DRY BEARING SLIDING LAYER TRANSVERSE FLEXIBILITY EFFECTS ON REAL SLIDING DISTANCE FOR RECIPROCATING MICROOSCILLATORY MOVEMENT OF FLAT CONTACT SURFACE

Rafał Gawarkiewicz
Gdansk University of Technology
Faculty of Mechanical Engineering
80-952 Gdańsk, ul. G. Narutowicza 11/12
tel.: (+48 58) 347-19-37, 347-28-17; fax: (+48 58) 347-27-42
e-mail: gawar@pg.gda.pl

Abstract

In the paper selected problems of the effects of mechanical properties and shape of dry bearing sliding layer on real sliding distance of contacting surfaces have been presented. Previously described experimental results and computer simulation results presented in that paper confirmed and explained why real sliding distance is significantly smaller than nominal one – assumed as sum of amplitudes of oscillations measured for elements of bearing unit. Numerical simulation results are allowing to determine geometrical recommendation for sliding surface geometry of bearing material ensuring the biggest possible reduction in real sliding distance. Elastic deformation of bearing elements, having different geometry, were analysed with the application of MES. Coulomb friction law was applied to perform calculations. ANSYS programme was used for solving the problem.

Keywords: sliding distance, vibrations, sliding layer, dry bearing material, flat surface friction contact, wear

1. Introduction

Within a framework of investigation that have been done at Faculty of Mechanical Engineering at Gdansk University of Technology, concerning prediction of the durability of sliding contact connections, working under microoscillations [7], theoretical and experimental researches of dry bearing materials of leading in the world greaseless bearing producers were performed [6]. These researches were carried out in order to identify these material's features, which are responsible for resistance to wear under microoscillation conditions. Performed analyses of results obtained from research made on real objects – bearings of guide vane of water turbines [1] – unequivocally indicates, that real sliding distance is a sum of distance resulted from the nominal working movements – occurring because of performing function of guide vans – and amplitudes of micro-movements generated by vibrations of bearing elements. The sliding distance generated by micro-oscillations appeared to be the one of most the important factor, influencing the wear of bearing unit [4], [2].

As it was proved by experiments, the bearing resistance to wear, caused by micro-oscillations, can be improved by reduction in real sliding distance through introducing the more flexible bearing layer. It can be obtained for instance by application of small transverse grooves in the bearing surface [5]. Researches performed on test rig [3], specially designed for this purpose confirmed this hypothesis.

The geometry of sliding surface, which ensure increase of wear resistance and sufficiently high fatigue endurance limit of sliding layer, was established using computer simulations for these type of sliding contacts.

2. The assumptions to numerical simulation

In order to diagnose the phenomena occurring during operation of bearing unit, 2D model consisting of specimen made of bearing material and steel counter-specimen, have been applied to perform analysis. ANSYS programme, which is based on finite element method (FEM), was used.

The following material properties were assumed for bearing material: Young's modulus $E_x = 2 \cdot 10^3$MPa, Poisson's factor $v_x = 0.4$. Stiffness of contacting elements is corresponding to steel stiffness.

Friction coefficient of analysed materials $\mu_{sx} = 0.2$ was assumed. This value is between these of static and kinetic coefficient of friction for chosen dry bearing material and steel.

The element PLANE42 for modelling of specimen made of bearing material was used – it is standard element of library elements of the ANSYS programme. Geometric model of steel counter-specimen is simplified to group contact elements CONTAC26 (which is simulating infinitely deep ground – dotted line in fig. 1) with stiffness corresponded to steel stiffness.

Relative movement between the specimen and the counter-specimen was being obtained by moving of the contact elements parallely to contact plane. The motion was being realised until the moment of appearance of contracted slide. As the *contracted slide* was assumed appearance of slide in each element within the area containing 90% of contact elements counted from centre of specimen. As the *slide of contact element* it is assumed that in contact nodes the friction in sliding direction is equivalent to maximum Coulomb's force friction. Relative displacement, after which occurrence of contracted slide was being checked, became limited to 1μm.

3. Numerical symulation

3. 1. Sliding layer with flat sliding surface

2D Geometry of specimen made of bearing material with flat sliding surface (fig.1) was described in the following way: height h = 15mm and length s_{gld} = 96mm. Specimen was

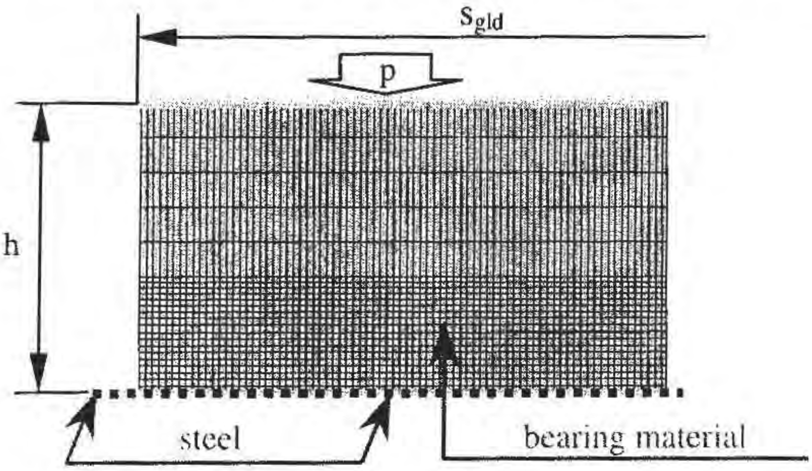

Fig. 1. Part of 2D FE model used for simulation of sliding between part made of bearing material and part made of steel (dotted line). p – specimens pressure loading

fixed in sliding direction at each nodes, which belong to its upper surface. Upper part of specimen was loaded with pressure p, which assure required amount of average of contact pressure into sliding region. Width of FE at contact zone was assumed as being 0.35mm.

As result of performed simulation, distribution of deformation of specimen under contact pressure equal to 15MPa was obtained (fig. 2 a).

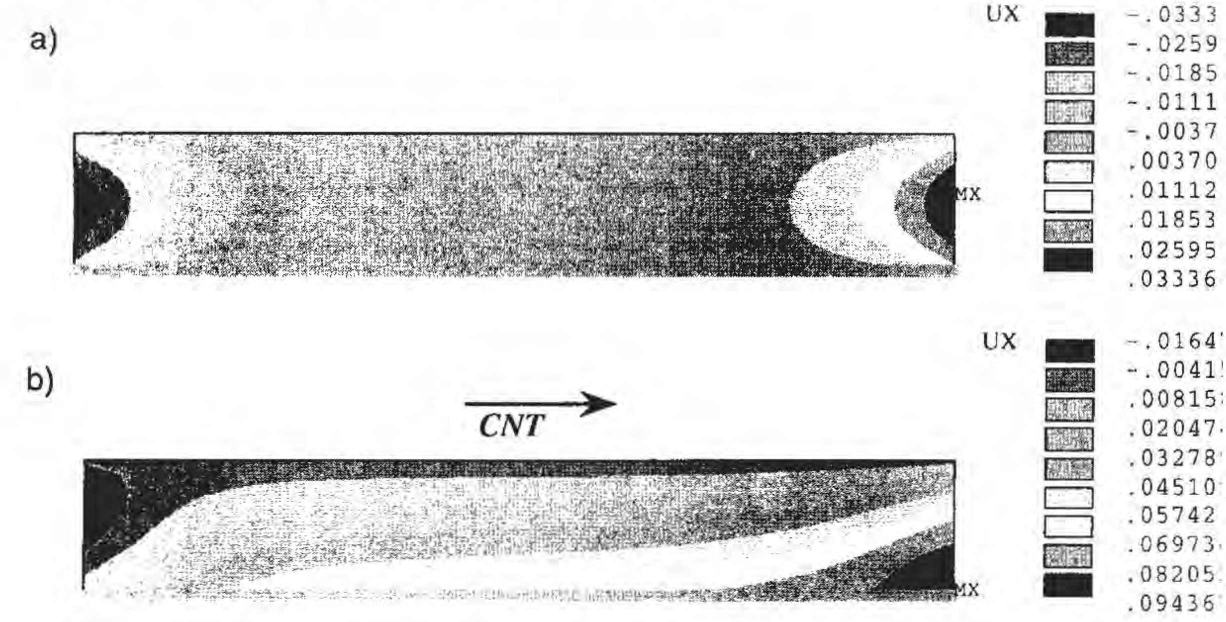

Fig. 2. Deformation of bearing material[mm], in direction of sliding, resulting from: a)contact pressure equal to 15MPa (without transverse total displacement) and b) displacement of steel part (equal to 82μm in CNT direction) under contact pressure equal to 15MPa

High flexibility of bearing material causes significant deformation in sliding direction in the areas at the beginning and ending of specimen material.
Figure 2 b shows distribution of horizontal deformation into specimen, in the time of occurrence of contracted slide in *CNT* direction, caused by forced movement of steel ground UX_{max} = 82μm under average amount of contact pressure equal to 15MPa. Both constant values of pressure and constant direction of displacement gradient in the centre zone are indicating, that increasing of thickness of bearing layer, causes proportional increase in maximum value of displacement of bearing contact surface relative to steel surface, which does not cause sliding yet. But the condition of assurance of such linearity of gradient of deformation is necessity of assurance of enough length of centre region of sliding layer. It helps to avoid disturbance of deformation at the edges of specimen as the result of described before deformations caused squeezes and bending effected by friction force.

3. 2. Bearing layer with transverse grooves on sliding surface

2D Geometry of specimen, made of bearing material, with grooves (fig. 3) was described in the following way: height h = 15mm (the same as for specimen with flat sliding surface), width of groves s_{rwk} = 0.5mm, depth of grooves g_{rwk} in the range from 2 to 10mm, length of bearing material between grooves s_{bznk} provisionally set in the range from 3 to 18mm, number of grooves was depended on length of the bearing material between groves – but it was not smaller than 2. After performance number simulations it turned out, that obtained results were significantly depended on number of used contact finite elements and also on distance between them. Hence geometry was built in such a way, that number of these elements were not varying more than about 10 (on 170 average used). Whole length of specimen it has been assumed that nominal length almost is not depend on the number and geometry of groove. Width of FE of bearing material at contact zone was established on 0.35mm.

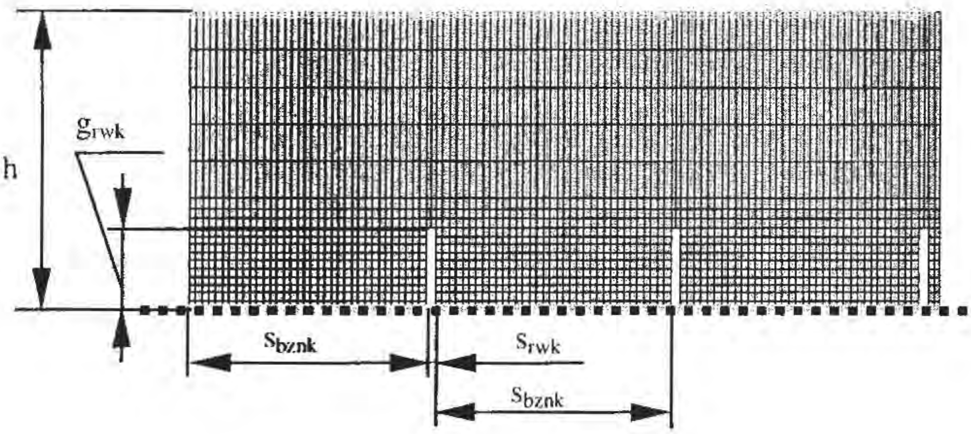

Fig. 3. 2D FE model of bearing material with grooves

After analysis of preliminary results obtained the maximum distance between grooves was enlarged to 51mm.

In the figure 4 picture of deformation in sliding direction for centre zone of bearing material with grooves of dimensions: $s_{rwk} = 0.5$mm, $g_{rwk} = 8$mm and $s_{bznk} = 4$mm, loaded from the upper surface by pressure giving in contact surface contact pressure equal to 15MPa was introduced. In addition, relative displacement of adjoined elements of both materials was forced. Contracted slide occurred in displacement of steel counter-specimen is equal to 148μm. This result along with the results obtained in previously performed researches [4], [2] and [5] allowed to formulate the hypothesis, that presented configuration of bearing unit, with flexible sliding layer, can significantly decrease the sliding distance – and thus decrease the abrasive wear– through balancing influence of microoscillations of sliding surface with amplitude up to 148μm.

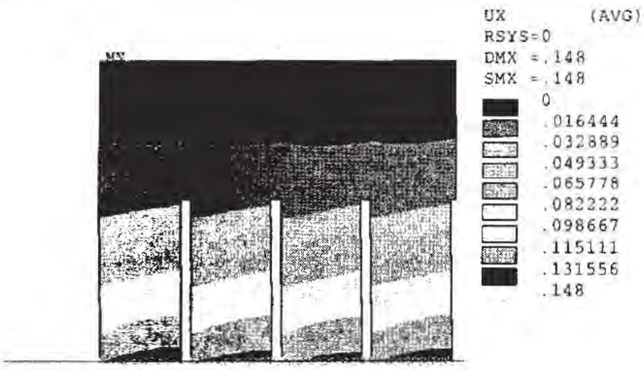

Fig. 4. Deformation of bearing material [mm], in direction of sliding, resulting from displacement of steel part (equal to 148μm in CNT direction) under contact pressure equal to 15MPa

Figure 5 shows, for centre part of bearing material between neighbouring grooves, distribution of normal stresses: in direction perpendicular to moving contact surface of steel counter-specimen (fig. 5 a), in parallel direction (fig. 5 b) and shear stress (fig. 5 c). Perpendicular to contact surface normal stresses are clearly under effect of angular misalignment of bearing material bar caused by friction forces. In the right corner these normal stresses decreased practically to 0.

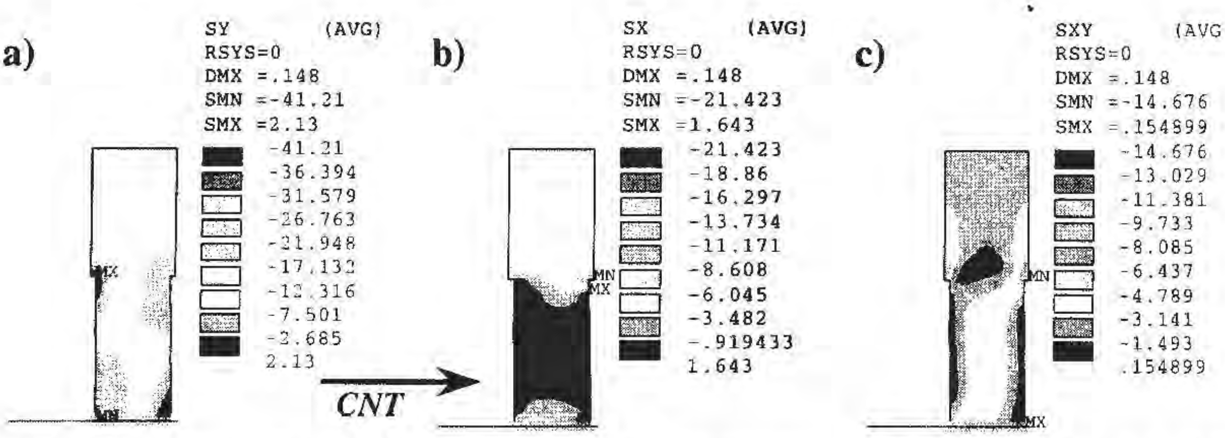

Fig. 5. Distribution [MPa] of: a) normal stress in vertical direction to the sliding, b) normal stress in sliding direction and c) tangent stress in bearing material resulting from displacement of steel part (equal to 148μm in CNT direction) under contact pressure equal to 15MPa

Unequal distribution of contact stress accelerates appearance of slide. Other kinds of stresses can have unequal distributions at sliding surface too, but to the considerably smaller degree. Presented maps of stresses demonstrate characteristic regions at the bottom of groove at which more flexibility of bearing layer is presented (fig. 5 b). This place gives effect called action of notch effect irregularity of geometrical shape of the bottom of groove.

4. Results

In order to find the most profitable geometry of the sliding layer, different dimensions of grooves and different distances between them, were considered. Comparison of the results in shape of chart: amount displacement of steel counter-specimen, which causes the contracted slide, versus depth groove and distance between them (in the range from 4 to 20 mm) was shown in figure 6. It can be stated that depth of the groove has significant influence on increase of flexibility of sliding layer of bearing material with grooves (cut transverse to expecting sliding direction). How it could be expected, increase of depth of grooves is causing increase in flexibility of bearing sliding layer. Decrease of distance between grooves has similar influence. The influence can be especially observed in the range of bearing material length from 4 to about 6mm. The minimum value equal to 4 mm – is resulted from technological and maintaince limits. For depth of groove equal to 10mm, contracted slid can occur after displacement of steel counter-specimen bigger than 224 μm. However, increase of distance between grooves more than 16mm do not give practically any effect. There is a part of chart, in which changes of $s_{b:nk}$ i g_{rwk} gives inverse effect. This area of chart is called as *area of low flexibility* (*ALF* in fig. 6). In the *ALF* area decrease of flexibility is visible. Point *A* is situated on the line of minimum flexibility of sliding layer (shaded line). It means that, this line contains points, for which contracted slide is occurring first when displacement of counter-specimen is equal to 88μm. Co-ordinates of *A* point are the length of bearing material specimen between grooves equal to 12mm and depth of grooves 7mm.

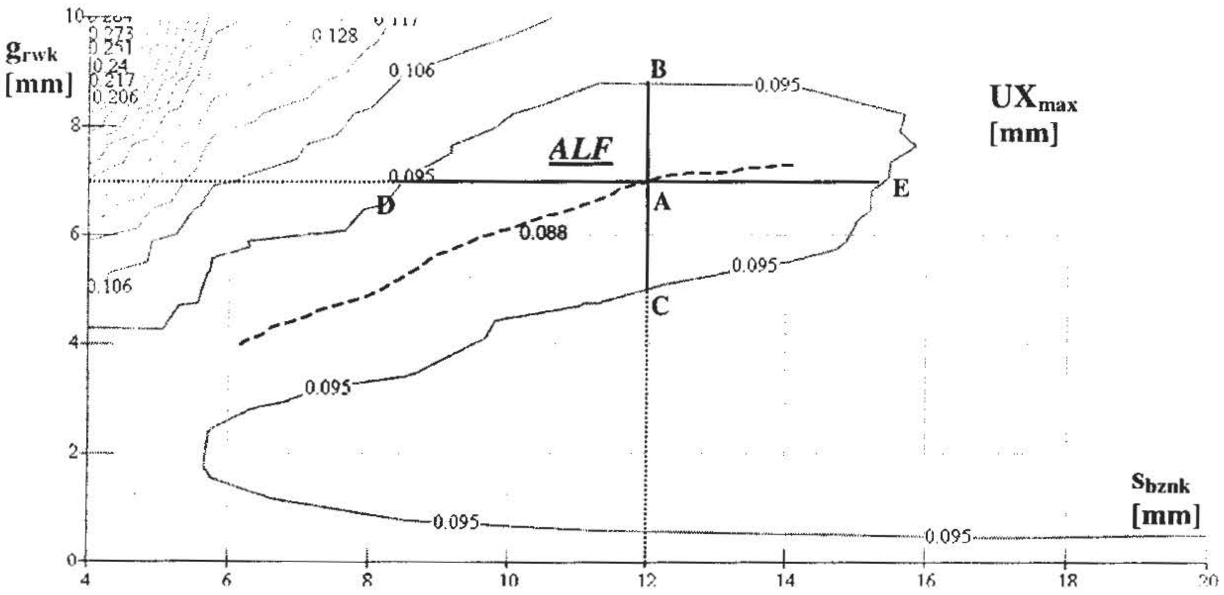

Fig. 6. Displacement of steel part UX_{max} [mm] relative to bearing material resulting from sliding versus depth of grove g_{rwk} [mm] and width of material between groves s_{bznk} [mm]: ALF – area of low flexibility of geometry sliding surface

Transition from *A* to *B* point (increase of g_{rwk}) is causing increase of sliding part flexibility, what confirms previously presented conclusions. Similar situation is on transition from *A* to *D* point (decrease of s_{bznk}). Both transition from *A* do *C* point (decrease of g_{rwk}), and transition from *A* do *E* point (increase of s_{bznk}) delays of the occurrence of slide. Earlier performed simulation for model of specimen, made of bearing material with near half bigger Young's module, with geometry with changing depth of groove in the range form 0.7 to 2mm and distance between them from 6 to 13mm is indicating, that increase of distance between grooves influences profitably the delay of appearance of slide – what at the beginning seemed to be contradictory engineering intuition. But in the light of discussed results it should be regarded as proper results, because searching area, in which previously the results were obtained, most probably was just located in the field corresponding to right part (from *BC* line) of *ALF* area. In order to check if observed *ALF* area is not an effect of numerical errors, caused by very high sensitivity of the solutions results to the assumed number of contact elements applied in model, simulation in this range of searching with different density of division on a finite elements was executed. The results obtained in this way were different in comparison with those presented on the chart with error in range from 0 to 8%. Because of that it was decided to present the results as in figure 6. The interpretation of the part of the chart was proposed as follows: for example for s_{bznk} equal to 12mm increase of depth of the grooves from 0 to about 5mm (*C* point) resistance of bearing material to deformations caused by bending is decreasing – although insignificantly. There is very small tendency to angular misalignment and thus smaller difference of contact stress is observed, what gives delay in occurrence of slide. Further increase of depth of grooves – going from *C* to *A* point – increase bending flexibility of bearing material but not to such a big extend so that it could be possible to obtain even uniform pressure distribution between bearing layer and steel surface. As result of that the effect of angular misalignment it is clear that decrease of resistance to slide of contacting surfaces is observed. Increase of height of bar of bearing layer over the value described by *A* point causes, that his bending flexibility is increasing to such a big extend, that contact surface of sliding layer has higher ability to fit to flat surface of counter-specimen. As a result of this situation, distribution of contact stress is becoming smaller again and slide is occurring later.

5. Conclusions

On the basis of performed research and analysis it was possible to explain, why under microoscillations real sliding distance in units with dry bearing materials is always smaller than nominal sliding distance. It is effect of elastic deformation of sliding layer caused by friction force. Observed phenomenon can be helpful to design the system allowing to reduce the wear of the bearing working under microoscillation. For applied dry bearing material – as it is shown in the figure 6 – it is possible to increase the resistance of sliding layer up to 273% (for layer with grooves) in comparison to resistance of bearing layer with flat contact surface.

The effect of high flexibility of sliding layer can be obtained for dry bearing either by application of highly elastic bearing material or by cutting deep grooves transverse to expecting slide direction on their sliding surface [5]. But there are same limits: bearing material of smaller elasticity can usually work with smaller contact stresses. Increase in depth of grooves distributed at small distances can lead (especially under dynamic load) to accelerated destruction of sliding layer.

To minimise the effect of stress concentration at the bottom of grooves it is necessary to correct the geometric shape (rounding at that region).

A special simulation programme have been developed for obtaining the optimum relation between elastic properties of the bearing layer and its wear rate.

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