Methodology Measurement of Inclination Gears in Operation

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Abstract. This article deals with the design of methodology for determining the behaviour of a gear on a needle bearing. The knowledge of behaviour of the gear on a needle bearing is important for the gear modification. The modification of the gear that is mounted on a needle bearing cannot be calculated only from the shaft deformation. There is a radial clearance between the shaft, gear hub and needle bearings so the gear cannot copy the deflection curve of the shaft. Inclination of gears on needle bearings is measured on the apparatus of own design. The results of inclination measurement determine the correct size of modification of the gear that will generate the least noise and vibration in a given operating range. The experimental determination of the modifications is time consuming and expensive.

Keywords: Inclination gears · transmission · needle bearings · gear modification · radial clearance

1 Introduction

In transmissions of personal vehicle are gears on first shaft made or pressed. However, the gears on the second shaft are mounted on a needle bearing and the torque is transmitted only after employing the synchrony. As the gears are deployed along the shaft and different torques must be transmitted during operation, modification is required. The calculation needed to design the modification is based on the deformation of the shafts or deformation is determined experimentally, as the case may be. Determining the modifications by calculating the shaft deformation does not lead to the correct results. There is a presumption from FEM calculations that due to the shifting of the load along the width of the teeth the oscillating tilting of the wheel occurs within the needle bearing clearance. The aim of this experiment will be to explore the dynamic behaviour of the gear mounted on a needle bearing.

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2 Materials and Methods

2.1 Measurement Device

The measurement will be carried out on an open trial stand (Fig. 1). This will be driven by an electric motor controlled by a frequency converter (1). A measurement apparatus will be located in the stand (2) and connected to the motor by velocity shaft. A torque sensor with telemetry (4) and a speed sensor (3) is placed on this shaft. The torque required for the experiment will result from resistance of a disc brake controlled by the brake cylinder lever (5).

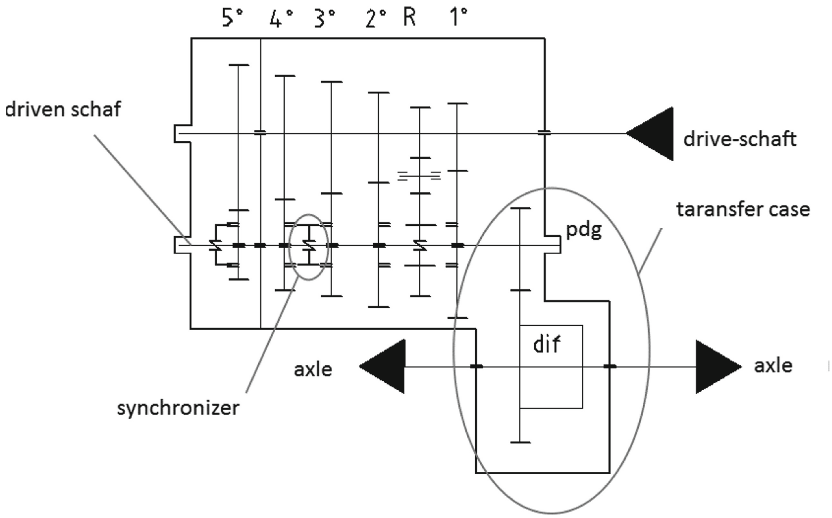

Fig. 1. A diagram of a two-shaft transmission [3].

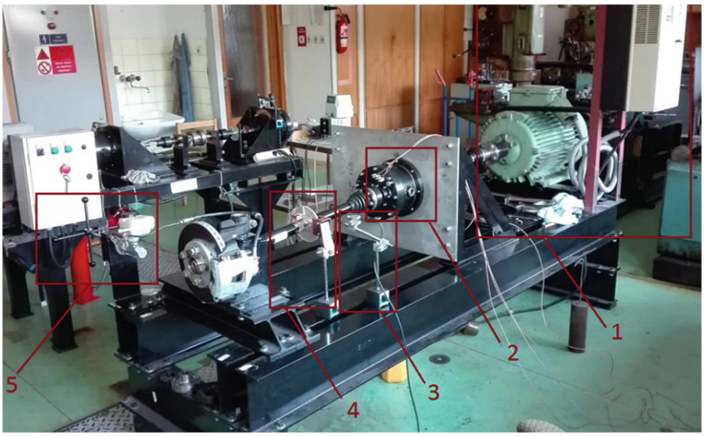

Fig. 2. Trial stand.

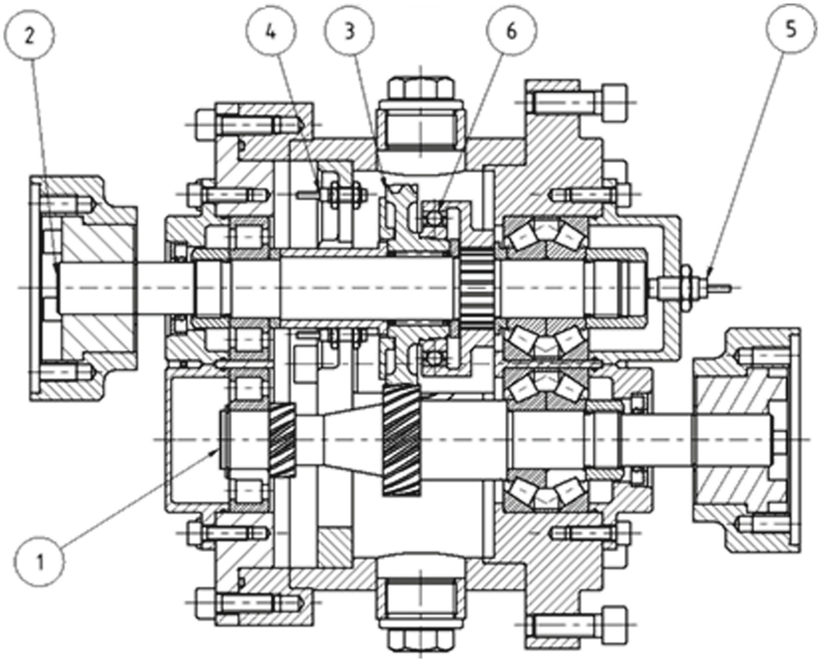

Fig. 3. Measuring apparatus.

The measuring apparatus consists of a stiff welded box containing both the drive shaft (1) and the driven shaft (2). The pinion of the gear is manufactured on the drive shaft. The gear on the drive shaft, (3) is mounted on the needle bearing. The behaviour of this gear will be subject to this experiment. In order to avoid affecting the measurement results by synchromesh, the synchronization clutch was replaced by clutch with balls. Tato clutch is the authors' own design. The gear inclination will be sensed by a triple sensor (3). In order not to affect the measurement results by axial oscillation of the driven shaft, the feed of the shaft face is sensed (Figs. 2 and 3).

3 Methodology of Experiment

In order to avoid affecting the measurement results by synchromesh, will be used in the measuring jig to transfer the torque from the wheel to the shaft of a special clutch design, allowing free inclination of the gear to the maximum extent possible, but to safely transfers torque. Thanks to this, we can find out how the gear behaves when its motion is not limited by the synchromesh. The inclination of the gear will be measured on the gear's front plane by three sensors monitoring eddy current that can be sensed even at higher speeds; moreover, the sensors are able to operate in oil mist. The three sensors will determine the plane inclination of the gear. The gear will operate under the conditions similar to those in a real car. Input speed for one measurement will be constant in the apparatus and it will range from 1000 rpm to 3000 rpm. The measurement will be performed at constant speed levels. For less frequent operating speeds, the speed level will be larger. For the most frequent speed regions, the level will be smaller. The torque during one measurement will be constant. The measurements will be made for wheels with different radial clearances. The radial clearance will be changed by grinding the inner cylindrical surface of the wheel. The experiment will be performed on a measuring stand where the measuring jig will be stored.

4 Results and Discussing

4.1 Measurement Evaluation

Measurements will be made using three contactless displacement sensors. The measured displacements will determine the axial swing of the gear or the inclination of the gear. The positioning of the sensors and the markings of the measured distances are shown in Fig. 4 respectively Fig. 5. The behaviour of the gear will be evaluated from one revolution of the driven shaft. The measured values for one revolution will then be filtered to the tooth frequency to determine how the wheel moves after hitting the teeth.

The Fig. 6 shows the axial displacement of the gear at 540 rpm and 10 Nm of torque. The values of the sensor are indicated by the curve a, the values of the sensor b are shown by the curve b, the values of the sensor c are shown by the curve c. The graph

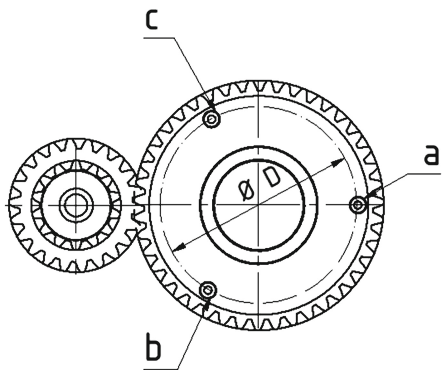

Fig. 4. Sensor layout.

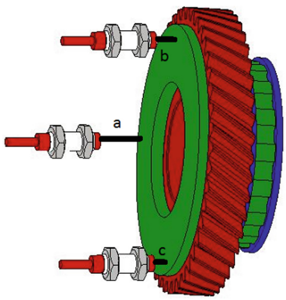

Fig. 5. Sensor layout.

shows the values of the axial displacements measured on the sensors because the curves a, b, c move separately. The bearing clearance might cause the radial displacement of the gear. The measuring apparatus is currently not able to record this fact, therefore it will be complemented with the appropriate sensors. Furthermore, it is apparent that the inclination of the gears occurs in two planes, so there will be two angles of inclination the gear (Fig. 7).

The maximum displacement value of 0.095 mm was measured on the sensor *a* for 540 rpm of the driven shaft and 10 Nm of torque. Therefore, at this case, the maximum amplitude of the gear displacement at the gear sensor *a* is 0.185 mm.

Figure 8 shows the axial displacement of the gear at 540 rpm and a torque of 67 Nm. The displacement of gear are similar as when to the same speed and torque of 10 Nm. With a torque of 67 Nm, the displacement values measured on sensors *a, b* increase. The value measured on sensor *c* remains the same as for the torque of 10 Nm. The maximum displacement measured on sensor *a* is 0.12 mm. Such increase means a 25% increase in displacement and thus in inclination compared to the value measured for 10 Nm of

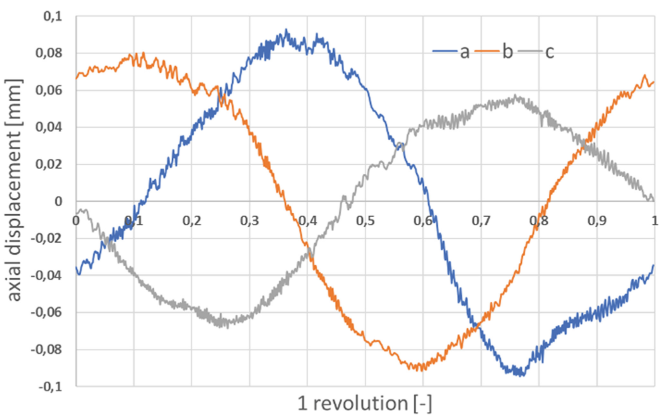

Fig. 6. Axial displacement at 540 rpm and of torque 10Nm per 1 revolution.

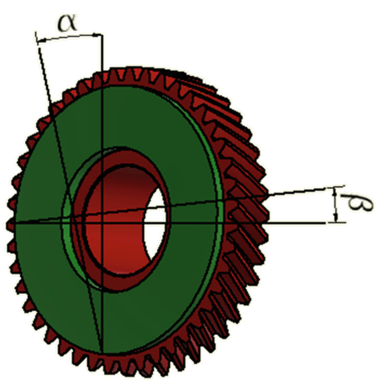

Fig. 7. Angles inclination the gear.

torque. Comparing the values measured on sensor *b*, the increase is similar. The values measured on sensor *c* do not seem depending on be torqued. With regard to the layout of the sensors, we can assume that the increase in inclination of the gear is in particular due to axial force affecting in the toothed. The maximum displacement amplitude of 0.25mm was measured on sensor *a*.

Figure 9 shows the course of the axial displacements of the gearwheel with filtering at the gearwheel frequency of the wheel at 540 rpm and a torque of 10 Nm. By filtering off all frequencies except gear-related, we get the axial displacement of the wheel for each tooth impact during gear engagement. From the curves measured it can be concluded that a slight inclination of the gear occurs with each tooth impact. The maximum movement

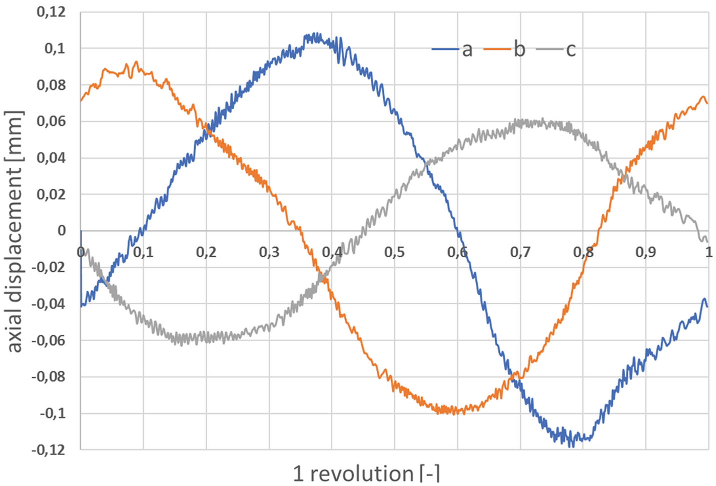

Fig. 8. Axial displacement at 540 rpm and of torque 67 Nm per 1 revolution.

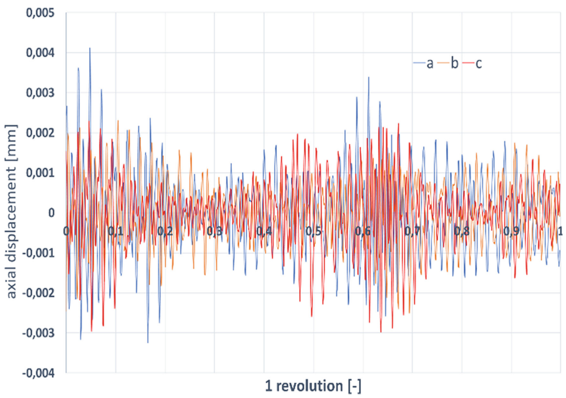

Fig. 9. Axial displacement of the gear with filtering one the gear-frequency at 540 rpm and of torque 10 Nm.

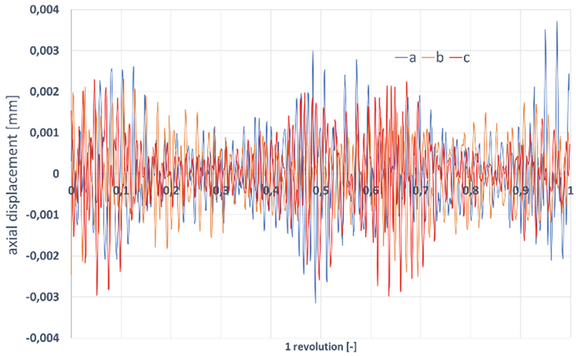

Fig. 10. Axial displacement of the gear with filtering one the gear-frequency at 540 rpm and of torque 67 Nm.

of a 0.0043 mm was measured on sensor *a*. The maximum tilt amplitude of 0.0072 mm was measured on sensor *a*.

Figure 10 shows the axial displacement of the gearwheel with filtering at the gear-wheel frequency at 540 rpm and a torque of 67 Nm. The maximum tilt value of 0.0037 mm was measured on the sensors. This value decreased by 16% compared to the value measured at 540 rpm and 10 Nm torque. The direction and size of the tilt of the wheel relates to the force distribution and wheel manufacturing deviations.

5 Conclusions

Inclination of the gears occurs on gears mounted on needle bearings. Its size cannot be determined from shaft deflections. There is a radial clearance among the gear hub, the needle bearing and the shaft; the gear thus does not copy the deflection curve of the shaft and is allowed to inclination movement. This inclination movement was found in FEM calculations. The task of this work is to confirm or disprove this movement. To measure the inclination of the gears, a measuring apparatus and a stand of the authors' own design were used. The behaviour of gear was measured by three contactless sensors. The three contactless sensors were used to capture the entire axial displacement, or inclination of the front plane of gear, as the case may be. The whole experiment with measuring the gear wheel inclination on a needle bearing is still at the beginning, so there are not enough data for unambiguous conclusions yet. The measured values were processed in two ways: the inclination of the gear for the revolution and the inclination of the gear with filtering at the gear frequency. By this filtration, the gear movement with each tooth impact was detected. During measurement of the gear inclination at 540 rpm and 10 Nm torque, the maximum gear movement of 0.095 mm per revolution on sensor *a*, and the maximum amplitude of 0.185 mm also on sensor *a* were measured. When comparing the motion curves measured during the above mentioned load and speed it is apparent, that the values on sensors *a, b* are almost identical. This suggests that the gear in this area moves at a common angle. The values measured on sensor *c* are different from those on sensors *a, b;* which indicates that the distance *c* is the coordinate of the second angle under which the gear is inclined. After comparing with the measurement results at the same speed, but with a torque of 67 Nm, a 25% increase in the measured values on sensors *a, b* is observed. The values measured at the sensor *c* can be considered identical. With regard to the layout of the sensors, it can be assumed that the direction and size of the axial force acting in the teeth engagement will have the greatest impact on the gear inclination. According to the curves measured, it can be assumed that there is no axial oscillation of the gear on the shaft. The gear rather inclines. The values measured show that the gear does not only incline axially, but can oscillate radially, as well. The measuring apparatus will therefore be complemented with measurement of the radial movement of the gear. The second aspect for evaluation of the inclination of the gear on a needle bearing was the displacement during the gear frequency which allowed detection of the gear displacement during impact on the teeth. A maximum displacement vaule of 0.0043 mm at 540 rpm and a torque of 10 Nm was measured on sensor *a*. The maximum speed at the tooth frequency on the same sensor decreased by 15% for the same speed but a torque of 67 Nm. This reduction in tilt can be attributed to the increased stiffness of the transmission as the torque increases.

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References

1. PAVLÍK, J., ZAČAL, J., PROKOP, J., FOLTA, Z. The growth of contact area of the tooth in depending of increasing the loading. In Proceedings of the 58th International Conference of Machine Design Departments - ICMD 2017: September 6th 2017 - September 8th 2017, Prague, Czech Republic. Prague: Czech University of Life Sciences Prague, 2017, s. 280–283. ISBN: 978–80–213–2769–6
2. TROCHTA, M., FOLTA, Z., PAVLÍK, J. Quality of gear mesh and its effects on transmission error. In Proceedings of the 58th International Conference of Machine Design Departments - ICMD 2017: September 6th 2017 - September 8th 2017, Prague, Czech Republic. Prague: Czech University of Life Sciences Prague, 2017, s. 404–407. ISBN: 978–80–213–2769–6
3. Mosler, V., Havlik, J., Pavlik, J. An apparatus for measurement of inclination of gears on needle bearings. In Proceedings of the 58th International Conference of Machine Design Departments - ICMD 2017: September 6th 2017 - September 8th 2017, Prague, Czech Republic. Prague: Czech University of Life Sciences Prague, 2017, s. 256–259. ISBN: 978–80–213–2769–6Author, F.: Contribution title. In: 9th International Proceedings on Proceedings, pp. 1–2. Publisher, Location (2010).
4. ZAČAL, J., FOLTA, Z., JANČAR, L. Desing of a sensor for measurement of bolt pretension. In Proceedings of the 58th International Conference of Machine Design Departments - ICMD 2017: September 6th 2017 - September 8th 2017, Prague, Czech Republic. Prague: Czech University of Life Sciences Prague, 2017, s. 426–429. ISBN: 978–80–213–2769–6

5. Moravec V., M., Dejl, Z., Němček, M., Folta, Z., Havlík, J. Spur gear in transmission car. Ostrava: MONTANEX a.s, 2009. ISBN 978–80–7225–304–3.
6. Fujimura, N., Beppu, M., Hibi, K., Murakami, H., Yokoi, M. Analysis of the behavior and resonant noise of needle roller bearings used for idler gears in transmission applications. SAE 1987, doi:https://doi.org/10.4271/871923