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EVALUATION OF THE APPLICATION OF SPHERICAL ROLLER BEARING IN FLYWHEEL USED IN BELT CONVEYORS

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Abstract. *The mining industry has presented over the years an incredible development of mechanical designs of components and equipment. Among the components, rolling bearings are elements of machines used in mining projects. These rolling bearings when they fail can cause serious accidents and equipment damage. Therefore, correct selection, monitoring and good maintenance can prevent or minimize the occurrence of failures. It has been observed that, in some cases, when spherical roller bearings are installed on the flywheel of drive belt conveyors, premature failure occurs. This work has the objective of evaluating the possible causes of these failures. In this way, two drive cases with flywheels installed in bearing housings with spherical roller bearing were studied. Thus, the calculations of all parameters required to verify the bearings analyzed were performed.*

Keywords: *belt conveyor, drive, flywheel, spherical roller bearing, failures.*

1. INTRODUCTION

Belt conveyors are equipment designed to carry any bulk material in a continuous and uniform flow (CEMA, 2007). They have particular characteristics according to their application, material transported and distances between the loading and unloading point (Fig. 1).

Figure 1. Belt conveyor

There are several possibilities for driving belt conveyors.

The Figure 2 shows some possible configurations:

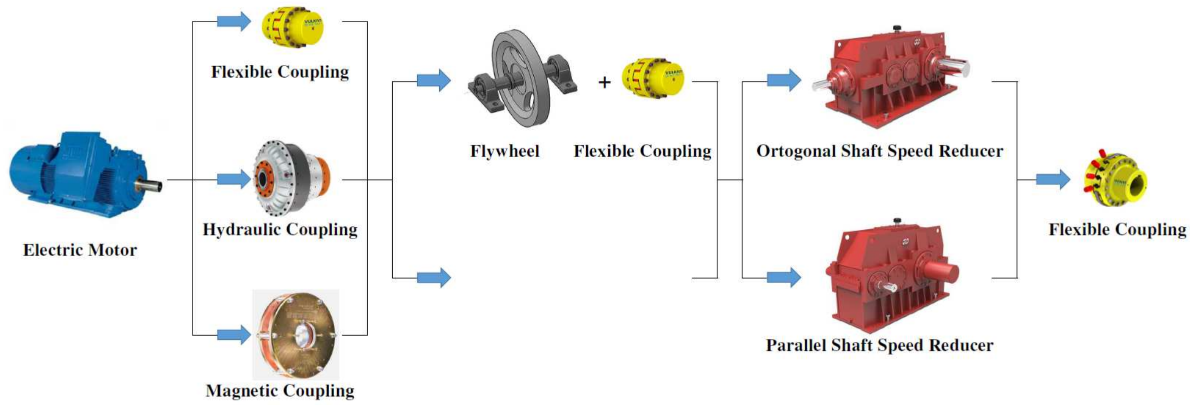


Figure 2. Possible belt conveyor drive configurations

In belt conveyor drive system, the flywheel has the function of increasing the starting and stopping time. The stopping times of conveyors installed in series must be compatible, since the moment a conveyor is switched off all the others must stop at the same time to avoid clogging of the transfer rails.

The inertia flywheel acts as a kinetic energy storage reservoir. This component, basically, is formed by a disc of steel of calculated mass, fixed to an axis that rotates in bearing housings (Collins, 2006).

The Figure 3 shows two examples of drives that have flywheels in their configurations.

Figure 3. Drives with flywheel

It has been observed that in some cases, when spherical roller bearings are installed in the flywheel, premature failure occurs. This work has the objective of evaluating the possible causes of these failures.

In this way, two cases of drives with flywheels installed in bearings with spherical roller bearing were studied. In this study, the calculations of all the parameters necessary to verify the bearings analyzed were performed.

2. METHODOLOGY

The methodology used for the development of this work was divided into two stages.

The first stage comprises the process of selection and verification of bearings. The equations presented were the basis for the evaluation of the bearings of the present work.

The second stage describes the two cases selected for study.

2.1 Selecting bearing size

The bearing selection process is performed through several factors (SKF, 2016):

- Loads (magnitude and direction);
- Available space;
- Misalignment;
- Speeds;
- Operating temperature;
- Contamination levels;
- Lubrication type and method.

First of all, in order to select a bearing type, it is indispensable to know the type of load that will be applied.
There are three types of loads in bearings (Melconian, 2009):

- Radial load - acts in the direction of the bearing radio;
- Axial load - acts in the longitudinal direction of the bearing;
- Combined load - simultaneously bearing a radial load and an axial load.

The radial bearings are generally subjected to combined loads in their applications.
The equivalent dynamic load is a constant load in intensity and direction and its application has the same effect on bearing life as an actual load.
To obtain the equivalent dynamic bearing load, the Equation (1) or Equation (2) are used:

$$P = F_r + Y_1 F_a \qquad \text{when} \qquad \frac{F_a}{F_r} \le e \tag{1}$$

or,

$$P = 0{,}67 F_r + Y_2 F_a \qquad \text{when} \qquad \frac{F_a}{F_r} > e \tag{2}$$

Where:
P – equivalent dynamic bearing load (kN)
F_r – radial load (kN)
F_a – axial load (kN)
Y_1 – calculation factor (dimensionless)
e – calculation factor (dimensionless)
Y_2 – calculation factor (dimensionless)

The values of Y_1, Y_2 and e are found in the product tables.
The Equation (3) shows the condition for bearing approval with respect to equivalent dynamic load:

$$P \le C \tag{3}$$

Where:
C – basic dynamic load rating (kN)

The basic dynamic load rating C represents the load of a bearing which results in a basic rating life of 1000000 revolutions, in accordance with ISO 281 standard. The value de C is found in the product tables.
The equivalent static bearing load charge comprises a hypothetical charge which, if applied in a bearing, will cause the same maximum load on the rolling elements as the real loads.
The Equation (4) is used to obtain the equivalent static bearing load:

$$P_0 = F_r + Y_0 F_a \tag{4}$$

Where:
P_0 – equivalent static bearing load (kN)
Y_0 – calculation factor (dimensionless)

The value of Y_0 is found in the product tables.
Similarly, The Equation (5) shows the condition for bearing approval with respect to equivalent static load:

$$P_o \le C_o \tag{5}$$

Where:
C_0 – basic static load rating (kN)

The value de C_0 is found in the product tables.

The rolling bearings always need to be loaded by a certain minimum load, primarily when operating at high speeds, or subjected to high accelerations or sudden changes in load direction.

The Equation (6) determines the minimum load value required to be applied to a spherical roller bearing:

$$P_m = 0{,}01C_0 \tag{6}$$

Where:

P_m – equivalent minimum load (kN)

The spherical roller bearings can be mounted in adapter sleeve, but the axial load inserted in these bearings needs to be checked. The Equation (7) determines this maximum permissible axial load:

$$F_{ap} = 0{,}003Bd \tag{7}$$

Where:

F_{ap} – maximum permissible axial load (kN)

B – bearing width (mm)

d – bearing bore diameter (mm)

The values of B and d are found in the product tables.

According to ISO 281 standard, the basic rating life of a bearing determines its operating time prior to the appearance of the first signs of metal fatigue in one of its rings or in the rolling elements Eq. (8):

$$L_{10} = \left(\frac{C}{P}\right)^p \tag{8}$$

Where:

L_{10} – basic rating life (at 90% reliability) (million revolutions)

p – exponent of the life equation, 10/3 for roller bearings (dimensionless)

The basic rating life can be expressed in hours of operation if the speed is constant Eq. (9):

$$L_{10h} = \frac{10^6}{60n} L_{10} \tag{9}$$

Where:

L_{10h} – basic rating life (at 90% reliability) (operating hours)

n – rotational speed (rpm)

In certain applications, modern high-quality bearings have a different basic rating life than actual service life. Since the life of a bearing depends on some factors, such as the level of contamination, lubrication, assembly accuracy and environmental conditions. In this way, ISO 281 standard presented a new formulation for the calculation of the basic rating life of bearings. It also proposed that the manufacturers themselves recommend an appropriate method of calculation for the life modification factor.

The SKF bearing manufacturer presented a modification factor based on the fatigue load limit, the lubrication conditions and the level of contamination of the lubricant. The Equation (10) expresses the formulation used by SKF:

$$L_{nm} = a_1 a_{SKF} L_{10} \tag{10}$$

Where:

L_{nm} – SKF rating life (million revolutions)

a_1 – life adjustment factor for reliability (dimensionless)

a_{SKF} – SKF life modification factor (dimensionless)

The SKF rating life can be expressed in hours of operation if the speed is constant Eq. (11):

$$L_{nmh} = \frac{10^6}{60n} L_{nm} \tag{11}$$

Where:

L_{nmh} – SKF rating life (operating hours)

The Table 1 presents the values of the life adjustment factor for reliability.

Table 1. Values for life adjustment factor a_1.

Reliability (%)	Failure probability (%)	SKF rating life L_{nm} (Million revolutions)	Factor a_1
90	10	L_{10m}	1
95	5	L_{5m}	0,64
96	4	L_{4m}	0,55
97	3	L_{3m}	0,47
98	2	L_{2m}	0,37
99	1	L_{1m}	0,25

The SKF life modification factors a_{SKF} are obtained by means of diagrams according to the type of bearing used (Fig. 4).

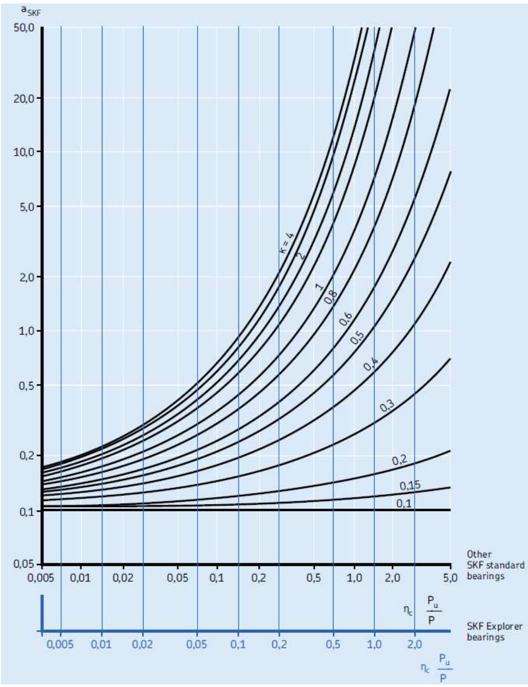


Figure 4. Diagram for radial roller bearings

The axis of the ordinates represents the SKF life modification factors a_{SKF} values and the axis of the abscissa represents the values of the relationship between the fatigue load limit P_u, equivalent dynamic bearing load and the contamination level of the bearing η_c.

As shown previously, the value of the equivalent dynamic bearing load P is calculated by Equations (1) or (2). The value of the fatigue load limit P_u is found in the table of products and the Table 2 shows the values of the level of contamination of bearings η_c.

Table 2. Guideline values for factor η_c for different levels of contamination.

Conditions	Factor η_c	
	d_m < 100 mm	$d_m \geq$ 100 mm
Extreme cleanliness	1	1
High cleanliness	0,8 – 0,6	0,9 – 0,8
Normal cleanliness	0,6 – 0,5	0,8 – 0,6
Slight contamination	0,5 – 0,3	0,6 – 0,4
Typical contamination	0,3 – 0,1	0,4 – 0,2
Severe contamination	0,1 – 0	0,1 – 0
Very severe contamination	0	0

The bearing mean diameter value must be calculated for the selection of the factor η_c Eq. (12):

$$d_m = 0{,}5(d + D) \tag{12}$$

Where:

d_m – bearing mean diameter (mm)

D – bearing outside diameter (mm)

Finally, the value of the viscosity ratio κ needs to be calculated for the selection of the curve shown in the diagram (Fig. 4). The viscosity ratio value is calculated from the actual operating viscosity of the lubricant and the rated viscosity of the lubricant Eq. (13):

$$\kappa = \frac{\nu}{\nu_1} \tag{13}$$

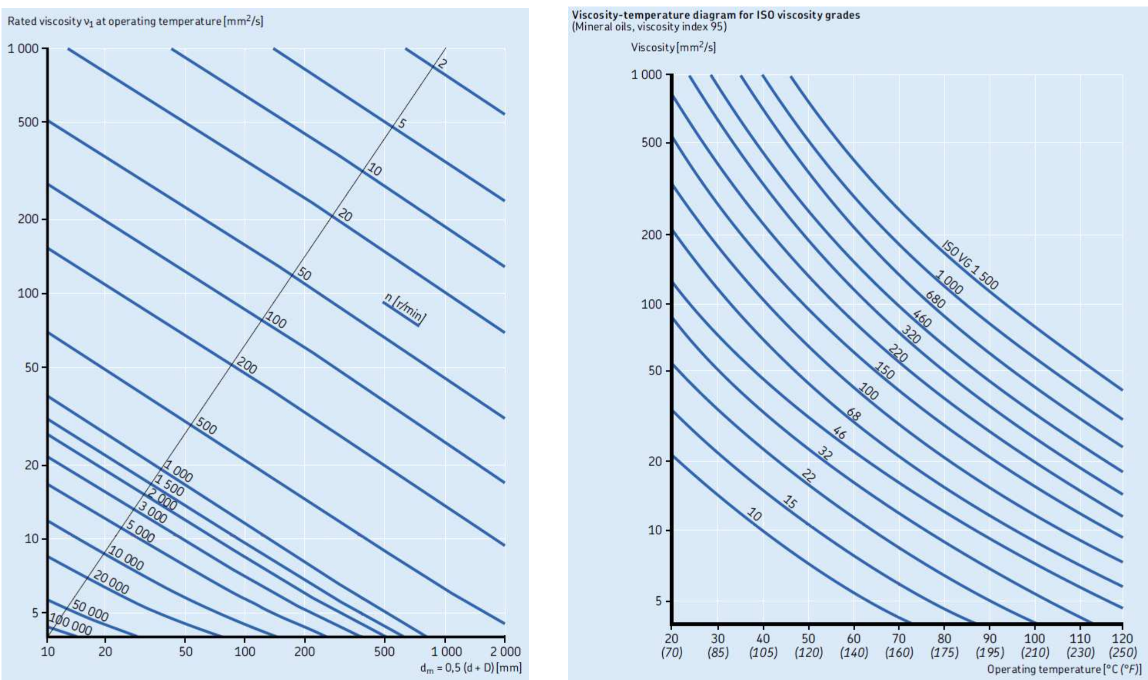
Where:

κ – viscosity ratio (dimensionless)

ν – actual operating viscosity of the lubricant (mm^2/s)

ν_1 – rated viscosity of the lubricant depending on the bearing mean diameter and rotational speed (mm^2/s)

The rated viscosity ν_1 is evaluated according to the bearing rotation and its mean diameter (Fig 5a). The actual operating viscosity of the lubricant ν is obtained by the operating temperature and the rated viscosity value ν_1 (Fig 5b).



(a) (b)

Figure 5. (a) Estimation of the rated viscosity ν_1; (b) Viscosity-temperature diagram for ISO viscosity grades

All bearings have a speed limit of operation and are generally related to the operating temperature of the lubricant or to the materials of the bearing components. The bearing catalogs have a nominal reference speed which is used to determine the permissible operating speed of bearings subjected to loads and certain viscosity values of the lubricant. The influence of the load and kinetic viscosity on the adjusted reference speed are obtained by means of diagrams.

The Equation (14) shows the adjusted reference speed of bearings lubricated to grease:

$$n_{ar} = n_r f_p \frac{f_{vav}}{f_{v150}} \tag{14}$$

Where:

n_{ar} – adjusted reference speed (rpm)

n_r – nominal reference speed (rpm)

f_p – adjustment factor for bearing load P (dimensionless)

f_{vav} – actual base oil viscosity (dimensionless)

f_{v150} – adjustment factor for oil viscosity ISO VG 150 (dimensionless)

The Figure 6 shows the diagram where the values of the adjustment factor for bearing load *P*, actual base oil viscosity and the adjustment factor for oil viscosity ISO VG 150 are selected.

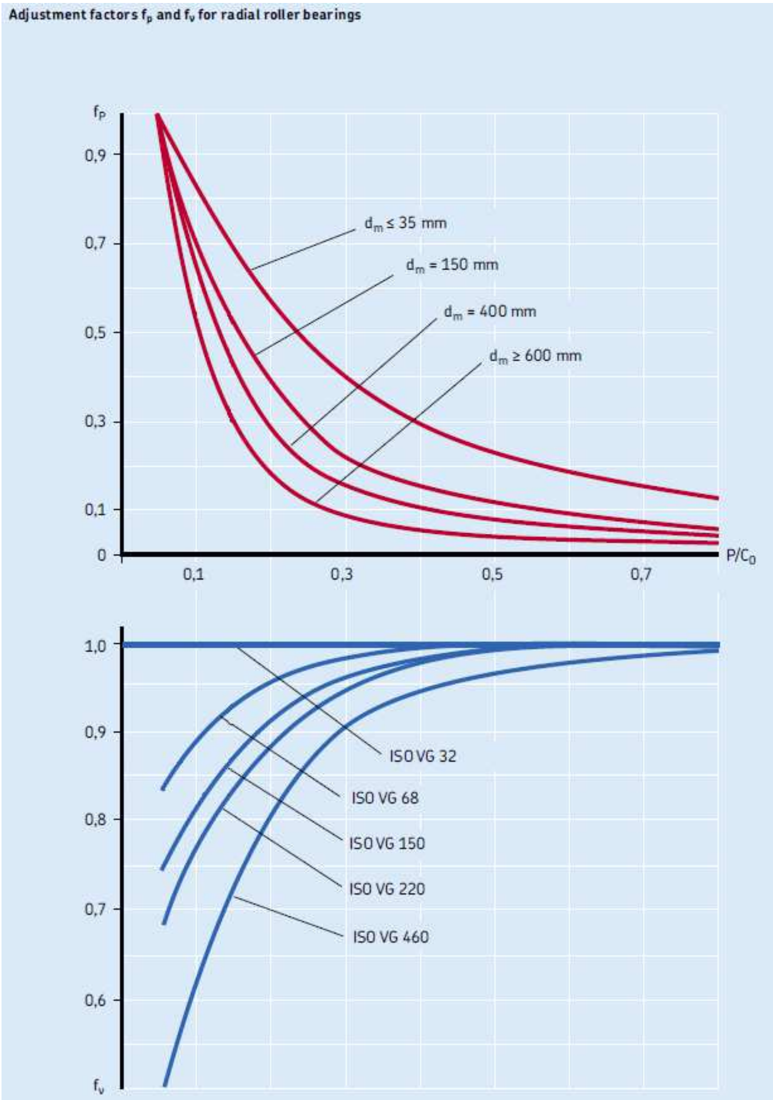
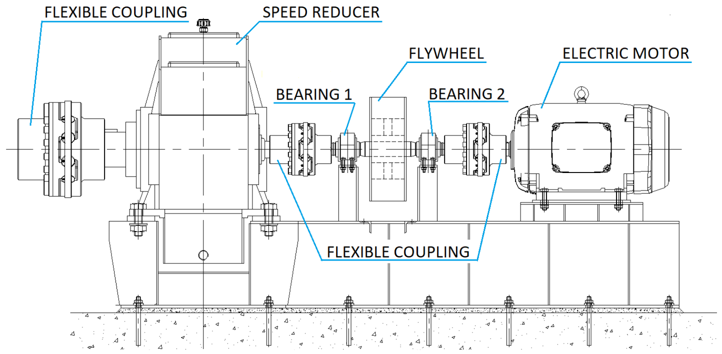


Figure 6. Adjustment factors f_p and f_v for radial roller bearings

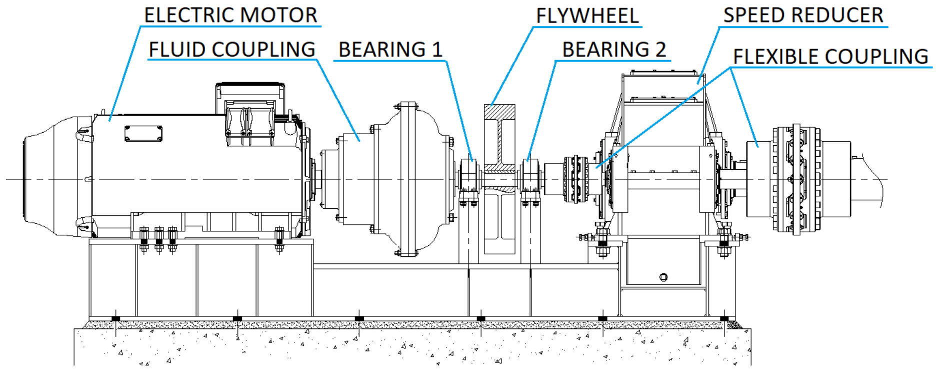
2.2 Cases studied

In order to evaluate the use of spherical roller bearings in flywheels, two cases were selected for study, called case A and case B.

The Figure 7 shows the configurations of the drives of the belt conveyors of these cases.



(a)



(b)

Figure 7. Cases studied (a) Case A ;(b) Case B

Table 3 describes all the components present in the drives of cases A and B.

Table 3. Drive components.

Components	Case A		Case B	
Electric motor	150 kW – VI poles – 440 V	868 kg	590 kW – IV poles – 4000 V	4150 kg
Flexible coupling	Flexible coupling with elastic elements	86 kg	Flexible coupling with elastic elements	186 kg
Hydraulic coupling			Hydraulic coupling with constant fill	878,6
Speed reducer	Parallel shaft speed reducer	3608,2 kg	Parallel shaft speed reducer	3940 kg
Flexible coupling	Flexible coupling with elastic elements	400 kg	Flexible coupling with elastic elements	858 kg
Flywheel	Ø645 x 230 mm	445 kg	Ø1000 x 200 mm	633,8 kg
Shaft	Ø80 x 980 mm – SAE 1045	40,6 kg	Ø100 x 1000 mm – SAE 1045	61,7 kg
Spherical roller bearings	22218EK Bearing with tapered bore	3,4 kg	22222EK Bearing with tapered bore	7 kg
Adapter sleeve	H318		H322	
Grease	Viscosity 68 mm^2/s		Viscosity 68 mm^2/s	

In case A, a radial load of 2803,6 N was found on each bearing.

In case B, the radial loads encountered in bearings 1 and 2 are different. Bearing 1 that is close to the hydraulic coupling had a radial load of 15549,2 N and bearing 2 had a radial load of 800 N.

According to the arrangement of the flywheel components, it can be seen that the axial loads in both cases have very low values, so these loads were disregarded.

The Table 4 shows all technical data for bearings 1 and 2 of cases A and B.

Table 4. Bearing technical data.

Cases		Case A		Case B	
Bearings		Bearing 1	Bearing 2	Bearing 1	Bearing 2
Spherical roller bearings		22218EK	22218EK	22222EK	22222EK
Radial load	F_r	2803,6 N	2803,6 N	15549,2 N	800 N
Axial load	F_a	Inconsiderate		Inconsiderate	
Calculation factors	e	0,24		0,25	
	Y_0	2,8		2,5	
	Y_1	2,8		2,7	
	Y_2	4,2		4,0	
Diameter (outside / bore)	D/d	160 mm / 90 mm		200 mm / 110 mm	
Bearing width	B	40 mm		53 mm	
Bearing mean diameter	d_m	125 mm		155 mm	
Basic dynamic load rating	C	325 kN		560 kN	
Basic static load rating	C_o	375 kN		640 kN	
Fatigue load limit	P_u	39 kN		63 kN	
Reference speed / Limiting speed	n_r/n_l	3800 rpm / 5300 rpm		3000 rpm / 4000 rpm	
Life adjustment factor for reliability	a_1	1		1	
Level of contamination	η_c	0,8		0,8	
Rated viscosity of the lubricant	ν_1	7,9 mm^2/s		8,5 mm^2/s	
Actual operating viscosity	ν	20,1 mm^2/s		20,1 mm^2/s	
Viscosity ratio	κ	2,5		2,3	
SKF life modification factor	a_{SKF}	50		50	
Adjustment factor for bearing	f_p	1,0		1,0	
Actual base oil viscosity	f_{vav}	1,1		1,1	
Adjustment factor for oil viscosity	f_{v150}	1,0		1,0	

By means of these technical data it was possible to perform all the calculations for the verification of the spherical roller bearings of the drives of cases A and B.

3. RESULTS AND DISCUSSION

The Table 5 shows the results of the calculations performed to check the bearings installed on the flywheels of the drives of cases A and B.

Table 5. Bearing calculation results.

		Case A		Case B	
		Bearing 1	Bearing 2	Bearing 1	Bearing 2
		Load			
Equivalent dynamic bearing load (kN)	P	2,8	2,8	15,5	0,8
Basic dynamic load rating (kN)	C	325	325	560	560
Equivalent static bearing load (kN)	P_o	2,8	2,8	15,5	0,8
Basic static load rating (kN)	C_o	375	375	640	640
Equivalent minimum load (kN)	P_m	3,75	3,75	6,4	6,4
Maximum permissible axial load (kN)	F_{ap}	10,8	10,8	17,5	17,5
		Bearing life			
Specification life (operating hours)		$\geq$ 60000	$\geq$ 60000	$\geq$ 60000	$\geq$ 60000
Basic rating life (million revolutions)	L_{10}	7628124	7628124	155903	3045510726
Basic rating life (operating hours)	L_{10h}	71025367	71025367	2183515	42654211848
SKF rating life (million revolutions)	L_{10m}	381406200	381406200	7795150	$\geq$ 1000000000
SKF rating life (operating hours)	L_{10mh}	$\geq$ 100000000	$\geq$ 100000000	$\geq$ 100000000	$\geq$ 100000000
		Speed			
Adjusted reference speed (rpm)	n_{ar}	4180	4180	3300	3300
Rotational speed (rpm)	n	1790	1790	1190	1190

From the calculations made, it can be observed that the bearings 22218EK installed in bearings housing 1 and 2 of case A do not reach the minimum loads of 3,75 kN. The minimum load of 6,4 kN of bearing 22222EK installed in bearing housing 2 of case B is also not achieved.

The bearings that operate with low load and at high speed can fail due to slippage (NSK, 2001). As can be seen in Figure 8, this type of failure damages the surface of the tracks.

Figure 8. Surface damaged by slipping.

When the minimum load is not reached, the rolling elements slide on the tracks. This slipping breaks the lubricant film, thus the rolling elements damage the surfaces of the bearing tracks. In these conditions, also the increase of the temperature of operation of the bearing, causing the wear or the bearing locking in operation (Almeida, 2013; FAG, 2017).

4. CONCLUSIONS

After performing the calculations, it can be seen that the specification of the spherical roller bearings for application in flywheels of belt conveyors should be better evaluated, especially in the minimum load requirement.

In the cases studied in this work, since the designs of the flywheels cannot be changed, it is recommended to replace the bearings of cases A and B. A study alternative for the selection of these new bearings would be the verification of self-aligning ball bearings with the same dimensions of the previously used bearings.

5. ACKNOWLEDGEMENTS

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