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Verification of stiffness and surface treatment of axial bearing levers by static tests

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Abstract

To eliminate misalignment between stator and rotor (especially in large rotary machines) the thrust bearing with a system of very precise manufactured levers has started to be used. The article deals with the static tests of self-equalizing elements (levers) made of 34CrNiMo6 steel, which are the critical parts of a newly developing self-equalizing thrust bearing. To verify the stiffness of the newly designed levers by static tests, the real levers were produced, which according to preliminary experiments and numerical simulations have the potential to be used the most in turbines. Based on basic tests of the pairs samples, that represent types of geometries going in contact within real conditions, it was found out that in terms of the surface treatment, the best results show electroless nickel-plated samples. So, due to this reason, the real levers were produced and their surfaces were processed in this way by electroless nickel-plating. Within the presented research, they were statically tested intending to determine the surface integrity and whether there was any development of damage to the surface layer. The evaluation was done using a stereomicroscope and a scanning electron microscope. The tests confirm sufficient rigidity of the levers including a suitable method of surface processing. Although, in some cases, these were surface defects caused by surface treatment technology, but no defects were found after static loading.

Keywords: bearing; lever; static test; surface treatment;

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1. Introduction

High requirements are currently imposed on modern machines, which concern not only their construction and technological parameters but also their reliability and related diagnostics. The most demanding is using a machine and its tools in unattended mode with continuous operation. Generally, the machines that are subjected to a variety of environmental conditions that contribute to corrosion, erosion, fouling and various temperature-related issues, are all rotary machines such as turbines, compressors and pumps. Their long-term reliability is a common goal for all plant operators. Achieving it requires a considered approach that takes into account a range of contributory factors and makes use of the most appropriate technology and manpower available to them.

Unfortunately, in large rotary machines, due to the deflections of the stator (but also rotor) parts, it is not guaranteed the necessary parallelism of the active surface of the segments with the active surface of the rotor collar. This misalignment is caused by many factors (thermal expansion, shaft deflection, "inaccuracy" in production, etc.). It results in a reduction in bearing capacity. (Martsinkovsky (2011))

One of the solutions how to compensate a misalignment between of the active surface of the bearing and the active surface of the rotor collar is using so called self-equalizing thrust bearings.

At least two elements are required for the slide bearing - the bearing itself and the rotor collar. The sliding bearing contains segments to which lubricating oil is supplied. Each segment is a separate carrier part of the bearing. The bearing surfaces (both bearings and shaft collars) are completely separated by an oil film with a thickness of approx. 20 - 40 μm. The oil film avoids the risk of contact and therefore abrasion of the bearing surfaces. (Milovanovic (2020); Avrampos (2017))

Self-equalizing thrust pad bearings consist of the following basic parts (Fig. 1): (Branagan (2015))

1. Bearing body/housing,
2. Thrust pad,
3. Self-equalizing element (lever),
4. Nozzle,
5. Floating pressure element.

For every thrust, the pad is necessary to use 2 levers. It means that for example at 18 pads bearing is necessary to use 36 levers.

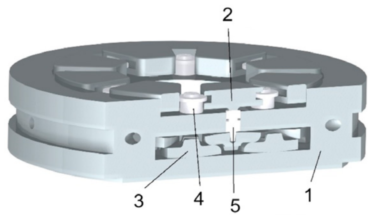


Fig. 1. Self-equalizing bearing with levers (1. Bearing body/housing, 2. Thrust pad, 3. Self-equalizing element (lever), 4. Nozzle, 5. Floating pressure element)

2. Preliminary tests

In the case of the thrust bearing, the most critical part is a system of very precise manufactured levers, which are in the close contacts each to other, so they have to be not only properly designed from the geometrical point of view but the important role plays also a quality of the functional surfaces of these levers. (Stratogiannis (2019); Abd El-Azim (1997))

The functionality of the bearing and its ability to transfer loads and compensate for misalignment is greatly affected by the geometry of the levers at the areas of contact. Kinematic and numerical analysis (which are not the subject of this study) pointed to the most suitable variants of contact pairs are namely (presented in Fig. 2)

a) „Cylinder/Cylinder“ + „Cylinder/Cylinder“,
b) „Cylinder/Cylinder“ + „Cylinder/Plane“,
c) „Cylinder/Plane“ + „Cylinder/Plane“.

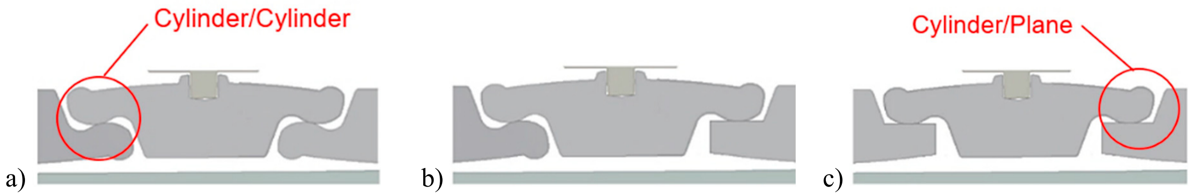


Fig. 2. Variants of contact surfaces of levers

During operation, the bearing is loaded in various ways, which take place simultaneously (static, friction and micro-friction, dynamically - frequency, random or rolling), which in practice causes different types of wear.

When designing the levers, it was, therefore, necessary to find the most suitable way of surface treatment, which together with the appropriate geometry would ensure the resistance of the bearing to wear with the best possible efficiency of production in terms of economic, time and process. There are several ways in which it is possible to improve the surface properties (mechanical, tribological, contact, etc.) of components such as e.g. surface hardening technology; laser hardening; cementation; nitriding; electroless nickel plating; rolling, grinding; sandblasting; thermal spraying and others. (Zhu (2017); Liu (2016); Borghi (2008))

To decide which of the surface treatment methods should be used in the research of the newly-designed self-equalizing bearing, the experiments were done and a study (Polasek (2016)) was elaborated that evaluated the available techniques in terms of hardness, depth of reinforcement of the surface layer or the need to use a finishing operation on the machine. After a basic analysis and synthesis of knowledge, the samples were made in the initial research from three materials: Non-alloy heat-treated steel (C45), Chrome-nickel-molybdenum heat-treated steel (34CrNiMo6), and Chrome-molybdenum heat-treated steel (42CrMo4).

All three basic materials have been basically refined to achieve high strength. As a result, however, it was shown that the only usable variant for further investigation was chromium-nickel-molybdenum heat-treated steel (DIN 34CrNiMo6 steel) to avoid the failures and damages during the bearing operation. (Pantazopoulos (2019); Vazdirvanidis (2008))

Nitriding and electroless nickel plating were chosen for this steel for further research into possible surface hardening due to its excellent tribological properties. Nitriding was chosen due to the uniform thickness of the formed layer without the need for further processing. (Polcar (2007)) Similarly, like nitriding, electroless nickel plating can only be used after final finishing without the risk of large dimensional changes to the product. (Mihalikova (2017)) The technique of surface treatment by tumbling seemed to be an alternative to the actual running of the rockers during operation. Here, too, there are no significant dimensional changes. There is only an adjustment of the roughness and there is a presumption that there could be a slight improvement in the tribological properties of the product. (Kuduzovic (2014)) Other surface reinforcement or surface treatment technologies did not meet some of the requirements and were therefore not considered further. Therefore, for the extensive preliminary research (Urban (2020)) carried out on 108 simplified samples in the shape of cylinders and a planar surface, which corresponded to the contact pairs of the lever "cylinder/cylinder" and "Cylinder/Plane", the following surface treatment technologies were selected: nitriding, electroless nickel plating, and tumbling.

Based on the research (Urban (2020)) results it could be stated that, overall, the samples treated by Electroless nickel plating showed the best properties from the static, tribological and dynamical point of view.

3. Static test of real levers

The levers were manufactured using the DMU 40eVo linear milling center. The machining strategies were chosen so that the workpiece was machined in two steps of fixing. Special clamping jigs for the first and second clamping positions have also been adapted to this strategy. The final height of the lever arm was measured with a probe with an accuracy of 0.1 µm. The resulting accuracy (when the clamping error was taken into account) was in the range of ±0.01 mm. Process of the lever machining, the lever after machining from one side and machined lever are shown in Fig. 3.

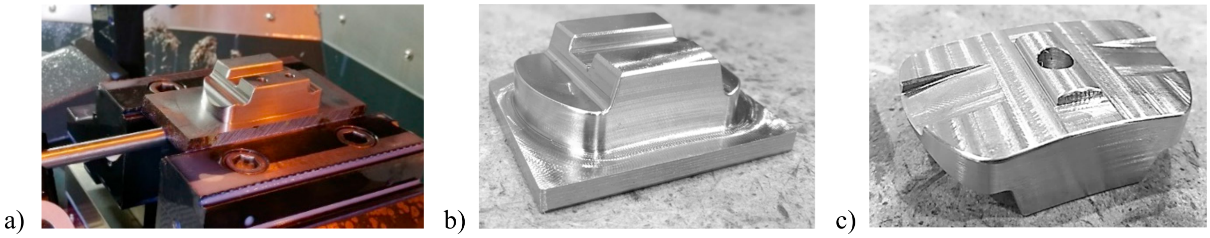


Fig. 3. a) Process of the lever machining; b) the lever after machining from one side; c) machined lever

Since the nickel-plated surfaces showed the best of all variants of surface treatment, the final experimental verification of tribological properties was started, for already real levers surface-treated with nickel plating. Due to the shape complexity of the levers, a frequency test was not considered and only a static test was performed. (Baragetti (2019)) The aim of the test was to determine whether there was any development of damage to the surface layer under quasi-static loading. The levers were made in seven variants differing not only by a surface treatment, but also in a feed *f* employing at their machining:

- Nickel-plated + tumbling
  - a) The lever was clamped from the side during tumbling
    - i. Lever 1.1 $f_1 = 0.08$ mm
    - ii. Lever 1.2 $f_2 = 0.12$ mm
    - iii. Lever 1.3 $f_3 = 0.16$ mm
  - b) The lever was clamped from above during tumbling
    - i. Lever 1.1 $f_1 = 0.08$ mm
    - ii. Lever 1.2 $f_2 = 0.12$ mm
    - iii. Lever 1.3 $f_3 = 0.16$ mm
- Nickel-plated (without tumbling)
  - a) i. Lever 3.1 $f_2 = 0.12$ mm

Prior to the static test, areas A and B were marked on the levers (Fig. 4), which were documented on a scanning electron microscope. For all lever arms, these indicated areas have been retained, i.e. the cylindrical contact area is labelled "A", the planar contact area is labelled B.

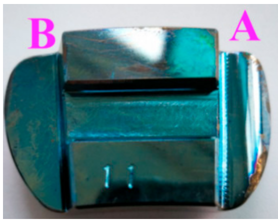


Fig. 4. A lever treated by electroless nickel plating before test

The values for the static load were determined by measuring the distribution of forces under the individual bearing segments. For this purpose, a special measuring device was made in cooperation with the company Doosan Škoda Power, while the method of measurement together with the construction of the stand is protected by a patent mark. The stand has the possibility to measure the maximum deflection of the bearing along with measuring the force spectrum under each segment in the horizontal and vertical position of the bearing. The ability to measure the bearing in a vertical position is very important because the vertical position is its working position, and the functionality of the bearing can be already limited due to so-called "levers collapse effect".

As a reference bearing, a bearing with 18 segments on a pitch circle of 516 mm was chosen, which with its size and number of segments represents the top range of self-equalizing bearings designed for industrial turbines. (Ettles (2003)) The bearing was divided into 4 quadrants as shown in Fig. 5.

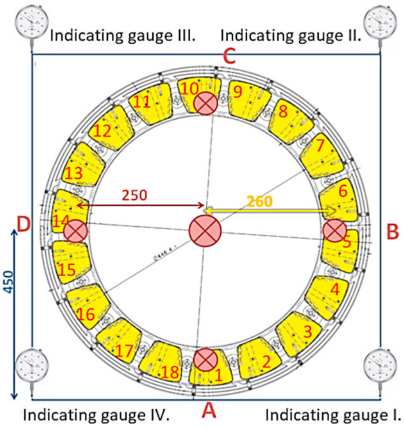
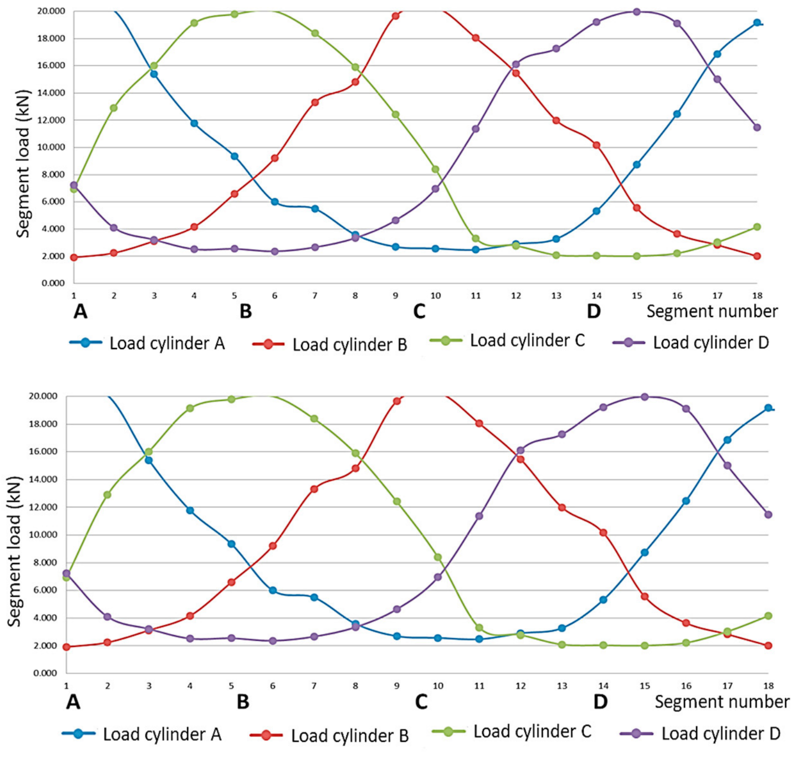


Fig. 5. Division of the bearing into 4 quadrants, with indication of the position of the load cylinders and the position of the sensors

All records from the measurement of forces acting on strain gauges and pressures in the hydraulic circuits were then processed through the bus to the measuring control panel and then to the computer, where all values were written and subsequently processed. The measurement was performed at a constant force of 100 kN from the central load cylinder and a force of 70 kN from the side load cylinders (A ÷ D), which had the task of deflecting the upper ground plate that correspond to the real operational load.

Within this experimental test, the levers with three basic variants of contact pairs (see Fig. 2) were measured in horizontal and vertical positions. The examples of force measurement records under the segments in the individual quadrants of the bearing for the contact pair Cylinder/Cylinder are shown in Fig. 6.



a)

b)

Fig. 6. The forces distribution under the individual segments a) in horizontal position of the bearing, b) in vertical position of the bearing

In all measurements, the maximum forces under the individual segments ranged up to 22 kN, so for experimental verification of the tribological properties of real levers surface-treated with nickel plating, a higher load with a value of 27 kN was chosen so that the results are unambiguous and demonstrable. Fig. 7 shows the setting of the lever in the press. The lever arms were supported on both sides on hardened cylinders. Since, in this case, the lever arm had a cylindrical contact area ("A") on one side and a contact area ("B") on the other plane, therefore, both contact pairs - Cylinder/Plane and Cylinder/Cylinder - could be statically tested at once.

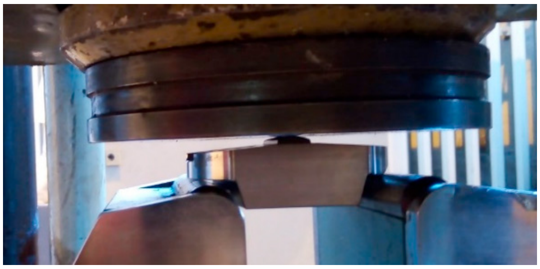
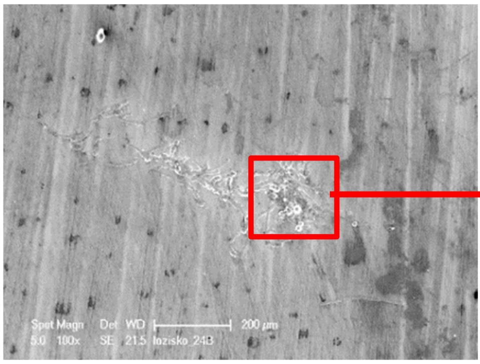
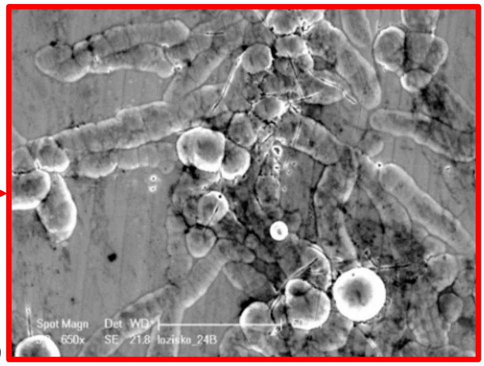


Fig. 7. Lever set-up within the pressure testing machine

After loading, all levers were visually inspected for the condition of the surface in areas A and B. This was done using a NIKON stereo microscope. Subsequently, each lever in areas A and B was also checked on a scanning electron microscope.

Minor defects were found in most levers, but subsequent analysis of the surface using a scanning electron microscope showed that the integrity of the surface is not significantly compromised in the observed defects. These were rather related to the surface reflective layers. The following Figures 8a) ÷ 8c) show some larger surface defects in selected lever 3.1 at both arms A and B.

a) 

b) 

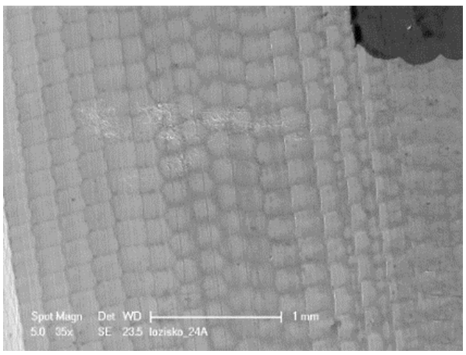
c) 

Fig. 8. Surface defects on the lever a) area B; b) detailed view on the defects in area B; c) area A

As follows from the monitored lever, it was not possible to specify the actual condition of the surface only on the basis of visual inspection (although when magnification by means of a stereomicroscope was performed). In all cases, when defects were detected by visual inspection using a stereomicroscope, these defects were refuted by subsequent observation with a scanning electron microscope. Only impurities that appeared as defects when visually observed were present on the surface of the levers. In some cases, these were surface defects, the cause of which was the surface treatment technology. These defects were more visible in the levers, which were not treated by tumbling.

Finally, it can be stated that no defects were found on any lever (at any surface roughness) after static loading, over more, no damage of the lever from the stiffness point of view was not observed and found out.

Conclusions

Within the long-term and extensive research, the aim of which has been a design of newly developed self-equalizing thrust bearing, a lot of experiments were done. One of the most important parts of such a bearing used in large rotary machines as are turbines or compressors are the levers that transfer the load and equal a misalignment resulted from various causes. After specification of the material and shape of the levers', also preliminary tests focused on the lever´s surface treatment were performed. The results pointed on the best properties electroless nickel plated samples. Based on that the real levers were made and their surfaces were treated by electroless nickel plating. They were experimentally tested by static tests with the goal to verify their stiffness and surface treatment.

The results of the static test showed that Only impurities that appeared as defects when visually observed were present on the surface of the levers. In some cases, these were surface defects, the cause of which was the surface treatment technology. These defects were more visible in the levers, which was not treated by tumbling. Finally, it can be stated that no defects were found on any lever (at any surface roughness) after static loading, over more, no damage of the lever from the stiffness point of view was not observed and found out. It led to that the nickel-plated levers have been produced and used for the production of the self-equalizing bearing which was tested at 3 various devices: experimental turbine DOOSAN Škoda Power TG 10, experimental gear stand built by Howden ČKD Compressors + GTW BEARINGS, and experimental compressor set Darina IV Howden ČKD Compressors. The bearings have fulfilled all the requirements and now they are implemented in real practice.

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