한국기계가공학회지, 제14권, 제2호, pp.14～18(2015.4) ISSN 1598~6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol.14, No.2, pp.14～18(2015.4) ISSN 2288-0771(Online)

http://dx/doi.org/10.14775/ksmpe.2015.14.2.014

◆특집◆ 기어

A Study on the Comparison of Transmission Error Prediction for a Helical Gear Pair

Lae-sung Kim*, Qi Zhang**, Chang Choi***, Longjun Liang***, Sung-ki Lyu***,#
*Creative AIMCEEP, Gyeongsang National Univ., **Shuanghuan Driveline Co., Ltd, Zhejiang, China
***School of Mechanical & Aerospace Engineering, ReCAPT, Gyeongsang National Univ.

헬리컬기어의 전달오차예측 비교에 관한 연구

김래성*, 장기**, 최창***,양용군***, 류성기***,#
*경상대학교 항공IT기계융합사업단, **Shuanghuan Driveline Co., Ltd,
***경상대학교 기계항공공학부, 항공기부품기술연구소

(Received 15 March 2015; received in revised form 30 March 2015; accepted 7 April 2015)

ABSTRACT

In recent years, world is faced with a transportation energy dilemma, and the transportation is almost dependent on a single fuel – petroleum. However, Hybrid Electric Vehicle (HEV) technology holds more advantages to reduce the demand for petroleum in the transportation by efficiency improvements of petroleum consumption. Therefore, there is a trend that lower gear noise levels are demanded in HEV for drivers to avoid annoyance and fatigue during operation. And meshing transmission error (T.E.) is the excitation that leads to the tonal noise known as gear whine, and radiated gear whine is also the dominant source of noise in the whole gearbox. In this paper, the analysis of gear tooth profile and lead modification is firstly presented, and then, the different transmission error of no mesh misalignment and mesh misalignment under one loaded torque for the 1st gear pair of HEV gearbox was investigated and compared. At last, the appropriate tooth modification was used to minimize and compare the transmission error of the gear pair with mesh misalignment under the loaded torque.

Keywords : Plugin HEV(플러그인 HEV), Helical Gear(헬리컬기어), Transmission Error(전달오차)

1. Introduction

World is faced with a transportation energy dilemma. And the transportation is almost dependent on a single fuel – petroleum. Its consumption rates in the emerging economies of China and India are rapidly expanding. Furthermore, experts believe world petroleum production may peak within the next 5-10 years[1]. Hybrid Electric Vehicle technology holds more advantages to reduce the demand for petroleum in the transportation by efficiency improvements of petroleum consumption. Development of powertrains used in HEV is more competitive than before. In order to keep competitive, powertrain manufacturers must optimize attributes, such as performance, cost, weight, durability and NVH while a new product is developed. For gear transmission, if the gear shapes are perfect, then the

Corresponding Author : sklyu@gnu.ac.kr
Tel: +82-55-772-1632, Fax: +82-55-772-1578

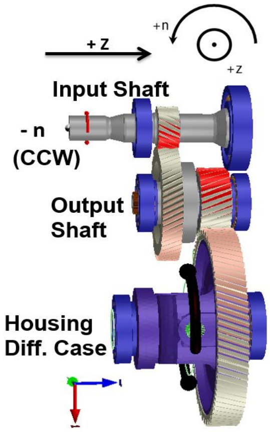

Fig. 1 The schematic model of the plugin HEV

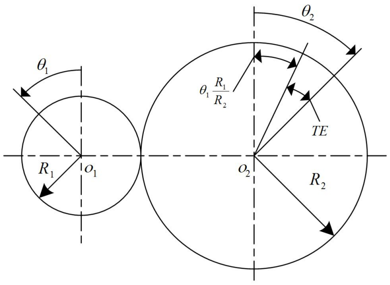

Fig. 2 The schematic of T.E. definition

gear tooth 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 following factors, like transmission error, mesh stiffness variation, axial shuttling force and bearing force, friction forces, air and lubricant entrainment, have been considered as possible excitations of gear whine noise[2-3]. For these factors, the transmission error is the main cause of gear whine which is affected by the deflection under load.

In this paper, the different transmission error of no mesh misalignment and mesh misalignment for a plugin HEV was investigated and compared, the first gear pair of the gearbox was modeled and simulated. At last, the appropriate tooth modification was used to minimize and compare the transmission error of the gear pair with mesh misalignment under the loaded torque. Figure 1 is the transmission model of the plugin HEV.

2. Background and Analysis

2.1 Gear transmission error

The origin of the gear whine noise is the gear mesh, in which vibrations are excited, mainly due to the transmission error which is expressed as an angular deviation, or a linear deviation measured at the pitch point and calculated at successive positions of the pinion as it goes through the meshing cycle[4]. Figure 2 is the schematic of T.E. definition. The T.E. of a pair of gears can be expressed in terms of a linear discrepancy tangential to pitch circle.

$$TE = \theta_2 r_{b_2} - \theta_1 r_{b_1} \quad (1)$$

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 respectively denote the pinion and wheel.

For the loaded transmission error, it takes tooth bending deflection, shearing displacement and contact deformation into account. When gears are operated at low speed, two additional factors, like a constant component due to the mean tooth compliance and a time varying component which is the function of gear tooth geometry and torsional mesh stiffness variation, including the manufactured transmission error, contribute to the transmission error.

2.2 Gear tooth modification

In order to reduce the gear noise and vibration, micro-geometric modifications are currently implemented. It includes the intentional removal of material from portions of the tooth surface, so that the shape is no longer a perfect involute. Such modifications compensate teeth deflections under load, and the resulting transmission error is also minimized under a specific torque. Micro-geometric modifications can be applied on the involute and lead of gear teeth.

Lead modifications in the form of either lead crowning or end relief compensate for manufactured lead errors, shaft misalignments and deflections. This modification is expected to achieve a unique load along the tooth face width. In narrow face width spur gears, lead modification is usually not used, but from medium to wide face widths, it is needed in order to compensate for lead errors and misalignment.

In involute modifications, tip relief is applied to minimize tooth corner contact and dynamic excitation (T.E.). This modification can compensate for the tooth bending and some part of manufacturing errors, as well as the peak-to-peak transmission error (PPTE) which is directly related to the noise level. The simplest modification is a linear tip relief on both gears, or linear tip and root relief on one or both gears. Besides these, another modification is a parabolic tip relief which is not used in this paper. Compared to the linear relief, this modification has an advantage in that the pressure angle of the profile does not have an instant change at the start point of the modification[5].

3. Procedure of Analysis and Discussion

In this paper, a helical gear pair of HEV gearbox will be optimized to minimize noise excitation under the design torque. The gear pair was analyzed and compared by two software. One is that gear geometry data is input directly in Romaxdesigner, and another analysis data was obtained from the company. Figure 3 shows the transverse plane schematic of helical gears in mesh. And Table 1 is a summary of the specification of this spur gear pair. By using the data in Table 1, the transmission error

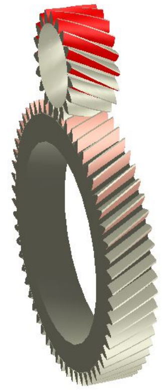

Fig. 3 Helical gear mesh in 3D dimension

Table 1 Helical gear pair specification

	Driving	Driven
Number of teeth	19	58
Module (mm)	1.81	
Pressure angle (deg.)	16.186	
Helix angle (deg.)	27.455	
Addendum mod. coeff.	0.9757	-0.097
Center distance (mm)	80	
Face width (mm)	20.5	19.5
Outside diameter (mm)	46.17	124.301
Root diameter (mm)	35.2	113.331
Standard pitch diameter (mm)	38.755	118.304
Transverse tooth thickness at SPD (mm)	4.359	3.089
Profile / face contact ratio	1.907	1.581
Total contact ratio	3.488	
Pinion speed (rpm)	3000	
Pinion torque (N-m)	195	

was calculated without any tooth modification and misalignment. Table 2 is the predicted data by two software, and Fig. 4 shows the predicted transmission error without gear modification and misalignment under the torque, and the PPTE is 1.7 um in Romax and another is 1.61 um. Although for the values of Max., Min. and Average, the predictions of Romax are higher than Co.'s, it is obtained that the difference of PPTE between these two software is tiny. And when gear mesh misalignment is considered

Table 2 The predicted data by two software (unit: um)

(u-m)	Max.	Min.	Average	PPTE
Romax	23.26	21.57	22.51	1.7
Co.	28.28	26.67	27.17	1.61

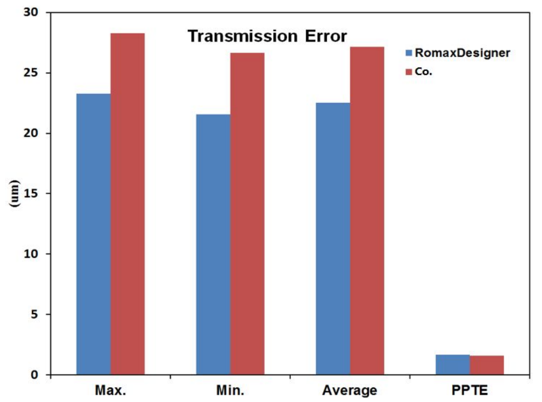

Fig. 4 Comparison of T.E. between two software without gear misalignment and micro-modification

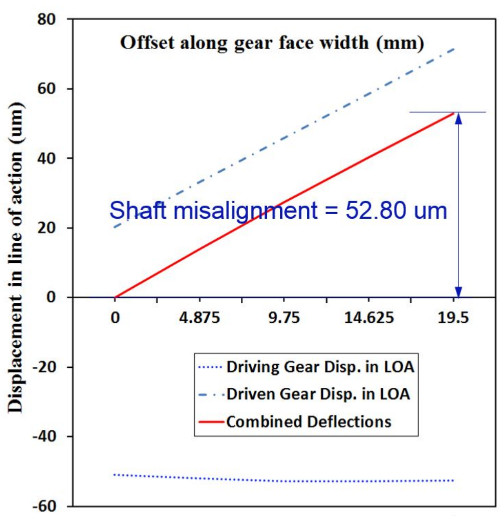

Fig. 5 Mesh misalignment for the helical gear pair

in this paper (Fig. 5), the combined defections between two gears is 52.80 um. After the simulation, Table 3 shows the predicted data by two software with gear mesh misalignment, but no tooth micro-

Table 3 The predicted data by two software (unit: um)

(u-m)	Max.	Min.	Average	PPTE
Romax	23.83	21.21	22.35	2.62
Co.	21.82	20.48	20.92	1.33

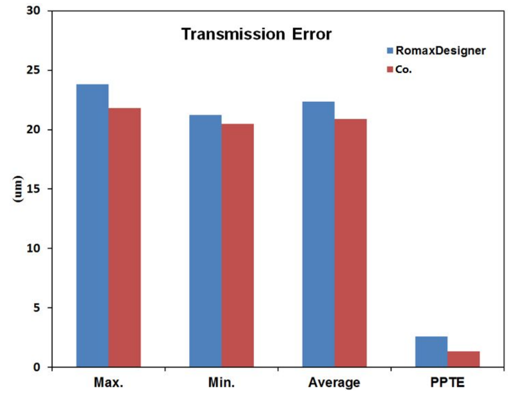

Fig. 6 Comparison of T.E. between two software with gear misalignment, no micro-modification

modification, and Fig. 6 shows the comparison of T.E. between two software with gear misalignment under the torque, and the PPTE is 2.62 um in Romax and another is 1.33 um. By comparing Fig. 4 and Fig. 6, it is obtained that the prediction of PPTE from Romax software is a little bit higher than Co.'s. It means the effect from the gear mesh misalignment in Romax is more clear than Co.'s.

The profile and lead modification are used to minimize the peak-to-peak transmission at this torque. Table 4 is the data of profile and lead modification for the driving and driven gears. After the simulation, Table 5 shows the predicted data by two software with gear mesh misalignment and tooth micro-modification, and Fig. 7 shows the comparison of T.E. between two software with gear misalignment and micro-modification under the torque, and the PPTE is 0.7 um in Romax and another is 1.75 um. Although for the values of Max., Min. and Average, the predictions of Romax are similar with Co.'s, it is obtained that the prediction of PPTE from Romax

Table 4 The data of profile and lead modification for the driving and driven gears

(unit: um)

	Driving gear	Driven gear
Involute barreling	5	5
Tip parabolic	35/34.28deg.	35/23.91deg.
Lead crown	10	10
Lead slope	15	15

Table 5 The predicted data by two software

(unit: um)

(u-m)	Max.	Min.	Average	PPTE
Romax	54.89	54.22	54.55	0.7
Co.	53.24	51.49	52.17	1.75

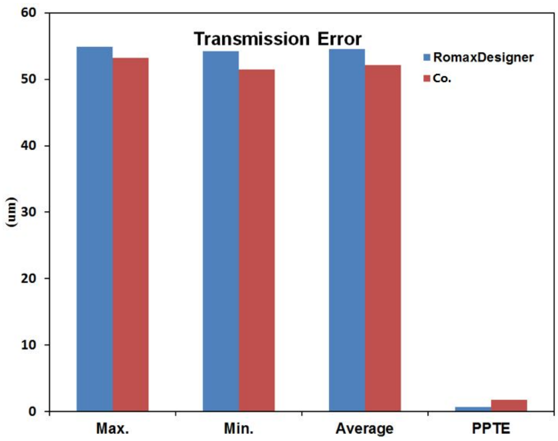

Fig. 7 Comparison of T.E. between two software with gear misalignment and micro-modification

software is lower than Co.'s. And it means the effect through gear micro- modification in Romax is more obvious than the software of Co's. And by comparing Fig. 6 and Fig. 7, it is observed that the peak-to-peak transmission error is reduced significantly from 2.62 um to 0.7 um in Romax, but in Co's, the value of PPTE is not reduced. Thus, by the comparison between two predictions, it is a good reference to understand the difference between these two software which would be helpful for the next simulation in gear design.

4. Conclusion

In this paper, the transmission of the gear pair of a plugin HEV was modeled and analyzed between Romax and the Co.'s. The first gear pair has been investigated through static analysis by two software. Thus, by the comparison between two predictions, it is a good reference to understand the difference between these two software which would be helpful for the next simulation in gear design.

ACKNOWLEDGMENT

This study was supported by the ATC Program of Ministry of Commerce and Energy (MOCIE) and many thanks for the help from Romax Technology Ltd & Mdesign S/W of Shanghai InfoMass Company.

REFERENCES

1. R. Hirsch, R. Bezdek, and R. Wendling, Peaking of World Oil Production: Impacts, Risks, and Mitigation, 2005.
2. D. R. Houser, J. Harianto and Y. Ueda, Determining the Source of Gear Whine Noise, Gear Solutions, 2004.
3. J. Harianto and D. R. Houser, “A Methodology for Obtaining Optimum Gear Tooth Microtopographies for Noise and Stress Minimization over A Broad Operating Torque Range,” ASME, DETC2007-34655, 2007.
4. D. B. Welbourn, “Fundamental Knowledge of Gear noise - A Survey,” Proc. Noise & Vib. Of Eng. And Trans., IMech E., Cranfield, Uk, pp. 9-14, 1979.
5. H. Sigg, “Profile and Longitudinal Corrections on Involute Gears,” AGMA Paper 109.16, 1965.