QUALITY EVALUATION OF THE BEVEL GEAR ASSEMBLY BASED ON ANALYSIS OF THE VIBRATION SIGNAL

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Summary

For the bevel gear assembly, the contact area is the main criterion of the assembly quality assessment. As it is obtained at a small load of the gear, it cannot fully ensure normal mating of the teeth, because under the load, the bodies, shafts, gear wheels, etc. are deformed. This paper assumes that there should be a relationship between the signal generated by the gear and the values characteristic for the contact area. Then, on the basis of vibration measurements it would be possible to evaluate the quality of assembly.

Keywords: bevel gear, assembly.

OCENAJAKOŚCI MONTAŻU PRZEKŁADNI STOŻKOWEJ NA PODSTAWIE ANALIZY SYGNAŁU DRGANIOWEGO

Streszczenie

W trakcie montażu przekładni stożkowych ślad współpracy jest głównym kryterium oceny jakości montażu. Ponieważ jest on uzyskany przy małym obciążeniu może w pełni nie gwarantować prawidłowej współpracy zębów, gdyż pod wpływem obciążenia następuje odkształcenie korpusów, wałów, kół zębatych itd. W pracy założono, że powinna zachodzić zależność między sygnałem generowanym przez przekładnię a wielkościami charakteryzującymi ślad współpracy. Wtedy na podstawie pomiarów drgań możliwa była by ocena jakości montażu.

Słowa kluczowe: przekładnia stożkowa, montaż.

1. INTRODUCTION

For a number of years engineers have tried to achieve the maximum ratio of driven power to gear weight. That is why they introduced into production special materials, heat treatment and great precision. However, even with a high manufacturing accuracy of the gear elements, assembly errors may cause greater dynamic excitation. The influence of the assembly deviations and tooth backlash on the bevel gear dynamic load has been the subject of a lot of research (e.g. Skoć [7]). For instance, it has been stated that there is no significant connection between the value of the tooth backlash and the gear's dynamics, if only it falls within the allowed limits. Yet, it affects the oil working temperature. However, as far as assembly deviations are concerned, it has been discovered that the gear dynamic load does not depend on the type and value of deviations but on the tooth contact area. This means that each of the set deviations has an equal influence on the gear's dynamic load if they cause comparable changes in the tooth contact area (the contact area was defined by a relative length).

For simple gears, composed of few elements, it is enough to prepare a general diagram of the order of assembly. For more complex gears, the assembly instructions should include a list of all assembly activities, required tools, necessary drawings and essential calculation formulas [1]. While assembling cylindrical gears, there is no possibility of improving the meshing as it is conditioned by the accuracy the gear wheels and the body were made with. In order to prevent tooth jamming during operation, the values of backlash and contact area – which confirm the quality of gear wheels and body – are checked in the first place [5]. In bevel gears, the body is designed in a way which enables shifting the wheels towards their axles. Therefore, during the assembly, it is possible to alter the size and position of the tooth contact area and the value of the backlash.

During the gear assembly, attention is focused on achieving the biggest tooth contact area. For cylindrical helical tooth gears the increase in the contact area causes a noticeable drop in the vibration speed measured on the body [8]. The factor of dynamic surpluses for bevel gears reaches the maximum value for the smallest relative length of the tooth contact area and the minimum value for the biggest [7].

The assembly is an important stage which conditions a gear's life and quietness. The tooth contact area is the main criterion of the assembly quality assessment. Obtained at a small load of the gear, it cannot fully ensure the right mating of the teeth, because under the load, the body, shafts, bearings, gear wheels, etc. are deformed (e.g. [7]).

The article presents a quality assessment of the bevel gear assembly, made with the use of the vibration signal. Vibration-based diagnostics were performed under load, during the usability tests.

2. THE METHOD AND SUBJECT OF THE TEST

Six identical gears, which had been properly assembled and tested, were analysed. They were single-phase bevel gears with wheel-curved teeth. After assembly, the gears were subjected to usability tests, the aim of which was to run in the gears and verify the quality of their assembly. Vibration signals were registered at the maximum load. The measurement was taken with two vibration acceleration sensors. The first signal analysis included calculating the signal mean and root-mean-square values for each gear. In the second variant of the analysis the signals were subjected to a filtration process to obtain the first three harmonics. The frequency of the first harmonic was 1960 Hz, the second 3920 Hz and the third 5880 Hz. Filtration of the signals produced 1/3-octave bands with constant relative bandwidths. Middle frequencies were 2000 Hz, 4000 Hz and 6300 Hz respectively. For a signal with three mesh harmonics, mean and root-mean-square values of vibration acceleration were calculated. The diagram of the stand and the measurement path are shown in figure 1.

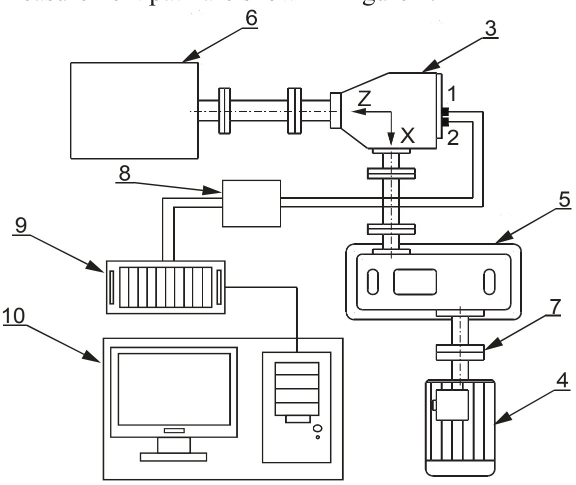

Fig. 1. Diagram of the measurement path and the test stand; 1, 2-triaxial piezoelectric vibration acceleration sensor by B&K, 4-driving motor, 5-multiplier, 6-water brake, 7-coupling, 8-signal conditioner, 9-NI measurement card, 10-PC

The correct contact area was described according to the assembly instructions. The dimensions defining the position and size of the contact area are shown in figure 2.

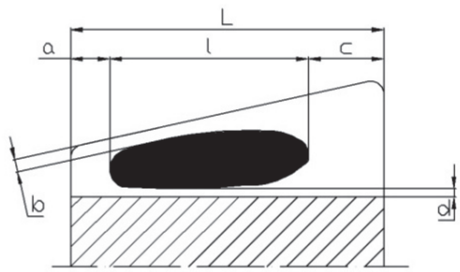

Fig. 2. The shape of the contact area with dimensions defining its position and size

The contact area was checked on three teeth spaced every 120°. Figure 3 depicts the examples of tooth contact areas with dimensions and surface areas.

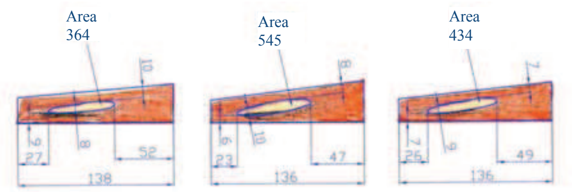

Fig. 3. Examples of the gear wheel contact areas with typical dimensions

The measure representing the contact area was its relative length L_w, specified with the dependence no. 1, and relative surface area P_w (dependence no. 2).

$$L_w = \frac{L}{L_c} \tag{1}$$

where:
L – the length of tooth contact area,
L_c – total length of tooth side surface.

$$P_w = \frac{P}{P_c} \tag{2}$$

where:
P – tooth contact surface area,
P_c – total tooth side surface area.

3. ANALYSIS OF THE RESULTS

As previously mentioned, the tooth contact area is the main criterion of the gear wheel quality assessment and the gear assembly correctness. It was assumed that there should be a relationship between the contact area and the vibration signal generated by the gear. Then, on the basis of the vibration measurements, it would be possible to judge the assembly quality. It was also accepted that the precision with which the gear wheels, bodies and other gear parts had been made had no significant influence on the generated vibrations. This project also assumes that the larger the contact area with the right position and shape, the smaller the gear vibrations should be.

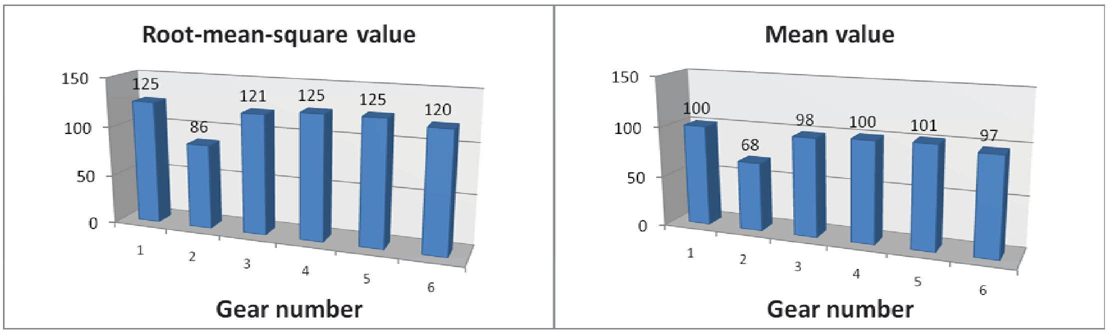

Fig. 4. Root-mean-square and mean values for non-processed signals

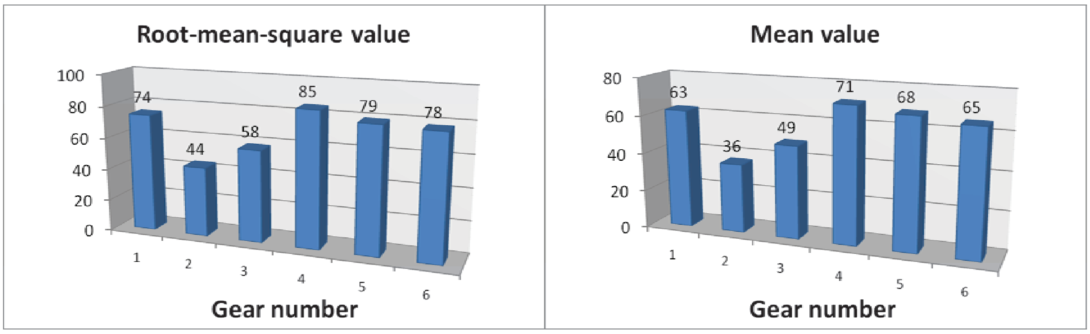

Fig. 5. Root-mean-square and mean values calculated for filtered signals

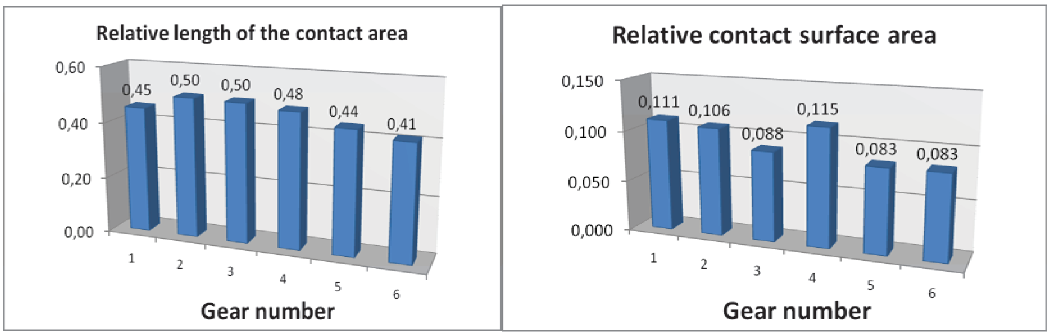

Fig. 6. Relative length of the contact area and relative contact surface areas

Comparing the root-mean-square and mean values in figure 4, we can see that the values for gear no. 6 are lower than the values for gears nos. 1, 3, 4 and 5. Similar data can be found in figure 5.

Figure 6 depicts two contact area measures, which estimate the same contact area differently, especially for gears 1 to 4. In other words, according to one measure, a particular gear was assembled in a better way compared to other gears, and according to the other measure it was not. By the words "better way" we mean higher value. Comparing the relative length and relative contact surface area with signal parameters, and remembering the earlier assumption, it should be stated that the contact area is described more appropriately by the relative contact area length. Having chosen one of the measures, we can continue further analysis. The value describing the contact area for gear no. 1 is not much bigger than for gear no. 5 (vibration parameter values should also remain at similar levels, as they do). The biggest contact area was achieved for gears nos. 2 and 3; root-mean-square and mean values should reach similar, the lowest levels. Figure 5 shows that the values are the lowest, but they are very different from one another. While in figure 4, the parameter value for gear no. 3 is at the same level as for gear no. 1. Gear no. 6 was assembled with the smallest contact area; the second in row is no. 5. Signal parameter values are not the highest for these gears but they are similar (figure 5), and the value is smaller for gear no. 6 (figure 4). The highest vibration signal parameter value is for gear no. 4, with the contact area bigger than the four other gears (figure nos. 4 and 5).

When compared to the non-processed signals, parameter values calculated for the filtered signals are closer to the contact area size. We can state this after the verification of parameter values, especially for gears 1, 3 and 5.

4. SUMMARY

The assembly of gears, especially bevel gears (with the possibility of changing the gear wheel position) is a crucial stage which influences the gear's durability. The assembly quality is also conditional on the competence of the staff. The order of the assembly and control actions is included in the assembly instructions and varies depending on the complexity of a gear [1].

The tooth contact area is the major indication of the gear assembly quality assessment. This work examines the relation between the size of the contact area and simple vibration signal measures. As a result of the research it has been shown that the size of the contact area represented by the relative length is a better measure than the relative contact trace surface area. Vibration signal parameters for filtered signals demonstrated greater compliance with the size of the contact area. The relation between the contact area size and the signal parameters was only partially confirmed. The most significant inconsistency was for gear no. 4, which, despite the third position as far as the contact area size is concerned, has the highest level of vibrations. Gears 2 and 3 (with the same contact area) also differ significantly as far as signal parameters are concerned. The reason for this may be inadequate initial signal processing or wrong signal parameters (signal analysis). In addition, defining the assembly quality only by the contact area size may not be enough. The solution to this problem may be the employment of artificial intelligence methods for the assessment of the assembly quality, and that is the direction in which further work will follow.

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