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Study of the Transmission Error Prediction of a Five-speed Manual Transmission System

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5속 수동 트랜스미션의 전달오차 예측에 관한 연구

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ABSTRACT

For the manual transmission gearbox used in the automotive industry, gear meshing transmission error is the main source of noise known as gear whine, and radiated gear whine noise plays an important role in the whole gearbox. Therefore, in order to keep competitive in the automotive market, the NVH performance of transmission gearboxes is increasingly important for automotive manufacturers when a new product is developed. In this paper, in order to achieve an optimized tooth contact pattern, gear tooth modification is applied to make up for the deformation of the teeth owing to load. A five-speed MT gearbox is firstly modeled in RomaxDesign software and the prediction of transmission error under the loaded torques is studied and compared. From the simulation, the transmission error and maximum contact stress are also simulated and compared after tooth modification of the loaded torques. Finally, the simulation results are used to optimize the whole gearbox design and the final gearbox prototype is testified to obtain NVH performance in a semi-anechoic room.

Key Words : Manual Transmission(수동 변속기), Tooth Modification(치형 수정), NVH(소음 진동)

1. Introduction

For the Manual Transmission (M.T.) gearbox used in automotive, gear meshing transmission error (T. E.) is the main source which causes the noise known as gear whine, and radiated gear whine noise plays an important role in the whole gearbox. So, in order to keep competitive in automotive market, NVH performance of transmission gearbox is more and more important for automotive manufacturers while a new product is developed.

For gear transmission, if the gear shapes are perfect, then the 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 have been considered as possible excitations of gear whine

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noise.[1-6] All of these factors, the transmission error plays the main role of gear whine which is affected by the load.

In this paper, in order to achieve an optimized tooth contact pattern, gear tooth modification is applied to make up for the deformation of the teeth due to load. A five speed MT gearbox is firstly modeled in RomaxDesign software and the prediction of transmission error under the loaded torques is also studied and compared. From the simulation, the transmission error and maximum contact stress are also simulated and compared after tooth modification of the loaded torques. At last, the simulation results are used to optimize the whole gearbox design, and the final gearbox prototype is testified to obtain NVH performance in semi-anechoic room. Fig. 1 is the transmission model of the manual transmission.

2. Background and Analysis

2.1 Gear Transmission Error

If a pair of perfect gears is meshed under zero load, the mathematics of involute geometry dictate that the driven gear follows exactly the rotation of the driving gear in proportion to the gear ratio. However in practice because there are errors in the profiles, (deliberate in the case of profile relief), the driven gear is often momentarily ahead or behind its theoretical position. This rotational difference is termed transmission error(T.E.).

And the transmission error is expressed as a linear value measured at the base radius. This eliminates the need to specify on which gear it is measured as is the case with angular measurements.

$$TE = \theta_2 r_{b_2} - \theta_1 r_{b_1} \tag{1}$$

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.

Transmission error is of very interest and troublesome because many researchers believe it is the excitation that leads to the tonal noise known as gear whine. This is a noise experienced by the driver and passengers which occurs at the tooth passing frequency and the harmonics of the driving gears within the gearbox. And Fig. 3 is the schematic of gear noise transmission path. Transmission error can be broken down into static transmission error and dynamic transmission error. Transmission error measurements made at very low speeds are termed “static”, while those made at relatively high speeds are called “dynamic”.

Static transmission error indicates the effects due to manufacturing errors and static loading effects, whereas dynamic transmission error also indicates the effects due to the dynamic characteristics of the gear drive system. This investigation is entirely concerned with static transmission error.

2.2 Gear Micro-Modification

Micro-geometry modifications can be applied on the lead and involute of the gear tooth. These two modifications and micro-geometry parameters are discussed in this section. The lead modifications sign convention and parameters used in RomaxDesigner are shown in Fig.4. Romax would normally

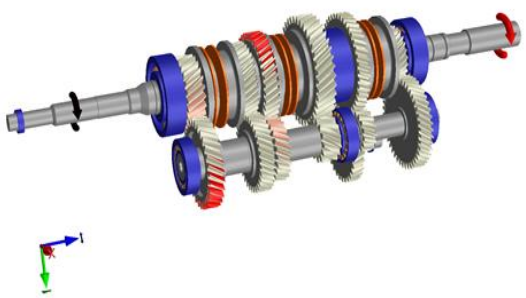

Fig. 1 The schematic model of the five speed M.T.

recommend that the lead modification evaluation limits (start of top and bottom edge relief) are at a distance of 0.15F from the edges of the gear face width.

F - Face Width

EDR1, EDR2 - Start of Edge Relief

C - Defined as the distance between the gear profile curve and slope between top and bottom diameters (EDR1 and EDR2)

S - Distance between modification at top and bottom start of edge relief

K1, K2 - From edge relief end to where slope between start of top and bottom edge relief

SAP	Start of Active Profile
RR	Root Relief
RMD	Root Measurement Diameter
EAP	End of Active Profile
TR	Tip Relief
TMD	Tip Measurement Diameter

Besides, RomaxDesigner software provides an adaptable method of reporting the measurements for the involute modifications. In the involute definition page, there are two distances you can set called measurement diameters. When set the bottom of the report will display additional measurements relative to these two diameters (Fig. 5).

Thus, the optimized gear micro-modification values for the gear pairs are based on experience or some suggestions from Sigg.[7] Besides, the conventional

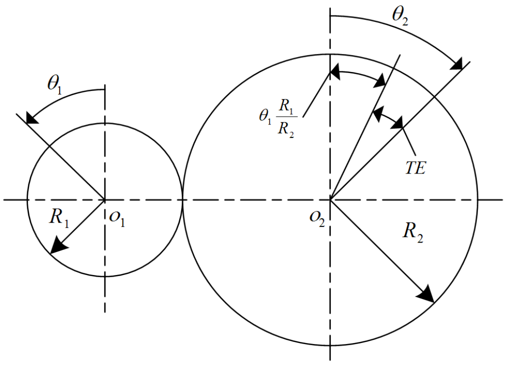

Fig. 2 The definition of transmission error

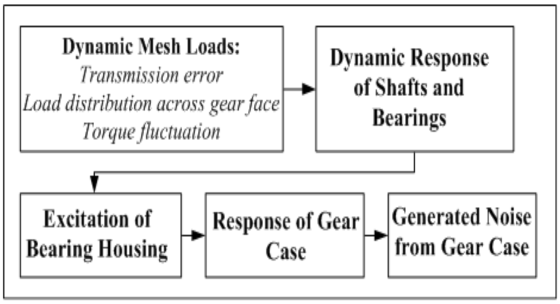

Fig. 3 Transmission path of gear noise

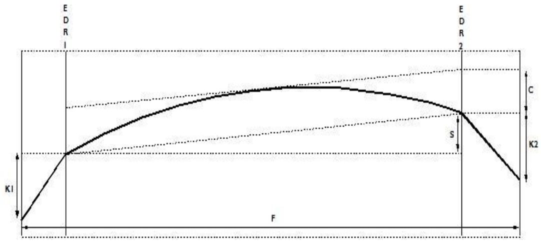

Fig. 4 Lead Modification

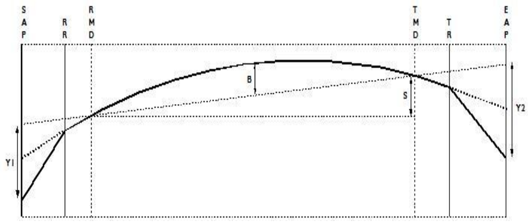

Fig. 5 Involute Modification

amount of tip relief is as given in the standards, such as British Standard (BS1970) and ISO (ISO/DIS1983), the maximum amount of relief and the length of relief. The standard tip relief limitation can be chosen as the reference values to calculate the actual modification amount, there are no precise recommendations for applying the modifications in all these standards. Other two profile modifications (crowning profile modification and slope profile modification) are not discussed in detail in this paper.

Lead modification in the formation of lead crowning or end relief compensate for lead errors,

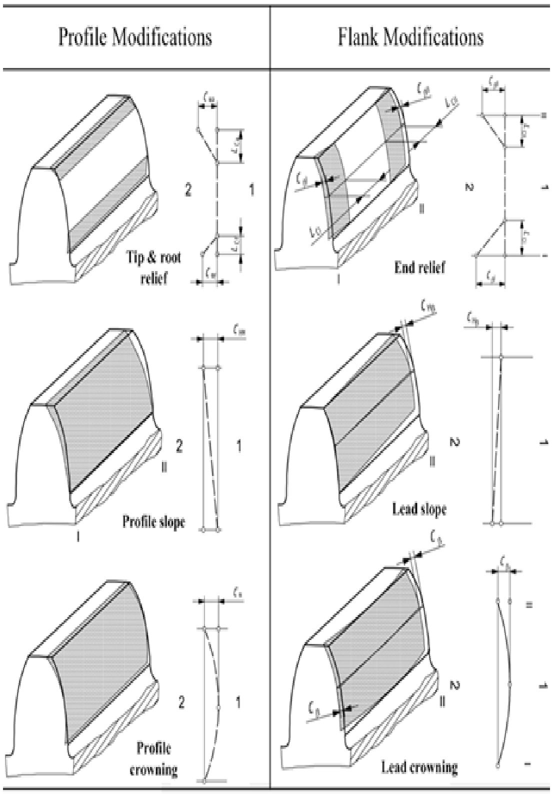

Fig. 6 Typical gear modification methods

misalignments and deflections. Lead modification was expected to provide a unique load along the tooth width. In narrow face width spur gears, the lead modification usage is not common, but from medium to wide face widths, it is needed in order to compensate for lead errors and misalignment. And Fig. 6 shows the typical gear modification methods which contains profile and flank modifications.

3. Procedure of Analysis and Discussion

In this paper, two helical gear pairs of the gearbox will be studied to optimize noise excitation under the loaded torque. One is the second speed drive, and the other one is constant mesh gear pair. The gear pairs were analyzed and compared by the Romax

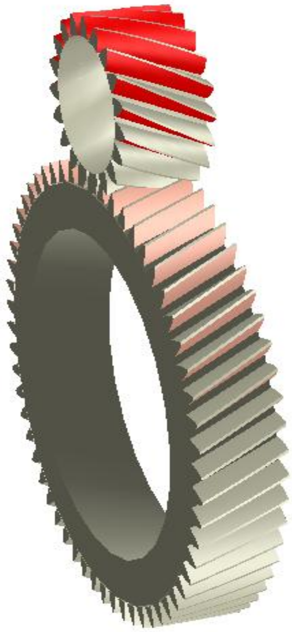

Fig. 7 Helical gear mesh in 3D dimension

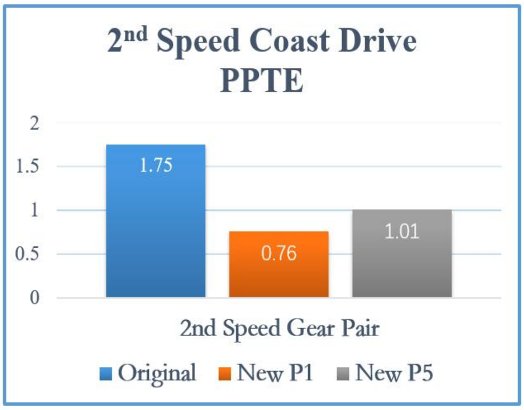

Fig. 8 Comparison of T.E. between the original modification and two new modifications

Designer software.

Fig. 7 shows the transverse plane of the meshing helical gear pair. By using the data from the production which weren't shown in details in this paper, the transmission errors were calculated with original tooth modification and two new

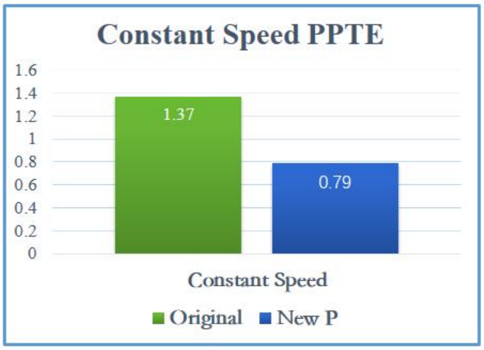

Fig. 9 Comparison of T.E. between the original modification and new modifications in constant speed

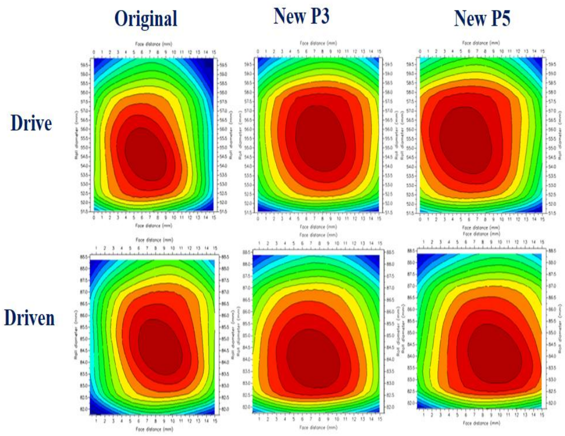

Fig. 10 Contact pattern for the helical gear pair of the 2nd speed gear pair

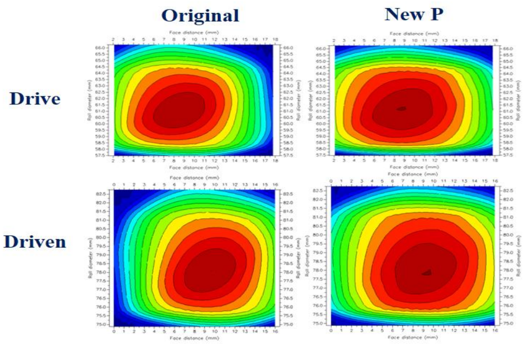

Fig. 11 Contact pattern for the helical gear pair of the constant speed gear pair

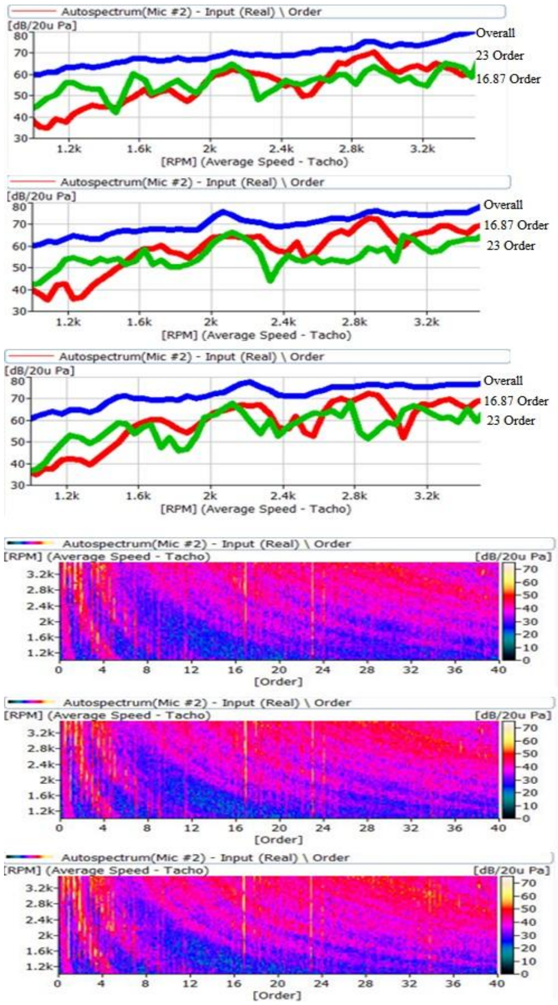

Fig. 12 NVH testing in semi-anechoic room

modifications. And the input torque: 102.9 Nm, the input speed: 3500 rpm, and the model was with misalignment which was calculated from the software. In Fig. 8, for the manual transmission. gearbox with misalignment under the torque, in 2nd speed gear pair, the P.P.T.E. of original proposal is 1.75 um in Romax Designer software, but for New P1, the P.P.T.E. is 0.76 um and New P5, the P.P.T.E. is 1.01 um. Thus, the P1 is the best among these three proposals. For constant speed in Fig. 10, the P.P.T.E. of which is better that the original proposal.

And the contact pattern for the helical gear pair of the 2nd original is 1.37 um, and the new proposal is 0.79 um speed gear pair is shown in Fig. 10, Fig. 11 is the contact pattern for the helical gear pair of the constant speed gear pair. All of these simulation results will be good references for the gear design before the NVH testing (Fig. 12). Thus, by the comparison between two predictions, software simulation is a good tool to understand the difference between original design and new proposals, which would be helpful for the NVH testing in gear design.

4. Conclusion

In this paper, the transmission of the gear pairs of a five-speed manual transmission. was modeled and analyzed in Romax Designer software. The gear pairs have been investigated through static analysis by the software. Thus, by the comparison between original design and new proposals, it is a good reference to understand the difference among these proposals which would be helpful for the next testing in gearbox design.

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