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RESEARCH ON MEASUREMENT OF ELASTIC ROLLER DEFORMATIONS IN ROLLER BEARINGS BY IMAGE CORRELATION METHOD

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Abstract: *Determining the deformations and the contact stress of the rollers in the roller bearing structure is difficult to achieve experimentally. Usually the research focuses on calculations of the contact stress at the roller-ring contact and considers the general model of the Hertz-type contact with various particularities. The aim of the paper is to develop a measuring methodology for the elastic deformations of the rollers in the structure of general-purpose roller bearing. Experimental work was performed on determining the elastic roller deformations for the most loaded roller using a non-contact and material-independent method based on the principle of digital image correlation (DIC) - without expensive and time-consuming preparations. The experimental data was used further to perform more accurate Finite Element Analysis.*

Key words: *roller bearings, digital image correlation, elastic deformation.*

1. INTRODUCTION

Roller bearings are essentially machine parts with simple construction but with a very complex geometry and strictly imposed geometric conditions for the components. Roller bearings fatigue life is affected by the stress state that is found at the contact between the raceway of the ring and the roller [1-2]. The requirements imposed on the bearings regarding durability, high load, low noise require improvements of the component elements rings, rollers, cages. On the other hand, the requirements related to the manufacturing costs require optimizations/ improvements of the technologies/technological paths of manufacturing the components.

In roller manufacturing a special attention is granted to the profile of the roller for edge stress reduction on the raceway - roller contact surface. The edge of the roller and the raceway of the ring are crowned for avoiding early fatigue failure of the rolling components caused by stress contraction named “edge loading” [3, 4, 5]. Usually cylindrical rollers are crowned only on a portion of the roller and remaining portion of the profile is cylindrical [3]. The analytical calculation of the geometry for the roller profile is based on the general model of the Hertz-type contact with various particularities [6, 7, 8, 9].

Lundberg suggested a mathematically logarithmic profile curve for uniform stress distribution [1]. But machining a rectilinear generator profile (uncrowned/ straight profile) for cylindrical or tapered rollers is preferable for convenient machining using less complicated grinding equipment.

In order to obtain rollers with a logarithmic or convex profile, a high precision of execution is required. Special attention must be paid to the phases of obtaining the final geometry of the roller in the rectification or super-finishing phases, since the reduced values of the camber must be obtained systematically for the entire roller in the analyzed batch. It should also be taken into account that a certain type of roller can be found in the construction of several types of bearings of different types and sizes. In the case of a logarithmic crowned profile the crown drop form successive axial points can be calculated to fraction of micrometres using the logarithmic mathematical model, but in order to materialize by external cylindrical grinding the grinding machine precision and repeatability particularly must be high.

When the rollers present a crowned profile, the maximum contact pressure between the rollers and the inner ring is greater than that between the rollers and the outer ring. For this reason, when considering the optimization of the roller profile, it is sufficient to consider the contact between the rollers and the inner ring.

The discontinuities that appear in the connection area between the cylindrical part of the roller and the crowned profile can cause the appearance of high contact stresses, reducing the nominal life of the bearing.

The high stresses that appear on the contact surface do not penetrate into the depth of the rolling bodies, because as the stress stresses the part, it is distributed in the material, as a result of which most of the defects of the running bodies appear on the running surface [3].

As a result, the determination of surface stresses and in the surface layers of rolling bodies is of particular interest for the calculation of bearings.

Contact deformations occur under the action of contact stresses. As a result of the rigid nature of the rolling elements, these deformations are generally small in size, eg 0.025 mm (0.001 inch) or less [3].

Experimental analysis of deformations is difficult to perform in order to determine elastic and contact deformation of the roller and raceway. The majority of experimental research is focused on durability and fault diagnosis using various experimental methods such as: vibration and noise analysis, temperature and infrared analysis, chemical and oil analysis.

Also, there are many studies focusing on durability testing in various conditions by using different test benches for bearings durability [10, 11, 12].

Another important research direction is focused on generating different geometry/ profile for the roller by using different mathematical models an afterwards simulating the roller – raceway contact in order to improve contact stress distribution. [1, 4, 7, 8, 9, 13]. Finite element analysis is a very powerful instrument for contact stress state evaluation but in order to obtain best results an experimental validation is necessary and in the case of roller-raceway contact pair is very difficult to experimental measure elastic and contact deformations. In order to correctly calibrate a finite element analysis experimental data is necessary or comparison with analytical solutions. Various experimental method are available for dimensional and stress measurement such as three-dimensional photo elasticity or digital image correlation [11, 14, 15]. Digital image correlation (DIC) method relies on comparing grayscale intensity of the captured images form one or more special camera of the test piece surface, that is usually prepared, under various loads in order to obtain information that are filtered with specific correlation criteria [11].

The aim of the paper is to develop a measuring methodology for the elastic deformations of the rollers in the structure of general-purpose roller bearing by using digital image correlation that can be used to further for accurate Finite Element Analysis.

2. MATERIALS AND METHODS

For the purpose of this paper a general purpose roller bearing was analyzed NU 318 E that uses 13 cylindrical roller, diameter 28 mm length 30 mm, presented in figure 1 a. Roller hardness after treatment is 62.5 HRC.

The logarithmic profile of the roller was determined by using ISO/TS 16281: 2008 standard [5].

$$P(x_k) = 0.00035 \cdot D_{we} \cdot ln\left[\frac{1}{1-(2\cdot\frac{x_k}{L_{we}})}\right] \quad (1)$$

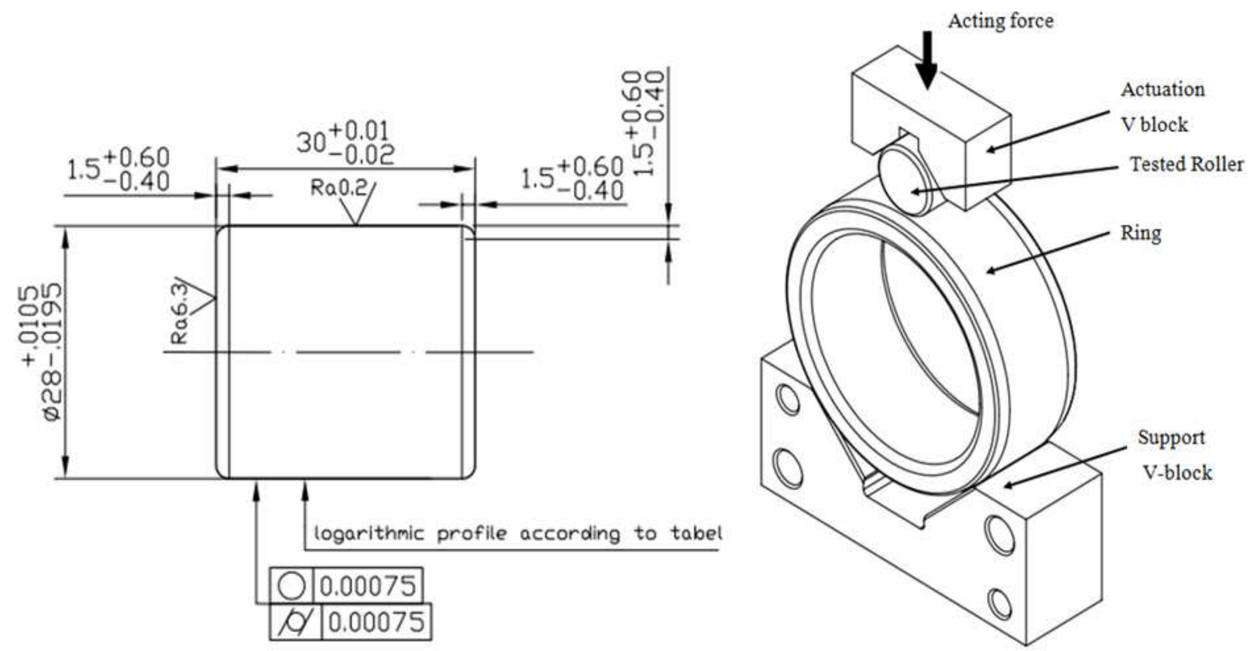
L_{we} - effective roller length, in millimeters, applicable in the calculation of load ratings.

Dwe - roller diameter, in millimeters, applicable in the calculation of load ratings,

x_k - distance, in millimeters, between centre of lamina *k* and roller centre.

The roughness Ra obtained has a mean value of 0.1705μm. Roller and ring material is 100CrMnSi6-4.

A test stand was constructed to highlight only the state of deformations under certain loads of a single roller in contact with the inner ring the basic diagram is presented in fig. 1.b.



a b

Fig. 1. a Tested roller **b**. Loading scheme.

The application of the forces was achieved by means of a prism that presses on the roller that is guided in the vertical direction. The guide does not allow the roller to slip/shift of the raceway.

The actuation force that will act on the roller will be 5 kN (500kgf) a value greater than 10% of the bearing's nominal capacity of 31.5 kN.

The data acquisition was carried out with 2 measuring equipments, namely the force measurement system – consisting of the S9 force transducer, Spider 8 multi-channel amplifier and computer and the GOM measurement system that ran the ARAMIS strain and stress measurement program.

The GOM non-contact measuring system uses high-resolution 3D stereo camera system, which provides precise 3D coordinates of reference points (markers). The lenses used by these cameras offer exceptional performance when associated with direct measurement programs.

For statically or dynamically requested components, ARAMIS provides accurate information regarding: 3D coordinates; 3D movements, speeds, accelerations; surface tensions. ARAMIS analyzes, calculates and documents displacements and deformations.

By graphically representing the measurement results, it provides an optimal understanding of the behaviour of the measured object.

ARAMIS recognizes the surface structure of the object to be measured by using digital camera images and assigns coordinates to the image pixels.

In order to perform the experiments, the following methodology were followed

1 – preparing the roller and ring by painting in black and white and aping a stochastic pattern, assembly all components in the stand,

2 – the application of a clamping force of 0.5 kN, to take up the clearances in the system and check the alignment of the respective components of the mobile prism is guided to prevent slippage/roll rotation.

3 – application of an acting force.

4 – measurement of roller deformations/ displacements using the DIC – Digital Image Correlation method.

3. RESULTS

The preformed experiments used logarithmic roller with a diameter of 28 mm and length of 30 mm in contact with a standard inner ring exterior diameter of 113 mm and a interior diameter of 90 mm, width 43 mm.

During the calculation, ARAMIS observes the deformation of the specimen through images by analyzing different square or rectangular images image details called facets.

Fig. 2. View of the test setup imagine undistorted, left and right camera.

The acting force is measured by HBM S9 force transducer. After recording the force evolution data, that was saved in Diadem format and later processed.

ARAMIS recognizes the surface structure of the object to be measured by using digital camera images and assigns coordinates to the image pixels.

The captured image from the measurement project presented in figure 2 represents the undeformed state of the object. During the deformation of the object to be measured, under the acting force additional images are recorded. ARAMIS then compares the digital images and calculates the displacement and deformation of the object's features.

If the object to be measured has only a few specific characteristics, as is the case with homogeneous surfaces, the surface must be prepared by appropriate methods, for example applying a stochastic by painting using a white layer and spraying a fine black layer.

At the start of the experiment images are recorded (monochrome, right camera, left camera) in different loading stages of the specimen, figure 2. An area of interest is defined (calculation mask) a start point for the displacement calculation is selected.

From the coordinates of the resulting 2D image of the facet (centre point of the facet) provide by the right and left imagines camera, the software now calculates the 3D position of the facet.

After calculating the 3D positions of a stage, the software automatically continues with the next stage. And here, in principle, the position of the facet is known thanks to the definition of the starting point. Now, the calculation of the facet's 3D position starts again. Finally, the calculation of the deformation of the part results from the displacements of the 3D points.

Figure 3 presents the view taken by the two stereo cameras of the GOM measurement system optical system 3D in the stressed state in stage 9 of the experiment. The photo acquisition frequency was 1 capture/s.

In order to complete the calculation the facets from the surface of the roller must be visible in all stages by the two cameras.

In the case of experimental determinations, the elastic deformations of the roller separate from the elastic deformation of the ring. The elastic deformations of the roller were highlighted by using a measuring line - L. Also, some contact deformations values can be extracted.

In order to highlight the deformations of the ring or the rigid movement of the roller, we can use the capture that shows the displacements of the lower, central and upper points during loading with a load of up to 5 kN.

In

de

m

In the case of L that is the closest line to vertical that can be used the length is 26.764 mm.

The system allows the tracking of this line for the entire load duration of the roll. In addition to the line marking the extremes, other points were ... the

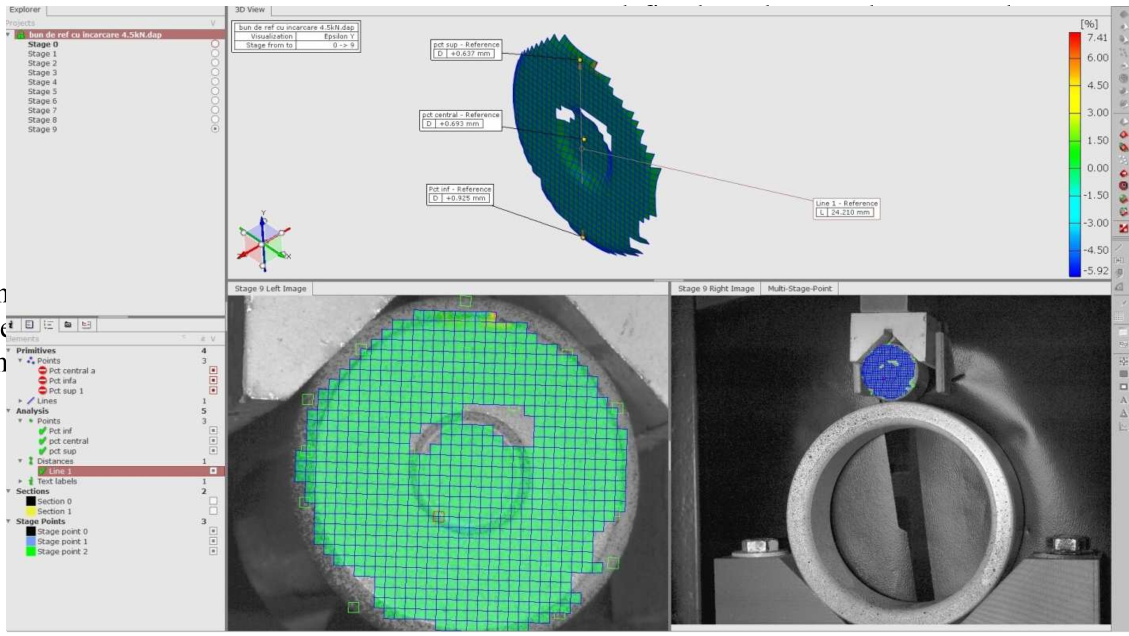


Fig. 3. View of the processed captured images.

The absence of the green marking, from fig. 3, on the screens of the 2 cameras leads to a lack of data and the calculations regarding the deformations of the analyzed piece cannot be performed.

By using points that are found in all image captured, as previously presented, the behaviour of the system can be determined with high precision.

In the presented captures, the area for which the deformation calculations were made was marked.

From the analysis of the untensioned and tensioned views of the roller, the extreme diametral points that can be visualized in each image captured by the GOM system are marked with L measurement line. L mark the points that are visible in all captured image from 0 to 9.

One disadvantage of DIC method is that for any reason in any one captured image of a facet is not visible a diametral line cannot be used to track deformations.

From the analysis of the change in the length of the line, which in stage 1 was 27.764 mm, in stage 9 it will be 27.760 mm result a deformation strain of 4 μm at a load of 5 kN.

Following the testing of rollers 13 roller, a similar behaviour is observed for all 13 namely:
- there is a tendency for the roller to rotate under load,
- the elastic deformations that can be highlighted for the extreme areas of the roller are 3 - 4 μm,
- the elastic deformations and the highlighted behaviour is similar during loading and unloading,
- carrying out the experiments is difficult as a result of the tendency of the roller to rotate and also there are small differences in the stochastic template of the applied paint which makes it difficult to perform measurements in the contact area of the roller ring. There are captured images that don't offer sufficient facet to calculate displacements.

A Finite Element Analysis was performed in Ansys 15, module Workbench, for the same testing conditions. All component were accurate model previously in Solidworks. Based on the experimental data in the Ansys V15.0 we could select the proper contact conditions in order to obtain similar behaviour for roller to the tested part.

The aim of the paper is to develop a measuring methodology for the elastic deformations of the rollers in the structure of general-purpose roller bearing by using digital image correlation that can be used to further for accurate Finite Element Analysis.

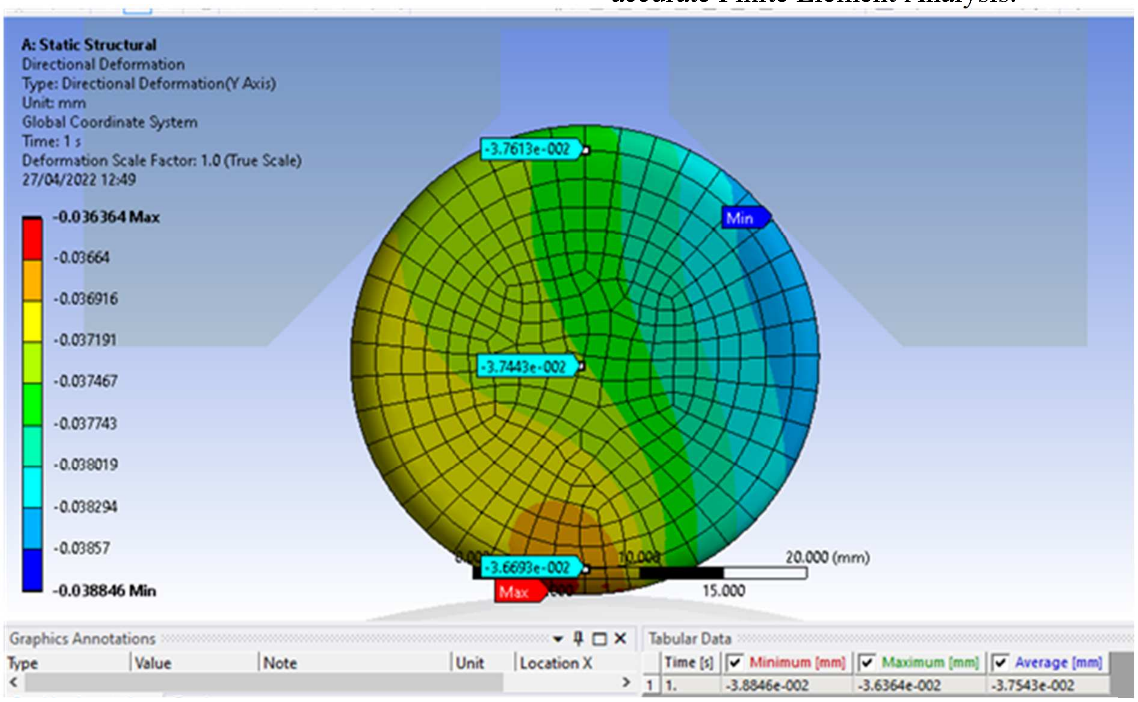


Fig. 4. View of the FEA verification,

Due to the various contact problems that can be defined in Ansys and the small variation of the profile for the roller the correct setting for the Finite Element Analyse can be hard to obtain.

From the deformations calculated for the roller for purely elastic deformation on the y-axis, according to the presented model, deformation values of 3-4 μm are observed when selecting areas similar to the areas where experimental measurements were made.

These values are determined considering only the difference between the elastic deformation in the upper and the lower part, as presented in figure 4.

Finite Element Analsys can be used detect impact of the differences in the profile through the distribution of the contact stresses and the maximum values of the calculated stresses.

4. CONCLUSION

Experimental analysis of deformations is difficult to perform in order to determine elastic and contact deformation of the roller and raceway.

In roller bearing construction a special attention is granted to the profile of roller mainly the edge of the roller and the raceway of the ring are crowned for avoiding early fatigue failure of the rolling components caused by stress contraction named “edge loading”.

By using different mathematical models the profile of roller can be accurately defined but this profile must be machine precisely and repeatedly. In order to obtain rollers with a logarithmic or convex profile, a high precision of execution is required by using several machining processes and specialized machines.

Since the evaluation of elastic strain and contact stress is difficult to perform even with Finite Element Analysis an experimental verification method is required.

Experiments were performed by analysing 13 roller from a NU318 roller bearing in contact with the inner ring. The data acquisition was carried out with 2 pieces of equipment, namely the force measurement system – consisting of the S9 force transducer, the Spider 8 multi-channel amplifier and the computer and the GOM strain measurement system that ran the ARAMIS strain and stress measurement program.

ARAMIS sensors measure statically or dynamically loaded samples and parts using a non-contact and material-independent method based on the principle of digital image correlation (DIC) - without expensive and time-consuming preparations of the test object. The measurement resolution reaches down to sub micrometer.

From the analysis of the change in the length of the most visible diametrical line, which in stage 1 was 27.764mm, in stage 9 was 27.760mm. Resulting an deformation of 4 μm at a load of 5 kN of the 28 mm diameter roller.

The contact deformations are difficult to assess because of the lack of visible facets in the contact area for all the experimental stage. Further experimental data is required in order to increase the result reliability.

Since the experimental results regarding the purely elastic deformations measured on the front surface of the tested rollers are close to the results provided by the finite element analysis, the contact stresses calculated using finite element methods can be considered accurate.

Further research will include the entire structure of the roller bearing both in experimental research and in Finite Element Analysis. Also, an increase in acting force is required.

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CERCETĂRI PRIVIND MĂSURAREA DEFORMĂȚIILOR ELASTICE ALE ROLELOR DIN RULMENȚII CU ROLE PRIN METODA CORELĂRII IMAGINILOR

Rezumat: Determinarea deformațiilor și a tensiunii de contact a rolelor din structura rulmenților cu role este dificil de realizat experimental. De obicei, cercetarea se concentrează pe calculele tensiunii de contact la contactul rolă-inel și are în vedere modelul general al contactului de tip Hertz cu diverse particularități. Scopul lucrării este de a dezvolta o metodologie de măsurare a deformațiilor elastice ale rolelor din structura rulmenților cu role, de uz general. Au fost efectuate cercetări experimentale de determinare a deformațiilor elastice ale rolei pentru cea mai solicitată rolă folosind o metodă de măsurare fără contact și independentă de material, bazată pe principiul corelației digitale a imaginii (DIC) – ce nu necesită pregătiri costisitoare și consumatoare de timp. Datele experimentale au fost utilizate în continuare pentru a efectua o analiză cu elemente finite mai precisă.

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