# On the Ball Speed Variation Phenomenon

In general, although many bearings operating at high speeds are mainly subjected to a predominant axial load, it cannot be excluded that a parasitic radial force or a misalignment torque come into play.

Cases in point are legion. For example, a pump impeller of a high-speed cryogenic turbo-pump cannot have a perfectly equitable distribution of pressure on the periphery of its volute. It is therefore likely to endure a significant radial force, in addition to the axial component. In the same vein, even if the bearings of spindles of machine tools are mounted with an axial preload, a significant radial load induced by the use of the device could lead to an asymmetry in the loading of the bearings.

This asymmetric loading, i.e. when the presence of a radial force or a misalignment torque is denoted, is not without consequence on the operation of the bearing. The kinematics of each ball is actually disrupted. Thus, by looking at what happens on the average radius of the bearing, on the path taken by the balls, it can be seen that the balls do not move at constant speed around the bearing. This phenomenon is called **ball speed variation**.

The appearance of ball speed variation is not without consequence; the bearings that are subjected to it see their lifespan suddenly shortened with, sometimes, dramatic consequences as a result. Sketching the outlines is therefore a necessity, in order to prevent any potential disastrous failure.

**Understand the phenomenon**

To try to explain the physics of the ball speed variation, it seems useful to examine the situation of the balls within the bearing.

Let's first imagine a bearing that is preloaded in the axial direction, as used in many assemblies. Such conditions imply a symmetrical distribution of the balls around the axis of the bearing. This configuration is shown in Fig. 1, by means of a cross-section of the bearing. As announced, the contact angles $\phi_1$ and $\phi_2$ of two diametrically opposed balls are equal. Direct consequence: if the bearing rotates, the self rotational speeds $\omega_1$ and $\omega_2$ of the balls are equal. So the balls rotate at the same speed around the axis of the bearing.

What happens if a misalignment torque is superimposed on this axial preload? In this case, the balls deviate from their initial symmetry and their contact angle changes according to their position on the circumference of the bearing. Fig. 2 indeed shows that the two diametrically opposed balls now have very different contact angles $\phi_1$ and $\phi_2$. However, if these angles differ, the kinematics of the two balls represented can no longer remain identical. Conclusion: the balls no longer rotate at a constant speed around the axis of the bearing. This is the so-called **ball speed variation**.

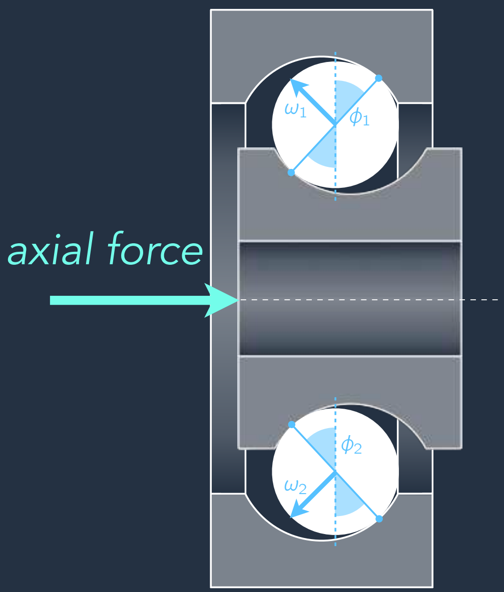


Fig. 1 – Symmetric loading

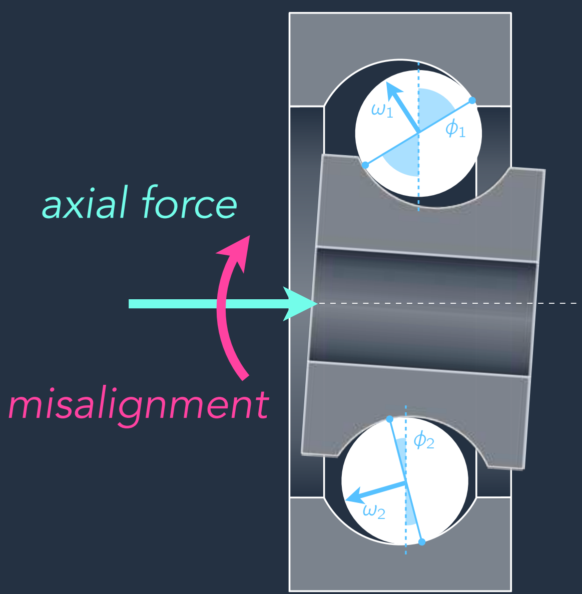


Fig. 2 – Asymmetric loading

**Where is the problem?**

The speed of the balls varies over the entire periphery of the bearing. But, in the end, is it so worrying? After all, the bearing is an object of revolution. From then on, all the balls end up going through the same states, slightly out of phase with each other.

In what way could these marginal disturbances constitute a subject of concern?

To understand it, we need to follow a ball in a bearing that is loaded with a combined load and compare its bumpy path to its symmetrical counterpart. Fig. 3 shows the different phases of a complete rotation of two balls around the axis of the bearing. The white ball moves at a constant speed (symmetrical load case) while the colored ball has its speed that fluctuates (asymmetrical load case). Suppose that the two balls start at the same time from the top (1) and that the colored ball has a higher initial speed (2). It is first caught up with the white ball (3), then overtaken by the

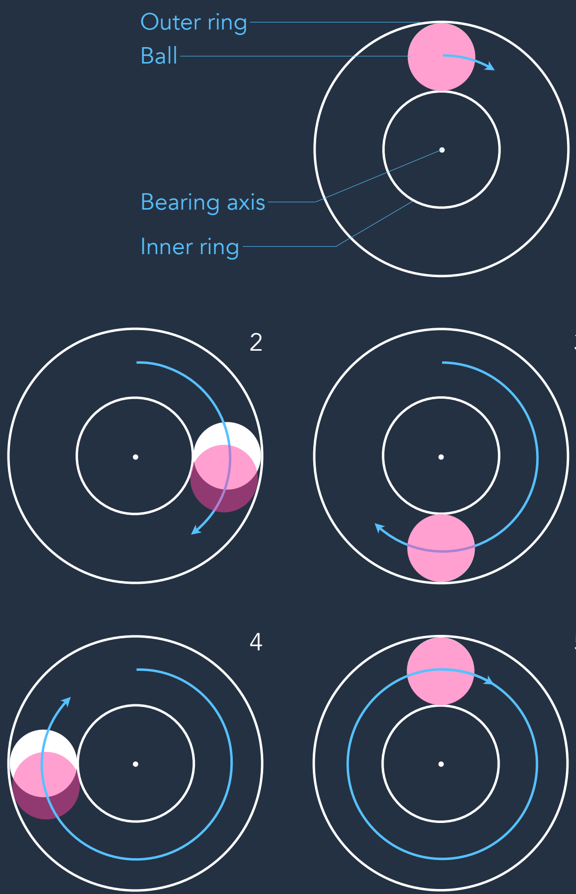


Fig. 3 – Motion of a ball, comparison between symmetric and asymmetric loadings

latter (4), before joining it in turn at the end of the cycle (5). Indeed, since the two bearings move at the same rotational frequency, the average displacement of the colored ball must equal that of the white ball.

**OK. But there is still no problem!**

The balls seem to adapt naturally and without any apparent major constraint to the loads, even if they are asymmetrical. But what about the cage?

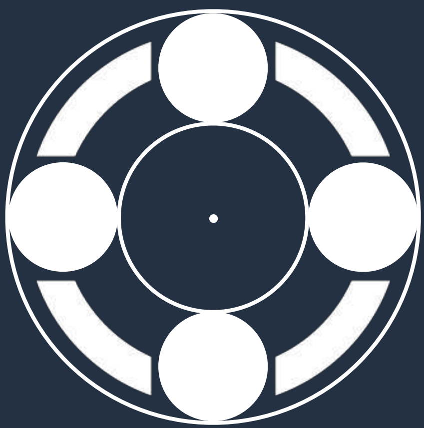

Fig. 4 - Cage of a symmetrically loaded bearing

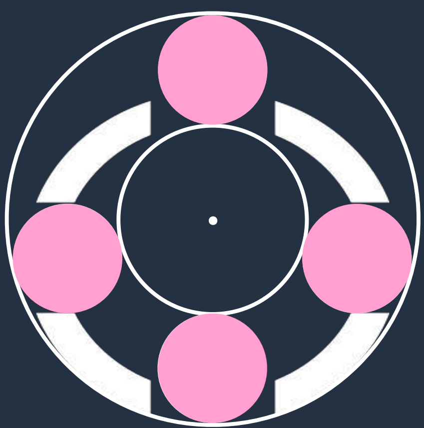

Fig. 5 - Cage of an asymmetrically loaded bearing

The symmetric load case does not affect the cage in any way. If the cage is correctly designed, it evolves freely between the balls and the rings of the bearing. Fig. 4 illustrates this for a simplified bearing comprising four balls. On the other hand, the kinematics imposed on the balls in the case of a combined loading singularly changes the situation. In fact, the clearances of the cage are quickly taken up, so that the balls compress the separator against the guiding ring, as shown in Fig. 5 for this same bearing of four balls. However, no separator can withstand the terrible constraints induced by the phenomenon.

APO-GEE has developed a new ball bearing adapted to difficult load conditions: the COBWEB bearing. Its objective is to counteract the effects of misalignment and to offer an alternative to existing products. Thus, this new bearing is able to accommodate a combination of axial and radial loads, just like deep groove and angular contact bearings, while improving the tolerable misalignment. The key lies in its ability to smooth the movement of the balls, which drastically reduces contact angle variations all around the bearing.

Christophe Servais
CTO APO-GEE