IMPACT OF INSTALLATION ERRORS OF THE GEAR ON THE KINEMATIC DEVIATION

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Summary

The primary purpose of the study is to assess of impact of various installation errors on the transmission error of the bevel gear with circular-curved teeth. To achieve that, simulation possibilities were used as a tool accelerating the time of analyses and requiring small financial outlays for the tests. Solid body models of toothed wheels were generated in accordance with Gleason's method, then the virtual installation of toothed wheels took place, and the simulation was conducted in the CAE (computer aided engineering) program environment. Single flank of toothed wheels was simulated for weather conditions and thus for small speed and load. Faulty performance of wheels was not simulated, and friction was not taken into account. As a result of simulation, the transmission error (kinematic deviation) of the bevel gear was obtained for various positions of the pinion in respect of the crown wheel (installation errors). Positions with the smallest and the largest influence on the transmission error were determined.

Keywords: bevel gear, kinematic deviation, single flank, assembly error.

WPŁYW BŁĘDÓW MONTAŻOWYCH PRZEKŁADNI NA ODCHYŁKĘ KINEMATYCZNĄ

Streszczenie

Głównym celem pracy jest ocena wpływu różnych błędów montażowych na błąd przełożenia przekładni stożkowej o zębach kołowo-łukowych. Aby to osiągnąć wykorzystano możliwości symulacji jako narzędzia przyśpieszającego czas analiz i wymagającego małych nakładów finansowych na badania. Wygenerowano modele bryłowe kół zębatych zgodnie z metodą Gleasona, następnie dokonano wirtualnego montażu kół zębatych, a symulacja odbyła się w środowisku programu CAE (computer aided engineering). Symulowano współpracę jednostronną kół zębatych dla warunków metrologicznych a więc dla małej prędkości i obciążenia. Nie symulowano błędów wykonawczych kół i nie uwzględniano tarcia. W wyniku symulacji otrzymano błąd przełożenia (odchyłkę kinematyczną) przekładni stożkowej dla różnych położeń zębnika względem koła talerzowego (błędów montażowych). Ustalono położenia o najmniejszym i największym wpływie na błąd przełożenia.

Słowa kluczowe: przekładnia zębata stożkowa, odchyłka kinematyczna, współpraca jednostronna, błędy montażowe.

1. INTRODUCTION

Among many factors having effect on durability and low-noise of toothed gear there is the stage of installation in the course of which correct placement of toothed wheels against each other is agreed [9]. This is possible owing to appropriate structure of shafts bearing in the bevel gear body on which the toothed wheels are embedded. In the case of roller gears, it is not possible to improve the mesh, because it is dependent on the accuracy of production of the gear elements [6].

The main criteria proving correct production and installation of the gears are a contact pattern and a backlash. A backlash can be measured in several ways. Most often, this is made using the shift sensor [7]. A contact pattern is determined in the course of installation for small load and small rotational speed, for verification purposes, it can also be checked for operating conditions [2]. Assessing the contact pattern, we check its position, size and shape. These three criteria are correct within certain limits. Apart from the accuracy of production of the gear elements, the quality of installation is also influenced by the installing assembly. This experience and qualifications influences the final correctness of installation.

In this study, analysis is conducted for various cases of bevel gear installation, during which correct installation distances were not reached, and thus the test covers the impact of errors of the toothed wheels position on the kinematic deviation (transmission error). This is done by means of a computer simulation of the single flank [8]. The whole of the issue has been implemented in the NX program by Siemens PLM Software and for processing the data from simulation and generation of charts, the Excel spreadsheet was used. On the basis of toothed wheels generated in accordance with the technology of Gleason processing, virtual installation of toothed wheels was done. Then, dynamic simulations were conducted for various positions of the pinion in respect of the crown wheel. Results have been exported to the spreadsheet, where their further analysis took place.

Single flank of toothed wheels is used mostly at serial production for current inspection and as the final inspection [7]. It allows to check the mesh error in real gear work conditions, as opposed to double flank [4,5]. Also the obtained results are easier in interpretation. In this article, the kinematic deviation (whose definition can be found in study [1]) is a measure of the installation correctness.

2. SOLID BODY MODELS OF TOOTHED WHEELS

The created models of toothed wheels (Fig. 1) correspond to the subject of the tests presented in previous studies, e.g. [3]. The number of the teeth for the pinion was 19, for the crown wheel it was 42, the transverse module was equal to 2.9 mm. Then, the virtual installation of wheels was done, by moving the pinion to different positions, in accordance with figure 2. In this figure, the rectangular coordinate system, marked with the letters H and V, was adopted, which is consistent with the system from Fig. 1. The shift in accordance with axis H is horizontal and with axis V - vertical. Four directions, along which the pinion was shifted, were considered. They have been shown in the form of various types of lines and by means of the suitable marking. Shifts took place every 0.1 mm from values -0.4 mm to 0.4 mm.

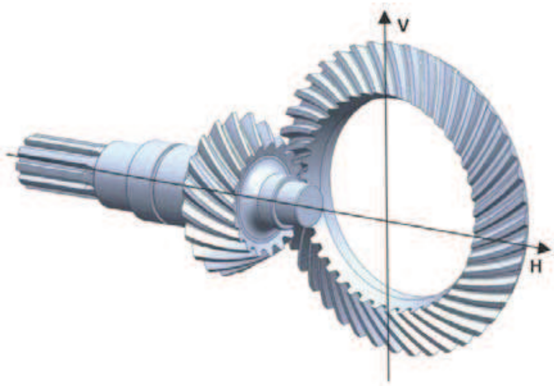

Fig. 1. Solid body models of bevel toothed wheels

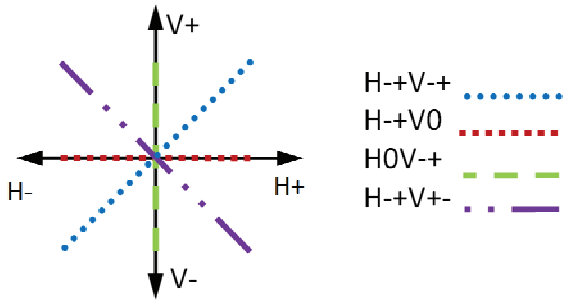

Fig. 2. Pinion shift directions:
H-+V-+ shift of the pinion by the same value on both axes in quarter 1 and 3 of the coordinate system, H-+V0 shift of the pinion only along axis H, H0V-+ Shift of the pinion only along axis V, H-+V+- shift of the pinion by the same value on both axes in quarter 2 and 4 of the coordinate system

3. SINGLE FLANK SIMULATION

As the material for the toothed wheels, steel has been adopted (density $\rho = 7829\ kg/m^3$, Young module $E = 20694 \times 10^{7}$ Pa, Poisson's coefficient $\nu = 0.288$). Single flank simulation took place for conditions prevailing during the previously conducted measurements (for small rotational speed and small load). The pinion rotated with the constant speed of 0.01745 rad/s (1/6 rpm). The results of the simulation were recorded every half degree of the pinion rotation. To ensure continuous contact between cooperating teeth edges, a torque directed opposite to the rotation direction was applied to the crown wheel, with the value of 0.01 Nm. The simulation lasted for one rotation of the pinion. The tests did not include friction. Small load value allows to state that toothed wheels in this simulation can be treated as rigid solid bodies.

4. ANALYSIS OF RESULTS

As a result of the conducted simulation, the position was obtained for the crown wheel and the pinion. Data were exported mainly to Excel, where, as a result of simple mathematic operations, a chart of the kinematic deviation (transmission error) was obtained. The following charts (Fig. 3,4,5,6) present the results for four analyzed directions of the pinion shift. For each direction, there were nine measuring points.

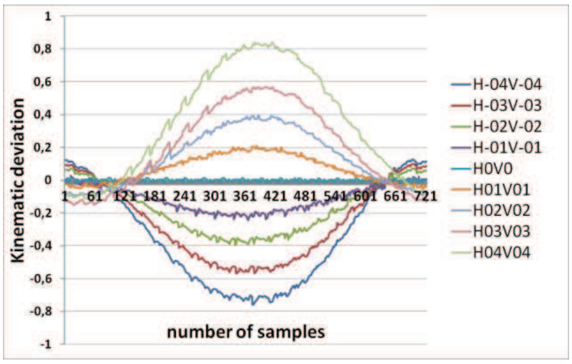

Fig. 3. Kinematic deviation for direction H-+V-+

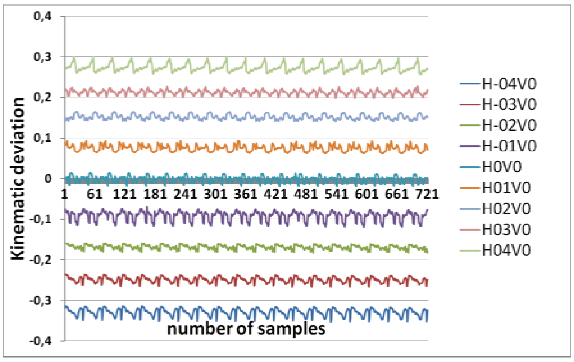

Fig. 4. Kinematic deviation for direction H-+V0

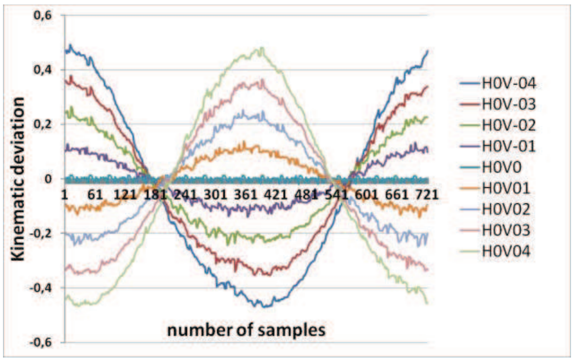

Fig. 5. Kinematic deviation for direction H0V-+

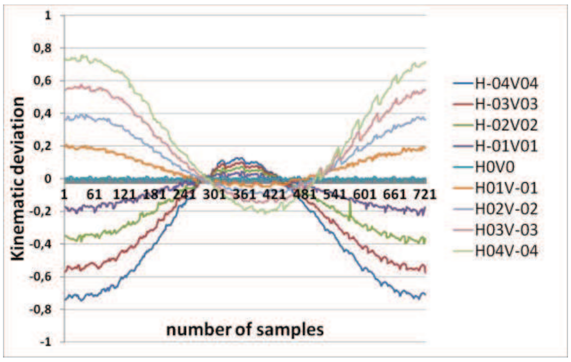

Fig. 6. Kinematic deviation for direction H-+V+-

To make it possible to compare the obtained results, not only in the graphic way, but also in the quantitative way, values of four measures were determined. In figure 7, we have the minimum value for four directions and nine measuring points. Similarly, in figure 8, the maximum value, the total transmission error calculated as the difference in the maximum and the minimum value (Fig. 9), as well as the standard deviation (Fig. 10).

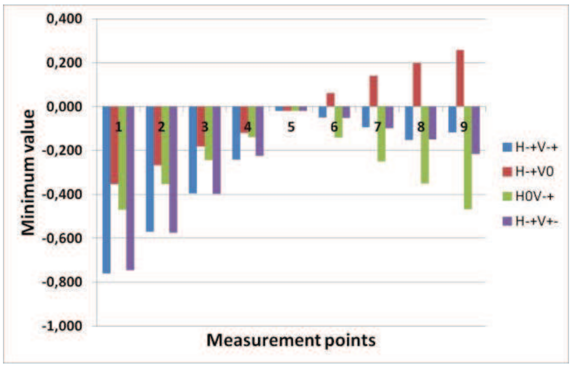

Fig. 7. Minimum value for the kinematic deviation

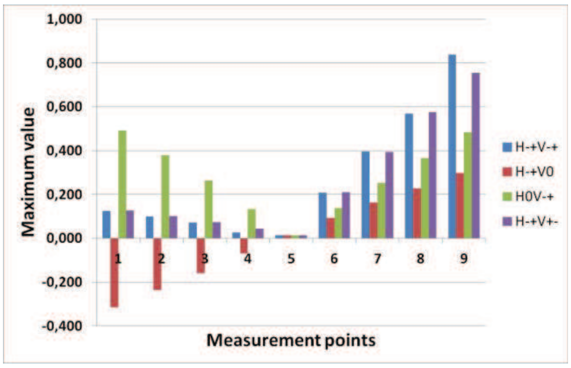

Fig. 8. Maximum value for the kinematic deviation

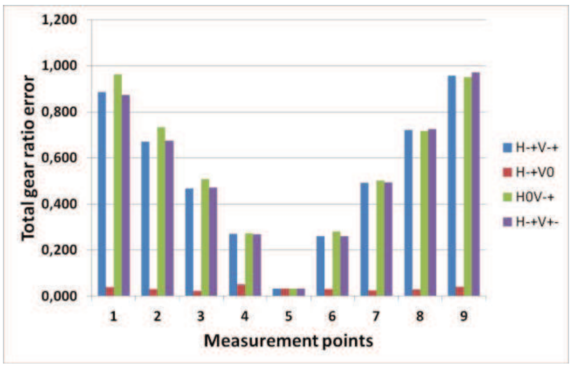

Fig. 9. Total transmission error

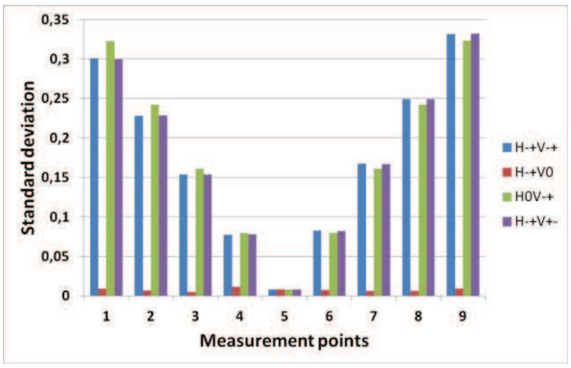

Fig. 10. Standard deviation for the kinematic deviation

Comparing the results for the maximum and the minimum value, the largest values were reached for the simultaneous pinion shift in respect of both axes, smaller ones in relation to the vertical axis and the smallest ones in relation to the horizontal axis, however, the largest differences between the directions are approximately double. It is different in the case of the total transmission error, which, for direction H-+V0, is smaller by the order of magnitude than the others. It means that the gear is least "sensitive" to installation errors related to the pinion shift in relation to its axis, if we talk about the transmission error. Also the standard deviation, which is the measure of size dispersion around the average value for the shift direction, consistent with the pinion axis, assumes the smallest values. In this case, the standard deviation may be interpreted as a measure of variability of the crown wheel's rotational speed.

5. CONCLUSION

Tests were conducted concerning the impact of toothed wheels position with respect to each other on the transmission error (kinematic deviation) of the bevel gear. Simulative tests have proven to be a useful tool, allowing to reflect the single flank of toothed wheels.

Analyzing the obtained results, it should be stated that the greatest transmission error occurs, when the pinion is shifted (from the correct position) in respect of both axes of the crown wheel and the larger this distance is, the greater the error is. The smallest sensitivity is present, however in the event of improperly selected installation distance of the pinion.

6. LITERATURE

[1].Chajda J., Mądry Ł.: *Odchyłki dynamiczne w badaniach kół zębatych*. Zeszyty Naukowe Politechniki Rzeszowskiej nr 259, Mechanika z. 75, Koła zębate KZ 2008, s. 32 – 45.

[2].Jaśkiewicz Z.: *Przekładnie stożkowe i hipoidalne, Układy napędowe samochodów*. Wydawnictwo Komunikacji i Łączności, Warszawa 1978.

[3].Jedliński Ł., Jonak J.: *Quality evaluation of the bevel gear assembly based on analysis of the vibration Signac*. Diagnostyka 53/2010, s. 23 – 26

[4].Mączak J.: *Wykorzystanie zjawiska modulacji sygnału wibroakustycznego w diagnozowaniu przekładni o zębach śrubowych*. Rozprawa doktorska, Warszawa 1998.

[5].Müller L.: *Przekładnie zębate, Projektowanie*. Wydawnictwo Naukowo-Techniczne, Warszawa 1996.

[6].Ochęduszko K.: *Koła zębate*, Tom drugi, Wykonanie i montaż. Wydawnictwo Naukowo-Techniczne, Warszawa 1976.

[7].Ochęduszko K.: *Koła zębate*, Tom trzeci, Sprawdzanie. Wydawnictwo Naukowo-Techniczne, Warszawa 1970.

[8].Skawiński P., Siemiński P.: *Badanie śladu współpracy i generowanie wykresów ruchowych spiralnych przekładni stożkowych w środowisku programów CAD*. Zeszyty Naukowe Politechniki Rzeszowskiej nr 259, Mechanika z. 75, Koła zębate KZ 2008, s. 188 – 197.

[9].Sobolak M.: *Zastosowanie systemu CAD do procedury V-H check dla kół przekładni stożkowej*. Zeszyty Naukowe Politechniki Rzeszowskiej nr 232, Mechanika z. 69, Koła zębate KZ 2006, s. 215 – 226.

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