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Torque loss model for axially pre-loaded tandem rolling element bearings

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A new torque loss model for tandem Tapered Roller Bearings (TRB) is derived from the loads and torques applied to each rolling element, following the rolling element model proposed by Houpert [3]. The most important novelty of this approach is to consider the static torque, used in the tandem assembly, as an input parameter for the model, instead of the axial pre-load. The comparison of the predictions of the model with experimental measurements in tandem rolling bearings, shows an excellent correlation, explained by the accuracy of the static torque used to assemble the bearings and its relevance for the bearing operation.

Keywords: Rolling bearings, static torque, torque loss.

1. Introduction

Rolling element bearings (REBs) assembled in tandem, either in “X“ and “O” arrangement, are a common design solution for mechanical systems [1, 2], for instance in automotive gear mechanical transmissions.

A common feature of this tandem design is that the rolling element bearings are always assembled with a significant axial pre-load, which assures the proper operation of the system.

One of the consequences of the axial pre-load is that it generates a static torque applied to the REB assembly. In fact, the highest is the static torque the highest will be the power loss generated by the tandem REBs. Figure 1. shows the torque loss measured in a tandem assembly of a pinion shaft, in the differential of a passenger car [1]. It is clear that, whatever the operating speed, the tandem torque loss increases when the static torque increases.

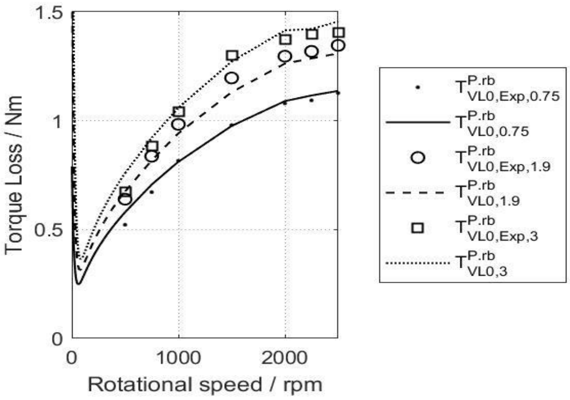

Figure 1: Torque loss in a tandem tapered roller bearing assembly in the differential of a passenger car.

2. Torque loss models

The torque loss models are be derived from the model proposed by Houpert [3] for the torque components applied to each rolling element, that is the torques due to the rolling friction force, dT_{FR}, the friction between the rolling element and the rib of the inner race, dT_{rib}, and the elastic rolling torque, dT_{MER}, due to the hysteresis losses,

$$dT = dT_{FR} + dT_{rib} + dT_{MER} \tag{1}$$

$$M = dT \cdot Z \tag{2}$$

Developing all these torque components, the overall torque applied to each tapered roller bearing becomes,

$$\begin{aligned} M = {} & 0.00825 \cdot \gamma^* \cdot \sin\alpha^* \cdot \\ & Z^{0.44} \cdot E'^{0.19} \cdot dm^{1.63} \cdot l^{0.63} \cdot (\eta \cdot \omega_i)^{0.44} \cdot F_a^{0.37} \\ & +0.424 \cdot B \cdot f \cdot Z \cdot \sin\alpha^* \cdot \phi_{rib} \cdot \mu_a \cdot F_a \\ & +0.424 \cdot B \cdot f \cdot Z \cdot \sin\alpha^* \cdot (1-\phi_{rib}) \cdot \mu_{oil} \cdot F_a \\ & +0.001912 \cdot \sin\alpha^* \cdot dm \cdot \phi_{mer} \cdot \mu_a \cdot F_a \end{aligned} \tag{3}$$

From equation (3) it is possible to define the starting torque, M_{st}, of the tandem TRBs, defined as

$$M_{st} = (K_1 \cdot \sin\alpha_1^* \cdot dm_1 + K_2 \cdot \sin\alpha_2^* \cdot dm_2) \cdot \mu_{bl} \cdot F_a$$

$$K_i' = C \cdot \frac{B_i \cdot f_i \cdot Z_i}{dm_i} \text{ and } K_i = (K_i' + D), i = 1,2 \tag{4, 5}$$

Applying equation (3) it to the tandem TRBs and replacing equations (4) and (5) in (3), the overall torque becomes,

$$M_{tandem}^{TRB} = (1-\phi) \cdot \frac{\mu_{EHD}}{\mu_{bl}} \cdot A \cdot M_{st} \tag{6}$$

$$+0.00825 \cdot B \cdot E'^{0.19} \cdot (\eta \cdot \omega_i)^{0.44} \cdot M_{st}^{0.37},$$

where A and B are defined as,

$$A = \frac{K_1' \cdot \sin\alpha_1^* \cdot dm_1 + K_2' \cdot \sin\alpha_2^* \cdot dm_2}{K_1 \cdot \sin\alpha_1^* \cdot dm_1 + K_2 \cdot \sin\alpha_2^* \cdot dm_2} \tag{7,8}$$

$$B = \cdot \frac{\gamma_1^* \cdot \sin\alpha_1^* \cdot Z_1^{0.44} \cdot dm_1^{1.63} \cdot l_1^{0.63} + \gamma_2^* \cdot \sin\alpha_2^* \cdot Z_2^{0.44} \cdot dm_2^{1.63} \cdot l_2^{0.63}}{[(K_1 \cdot \sin\alpha_1^* \cdot dm_1 + K_2 \cdot \sin\alpha_2^* \cdot dm_2) \cdot \mu_{bl}]^{0.37}}$$

The correlation between the experimental measurements and the predictions of equation (6) is excellent (see Figure 1). Such excellent agreement relies on the fact that the starting torque, M_{st}, as shows equation (5), includes crucial information about the tandem TRB axial load, geometry, contact angle and the rolling element / rib coefficient of friction.A similar equation can developed for tandem Angular Contact Ball Bearings.

3. References

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