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ANALYSIS OF THE IMPACT OF NON-PARALLELISM OF SHAFTS' AXES ON THE CONTACT AREA OF COOPERATING TEETH AND GEARBOX'S COMPONENTS VIBRATIONS

Summary. In this article, the results of experimental research and simulation studies using a geometric model made in CAD software were presented. The aim of the conducted research and simulations was to determine the influence of non-parallelism of shafts' axes on gearbox vibroactivity and the contact area of the cooperating teeth. The results showed that the change of the non-parallelism of shafts' axes significantly affects the vibrations of selected components of the operating gearbox and the contact area of cooperating teeth.

Keywords: non-parallelism of shaft axes, gearbox vibrations, contact area of cooperating teeth.

1. INTRODUCTION

Gearboxes are an element of complex drive systems used in many types of transport means, such as vehicles, trains, aircraft or vessels [3,4]. Regardless of the purpose of the transmission, the demands placed on them are similar. The transmissions should transfer power and torque with minimal losses while maintaining an adequate level of reliability [10,11]. This is particularly important considering the global tendencies to reduce

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the dimensions of the transmissions and attempts to use unconventional materials while the values of transferred loads remain unchanged. It also imposes keeping slight deviations of the transmission's components and their correct assembly.

A very important factor is the impact of the operating transmission on the immediate surroundings. The operating gearbox generates vibrations and noise, which has a negative impact on the users and passengers of various means of transport. Analysing the research works of world-class scientific centres, many concepts of searching for vibration reduction of an operating transmission can be noticed. It includes investigations on the shape of the gearbox housing, the study of the influence of the type of lubricant used, the study of the influence of the characteristics of the clutches cooperating with the transmission and many more [1,6,7,9]. The tendency to improve the well-known models and the development of new transmission models is also noticeable [2,5,8]. Undoubtedly, these are valuable scientific works, but it should be noted that, in the case of gearboxes, the main source of vibrations is the meshing zone, which involves the issues connected with the surface of the contact area and load distribution along the line of action. These issues have a significant impact on the level of vibrations generated during the operation of transmission. One of the reasons for the deterioration of the value of the surface of the contact area and load distribution along the line of action is the non-parallelism of the transmission axes, which may be the result of deviations in the transmission components, errors during assembly or excessive shafts deflection and housing deformation. The paper presents the results of experimental research and simulation made in CAD software showing the effect of non-parallelism of the transmission axes and change of the value of this phenomenon on the surface of contact area of cooperating gears and vibrations of selected transmission components.

2. EXPERIMENTAL STUDIES

2.1. Experimental studies – description of test stand

In order to evaluate the impact of non-parallelism of gearbox' axes on the vibrations of its components, experimental studies were conducted using a specially modified back-to-back test stand. The test stand modifications included disassembly of the closing gearbox and its shafts in order to eliminate additional sources of undesired disturbances. In the tested transmission, the shaft of the driven gear was replaced by a stationary axis. The bearings of the stationary axis were fixed by eccentric bushings whose rotation enabled the mutual position of the transmission's axes to be changed. One full rotation of the eccentric bushing was divided into 24 positions in intervals of 15 degrees. Because of made modifications, during the tests, the transmission operated without load. Table 1 presents selected parameters of the used transmission.

Piezoelectric sensors were used to measure vibrations accelerations. The sensors were placed on the gearbox's housing and on the stationary axis of driven gear (Fig. 1) to obtain the smallest distance between the meshing zone and the sensor. The tests were carried out for various rotational frequencies of the drive gear. During the tests, the mutual position of the transmission's axes was changed by rotation of the eccentric bushing.

Tab. 1

Selected parameters of tested gearbox

Parameter	Value
Number of teeth – driven gear z_1 [-]	16
Number of teeth – drive gear z_2 [-]	24
Module m_n [mm]	4,5
Helix angle β [°]	0
Face width b [mm]	20
Axes distance [mm] (changing during tests)	91,75
Profile shift coefficient – driven gear x_1	0.864
Profile shift coefficient – drive gear x_2	-0,5

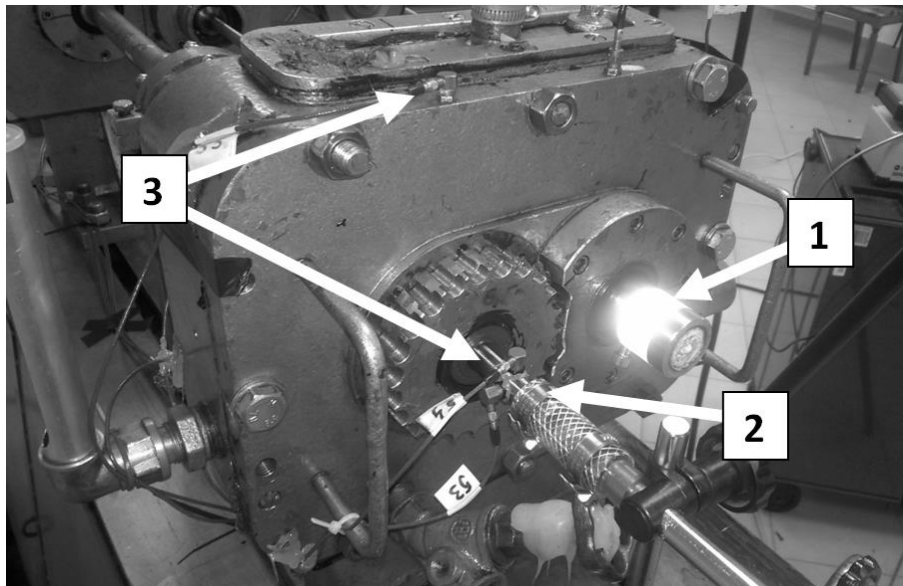


Fig. 1. Modified back-to-back test stand. 1- shaft of drive gear, 2 - stationary axis of driven gear, 3 -vibration sensors

2.2. Experimental studies – obtained results

Based on the vibration signals recorded during the tests, their relative mean square (RMS) values were calculated. The obtained values are shown below in the function of bearing position of stationary axis. The results are presented for two selected rotation frequencies of the drive gear.

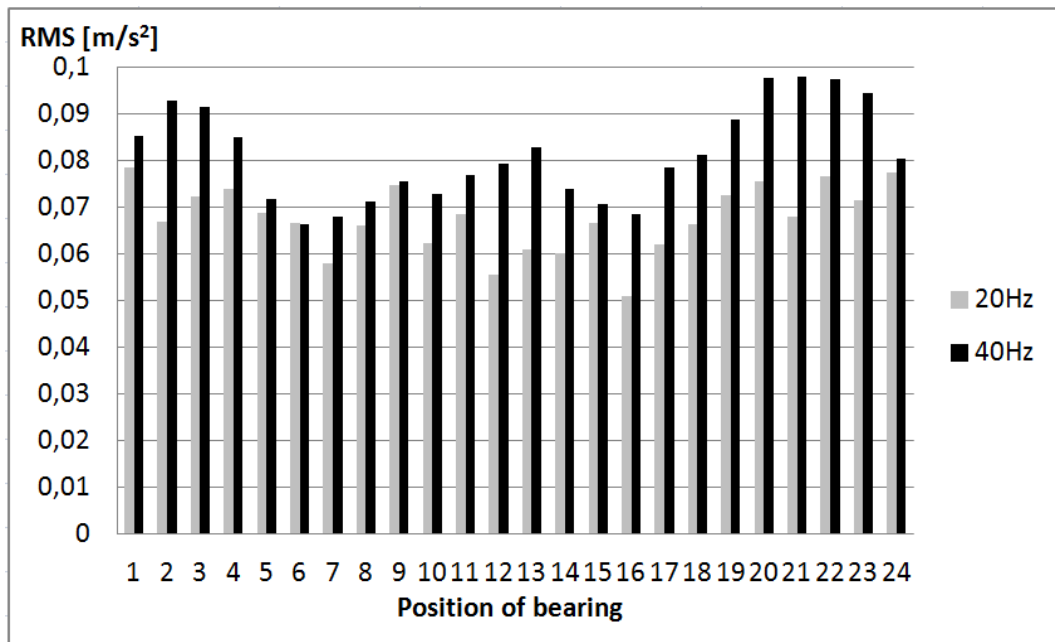


Fig. 2. RMS values of vibration signal measured at gearbox's housing for two selected rotational frequencies 20Hz and 40Hz in function of bearing position

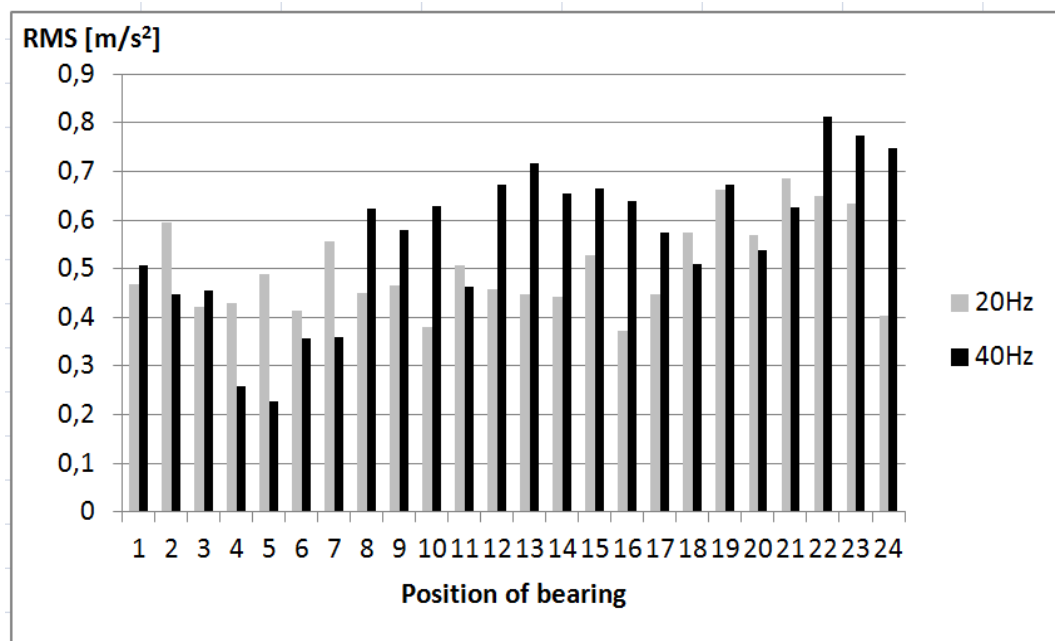


Fig. 3. RMS values of vibration signal measured at stationary axis for two selected rotational frequencies 20Hz and 40Hz in function of bearing position

3. SIMULATION TESTS USING THE AUTODESK INVENTOR SOFTWARE

3.1. Description of developed 3D model

The geometric 3D model of the gearbox was created using the Autodesk Inventor software. The model reflects all important parameters of the actual transmission used during experimental research. In addition, it is also possible to change the non-parallelism of the gearbox's axes. The created model was used to determine the surface of the contact area of cooperating gears. The measurement was made for 24 positions reflecting the bearing position of the driven gear due to use of the eccentric bushing. The tests were carried out for two selected values of solids penetration, which simulated flattening of the flank of the teeth because of the transferred load. The created transmission model is shown in Fig. 4.

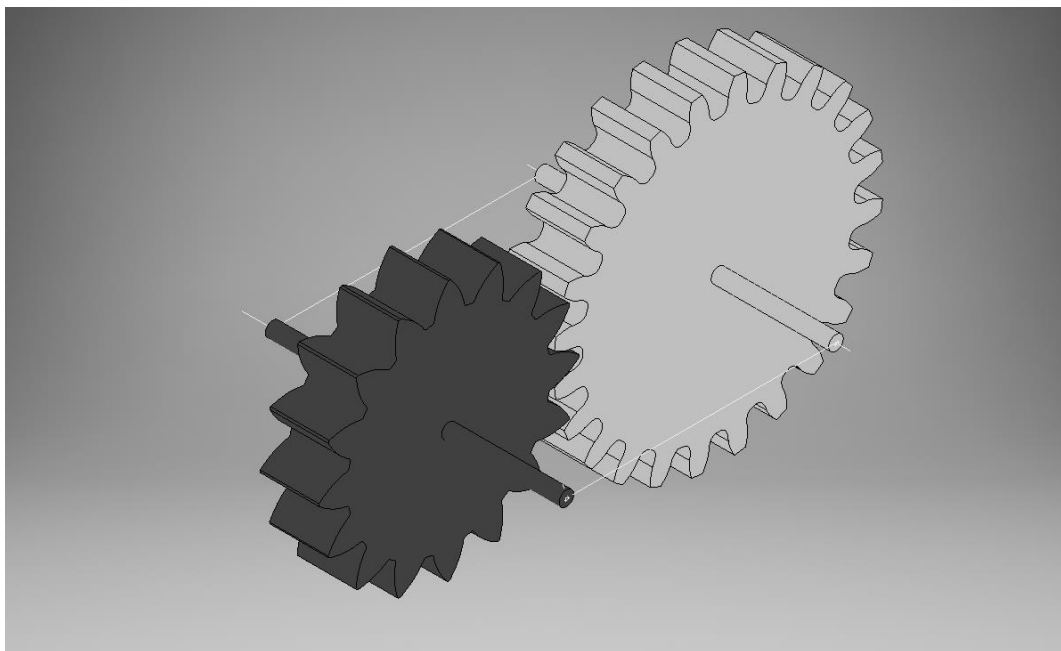


Fig. 4. Developed 3D model of tested gearbox

3.2. Simulation tests – obtained results

Using the developed model, the analysis of the change of surface of the contact area of cooperating teeth depending on the position of the driven gear bearing was made. The results are presented for two selected tooth flattening values: 5 and 10 μm . An example of the obtained surface of the contact area is shown in Fig. 5. Area of contact of cooperating teeth in function of bearing position for two selected values of tooth flatterring is shown in Fig. 6.

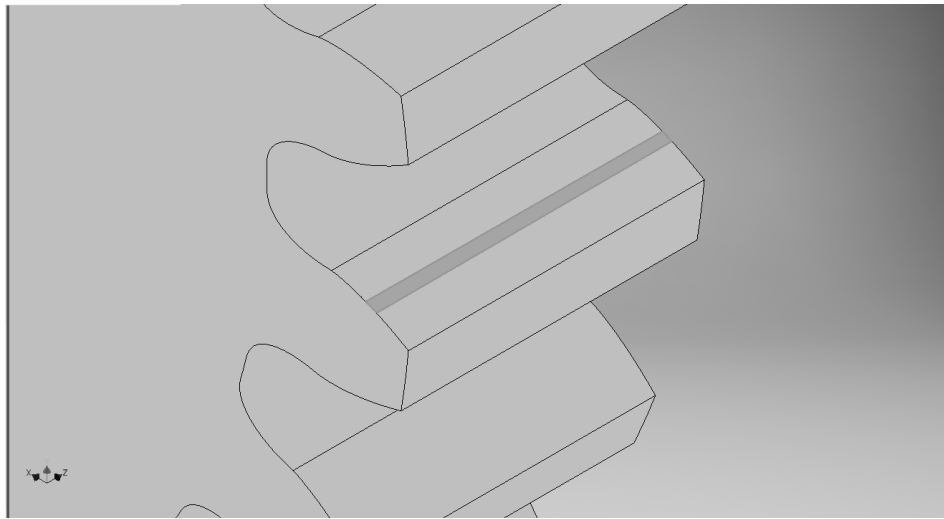


Fig. 5. Example of obtained contact area

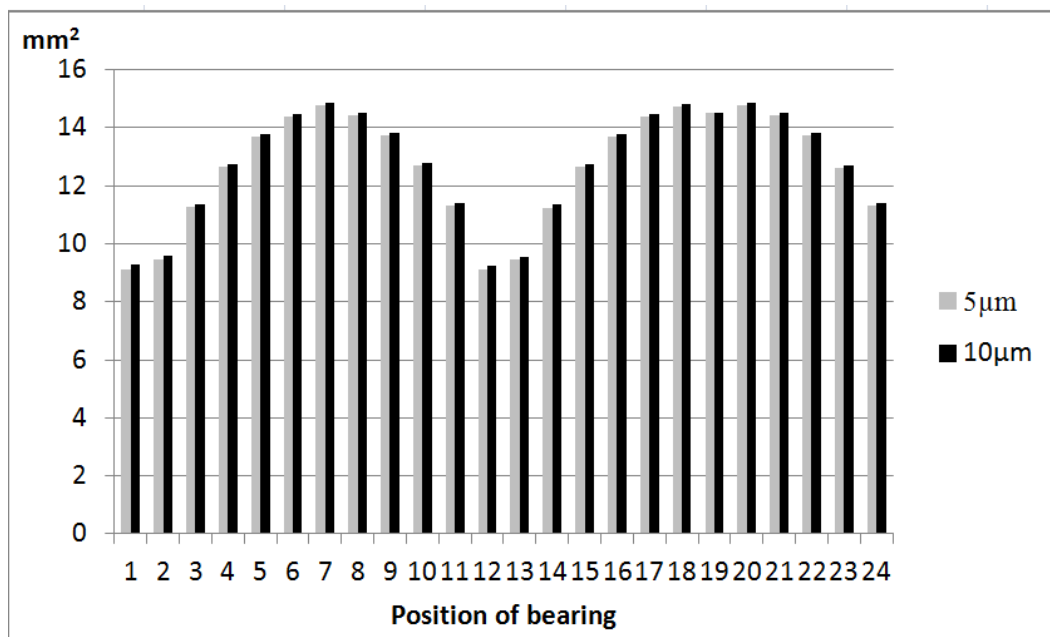


Fig. 6. Area of contact of cooperating teeth in function of bearing position for two selected values of tooth fluttering

3.3. Comparison of experimental studies results and simulation studies results

Figures 7 and 8 present the course of changes in the values of surface of the contact area and obtained RMS values of recorded signals as a function of the bearing position of stationary axis. The values presented in the diagrams, in the majority of analysed cases, confirm the relationship between the change in the surface of contact area of the cooperating teeth and the level of vibrations recorded on selected elements of the transmission.

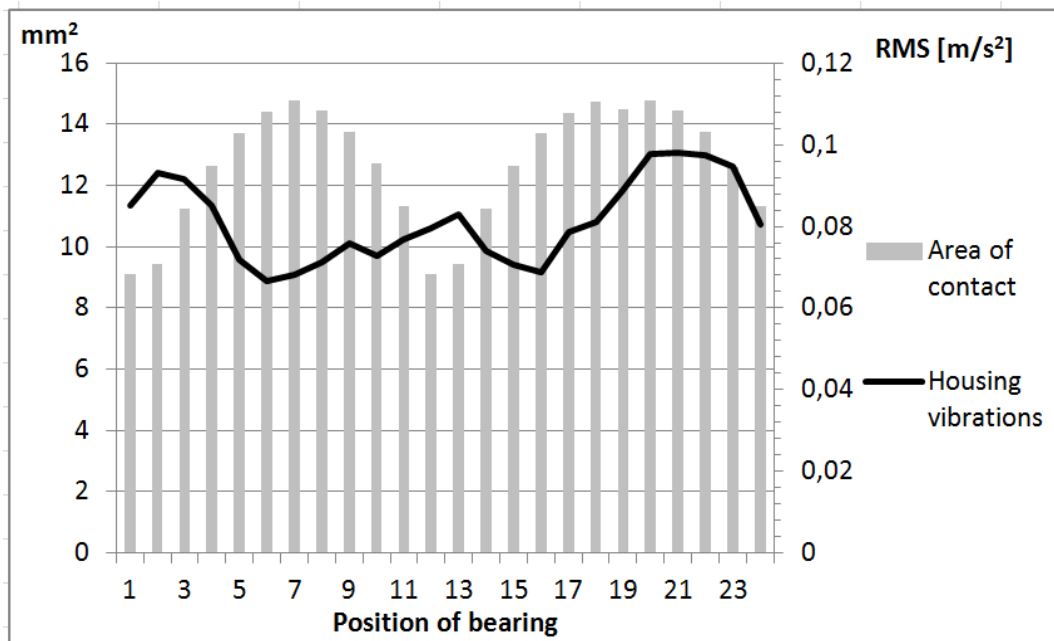


Fig. 7. Area of contact of cooperating teeth and RMS values of vibration signals in function of bearing position

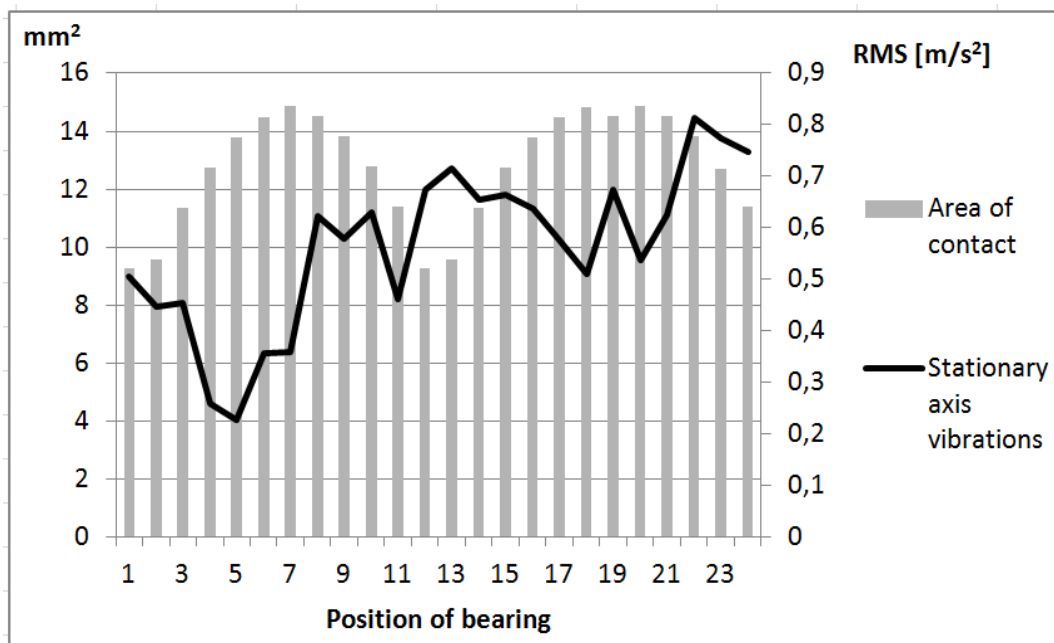


Fig. 8. Area of contact of cooperating teeth and RMS values of vibration signals in function of bearing position

4. CONCLUSION

Based on analysis of results obtained during experimental studies, it was discovered that the occurrence of the non-parallelism of the gearbox shafts' axes and its change during test significantly affects the level of vibrations measured at transmission's components. Differences of vibration signals' RMS values, depending on the position of the stationary axis' bearing, was even tens of per cent.

Using the geometrical model made in the CAD software of the gearbox, the change of contact area of cooperating teeth was presented for two selected tooth-flattening values. Results obtained during simulation show dependence of the contact area of cooperating teeth and non-parallelism of the gearbox shafts' axes. The change of non-parallelism of the gearbox shafts' axes significantly affects the size of the contact area, which changes reached several dozen per cent.

Comparatively, changes in the RMS values of vibration signals and values of the contact area of cooperating gears were found to be in majority of analysed cases of stationary axis' bearing positions, the increase surface of contact area resulted in lowering the level of recorded vibrations. This phenomenon confirms the relationship between the surface of contact area of the cooperating teeth and the vibrations generated by the operating transmission.

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