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THE EFFECT OF LASER SURFACE MODIFICATION ON PERMEABILITY AND LOAD CAPACITY OF POROUS SLEEVES

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Abstract

In this article some results of the research on the new generation slide porous bearings sintered from Höganas NC.100.24 iron powder, with 2.5% addition by weight of copper, with micro-segments (paths) made on their sliding surface with CO_2 laser, with increased hardness and locally reduced surface porosity, are presented. The research was carried out within the framework of PBR/15-249/2007/WAT-OR00002904 Research Project financed by the Ministry of Science and Higher Education, during 2007 – 2011 [1]. Significant increase of the load capacity of the porous sleeves with paths, in comparison with the same Ø25/Ø35 x 20 mm sleeves without paths, was obtained. Durability of the bearings was also slightly higher; however, in comparison with the sleeves with macro-segments made of solid material, durability of the new generation bearings was several times higher. The sleeves sintered from iron powder with micro-segments made on their surface with the laser technique have not been previously known. Promising results in terms of increase of load capacity and durability caused that authors decided to submit a proper patent claim to the Polish Patent Office [2].

Keywords: *porous sleeves, iron sinter, laser-made micro-segments*

1. Introduction

The attempts of manufacturing of segment bearing are worldwide known. These segments (with the length corresponding to the bearing length), made of solid material, are embedded in the sliding surface of the porous bearing [3, 4].

That solution allows increasing the bearing load capacity, but – simultaneously – it significantly decreases both total and open porosity, and, in consequence, decreases the oil capacity of the bearing. As a result, considerable decrease of the bearing durability, mainly limited by the amount of lubricating substance in the porous structure, can be observed. Furthermore, it is technically complicated structure, difficult to manufacture, and causes the significant rise of the production costs. Probably that is why such bearings are not being produced in Poland, even in case of the large dimensions bearing. Some other constructional ways of increasing the load capacity and durability of the porous bearings are being presented in the scientific literature, such as:

- bearings made of the materials with variable porosity – low porosity on the loaded side and high porosity on the non-loaded side (which is technically complicated),

- making some grooves with the machining methods (for example spirally on the sliding surface), functioning as the lubricant "pockets".

Whereas, the porous sleeves with the micro-segments (paths) on the sliding surface made with the laser technique, have not been known yet. Owing to this fact, these sleeves are characterized by higher durability and load capacity, when proper lubricating oil is used.

For the comparative tests some standard porous sleeves Ø25/ Ø35 x 20 mm, made of sintered iron containing 2.5% of copper (Polmo Łomianki S.A) were chosen. The sleeves were modified by producing up to eight micro-segments (paths) on the sliding surfaces with CO_2 Lumonics VFA 2500 laser (par. 2). The tribological research was performed on PŁS-01 test stand (par. 3). The best oils, among all tested, were used for the lubrication (impregnation) during the experiment, i.e. Hipol15F 85W/90 (0-3), Mobilube 1SHC 75W/90 (0-26) and the mixture of PAO-8 and PAO-40 (55%/45%) basic oils (O-30). Other tested oils, e.g. Antykol TS120 used by Polish manufacturers of the porous bearings or, recommended by Klüber Lubrication, Klüberalfa DH3-100 oil, turned out to be much worse [1]. One of the fundamental parameters, determining durability and load capacity of the porous sleeves (defined mainly by their porosity), is oil and air permeability of the sleeve (defined for actually used fluid) and the variability of this parameter versus time, which is mainly influenced by the nature of physical and chemical reaction between the lubricating liquid and the porous structure (par. 4).

2. Methodology of manufacturing the micro-segments (paths) with a laser

The micro-segments (paths) were exemplary made with CO_2 Lumonics VFA 2500 laser, with power of P = 0.83 kW, the laser travel speed along vertical and horizontal axes of v = 2000 mm/min and the laser beam spot diameter of 5 mm. Due to the size of the sleeve (Ø25/Ø35 x 20 mm) and limited access to the sliding surface, the laser beam was operating at an angle of 45° to that surface. The sleeve was fixed at an angle of 45° to the table, in a rotary grip. In order to ensure the constant size of the laser spot during travelling towards horizontal axis (along the sliding surface), the laser was moving with the same speed along vertical axis (up). Travels in vertical and horizontal axes in the distance about 8.5 mm gave, on the sloping internal surface of the sleeve, the distance between the centres of the spot at the level about 12 mm. Taking into account the radius of the spot, the total length of the laser path was about 17 mm (Fig. 1 and 2).

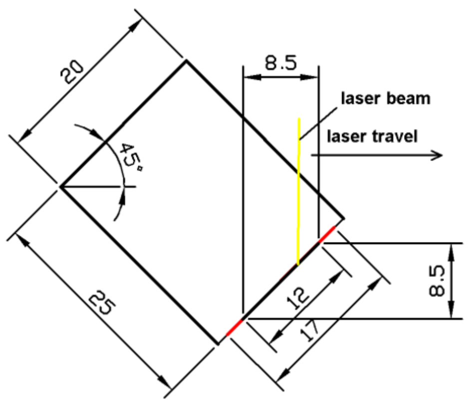


Fig. 1. Scheme of sleeve set-up in relation to the laser beam

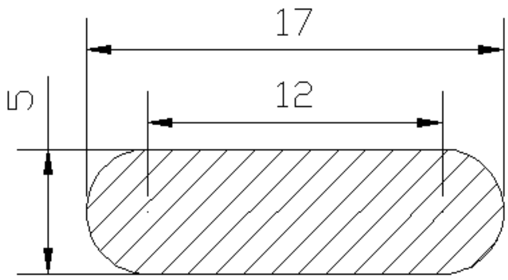
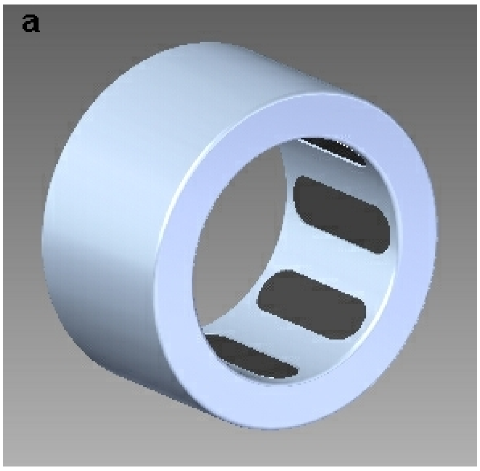


Fig. 2. Exemplary geometric dimensions of the path (micro-segment)

Making the paths along the whole length of the sleeve (20 mm) was causing deterioration of the material close to the edges, so it was decided to leave about 1.5 mm interval from the edges on both sides of the sleeve. It concurrently provided lubrication more effective in the edge area of the bearing (better oil inflow from the porous structure).

After one path, making the sleeve was being rotated by 45° around its symmetry axis, with simultaneous return of the laser to its initial position. This way, rotating the sleeve by 360°, eight laser paths was produced (Fig. 3), less than two micrometres in depth.



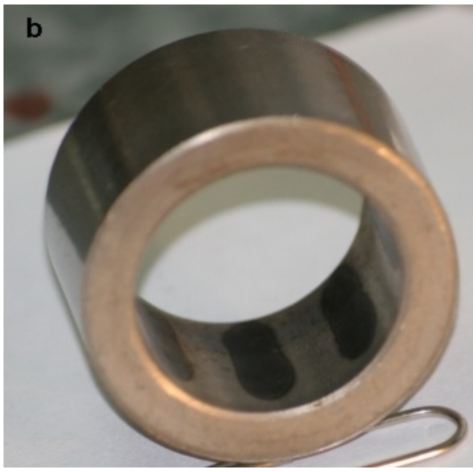


Fig. 3. Paths made with CO_2 laser beam on the sliding surface of Ø25/Ø35 x 20 mm sleeve: numerical model, b) real sleeve

Laser radiation caused the partial remelting of the top part of the material asperities within the modified area. As the result, the significant changes of the material hardness and porosity within the micro-sections (paths) area appeared – up to 40 µm in depth. The micro-hardness test conducted with Vickers indenter proved that, in the discussed case, hardness of the material near the sliding surface of the sleeve increased even three times compared with the native material. In the area modified with laser there was also observed some local decrease of surface porosity, rated as the ratio of the pore surface to the whole micro-section surface, from about 20% to about 10%. Similar porosity changes appeared also in the cross-section of the micro-segment (path), what is presented in Fig. 4.

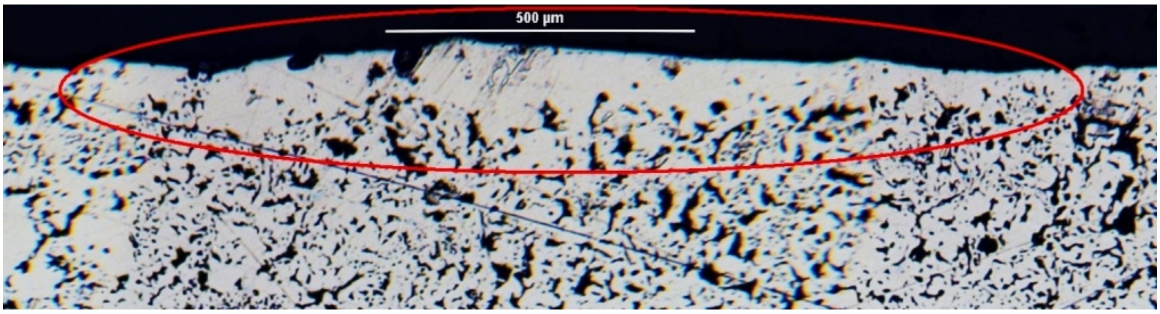


Fig. 4. Cross-section of the path made with CO_2 laser

The “paths” contributed to increase of the load capacity of the sleeves (marked as ST-1-x) in comparison to standard sleeves without such paths (T-1-x), what is described in the next section of this article.

3. Methodology and results of the tests made with the use of PŁS-01 machine

PŁS-01 test stand is shown in Fig. 5 and 6. The drive assembly consists of two electric motors with nominal rotational speed of n = 1450 rpm and power of 4.5 kW. The rotational speed control system allows selecting a required speed within the range of 0…1500 rpm, for sixteen tested bearings simultaneously. PŁS-01 machine was constructed in the Department of Tribology, Surface Engineering and Service Fluids Logistics of MUT especially for testing of the porous slide bearings.

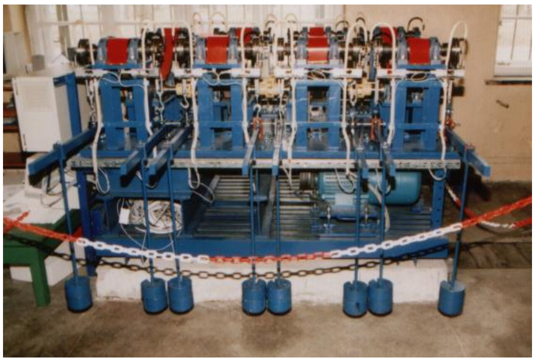


Fig. 5. Side view of PŁS-01 stand

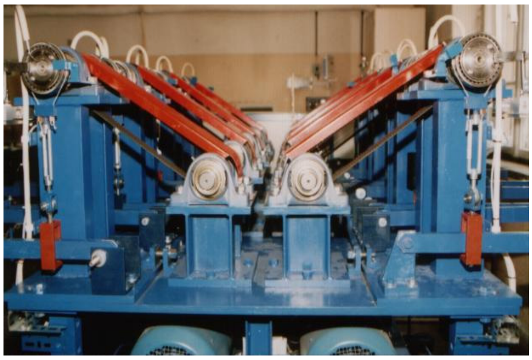


Fig. 6. Back view of PŁS-01 stand

Load capacity tests of T-1-x porous slide bearings (without micro-segments) and ST-1-x (with micro-segments) was made for three rotational speeds, i.e.: n_1 = 600 rpm (v_1 = 0.79 m/s); n_2 = 1000 rpm (v_2 = 1.31 m/s) and n_3 = 1400 rpm (v_3 = 1.83 m/s). The load was being gradually (step by step) increased every time (by 0.4 MPa) after stabilization (and/or decrease) of resistance to motion and temperature of the bearing. It was assumed that the limit pressure (p_{gr}) was the one, which was preceding the pressure causing seizing (p_z). The following parameters were assumed as the seizing criterion:

- rapid increase of resistance to motion, i.e. when moment of friction M_t > 2 Nm and friction coefficient μ > 0.3;
- instable work of bearing, i.e. when some oscillations, sudden changes of parameters of work appeared (momentary seizing etc.);
- the bearing temperature was increasing rapidly up to T > 200...220ºC.

The influence of the modification of ST-1-x sleeves (with "paths") in comparison to standard T-1-x sleeves without such segments, on their load capacity is shown in figures 7 and 8. The sleeves were lubricated (impregnated up to about 97-98%) with the following oils: Hipol 15F 85 W/90 (0-3), Mobilube 1SHC 75 W/90 (0-26) and the mixture (55%/45% by weight) of PAO-8 and PAO-40 basic oils (0-30). The results of the tests were also related to the actual conditions of sleeves' work, obtained for commonly recommended for porous slide bearings lubricating oils: Klüberalfa DH3-100 (for n = 1000 rpm: p_{gr} = 0.94 and $p_{gr} \cdot v$ = 1.22 MPa $\cdot$ $m \cdot s^{-1}$) or Antykol TS120 (for n = 1000 rpm: p_{gr} = 1.18 MPa and $p_{gr} \cdot v$ = 1.54 MPa $\cdot$ $m \cdot s^{-1}$). These values are hardly within the range of $p \cdot v$ = 0.9…2.1 MPa $\cdot$ $m \cdot s^{-1}$, commonly assumed as an adequate for the standard porous slide bearings (T-1-x). The mentioned range was marked with the dashed lines in figure 8.

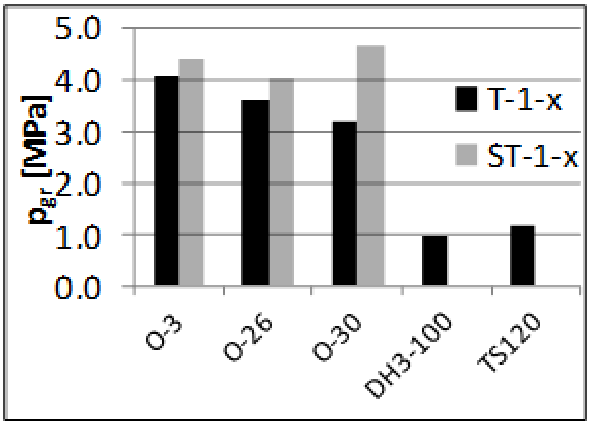


Fig. 7. Influence of the micro-segments of ST-1-x sleeves on p_{gr} increase at 1000 rpm

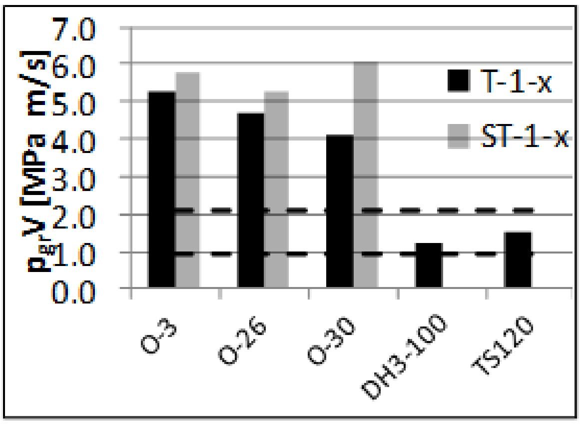


Fig. 8. Influence of the micro-segments of ST-1-x sleeve on increasing of $p_{gr} \cdot v$ product at 1000 rpm

The micro-segments (paths), made on the sliding surface of the sleeve (ST-1-x type) with the use of the laser technique, caused noticeable load capacity increase, in comparison to the sleeves without mentioned micro-segments (T-1-x type), providing practically the same, or even a little higher, durability. The increase of the load capacity of ST-1-x sleeves lubricated with gear oils was observed for the entire range of rotational speed (600 rpm – 1400 rpm) and amounted from several to several dozen per cent. The greatest increase of load capacity in discussed tests was observed for the sleeves impregnated with 0-30 oil (about 50% higher at the speed of 1000 rpm). Obtained values of $p_{gr} \cdot v$ product even above 5.75 MPa $\cdot\, m \cdot s^{-1}$ are about 2.5 times higher than a standard range required for this type of the iron slide bearings ($p \cdot v$ = 0.9… 2.1 MPa $\cdot\, m \cdot s^{-1}$) [5-8] at low temperature (T < 80ºC) and a very low friction coefficient ($\mu \approx 0.01$). Moreover, obtained load capacity also reached $p \cdot v$ = 5.4 MPa $\cdot\, m \cdot s^{-1}$ value applying to porous bearings with the reduced porosity zones (e.g. with segments made of solid material) [4].

4. Methodology and the results of the porous sleeves permeability tests

The oil circulation inside the porous structure and its inflow to the lubrication slot between a sleeve and a roller depends on the porous sleeves permeability. Permeability, because of its strong connection with sleeve porosity and interaction between porous structure and lubricant, determines also the porous bearing load capacity and durability. It is recommended to carry out the assessment of the porous structure permeability by means of the gases (PN-EN ISO 4022: 2007 “Permeable sintered metal materials. Determination of fluid permeability”), due to the formation of the nanolayer of surface-active substances (present in oils), is on the internal walls of the pores. Whereas the comparative assessment of the sleeve permeability with the use of real lubricating oils containing various chemically active additions, allows determining (explain) the quality of substance functioning as the lubricant for the porous slide bearings.

Sleeve air permeability determination was made in accordance with PN-EN-ISO 4022: 2007 standard. In order to assess air permeability, the volumetric airflow rate and pressure drop during the air infiltration through porous wall (with known active surface and thickness) were measured. The test was realized under laminar flow conditions, using the test stand presented in figures below (Fig. 9 and 10). The determination of the oil permeability of the sleeves for real oils was performed according to the same standard on the appropriately prepared test stand.

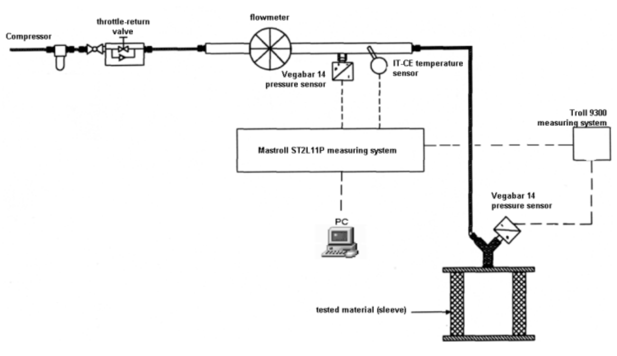


Fig. 9. Schematic diagram of the test stand for air permeability measurements

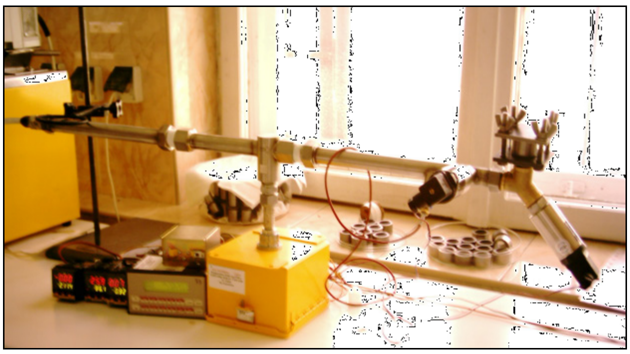


Fig. 10. General view of the test stand for air permeability measurements

In the next figures, (Fig. 11 – 14) the summary graphs of T-1-x and ST-1-x porous sleeves air and oil permeability (α) are shown. The oil permeability was measured for the two gear oils: 0-3 (Hipol 15F 85 W/90) and 0-26 (Mobilube 1SHC 75 W/90).

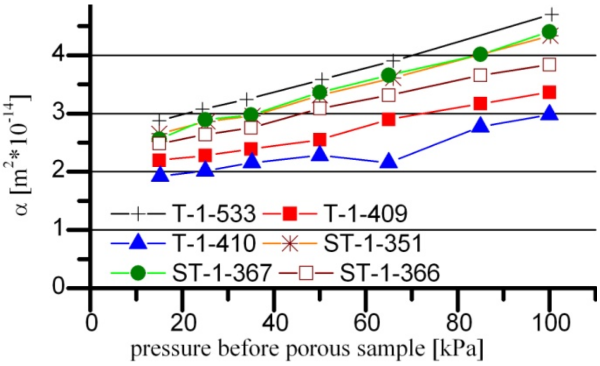


Fig. 11. Air permeability of standard (T-1-x) and new generation (ST-1-x) sleeves

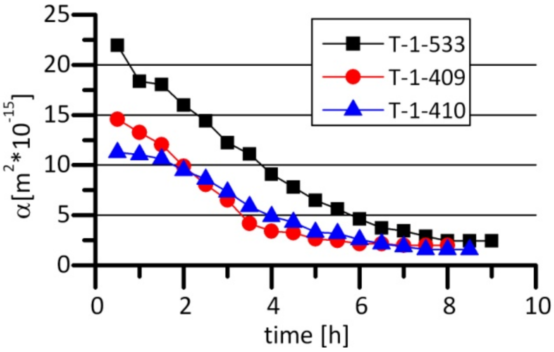


Fig. 12. Oil permeability of standard T-1-x sleeves (Hipol 15 F (O-3) oil)

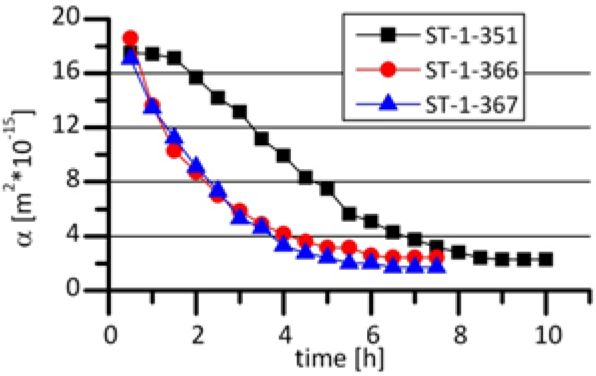


Fig. 13. Oil permeability of new generation ST-1-x sleeves (Hipol 15 F (O-3) oil)

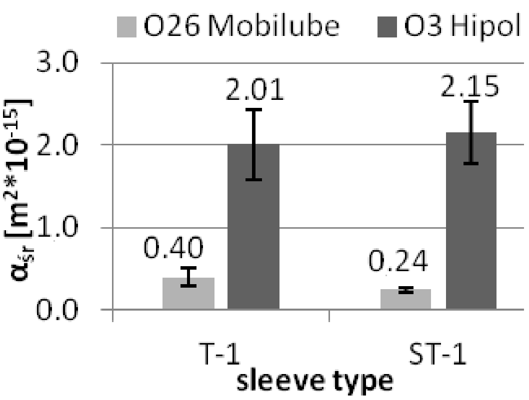


Fig. 14. The comparison of average oil permeability of the tested sleeves for 0-3 (Hipol) and 0-26 (Mobilube) oils

5. The analysis of the test results

The analysis of the tests results did not show essential difference between air permeability of standard T-1-x and new generation ST-1-x sleeves. Some of the standard sleeves were characterized by even lower permeability, than the ones with modified sliding surface. It proves that the modification was of quite slight and superficial nature (despite the decrease of local porosity and significant increase of hardness). In consequence, neither essential difference in character of permeability changes, nor differences in final values between T-1-x and ST-1-x have been noticed. The time of flow rate stabilization (and consequently, time of permeability stabilization) was similar for both sleeve types (about 6-8 hours).

Analogous tests were carried out with the use 0-26 (Mobilube) oil. There were also no essential differences in character of oil permeability changes and final stable values between traditional and new type of sleeves. However, it have been observed, that the time of flow rate stabilization (as well as time of oil permeability stabilization) was different for both types of sleeves. For T-1-x sleeves, it was about 4-6 hours but for ST-1-x it was only about 3-5 hours. In both cases, stabilization time was fairly shorter than for Hipol oil (6-8 hours). Moreover, comparison of the final oil permeability values shows that the ones obtained for Mobilube oil (which is more than two times less viscous than Hipol oil at the temperature of 25°C) are much lower. Changes of permeability observed during measurements, from initial to final stable value, were much more dynamic and greater in case of Mobilube oil.

The results of the tests proved that, because of the presence of laser-modified areas ("paths"), noticeable increase of the load capacity was obtained. In the tested examples of the sleeves impregnated with 0-3, 0-26 or 0-30 oil, the increase reached up to 50% when compared to the same type unmodified standard iron sleeves containing 2.5% of Cu. Regarding to standard oils used for impregnation of the porous bearings, i.e. for example Antykol TS120 or Klüberalfa DH3-100, the increase is many times higher. The durability of such modified sleeves was even slightly higher than for the standard sleeves and far higher than for the sleeves with macro-segments made of solid material. First of all, it was caused by their lower wear and more stable operating associated with oil steady circulation in the lubrication slot. On the other hand, it was mainly caused by additional oil volume under the micro-segments (paths), which had not been occupied by the solid material segments. Such new type sleeves (ST-1-x type), when lubricated with 0-3 oil, allowed to achieve $p_{gr} \cdot v$ product value exceeding even 5.75 MPa $\cdot\, m \cdot s^{-1}$, which is almost three times higher than the range required for the standard iron slide bearings lubricated with typical oils (Antykol TS120 or Klüberalfa DH3-100 – $p \cdot v$ = 0.9 … 2.1 MPa $\cdot\, m \cdot s^{-1}$), concurrently providing low operating temperature (T < 80º C) and small friction coefficient ($\mu \approx 0.01$). Value of $p \cdot v$ = 5.4 MPa $\cdot\, m \cdot s^{-1}$, reaches by the porous bearings with the reduced porosity zones with the solid material segments, was also exceeded. The results of tribological tests also proved, that the parameters of work, load capacity and durability of sleeves impregnated with Hipol oil were more favourable than them impregnated with Moblilube oil (for both T-1-x and ST-1-x sleeves). The weight loss of 0-3 (Hipol) oil in comparison to Mobilube oil was slightly smaller, which resulted in little lower durability of the sleeves impregnated with Mobilube oil. With regard to Klüberalfa DH3-100 or Antykol TS120 oils commonly recommended for porous bearings impregnation, the weight loss is 2-4 times smaller, what results in 2-4 times higher increase of sleeves durability, when lubricated with Hipol oil, if there are no unexpected negative obstacles. During the durability test lasting over 400 h without seizing, under load of 2000 N, which gives the value of $p_{gr} \cdot v$ = 5.24 MPa $\cdot\, m \cdot s^{-1}$ the linear wear of the sleeves lubricated by Hipol (0-3) oil was only 3 μm, friction factor $\mu \approx 0.008$ and temperature $T \approx$ 70° C.

6. Summary

The proposed modification of sliding surfaces of porous sleeves, leading to increase their load capacity and durability, combined with appropriate selection of oil for impregnating the sleeve will lead to saving energy needed to drive mechanisms, equipped with modified sleeves (with microsegments made by laser). Even greater savings result from the production process of these sleeves, compared with the complicated production process of the sleeves with the solid material segments. That is why it was decided to submit a patent claim to the Polish Patent Office [2].

The subject of this claim are exactly the tested iron porous slide bearings (sleeves) designed for working with increased load and medium rotational speed within the wide temperature range, both minus and plus (depending on the oil used for impregnating the porous sleeves), on which on sliding surface (inner) up to 8 micro-segments (paths) are being made. These paths (if there are 5-8 of them) are being disposed on the hole perimeter, what makes it possible to set them up freely during assembling in a tribological node. In case of the little number of segments (up to 4), all of them should be located on the loaded side of the bearing, i.e. on the side with a hydrodynamic “oil wedge” generating proper pressure distribution, which counterbalances the bearing external load. The process of making the micro-segments (paths) with the laser beam is aimed at hardness increasing and partial decreasing of porosity of the modified zones by partial melting of the top parts of the material asperities, and – owing to this fact – increases the bearing load capacity. The micro-segments (paths) could be less than 2 μm in depth, so they do not reduce bearing volume, which is necessary for oil impregnation. Additionally, paths do not form the interference threshold for oil film pressure distribution, which counterbalances the bearing external load. Moreover, they can operate as the lubrication “mini-pockets” too. Therefore, the bearings being the subject of the patent application will not be less durable (mainly limited by oil quantity in the porous structure) than the standard porous bearings without such micro-segments (paths), whereas it is supposed that they will be much more durable than the same bearings with the built-in macro-segments made of solid material, highly decreasing oil volume of the porous structure. The load capacity and resistance to motion of the bearings, which are the subject of the patent application, will be depended on the quality of the process, determined by parameters of the laser beam (including the depth, width, hardness) and, first of all, porosity in the area of the micro-segments, the number of segments and selected lubricant.

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