JAIPUR EGINEERING COLLEGE AND RESEARCH CENTRE

Design of Machine Elements – II {6ME4-04}

Unit – V

CO4 :- To Identify the different types of bearing under various loads.

Contents :- Design of Sliding and Journal Bearings : Methods of lubrication, hydrodynamic, hydrostatic, boundary, etc. Minimum film thickness and thermal equilibrium.

Selection of anti-friction bearings for different loads and load cycles, Mounting of the bearings, Method of lubrication.

DME-II

Unit-5

Bearings.

Rolling Contact bearing :-

→ Bearings are used to reduce friction when there is relative motion between two parts like shaft and housing. There are two major groups of bearings :-

ⓐ Sliding contact bearings are also called journal bearings or bush bearing.

ⓑ Rolling contact bearings are called antifriction bearings or simply ball bearings.

The design of ball bearing consists of selection of the bearing with requisite dynamic load capacity from the manufacturer's catalogue.

Uses of Rolling Contact bearings :-

Rolling contact bearings are used in following applications :-

(i) machine tool spindles
(ii) automobile front and rear axles
(iii) gear boxes
(iv) small size electric motors
(v) rope sheaves, crane hook and hoisting drum.

Types of Rolling contact bearing :-

Q. Why rolling contact bearings are called antifriction bearing.?

Ans. For starting conditions and at moderate speeds, the frictional losses in rolling contact bearing are lower than that of equivalent hydrodynamic journal bearing. This is because the sliding contact is replaced by rolling contact resulting in low coefficient of friction. Therefore, rolling contact bearings are called

→ A rolling contact bearing consists of four parts — inner and outer races, a rolling element like ball, roller or needle, and a cage which holds the rolling elements together and spaces them evenly around the periphery of the shaft.

→ Depending upon the type of rolling element the bearings are classified as:—

1. ball bearing.
2. cylindrical roller bearing
3. taper roller bearing
4. Needle bearing.

→ Depending upon the direction of load, the bearings are also classified as:-

1. Radial bearing
2. Thrust bearing

Selection of bearing-type :-

The selection of the type of bearing in a particular application depends upon the requirement of the application and the characteristics of different types of bearings. The guidelines for selecting a proper type of bearing are as follows:-

(i) For low and medium radial loads, ball bearings are used, whereas for heavy loads and large shaft diameter, roller bearings are selected.

(ii) Self-aligning ball bearings and spherical roller bearings are used in applications where a misalignment between the axes of shaft and housing is likely to exist.

(iii) Thrust ball bearings are used for medium thrust loads whereas for heavy thrust loads, cylindrical roller thrust bearings are recommended. Double acting thrust bearings can carry the thrust load in either direction.

(iv) Deep groove ball bearings mainly take radial load and a limited amount of thrust load. Angular contact bearings and spherical roller bearings are suitable in applications where the load acting on the bearing consists of two components viz radial & thrust.

(v) The maximum permissible speed of the shaft depends upon the temperature rise in the bearing. For high speed applications, deep groove ball bearings, angular contact bearings, and cylindrical roller bearings are recommended.

(vi) Rigidity controls the selection of bearing in certain applications like machine tool spindles. Double row cylindrical roller bearings or taper roller bearings are used under these conditions. The 'line contact' in these bearings, as compared with the 'point contact' in ball bearings, improves the rigidity of the system.

(vii) Noise becomes the criterion of selection in appliances like household appliances. From noise consideration, 'point contact' creates less noise than ('line contact'. For such appliances, deep groove ball bearings are recommended.

Static load carrying capacity :- Static load is defined as the load acting on the bearing when the shaft is stationary. It produces permanent deformation in balls and races, which increases with increasing load. The permissible static load, therefore, depends upon the permissible magnitude of permanent deformation.

From past experience, it has been found that a total permanent deformation of 0.0001 of the ball or roller diameter occurring at the most heavily stressed ball and race contact, can be tolerated in practice, without any disturbance like noise or vibration.

The static load carrying capacity of a bearing is defined as the static load which corresponds to a total permanent deformation of balls and races, at the most heavily stressed point of contact, equal to 0.0001 of the ball diameter.

Dynamic load carrying capacity :- The life of a ball bearing is limited by the fatigue failure at the surfaces of balls and races. The dynamic load carrying capacity of the bearing is, therefore based on the fatigue life of the bearing.

The dynamic load carrying capacity of a bearing is defined as the radial load in radial bearings (or thrust load in thrust bearings) that can be carried for a minimum life of one million revolutions. The minimum life in this definition is the L_{10} life, which 90% of the bearings

The dynamic load carrying capacity is based on the assumption that the inner race is rotating while the outer race is stationary.

Equivalent bearing load :-

The expression for the equivalent dynamic load is written as :-

$$P = XVF_r + YF_a$$

{ P = equivalent dynamic load (N)
F_r = radial load (N)
V = race-rotation factor }

X & Y are radial & thrust factors respectively.

{ V = 1 → when the inner race rotates while the outer race is held stationary.
V = 1.2 → when the outer race rotates w.r.t load, while the inner race remains stationary }

→ taking V = 1, the general equation for equivalent dynamic load is given by :-

$$P = XF_r + YF_a$$

→ when the bearing is subjected to pure radial load F_r, then $P = F_r$

→ when the bearing is subjected to pure thrust load F_a, then $P = F_a$

Load - Life Relationship :-

The relationship between the dynamic load carrying capacity, the equivalent dynamic load, and the bearing life is given by,

$$L_{10} = \left(\frac{C}{P}\right)^p$$

{ L_{10} = rated bearing life (in million revolution)
C = dynamic load capacity (N)
p = 3 (for ball bearing) }

$$C = P(L_{10})^{1/p}$$

→ The relationship between life in million revolutions and life in working hours is given by :—

$$L_{10} = \frac{60\, n\, L_{10h}}{10^6}$$

L_{10h} = rated bearing life (hours)
& n = speed of rotation (rpm)

Selection of bearing from Manufacturer's Catalogue :-

The basic procedure of the selection of bearing from the manufacturer's catalogue consists of the following steps :-

(a) Calculate the radial and axial forces acting on the bearing and determine the diameter of the shaft where the bearing is to be fitted.

(b) Select the type of bearing for the given application.

(c) Determine the values of X and Y, the radial and thrust factors, from the catalogue. The values depend upon two ratios, $\left(\frac{F_a}{F_r}\right)$ and $\left(\frac{F_a}{C_o}\right)$, where C_o is the static load capacity. The selection of the bearing is, therefore done by trial and error. ~~the static and dynamic~~ To begin with, a bearing of light series, such as 60, is selected for the given diameter of the shaft and the value of C_o is found from the table. Knowing the ratios $\left(\frac{F_a}{C_o}\right)$ & $\left(\frac{F_a}{F_r}\right)$, the values of X and Y factors are found.

(d) Calculate the equivalent dynamic load from the equation :-

$$P = XF_r + YF_a$$

(e) Make decision about the expected bearing life and express the life L_{10} in million revolutions.

(f) Calculate the dynamic load capacity from the equation :-

$$C = P(L_{10})^{1/3}$$

(g) Check whether the selected bearing of series 60 has the required dynamic capacity. If not, select the bearing of the next series and go back to step (c) and continue.

Design for cyclic loads and speeds :- In certain applications, ball bearings are subjected to cyclic loads & speeds. Under these circumstances, it is necessary to consider the complete work cycle while finding out the dynamic load capacity of the bearing. The procedure consists of dividing work cycle into a number of elements, during which the operating conditions of load and speed are constant.

Suppose that the work cycle is divided into x elements. Let $P_1, P_2 ----, P_x$ be the loads and $n_1, n_2, ---n_x$ be the speeds during these elements. According to load life relationship, during the first element, the life L_1 corresponding to load P_1 is given by :-

$$L_1 = \left(\frac{C}{P_1}\right)^3 \text{ million revolution}$$

or $$L_1 = \left(\frac{C}{P_1}\right)^3 \times 10^6 \text{ rev}$$

In one revolution, the life consumed is $\left(\frac{1}{L_1}\right)$ or $\left(\frac{P_1^3}{C^3} \times \frac{1}{10^6}\right)$

Let us assume the first element consists of N_1 revolutions. Therefore, the life consumed by the first element is given by :

$$\frac{N_1 P_1^3}{10^6 C^3}$$

Similarly, the life consumed by the second is given by, $\frac{N_2 P_2^3}{10^6 C^3}$

Adding these expressions, the life consumed by the complete work cycle is given by :-

$$\frac{N_1 P_1^3}{10^6 C^3} + \frac{N_2 P_2^3}{10^6 C^3} + --- + \frac{N_x P_x^3}{10^6 C^3} \quad \text{———— (a)}$$

If P_e is the equivalent load for the complete work cycle, the life consumed by the work cycle is given by, $\frac{N P_e^3}{10^6 C^3}$ — (b) {where $N = N_1 + N_2 + ---+ N_x$}

Equating expression (a) & (b) :-

$$N_1 P_1^3 + N_2 P_2^3 + ------ + N_x P_x^3 = N P_e^3$$

$$P_e = \sqrt[3]{\left[\frac{N_1 P_1^3 + N_2 P_2^3 + ---}{N_1 + N_2}\right]}$$

or

} These equation is used for calculating the dynamic load capacity of a bearing.

When the load does not vary in steps of constant magnitude, but varies continuously with time, the above equation is modified & written as :-

$$P_e = \left[\frac{\int_0^N P^3\, dN}{\int_0^N dN}\right]^{1/3} \quad \text{or} \quad P_e = \left[\frac{1}{N}\int P^3\, dN\right]^{1/3}.$$

<u>Note</u> :- In case of bearings, where there is a combined radial and axial load, it should be first converted into equivalent dynamic load before the above computations are carried out.

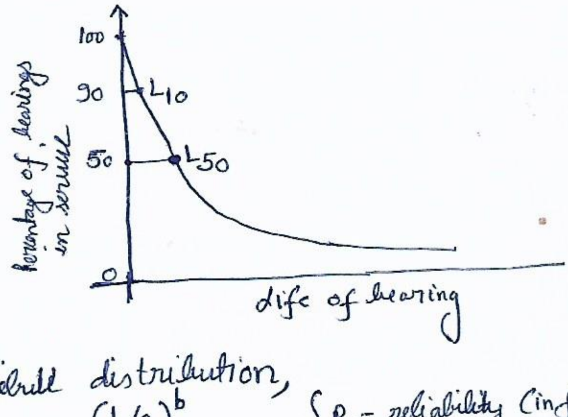
Reliability of Bearings :- In the definition of rating life, it is mentioned that the rating life is the life that 90% of a group of identical bearings will complete or exceed before fatigue failure.

The reliability <u>R</u> is defined as :-

$$R = \frac{\text{No. of bearings which have successfully completed } L \text{ million revolutions}}{\text{Total number of bearings under test}}$$

Therefore, the reliability of bearings selected from the manufacturer's catalogue is 0.9 or 90%.

→ The relationship between bearing life and reliability is given by a statistical curve known as Weibull distribution.



For Weibull distribution,

$$R = e^{-(L/a)^b}$$

{R = reliability (in fraction)
L = corresponding life
a, b = constants}

Rearranging the above equation, we have,

$$\left(\frac{1}{R}\right) = e^{(L/a)^b} \qquad \log_e\left(\frac{1}{R}\right) = \left(\frac{L}{a}\right)^b \quad \text{—— (a)}$$

If L_{10} is the life corresponding to a reliability of 90% or R_{90} then :-

$$\log_e\left(\frac{1}{R_{90}}\right) = \left(\frac{L_{10}}{a}\right)^b \quad \text{—— (b)}$$

Dividing eqn (a) by eqn (b), we have :-

$$\left(\frac{L}{L_{10}}\right) = \left[\frac{\log_e\left(\frac{1}{R}\right)}{\log_e\left(\frac{1}{R_{90}}\right)}\right]^{1/b} \quad \text{—— (c)}$$

→ This equation is used for selecting the bearing when the reliability is other than 90%.

where $R_{90} = 0.9$

The values of $a = 6.84$ and $b = 1.17$

These values are obtained from the condition :- $L_{50} = 5L_{10}$, where L_{50} is the median life or life which 50% of the bearings will complete or exceed before fatigue failure.