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스퍼기어의 전달오차에 관한 연구

Study on the Transmission Error Prediction for a Spur Gear Pair

장기 [1], 장정 [1], 주충강 [1], 왕진영 [1], 허철수 [2], 류성기 [2,✉]
Qi Zhang[1], Jing Zhang[1], Zhong Gang Zhu[1], Zhen Rong Wang[1], Zhe-zhu Xu[2], and Sung Ki Lyu[2,✉]

1 절강쌍환전동 유한회사 (Shuanghuan Driveline Co., Ltd, China)
2 경상대학교 기계공학부 항공연 (School of Mechanical Engineering, ReCAPT, Gyeongsang National University)
✉ Corresponding author: sklyu@gnu.ac.kr, Tel: +82-55-772-2643

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Nowadays, lower gear vibration and noise are necessary for drivers in automotive gearbox, which means that transmission gearbox should be optimized to avoid noise annoyance and fatigue before quantity production. Transmission error (T.E.) is the excitation factor that affects the noise level known as gear whine, and is also the dominant source of noise in the gear transmission system. In this paper, the research background, the definition of T.E. and gear micro-modification were firstly presented, and then different transmission errors of loaded torques for the spur gear pair were studied and compared by a commercial software. It was determined that the optimum gear micro-modification could be applied to optimize the transmission error of the loaded gear pair. In the future, a transmission test rig which is introduced in this paper is about to be used to study the T.E. after gear micro-geometry modification. And finally, the optimized modification can be verified by B&K testing equipment in the semi-anechoic room later.

KEYWORDS: Spur gear (스퍼 기어), Transmission error (전달 오차), Tooth micro-modification (치형 수정)

1. Introduction

Transmission error (T.E.) is the most important factor of gear noise and vibration because transmission errors affect the changes of the force and the speed of gears. It can usually be expressed as an angular deviation, or a linear deviation which is measured at the pitch point and calculated at successive positions of the pinion during gear meshing cycle.[1]

For gear transmission, if the gear shapes are ideally perfect, then the gear meshing is better, therefore the gears will transmit the input torque in a more efficient manner without the generation of high frequency sounds from engine fluctuation. The affected factors, like transmission error, mesh stiffness, axial shuttling force and bearing force, friction forces, air and lubricant entrainment, have been considered as possible excitations of gear whine noise. The transmission error of these factors is the lead cause of gear whine which is affected by the deflection under loaded torques.[2,3]

In this paper, two kinds of tooth profile modifications were firstly introduced. And then, a spur gear pair was modeled and simulated by RomaxDesigner software, which different tooth micro-modifications were investigated and compared. At last, it was found that the optimum gear micro-modification could be applied to minimize the transmission error of the loaded torques. In the future, a transmission test rig which is introduced in this paper is going to be used to study the T.E. and vibration & noise after gear micro-geometry modification. And the optimized modification can be verified by B&K testing equipment in the semi-anechoic room later.

2. Background and Analysis

2.1 Transmission Error Definition

As we all know, gear mesh is the origin of the gear whine noise, in which vibrations are excited by transmission error during gear transmission, and T.E. can be expressed as an angular deviation, or a linear deviation which is measured at the pitch point and calculated at successive positions of the pinion during gear meshing cycle.[2] Fig. 1 is the schematic of T.E. definition. The T.E. of a pair of gears can be written in terms of a linear discrepancy tangential to pitch circle.

$$TE = \theta_2 r_{b2} - \theta_1 r_{b1} \quad (1)$$

Where θ is the angle of gear rotation, r_b is the base radius and z is the number of gear teeth. Subscripts 1 and 2 mean the driving and the driven respectively.

For the loaded static transmission error, gear tooth bending deflection, shearing displacement and contact deformation will be considered while gears are operated at low speed.

2.2 Gear Tooth Modification

For the reduction of the gear noise and vibration, gear tooth micro-modifications are now implemented in gear industry. It means the material is removed from the original positon of the tooth surface, so that the shape is no longer a designed involute flank. Such modifications can be utilized to make up for the teeth deflections under the loaded torques. Micro-modifications can be applied on the involute and lead of gear teeth.[4]

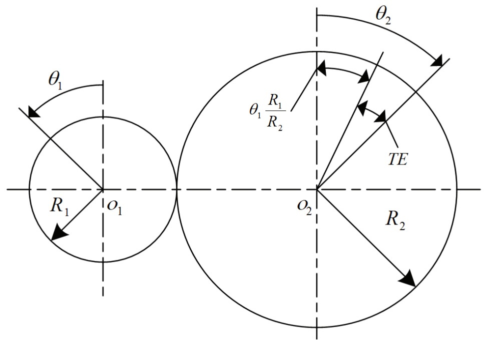
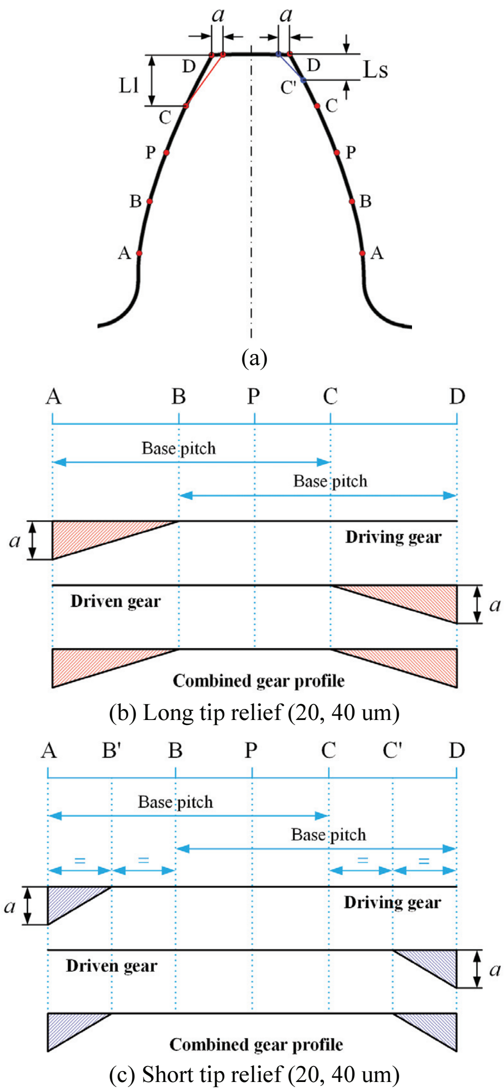


Fig. 1 The schematic of T.E. definition



(a)

(b) Long tip relief (20, 40 um)

(c) Short tip relief (20, 40 um)

Fig. 2 The schematic and definition of long tip relief and short tip relief

For gear lead modifications, lead crowning or end relief can be utilized to make up for manufactured lead errors, shaft misalignments and deflections. This modification is called upon to achieve a unique load along the tooth face width. But for narrow face width spur gears, lead modification is usually not applied, only from medium to wide face widths, it is necessary to compensate for lead errors and misalignment.

For gear profile modifications, tip relief is used to decrease tooth corner contact and dynamic excitation of the gear pair. It can be utilized to make up for the tooth bending and some part of manufacturing errors, and the noise level is a direct result of the peak-to-peak transmission error (PPTE). The commonly used modification curves are a linear tip relief on both gears, or linear tip and root relief on one or both gears. In this paper, two kinds of tip relief are used to investigate the T.E. of the spur gear, as shown in Fig. 2.

2.3 Design of Test Rig

By the analysis of T.E. measurement system,[5-12] the final selection of the test rig structure is shown in Fig. 3. Here, the input power is a brushless DC motor. Combined with the company's own hardware resources, RV reducer is used to decrease the input speed and increase the input torque. And the steady rotational torque and rotational speed can be read by the torque meter. The absorbing torque is from a magnetic power brake. Finally, all parts are connected by metal flexible diaphragm couplings.

And the T.E. test rig is shown in Fig. 4. In the future, the transmission test rig which is introduced in this paper is going to be used to study the T.E. and vibration & noise after gear micro-geometry modification. Its measurement is based on the use of HEIDENHAIN incremental angle encoders (RON 287 & RON 785). And HEIDENHAIN PC counter card is applied to acquire encoder signals. Its principle role is to convert the electrical signals of encoders to precise angle measurements, and transmit the measured values to a PC or computer test software.

3. Analysis and Discussion

In this paper, Table 1 shows the specification of the spur gear pair. From the data in Table 1, 11 the T.E. was simulated and investigated by software to minimize noise excitation of the design torques. Input torques are from 50 to 400 Nm, incremental interval is 50 Nm.

The first four harmonics of no micro-modification is shown in Fig. 5. Similarly, Fig. 6 is long tip relief 20 um, Fig. 7 is long tip relief 30 um, Fig. 8 is long tip relief 40 um, Fig. 9 is short tip relief 20 um, Fig. 10 is short tip

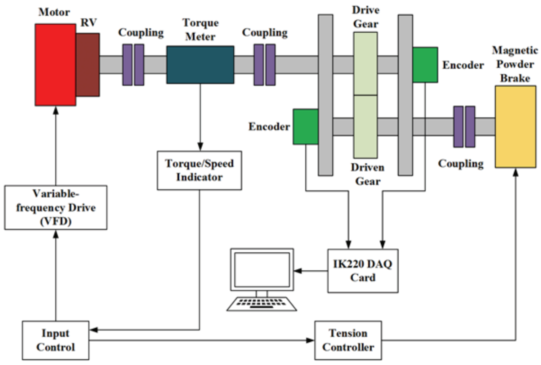


Fig. 3 The schematic of T.E. test rig

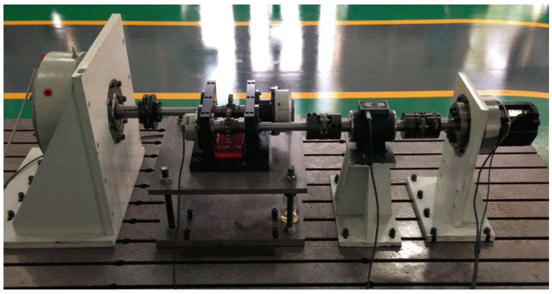


Fig. 4 T.E. test rig

Table 1 The specification of the spur gear pair

Specification	Driving / Driven
Number of teeth	24
Module (mm)	4.5
Pressure angle (deg.)	20
Helix angle (deg.)	0
Addendum mod. coeff.	0.171
Center distance (mm)	109.5
Face width (mm)	14
Outside diameter (mm)	118.35
Root diameter (mm)	97.85
Standard pitch diameter (mm)	108
Transverse tooth thickness at SPD (mm)	7.564
Profile / face contact ratio	1.34/0
Total contact ratio	1.34

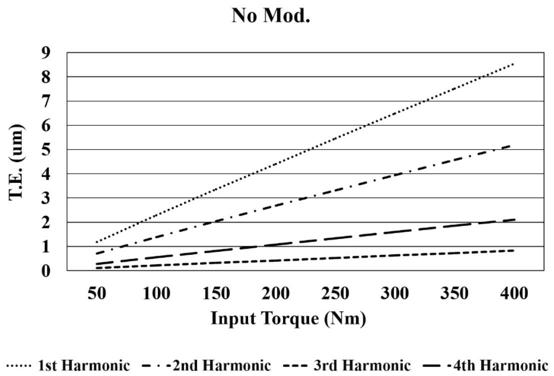


Fig. 5 No miciro-modification

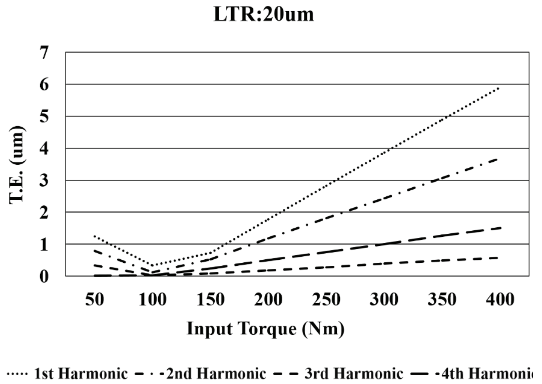


Fig. 6 Long tip relief 20 um

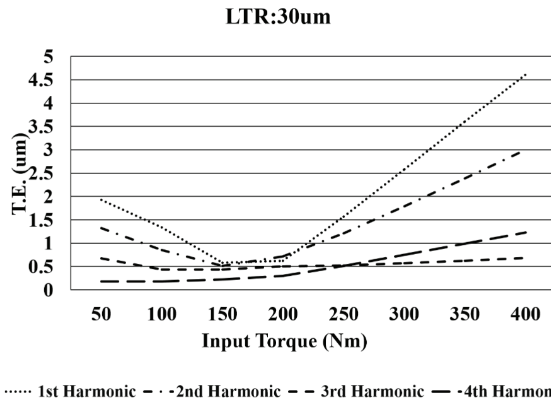


Fig. 7 Long tip relief 30 um

relief 30 um, Fig. 11 is short tip relief 40 um, and Fig. 12 is PPTE comparison of all these results. In Fig. 5, for no micro-modification, the T.E. is increased with the increase of torques. And the first harmonic is obvious.

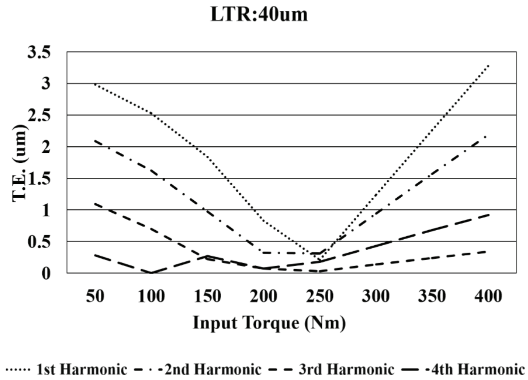


Fig. 8 Long tip relief 40 um

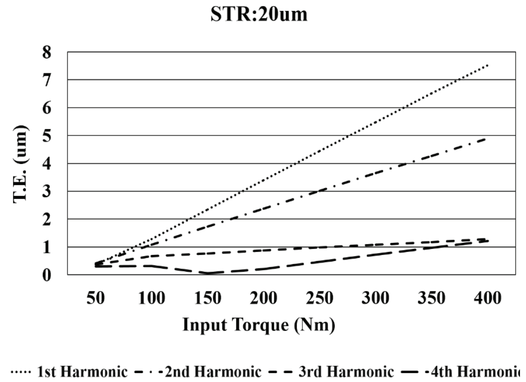


Fig. 9 Short tip relief 20 um

In Fig. 6, for long tip relief 20 um, T.E. is firstly decreased until one optimum load (about 100 Nm), and then increased with the increase of the left torques. Near the torque 100 Nm, the T.E. reaches a minimum which means the transmission error can be minimized under the designed torque with the optimum micro-modification length and amount.

In Fig. 7, for long tip relief 30 um, the content is roughly consistent with the Fig. 6, except an optimum torque is between 150 and 200 Nm. And in Fig. 8, the optimum torque is about 250 Nm. From Fig. 6 to Fig. 8, it is found that the optimum amount of micro-modification is increased with the increase of the loaded torque.

For all short tip reliefs (from 20 to 40um), the results are similar, like Fig. 5, which the T.E. is increased with the increase of torques. And the first harmonic is obvious. It also replies that the modification length is dominant for gear optimum micro-modification under the loaded

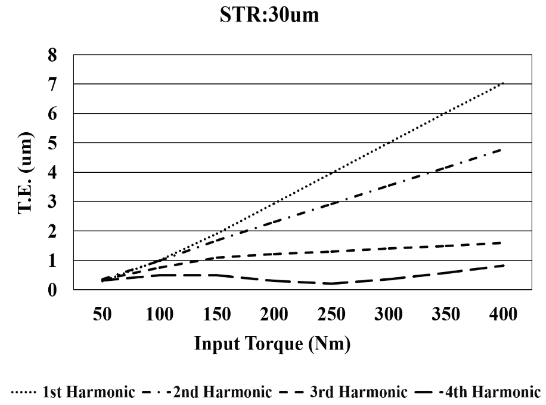


Fig. 10 Short tip relief 30 um

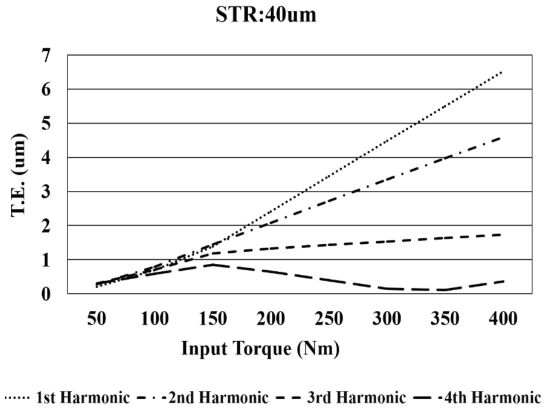


Fig. 11 Short tip relief 40 um

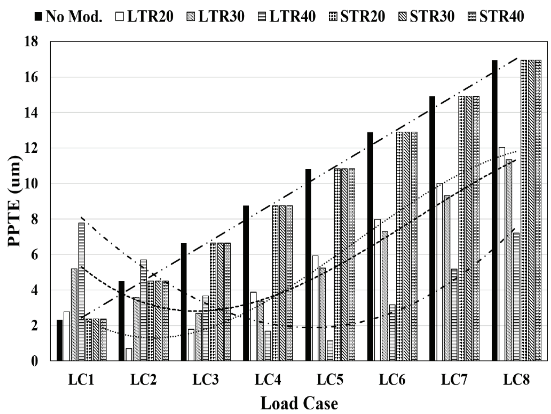


Fig. 12 PPTE comparison

torques. Finally, Fig. 12 is the PPTE comparison of all these. And they are going to be verified in the introduced test rig in the future.

4. Conclusions

In this paper, the transmission of the spur gear pair was modeled and analyzed by RomaxDesigner. The gear pair has been investigated through static analysis by the software. Thus, by the comparison between two micro-modifications, it is a good reference to understand the T.E. and be verified in the test rig in the future. All of the details should be taken into consideration in the next upgraded test rig which are listed as follows:

(1) In order to accurately control the hardware (e.g. input motor and absorbing dynamometer), DASYLab software package with some extra hardware can be chosen as an optimal control tool for the next test rig.

(2) Additional business measurement software, like Rotec -RAS from Germany, can be used to verify the accuracy of the VI testing software.

(3) Gear micro-geometric modifications are currently applied to reduce the gear noise and vibration. And the optimum modification can be verified by B&K testing equipment in the semi-anechoic room later.

(4) In the cases of long tip relief (from 20 to 40 um), comparing with the no micro-modification cases, the T.E. is increased with the increase of torques. And the first harmonic is obvious.

(5) For all short tip reliefs (from 20 to 40 um), the results are similar with long tip relief cases, which the T.E. is increased with the increase of torques. And the first harmonic is obvious.

(6) It also replies that the modification length is dominant for gear optimum micro-modification of the loaded torques in this paper.

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