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HIGH RESOLUTION MICROSCOPY AS TOOLS FOR SLIDING MICROBEARING RADIAL CLEARANCE AND GROOVES GEOMETRY MEASUREMENTS

MIKROSKOPY O WYSOKIEJ ROZDZIELCZOŚCI JAKO NARZĘDZIA DO POMIARU PROMIENIOWEGO LUZU ORAZ GEOMETRII ROWKÓW W MIKROŁOŻYSKU

Key words:

AFM, SEM, radial clearance, grooves geometry, measurements

Słowa kluczowe:

Mikroskop AFM, SEM, luz promieniowy, geometria rowków, pomiary

Summary

This paper presents a new non-classical method of radial clearance measurements in slide micro-bearing with grooves.

In this paper, the authors show that measurements of the radial clearance of micro-bearings cannot be determined with the required accuracy for

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hydrodynamic calculations and wear analysis just through subtraction from the internal diameter of the sleeve to the external diameter of the journal. Therefore, it is proposed to measure clearance directly by high-resolution microscopy using a metallographic sample of the cross-section of the assembly of sleeve and journal with the gap filled with glue.

The measurements are performed using an optic microscope, a SEM, and an AFM.

Analysis of lubrication shows that the ventilator or cooling fan micro-bearing has a hydrodynamic type of lubrication and the HDD micro-bearing has an elasto-hydrodynamic type of lubrication.

INTRODUCTION

Fluid dynamic bearings (FDB) with grooves are widely used in hard disk drives (HDD) and ventilators or cooling fans, because they have a better service performance than ball bearings [**L. 1, 2**]. Hydrodynamic lubrications (HDL) can produce spherical or ring-like bubbles in oil that reduces the bearing stiffness. Radial clearance, the number of grooves, and the groove geometry substantially influence on the rate of bubble mixture and HDL condition of sliding bearing [**L. 2–4**].

The radial clearance (RC) of a bearing is formed by the outer cylindrical surface of the journal and the inner cylindrical surface of the sleeve. In areas of grooves, the RC is increased in relation to the value of the depth of the elements. The RC of large-scale bearings is usually measured by contact methods using probes, removable strips, gauges and micrometers with a maximum accuracy of about 2 μm. Such resolution is not applicable for micro-bearings, since micro-bearings can have the following parameters according to specifications mentioned in publications:

- An RC with a value of 2.8 μm, radius of journal – 2 mm, 15000 rpm, groove angle 26°, groove type – herringbone, number of grooves – 8 see [**L. 5**];
- An RC with a value of 3.15 μm, radius of journal – 1.995 mm, 5000-10000 rpm, groove angle 26°, groove type – herringbone, number of grooves – 8 see [**L. 4**];
- An RC with a value of 5 μm and 15 μm, radius of journal – 2.5 mm, 20000 rpm, groove angle 15, 30 and 60°, groove type – herringbone, number of grooves - 8 and 16 see [**L. 2**].

In the present paper, we show the methods of high-resolution control based on the use of various types of microscopy for geometric analysis of micro-bearing components.

EXPERIMENTAL PROCEDURE

Optical microscopes, scanning electron microscopes (SEM) and atomic force microscopes (AFM) have been utilised for RC measurement of micro-bearings. All measurements have been performed on metallographic samples that have representative cross-sections of components. Metallographic samples have been prepared using standard procedure without any etching treatment of polished samples.

Two types of samples were produced for geometrical measurements: a) journal and sleeve separately, and b) journal and sleeve assembled together. The first types of samples were used for measurement of the outer diameter of the journal and the inner diameter of the sleeve for the calculation of RC. The second types of samples were utilised for direct measurements of RC. All tests have been done on an optic microscope (Micro 200, Planar, Belarus) with magnification 200X and 400X; SEM (Mira, Oxford Instruments) and AFM (NT-206, Belarus). Linear dimensions of component elements were determined by geometrical analysis and using software «Distance Measurement» for optic microscopy and SEM. AFM measurements were performed on the basis of 2D and 3D AFM-images, lateral force imaging (Torsion mode) and surface profiles of the components. Two types of commercial sliding micro-bearings have been tested: a) an extra long life ventilator or cooling fan with “V” shaped grooves onto the sleeve surface (120 000 hrs, 2900 rpm, 80 mm case fan) and b) a HDD fluid dynamic bearing (7200rpm, 80 Gb, 3.5”).

RESULT AND DISCUSSION

The measurement of the outer diameter of the journal and the inner diameter of the sleeve and the resulting calculation of RC were performed by SEM **(Fig. 1)** and by optical microscope under full observation of the component cross-sections. It is established that the SEM technique allows one to see the cross-sections of the sleeve more clearly than with an optical microscope, in spite of the fact that the maximum difference of the diameter registered in four measurements was 40 µm even for the Scanning Electron Microscope. Moreover, the AFM technique cannot be used for such measurements at all, because it has a very small scanning area (maximum 100x100 µm) that does not allow complete observation of the component cross-section.

Analysis of the preparation procedure for metallographic samples showed that the accuracy of cutting, press-fitting, grinding and polishing of the components result in a deviation from the perpendicularity of sample cross-sections. The deviations can very easy reach 1-3 degrees, especially in consideration of small sizes of the components. In practice, the real cross-section will always be oval rather than perfectly circular.

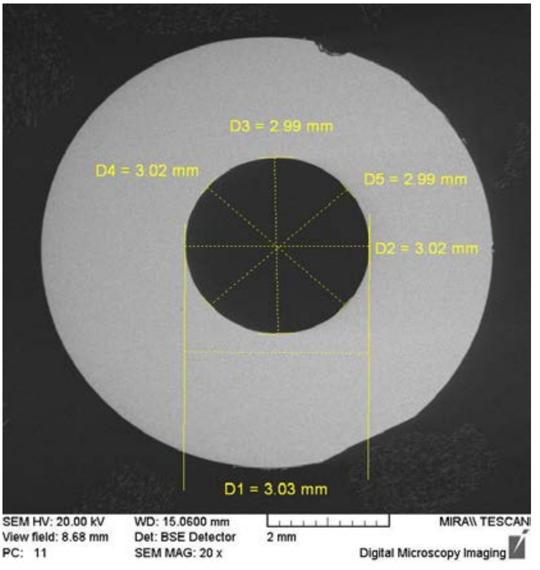

Fig. 1. SEM image of the cross-section of ventilator or cooling fan sleeve with dimension data markers
Rys. 1. Obraz przekroju poprzecznego panewki wentylatora z oznaczonymi wymiarami wykonany za pomocą Scanning Electron Microscope SEM

For example, an inaccuracy of a 2 mm diameter sample preparation can leads to a 4 µm difference for one component (see **Fig. 2**). A total 8 µm difference for a micro-bearing (journal and sleeve) is not permissible for RC measurements. Preparation of samples that includes the journal and sleeve assembled together allows observing the RC (**Fig. 3**) of the micro-bearing directly. Optical microscopy shows two types of RC: a) RC with groove depth in **Fig. 3a** and **b**) RC without a groove in **Fig. 3b**. The full area SEM observation of the sample cross-section provides the data on the quantity of the grooves manufactured into the inner surface of the sleeve (**Fig. 4**). Eight grooves are recognised for a ventilator or cooling fan and HDD micro-bearings. The real value of ventilator or cooling fan groove width (225 µm) is determined in **Fig. 4b** on the basis of the measurement of the groove cross-section width, taking into account the axial angle of the groove (26°).

The RC dimension procedure should include geometrically opposing measurements on the diameter and subtraction of groove depth. The value of groove depth is determined according to two measurements: a) RC without groove, b) RC with groove. The main advantage of this RC measurement is high accuracy, because the sample preparation procedure does not significantly affect the accuracy of measurement. For example, in **Fig. 2b**, an inaccuracy of 5 µm RC measurement is only 10 nm.

a) b)

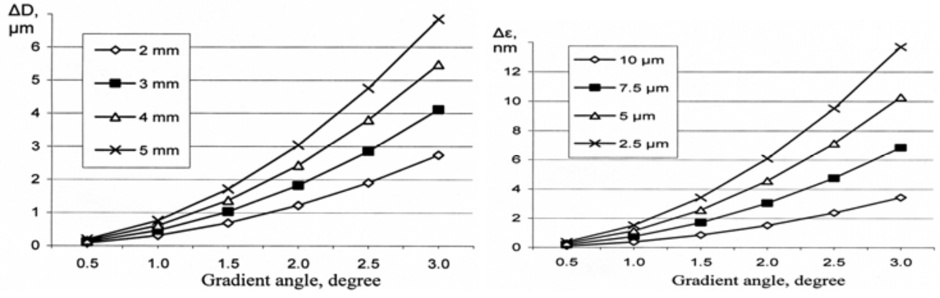

Fig. 2. Dependence of size deviation vs. sample surface slope
Rys. 2. Zależność wymiaru odchylenia od pochyłości powierzchni próbki

a) b)

Fig. 3. Optic microscope image of the radial clearance between sleeve and journal, x400: a – groove clearance; b – clearance without groove
Rys. 3. Obraz wykonany mikroskopem optycznym pokazujący luz promieniowy pomiędzy panewką i czopem, x400, a – luz z rowkami, b – luz bez rowków

a) b)

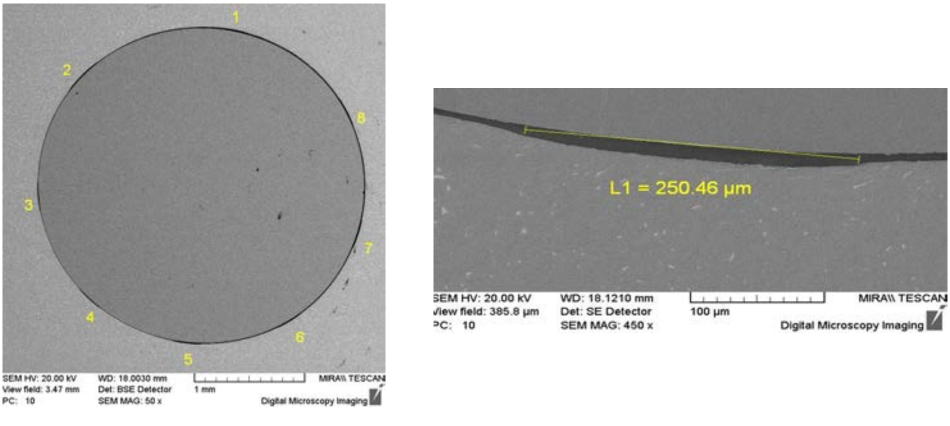

Fig. 4. SEM image of the cross-section of examined micro-bearing: a – RC with marked grooves; b – width of the chosen groove
Rys.4. Obraz SEM przekrojów poprzecznych badanych mikrołożysk: a – luz promieniowy z zaznaczonymi rowkami, b – szerokość wybranego rowka

Optical microscopy measurements of the clearance and depth of groove were done 20 times under a magnification of 400X for each size (**Fig. 3**). Average values of the clearance are presented in **Table 1.** SEM measurements were done three times for each size under magnifications of 5,000X–10,000X (**Figs. 5** and **6**). Average values of SEM data are presented in the **Table 1**. The AFM technique was utilised one time for each size (**Figs. 7** and **8**). The values of AFM measured data are presented in **Table 1**

Table 1. Results of performed measurements utilising different techniques
Tabela 1. Rezultaty dokonanych pomiarów z wykorzystaniem różnych technik

Technique	Long Life Ventilator or cooling fan		3.5' HDD	
	RC, µm	Groove Depth, µm	RC, µm	Groove Depth, µm
Optical microscope	6.9	5.4	2.60	3.10
SEM	7.23	7.62	2.55	2.90
AFM	6.7	5.9	2.7	-

a) b)

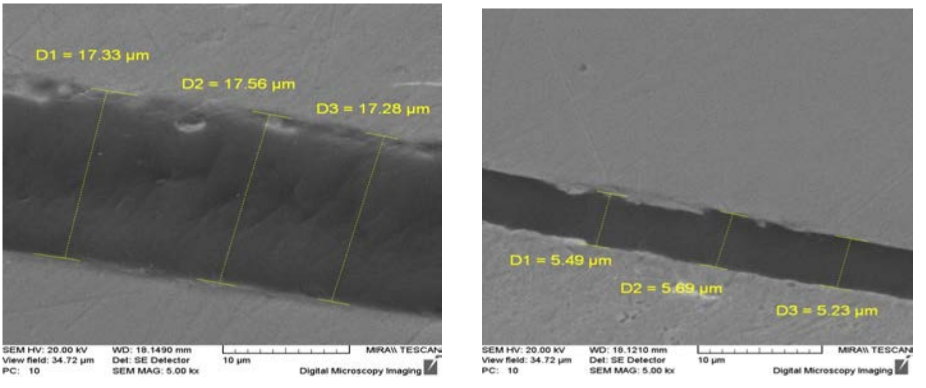

Fig. 5. SEM image of two opposite measurements of the clearance for micro-bearing ventilator or cooling fan: a – clearance with groove; b – clearance without groove
Rys. 5. Obrazy SEM dwóch przeciwstawnych pomiarów luzu promieniowego dla wentylatora mikrołożysk: a – luz promieniowy z rowkami; b – luz promieniowy bez rowków

Hard materials (metal base alloys used for journal and sleeve) are ground and polished more slowly than soft material (glue) during the preparation of the metallographic samples. Consequently, a step occurs on the border of two materials. This step is not horizontal but has a radius of curvature that causes an error in the measurement while using different types of microscopy. In addition, the softer material can be partially rubbed onto the interface of the two materials, which also creates difficulties in recognising the border.

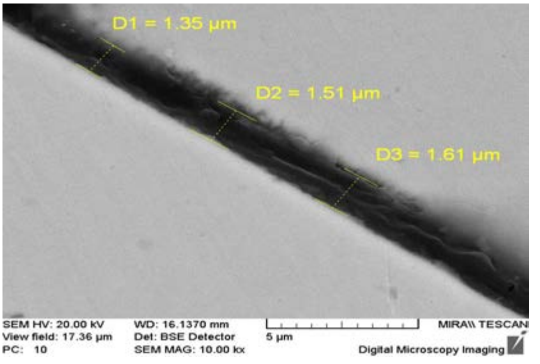

Fig. 6. SEM image of the extremely low value of radial clearance in HDD micro-bearing

Rys. 6. Obraz SEM dla ekstremalnie małych wartości luzu promieniowego w mikrołożyskach HDD

We believe that the AFM technique allows one to determine the interface (border) between two materials more accurately than optical and SEM microscopy. This is indicated in **Fig. 8** by co-analysis of the topography profile, torsion image and torsion profile.

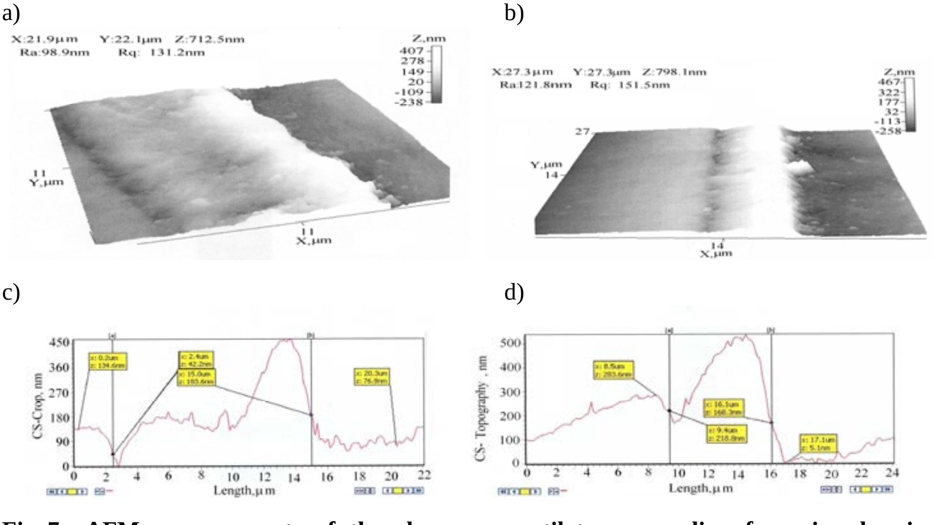

Fig. 7. AFM measurements of the clearance ventilator or cooling fan micro-bearing: a – 3D AFM image of 12.6 µm clearance with groove; b – surface profile (middle line from Fig. 7a image); c – 3D AFM image of 6.7 µm clearance without groove; d – surface profile (middle line from Fig. 7c image)

Rys. 7. Pomiary luzu promieniowego w mikrołożysku wentylatora z użyciem mikroskopu 3D AFM: a – Obraz 3D dla luzu promieniowego 12,6 µm; c – obraz 3D dla luzu promieniowego 6,7 µm z rowkami**;** b – profil powierzchni obrazu przedstawionego na rysunku a; d – profil powierzchni obrazu przedstawionego na rysunku c

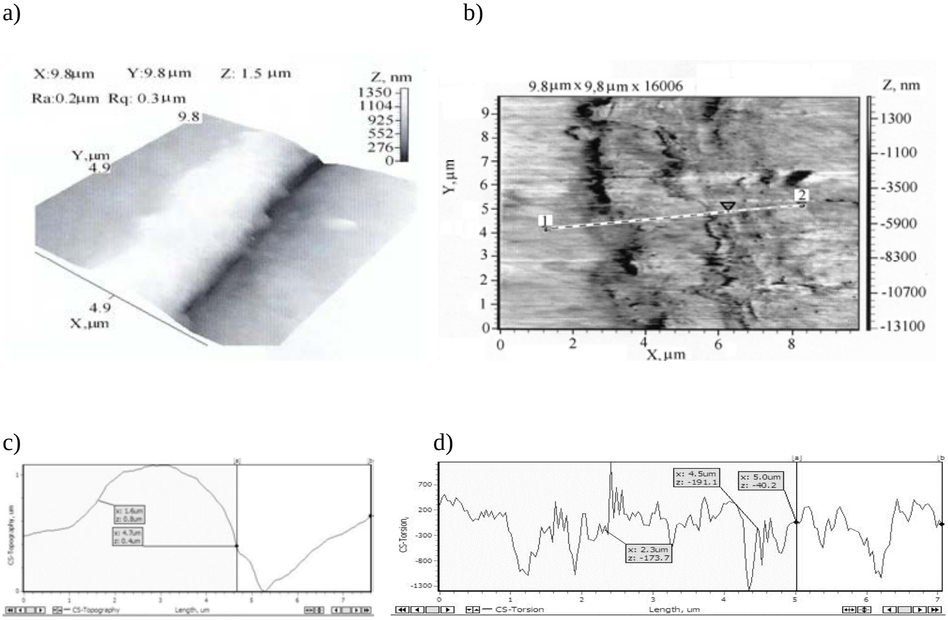

Fig. 8. AFM measurements of 3.1 µm radial clearance in HDD micro-bearing: a - 3D AFM **image of the clearance without groove;** ***b*** **– surface profile (middle line from Fig. 8a image);** ***c*** **– 2D AFM Torsion image of t**he **clearance (the same area that presented in Fig. 8a);** ***d*** **– Torsion profile (1-2 line from Fig.8c)**

Rys. 8. Pomiary luzu promieniowego 3,1 µm w mikrołożysku HDD z użyciem AFM: a – obraz 3D AFM dla luzu promieniowego bez rowków, b – profil powierzchni obrazu przedstawionego na rysunku a; c – obrócony obraz 2D AFM względem obrazu dla luzu promieniowego na rysunku a**;** d – profil powierzchni obróconego obrazu wzdłuż linii przedstawionej na rysunku c

According to [**L. 6, 7**], RC and surface roughness are the main parameters for HDL, micro-bearing surface roughness which has been studied by AFM. Typical roughness profiles for micro-bearing component are represented in **Fig. 9**. It is established that the value of the dimension tolerance for HDD and ventilator or cooling fan components for all surfaces is about 320 nm. Moreover, the arithmetical average of the roughness profile has value R_a of 12-48 nm. The maximum clearance difference caused by the roughness of the journal and sleeve surfaces can reach 640 nm. This data corresponds to the measured data presented in **Table 1.**

Checking the lubrication regime was done using the film parameter Λ, which is calculated though the minimum film thickness and roughness of the two components [**L. 7**]. According to [**L. 7**], Λ = 10 is the stipulated limit for HDL and elasto-hydrodynamic lubrication (EHDL). EHDL regimes are

a) b)

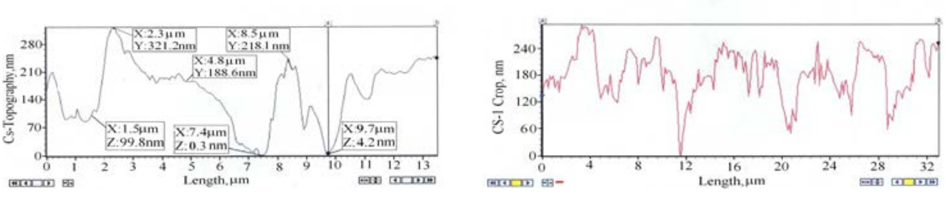

Fig. 9. Typical roughness profile for micro-bearing component: a – journal of ventilator or cooling fan; b – HDD sleeve

Rys.9. Typowe profile chropowatości elementów mikrołożyska: a – dla czopa wentylatora; b – dla panewki mikrołożyska HDD

recognised when the Λ parameter is between 3.5 and 10, the HDL – Λ is more than 10, and the mixed lubrication – 1.5-3.5. Lubrication regimes are analysed with the assumption that the measured value of RC presented in **Table 1** is the minimum film thickness, and it means that we have used larger value of parameter Λ than can be in real operation conditions. Analysis of lubrication shows that the micro-bearing fan has a HDL type of lubrication with a low friction coefficient (Λ = 14.85), and the HDD micro-bearing has an EHL type of lubrication with a medium friction coefficient (Λ = 5.98). The lowest value of RC – 1.35 µm was measured for the HDD micro-bearing in **Fig. 6** with Λ=2.99 and mixed lubrication with a high coefficient of friction.

CONCLUSIONS

It has been shown that measurements of the radial clearance of micro-bearings cannot be determined with the required accuracy for hydrodynamic calculations and wear analysis just through subtraction from internal diameter of sleeve to external diameter of the journal. It is proposed to measure clearance directly by high-resolution microscopy using a metallographic sample of the cross-section of the assembly of the sleeve and journal with the gap filled with glue.

Precise measurements of the radial clearance and groove depths have been done using optical, SEM and AFM techniques for the ventilator or cooling fan and the HDD micro-bearings with a journal diameter 3 and 4 mm, correspondingly. The radial clearance for the ventilator or cooling fan long-life micro-bearing is 6.7…7.23 µm, and the depth of the groove is 5.4…7.62 µm, for the HDD micro-bearing RC is 2.5-2.7 µm and groove – 2.9…3.10 µm. The accuracy of measurement is limited to the quality of the preparation of the metallographic sample and the accuracy of the alignment of the measuring markers.

Dimension tolerance of micro-bearing diameters is determined through the analysis of roughness profiles for different components. It is established that the value of dimension tolerance for the HDD and ventilator or cooling fan components is the same for all surfaces - about 320 nm and the arithmetic average of the roughness profile Ra 12-48 nm. It is shown that maximum difference in clearance caused by the roughness of the surface can reach 640 nm. Analysis of lubrication shows that the ventilator or cooling fan micro-bearing has a hydrodynamic type of lubrication and HDD micro-bearing has an elasto-hydrodynamic type of lubrication.

The proposed method can also be used for quality control of adhesive, soldered or welded joints, in which the thickness of the layer of solder or glue is up to 40-70 microns, which is limited by the area of AFM scanning. In addition to the measurement of the gap, information can be collected about the continuity of the joint, the structural homogeneity, and physical, mechanical and electrical properties of the adhesive or solder.

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Streszczenie

Hydrodynamiczne smarowanie z rowkami na powierzchni panewki lub czopa w mikrołożyskach ślizgowych twardych dysków komputerowych oraz w mikrołożyskach wentylatorów komputerowych staje się coraz bardziej powszechne ze względu na fakt, że mikrołożyska ślizgowe są lepsze w eksploatacji niż łożyska toczne, a przede wszystkim rowki redukują pęcherze kawitacyjne, przez co zwiększają sztywność łożyska.

W przypadku mikrołożyska, a tym bardziej mikrołożyska z rowkami, klasyczne metody pomiaru luzu promieniowego o dokładności do 1–2 μm są mało skuteczne.

Luzy promieniowe w mikrołożyskach z rowkami o pochyleniu od 30 do 60 stopni oraz różnym kształcie, zazwyczaj w literkę V oraz jodełkę, mają wysokość 2–3 μm i dlatego w niniejszej pracy wykonano ich pomiar z użyciem różnego typu przyrządów elektronowych, takich jak: optyczny mikroskop Micro 200, Planar Belarus; optyczny skaningowy mikroskop Mira, Oxford Instrument (SEM) oraz mikroskop sił atomowych typu NT-206 Belarus (AFM).

Pomiary prezentowane w pracy zostały wykonane na metalograficznych próbkach przedstawiających przekroje poprzeczne elementu bez wytrawiania oraz polerowania. Przeprowadzono dwa typy pomiarów, a mianowicie czop i panewka oddzielnie oraz czop i panewka razem. W tym drugim typie pomiaru dokonano wyznaczenia rzeczywistej wartości luzu promieniowego.

Odległości geometryczne związane z luzem promieniowym zostały wyznaczone wyżej opisanymi przyrządami SEM, AFM w obrazach dwu- oraz trójwymiarowych, posługując się profilami powierzchni w skali mikro i nano oraz wyznaczonymi elektronicznie siłami poprzecznymi i skrętnymi.

Wyznaczono luzy promieniowe długich mikrołożysk wentylatorów komputerowych (120 000 h, 2900 obr./min, 80 mm) oraz mikrołożysk twardych dysków komputerowych HDD (7200 obr./min, 80Gb, 3.5”).

Na podstawie dokonanych pomiarów autorzy wykazują, że tradycyjne wyznaczanie promieniowego luzu w przypadku mikrołożysk ślizgowych poprzez różnicę mierzonych wartości promienia czopa i panewki prowadzi do mało dokładnych wyników.

Wymiarowa tolerancja mierzonych średnic czopa i panewki mikrołożysk z uwzględnieniem chropowatości powierzchni sięga 320 nm.

Pomiary SEM iAFM powierzchni mikrołożyska HDD wykazały cechy elasto-hydrodynamicznego smarowania.