SKF Racing TechNote

Calculation of wheel bearings loads

Factors necessary for bearing load calculation in wheel applications vary considerably. To obtain an exact expression for the resultant bearing loads is consequently impossible. Values based on experience with previous bearing arrangements are usually used for new designs.

The calculation for front and rear hub bearing arrangements are normally similar; no consideration is taken of the fact that one pair of wheels is driven. Only in special circumstances is account taken of the power transmitted.

The following survey is based on a hub bearing arrangement, incorporating two taper roller bearings as shown in Fig. 1, but the method of calculation also applies to other bearing arrangements having two pressure centres, for example, using two single row angular contact ball bearings or one double row.

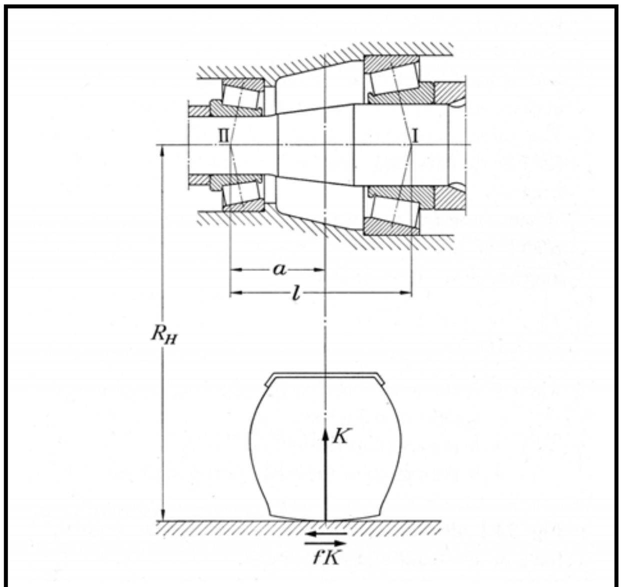

Fig. 1 Hub bearing loads when driving straight ahead

The static hub load K for a loaded vehicle is obtained from

$$K = K^{'} - K^{''}$$

where $K^{'}$ is the force between tyre and road (half axle load)

$K^{''}$ is the weight of one wheel

When rough operating conditions have to be considered, the static load K is increased by 20 per cent.

The effect of the camber angle (in Fig. 1, the angle of the line I-II with the horizontal plane) may usually be ignored, as well as the influence of the driving and rolling resistance forces, which are small compared to the vertical forced caused by gravity. However, where the camber angle is considerable the axial component of the static load K must be taken into account.

In addition to the static load it is necessary to consider other loads, both radial and axial, which are due, for instance, to road surface irregularities. The resultant bearing loads obviously depend on wheel diameter and the distance between the bearings and are taken into account by an additional force fK.

On a straight route the following radial bearing loads should thus be considered, the axial loads ignored.

$$\left.\begin{aligned} F_{rI1} &= \varepsilon_1 K + \varepsilon_2 fK \\ F_{rII1} &= (1-\varepsilon_1)K \pm \varepsilon_2 fK \end{aligned}\right\} \qquad 2.1$$

Indexes I and II denote the inner and outer bearing respectively and with reference to Fig. 1, $\varepsilon_1 = a/l$ and $\varepsilon_2 = R_H/l$. In the second equation the plus sign applies when $\varepsilon_1 < 1$ and the minus sign when $\varepsilon_1 > 1$. The value recommended for the coefficient f is 0.05 for private cars and commercial vehicles.

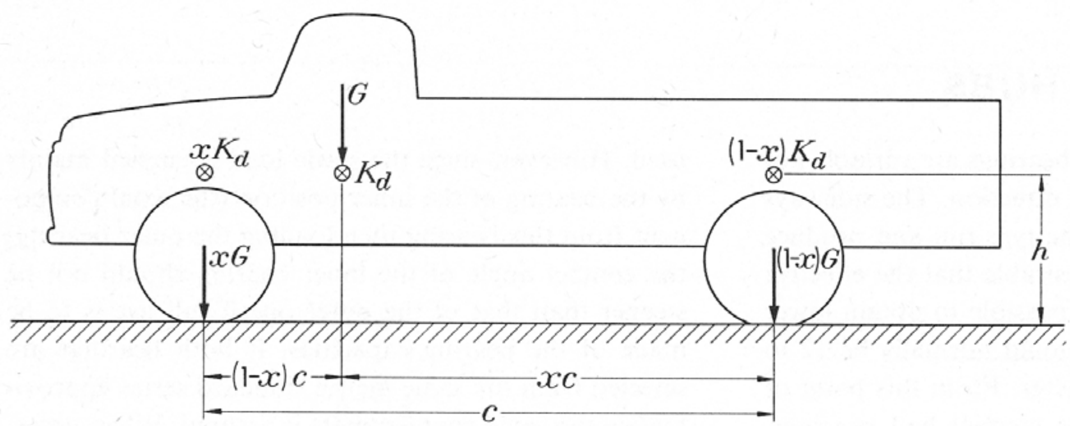

Fig. 2a Effect of gravity and centrifugal force on a motor vehicle

When cornering a centrifugal force K_d kg acts at the centre of gravity of the vehicle; see Fig. 2a. Its magnitude is obtained from

$$\frac{K_d}{G} = \frac{1}{127} \times \frac{v^2}{r}$$

where:

G is the maximum weight of the vehicle less the weight of the wheel, kg

v is the speed of the vehicle in km/h

r is the radius of the curve in the road, m

Fig. 2a also shows the effect the forces G and K_d have on the front and rear wheels.

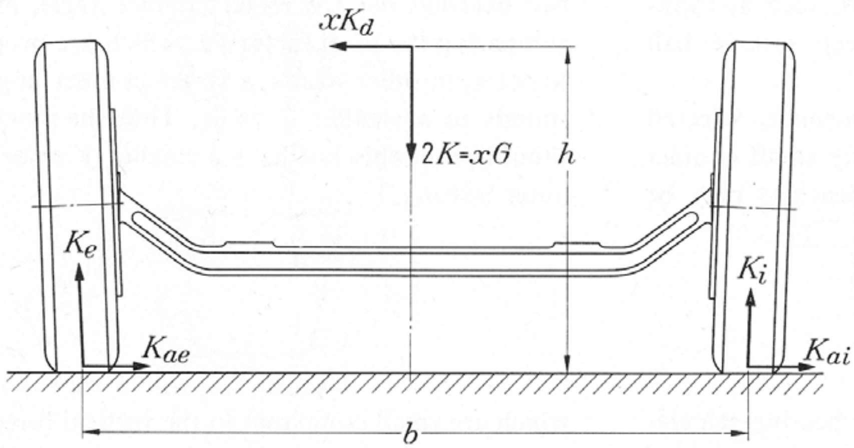

Fig. 2b Load diagram for a pair of wheel when negotiating a right-hand curve

The forces on the front wheel and distances referred to below are given in Fig. 2b. Equilibrium is obtained when

$$\left.\begin{aligned} K_e &= (1+2\tfrac{h}{b}\tfrac{K_d}{G)})K \\ K_i &= (1-2\tfrac{h}{b}\tfrac{K_d}{G})K \\ K_{ae} + K_{ai} &= xK_d \end{aligned}\right\} \qquad 2.2$$

When the vehicle is about to overturn, the forces K_i and K_{ai} on the inside wheel are zero, which gives $K_e = 2K$, and, since $K = \frac{xG}{2}$ then $K_{ae} = \frac{b}{h} K$

Equation 2.2 may also be applied to the rear wheels if factor x is replaced by (1 – x).

If conditions of friction are assumed to be the same for the outside and the inside wheel the axial forces will be

$$\left.\begin{aligned} K_{ae} &= \frac{K_d}{G}(1 + 2\frac{h}{b}\frac{K_d}{G})K \\ K_{ai} &= \frac{K_d}{G}(1 - 2\frac{h}{b}\frac{K_d}{G})K \end{aligned}\right\} \qquad 2.3$$

Using the radial and axial forces obtained in Equation 2.2 and 2.3 the bearing loads when negotiating corners can be calculated as follows. For the outside wheel hub bearings

$$\left.\begin{aligned} F_{rI2} &= \varepsilon_1 K_e + \varepsilon_2 K_{ae} \\ F_{rII2} &= (1-\varepsilon_1) K_e - \varepsilon_2 K_{ae} \\ K_a &= K_{ae} \end{aligned}\right\} \qquad 2.4$$

Where K_{ae} (direction I-II, case 2b or 2c, from 'Axial loading of taper roller bearings' table in taper bearing section of SKF General Catalogue.

For the inside wheel hub bearing

$$\left.\begin{aligned} F_{rI3} &= \varepsilon_1 K_i - \varepsilon_2 K_{ai} \\ F_{rII3} &= (1-\varepsilon_1) K_i + \varepsilon_2 K_{ai} \\ K_a &= K_{ai} \end{aligned}\right\} \qquad 2.5$$

Where K_{ai} (direction II-I, case 1b or 1c, from 'Axial loading of taper roller bearings' table in taper bearing section of SKF General Catalogue.

Normally it is assumed the Kd/G = 0,25, which applies when for instance driving at a speed of 40 km/h round a curve having a radius of 50 m or at 20 km/h round a curve having a radius of 12 m. If, in addition, h/b = 0,5 Equations 2.2 and 2.3 give

$$\left.\begin{aligned} K_e &= 1.25K \\ K_i &= 0.75K \\ K_{ae} &= 0.31K \\ K_{ai} &= 0.19K \end{aligned}\right\} \qquad 2.6$$

The equivalent bearing loads for bearing I when driving straight ahead (P_{I1}), round a left-hand curve (P_{I2}) and round a right-hand curve (P_{I3}) are used to determine the mean equivalent load P_{Im}. If it is assumed that 90 per cent of the route is straight, 5 per cent curved to the left and 5 percent curved to the right, therefore

$$P_{Im} = \sqrt[3]{0.90 P_{I1}^3 + 0.05 P_{I2}^3 + 0.05 P_{I3}^3} \; [N] \qquad 2.7$$

For bearing II the loads are calculated similarly.

Finally, if the rolling radius of the wheels is R_H mm, the bearing life will be

$$L_s = 2\pi R_H (\tfrac{C}{P})^p [km] \qquad 2.8$$

This simplified wheel calculation is offered as a guide for bearing selection. SKF employ advanced calculation programs to more accurately determine bearing life and performance.

Example 1

A truck front wheel hub using a pair of taper roller bearings:-

Inboard, 32310: C_I=161000N, e_I=0.35, X_I=0.4, Y_I=1.7

Outboard, 32307: C_{II}=89700N, e_{II}=0.31, X_{II}=0.4, Y_{II}=1.9

Static hub load, K = 20000N

Wheel radius, R_H = 400mm

Distance between pressure centres, l = 100mm

Load line, a = 90mm (from outboard pressure centre towards car centre)

Thus $\varepsilon_1 = \frac{a}{l} = 0.9$ & $\varepsilon_2 = \frac{R_H}{l} = 4$

Assuming $\frac{K_d}{G} = 0.25$ & $\frac{h}{b} = 0.5$

Calculate the lives of the bearings.

When driving straight ahead - Equation 2.1 gives

$$F_{rI1} = (0.9 \times 20000) + (4 \times 0.05 \times 20000) = 22000N$$
$$F_{rII1} = ((1 - 0.9)20000) + (4 \times 0.05 \times 20000) = 6000N$$

Referring to 'Axial loading of taper roller bearings' table from the General Catalogue, $\frac{F_{rI1}}{Y_I} > \frac{F_{rII1}}{Y_{II}}$ and $K_a = 0$ therefore case 1a applies, so the internal axial load becomes

$$F_{aI1} = \frac{0.5F_{rI1}}{Y_I} = \frac{0.05 \times 22000}{1.7} = 6470N = F_{aII1}$$

Hence $$\frac{F_{aI1}}{F_{rI1}} = \frac{6470}{22000} = 0.29 \ (< e_I)$$

and $$\frac{F_{aII1}}{F_{rII1}} = \frac{6470}{6000} = 1.08 \ (> e_{II})$$

The equivalent bearing loads become

$$P_{I1} = F_{rI1} = 22000N$$
$$P_{II1} = X_{II}F_{rII1} + Y_{II}F_{aII1} = (0.4 \times 6000) + (1.9 \times 6470) = 14690N$$

When cornering - outside wheel - Equation 2.6 gives

$$K_e = 1.25 \times 20000 = 25000N$$

$$K_{ae} = 0.31 \times 20000 = 6250N$$

From Equations 2.4

$$F_{rI2} = 0.9 \times 25000 + 4 \times 6250 = 47500N$$

$$F_{rII2} = (1 - 0.9) \times 25000 - 4 \times 6250 = (-)22500N$$

Referring to 'Axial loading of taper roller bearings' table from the General Catalogue, case 2c applies since

$$\frac{F_{rI2}}{Y_I} > \frac{F_{rII2}}{Y_{II}} \text{ and } 0.5\left(\frac{F_{rI2}}{Y_I} - \frac{F_{rII2}}{Y_{II}}\right) = 8050 > K_{ae}$$

Consequently

$$F_{aI2} = \frac{0.5 \times F_{rI2}}{Y_I} = \frac{0.5 \times 47500}{1.7} = 13970N$$

$$F_{aII2} = F_{aI2} - K_{ae} = 13970 - 6250 = 7720N$$

Hence $\frac{F_{aI2}}{F_{rI2}} = \frac{13970}{47500} = 0.29 \ (< e_I)$

and $\frac{F_{aII2}}{F_{rII2}} = \frac{7720}{22500} = 0.34 \ (> e_{II})$

The following equivalent loads are obtained

$$P_{I2} = F_{rI2} = 47500N$$

$$P_{II2} = X_{II}F_{rII2} + Y_{II}F_{aII2} = (0.4 \times 22500) + (1.9 \times 7720) = 23670N$$

When cornering - inside wheel - Equation 2.6 gives

$$K_i = 0.75 \times 20000 = 15000N$$

$$K_{ai} = 0.19 \times 20000 = 3750N$$

From Equations 2.5

$$F_{rI3} = 0.9 \times 15000 + 4 \times 3750 = (-)1500N$$

$$F_{rII3} = (1 - 0.9) \times 15000 - 4 \times 3750 = 16500N$$

Referring to 'Axial loading of taper roller bearings' table from the General Catalogue, case 1c applies since

$$\frac{F_{rII3}}{Y_{II}} > \frac{F_{rI3}}{Y_I} \text{ and } 0.5\left(\frac{F_{rII3}}{Y_{II}} - \frac{F_{rI3}}{Y_I}\right) = 3900 > K_{ai}$$

Consequently

$$F_{aII3} = \frac{0.5 \times F_{rII3}}{Y_{II}} = \frac{0.5 \times 16500}{1.9} = 4340N$$

$$F_{aI3} = F_{aII3} - K_{ai} = 4340 - 3750 = 590N$$

Hence $\frac{F_{aI3}}{F_{rI3}} = \frac{590}{1500} = 0.39 \ (> e_I)$

and $\frac{F_{aII3}}{F_{rII3}} = \frac{4340}{16500} = 0.26 \ (< e_{II})$

The following equivalent loads are obtained

$$P_{I3} = X_{II} F_{rI3} + Y_{II} F_{aI3} = (0.4 \times 1500) + (1.7 \times 590) = 1600N$$

$$P_{II3} = F_{rII3} = 16500N$$

Summary of equivalent dynamic loads in N

	Inboard Brg I	Outboard Brg II
Straight ahead driving	22000	14690
Cornering, Outer Wheel	47500	23670
Cornering, Inner Wheel	1600	16500

The mean equivalent bearing load is determined using equation 2.7

$$P_{\mathrm{Im}} = \sqrt[3]{0.9 \times 22000^3 + 0.05 \times 47500^3 + 0.05 \times 1600^3} = 25090N$$

$$P_{I\,\mathrm{Im}} = \sqrt[3]{0.9 \times 14690^3 + 0.05 \times 23670^3 + 0.05 \times 16500^3} = 15590N$$

The corresponding bearing lives are

$$L_I = \pi 2 R_H \left(\frac{C_I}{P_{\mathrm{Im}}} \right)^{\frac{10}{3}} = \pi 2 \times 400 \left(\frac{161000}{25090} \right)^{\frac{10}{3}} = 1{,}234{,}000 Km$$

$$L_{II} = \pi 2 R_H \left(\frac{C_{II}}{P_{I\,\mathrm{Im}}} \right)^{\frac{10}{3}} = \pi 2 \times 400 \left(\frac{89700}{15590} \right)^{\frac{10}{3}} = 858{,}000 Km$$

Example 2

A single seater racer car uses a double row angular contact bearing (HBU1). This will be treated as 2 separate rows with the following data:-

Designation BA2B 633816

C_I and C_{II} rating = 27600 per row (44900N per unit)

e_I, e_{II} = 0.86, X_I, X_{II} = 0.38, Y_I, Y_{II} = 0.72

Static hub, K = 800N

Wheel radius, R_H = 250mm

Distance between pressure centres, l = 51mm

Load line, a = 27mm (from outboard pressure centre towards car centre)

Distance from road to vehicle centre of gravity, h = 300mm

Track distance, b = 1800mm

Thus $\varepsilon_1 = \frac{a}{l} = 0.53$, $\varepsilon_2 = \frac{R_H}{l} = 4.9$ & $\frac{h}{b} = 0.167$

Assuming $\frac{K_d}{G} = 0.25$

Calculate the lives of the bearings.

When driving straight ahead - Equation 2.1 gives

$$F_{rI1} = (0.53 \times 800) + (4.9 \times 0.05 \times 800) = 620N$$

$$F_{rII1} = ((1 - 0.53)800) + (4.9 \times 0.05 \times 800) = 572N$$

Referring to 'Axial loading of single row angular contact ball bearings' table from the General Catalogue, $F_{rI1} > F_{rII1}$ and $K_a = 0$ therefore case 1a applies and the internal axial load becomes

$$F_{aI1} = e_I \times F_{rI1} = 0.86 \times 620 = 533N = F_{aII1}$$

Hence $\frac{F_{aI1}}{F_{rI1}} = \frac{533}{620} = 0.86 \ (= e_I)$

and $\frac{F_{aII}}{F_{rII1}} = \frac{533}{572} = 0.93 \ (> e_{II})$

The equivalent bearing loads become

$$P_{I1} = F_{rI1} = 620N$$

$$P_{II1} = X_{II} F_{rII1} + Y_{II} F_{aII1} = (0.38 \times 572) + (0.72 \times 533) = 601N$$

When cornering - outside wheel - Equation 2.2 and 2.3 gives

$$K_e = (1 + (2 \times 0.167 \times 0.25))800 = 867N$$

$$K_{ae} = 0.25(1 + (2 \times 0.167 \times 0.25))800 = 217N$$

From Equations 2.4

$$F_{rI2} = 0.53 \times 867 + 4.9 \times 217 = 1523N$$

$$F_{rII2} = (1 - 0.53) \times 867 - 4.9 \times 217 = (-)656N$$

Referring to 'Axial loading of single row angular contact ball bearings' table from the General Catalogue, case 2c applies since

$F_{rI2} > F_{rII2}$ and $0.86(F_{rI2} - F_{rII2}) = 746 > K_{ae}$

Consequently

$$F_{aI2} = e_I \times F_{rI2} = 0.86 \times 1523 = 1310N$$

$$F_{aII2} = F_{aI2} - K_{ae} = 1310 - 217 = 1093N$$

Hence $\frac{F_{aI2}}{F_{rI2}} = \frac{1310}{1523} = 0.86 \ (= e_I)$

and $\frac{F_{aII2}}{F_{rII2}} = \frac{1093}{656} = 1.66 \ (> e_{II})$

The following equivalent loads are obtained

$$P_{I2} = F_{rI2} = 1523N$$

$$P_{II2} = X_{II} F_{rII2} + Y_{II} F_{aII2} = (0.38 \times 656) + (0.72 \times 1093) = 1036N$$

When cornering - inside wheel - Equation 2.2 and 2.3 gives

$$K_i = (1-(2\times 0.167\times 0.25))800 = 733N$$
$$K_{ai} = 0.25(1-(2\times 0.167\times 0.25))800 = 183N$$

From Equations 2.5

$$F_{rI3} = 0.53\times 733 - 4.9\times 183 = (-)508N$$
$$F_{rII3} = (1-0.53)\times 733 + 4.9\times 183 = 1241N$$

Referring to 'Axial loading of single row angular contact ball bearings' table from the General Catalogue, case 1c applies since

$F_{rII3} > F_{rI3}$ and $0.86\left(F_{rII3} - F_{rI3}\right) = 630 > K_{ai}$

Consequently

$$F_{aII3} = e_{II}\times F_{rII3} = 0.86\times 1241 = 1067N$$
$$F_{aI3} = F_{aII3} - K_{ai} = 1067 - 183 = 884N$$

Hence $\quad \dfrac{F_{aI3}}{F_{rI3}} = \dfrac{884}{508} = 1.74\ (> e_I)$

and $\quad \dfrac{F_{aII3}}{F_{rII3}} = \dfrac{1067}{1241} = 0.86\ (= e_{II})$

The following equivalent loads are obtained

$$P_{I3} = X_{II}F_{rI3} + Y_{II}F_{aI3} = (0.38\times 508) + (0.72\times 884) = 830N$$
$$P_{II3} = F_{rII3} = 1214N$$

Summary of equivalent dynamic loads in N

	Inboard Brg I	Outboard Brg II
Straight ahead driving	620	601
Cornering, Outer Wheel	1523	1036
Cornering, Inner Wheel	830	1214

The mean equivalent bearing load is determined using equation 2.7

$$P_{\mathrm{Im}} = \sqrt[3]{0.9\times 620^3 + 0.05\times 1523^3 + 0.05\times 830^3} = 749N$$
$$P_{I\,\mathrm{Im}} = \sqrt[3]{0.9\times 601^3 + 0.05\times 1036^3 + 0.05\times 1214^3} = 703N$$

The corresponding bearing lives are

$$L_I = \pi 2 R_H \left(\frac{C_I}{P_{\mathrm{Im}}} \right)^3 = \pi 2 \times 250 \left(\frac{27600}{749} \right)^3 = 78{,}685{,}000 Km$$

$$L_{II} = \pi 2 R_H \left(\frac{C_{II}}{P_{I\,\mathrm{Im}}} \right)^3 = \pi 2 \times 250 \left(\frac{27600}{703} \right)^3 = 95{,}302{,}000 Km$$

Please contact the Racing Unit for more information: racing@skf.com.