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ATTEMPT AT EVALUATING THE INFLUENCE OF BENDING STRESS ON SHAFT WEAR PROCESSES IN WATER LUBRICATED SLIDING BEARING WITH A RUBBER BUSHING

PRÓBA OCENY WPŁYWU NAPRĘŻEŃ ZGINAJĄCYCH NA PROCES ZUŻYCIA CZOPA W ŁOŻYSKU ŚLIZGOWYM SMAROWANYM WODĄ Z GUMOWĄ PANWIĄ

Key words: water lubrication, rubber bearings, wear.

Abstract: Water lubricated bearings find increasingly wide application in shipbuilding or the hydropower industry, with the popularity stemming from their numerous advantages. Unfortunately, as it turns out, water lubricated bearings do not always meet expectations, because, on occasion, they become subject to intense, premature wear, which requires costly repair. One of the still unexplained phenomena is the process of excessive bearing wear, in particular, that of shaft journal co-working with rubber bushings. The research goal was to evaluate the influence of shaft bending stress on the degree of its wear. Experimental tests were carried out on a purpose-designed test stand. The results of the first test series confirmed that the shaft bending stresses do have impact on the magnitude of wear.

Słowa kluczowe: smarowanie wodą, łożyska gumowe, zużycie.

Streszczenie: Łożyska smarowane wodą coraz powszechniej stosowane są w okrętownictwie czy energetyce wodnej. Wynika to z wielu zalet takiego rozwiązania. Niestety okazuje się, że nie zawsze łożyska smarowane wodą są w stanie sprostać oczekiwaniom i czasem dochodzi do ich intensywnego, przedwczesnego zużycia i konieczne staje się przeprowadzenie kosztownego remontu. Jednym z niewyjaśnionych dotąd zjawisk jest proces nadmiernego zużycia łożyska, a zwłaszcza czopa wału współpracującego z gumową panwią. Za cel badawczy postawiono sobie zbadanie wpływu naprężeń zginających występujących w wale na stopień jego zużycia. Badania eksperymentalne przeprowadzono na specjalnie zaprojektowanym stanowisku badawczym. Wyniki pierwszej serii badań potwierdziły, że naprężenia zginające w wale mają wpływ na wielkość zużycia.

INTRODUCTION

The history of the intensive development of water lubricated sliding bearings in shipbuilding goes back to the time when mechanical propulsion was first used on ships. A widely known and described bearing problem is the case of the 200-meter long sailing steam ship "Great Eastern" which was launched in 1863. The water-lubricated bearings with white metal bushing employed on the ship suffered excessive wear on the vessel's maiden voyage. The decision was then taken to employ wooden bushings. This solution proved so successful that it did not required any repair until the end of ship's life **[L. 1]**.

In time, as new materials were developed, sliding bearings with rubber bushings appeared on the market. Initially, they were made of natural rubber and later of synthetic rubber (the so-called NBR-nitrile rubber) **[L. 2]**. After World War II, new solutions with polymer, composite, sintered metal or ceramic bushings were implemented. Despite that, rubber NBR bearings remain in use until today. This is due to the numerous advantages they offer, which include relatively low price, the ability to absorb vibrations and limited susceptibility to rapid wear caused by shaft-bushing misalignment, which is a problem commonly encountered in the shipbuilding industry.

Despite the advantages connected with the use of rubber bushings, the practical experience of ship owners shows that, in certain cases, due to reasons that remain unclear, excessive shaft wear does take place.

Rubber bearings have been a subject of much research with attempts made at forming mathematical

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relationships describing their wear process **[L. 3–5].** However, until the present, the stresses appearing in the shaft have not been considered as the potential cause of excessive journal wear **[L. 6]**. This possibly might have been caused by the phenomenon discovered by Peter Rebinder who dealt with properties of oils with active additives and investigated changes in the value of free surface energy occurring under the influence of these additives **[L. 7–9]**.

The phenomenon known as the Rebinder effect consists of an adsorption drop in mechanical strength that facilitates the deformation and fracturing of metal objects as a result of lowering surface energy of the object, for instance, due to active bending or shear stresses. The adsorption effect does matter if it occurs simultaneously with the breaking of bonds at the moment of their creation. Significantly important is the penetration of active atoms or molecules into the fracture zone or in fact into fracture crowns **[L. 10]**.

Such a hypothesis was put forward by Professor Zygmunt Rymuza, after he had familiarized himself with the results of sliding bearing research that has been conducted at the Gdansk University of Technology's Faculty of Ocean Engineering and Ship Technology since the year 2000. In cooperating with shipyards, which carry out repairs of such bearing, it was observed that, at identical surface pressures and sliding speeds, there sometimes appeared intensive wear of shaft's journal in the working location of ship stern tube bearings while, on other occasions, the degree of wear was rather low.

TEST METHOD

The experimental and numerical studies on the wear of shafts and water lubricated bearings that have been carried out so far, and they can be found in the literature **[L. 11–15].**

In order to carry out tests under conditions similar to those present in a highly loaded ship stern tube bearing, a special test stand was designed and constructed, as presented below **(Fig. 1)**. This allowed for the controlled application of bending load on the journal of tested sliding bearing (2). The value of bending stresses is modified by moving the bearing (positions from A to D), the load placement location (position F1 or F2), as well as the diameter of shaft. In the future, the test stand is to be expanded by the addition of a module for the application of torsional loads.

The electric engine powering the stand is connected to the shaft by a clutch. The shaft (1) has the diameter of 30 mm and is made of steel 1H18N9, which is resistant to marine saltwater. It is partially located in the water-filled tank (5). The shaft is supported on two bearings: on the left side, on a self-aligning rolling bearing (3), located on the right side, the casing of the tested sliding bearing (2). Mounted in front of the tank is a rolling bearing which is meant to ensure the coaxiality of the shaft with the sealing (7) protecting it against water leakage from the tank. Located at the end of the shaft is a sliding bearing (4) through which load is applied.

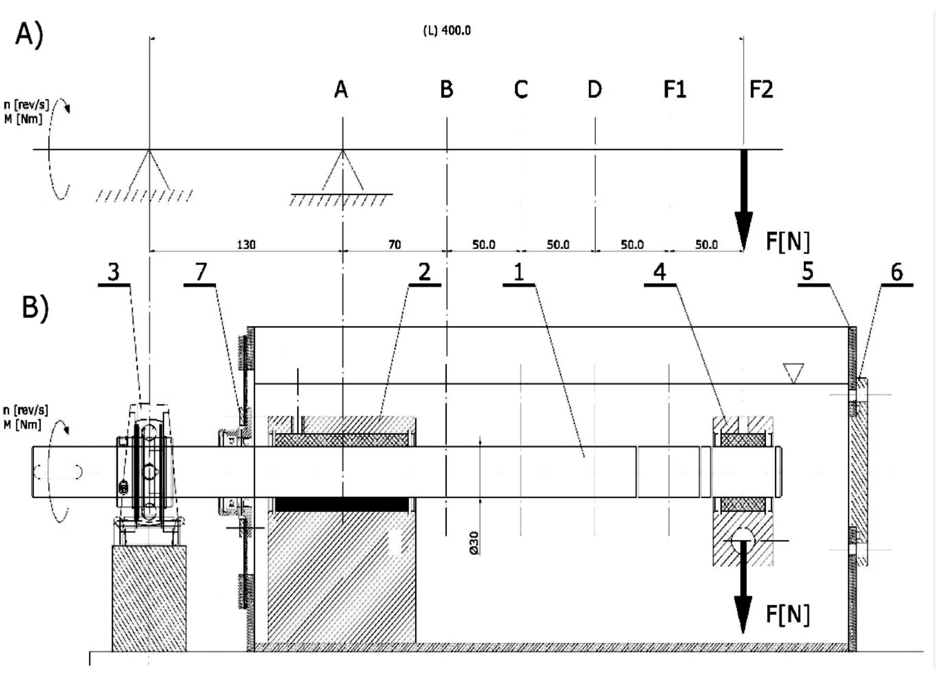

Fig. 1. Test stand, tested bearing in position A, load in position F2; test stand diagram, A) test stand diagram, B) test-stand cross-section: 1 – shaft, 2 – support of tested bearing, 3 – rolling bearing 4 – sliding bearing through which load is applied, 5 – tank filled with water, 6 – cover, 7 – seal

Rys. 1. Stanowisko pomiarowe, badane łożysko w pozycji A, obciążenie w pozycji F2; schemat stanowiska, A) schemat stanowiska, B) przekrój przez stanowisko: 1 – wał, 2 – podpora badanego łożyska, 3 – łożysko toczne 4 – łożysko ślizgowe, za pośrednictwem którego wywierane jest obciążenie, 5 – zbiornik wypełniony wodą, 6 – pokrywa, 7 – uszczelnienie

In planning the experiment, it was assumed that all of the bearings would be tested in identical conditions, so that the impact of bending stresses on the shaft's journal wear could be evaluated **[L. 11]**. It was decided that, for the first 14 hours when the running in of the pair is taking place, the rotational speed of the engine would be 600 rpm, and then the speed would be raised to 1000 rpm. It was also emphasized that the test stand would be activated the same number of times, since, during the start-up process, the process of wear might be particularly intensive. After 70 hours, the test stand was disassembled and the sample preparation process could be initiated.

The wear of shaft's journal was measured in the sliding bearing mounting location that was completely submerged in water, (positions A and B), as well as in the location of applying the force F (F1 or F2). As already mentioned, the time of work and the number of start-ups should be the same for all of the investigated bearings. In order for the surface pressures to be identical at various locations, the length of bearing's bushing in the location F is fixed (28 mm), while it changes in locations A and B, as shown in **Table 1**. In order to obtain different values of bending stresses, some of the shafts were hollowed.

Following 70 hours of work, the shaft journal's diameter change resulting from the wear process as well as its shape faults were minimal and difficult to identify. Consequently, the samples were examined using a profilagraphometer, in order to compare the degree of surface degradation due to wear based on surface roughness profiles.

Presented below are the samples, i.e. cut out shaft journals.

EXPERIMENTAL TESTS

Mass-produced NBR – synthetic rubber bushings meant for small watercraft were used in the tests. Due to budgetary constraints, shafts and bushings were ordered in two series. It was difficult to observe any differences between shafts in the successive shipments delivered by a specialized transport company, but the same could not be said about the bushings that were clearly not identical. They differed from each other in their external diameters and additionally came from different production series. Therefore, the test results should be considered as preliminary, and it was difficult to perform their complete comparison and analysis. In order to avoid similar problems in the future, all of the elements for successive tests were obtained through a single order.

Most of the attention was directed at the shaft journals, but uneven wear of the bushings was also observed. Interestingly, despite the fact that the working conditions of bearings remained the same every time, during bearing tests in the position A and F1 (bending stress of 32 MPa), there clearly occurred overheating of water whose temperature nearly reached the boiling point. The tested bushing became almost completely damaged (material loss) and its rubber was locally transferred onto the journal **(Fig. 2A)**.

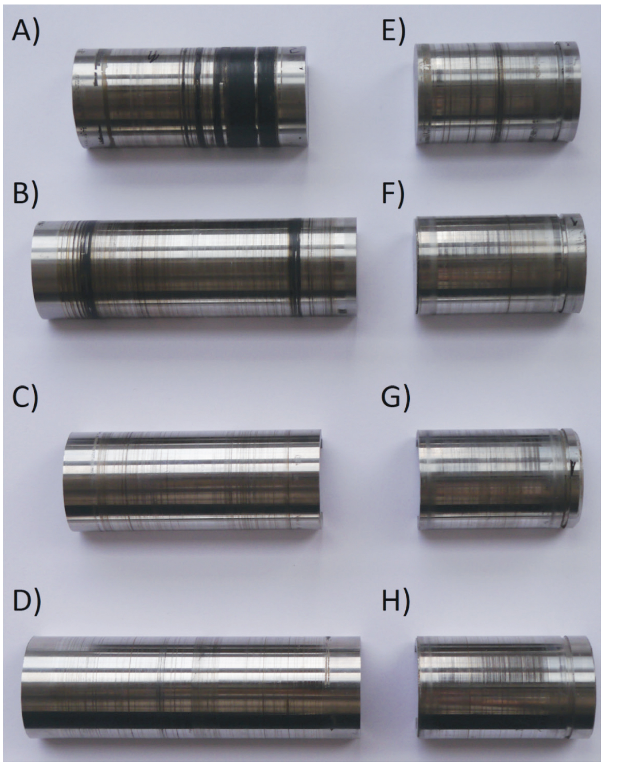

Fig. 2. Samples, tested shaft journals, in the same order as in Table 1

Rys. 2. Próbki, badane czopy wałów, kolejność jak w **Tabeli 1**

Table 1. Measurement table

Tabela 1. Tabela pomiarów

Data		Calculated values				
Position of support G and application of force F (Fig.1,Table 1)	Bush length B	Reaction in the tested bearing (2)	Bending		Pressures	
			Bending moment in journal	Bending stresses	In tested bearing	In the load applying bearing
-	mm	N	Nm	MPa	MPa	MPa
B, F1 (A, E)	50	961	82.40	32.5	0.641	0.654
A, F1 (B, F)	80	1479	120.80	47.7	0.616	0.654
B, F2 (C, G)	57	1098	109.87	73.5	0.643	0.654
A, F1 (D, H)	77	1479	120.86	80.8	0.640	0.654

RESULTS

Presented below are the results of shaft journal wear tests in individual measurements. Shown in pairs are journal profiles of the tested bearing and journal profiles of the load exerting bearing with no bending moment.

A) E)

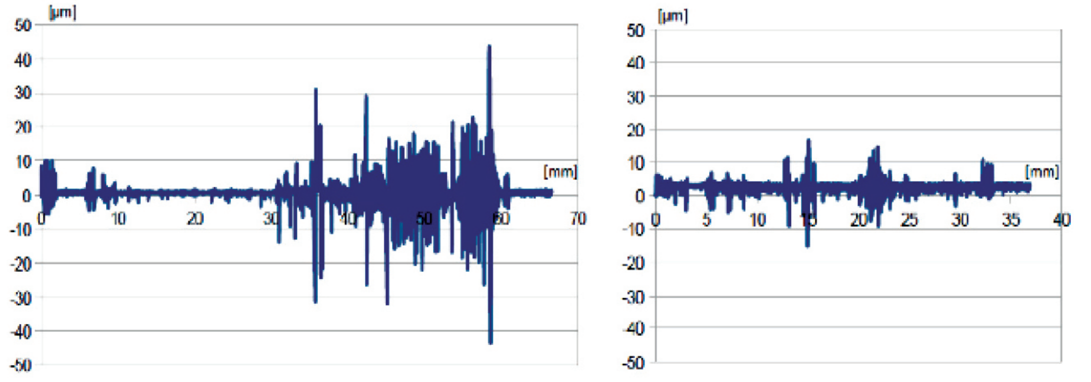

Fig. 3. Roughness profile measured using a profilographometer, bushings in positions. B and F1 (Fig. 3A and 3E)
Rys. 3. Zmierzony profil chropowatości za pomocą profilografometru, panwie w pozycjach B i F1 **(Rys. 3A i 3E)**

B) F)

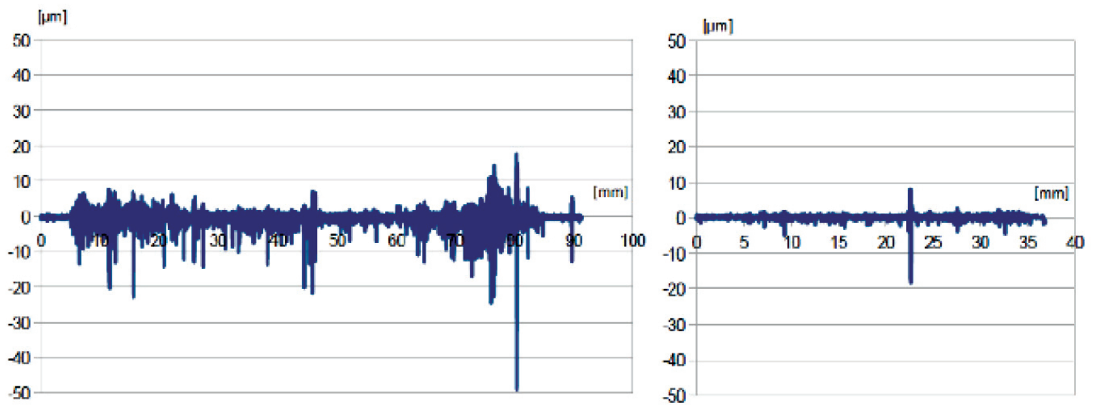

Fig. 4. Roughness profile measured using a profilographometer, bushings in positions A and F1 (Fig. 4B and 4F)
Rys. 4. Zmierzony profil chropowatości za pomocą profilografometru, panwie w pozycjach A i F1 **(Rys. 4B i 4F)**

C) G)

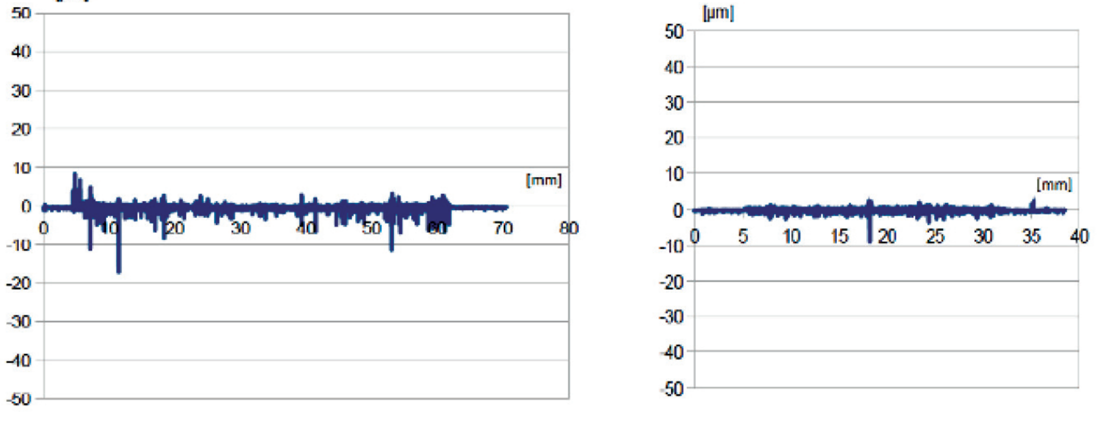

Fig. 5. Roughness profile measured using a profilographometer, bushings in positions B and F2 (Fig. 5C and 5G)
Rys. 5. Zmierzony profil chropowatości za pomocą profilografometru, panwie w pozycjach B i F2 **(Rys. 5C i 5G)**

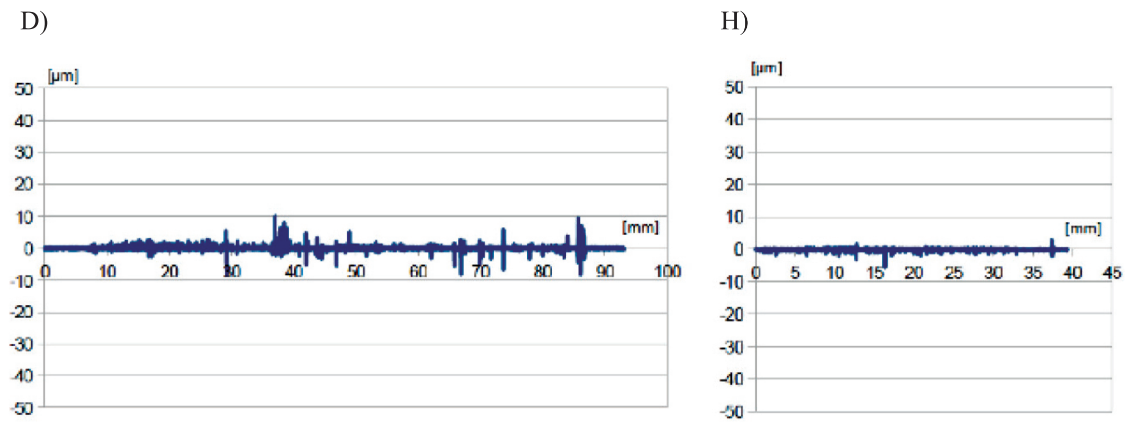

Fig. 6. Roughness profile measured using a profilographometer, bushings in positions A and F1 (Fig. 6D and 6H)
Rys. 6. Zmierzony profil chropowatości za pomocą profilografometru, panwie w pozycjach B i F1 **(Rys. 6D i 6H)**

DISCUSSION

Presented on the diagrams (Figs. 3-6) are the roughness profiles of individual samples. The zero value adopted in the diagrams is the average value for individual measurements. Due to lack of a reference point to the initial roughness, a larger range of samples was profiled than presented in the table (the few millimetres at the beginning and the end of the diagrams are the areas that did not cooperate with the rubber bush). The "0" point was set on this basis.

Negative values represent the loss of material, including furrows caused by the shaft's work in the sliding bushing, i.e. excessive wear. Positive values represent the material brought onto the shaft (bearing bush rubber) following an excessive temperature increase of the water in the tank.

The height of the roughness in **Fig. 3A** reaches approx. 45 µm, which is caused by the transfer of the bearing bushing rubber due to the high water temperature and partial melting of the rubber. For the same reason, the values of roughness in the load exerting bearing **(Fig. 3E)** are also higher and reach approx. 20 µm. A similar situation but somewhat less intensive appeared in the case of another sample **(Fig. 4B)**. In the remaining cases, the process was of a less intensive nature, which may be witnessed on their diagrams, where the roughness height reaches the value of 10 µm.

Such large divergences in the obtained results are caused by the use of non-identical rubber bushings, the overheating of water in the tank, as well as temporary dustiness of the laboratory in which the measurements were taken.

The research goal was to evaluate the influence of shaft bending stress on the degree of its wear. As shown in **Table 1** and roughness profiles for each sample, **(Fig. 3–6)** with increasing bending stress of the shaft journal wear should be higher. However, the roughness profiles show that the greatest wear of the shaft is at the lowest bending stress.

CONCLUSIONS

The set goals were not achieved in the first series of tests, because the tests were carried out on non-identical bushings, which came from two successive shipments, which proved difficult to complete a reliable comparative analysis of the results. However, one may notice a trend that points to the conclusion that the magnitude of bending stress bears an influence on the condition of journal surfaces. Particularly worthy of attention are the measurement results of shaft's journal in the bearing location F (F1 or F2) through which the load was applied (E-H). In all the analysed cases, the roughness height is a few times lower than the roughness height in the shaft's journal of the examined bearing (A-D), which is indicative of a slower progression rate of the wear process. This trend is the opposite of the one expected prior to starting measurements, since with the same working conditions of both pairs in each measurement along with the increase in bending moment in the bearing exerting the load, the wear process should be run more intensively. Therefore, it may be ventured to make a statement that the presumed hypothesis was qualitatively confirmed.

The conducted tests and analysis of the measurement results allowed for drawing a number of important conclusions as to the method of continuing further research.

The literature on material wear is generally available; however, among the newest works, one will not find positions on wear that might be caused by occurrence of the Rebinder effect.

In the opinion of the authors, the results are of a promising nature and the research will be continued.

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