The Degrading Phenomenon of the Cylindrical Bearing Rollers Due to Multiple Collisions During the Manufacturing Process

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Abstract. In the various production phases of the bearing rollers, multiple collisions occur, which lead to defects in the finite product. These small defects (dents) have a negative effect during exploitation: they can be the initiation point in fissure spreads which lead to vibrations and a high level of noise. Thus, the bearing is degrading. For the current study various analytical calculations have been performed in order to highlight the energy transfer between the two elements. They have been validated through the finite element method (FEM). The results obtained emphasize that critical areas may appear in the test piece. In those areas the equivalent stress is close to the yield point of the material used in bearing rollers manufacturing.

1. Introduction

During the manufacturing process of the bearing rollers, one of the causes which lead to defects is the collision of the rollers at various working stations. These collisions lead to dents which can later produce bearing failures. [1] The defect analysis can be approached under many different angles [2-4]. If rollers with significant permanent deformations are part of the bearing assembly, vibrations and noises are to be expected during its functioning, see [5],[6]. The vibration phenomenon is studied by consecrated researchers related to this topic [7],[8]. The basic rating life which is the life associated with 90 % reliability, with commonly used high quality material, good manufacturing quality and with conventional operating conditions is treated under the ISO 281:2007 norm [9]. However, the norm is only a guideline for the lifetime assessment and it cannot introduce parameters for a large variety of factors that influence the bearing life rating: rolling elements with/without defects, corrosion, electrical erosion, etc.

Thus, it is important to analyse the multiple collisions during the workflow in order to evaluate the critical manufacturing process where the defects occur. The contact problems of bodies are approached by Hertz [10], Hartnett [11], de Mul [12] and other researchers specialised in this engineering field [13-15]. Due to the complexity of the manufacturing processes and regarding the fact that the mass production of the rollers is not able to handle them in a one piece flow, the defects cannot be totally eliminated, but with the proper approach they can significantly be reduced.

This paper contains an extensive study of the 16x24 mm cylindrical rollers using two distinctive methods: analytic and FEM for the rollers at the classification working station. The aim of the current
article is to study the energy transfer during the impact of the rollers and to conclude if it could lead to permanent deformations.

2. Analytic study
Analytic calculations have been performed for a roller bearing 16x24 mm. For the chosen type the preconditions have been determined as presented in table 1: A-section surface; V - volume; M - mass; G – weight. In addition, the Earth gravity is considered g=9.8 [m/s^2].

| d [mm] | L [mm] | A [mm^2] | V [mm^3] | M [kg] | G [N] |
|--------|--------|----------|----------|--------|-------|
| 16     | 24     | 201,06190| 4825,4856| 0,037880| 0,3712|

The path of a roller bearing from the manufacturing machine (CP) to the collecting recipient (MB) is presented in figure 1. Following notations occur: the sliding surface at a 30 degree angle (J), the orifice that connects the sliding surface with the collecting recipient (O), (G) - the roller weight, I and II represent the roller position (horizontal and vertical) and h1, h2, h3 are the height of the sliding surface, the orifice and the height of the collecting recipient. h1+h2+h3= h (total height) 430mm. V is the notation for the velocity of the roller.

The analysis has been performed for two cases: A - Collision head to head, and B - Collision head to generatrix, with an angle between 0 and 60 degrees. The two cases are specific for the analysed manufacturing line. For other geometry of the collecting recipient and different velocity of the rollers the collision angles are different, thus another analysis should be performed.

In order to calculate the velocity of the rollers when they reach the bottom of the collecting recipient, the law of mechanical energy conservation is applied.

\[ E_p = E_c \]  \hspace{1cm} (1)

where Ep represents the potential energy of the roller at CP and Ec is the kinetic energy when the roller reaches the collecting recipient in case I or II.
The maximum velocity at the impact moment can be calculated:

\[ v_{\text{max}} = \sqrt{2gh} \]  

(2)

where \( h \) is the maximum height before fall = 0.43 [m]

For the above mentioned values: \( v_{\text{max}} \approx 2.903 \approx 3.0 \) [ms\(^{-1}\)].

The approximate analytical solution regarding shock between solids can be approached using the law of mechanical energy conservation.

It is defined as an impact coefficient or dynamic multiplier (\( \Psi \)) the ratio between the instantaneous force at the impact moment \( P \) and the weight \( G \) of the moving body. In fig.1 \( h \) is the height and the solid body deformation arrow is measured in the impact direction.

\[ \Psi = \frac{P}{G} \]  

(3)

Due to the small deformations values, a simplified equation will be used to determine the impact coefficient:

\[ \Psi = \frac{2h}{\sqrt{\Delta s}} \]  

(4)

\( \Delta s \) (static deformation) will be calculated for the roller chosen in table 1 and the two impact situations A and B (fig. 4).

Between the static and dynamic deformation, static and dynamic stress, following relations occur:

\[ \Delta \text{din} = \Psi \Delta s \]  

(5)

\[ \sigma\text{din} = \Psi \Delta s \]  

(6)

For the analytical calculation case I-A (fig.2) the static stress and deformation are calculated using the relation (7) and (8):

\[ \sigma = \frac{G_i}{A_i} \]  

(7)

\[ A_{si} = \frac{G_i \mu_i}{E A_i} \]  

(8)

where \( E \) is Young’s Modulus of the roller material.

The formulas for the analytical calculation of case II B are as following: static stress (9), maximum bending moment (10), axial stress (11), static deformation (12), axial inertia moment (13) as listed below:

\[ \sigma_{si} = \frac{M_{\text{imax}}}{W_i} \]  

(9)

\[ M_{\text{imax}} = \frac{G_i l_i}{4} \]  

(10)

\[ W_i = \frac{\pi d_i^3}{32} \]  

(11)

\[ A_{si} = \frac{G_i l_i^3}{48E I_i} \]  

(12)

\[ I_i = \frac{\pi d_i^4}{64} \]  

(13)

It is necessary to calculate the value of the dynamic force (instantaneous force at the impact moment) with the relation (14.a), the static force is the weight of the roller (14.b).

\[ F\text{din}_{i} = \Psi Fst_{i} \]  

(14.a)

\[ Fst_{i} = G_i \]  

(14.b)
The analytical calculations performed for the cases A and B are centralized in Table 2 and Table 3, with the initial data $E=2.1 \times 10^5$ N/mm$^2$ and $h=0.43$ m.

### Table 2. Head-head contact

|          |       |       |       |
|----------|-------|-------|-------|
| $\sigma_{s1}$ | MPa   | 0.0018463170 | $\Delta_{s1}$ | mm |
| $\Psi_{1}$    | (2h/$\Delta s$)$^{0.5}$ | 63841.0645468651 | $F_{din1}$ | N |
| $\sigma_{din1}$ | MPa   | 117,8708414938 | $\Delta_{din1}$ | mm |

### Table 3. Head-generatrix contact (impact angle 0)

|          |       |       |       |       |       |
|----------|-------|-------|-------|-------|-------|
| $F_{i}=G_{i}$   | N     | 4,154 | $M_{max1}$ | Nmm |
| $Iz_{1}$ | mm$^4$  | 3216.990877 | $W_{z1}$ | mm$^3$ |
| $\sigma_{s1}$ | MPa   | 0.00184632 | $\Delta_{s1}$ | mm |
| $\Psi_{1}$    | (2h/$\Delta s$)$^{0.5}$ | 73717.31707 | $F_{din1}$ | N |
| $\sigma_{din1}$ | MPa   | 136,1055342 | $\Delta_{din1}$ | mm |

The study for the rollers collision was conducted through FEM for two cases: A head to head and B head to generatrix, angle 0 and 45 degrees.

**Dynamic analysis head to head impact (Case A).** The FEM model contains two bearing rollers: the first is in motion with a velocity of 3 m/s and the second is static (fig. 2). The mesh has a total of 70329 nodes and 65150 elements (fig. 3). The maximum von Misses stress is 151.8 [MPa] as shown in figure 4, located at the lower part of the roller (fig. 5). The maximum deformation is 0.22697 [mm] (fig. 6 and 7).

**Figure 2.** Rollers impact  
**Figure 3.** Grid  
**Figure 4.** Von Misses Equivalent Stress  
**Figure 5.** Equivalent Stress
Dynamic analysis of the head-generatrix impact (angle 0°, case B). The FEM model contains two bearing rollers: the first is in motion with a velocity of 3 m/s and the second is static (fig. 8). The mesh has a total of 79380 nodes and 73617 elements (fig. 9). The maximum von Misses stress is 266.86 [MPa] as shown in fig 10., located at the impact area of the two rollers (fig. 11). The maximum deformations are shown in fig. 12 and 13.
Dynamic analysis of the head-generatrix impact (angle 45°, case B). The FEM model contains two bearing rollers: the first is in motion with a velocity of 3m/s and the second is static (fig.14). The mesh has a total of 62500 nodes and 57720 elements (fig. 15). The maximum von Misses stress is 428.33 [MPa] as shown in fig 16., located at the edge of the roller at the impact area (fig. 17). The maximum deformation is 0,27885 [mm] (fig. 18 and 19).

3. Result comparison
The comparison between the maximum values of the von Misses stress and total deformations calculated analytical and FEM results are centralized in Table 4 (von Misses stress ) and Table 5(total deformations).
Table 4. Maximum equivalent stress [MPa]

| A head - head      | B head - generatrix |
|-------------------|---------------------|
| Analytic          | 117.87              |
| FEM               | 151.8               |
| Analytic          | 136.1               |
| FEM               | 266.86              |

Table 5. Total maximum deformations [mm]

| A head - head      | B head - generatrix |
|-------------------|---------------------|
| Analytic          | 0.01347             |
| FEM               | 0.22697             |
| Analytic          | 0.01167             |
| FEM               | 0.03448             |

4. Conclusions

Collisions are phenomenons during which the bodies exchange between themselves energy. The duration is short enough so that the external loads have are not able to modify the system impulse.

The studies conducted present the contact in two distinct cases: rollers hit each other head and head-generatrix with the angle 0-60 degrees. These situations occur frequently during the manufacturing process of the small bearing rollers. The worst case is when the collision angle is 30 degrees.

The von Misses equivalent stress distribution show that the critical points (where the yield point is exceeded) appear inside the rollers body and can cause permanent deformations on the rollers surface.

5. References

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