meshing, F_t= (power*1000*C_v)/V

Here, Velocity factor, C_v= 1,

Pitch line velocity, V= πDN/60 (T_j=32, N_j =460rpm)

Or, V= (π*32m*460)/(60*1000) m/s

[Where, D and N are the diameter and the rpm of gear J]

= 0.771m m/s

or, F_t= (2*1000*1)/0.771m

or, F_t= 2594.03/m N

Now C_v= 3/(3+V) = 3/(3+0.771m)

(for pitch line velocity, V<7.5m/s, ordinary spur gear)

Therefore, The beam strength of the gear tooth, F_{db}= σ_b*C_v*m*b*Y

Lewis form factor foe 20^o full depth involutes system, Y= 3.14*{ 0.154- (0.912/T)}

= 3.14*{ 0.154- (0.912/20)}

= 0.340

Therefore, equating F_{db} and F_t , we get:

2594.03/m = (350*3*m*10m*0.340)/(3+0.771m)

or, 2594.03/m = $3570m^2$/(3+0.771m)

or, 7782.09+ 1999.99m = $3750m^3$

or, $3750m^3$ – 1999.99m – 7782.09 = 0

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

a1 = (Tc + Td)*m/2

(a1 is the center distance between the shaft 1 and shaft2) (3)

= (20+40)*1.5/2

=45mm

a2 = (Tg + Th)*m/2 (a2 is the center distance between the shaft2 and shaft3) = (24 + 30)*1.5/2 = 40.5mm

(Here a1 and a2 are the centre distance between the 3 shafts respectively)

Ft = 2594.03/m (m = 1.5mm)

Ft = 1729.35N

Now, assuming the length of the shaft (L) = 265mm

Force acting along the pressure line, Fn = Ft/cos20o = 1840.33N

(Since we are considering 20o involutes teeth)

Therefore, Bending Moment of the shaft due to Fn = Fn*L/4

Or, Bending Moment (BM) = 1840.33*265/4

= 121922.249N-mm

Now, we are considering maximum permissible shear stress (τ) to be 55N/mm2

Te = (BM2 + T2)1/2

where T= Torque acting on the gears

= (121922.249 2 + 41.512)1/2

T=P*60/ (2πN) [TAKING N=460rpm]

=121.922*103 N-mm

Te= equivalent twisting moment

T= 16Te/ (3.14*d3)

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 I
DIMENSIONS AND STATIC LOAD CAPACITIES OF SINGLE ROW DEEP GROOVE BALL BEARINGS

Principal dimensions (mm)			Basic load ratings (N)		Designation
d	D	B	C	C_0	
10	19	5	1480	630	61800
	26	8	4620	1960	6000
	30	9	5070	2240	6200
	35	11	8060	3750	6300
12	21	5	1430	695	61801
	28	8	5070	2240	6001
	32	10	6890	3100	6201
	37	12	9750	4650	6301
15	24	5	1560	815	61802
	32	9	5590	2500	6002
	35	11	7800	3550	6202
	42	13	11400	5400	6302
17	26	5	1680	930	61803
	35	10	6050	2800	6003
	40	12	9560	4500	6202
	47	14	13500	6550	6303
	62	17	22900	11800	6403
20	32	7	2700	1500	61804
	42	8	7020	3400	16404
	42	12	9360	4500	6004
	47	14	12700	6200	6204
	52	15	15900	7800	6304
	72	19	30700	16600	6404
25	37	7	3120	1960	61805
	47	8	7610	4000	16005
	47	12	11200	5600	6005
	52	15	14000	6950	6205
	62	17	22500	11400	6305
	80	21	35800	19600	6405

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.

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