

NUMERICAL MODELING OF RESIDUAL STRESSES GENERATED AFTER PROCESSING THROUGH ROUGHING GRINDING OF THE BEARINGS RACEWAYS

Iurea Pavel, Constantin Carausu

“Gheorghe Asachi” Technical University of Iasi, Blvd. Mangeron, No. 59A, 700050, Iasi, Romania

Corresponding author: Constantin Carausu, c_carausu@yahoo.com

Abstract: The aim of this work is the numerical modeling of residual stresses generated at roughing grinding of the raceways of the bearing rings and the validation of modeling by comparing the numerical results with those obtained experimentally. To simulate the residual stresses generated after the roughing grinding has been used the finite element analysis method. In order to simulate the finite element analysis model was used ANSYS software package. Numerical analysis results were compared with the experiments carried out on the outer bearing rings in service at S.C. Rulmenti Barlad SA, the material of the bearing rings being 100CrMnSi6-4 steel. In the case of roughing grinding of the raceway of the bearing rings, numerical simulation results are almost identical to the experimental results. In the top layer of the material to a certain depth can be observed tensile residual stresses, which are generated due to mechanical and thermal effects caused by severe grinding conditions. In more depth, residual stresses are compressive, which are favorable for increasing the fatigue strength of bearings service.

Keywords: bearing rings, characteristics of bearing steel, roughing grinding, residual stresses, finite elements analysis, ANSYS.

1. INTRODUCTION

In specialty literature there are studies that address the issue of the integrity and accuracy of the raceways surfaces of the bearing rings processed through grinding [1, 2]. Grinding roughing of the inner cylindrical surfaces ensures a diameter accuracy in steps 6 - 7 ISO and a roughness $R_a = 0.8$ to $1.6 \mu\text{m}$. The integrity of the surfaces is influenced by residual stresses generated due to the formation of a severe thermal gradient of plastic deformation near the surface layer, under the influence of mutual interaction of mechanical and thermal loads [3,4].

The functional behavior of the bearing can be improved or affected by residual stresses. It is therefore essential to provide and control the residual stresses on the processed surfaces of the bearing rolling elements.

In some studies [5], it is mentioned that the grinding,

even if it can eliminate the residual stresses of the traction generated on the surface of the material in the operation of previous work, it can generate new distribution of residual stresses due to high temperatures, at the contact between the abrasive disc and the material to be processed [6]. Depending on the level at which the material structure is affected, may be found macro or micro residual tensions. The determination of these tensions from the surface raceways is very important to be done before the final finishing operations of the bearing rings. At the processing through grinding, the surface residual stresses may affect, on the one hand the behavior and integrity of the bearing in service, and, on the other hand, can cause changes in shape or in the parameters precision of bearing elements, changes that are caused by elastic resilience phenomenon.

Through a rigorous control of processing parameters (cutting depth, feed, cutting speed etc.) it has been found that elastic recoil effects can be easily prevented and will be relatively small, [7] Macroscopic residual stresses have a direct influence on the strains and the strength of bearings and microscopic residual stresses influence microdeformations, which have an important role in the stability of the fatigue parts.

The primary objective of this paper is the numerical modeling of the residual stresses generated at the roughing grinding of the raceways of the bearing rings and the numerical model validation realized through comparing the results obtained at the numerical simulations with the results obtained experimentally.

2. MATERIAL AND METHOD

2.1 The experimental method

2.1.1 The material of the bearing ring

The material of the bearing ring from the experimental testing is bearing steel 100CrMnSi6-4 whose chemical composition and technical features can be found in tables 1 and 2.

Table 1. The chemical composition of steel bearing, [7]

Steel Mark	Equivalent Mark	Chemical composition, %								
		C	Mn	Si	Cr	Mo max.	S max.	P max.	Ni max.	Cu Max.
100CrMnSi6-4	100CrMnSi6-4 ISO 683-17	0.93	1.00	0.45	1.4	0.10	0.015	0.025	0.25	0.25
		÷	÷	÷	÷					
		1.05	1.2	0.75	1.65					

Table 2. Characteristics and mechanical properties of the bearing steel, [7]

Steel Mark	Structure type after secondary heat treatment	Hardness (HRC)	Tensile strength R_m (MPa)	Stressflow $R_{p0.2}$ (MPa)	Breakage elongation A_s (%)	Breakage strangle Z (%)
100CrMnSi6-4 (ISO 683-17)	Martensit	61÷64	2300	1700	2	2

Experimental investigation of residual stresses was performed after the hardening heat treatment and surface grinding roughing of the raceway bearing rings. Experiments for the determination of residual stress were made on the raceways of the outer bearing rings. The processing of the bearing ring by grinding roughing operation at the diameter of the raceway, was executed inside round grinding machine SIP-315, using as an abrasive cutting tool 250x80x75 / 66A80 / 16K5V217, using technological parameters in table 3. After the grinding roughing was obtained the outer bearing ring shown in figure 1.

drilling method of the tensometric brand [10, 11]. For the precision of experiments the bearing ring was set in a holder designed specifically for RESTAN_MTS3000 equipment and for making measurements (figure 2). The type of tensometric brand is RY-61, with special destination for measuring residual stresses on curved surfaces.

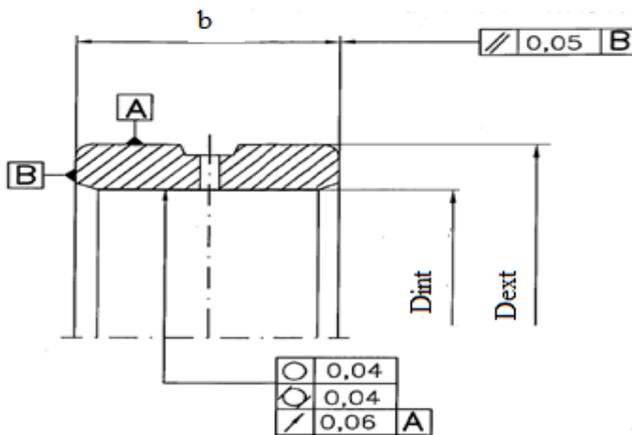


Fig. 1. The sketch of the outer bearing ring after grinding roughing operation of the raceway of the the bearing ring

Table 3. Technological parameters used at the grinding roughing of the raceway of the the bearing ring

Average for the removed machining add, [mm]	0,575
Depth cutting /crossing [mm]	0,05
Number of crosses	12
Rotation speed grinding wheel, [rot/min]	80
Cutting speed, [m/s]	35
Advance / crossing, [mm/min]	0,5

2.1.2 The measurement methodology

Residual stresses determination was made using the RESTAN-MTS300 equipment [8, 9] and incremental

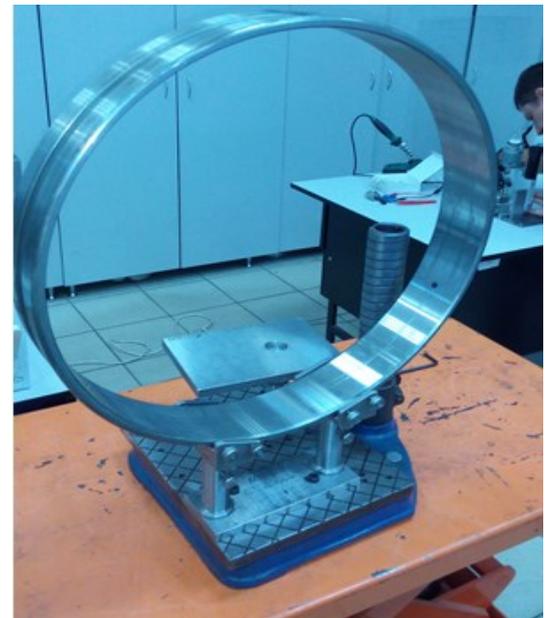


Fig. 2. Fixing the bearing ring in the test device

Holder assembly fixing bearing ring - RESTANT-MTS 3000 equipment for determining the residual stresses on the ring raceway is shown in figure 3.

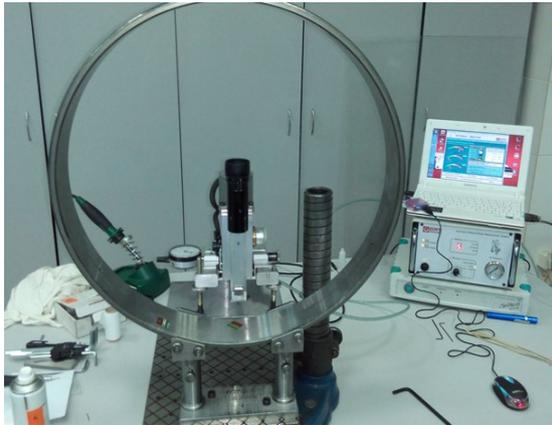
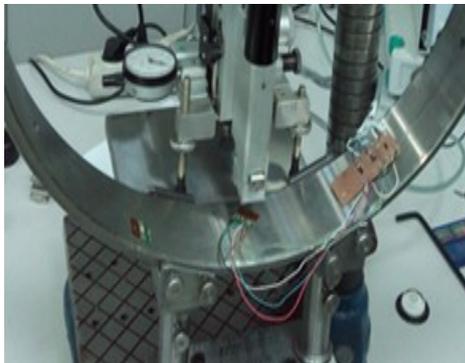


Fig. 3. Presentation of mounting bracket assembly - bearing ring - RESTAN-MTS3000 equipment- for determining residual stresses

The experimental method consists of bonding tensometric brand RY 61 on the runway surface of the outer bearing ring and tensometric brand elements were connected to indicator strains (figure 4a). Drill Stand in which is mounted in a milling drill with 1.6 mm diameter inverted cone, was aligned in the center of the rosette tensometric (figure 4b), for the execution hole in its center.



a



b

Fig. 4. Strain gauge bonded on the raceway of the bearing ring and its connection to indicator strains (a); drill centering support center of the strain gauge rosette (b)

RESTAN MTS3000 equipment has a microscope that will be used for axial positioning of high speed air turbine (where the drill milling support with inverted cone is) in the center of the strain gauge rosette.

The microscope has a dual function: first, to allow the perfect alignment of the hole drill in terms of the benchmarks from the center of the strain gauge rosette; second, to measure the diameter of the hole and its inspection after the drilling operation (measurement of the eccentricity of the executed hole), [8].

The drilling was performed in 16 incremental steps (0.05mm pitch) to a depth of 0.8 mm (maximum 0.7 from the diameter of the drill milling), equipment software measuring the deformations of the executed hole for each depth increase. Material removal caused a relaxation of residual stress around the hole from the center of the rosette, meaning that the equilibrium state will be destroyed and there will be another residual stress distribution around distorted material, namely a relief.

Around the executed hole the material will relax and the existing residual stresses can cause deformations in the area of the processed material which are detected and measured by an indicator of strains. The obtained values of the strains will be used for calculation of residual stresses by integral method.

2.2 Numerical modelling

3D physical model for simulating the plastic deformation process in case of roughing grinding bearing rings is shown in figure 5. It was used the finite element analysis method and the numerical software package ANSYS [12, 13]. It will shape the state of stresses in raceway layer of the bearing outer ring [14, 15]. The bearing ring was discretized in 2337 quadrilateral elements and 16185 nodes. The contact between the bearing ring and the abrasive disk grinding will be considered a linear contact.

As material for bearing ring, it has been chosen bearing steel with the following properties:

- Young's modulus $E = 210000 \text{ N} / [\text{mm}]^2$
- Poisson's ratio $\mu = 0.3$
- flow strength $\sigma_c = 1700 \text{ MPa}$

As input, were considered cutting forces values (F) and temperature (T) of the processed material after the grinding operation, meaning that were taken into account both thermal and mechanical effects. The contact pressure p will be tracked, as an input parameter in the simulation, so the pressure value to be close to abrasive disk to the grinding operation (equation 1).

$$f(F, p, T) \rightarrow \varepsilon, \sigma \quad (1)$$

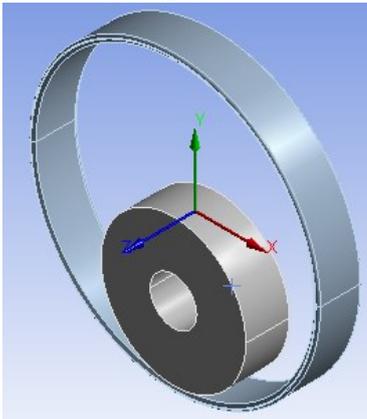


Fig. 5. 3D CAD model of numerical simulation in case of grinding roughing of the bearing ring

The roller bearing ring is subjected to mechanical deformation under the action of grinding disk considering a uniformly distributed pressure of 20sqm and a force deformation 5777N (resultant after normal force of 4800 N and 2800 N tangential force) (figure 6). It will also take into account the thermal effects on the bearing ring by heating it to a temperature of 40 degrees Celsius.

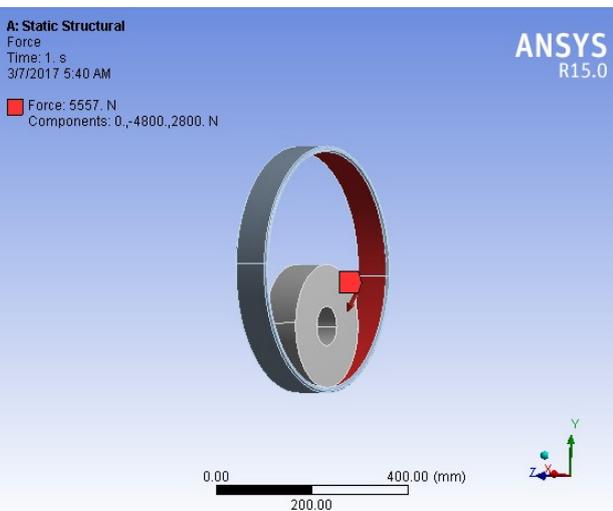
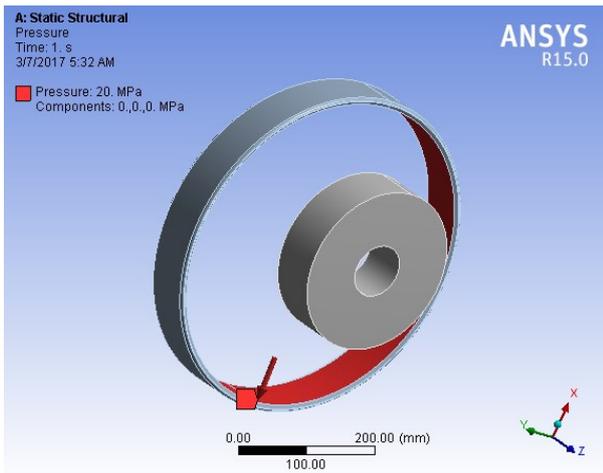


Fig. 6. The bearing ring subjected to deformation tasks, 20sqm uniformly distributed pressure and load deformation of 5777N

3. RESULTS AND DISCUSSIONS

After modeling the contact bearing ring - grinding disk with the ANSYS software package were obtained strains and equivalent stresses shown in figure 7 and 8. It can be observed that the maximum total deformations are in the middle of the raceway of the bearing ring and their value decreases towards the edges of the bearing ring.

The bearing ring material subjected to deformation due to loads of numerical simulation tends to discharge from the raceway center to its edge. The maximum value of total strains is 0.0943 mm in the case of numerical simulation and the maximum deformations value in the case of determining experimental values from 0.014-0.017 mm, measured in the surface layer of the bearing ring in the axial direction.

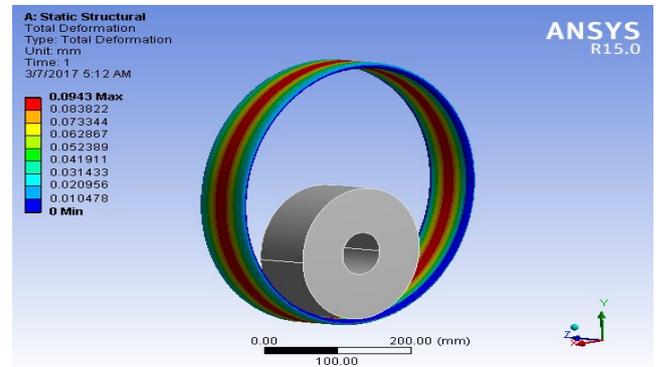


Fig.7 Total deformations of the raceway for bearing ring

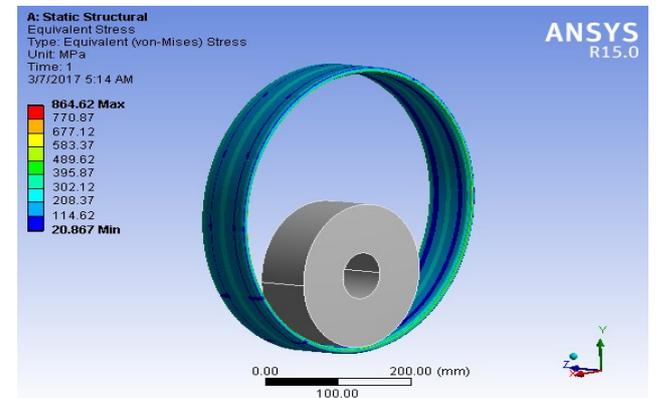


Fig. 8. Equivalent tensions on the raceway of the bearing ring

Experimental results obtained by incremental hole method of the strain gauge rosette using RESTAN MTS 3000 equipment are presented in table 4 and figure 9.

In the surface layer of the material have been determined experimentally, maximum tensile residual stresses of about 843 MPa to a depth of 0.15um (figure 9). These maximum stresses were generated due to mechanical and thermal effects caused by severe grinding roughing conditions.

Table 4. Outer bearing ring

Measurement Depth [mm]	Minimum residual stress [N/mm ²]	Maximum residual stress [N/mm ²]	Von Misses [N/mm ²]
0.025	-85.218	170.319	225.355
0.075	130.22	838.853	781.918
0.125	102.691	843.286	796.918
0.175	-104.622	63.962	147.406
0.225	-271.63	-115.262	236.134
0.275	-250.47	-40.033	233.047
0.325	-128.437	6.163	131.627
0.375	-70.353	16.616	79.967
0.425	-78.714	11.257	84.904
0.475	-42.255	22.819	57.188
0.525	-84.847	-17.606	77.557
0.575	-72.01	-16.731	65.273
0.625	17.476	39.038	33.87
0.675	-95.595	-26.887	85.388
0.725	-10.579	18.029	25.054
0.775	-23.469	7.841	28.219

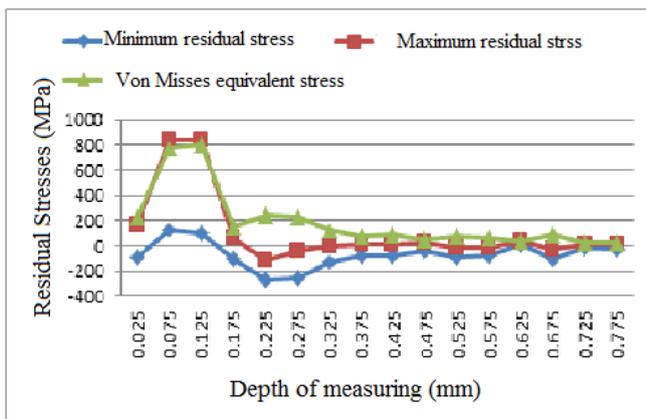


Fig. 9. Minimum, maximum and Von Mises experimental residual stresses on the raceway of the bearing ring

Analyzing Von Mises equivalent stresses is observed that in the superficial layer of the bearing ring material their maximum value is 864.62 MPa, noting that the values are close to determining both the experimental and numerical simulation. With increasing depth layer of the raceway, maximum and minimum residual stresses are compressive with a downward trend towards zero, including stress Von Mises, both experimental and in case of numerical simulation.

4. CONCLUSIONS

Experimentally and numerically have been determined residual stresses and Von Mises

equivalents stresses in the surface layer of the raceway of an outer bearing ring after grinding roughing operation. To the depth of 0.125 mm the resulting value indicates an increase in the maximum residual stress of 170 MPa tensile at 843 MPa and the Von Misses equivalent stress from 225 MPa to 796MPa. This increase is largely due to higher thermal effects from the surface layer during the grinding roughing.

At depths greater than 0.2 mm in the surface layer, the maximum and minimum residual stresses have small values of compression, which are favorable for increasing the fatigue strength of bearings in service. Von Mises equivalent stress has the same downward trend towards zero, both when determining experimental and numerical modeling.

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