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THE PRELIMINARY RESEARCH OF THE INFLUENCE OF GREASE MICROCONTAINERS MADE ON THE SURFACE OF THE SLIDE ASSOCIATION ON THE VIBRATION SIGNAL RECORDED FOR THIS ASSOCIATION

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Abstract

There is shown the construction of an elaborated test stand for the test research of sliding friction associations. The following properties of tested friction associations are described: type (chemical composition) and hardening of applied materials, as well as the results of the analysis of topography of their collaborating surfaces (base material and then after creating grease microcontainers in it). The methodology and the range of performed researches are described. The researches were conducted using the accelerometer A0760GP and the industrial measurement device Emerson CSI 2130. On the basis of recorded vibration signals, their amplitude spectra were determined. These spectra were being compared and analysed in reference to the possibilities of application of measurements of vibration signals to indication of the process of association wear. It was found that the process of wear of the tested sliding association without lubrication from grease microcontainers is visible as the change of form of vibration signals recorded for this association as even over-a-dozen-fold changes in the value of amplitudes of some special harmonic components of those signals, especially high-frequency components within the analysed range of frequencies. It was also found that the application of the grease microcontainers on the surface on which rollers slide (not roll) allowed to acquire a significant reduction of the process of wear of the tested slide association, showed by the slower pace of growth of the value of all harmonic components, especially high-frequency components within the analysed range of frequencies. At the end there were provided directions of further researches.

Keywords: *vibration, slide association, friction, wear, grease microcontainers*

1. Introduction

As a part of wide-ranging works, in the field of using grease microcontainers to lubricate races of rolling bearings, it was conducted a cycle of durability tests for slide associations. Their aim was to examine to which degree the application of lubricating from microcontainers made in the race on which the rollers roll may lengthen the time of efficiency of the slide association in case of a sudden slide, or even a total blockage of rollers. During the researches described in the following report there were taken into consideration only the changes of vibration signals recorded for slide associations with and without lubrication from microcontainers made in flat side (working) surface of the part called here a slide ring, the surface (called a race) on which the rollers were sliding (not rolling) with their cylindrical side surfaces. The race of a slide ring was a surface simulating a race of a rolling bearing and was motionless on the test stand. Rollers were the parts simulating rolling parts of the bearing and were moveable on the test stand. From obvious reasons, the vibration signals were recorded at the outer cylindrical surface of a slide ring. A simplified scheme of the test stand is shown in the Fig. 1. In the sample-anti-sample tested system the races of the slide rings were the samples (they differentiated the collaborating parts of the test stand) and the fragments of cylindrical surfaces of the rollers were the anti-samples (they were identical, provided a repeatability of production process).

The issue of grease microcontainers is well known to the researchers of wear, and the literature in this subject is extensive [e.g. 6-10]. The issues of vibration of bearings, both rolling bearings and slide bearings [2, 4, 5] are also popular. Simultaneously it seems that the assessment of the dependence of vibration signals to the application of grease microcontainers, hereby described, is the subject of researches quite seldom.

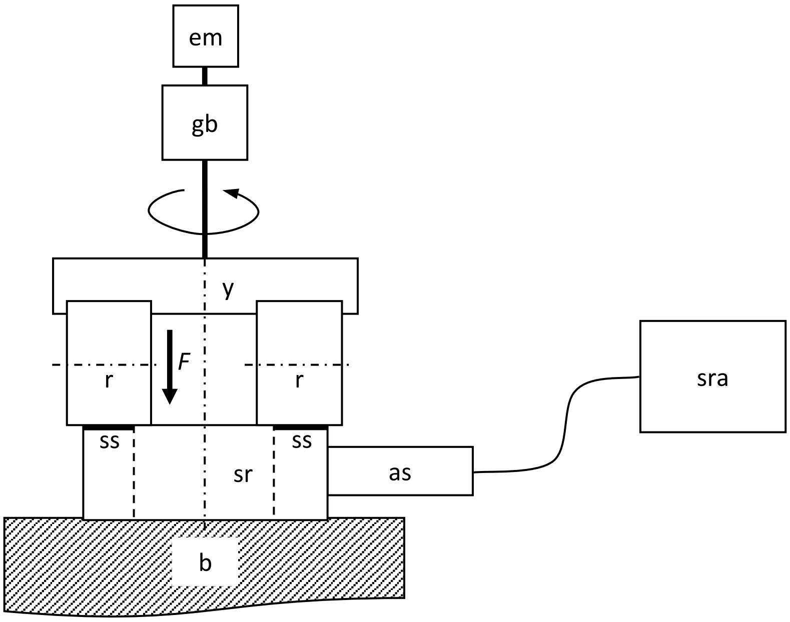

Fig. 1. Scheme of the test stand: em – electric motor, gb – gearbox, y – yoke, r – roller, sr – slide ring, ss – sliding surface, b – base, as – acceleration sensor, sra – signal recorder and analyser, F – force pressing the rollers to the slide ring

2. Description of the tested association and research methodology

Power was driven from electric motor working with constant rotational speed, connected with mechanical twelve-gear gearbox allowing for step changes of rotational speed of the output shaft, which was the working end of the drive source. This power source was chosen due to its accessibility and usefulness in basic durability tests, with full awareness of the fact that, from the point of view of the vibration signals analysis, application of this type of drive source results with significant disturbances (each association of gearwheels within the mechanical gearbox is a source of its characteristic vibration signal, propagating in the stand, interfering with the other disturbance signals and the signal of the tested slide association, and being recorded at the measurement point). Provided that it is impossible to explicitly identify the source of a vibration signal being a disturbance for the signal of the tested slide association, the spectral analysis was mainly conducted within the range of the differences between the spectra by the time of the progress of wear process of both types of associations (with and without lubrication from grease microcontainers). Simultaneously, the direct cause of these differences was not determined, which makes the issue of possible further researches.

The drive source powered the yoke with two identical rollers with a diameter 12 mm placed at its both sides. The rollers were placed in the way that their axes of rotation were parallel to the direction of length of the yoke and perpendicular to its axis of rotation, so they touched the race of the slide ring with their cylindrical side surfaces. The rollers in the yoke were implanted motionlessly – they had no possibility to move along the yoke (along their axes) nor to rotate around their own axes and to roll at the race of the slide ring. The yoke rotated with the speed of 500 rpm (the most optimal speed from the available ones in the drive source for determining and analysing of spectra of recorded vibration signals) and moved towards the slide ring, pressing the rollers to its race with a constant force. Rollers were made of bearing steel 100CrMnSi6-4 and fully hardened to hardness

800 HV0.1 (62-65 HRC). Initial surface roughness of the rollers touching the race of the slide ring was $R_a = 0.23$ μm. Slide ring, made of the same bearing steel as the rollers and of similar hardness, had an outer diameter 128 mm and the width of the race 5.5 mm. It was stiffly mounted to the base in the way that the race was perpendicular to the axis of rotation of the yoke. Initial surface roughness of the race of the slide ring also equalled $R_a = 0.23$ μm. Axes of the slide ring and of rotation of the yoke were overlapping (as a result, the direction of the yoke was always overlapping with the diameter of the slide ring). The height of the rollers was bigger than the width of the race of the slide ring.

From popular textbooks about slide bearings and other reports dedicated to them [1, 2, 4, 5] it is implicated that when between the collaborating surfaces there lacks oil film, the sources of vibration are the unbalance of the rotating masses (the frequency typical to rotational motion of an unbalanced yoke with the rollers equals to the frequency of its rotation $f_y = 8,(3)$ Hz) and roughness of the rubbing surfaces (the frequency typical to the wear of micro-irregularities f_r for an average diameter of the race of the slide ring $d = 122.5$ mm, for relative linear speed of the rubbing surfaces $V_r \approx 3.2$ m/s and for their roughness, equals to a value between a few and a few hundred MHz, so it is out of the range of the majority of industrial devices for vibration measurements).

The experiment was done for two slide rings of identical size, made of the same material, of the same roughness and hardness, but in the slide race of one of them were laser-made lubricating microcontainers of diameter 60 μm and depth 10 μm, covering approximately 25% of the race surface and placed in lines equally distant from one another: rows and columns (in the knots of the net with square meshes – Fig. 2). As a result, microcontainers were perfectly fitted along the four radiuses of the race, which created two perpendicular diameters of this race. For the applied set of two rollers, it created a situation in which the theoretical line of contact of the side surfaces of the rollers with the race of the slide ring overlapped with the line along which the microcontainers were located twice per rotation of the yoke.

Microcontainers were filled with grease ŁT43 (the race without microcontainers was also covered with the thin layer of this grease). For the slide race without grease microcontainers, it was assumed that the subject of tests was a semi-dry slide association changing into the dry slide association – during the experiment, the grease heaping in the association at the time of contact between the rubbing surfaces was pushed out of the association. For the slide race with grease microcontainers, it was assumed that the subject of tests was a semi-dry slide association. The grease, which was in microcontainers, was constantly sucked out of them and pressed back, covering the association with a thin layer. In the beginning of the experiment, the point of contact of the rollers with the race was theoretically a segment (in reality, after taking the deformation of the surfaces pressed to each other into consideration, it was a very thin rectangle). During the experiment, the contacting surfaces of the rollers and the slide ring wore away on each other. After the experiment (after 40 minutes and 7.7 km slid by the rollers on the race), on the cylindrical surfaces of the rollers were observed material decrements shaped as rectangles sized 5.5×*b* mm and the maximal decrement measured along the diameter, of an average value of *h* mm (Fig. 3 and Tab. 1).

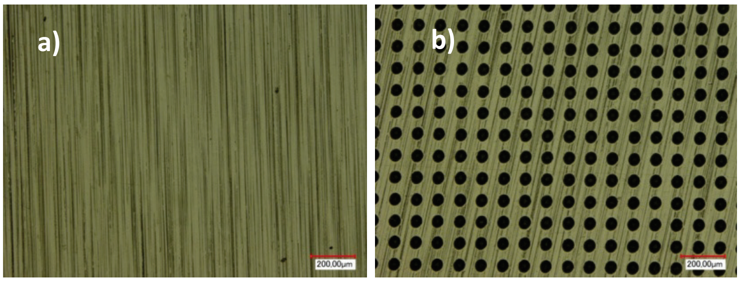

Fig. 2. Microscope view of the surface of the race of the slide ring before the experiment: a) without grease microcontainers, b) with grease microcontainers filled with grease

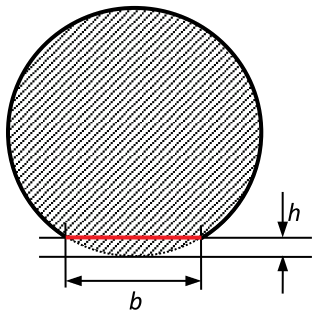

Fig. 3. Decrement of material of the roller sliding on the race of the slide ring (crosshatched contour – area of a crosswise intersection of a roller before the experiment, bold black-red line contour – area of a crosswise intersection of a roller on the height of contact with the race after the experiment)

Tab. 1. Parameters characterizing the decrement of material in the rollers (sizes b and h according to Fig. 3)

Race of the slide ring	*b* [mm]	*h* [mm]
without grease microcontainers	3.200	0.1072
with grease microcontainers	1.780	0.0331

The experiment lasted for 40 minutes without a pause for each of the rings. This time is longer than needed to create clear decrements in the rollers where they touched the race of the slide rings. Obviously, each of the experiments was done with new rollers randomly chosen from the set of potentially identical rollers. The records of vibration signals were taken the moment before the first contact of the parts of association (these measurements, finished before the contact, provided information on the background of the following measurements), at the time of first contact and every minute starting from the time of contact (these measurements provided information on the changes of vibration signals during the experiment).

3. Analysis of the obtained spectra of recorded vibration signals

The records of vibration signals were made using the device Emerson CSI 2130 cooperating with one-direction accelerometer A0760GP [3]. The sensor was placed at the outer cylindrical wall of the tested slide ring in the half of its height by a permanent pole piece magnet – the accelerations of vibrations on the surface perpendicular to the surface of a slide association were recorded. From the available settings of the device for doing FFT of the recorded signal, it was chosen to obtain the spectra with the resolution 0.25 Hz in range 0 -1.6 kHz. For these parameters of the analysed signals, the frequency f_y = 8,(3) Hz is close to the 33rd line of the obtained spectra, the line of frequency 8.25 Hz. The settings chosen for the researches were, in view of the authors, the best compromise between: the range of analysed frequencies, the resolution of the obtained spectra, the proximity of frequencies of obtained spectral lines and the characteristic frequencies of analysed signal, and the time of recording (sampling) the signal amidst the combinations of rotational speeds of the yoke possible to obtain on the test stand, and the spectra resolution possible to obtain in the measuring-analytical device.

The form of the spectra of the background signals clearly indicates that the applied test stand (more precisely – its drive source) is a major source of disturbances of the analysed vibration signals, hindering the possibility of easily tracking the changes of vibration signals caused by the wear of the slide association. The most basic example is the appearance in all recorded spectra a very big component of frequency 84 $f_y \approx 700$ Hz, probably arising from the work of the gearshift in the drive source, reducing the rotational speed of electric motor to a chosen rotational speed of the yoke.

Figure 4 shows exemplary full spectra recorded for: the lack of contact of the rotating rollers with the race (these are the background for the following spectra recorded for the rubbing surfaces), the moment after pressing the rollers to the race, before and after the significant rise of the values of the high-frequency components and the moment of the end of the experiment. The obtained spectra are exquisitely similar, but not identical. It is clear that the recorded vibration signals consist of a series of the components of frequencies which are integer multiples of frequency f_y. This can be easily spotted on Fig. 5, which shows the recorded changes of zoomed fragments of spectra containing the components of distinctively changing values. These fragments have the range of 60 Hz (with an exception of the figures in the first row, with the range of 62.5 Hz) and they contain 7 components of frequencies which are integer multiples of frequency f_y each. And so:

– range 0-62.5 Hz contains the components of frequencies 1-7 f_y,
– range 120-180 Hz contains the components of frequencies 15-21 f_y,
– range 195-255 Hz contains the components of frequencies 24-30 f_y,
– range 395-455 Hz contains the components of frequencies 48-54 f_y,
– range 725-785 Hz contains the components of frequencies 88-94 f_y,
– range 1465-1525 Hz contains the components of frequencies 176-182 f_y.

Presentation of only these fragments is supported by the fact that, in view of the authors, they show the most characteristic (to be clear – not the only) changes in spectra of the recorded vibration signals. Obviously, the values of spectra obtained for frequencies per 0.25 Hz and non-equal to integer multiples of f_y are almost zero. Such forms of amplitude spectra allows to treat the recorded signals as the determined periodic polyharmonic signals $a(t) = \sum_{k \in \mathbf{N}} a_k \sin(2\pi k f_y t + \varphi_k)$, where a_k and φ_k are the amplitudes and phases of the harmonic components of frequencies kf_y.

The comparison of the obtained spectra for the tested slide association allows seeing the constant amplitudes of the majority of harmonic components. Small changes may be a result of random disturbances, minor fluctuations of rotational speed of the drive source and small changes of the base frequency, which causes small differences between the frequencies of harmonic components of the recorded vibration signals and the frequencies for which the measurement device determines the spectral values (frequencies of the lines of the obtained spectra variously do not match the frequencies of harmonic components of the recorded and analysed vibrations signals) etc. An example of a constant component is a component of frequency 8.25 Hz, closest to the theoretical frequency f_y =8,(3) Hz.

However, after analysing the harmonic components that change during the experiment with the race without grease microcontainers, the experiment can be divided into three periods, clearly visible in the Fig. 6, which shows the changes of values of the amplitudes of the chosen harmonic components obtained during the whole experiment. During the first, four-minute period, the spectra of the recorded vibration signals stay in almost unchanged form. After this period, there has been an evident rise of the values of the amplitudes of some components, for example those of frequencies $6f_y \approx 50$ Hz (this is also a frequency of the alternating current powering the stand), $18f_y \approx 150$ Hz, $26f_y \approx 216.75$ Hz, $28f_y \approx 233.25$ Hz, $29f_y \approx 241.75$ Hz, $30f_y \approx 250$ Hz, $50f_y \approx 416.75$ Hz, $52f_y \approx 433.25$ Hz or $94f_y \approx 783.25$ Hz and in almost all components of frequencies higher than 1300 Hz (high-frequency components within the analysed range of frequencies). The observed rise of values of the amplitudes of some components is probably caused by the fact that in the first part of the experiment, when there were still some layers of grease between the rollers and the race without grease microcontainers, and in the short time after the grease was gone, the smoothness and the hardness of the rubbing surfaces were sufficient to prevent the process of wear. Unfortunately, after the mentioned time, the process of wear had begun, especially for the rollers (with the same surface of contact with the changing surface of contact on the slide ring, more precisely, with the fragment of the race along its circumference, with which the rollers contact during their movement) and the cutting of a slide ring into them. The appearance of a strong rise of the values of the amplitudes of only some harmonic components of the recorded vibration signals is probably caused by the small deviations of the profile of a slide ring from a perfect circle, small deviation of the axis of rotation of the yoke with the rollers from the perfect coaxial symmetry with the axis of the slide

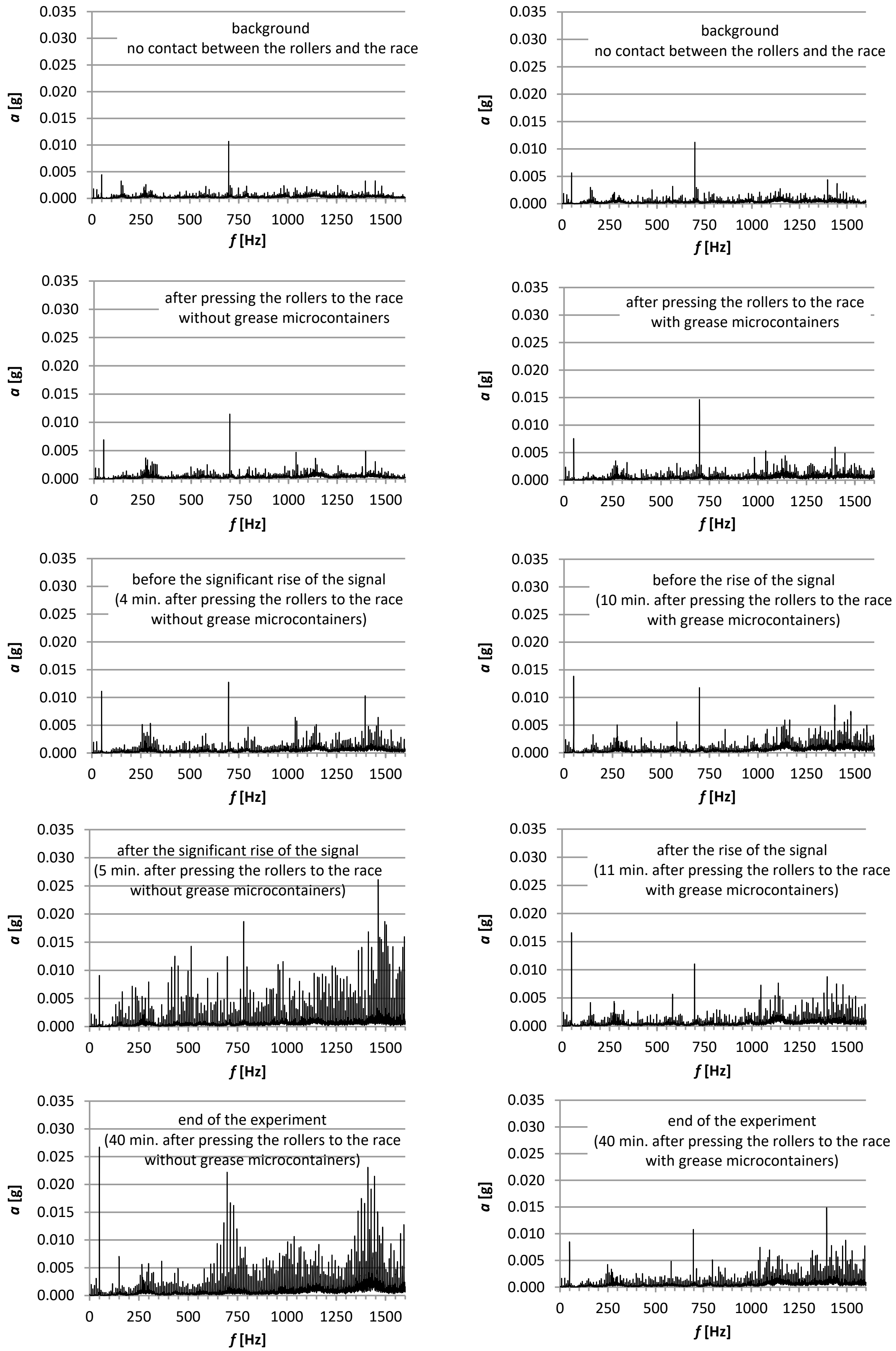

Fig. 4. Full spectra of vibration signals recorded in different stages of the experiment for both tested slide races (with and without grease microcontainers)

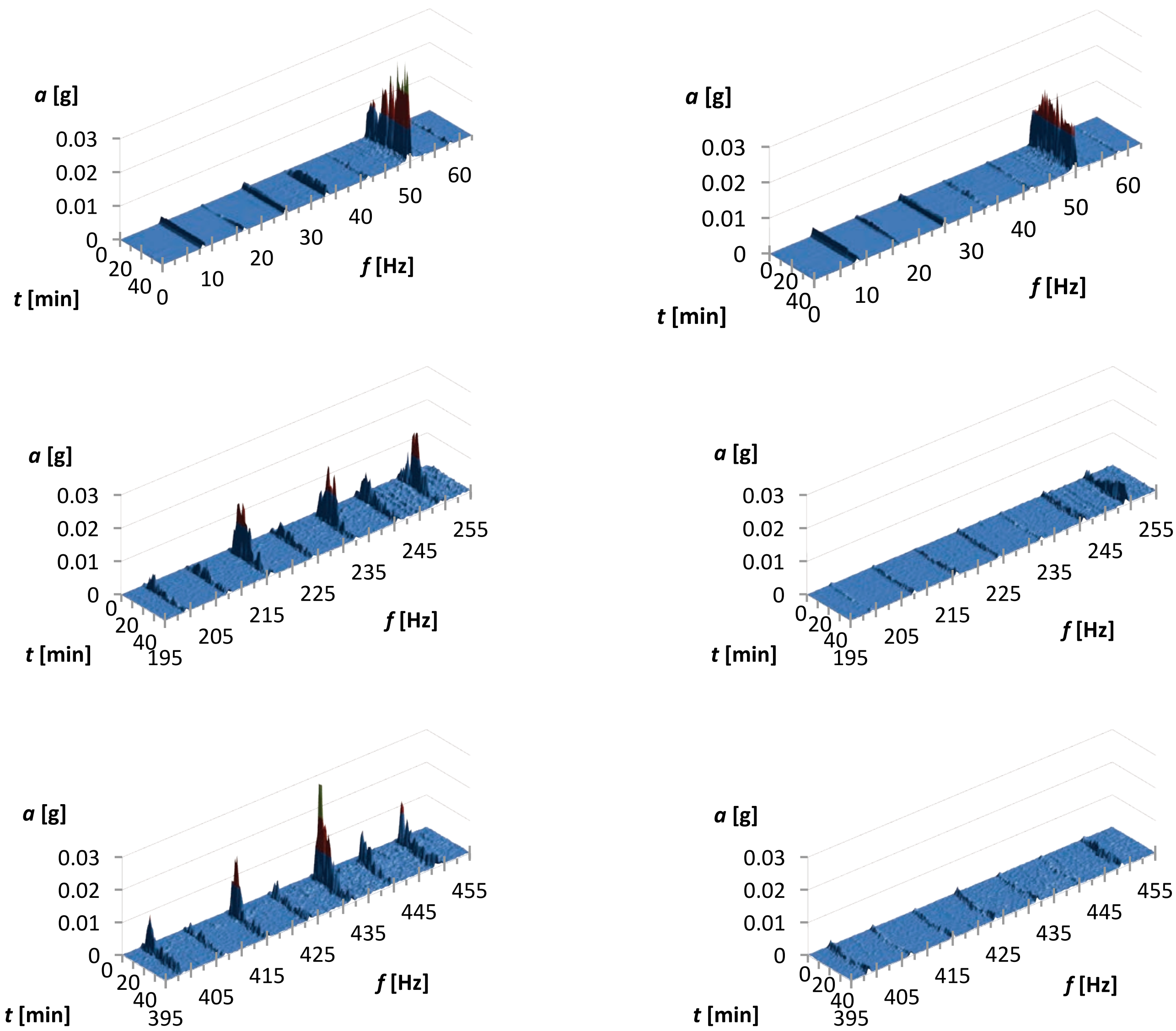

Fig. 5. Changes of the chosen fragments of the spectra of vibration signals during the whole experiment for the slide race without (left column) and with (right column) grease microcontainers

ring, or the small deviation of the yoke from the perfectly perpendicular direction to the axis of its rotation and the consequent knocking of the borders of the cuttings cut (wore) in the rollers at the slide ring and knocking of the cut grains of materials of the rollers and the slide ring after the wear of their outer, hardest layer. And so, the component of frequency 6 times higher than the frequency of the rotation of the yoke with two rollers placed along the diameter of the slide ring and rubbing on the slide ring may suggest that there has been a deformation of the profile of the slide ring into the equilateral triangle or that on the race of the slide ring have appeared three bulges (or holes) evenly placed along its circumference. It should be mentioned that for the rubbing of the rollers on the race of the slide ring with grease microcontainers analogical change of the recorded vibration signals did not occur. This suggests a smoother progress of the process of wear of the tested slide association by the constant presence of even little quantity of grease.

After the second period came the third, the last one in the experiment with the race without grease microcontainers, in which most of the amplitudes of the chosen harmonic components decreased almost constantly. The most straight-line decrease in the values of the amplitudes amidst the considered harmonic components was observed for the components of frequencies $18f_y \approx 150$ Hz, $26f_y \approx 216.75$ Hz, $50f_y \approx 416.75$ Hz and $52f_y \approx 433.25$ Hz. For the rest of the considered components the decrease of values is less regular, but creating a clear manner. It was probably caused by the smoothing of the rubbing surfaces and the wear of materials of the collaborating parts to the layers of little smaller hardness. Basically, the only exception among the chosen components is the component of frequency $6f_y \approx 50$ Hz, which amplitude increased. This increase was probably caused by the growing role of side knocks (in the perpendicular direction to the direction of movement of the rollers on the race) in the association, resulting from the mentioned deviations: the profile of the slide ring from a perfect circle, the axis of the rotational movement of the yoke with the rollers from the perfect coaxial symmetry with the axis of the slide ring and the yoke from the perfectly perpendicular direction to its axis of rotation.

By analysing those characteristic harmonic components for the experiment with the race with grease microcontainers, it can be stated that during the whole experiment the obtained spectra of the recorded vibration signals basically maintain the same, unchanged form. Additionally, taking the size of the decrement of material checked at the end of the experiment into consideration, it could be stated that this is caused by the constant lubricating of the tested association with the grease taken from and returned to the microcontainers.

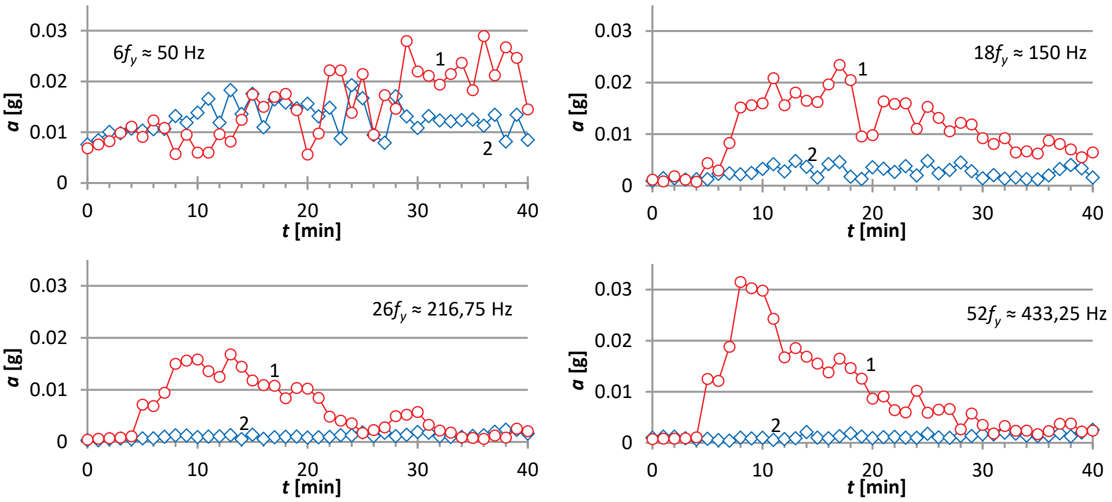

Fig. 6. Changes of the chosen harmonic components of the vibration signals during the whole experiment for the slide race without (1) and with (2) grease microcontainers

4. Conclusions

1. The used test stand, useful for the durability (tribological) tests does not fully meet the needs of the tests of the vibration signals of the slide association due to the presence of significant disturbances generated by the drive source.
2. The recorded vibration signals are the determined polyharmonic signals of basic frequency equal to the frequency of rotation of the yoke with the rollers, which is the output shaft from the drive source.
3. The processes of wear of the tested slide association without lubrication from grease microcontainers are visible as changes of the form of the vibration signals recorded for this association even as the over-a-dozen-fold changes of the values of the amplitudes of some characteristic harmonic components of these signals, especially the high-frequency components within the analysed range of frequencies.
4. The application of grease microcontainers on the surface on which the rollers slide (not roll) allowed to obtain a major reduction of the process of wear of the tested slide association, visible as the lower pace of growth of values of all harmonic components, especially the high-frequency components within the analysed range of frequencies.
5. Possible further researches on the described test stand will be conducted with the rollers of height equal to the width of the slide race. The intention of the authors is the elimination of disturbances connected with the side knocks in the association race-rollers (sample-anti-sample), occurring during the experiment due to the process of wear of material of the rollers.

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