# RESIDUAL STRESSES GENERATED AT ROUGHING GRINDING AND HARD TURNING OF RACEWAYS OF BEARING RINGS

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***Abstract:*** Cutting processing can generate in the bearing rings residual stresses that influence the behavior in operating of the bearings. The size of the residual stresses depends on the type and parameters of cutting processing, geometric parameters and cutting tool condition. Grinding and hard turning represent finishing processes of bearing rings, influencing differently the generation of residual stresses in the surface layer and in the depth of the raceways. The paper presents the results of the measurement of residual stresses in the processed depth surface of raceways of bearings rings through two processes of finishing, grinding and hard turning. Experimental tests were conducted at SC Rulmenti Barlad and for the measurement of residual stresses was used incremental drilling method of rosette strain gauge, using the equipment RESTAN-MTS3000. Measurements of the dimensional and shape deviations were made to determine their correlation with the size of the residual stresses.The study results recommend the use of cutting processing by hard turning for the raceway of bearing rings finishing, because it provides compressive residual stresses for a depth higher than grinding operations raceways. In addition, the greater depth of compressive residual stresses for hard turning is much more beneficial in terms of fatigue resistance of the bearings than the less deep but outsized tensions generated after grinding. Elastic deformations due to fixation of bearing rings during processing have a greater influence than residual stresses both on the out of roundness and the rectilinearity deviations. This study has identified differences between the integrity of grinded and hard turned surfaces due to the nature and size of generated residual stresses and their subsequent impact on the bearings precision and resistance to fatigue in rolling contact.
***Key words:*** residual stresses, bearing ring, grinding, hard turning, dimensional deviations, shape deviations.

## 1. INTRODUCTION

As a result of cutting processing of the bearings rings performed after secondary hardening heat treating, residual stresses are generated. Finishing processes (grinding, hard turning, etc.) determine during the cutting process a number of requests over the elastic limit, after which the residual stresses are generated, [1]. In these conditions, the residual stresses are generated due to the formation of a thermal gradient of plastic deformation near the surface layer by the mutual interaction of mechanical, thermal loads and metallurgical phase transformations, [2]. Bearings rings contain residual stresses generated after previous mechanical processing of the material (Figure 1) and the next cutting process generates in turn new residual stresses which modifies the initial state of existing stresses, [3].

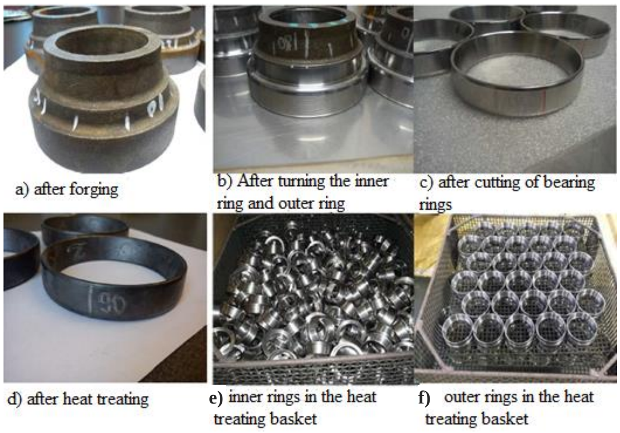



Fig.1. Rings bearings after various manufacturing processes, [3]

The nature, size and distribution of residual stresses are influenced by cutting parameters (cutting speed, feed, depth of cut), the geometry of the cutting tool (rake angle, setting angle, the cutting edge of the cutting tool), physical and thermal properties of the cutting tool material and the material to be processed, the mode of lubrication, etc.

Besides the mentioned parameters, residual stresses are influenced by a number of other specific factors such as the interaction between tool and workpiece, tool and removed splinter, thermal expansion of the workpiece and operating conditions of the machine tool (stability, rigidity, vibration). In chip removal

processes, due to plastic deformation, occurs a propagation of deformations, which leads to residual stress areas development that depend on the depth of metal removal, sharpening tools and chip removing workability of the workpiece material.
Brinksmeier et al., [4] showed that the elastic deformation of bearings rings after their fixing in the chuck, leads to a variation in depth of cut, this being the reason of the occurrence of form deviations after cutting processing operations. In addition, the machining process induces, locally different stresses, which also contributes to the appearance of the dimensional and form deviations of machined rings. If after the processing operation by turning, the out of roundness deviation was 200μm, after secondary heat treating it was measured a deviation from circularity of 240μm (Figure 2). This increase is due to relaxation of residual stresses generated after processing.

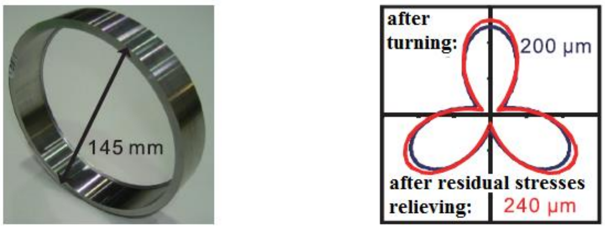


Fig. 2. Out of roundness caused by residual stresses generated during processing, [4]

In Brinksmeier's studies are presented and discussed the results of experimental investigations of distortion of bearings rings, obtaining strategies for minimizing these distortions.

## 2. MATERIAL AND METHOD

### 2.1. Experiments planning

The bearing rings material from the experimental tests is 100CrMnSi6-4 bearing steel whose chemical composition and technical features can be found in Tables 1 and 2.

Table 1. The chemical composition of the bearing steel

| Steel Mak/ Equivalent Mark | Chemical composition, % | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | Cr | Mo max. | S max. | P max. | Ni max. | Cu Max. |
| 1100CrMnSi 6-4/ 100CrMnSi6-4 ISO 683-17 | 0.93 ÷ 1.05 | 1.00 ÷ 1.2 | 0.45 ÷ 0.75 | 1.4 ÷ 1.65 | 0.10 | 0.015 | 0.025 | 0.25 | 0.25 |

Bearing rings were processed using standard technological direction. It started from the forged workpiece obtaining the finished bearing ring, applying including the secondary heat treatment, quenching and tempering. The present experiments were done on the raceway of two bearings rings, one of the ring being processed by roughing grinding and the other by hard turning. Processing of bearing ring through roughing grinding operation by the diameter of the raceway, was done on the machine SASL 200 (centerless grinding machine) using an abrasive wheel bakelite 500x(2x250)x305-11A60N, using technological parameters presented on the table 3.

Table 2. Characteristics and mechanical properties for the bearing steel

| Steel Mark | Structure type after secondary heat treatment | Hardness (HRC) | Tensile strength $R_m$ (MPa) | Stress flow $R_{p0.2}$ (MPa) | Breakage elongation $A_5$ (%) | Breakage strangle Z(%) |
|---|---|---|---|---|---|---|
| 100CrMnSi6-4 (ISO 683-17) | Martensit | 61÷64 | 2300 | 1700 | 2 | 2 |

Table 3. Technological parameters used to roughing grinding

| Average for the removed machining add, [mm] | Depth of cutting / crossing, [mm] | Number of crosses | Rotation speed grinding wheel, [rot/min] | Cutting speed, [m/s] | Feed rate / crossing, [m/min] |
|---|---|---|---|---|---|
| 0.3 | 0.15 | 2 | 1200 | 29.5 | 0.5 |

The processing of bearing ring through the operation of hard turning to the diameter of the runway, was executed on the lathe type ECOCA MT 312-CNC, using a knife lathe having inset with cubic boron nitride (CBN), type VBGW 160404 NU2 (Sumitomo) using the following technological parameters from Table 4.

Table 4. Technological parameters used in hard turning

| Depth cutting / crossing, [mm] | Processing add, [mm] | Number of crosses | Rotation speed workpiece, [rot/min] | Longitudinal feed rate, [mm/min] |
|---|---|---|---|---|
| 0.05 | 0.1 | 2 | 600 | 20 |

## 2.2 Methodology

For the determination of residual stresses was used the RESTAN-MTS300 equipment [5] as well as the incremental drilling method of the strain gauge rosette [6, 7, 8, 9]. The method consists in sticking the strain gauges rosette RY 61 (highly sensitive) on the the raceway surface of the bearing ring (in a tensioned state of equilibrium) and the elements of strain gauges rosette are connected to an indicator of deformation (Figure 3).

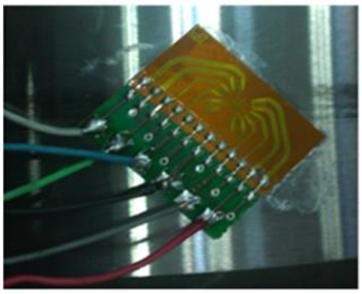


Fig.3. Bonding strain gauge rosette on the raceway of the bearing ring and connecting it to a deformations indicator

The drill support, having a cutter drill with 1.6 mm diameter inverted cone, was aligned in the center of the strain gauges rosette (Figure 4), to execute a hole in its center. During drilling operations, the microscope is perfectly axially positioned with high speed air turbine where the drilling support is. The microscope has a double function: first, to allow perfect alignment of the cutter in terms of benchmarks in central strain gauges rosette; second, to allow its inspection and measuring the diameter of the hole (measurement of hole eccentricity executed).

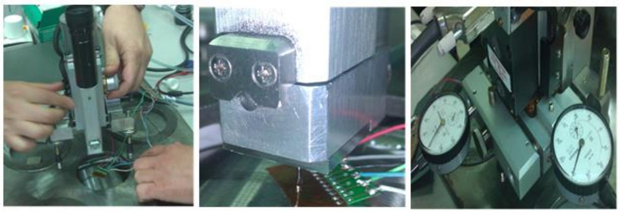


Fig. 4. Centering the drill cutter in center of the strain gauges rosette

The drilling was performed in 16 incremental steps (0.05mm on step) to a maximum depth of 0.8 mm, measuring strains at each increment of depth (Figure 5).

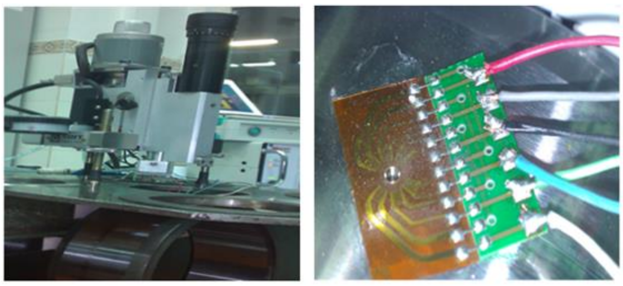


Fig. 5. Ring bearing assembly - MTS 3000 equipment

The material removing caused a relaxation of residual stress around the hole from the center of the rosette, therefore the equilibrium state will be destroyed and a new distribution of residual stress around deformed material will be realized, namely a relief. Around the executed hole the material will relax and the existing residual stresses can cause strains in the area of the processed material, which are detected and measured by a strains indicator. The obtained values of strains will be used for calculation of residual stresses.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Measurement of the dimensional and shape of the bearing rings

Measurement of the diameter of the tread of the bearings rings was performed with ULM 02-600 instrumental and the results are presented in Table 5.

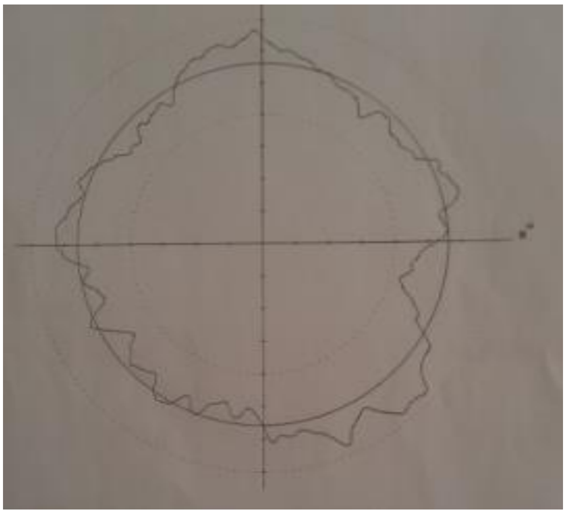
Table 5. Dimensional and form deviations for bearings rings after roughing grinding and hard turning

| No. | Bearing ring NU2232 MA-20 | Raceway diameter, [mm] | Out of roundness, [µm] | Deviation from rectilinearity, [µm] | Roughness Ra, [µm] | Roughness Rz, [µm] |
|---|---|---|---|---|---|---|
| 1 | Bearing ring grinded | 194.933 | 2.45 | 2.686 | 0.279 | 2.075 |
| 2 | Bearing ring hard turned | 194.809 | 5.45 | 5.633 | 0.229 | 1.151 |

In order to measure the out of roundness raceways of the bearings rings subjected to tests, it was used measuring machine out of roundness Talyrond 73. The results are shown in Table 5 and Figure 6.

FORM TALYSURF SERIES 2 is an instrument type PGI (laser), which was used for measuring straightness deviations (Figure 7) and the roughness Ra and Rz (Figure 8), for the raceway of the bearing rings. The results are present in Table 5.

The geometrical characteristics of the cutting edge of cutting tool in hard turning and of the abrasive grains from the grinding wheel material led to the creation of different surface structures. After roughing grinding may be obtained surfaces with Ra roughness less than 0.3µm. After hard turning may be obtained equivalent surfaces with surface Ra roughness less than 0.23µm.



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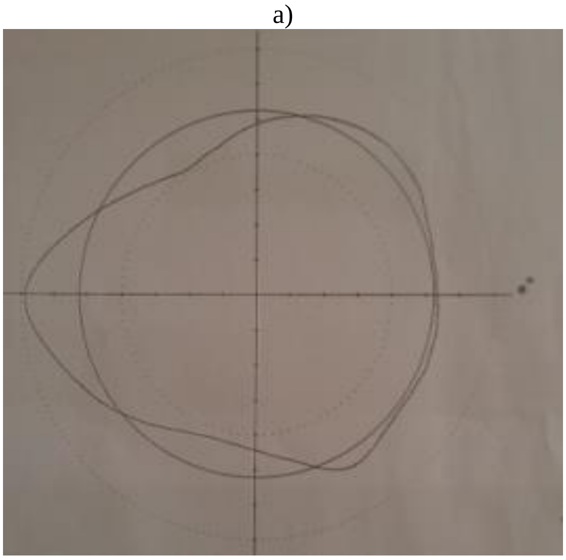
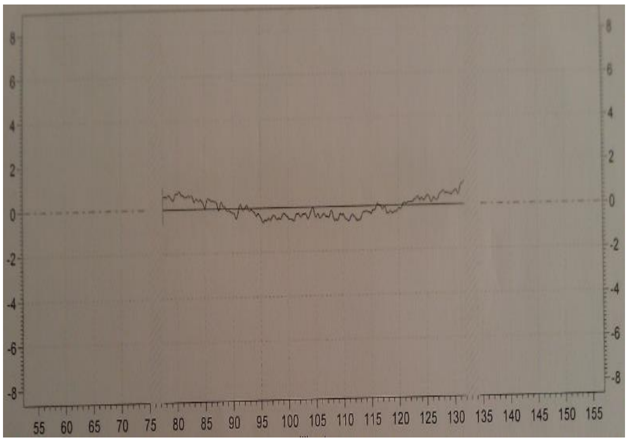


b)

Fig. 6 The profile of the out of roundness raceways using the tool TALYROND 73: a)-after grinding; b)-after hard turning

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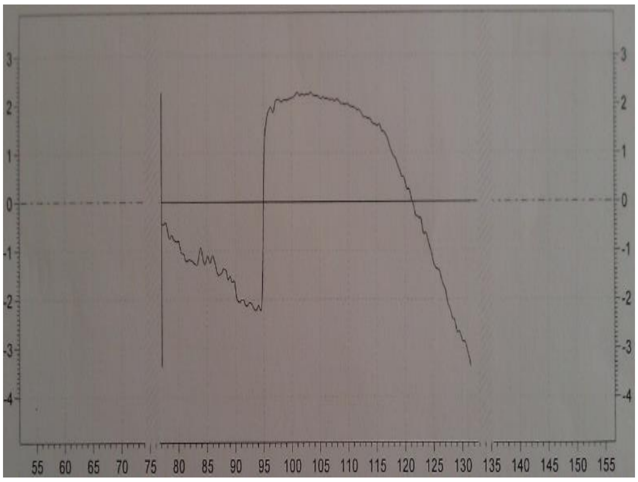
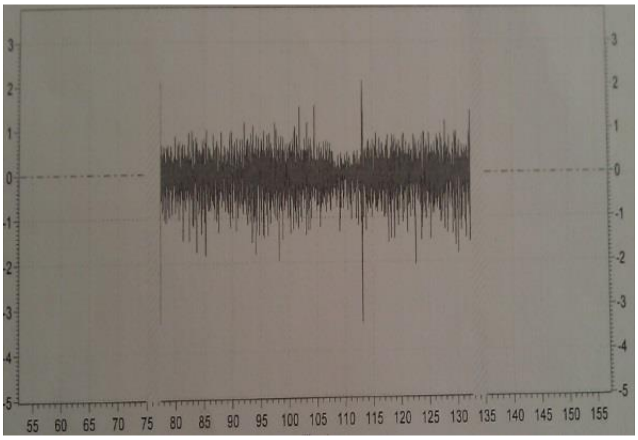
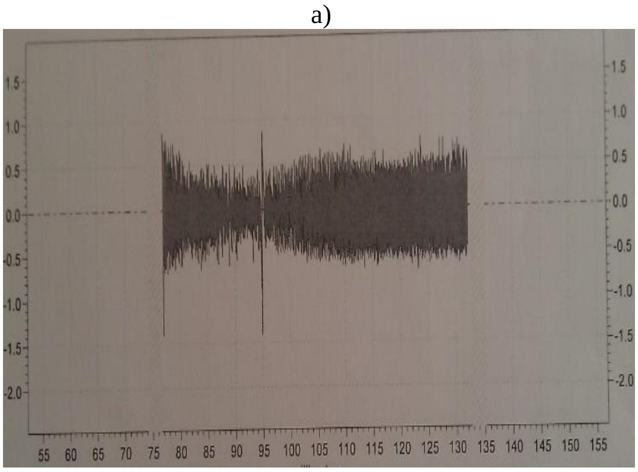



b)

Fig. 7. The profile deviations from rectilinearity for raceway of bearings rings: a) - after grinding; b) - after hard turning




a)




b)

Fig. 8 The roughness profile for raceway of bearings rings: a) - after grinding; b) - after hard turning

**3.2. Measurement of strains. Calculation of residual stresses by the integral method**

As mentioned above, using the incremental drilling method of strain gauges rosette as well as the RESTAN-MTS300 equipment, on the bearing ring raceway, in the center of the strain gauges rosette were executed 1.6 mm hole to a depth of 0.8mm and the actual drilling operations was executed in 16 incremental drilling steps with an increase of 0.05mm at each step.

The strains measurement was performed at every step of the drilling and using the integral method were calculated residual stresses. For each strain gauge rosette located on the ring bearings raceway were obtained three strain values in three distinct points at the angular distances equal to 120° of the executed hole. Strains values measured are presented in Tables 6 and 7, and these values are used by the software package used to calculate residual stress.

Table 6. Measured strains for grinding bearing ring

| No. | Depth of measurement [mm] | Strain (a) $\varepsilon_a$ | Strain (b) $\varepsilon_b$ | Strain (c) $\varepsilon_c$ |
|---|---|---|---|---|
| 1 | 0.025 | 3.103 | 5.101 | 2.764 |
| 2 | 0.075 | 3.469 | 5.297 | 2.913 |
| 3 | 0.125 | 3.181 | 5.227 | 2.791 |
| 4 | 0.175 | 3.249 | 5.255 | 2.594 |
| 5 | 0.225 | 3.223 | 5.078 | 2.095 |
| 6 | 0.275 | 2.453 | 4.281 | 1.100 |
| 7 | 0.325 | 0.889 | 2.787 | -0.410 |
| 8 | 0.375 | -1.008 | 1.007 | -2.182 |
| 9 | 0.425 | -2.795 | -0.616 | -3.843 |
| 10 | 0.475 | -4.432 | -2.099 | -5.266 |
| 11 | 0.525 | -6.166 | -3.714 | -6.667 |
| 12 | 0.575 | -8.146 | -5.441 | -8.228 |
| 13 | 0.625 | -10.316 | -7.162 | -9.875 |
| 14 | 0.675 | -12.669 | -9.281 | -11.674 |
| 15 | 0.725 | -14.806 | -11.006 | -13.246 |
| 16 | 0.775 | -16.827 | -12.647 | -14.858 |

Table 7. Measured strains for hard turning bearing ring

| No. | Depth of measurement [mm] | Strain (a) $\varepsilon_a$ | Strain (b) $\varepsilon_b$ | Strain (c) $\varepsilon_c$ |
|---|---|---|---|---|
| 1 | 0.025 | -1.290 | -0.848 | -0.727 |
| 2 | 0.075 | 2.778 | 3.518 | 3.446 |
| 3 | 0.125 | 4.075 | 4.132 | 4.837 |
| 4 | 0.175 | 4.684 | 4.731 | 5.565 |
| 5 | 0.225 | 6.356 | 6.561 | 6.652 |
| 6 | 0.275 | 7.909 | 7.984 | 7.198 |
| 7 | 0.325 | 8.022 | 8.076 | 6.851 |
| 8 | 0.375 | 7.290 | 7.722 | 6.441 |
| 9 | 0.425 | 6.583 | 7.561 | 6.288 |
| 10 | 0.475 | 5.182 | 6.701 | 5.493 |
| 11 | 0.525 | 2.977 | 5.049 | 4.209 |
| 12 | 0.575 | 2.377 | 4.696 | 4.434 |
| 13 | 0.625 | 0.725 | 3.295 | 3.534 |
| 14 | 0.675 | -12.407 | -7.869 | -6.745 |
| 15 | 0.725 | -11.200 | -7.966 | -6.454 |
| 16 | 0.775 | -14.480 | -11.675 | -9.275 |

Minimum and maximum residual stresses and the Von Misses stress, calculated through the integral method using the calculation software of the MTS 3000 equipment are presented in Tables 8 and 9 and graphs in Figures 9 and 10.

Table 8. Residual stresses calculated for grinding bearing ring

| No. | Depth of measurement, [mm] | Angle α, [degree] | Minimum residual stress, $\sigma_{min}$ [MPa] | Maximun residual stres, $\sigma_{max}$ [MPa] | Residual stress for von Misses criteria, [MPa] |
|---|---|---|---|---|---|
| 1 | 0.025 | -47.239 | -141.442 | -45.297 | 125.103 |
| 2 | 0.075 | 52.501 | -1.418 | 13.017 | 13.780 |
| 3 | 0.125 | 19.415 | 16.172 | 22.224 | 19.900 |
| 4 | 0.175 | 66.252 | 8.487 | 15.242 | 13.228 |
| 5 | 0.225 | 75.160 | 11.416 | 20.594 | 17.870 |
| 6 | 0.275 | -83.185 | 25.977 | 29.345 | 27.815 |
| 7 | 0.325 | 22.583 | 47.861 | 52.439 | 50.307 |
| 8 | 0.375 | 11.994 | 53.938 | 58.968 | 56.621 |
| 9 | 0.425 | -4.316 | 46.653 | 50.143 | 48.492 |
| 10 | 0.475 | 10.256 | 36.837 | 42.186 | 39.782 |
| 11 | 0.525 | 17.097 | 36.022 | 44.508 | 40.930 |
| 12 | 0.575 | 1.307 | 51.668 | 60.868 | 56.829 |
| 13 | 0.625 | -16.870 | 60.799 | 74.543 | 68.710 |
| 14 | 0.675 | 10.901 | 74.862 | 87.848 | 82.129 |
| 15 | 0.725 | -10.865 | 67.259 | 80.818 | 74.964 |
| 16 | 0.775 | -22.867 | 71.408 | 82.381 | 77.479 |

Table 9. Residual stresses calculated for hard turning bearing ring

| No. | Depth of measurement, [mm] | Angle α, [degree] | Minimum residual stress, $\sigma_{min}$ [MPa] | Maximum residual stress, $\sigma_{max}$ [MPa] | Residual stress for von Misses criteria, [MPa] |
|---|---|---|---|---|---|
| 1 | 0.025 | -14.849 | 13.234 | 16.685 | 32.145 |
| 2 | 0.075 | -42.731 | -129.964 | -140.843 | 125.652 |
| 3 | 0.125 | 44.627 | -40.06 | -9.838 | 36.159 |
| 4 | 0.175 | 25.725 | -2.295 | -0.999 | 1.993 |
| 5 | 0.225 | -61.918 | -32.458 | -10.597 | 28.669 |
| 6 | 0.275 | -69.741 | -25.229 | -0.441 | 25.012 |
| 7 | 0.325 | -69.196 | 16.379 | 25.023 | 22.013 |
| 8 | 0.375 | -10.260 | 26.813 | 37.691 | 33.60 |
| 9 | 0.425 | -15.527 | 14.749 | 29.979 | 25.963 |
| 10 | 0.475 | -13.464 | 37.416 | 51.128 | 45.837 |
| 11 | 0.525 | -1.308 | 57.49 | 74.967 | 67.936 |
| 12 | 0.575 | 17.973 | 13.015 | 5.92 | 16.777 |
| 13 | 0.625 | 15.936 | 44.249 | 59.506 | 53.534 |
| 14 | 0.675 | -11.083 | 10.252 | 8.764 | 14.432 |
| 15 | 0.725 | 63.534 | 31.547 | 47.842 | 50.762 |
| 16 | 0.775 | 39.168 | 8.246 | 6.456 | 10.764 |

Figure 9 shows that for grinding bearing ring both the minimal residual stress (-150MPa) and the maximum (-50MPa) are compressive, being descending to a depth of about 0.1mm, so beneficial to bearing ring raceway, becoming then tensile, with maximum values around 75mp. As observed in Figure 10, in case of the bearing ring whose raceway was processed by hard turning, both the maximum, (-140MPa) and the minimum (-130MPa) residual stresses are compressive maintained to a depth of 0.320mm, being beneficial to a depth higher than the calculated residual stresses for the grinding bearing ring.

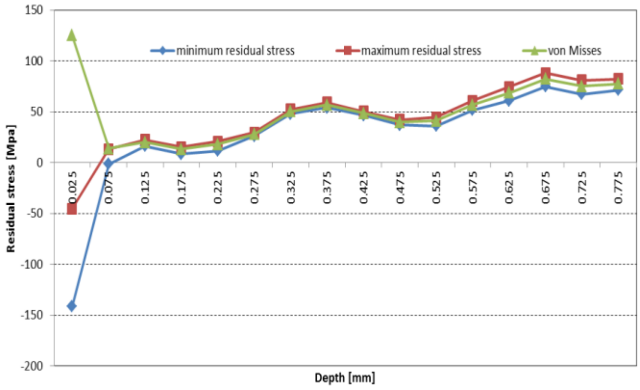



Fig. 9. Minimum and maximum residual stresses and the von Misses depending on the depth of incremental cutting for grinding bearing ring

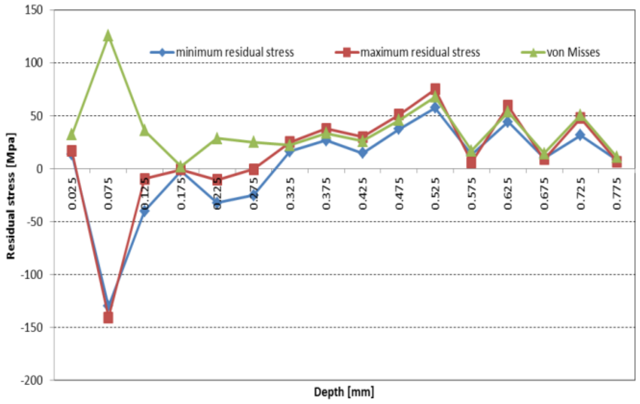



Fig. 10. Minimum and maximum residual stresses and the von Misses depending on the depth of incremental cutting for hard turning bearing ring

## 4. CONCLUSIONS

The most significant difference between hard turning and grinding is that hard turning can generate a compressive residual stress relatively deeper (0.320mm), while the grinding produces the maximum of the surface residual stress (0.1mm). Compressive residual stresses generated by hard turning (-140MPa) and grinding (-150MPa) are observed in the superficial layer of the bearing raceways and this will improve fatigue resistance in running contact. In addition, the greater depth of compressive residual stresses for hard turning is much more beneficial in terms of fatigue resistance of the bearings than the less deep but outsized tensions generated after grinding. The study showed that distinct patterns of the residual stresses do not affect more the size neither the peaks locations od the stresses and depth strains. It is seen that they have an important influence on surface strains. Direction and depth of a compressive residual stress are key factors for fatigue resistance in running contact (RCF).

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Received: May 25, 2016 / Accepted: December 10, 2016 / Paper available online: December 20, 2016 © International Journal of Modern Manufacturing Technologies.