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OPERATING CONDITIONS OF SLIDE BEARINGS OF MILLS USED IN KGHM POLSKA MIEDŹ S.A.

WARUNKI PRACY ŁOŻYSK ŚLIZGOWYCH MŁYNÓW UŻYTKOWANYCH W KGHM POLSKA MIEDŹ S.A.

Key words:

hydrodynamic bearing, copper ore processing, ball mill, computer simulation

Słowa kluczowe:

łożyska hydrodynamiczne, młyny kulowe, mielenie, symulacja komputerowa

Abstract

The paper contains the results from a technical analysis of the conditions of the operation of hydrodynamic bearings supporting the drums of ore processing mills at KGHM Polska Miedź S.A. A theoretical analysis was performed on the grounds of onsite examination and measurements of principal dimensions of the bearings of interest. The computer simulation covered the characteristics of the oil film in the bearings as a function of bearing clearance, load, lubricant viscosity, and journal tilting in relation to two planes (horizontal and vertical).

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The results of the analysis indicate that the bearings currently operate close to maximum capacity and that there is a significant deflection of the bearing journals under the applied joint load of the drum's own weight and the process load of grinders and slurry. The current extent of tilting can cause oil film breakage at the bearing's edge. The result of calculations amended by bearings' examination and measurements allowed the formulations of conclusions regarding the current state of the bearings and evaluated load conditions. Guidelines were established for later developments in the capacity and reliability of the bearings.

INTRODUCTION: AIM OF THE RESEARCH

KGHM Polska Miedź S.A. is currently the largest supplier of silver in the world and is among the largest producers of gold, copper, and other precious metals **[L. 1]**. Currently, one of the most prominent strategic goals of the company is the increase of efficiency at maintained output. This applies equally to raw ore production, ore processing, and sales.

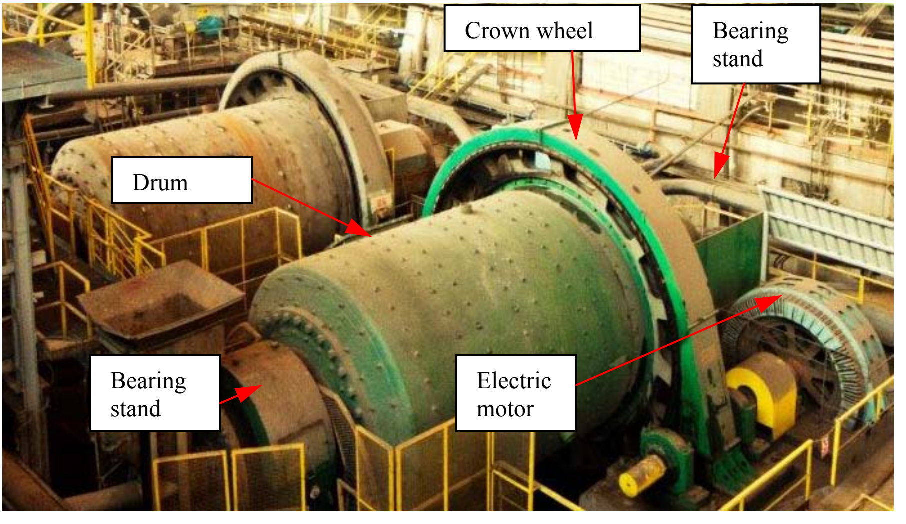


Fig. 1. A general view of a large drum mill for ore processing [L. 1]
Rys. 1. Widok ogólny młyna bębnowego do mielenia rudy **[L. 1]**

The task is difficult because the excavation has to be done from depth in excess of 800 m, which results in stringent requirements regarding reliability, availability and efficiency of the equipment used for raw ore processing and ore concentrate preparation for the smeltery branch of the facility.

The milling of copper ore in drum mills is a crucial stage of processing carried out after initial comminution in crushers. The mills are filled with grinding medium, which is usually in the form of alloy cast steel balls or rods. In order to increase the system's throughput while maintaining the machinery, it is necessary to increase the working load. In consequence, it is necessary to modernize the existing mills to upgrade operational characteristics.

The work presented was done in order to evaluate the current conditions of the operation of hydrodynamic bearings used in mills, the resistance to wear, and stability, which are the decisive factors for durability and reliability.

A typical drum mill is presented in **Fig. 1**. It is composed of a cylindrical drum supported at each end in a hydrodynamic journal bearing. The drum is rotated by an electric motor coupled to the drums crown wheel through a pinion.

The journals are hollow to allow for the slurry to flow through the machine. The slurry is fed into the mill at one end and collected at the opposite end. The axis of the drum is tilted by a few degrees, so the exit end is lower than the inlet. The configuration one of the bearings is equipped with thrust plate to carry the axial load, while the opposite bearing allows for axial movements of the journal to compensate for axial strain. The milling medium remains in the drum and is resupplied as it is worn.

Mill's journal bearing

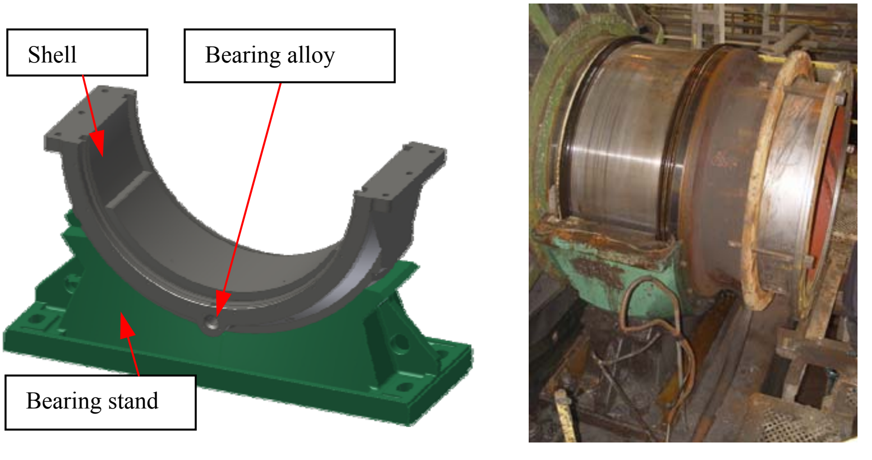


Fig. 2. A 3D computer model of the bearing stand with shell fitted for an MSZC type mill (left) and a photo of the bearing with the journal fitted (right) [L. 2, 14]

Rys. 2. Model komputerowy łożyska ślizgowego młyna MSZC oraz zdjęcie łożyska z zamontowanym czopem **[L. 2, 14]**

A thorough examination was carried out on the actual mill, bearing journals, and shells, and there was a thorough study of the technical documentation of the mill. On that basis, an input data set required to perform calculations was prepared.

A general view of the bearing considered is presented in **Fig. 2**. It is composed of a cast steel stand with a spherical seat machined into the top surface and serving as a support for a cast steel half shell cladded with Ł-83 grade white metal (PN). There is a forced circulation of oil in the bearing with the feed pipe situated above the bearing journal. The bearing shell seated in the spherical seat can be aligned with the journal on assembly.

Analysis method

Bearing calculations were carried out with the use of an ARTbear 7.0 software package providing tools for the evaluation of full characteristics of the oil film in radial journal bearings, both static and dynamic. The software was developed at the Mechanical Engineering Faculty of the Gdansk University of Technology in co-operation with the bearing industry and bearing users. It was verified in practice on numerous bearing developments for ABB, ALSTOM Power, SIEMENS, VA-TECH, VOITH-HYDRO, MAAG, and others.

The most recent version of the software employs an advanced adiabatic model of the slide bearing, which allows for the simulation of the influence of crevices in the bearing material, bearing shell shape errors, undercuts in the shell (e.g., hydrostatic support chambers). Moreover, the effects of journal tilting can be simulated with the evaluation of the resultant tilting torque in the bearing. This feature allows for the analysis of the bearing's capability for self-alignment in the spherical seat **[L. 3, 4]**. The features of the program and its structure has been presented in earlier publications **[L. 4, 9, 10]**.

In this paper, the presentation was limited to the influence of the four most important parameters describing the mill's hydrodynamic bearing:

- Radial clearance,
- Oil viscosity,
- Journal tilting, and
- Load.

The following data set was used in the calculations:

Journal diameter 'Ø'[mm]	1350
Shell length 'L' [mm]	490
Wrapping angle [°]	116
Maximum load [kN]	960
Rotational velocity [RPM]	16
Relative clearance (odpowiednio)	0.00077, 0,001, and 0.005
Oil grade	AN-69, TU-150
Feed oil temperature	20°C

The model is adiabatic.

The influence of bearing clearance

Usually, a decrease in bearing clearance results in load capacity increase at the cost of increased oil temperature in the oil film. In high-speed machines, excessively low bearing clearance may lead to the occurrence of temperatures greater than allowable for the oil to properly flow. In the case analysed (of a slowly rotating shaft), a decreased bearing clearance will cause an increase in capacity; however, when selecting an optimum clearance, it must be remembered that machining accuracy is limited for both journal and shell, and that when in use, the bearing is subjected to the influence of thermal and elastic deformations caused by heat and mechanical loading.

Figure 3 illustrates the influence of bearing clearance changes on the minimum oil film thickness, friction losses, and maximum temperature in the oil film. The calculations were carried out at a maximum radial load of 960 kN for three different values of relative bearing clearance: 0.005, 0.00077, and 0.001.

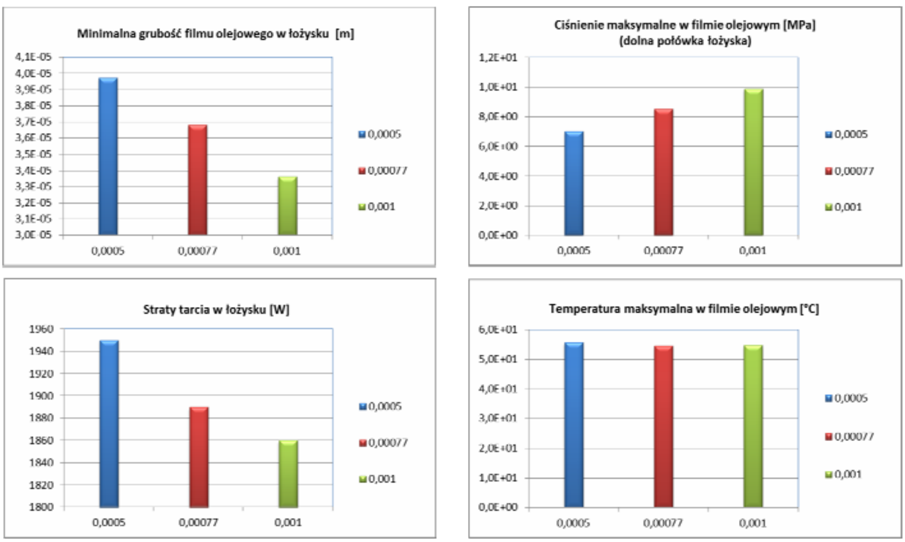


Fig. 3. The influence of bearing clearance on the oil film thickness and friction losses in an MSZC type mill bearing

Rys. 3. Wpływ względnego luzu łożyskowego na grubość filmu olejowego oraz straty tarcia w łożysku analizowanego młyna MSZC

When the clearance in the bearing is decreased, the calculated oil film thickness increases and the maximum hydrodynamic pressure in the oil film decreases. The minimum thickness of the oil film changes from 0.033 to 0.04 mm.

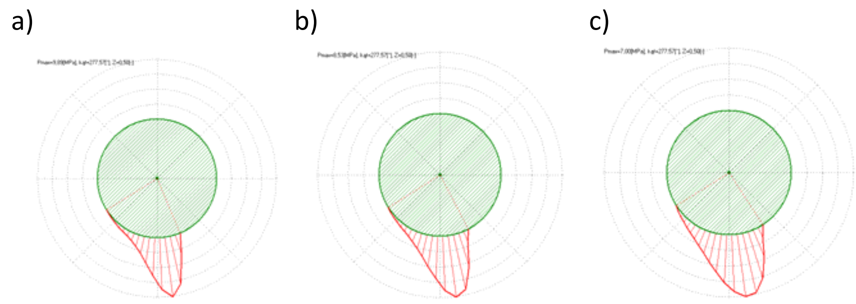


Fig. 4. Bearing clearance influence on the hydrodynamic pressure distribution in the bearing at (a) p_{max} = 9.9 MPa, (b) p_{max} = 8.5 MPa, and (c) p_{max} = 7 MPa (note: different pressure scale in each plot)

Rys. 4. Wpływ zmiany wartości luzu łożyskowego na rozkład ciśnienia hydrodynamicznego, a) p_{max} = 9,9 MPa, b) p_{max} = 8,5 MPa, c) p_{max} = 7 MPa (różna podziałka)

Figure 4 illustrates the influence of bearing clearance changes on the distribution of the hydrodynamic pressure in the bearing. A change in the pressure distribution profile is visible along with its asymmetric shape. An increase in bearing clearance causes an increase in the maximum pressure in the oil film. Based on the pressure profiles plots, the actual wrapping angle in the bearing can be calculated. It ranges from 85° to 100°, and it is not symmetrical in relation to the vertical plane.

The influence of lubricating oil viscosity

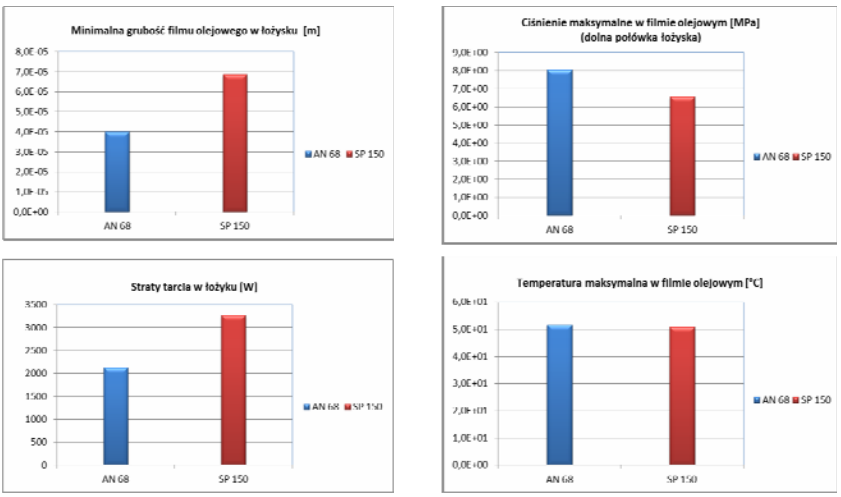


Fig. 5. The influence of the oil viscosity on the minimum oil film thickness, friction losses, and the maximum temperature in the bearing

Rys. 5. Wpływ lepkości oleju smarującego na minimalną grubość filmu, ciśnienie maksymalne oraz straty tarcia i temperaturę maksymalną

In slowly rotating sliding bearings, the viscosity of lubricant is a very important factor influencing the bearing's characteristics. In the plots below, the influence of that factor is illustrated on the minimum oil film thickness and friction losses in the bearing. Two oil grades are compared: AN68 and SP 150.

The increase in oil viscosity results in almost twice the thickness of the oil film. The friction losses generated in the film also increase, but the maximum temperature remains at an almost unchanged level.

The influence of journal tilting

Load distribution and the location of supports in drum mills results in large bending torques developing in the system and causing significant elastic tilting of the bearing journals. The bearings are designed with necessary adjustment screws for the bearing stand's alignment on a foundation block and spherical bearing shell seat for easy journal tilt compensation at assembly. The authors' earlier experience and onsite examination confirmed that the friction at the spherical seat surface is too great for continuous compensation of journal misalignment in this particular type of bearing **[L. 14]**.

Calculations done earlier with the use of FEM **[L. 14]** indicated that the journal misalignment can reach more than 0.1 mm along bearing's width. For that reason, an additional session of calculations was necessary to evaluate bearing characteristics with the journal tilted. Two directions of journal tilt were considered: horizontal (assembly errors, spur gear reaction forces) and vertical (weight inflicted drum's strain).

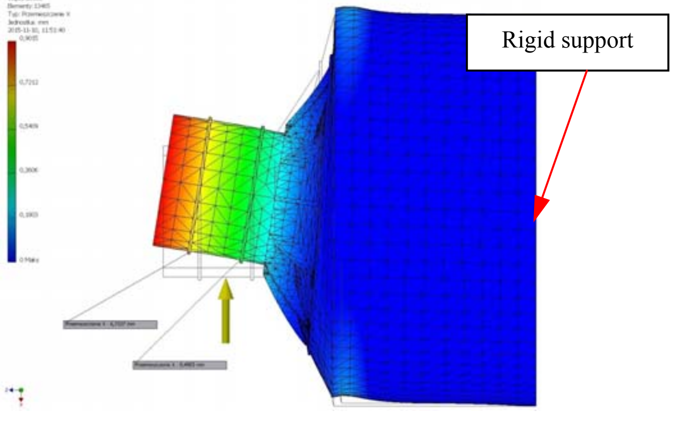


Fig. 6. A half–model of the mill's drum with the end plate and journal. FEM calculation results of linear deformation in the direction of action of the load presented as model deflection and colour map

Rys. 6. Połówkowy model MES walczaka z dennicą i czopem. Mapa barwna odpowiada odkształceniom liniowym w kierunku działania obciążenia. Widoczne znaczne ugięcie czopa

Three cases of journal orientation in the bearing were considered: parallel axes (lambda = 0), slightly tilted journal axis (lambda = 0.15), and highly tilted journal axis (lambda = 0.3). The '*lambda*' coefficient represents the proportion between the radial tilt at the edge of the shell and the absolute radial clearance.

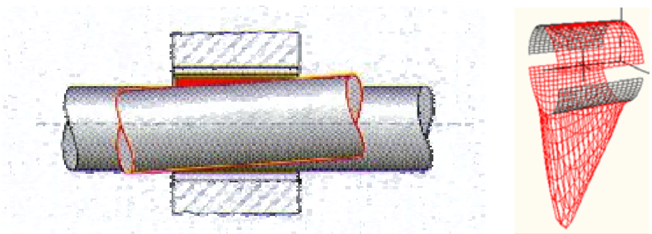


Fig. 7. Journal tilting in the slide bearing and the resultant asymmetrical distribution of hydrodynamic pressure in the oil film

Rys. 7. Ukosowanie czopa w panewce. Czop w panewce oraz niesymetryczny rozkład ciśnienie hydrodynamicznego wywołany ukosowaniem

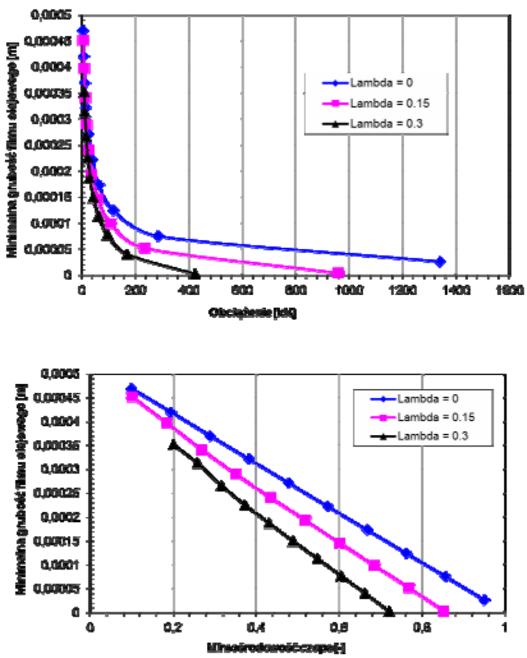


Fig. 8. Influence of vertical tilting of the journal on minimum oil film thickness as a function of load (top) and journal's eccentricity (bottom) in an MSZC type mill's main bearing. Lambda = 0 – journal parallel to shell, lambda = 0.15 – medium tilting, lambda = 0.3 – severe tilting

Rys. 8. Wpływ ukosowania czopa w płaszczyźnie pionowej na minimalną grubość filmu olejowego w łożysku młyna MSZC. Lambda = 0 – czop równoległy, lambda = 0,15 – czop średnio zukosowany, lambda = 0,3 – czop mocno zukosowany

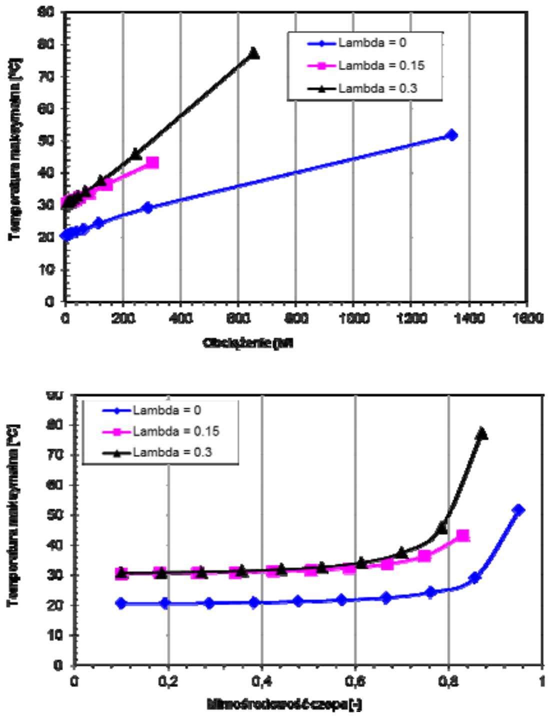
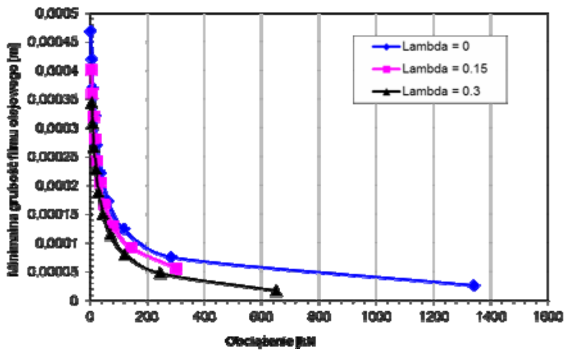


Fig. 9. Influence of vertical tilting of the journal on maximum temperature in the oil film as a function of load (top) and journal's eccentricity (bottom) in an MSZC type mill's main bearing. Lambda = 0 – journal parallel to shell, lambda = 0.15 – medium tilting, lambda = 0.3 – severe tilting

Rys. 9. Wpływ ukosowania czopa w płaszczyźnie pionowej na temperaturę maksymalną filmu olejowego w łożysku młyna MSZC. Lambda = 0 – czop równoległy, lambda = 0,15 – czop średnio zukosowany, lambda = 0,3 – czop mocno zukosowany



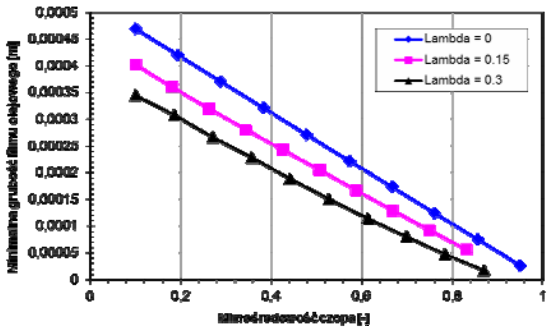


Fig. 10. Influence of horizontal tilting of the journal on minimum oil film thickness as a function of load (top) and journal's eccentricity (bottom) in an MSZC type mill's main bearing. Lambda = 0 – journal parallel to shell, lambda = 0.15 – medium tilting, lambda = 0.3 – severe tilting

Rys. 10. Wpływ ukosowania czopa w płaszczyźnie poziomej na minimalną grubość filmu olejowego w łożysku młyna MSZC. Lambda = 0 – czop równoległy, lambda = 0,15 – czop średnio zukosowany, lambda = 0,3 – czop mocno zukosowany

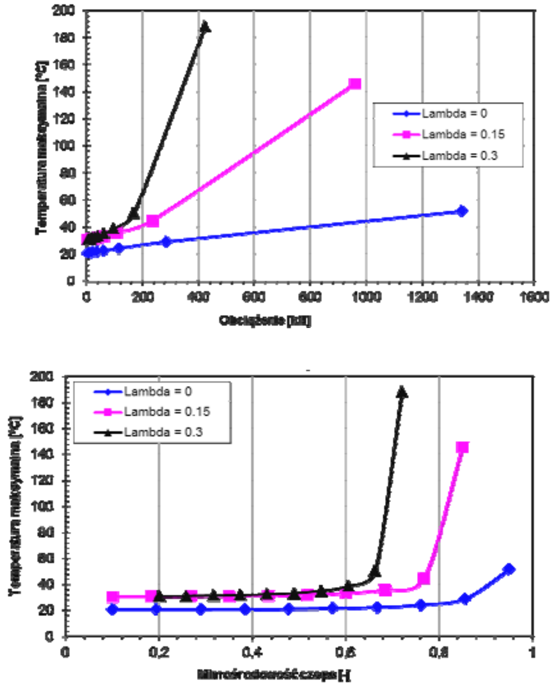


Fig. 11. Influence of horizontal tilting of the journal on maximum temperature in the oil film as a function of load (top) and journal's eccentricity (bottom) in an MSZC type mill's main bearing. Lambda = 0 – journal parallel to shell, lambda = 0.15 – medium tilting, lambda = 0.3 – severe tilting

Rys. 11. Wpływ ukosowania czopa w płaszczyźnie poziomej na temperaturę maksymalną filmu olejowego w łożysku młyna MSZC. Lambda = 0 – czop równoległy, lambda = 0,15 – czop średnio zukosowany, lambda = 0,3 – czop mocno zukosowany

CONCLUSIONS

Based on the results from analyses carried out the following conclusions can be formulated:

- The currently used bearings operate in difficult conditions and are heavily loaded. The minimum oil film thickness is less than 0.04 mm.
- Decreased bearing clearance may increase the oil film thickness, but it is a measure to be used with great caution, after a detailed technical analysis and with a stringent control of the effective resultant assembly and manufacturing clearances, and thermal deformations of both the journal and bearing shell.
- An increased oil viscosity (change from AN68 oil to T150) is beneficial to the bearing's load capacity, and, in the analysed case, it can result in an almost 100% increase in the minimum thickness of the oil film.
- Journal tilting is detrimental to the bearing's performance. The analysis shows that the bearings are more sensitive to vertical tilting (drum bending under weight) than to horizontal tilting. The occurrence of tilting can cause oil film breakage at the bearing edge and seizure.
- The increase in load capacity and reliability can be achieved by the use of more viscous oil, a decreased bearing clearance, and by providing the bearing shell with the capacity for self-alignment to the journal. It should also be considered whether it is economically feasible to upgrade the bearings with hydrostatic augmentation, which would result in simultaneous increase of load capacity and a reduction of friction losses generated in the bearing.

Acknowledgements

The authors would like to gratefully acknowledge the effective cooperation and kind support provided to us by KGHM Polska Miedź S.A. O/ZWR, A&O Expert and the Mechanical Engineering Faculty of the Gdansk University of Technology while the project was carried out. The paper is based on the joint effort of all the parties mentioned.

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Streszczenie

W artykule przedstawiono analizę warunków pracy łożysk hydrodynamicznych młynów rudy zainstalowanych w KGHM Polska Miedź S.A. Analiza teoretyczna została poprzedzona wizją lokalną oraz wykonaniem stosownych pomiarów geometrii czopów i łożysk. Symulacja komputerowa charakterystyk filmu olejowego łożysk obejmowała zbadanie

wpływu wartości luzu łożyskowego, obciążenia, lepkości oleju smarującego oraz ukosowania czopa w dwóch płaszczyznach (poziomej i pionowej).

Analiza wskazuje, że zainstalowane łożyska pracują na granicy swojej nośności, a ugięcie osi czopów spowodowane ugięciem walczaka pod działaniem ciężaru własnego i nadawy wywołuje znaczne ukosowanie czopa w panwi mogące prowadzić do przerywania filmu olejowego na krawędziach zewnętrznych. Przeprowadzone obliczenie uzupełnione o oględziny pomiary łożysk wykonane w KGHM Polska Miedź S.A. pozwoliły na sformułowanie wniosków odnośnie do stanu istniejących łożysk, ich obciążenia oraz możliwości zwiększenia nośności i niezawodności.