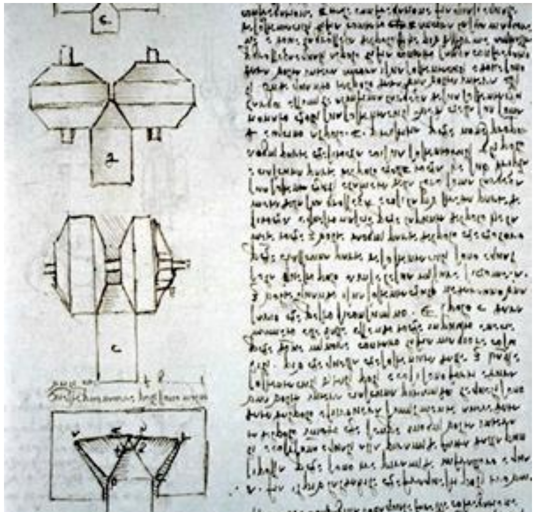
Rolling Element Bearing

ME 423: Machine Design
Instructor: Ramesh Singh

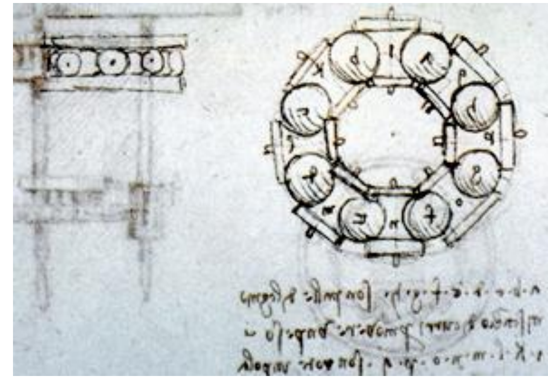
Outline

- Bearing type
- Bearing life
- Bearing reliability

Leonardo’s Bearings



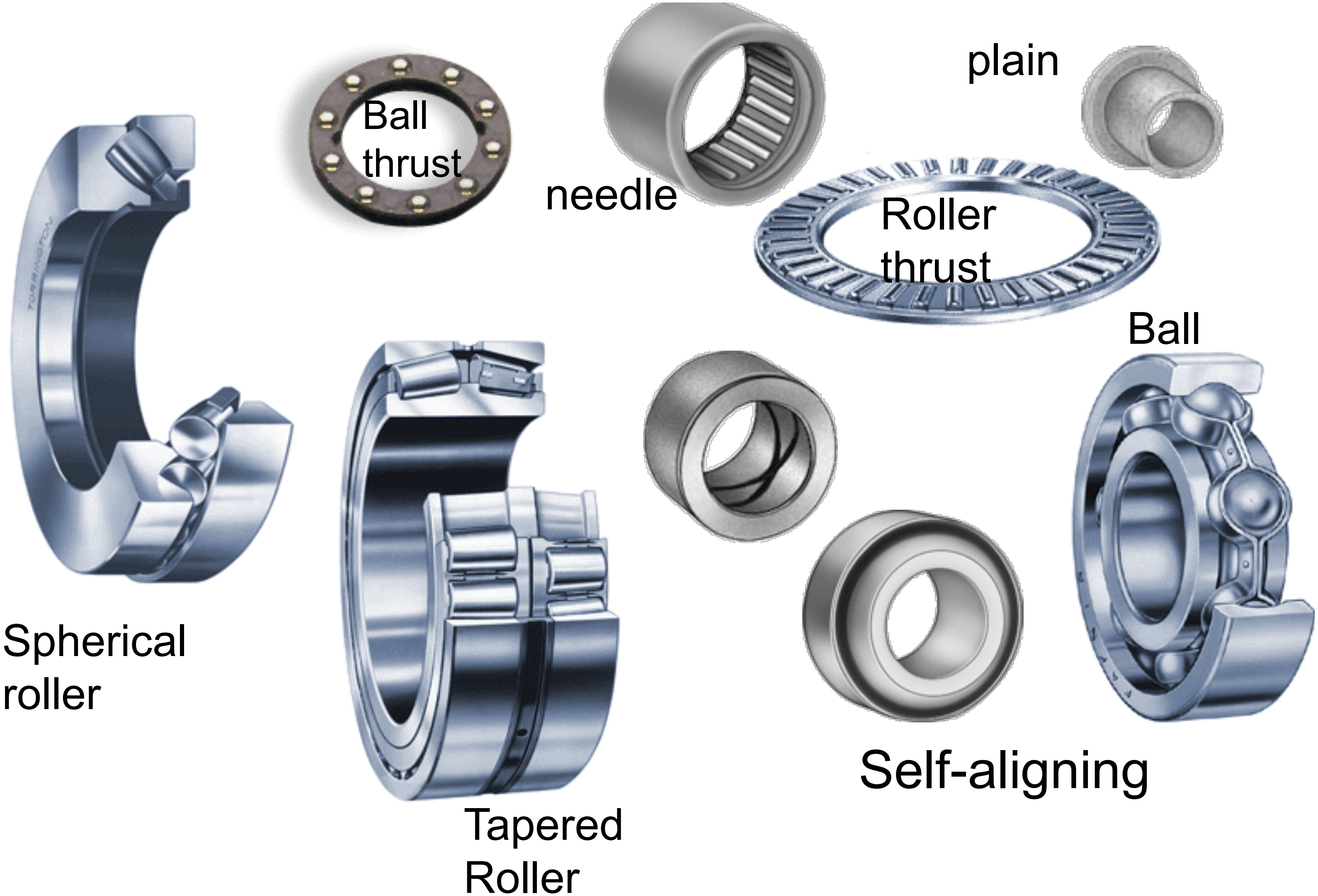
Roller and ball bearings for cone-tipped vertical axles



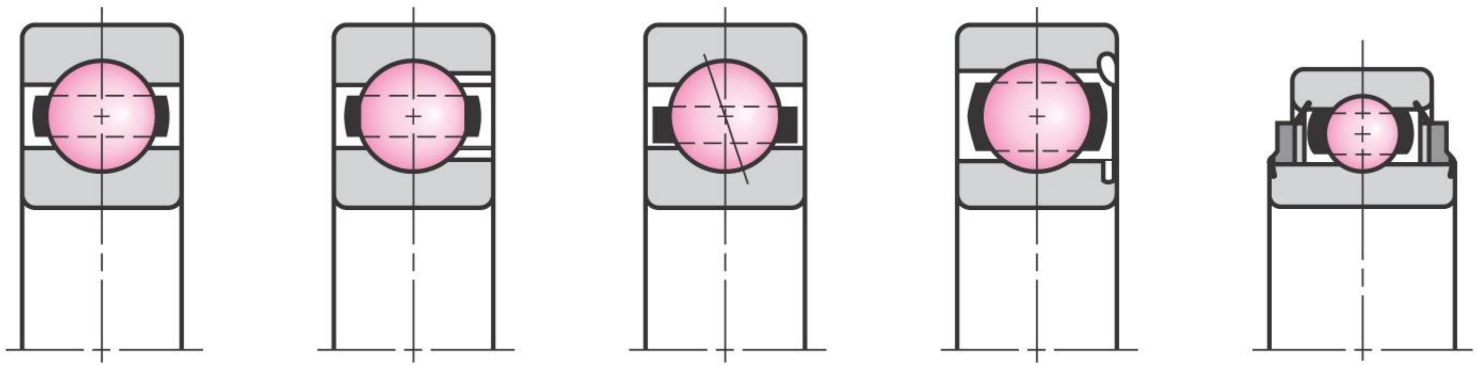
Pressure-resistant ball bearing

Courtesy: Museo Galileo

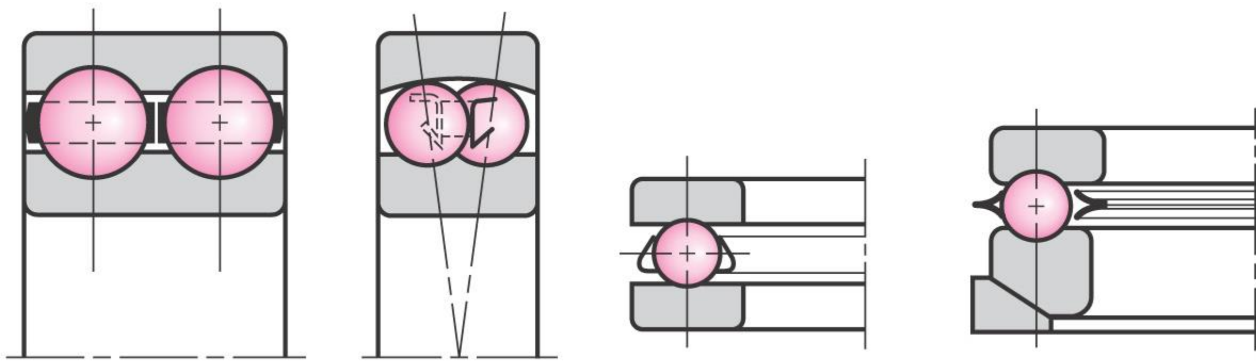
Types of Bearings



Types of Ball Bearing

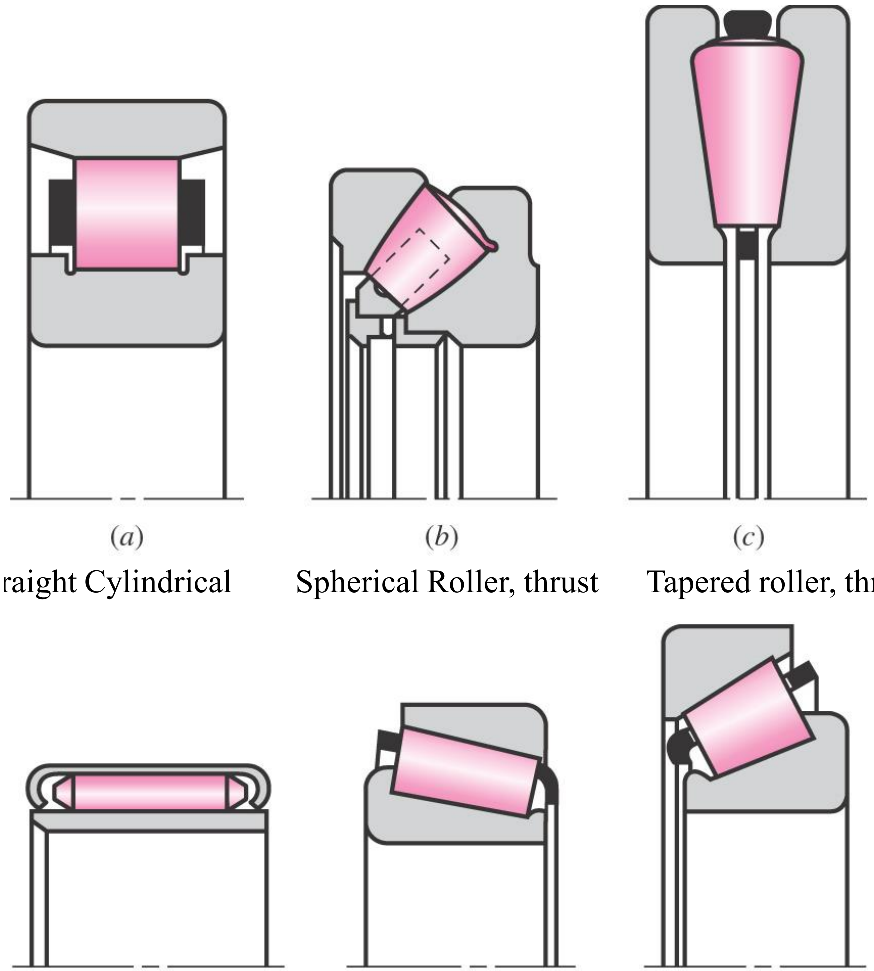


(a) Deep groove | (b) Filling notch | (c) Angular contact | (d) Shielded | (e) Sealed



(f) External self-aligning | (g) Double row | (h) Self-aligning | (i) Thrust | (j) Self-aligning thrust

Types of Roller Bearing

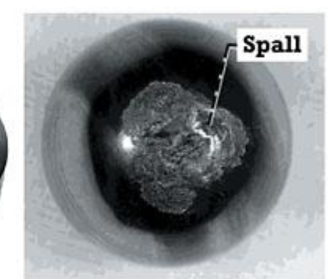


(a) raight Cylindrical (b) Spherical Roller, thrust (c) Tapered roller, thrust

(d) Needle (e) Tapered roller (f) Steep-angle tapered roller

Bearing Life Definitions

- Bearing Failure: Spalling or pitting of an area of 0.01 in^2
- Life: Number of revolutions (or hours @ given speed) required for failure
  - For one bearing
- Rating Life: Life required for 10% of sample to fail.
  - For a group of bearings
  - Also called Minimum Life or L_{10} Life
- Median Life: Average life required for 50% of sample to fail.
  - For many groups of bearings
  - Also called Average Life or Average Median Life
  - Median Life is typically 4 or 5 times the L10 Life



Load Ratings

- Catalog Load Rating, C_{10}: Constant radial load that causes 10% of a group of bearings to fail at the bearing manufacturer's rating life
  - Depends on type, geometry, accuracy of fabrication, and material of bearing
  - Also called Basic Dynamic Load Rating, and Basic Dynamic Capacity
- Basic Load Rating, C: A catalog load rating based on a rating life of 10^6 revolutions of the inner ring.
  - The radial load that would be necessary to cause failure at such a low life is unrealistically high.
  - The Basic Load Rating is a reference value, not an actual load.

Load Ratings

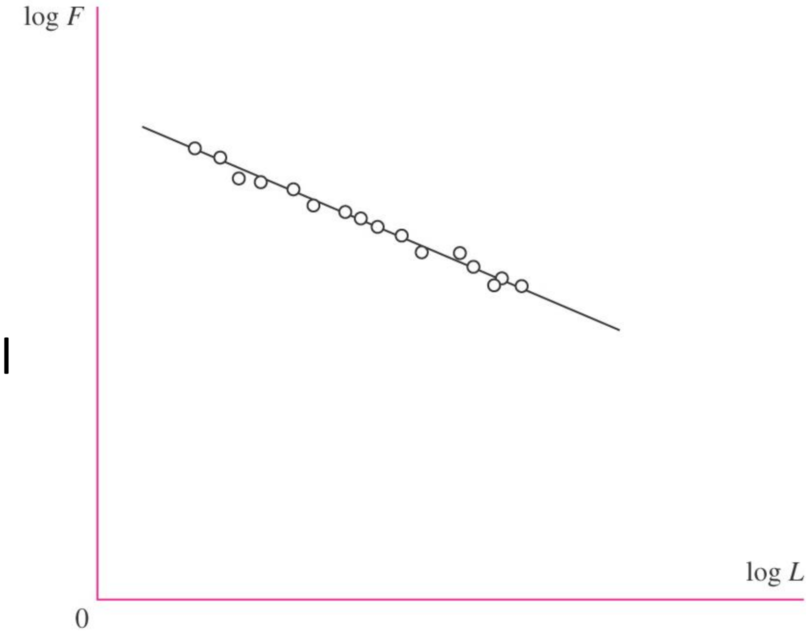
- Static Load Rating, C_o:
  Static radial load which corresponds to a permanent deformation of rolling element and race at the most heavily stressed contact of 0.0001d.
  - d = diameter of roller
  - Used to check for permanent deformation
  - Used in combining radial and thrust loads into an equivalent radial load
- Equivalent Radial Load, F_e:
  Constant stationary load applied to bearing with rotating inner ring which gives the same life as actual load and rotation conditions.

Load-Life Relationship

- Nominally identical groups of bearings are tested to the life-failure criterion at different loads.
- A plot of load vs. life on log-log scale is approximately linear.
- Using a regression equation

$FL^{\frac{1}{a}} = constant$ (11-1, Shigley)

  - a = 3 for ball bearings
  - a = 10/3 for roller bearings (cylindrical and tapered roller)



Applying Eq. (11–1) to two load-life conditions,

$$F_1 L_1^{1/a} = F_2 L_2^{1/a} \tag{11–2}$$

Denoting condition 1 with R for catalog rating conditions, and condition 2 with D for the desired design conditions,

$$F_R L_R^{1/a} = F_D L_D^{1/a} \tag{a}$$

The units of L are revolutions. If life $\mathscr{L}$ is given in hours at a given speed n in rev/min, applying a conversion of 60 min/h,

$$L = 60\, \mathscr{L} n \tag{b}$$

$$F_R(\mathscr{L}_R n_R 60)^{1/a} = F_D(\mathscr{L}_D n_D 60)^{1/a}$$

- F_R: catalog rating, lbf or kN
- $\mathscr{L}_R$: rating life in hours
- n_R: rating speed, rev/min
- F_D: desired radial load, lbf or kN
- $\mathscr{L}_D$: desired life, hours
- n_D: desired speed, rev/min

Load-Life Relationship

$$C_{10} = F_R = F_D \left(\frac{L_D}{L_R} \right)^{1/a} = F_D \left(\frac{\mathcal{L}_D n_D 60}{\mathcal{L}_R n_R 60} \right)^{1/a}$$

- The desired design load F_D and life L_D come from the problem statement.
- The rated life L_R will be stated by the specific bearing manufacturer. Many catalogs rate at $L_R = 10^6$ revolutions.
- The catalog load rating C_{10} is typically used to find a suitable bearing in the catalog.
  - a = 3 for ball bearings
  - a = 10/3 for roller bearings (cylindrical and tapered roller)

(a) Select the roller bearing for location D.

(b) Select the ball bearing (angular contact) for location C, assuming the inner ring rotates.

the gear force transmitted to the second shaft are shown in Fig. 11–12, at point A. The bearing reactions at C and D, assuming simple-supports, are also shown. A ball bearing is to be selected for location C to accept the thrust, and a cylindrical roller bearing is to be utilized at location D. The life goal of the speed reducer is 10 kh, with e

of 5000 h at 1725 rev/min with a load of 400 lbf with a reliability of 90 percent, for which catalog rating would you search in an SKF catalog?

Solution The rating life is $L_{10} = L_R = \mathcal{L}_R n_R 60 = 10^6$ revolutions. From Eq. (11–3),

Answer

$$C_{10} = F_D \left(\frac{\mathcal{L}_D n_D 60}{\mathcal{L}_R n_R 60} \right)^{1/a} = 400 \left[\frac{5000(1725)60}{10^6} \right]^{1/3} = 3211 \text{ lbf} = 14.3 \text{ kN}$$

Example Problem

The second shaft on a parallel-shaft 25-hp foundry crane speed reducer contains a helical gear with a pitch diameter of 8.08 in. Helical gears transmit components of force in the tangential, radial, and axial directions (see Chap. 13). The components of the gear force transmitted to the second shaft are shown in Fig. 11–12, at point *A*. The bearing reactions at *C* and *D*, assuming simple-supports, are also shown. A ball bearing is to be selected for location *C* to accept the thrust, and a cylindrical roller bearing is to be utilized at location *D*. The life goal of the speed reducer is 10 kh, with

(*a*) Select the roller bearing for location *D*.
(*b*) Select the ball bearing (angular contact) for location *C*, assuming the inner ring rotates.

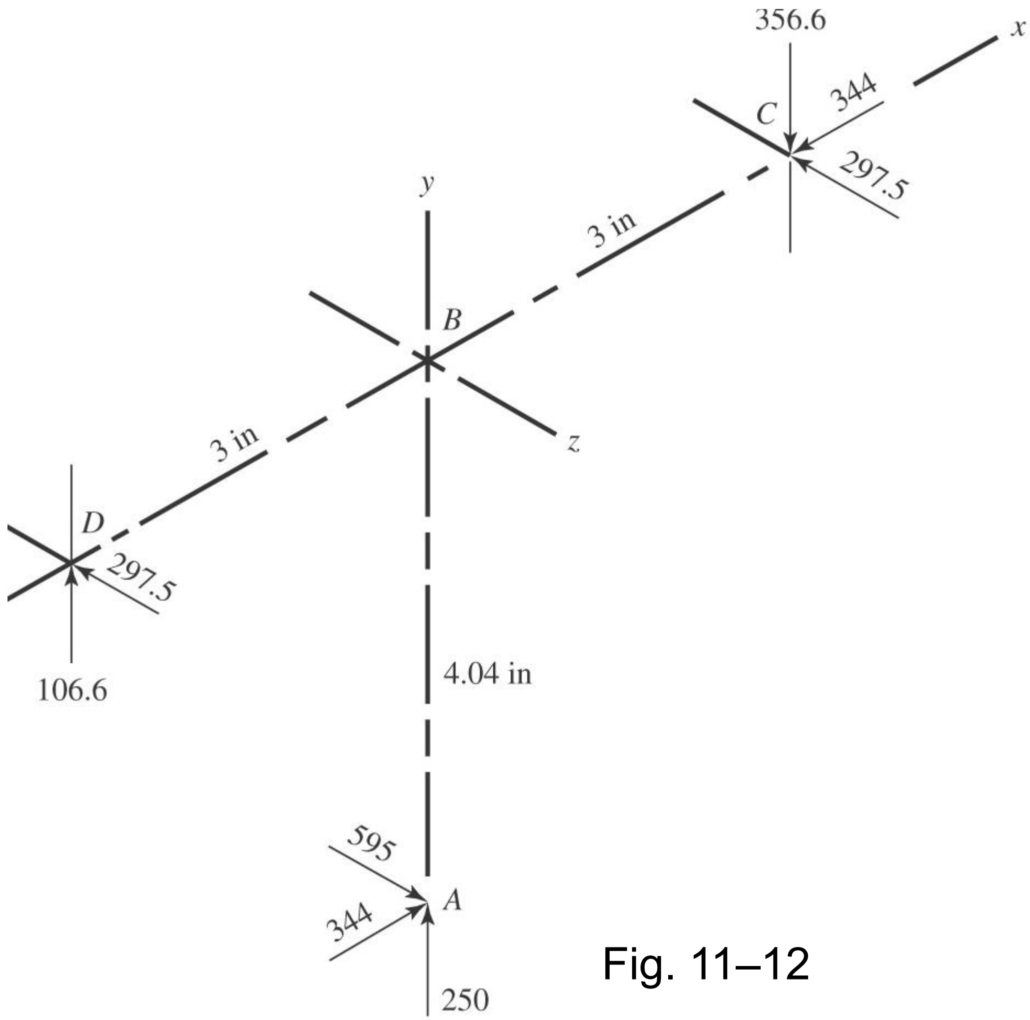


Fig. 11–12

Solution

The torque transmitted is $T = 595(4.04) = 2404$ lbf · in. The speed at the rated horsepower, given by Eq. (3–42), p. 116, is

$$n_D = \frac{63\,025H}{T} = \frac{63\,025(25)}{2404} = 655.4 \text{ rev/min}$$

The radial load at D is $\sqrt{106.6^2 + 297.5^2} = 316.0$ lbf, and the radial load at C is $\sqrt{356.6^2 + 297.5^2} = 464.4$ lbf. The individual bearing reliabilities, if equal, must be at least $\sqrt[4]{0.96} = 0.98985 \approx 0.99$. The dimensionless design life for both bearings is

$$x_D = \frac{L_D}{L_{10}} = \frac{60\mathcal{L}_D n_D}{L_{10}} = \frac{60(10\,000)655.4}{10^6} = 393.2$$

$$C_{10} = F_R = F_D \left(\frac{L_D}{L_R}\right)^{1/a} \qquad x_D = L_D/L_R$$

$$C_{10} = 464.4(393.2)^{1/3} = 3402.\,lbf$$ For ball bearing @ C

$$C_{10} = 316(393.2)^{3/10} = 1897.\,lbf$$ For roller bearing @ D

Reliability Vs. Life

- At constant load, the life measure distribution is right skewed.
- The Weibull distribution is a good candidate.
- Defining the life measure in dimensionless form as $x = L/L_{10}$, the reliability is expressed with a Weibull distribution as

$$R = \exp\left[-\left(\frac{x - x_0}{\theta - x_0}\right)^b\right] \tag{11–4}$$

where R = reliability

x = life measure dimensionless variate, L/L_{10}

x_0 = guaranteed, or "minimum," value of the variate

θ = characteristic parameter corresponding to the 63.2121 percentile value of the variate

b = shape parameter that controls the skewness

Because there are three distributional parameters, x_0, θ, and b, the Weibull has a robust ability to conform to a data string. Also, in Eq. (11–4) an explicit expression for the cumulative distribution function is possible:

$$F = 1 - R = 1 - \exp\left[-\left(\frac{x - x_0}{\theta - x_0}\right)^b\right] \tag{11–5}$$

Weibull Distribution

- R=1-p, where p is the probability of a value of x occurring between –θ and x, and is, the integral of the probability distribution, f(x)=-dR/dx:

$$f(x) = \frac{b}{\theta - x_0}\left(\frac{x - x_0}{\theta - x_0}\right)^{b-1} e^{-\left(\frac{x-x_0}{\theta-x_0}\right)^{b}} \qquad x \geq x_0 \geq 0$$

$$f(x) = 0 \qquad x < x_0$$

Weibull Distribution

The mean and standard deviations are given by,

$$\mu_x = x_0 + (\theta - x_0)\Gamma\left(1 + \frac{1}{b}\right)$$

$$\sigma_x = (\theta - x_0)\sqrt{\Gamma\left(1 + \frac{2}{b}\right) - \Gamma^2\left(1 + \frac{1}{b}\right)}$$

Where Γ is gamma function

$$x = x_0 + (\theta - x_0)\left(ln\frac{1}{R}\right)^{\frac{1}{b}}$$

Example Problem

Construct the distributional properties of a 02-30 millimeter deep-groove ball bearing if the Weibull parameters are $x_0 = 0.02$, $(\theta - x_0) = 4.439$, and $b = 1.483$. Find the mean, median, 10th percentile life, standard deviation, and coefficient of variation.

Solution

From Eq. (20–28), p. 991, the mean dimensionless life μ_x is

$$\mu_x = x_0 + (\theta - x_0)\Gamma\left(1 + \frac{1}{b}\right) = 0.02 + 4.439\Gamma\left(1 + \frac{1}{1.483}\right) = 4.033$$

The median dimensionless life is, from Eq. (20–26) where $R = 0.5$,

$$x_{0.50} = x_0 + (\theta - x_0)\left(\ln\frac{1}{R}\right)^{1/b} = 0.02 + 4.439\left(\ln\frac{1}{0.5}\right)^{1/1.483}$$

$$= 3.487$$

Example Problem

The 10th percentile value of the dimensionless life x is

$$x_{0.10} = 0.02 + 4.439\left(\ln\frac{1}{0.90}\right)^{1/1.483} \doteq 1 \qquad \text{(as it should be)}$$

The standard deviation of the dimensionless life is given by Eq. (20–29):

$$\hat{\sigma}_x = (\theta - x_0)\left[\Gamma\left(1+\frac{2}{b}\right) - \Gamma^2\left(1+\frac{1}{b}\right)\right]^{1/2}$$

$$= 4.439\left[\Gamma\left(1+\frac{2}{1.483}\right) - \Gamma^2\left(1+\frac{1}{1.483}\right)\right]^{1/2} = 2.753$$

The coefficient of variation of the dimensionless life is

$$C_x = \frac{\hat{\sigma}_x}{\mu_x} = \frac{2.753}{4.033} = 0.683$$