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MATHEMATICAL MODEL TO SIMULATE AXIAL STIFFNESS IN AXIAL PRELOADED SLEWING RINGS WITH DUPLEX RINGS UNDER AXIAL LOAD

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ABSTRACT

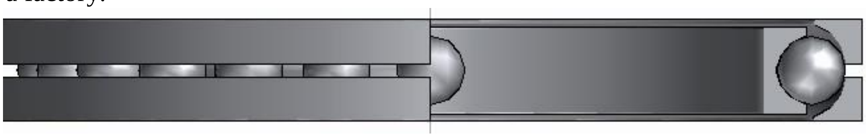
There are many cases when the large dimensions slewing rings have to assure an initial preload or a small negative clearance. In this case a useful solution is to create and control the preload using a "preload gap" between the duplexes races. In this paper, an external ring from a slewing ring is machined from 2 distinct parts as a sum of a duplex rings.

Keywords: slewing rings, preload gap, quasi static analysis, axial stiffness, duplex rings, axial preload, negative clearance

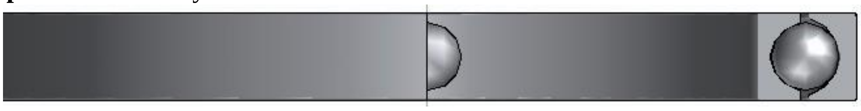
1. STEPS FOR CONTROLLING THE PRELOAD GAP IN SLEWING RINGS

To obtain an axial preload or a small negative clearance in slewing rings, the following steps are necessary:

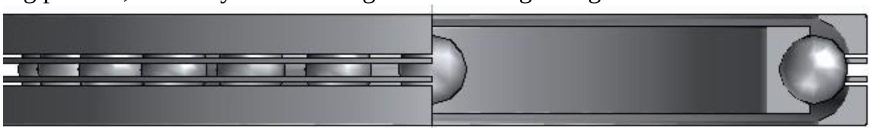
Step 1. A duplex outer ring from a slewing ring has to be assembled on the mounting mass in a factory.



Step 2. It is necessary to measure the the radial clearance.



Step 3. Compute the unnecessary material height that have to be removed by a grinding process, from any external ring or from a single ring



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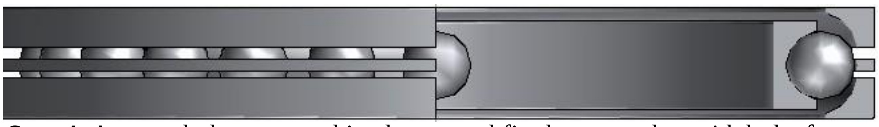
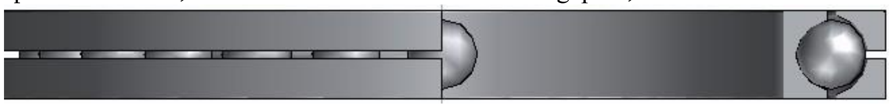
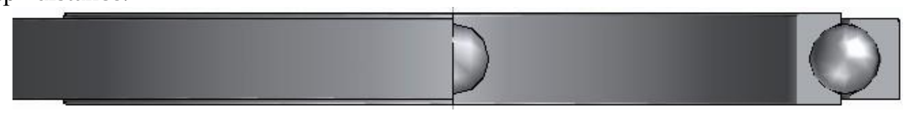


Step 4. Approach the two machined parts and fix them together with bolts for example. In this case, a small interstitial distance – “the gap” –, can result.



Step 5. The maximum approach position resulted as complete elimination of the “gap” distance.



2. MATHEMATICAL MODELISATION

For a four point contact angle slewing rings the initial position of the curvature center mass and the ball center can be described as an SSRB-4PCBB structure in an IOE case [1]. The geometric center of raceways is presented in Fig. 1, where: O1 and O2 are the curvature centers of the inner ring and O3 and O4 are the curvature centers of the outer raceways.

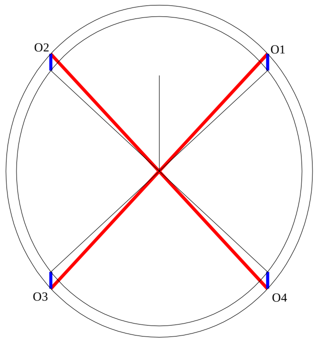


Fig. 1. Initial position of curvature center corresponding to raceways

In this case, some specific elements are defined as:

$$Loi = Dw \cdot (f_i - 0.5) \tag{1}$$

$$Loe = Dw \cdot (f_e - 0.5) \tag{2}$$

where Dw represents the ball diameter, f_i and f_e are the ring conformities of the raceways, ui and ue are the shim angles [2] of the raceways.

A Duplex External Ring Preloaded Example

In the case, when two separate external rings are used to eliminate axial and radial play, named Jd, the two rings have to be displaced with a “depl” value.

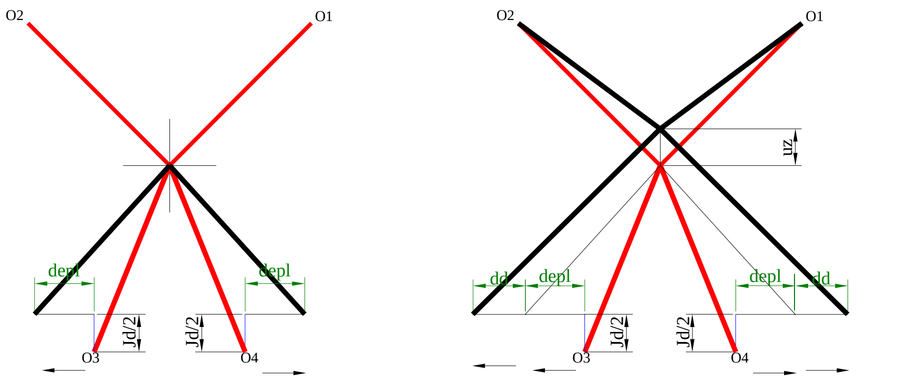


Fig. 2. Geometric parameters used to describe the process elimination of the radial and axial play

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In the mathematical formulation, O3 and O4 points have to be translated and, at the same time, O1 and O2 must remain in the initial position. The “depl” distance is a function expressed as depl=depl(fe,ue,Dw, Jd) and its maximum value assures a zero load contact value. A supplementary value “dd” assures a contact load greater than zero. In this case, a small displacement “uz” occurs. In this case, uz is a function of uz=uz(fi,fe,ui,ue,depl(..,Jd),Dw). The arrows indicate the direction of displacements “depl” and “dd”.

Figure 3 represents a schematic view of the “depl” and “dd” distances that have to be removed from a complete external ring to eliminate radial and axial play or to assure a small negative clearance.

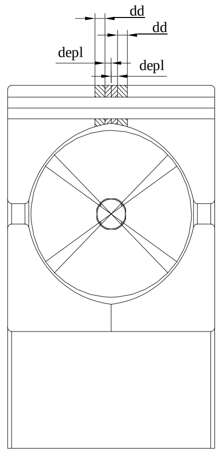

Fig. 3. “depl” and “dd” parameters in initial external complete ring

When an axial displacement “DAX” is superimposed on the outer or inner complete ring, which is equivalent to an external axial load “FA”, where FA=FA(DAX), O1 and O2 points are displaced if the inner ring is displaced or O3 and O4 are displaced if the outer ring is displaced. In all these cases, there are two displacements of the ball center mass in axial direction with “ux” value and, in radial direction, with “uz” value. All these displacements are presented in Fig. 4.

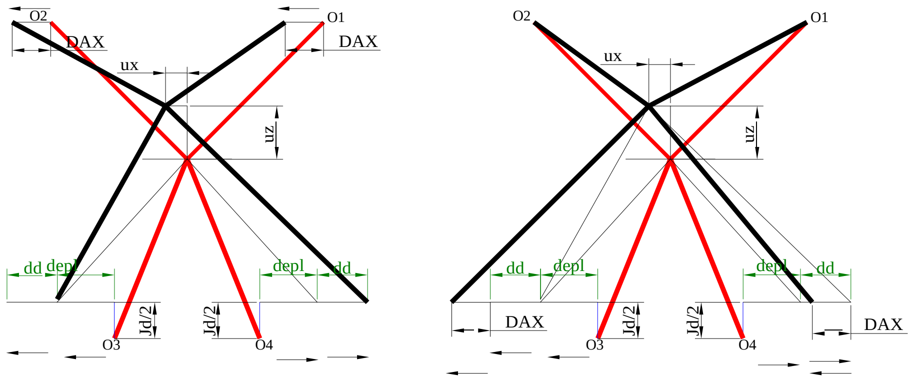

Fig. 4. Geometric parameters used to describe the effect of relative ring displacement

3. MATHEMATICAL MODEL FOR EXTERNAL OR INTERNAL DUPLEX RING PRELOADED

In order to describe the preload consequence in the quasi-static parameters, some vectors are used, according to Table 1.

The load distribution in the “Q(idx)” contact is considered as a Hertz contact, where “idx” is the contact index, k(idx) represents the contact stiffness corresponding to “idx” and $Q(idx)=k(idx).\delta(idx)^{1.5}$ [2, 3].

In order to compute the quasi-static effect, the following functions are used:

$$L_{idx} = Dw \cdot \left(f_{idx} - 0.5\right) \tag{3}$$

$$LS_{idx} = L_{idx} \cdot \sin\left(\alpha_{idx}\right),\; LC_{idx} = L_{idx} \cdot \cos\left(\alpha_{idx}\right) \text{ and } Jd2 = jd / 2\,. \tag{4}$$

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Table 1. Vector components for ORR case (outer ring rigid)

Parameters and function used to describe the mathematical model for ORR case [1]								Preload in		CU components vector as a function of the resulted geometry		
								outer ring	inner ring			
idx	α	f	sdx	sdz	sduz	sdux	sign	Pr	Pr	CU	CU	CU
1	ui	fi	1	1	1	1	-1	0	1	1	1	1
2	ui	fi	-1	1	1	-1	-1	0	1	1	1	0
3	ue	fe	0	0	-1	-1	1	1	0	1	0	1
4	ue	fe	0	0	-1	1	1	1	0	1	1	1

If one takes into account a duplex outer ring, assuming idx=3, and if one takes into account n duplex inner ring, assuming idx=1, the following parameter may be computed:

$$depl = -LS_3 + \sqrt{LS_3^2 + LC_3 \cdot Jd - \frac{Jd^2}{4}} \quad (5)$$

$$\alpha_{3,4} = \operatorname{atan}\left[\frac{LS_3 + depl}{LC_3 - Jd/2}\right] \quad (6)$$

and $\alpha_{1,2} = ui$ remains as the initial value.

If one takes into account a duplex inner ring, assuming idx=1, the following parameter may be computed:

$$depl = -LS_1 + \sqrt{LS_1^2 + LC_1 \cdot Jd - \frac{Jd^2}{4}} \quad (7)$$

$$\alpha_{1,2} = \operatorname{atan}\left[\frac{LS_1 + depl}{LC_1 - Jd/2}\right] \quad (8)$$

and $\alpha_{3,4} = ue$ remains as the initial value

When a supplementary displacement "dd" is superimposed, a negative clearance will appear and the load distribution in the "idx" contacts will be greater than zero.

To compute the "dd" effect on the quasi-static parameter on the "idx" contact, the following functions are necessarry :

$$X(idx,dd) = L_{idx} \cdot \sin(\alpha_{idx}) + dd \cdot Pr_{idx} \quad (9)$$

$$Z(idx,uz) = L_{idx} \cdot \cos(\alpha_{idx}) + uz \cdot sduz_{idx} \quad (10)$$

$$\beta(idx,dd,uz) = \operatorname{atan}\left[\frac{X(idx,dd)}{Z(idx,uz)}\right] \cdot CU_{idx}, \quad (11)$$

$$Q(idx,dd,uz) = k_{idx} \cdot \left[\sqrt{X(idx,dd)^2 + Z(idx,uz)^2} - L_{idx}\right]^{1.5} \cdot CU_{idx} \quad (12)$$

if $\sqrt{X(idx,dd)^2 + Z(idx,uz)^2} > L_{idx}$.

Solving the following equation,

$$\sum_{idx}\left[Q(idx,dd,uz) \cdot \cos[\beta(idx,dd,uz)] \cdot sduz_{idx}\right] = 0, \quad (13)$$

"uz" results as a function uz=uz(dd,α,Pr) and also Q(idx,dd,uz) values.

With "uz" as solution, the equivalent external load as effect of "dd" displacement is given as $Fax_{eq} = Q(3, dd, uz) \cdot \sin(\beta(3, dd, uz))$

If one takes into account a duplex outer ring, $Fax_{eq} = Q(1, dd, uz) \cdot \sin(\beta(1, dd, uz))$, for duplex inner ring.

When an external axial load acts in a preloaded duplex outer ring bearing, the geometric curvature centers of the raceways and the ball mass center will be displaced according to Fig. 4. If FAX is the axial load and "depl" and "dd" exist as initial displacements and ORR case is considered, then the quasi-static parameters are computed using the following relations:

$$X(idx, dd, DAX, uz) = L_{idx} \cdot \sin(\alpha_{idx}) + dd \cdot Pr_{idx} + DAX \cdot sdz_{idx} + uz \cdot sduz_{idx} \tag{14}$$

$$Z(idx, uz) = L_{idx} \cdot \cos(\alpha_{idx}) + uz \cdot sduz_{idx} \tag{15}$$

$$\beta(idx, dd, uz, DAX, ux) = \operatorname{atan}\left[\frac{X(idx, dd, DAX, uz)}{Z(idx, uz)}\right] \cdot CU_{idx}, \tag{16}$$

$$Q(idx, dd, uz, DAX, ux) = k_{idx} \cdot \left[\sqrt{X(\ldots)^2 - Z(\ldots)^2} - L_{idx}\right]^{1} \cdot 5 \cdot CU_{idx} \tag{17}$$

if $\sqrt{X(\ldots)^2 + Z(\ldots)^2} > L_{idx}$.

Solving the following equations

$$\begin{gathered} \sum_{idx=1,2} [Q(idx, \ldots) \cdot \sin[\beta(idx, \ldots)]] = FAX \\ \sum_{idx} [Q(\ldots) \cdot \cos[\beta(\ldots)] \cdot sdux_{idx}] = 0 \\ \sum_{idx} [Q(\ldots) \sin[\beta(\ldots)] sdux_{idx}] = 0, \end{gathered} \tag{18}$$

it results the following parameters: DAX, uz, ux paramter's, where DAX is the axial displacement under the effect of the FAX axial force.

Example. The axial stifnesses under an external load was realized for a 4-point contact ball bearing with Dw=20 mm, inner and outer raceway conformity of 0.52 and inner ring shim angle of 45°. Figure 5 shows the axial displacement of the inner ring under the effect of several values of the axial load.

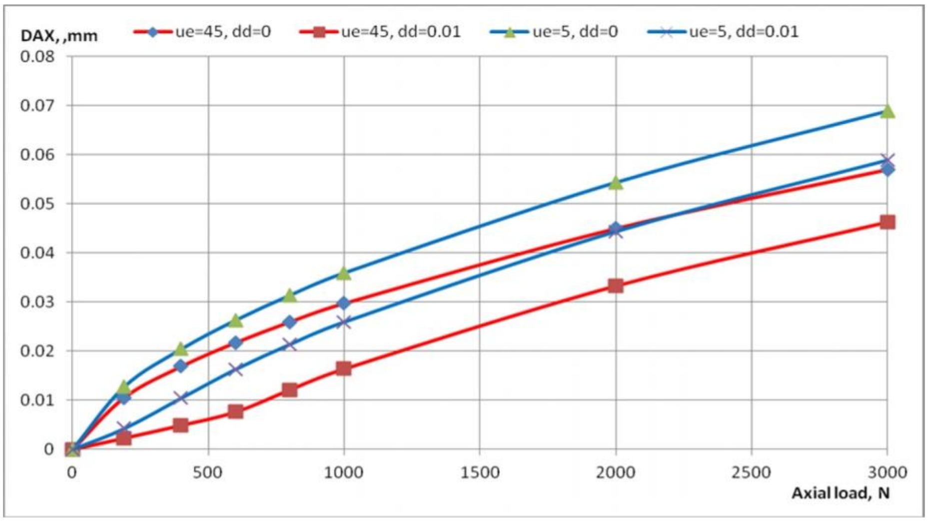

Fig. 5. Axial stifnesses as a function of the external load outer ring schim angle and "dd" parameter

In this case, the variable parameters werethe initial schim angle of the outer ring and also the initial “dd”displacement, which produce an internal negative clearance.

Figure 6 presents the “depl” parameter, useful for machining the duplex outer rings. This parameter is presented as function of the measured diametral clearance and the initial outer ring schim angle. Also, in Fig. 6, the inner ring schim angle is 45 degrees. The chart in Fig. 6 helps the slewing ring constructors to decide on the grinding depth.

The “depl” and “dd” have to be permitted by the two semi-rings displacement if they are not limited by the real geometry contact between the two semi-rings.

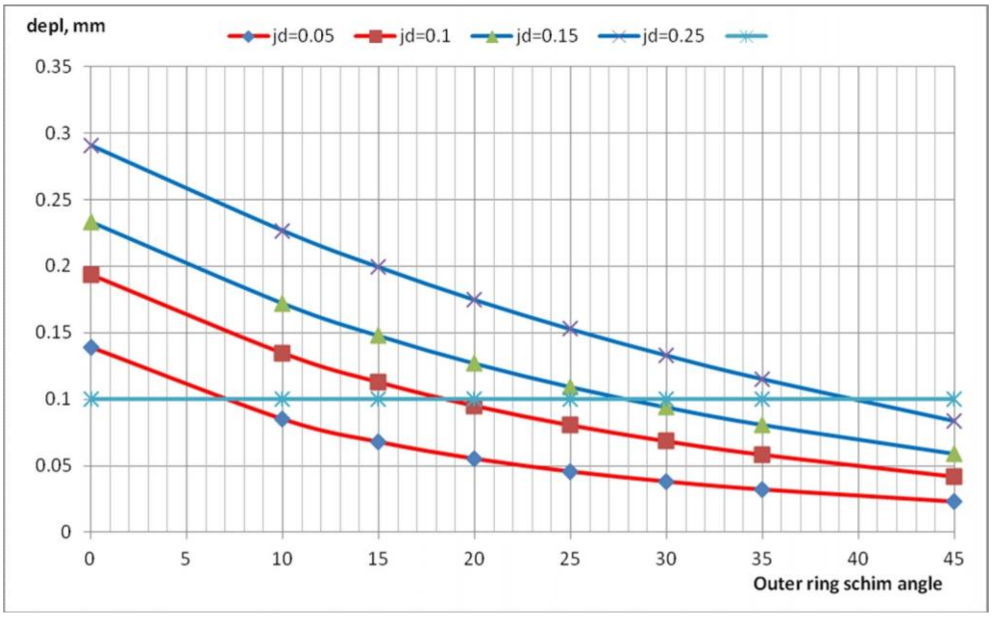

Fig. 6. The necessary grinding depth on each semi-ring, “depl”, as a function of the outer ring angle and the measured diametral clearance “Jd”

CONCLUSIONS

The preload is required in applications as wind turbine blade bearings, robotics and many others. In order to controll the pleload in slewing rings, several steps must be followed together with an attent of acurrately measuring the radial clearance in the first measurement. That analysis indicate also several internal geometric aspects concerning the initial the shim angle, the axial stiffnesses evolution and the grinding depth.

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