BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 62 (66), Numărul 3, 2016
Secţia
CONSTRUCŢII DE MAŞINI

PROFILE EVOLUTION IN CYLINDRICAL ROLLER BEARINGS

II. RATING LIVES EVALUATION

BY

MARCELIN BENCHEA* and SPIRIDON CREȚU

“Gheorghe Asachi” Technical University of Iaşi,
Department of Mechanical Engineering, Mechatronics and Robotics

Received: October 5, 2016
Accepted for publication: October 20, 2016

Abstract. The roller profile appears to be the key element to attain a longer rating life for both cylindrical and tapered roller bearings. The class I discontinuities that exist along cylindrical-crowned roller profile generate high pressure peaks in pressure distributions that diminish considerably the modified rating life as is defined by ISO 16281:2008. After a certain number of cycles the material will shakedown elastically to a slightly modified roller profile and a stable state of compressive residual stresses. If were taken place, these changes have to be considered in the life evaluation.

In a previous paper, an analysis model has been developed to simulate the nonlinear strain rate dependent deformation of rolling bearing steel stressed in the elastic-plastic domain. An experimental validation of the developed elastic-plastic model is pointed out in the first part of the present paper.

In the second part of the paper, the basic reference rating lives have been evaluated using the methodology given in ISO 16281:2008. In this respect, pure elastic conditions as well as elastic-plastic material, able to undertake plastic modification of the roller profile, have been considered.

*Corresponding author; *e-mail*: marcelin.benchea@tuiasi.ro

The favourable effect of roller profile changes as result of the local plastic deformations has revealed.

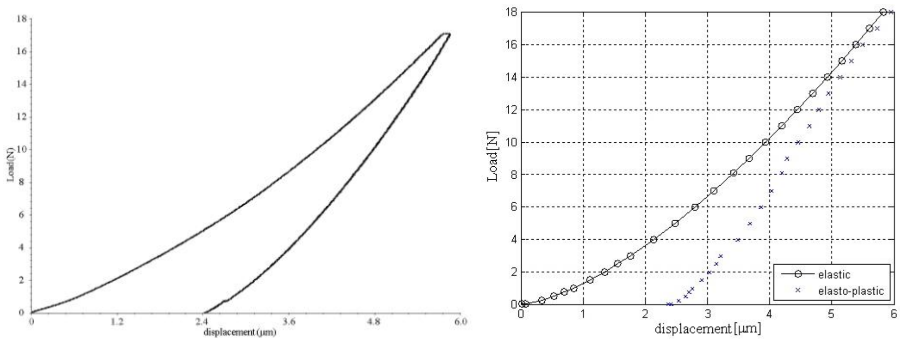
Keywords: elastic-plastic contact; residual stresses; cylindrical roller bearings; reference rating life.

1. Introduction

The cross-section roller's profile controls the pressure distribution in the contact area and radically affects the bearing dynamic load rating and life (Harris and Kotzalas, 2007; Ioannides *et al.*, 1999; ISO 16281:2008). Consequently the primary target has been to reduce the stresses in the roller-raceway contact by optimizing the roller profile. The diversity of crowning profiles includes: the single straight line with chamfer ends, single circular arc or a combination of multiple circular arcs, cylindrical-crowned known also as ZB profile. When Lundberg's logarithmic profile is used, (Lundberg, 1939), the distribution of contact pressure might results axially uniform. Still this theoretical profile has an infinite drop at the end of the effective contact length. In an elastic analysis, as is admitted in (ISO 16281:2008), these end increases in pressure distribution cause a severe diminishing of both the reference dynamic load rating and modified rating life.

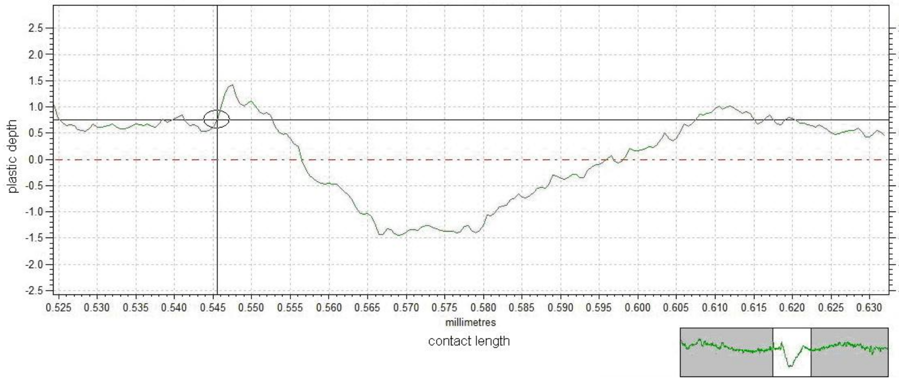
2. Experimental Validation of Improved Incremental Algorithm

The CETR UMT-2 tribometer and test specimen of 51206 axial bearing ring were used to perform the indentation tests and Taylor-Hobson Form Talysurf I50 profilometer was used to perform the micro-indentation measurements (Benchea and Crețu, 2010). For a normal load of 18 N the experimental and numerical values are comparatively depicted in Fig. 1.

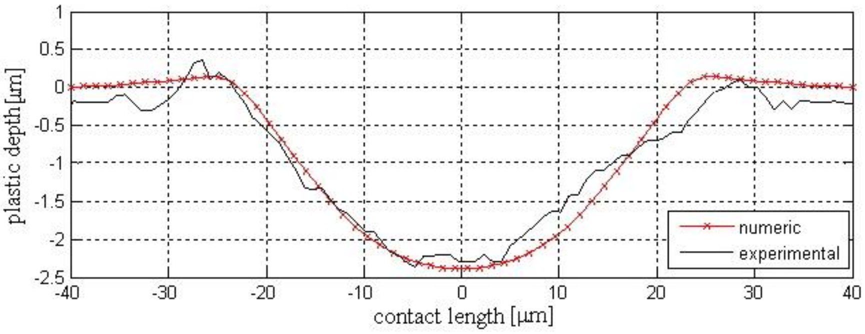


a *b*

Fig. 1 – Displacements vs. loading force:
a – experimental; *b* – numerical.



a



b

Fig. 2 – Indenter print depth:
a – experimental; *b* – experimental and numerical.

The Fig. 2 presents comparatively the measured profile of the indentation versus the profile obtained numerically with the elastic-plastic model.

The experimental profile has diameter of 46.65 μm and a depth of 2.40 μm that are very close to those obtained numerically, 46.24 μm for the diameter and 2.38 μm for the depth.

3. Method for Calculating the Reference Rating Lives

3.1. Lamina Model

For the case where the raceways of rolling bearings are cylindrical, the elastic deflection of a misaligned rolling element can be described by a lamina model.

To calculate the elastic deflection, the roller is divided into n_s identical laminas, Fig. 3*a*. According to (ISO 16281:2008) the number of laminas shall be at least $n_s = 30$.

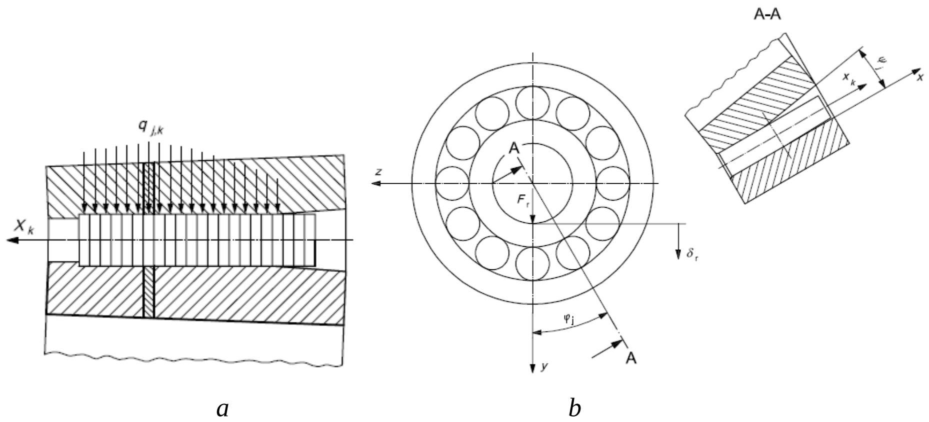


Fig. 3 – Roller bearing internal load distribution (ISO 16281:2008):
a – lamina model; *b* – roller bearing misalignment.

The load $q_{j,k}$ on lamina *k* of the roller *j* is:

$$q_{j,k} = c_s \cdot \delta_{j,k}^{10/9} \tag{1}$$

where: $c_s = \dfrac{35948 \cdot L_{we}^{8/9}}{n_s}$, L_{we} – roller length.

For a radial load of the inner ring, the elastic deflection of the rolling element *j* is:

$$\delta_j = \delta_r \cdot \cos\varphi_j - \frac{s}{2} \tag{2}$$

where: *s* – radial clearance of bearing, φ_j – angular position of rolling element, δ_r – radial displacement given by load.

3.2. Rating Lives for Roller Bearings

For a normal load distribution, the difference between the dynamic equivalent rolling element loads for a rotating and a stationary inner ring is less than 2% (ISO 16281:2008). Generally, the inner ring is considered to be rotating and the outer ring to be stationary.

Basic reference rating life, L_{10r}, is given by:

$$L_{10r} = \left(\sum_{k=1}^{n_s} \left(\left(\frac{q_{kci}}{q_{kei}} \right)^{-4.5} + \left(\frac{q_{kce}}{q_{kee}} \right)^{-4.5} \right) \right)^{-\frac{8}{9}} \quad (3)$$

where: q_{kci} – basic dynamic load rating of a bearing lamina of the inner ring, q_{kce} – basic dynamic load rating of a bearing lamina of the outer ring, q_{kei} – dynamic equivalent load on a lamina k of a rotating inner ring, q_{kee} – dynamic equivalent load on a lamina k of a stationary outer ring.

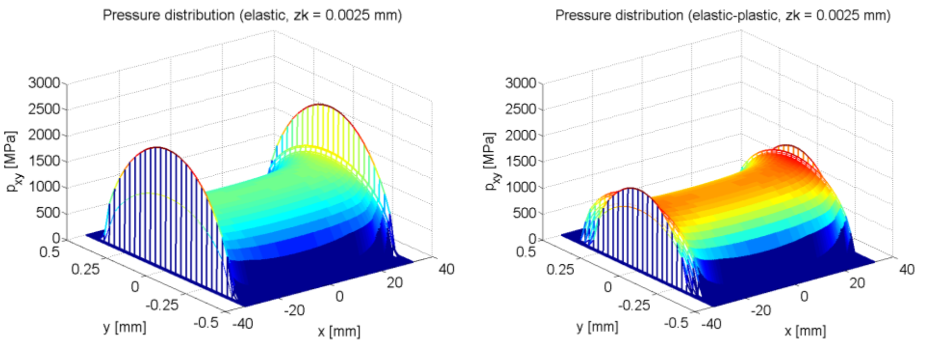
According to (ISO 16281:2008), the dynamic equivalent loads on each lamina of the rotating inner ring and of each lamina of the stationary outer ring are computed as a function of the stress riser coefficients evaluated for each lamina of each roller. The stress risers are calculated considering the actual pressure distribution on the corresponding lamina versus and ideal hertzian pressure.

4. Basic Reference Rating Lives Evaluation

4.1. Effect of a Transient Overload on Pressure Distributions

Transitory overloads may induce permanent profile changes that modify the elastic pressure distributions for the subsequent normal running load. Fig. 4*a* exemplifies the elastic pressure distributions along profile of the most loaded rollers of a cylindrical roller bearing that supports 100 kN radial load.

If the cylindrical roller bearing was subjected to a transient overload of 450 kN the elastic shakedown took place and roller profile changes due to plastic deformations.



a *b*

Fig. 4 – 3D Elastic pressure distributions,
(F_R = 100 kN, profile: $R1$ = 8100 mm, zk = 0.0025 mm):
a – before a transient overload of 450 kN; *b* – after a transient overload of 450 kN.

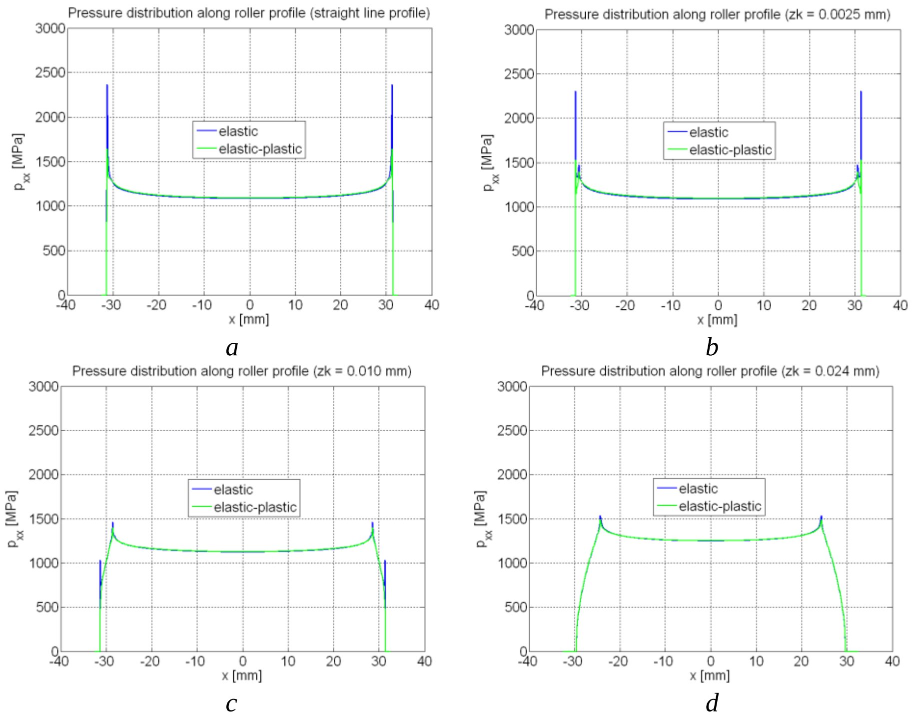


Fig. 5 – 2D Elastic pressure distributions for F_R = 100 kN,
before and after a transient overload of 450 kN:
a – straight line profile; *b* – crowned profile: *R*1 = 8100 mm, *zk* = 0.0025 mm;
c – crowned profile: *zk* = 0.010 mm, *d* – crowned profile: *zk* = 0.024 mm.

The induced plastic deformations alter the elastic pressure distributions, as in Fig. 4*b* and Fig. 5.

4.2. Normal Loading Conditions with Transient Overloading

Experimental investigations, (Crețu and Popinceanu, 1985; Muro *et al.*, 1973), as well as theoretical and computer simulations, (Chen *et al.*, 1988; Crețu *et al.*, 2007; Ko and Ioannides, 1988), have shown that the presence of compressive residual stresses can have a positive effect on fatigue lives of rolling bearings.

The slicing technique recommended in (ISO 16281:2008) make possible to consider the profile modifications in the evaluation of the basic reference rating life of a roller bearing. It does not include the role played by residual stresses. The basic reference rating lives, evaluated for a radial load of 100 kN and basic design roller profile are presented in Table 1. The value of basic rating life provided by standard (ISO 281:2007) is added.

Table 1
Basic Reference Rating Lives for Normal Loading Conditions (F_R = 100 kN)

Roller profile	Profile drop zk, μm	Basic rating lives, L_{10} hours, (ISO 281)	Basic reference rating lives, L_{10r}, hours, (ISO 16281)	
			Design profile	Elastic shake-down profile
Straight	–	$4.43\cdot10^4$	$3.80\cdot10^4$	$1.20\cdot10^5$
ZB	2.5	$4.43\cdot10^4$	$5.28\cdot10^4$	$1.26\cdot10^5$
ZB	10	$4.43\cdot10^4$	$1.09\cdot10^5$	$1.10\cdot10^5$
ZB	24	$4.43\cdot10^4$	$5.19\cdot10^4$	$5.28\cdot10^4$

The results from Fig. 4*b*, Fig. 5 and Table 1 reveal that a very short overload, able to induce small alterations of roller's profile, attenuates the pressure peaks with a beneficial effect on fatigue life.

4.1. Very Heavy Loading Conditions

Bearings incorporating rollers with unmodified profiles as well as bearings with modified roller profiles by elastic-shakedown process have been considered. The basic reference rating lives, L_{10r}, (ISO 16281:2008), evaluated for a running load of 450 kN are exemplified in Table 2.

Table 2
Basic Reference Rating Lives for Very Heavy Loading Conditions (F_R = 450 kN)

Roller profile	Profile drop zk, μm	Basic rating lives, L_{10} hours, (ISO 281)	Basic reference rating lives, L_{10r}, hours, (ISO 16281)	
			Design profile	Elastic shake-down profile
Straight	–	$2.94\cdot10^2$	$1.15\cdot10^1$	$3.37\cdot10^1$
ZB	2.5	$2.94\cdot10^2$	$1.29\cdot10^1$	$5.15\cdot10^1$
ZB	10	$2.94\cdot10^2$	$3.17\cdot10^2$	$3.98\cdot10^2$
ZB	24	$2.94\cdot10^2$	$2.49\cdot10^2$	$3.36\cdot10^2$

The profile modifications caused by plastic deformations evolved at discontinuities zones significantly diminish the peak pressures and finally led to longer fatigue lives.

5. Conclusions

The methodology presented in ISO 16281:2008 has been involved to evaluate the basic reference rating lives. The favourable effect of roller profile changes as result of the local plastic deformations has revealed.

The elastic-plastic model, presented in first part of the paper, is useful for a more realistic evaluation of the basic reference rating life of roller bearings for normal loading condition, after a high transient overload.

REFERENCES

Benchea M., Crețu S., *Experimental Tests and Numerical Analysis in Elastic-Plastic Domain of Concentrated Contacts*, Proceedings of ROTRIB'10, Iași, Paper RO-066, 2010.

Chen Q., Hahn G.T., Bhargava V., *The Influence of Residual Stresses on Rolling Contact Mode-Driving Force in Bearing Raceway*, Wear, **26**, 17-30, 1988.

Crețu S., Popinceanu N., *Influence of Residual Stresses on Rolling Contact Fatigue*, Wear, **105**, 153-170, 1985.

Crețu S., Benchea M., Crețu O., *Compressive Residual Stresses Effect on Fatigue Life of Rolling Bearings*, Proceedings of IMECE-07, Seattle, Paper 43561, 2007.

Harris A.T., Kotzalas N.M., 2007, *Rolling Bearings Analysis-Advanced Concepts of Bearing Technology*, Taylor & Francis Group.

Ioannides E., Bergling G., Gabelli A., *An Analytical Formulation for the Life of Rolling Bearings*, Acta Polytechnica Scandinavica, Me, **137**, 1-80, 1999,

Ko C.N., Ioannides E., *The Associated Residual Stresses and their Effect on the Fatigue Life of Rolling Bearing-an FEM Analysis*, Proc. 15th Leeds-Lyon Symp., Leeds, 199-207, 1988.

Lundberg G., *Elastiche Beruhrung zweier Halbraume*, Forschung auf den Gebiete des Ingenieurwesen, **10**, 201-211, 1939.

Muro H., Tsushima N., Nunome K., *Failure Analysis of Rolling Bearings by x-Ray Measurements of Residual Stresses*. Wear, **25**, 345-356, 1973.

*** ISO 281:2007, *Rolling Bearings-Dynamic Load Ratings and Rating Life*, ISO, Geneva, Switzerland.

*** ISO 16281:2008, *Rolling Bearings-Methods for Calculating the Modified Reference Rating Life for Universally Loaded Bearings*, ISO, Geneva, Switzerland.

EVOLUŢIA PROFILULUI ROLEI LA RULMENŢII CU ROLE

II. Evaluarea durabilităţii

(Rezumat)

Pentru condiţii severe de funcţionare (C/P > 0.3) a rulmenţilor cu role, vârfurile de presiune, prezente în zonele de discontinuitate ale profilului rolei, sunt capabile să depăşească limita de elasticitate şi să inducă local modificări ale stării de tensiuni remanente şi de deformaţii plastice. În prima parte lucrarea prezintă validarea experimentală a algoritmului utilizat pentru obţinerea profilului modificat al rolei. În partea a doua a lucrării este prezentată metodologia de determinare a durabilităţii rulmenţilor conform standardului ISO 16281:2008. S-a evidenţiat faptul că profilul rolei modificat prin considerarea deformaţiilor plastice atenuează vârfurile de presiuni apărute la zonele de discontinuitate ale profilului determinând creşteri semnificative ale durabilităţii rulmentului.