한국기계가공학회지, 제16권, 제5호, pp.1～6(2017.10) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 16, No. 5, pp.1~6(2017.10) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2017.16.5.001

# Study on Tooth Micro-geometry Optimization of Rear Gear Set in 2 Speed Planetary Gear Reducer

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# 2단 유성기어 감속기의 후부기어 치형수정에 관한 연구

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(Received 6 March 2017; received in revised form 11 March 2017; accepted 14 March 2017)

## ABSTRACT

Gear tooth micro-geometry modifications include the intentional removal of material from the gear teeth flanks, so that the shape is no longer a perfect involute. If the gear shapes are perfect, then the gear tooth meshing is better, therefore the gears will transmit input torque in a more efficient manner without the generation of high frequency engine fluctuation noise. In this paper, we study tooth micro-geometry optimization of rear gear set in 2 speed planetary gear reducers. Analysis revealed problems which are need of modification. Based on the results, tooth micro-geometry was used to deal with load distributions on the rear gear set.

**Key Words :** Gear Transmission System(기어트랜스미션 시스템), Planetary Gear Reducer(유성기어 감속기), Micro-geometry Optimization(마이크로 치형 최적화), Load Distributions(하중분포)

## 1. Introduction

The driving speed reducer is an important power transmission device which is applied to many types of equipment which require caterpillar track systems, such as construction excavators, tunnel excavators, agricultural excavators, crushers for construction, removable crushers, construction cranes.

The planetary gear reducer significantly reduces the ratio with a sample structure used in automobiles, ships and construction industries. However, because of the difficulty in designing gears and in maintaining quality after assembling the tooth surface, damage caused by the load distribution and production arrow technologies have encouraged speed reducer manufacturers.

Low-priced driving speed reducers are produced domestically, but high-quality driving speed reducers used for devices that require high reliability are dependent on

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imports. Therefore research on this is needed.

Recently, researchers are attempting to minimize the noise and vibration of the speed reducers which are used in high precision industrial machinery.[1-6] Especially since the transmission errors are the leading cause of gear-noise-vibration, it takes the time to measure transmission error accurately. It is necessary to repeat the experiment while gradually changing the gear tooth profile to find the point where the transmission errors are minimized to optimize the tooth file. In fact, the optimization work through production is very inefficient regarding time and cost. Therefore the simulation of gear modeling to optimize the micro-geometry may reduce gear tooth design time and cost.[7-10]

In this research, to optimize the tooth form of the rear gear of the 2-stage planetary gear reducer, we studied the rear gear of the 2-ton class planetary gear driving speed reducer. Through 3D modeling and the 2-ton class planetary gear driving speed reducer simulation, modifying the tooth profile of the rear gear optimizes the load distribution and minimizes transmission errors. We also studied the optimization methods of the tooth profile of the 2-stage planetary gear reducer rear gear which can reduce driving errors in production.

## 2. Modeling of 2-stage Planetary Gear Reducer

The 2-stage planetary gear reducer gear system and case were analyzed and designed based on the design specifications as shown in Table 1. The structure of the 2-stage planetary gear reducer is as shown in Fig. 1, the input of front parts is a drive (sun gear) gear, the output is a carrier (holder), the input of the rear part is sun gear, and the output is ring gear.

The drive sequence is Drive gear → Rear planetary gear → Carrier (holder) → Sun gear → Front planetary gear → Ring gear.

As a result, the input is the drive gear; the ring gear powers the output. Table 2 shows the details of the planetary gears. As shown in the Fig. 1, the gear system of this reduction gear consists of two-stage planetary gears. In this paper, we optimized rear gear set.

## 3. Results and Discussion before Tooth Profile Modification

The tooth profile of the 2-stage planetary gear reducer was designed on the involute tooth profile, and the boundary condition was set based on this. After modeling and analysis, obtained results such as life vs. load distribution, life vs. the damage rate of gears and bearings of gear reducer.

Fig. 2 and Fig. 3 shows the analysis results of stress distribution of the gear teeth of each planetary gear and sun gear at the rear part of the 2-stage planetary gear reducer. These results show that the load received by the tooth surface is concentrated at the tip of the tooth. Accordingly, it is necessary to move the distribution of the burden to the middle of the gear tooth surface via tooth profile modification. These stress concentrations may cause gear damage on the tooth surface due to the gear stress exceeding the yield stress. Fig. 4 shows the load distribution of the three-dimensional situation. Gear tooth profile modifications can solve these problems by optimizing the gear tooth micro-geometry shape.

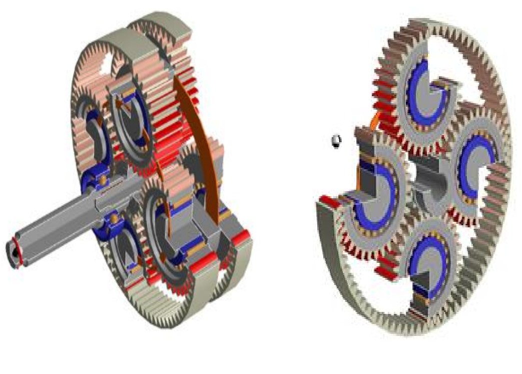


**Fig. 1 Structure of gear system modeled & Separated rear gear set**

**Table 1 Specifications of 2 ton planetary gear drive reducer**

| Parameter | Dimension |
|---|---|
| Max output torque | 5390 Nm |
| Max total displacement | 1992 cm3/rev |
| Max motor displacement | 33.8 cm3/rev |
| Gear ratio | 53 |
| Max speed | 60 rpm |
| Max shaft speed | 3300 rpm |
| Speed ratio | 2 |
| Max flow | 60 L/min |
| Max pressure | 27.5 MPa |
| Brake torque | 49 Nm |

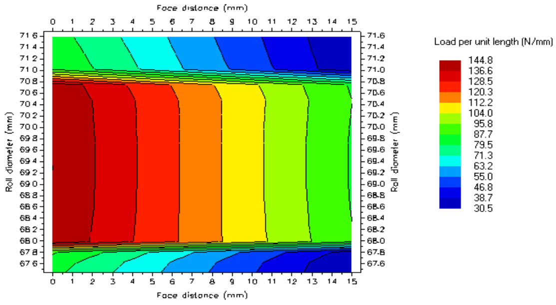
**Table 2 Specifications of planetary gear of 2ton drive reducer**

| Parameter | | Sun | Planet | Ring |
|---|---|---|---|---|
| Front Set | Tooth No. | 16 | 32 | 80 |
| | Width | 24 mm | 24 mm | 24 mm |
| | Module | 2 | | |
| | Pressure angle | 20° | | |
| | Displacement factor | -0.1 | -0.05 | 0.05 |
| | Gear ratio | 6 | | |
| Rear set | Tooth No. | 10 | 35 | 80 |
| | Width | 16 mm | 16 mm | 16 mm |
| | Module | 2 | | |
| | Pressure angle | 20° | | |
| | Displacement factor | 0.05 | -0.05 | 0.05 |
| | Gear ratio | 9 | | |
| Total gear ratio | | 53 | | |

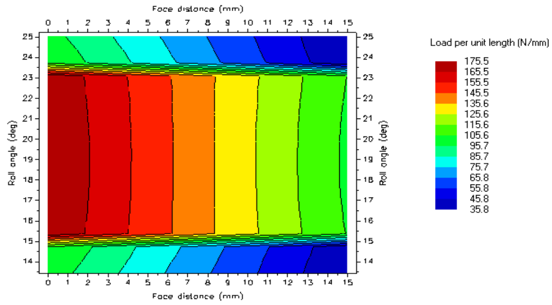
## 4. Analysis Results and Discussion after Tooth Profile Modification

According to the analysis, the front section shows the load concentration phenomenon of the gear teeth surface and the damage rate of the gear and bearing become high.

A way to solve these problems is micro gear geometry, a way to optimize the gear tooth profile. We used the Romax designer to modify the profile and gear lead and repeated the simulation to find the optimal gear modification.

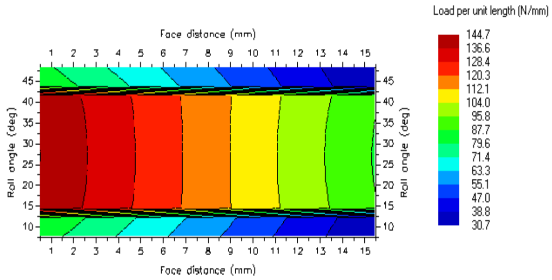



a) Planetary gear No. 1

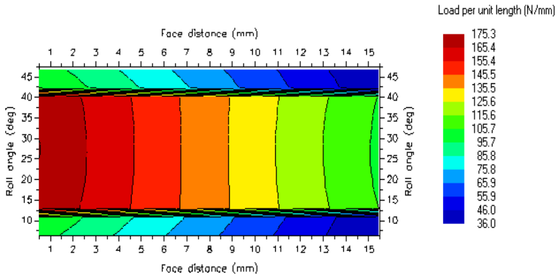



b) Planetary gear No. 2

**Fig. 2 Planetary gear load distribution of rear gear set**

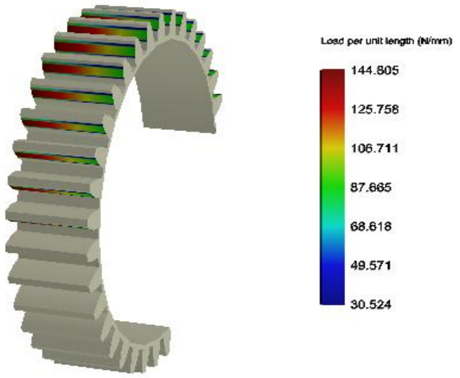



a) Sun gear No. 1

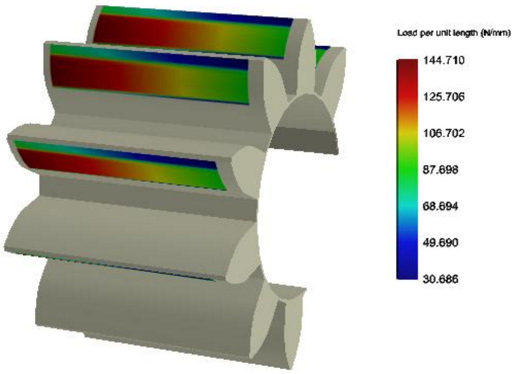



b) Sun gear No. 2

**Fig. 3 Sun gear load distribution of rear gear set**




a) Planetary gear




b) Sun gear

**Fig. 4 Gear load distribution of rear gear set (3D situation)**

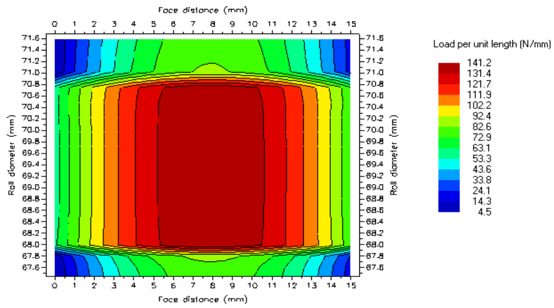
The profiles and lead values before modifying the gear are all set to 0. The modified value of optimization was adjusted to ensure there is no stress at the end of the gear. We also reduced the shocks occurring due to rapid stress changes between the one or two contact parts. As these shocks decrease, the vibration is expected to decrease as well, additionally, it is possible to extend the life of the gear and the bearing and to reduce the damage rate.

In this paper, we optimized the tooth profile by modification and repeated simulation. The profiles and lead values before modifying the gear are all set to 0. We adjusted the modified value of optimization. In these optimization processes, profiles and leads were randomly specified first, and iterative analysis was performed until an optimum result was obtained. Table 3 shows the results of tooth profile modification.

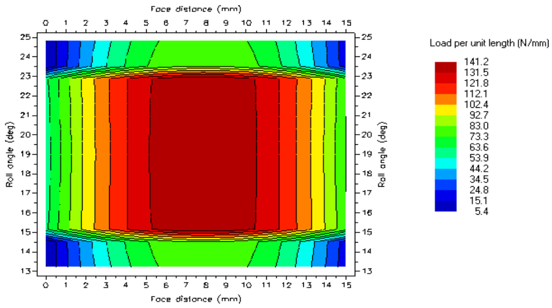
Fig. 5 and Fig. 6 shows the gear tooth surface stress distribution results of each planetary gear and sun gear in the rear gear set of the gear reducer after optimization.

**Table 3 Tooth modification detailed results**

| Parameter | | Rear (Planet) | Rear (Sun) |
|---|---|---|---|
| Before modification (㎛) | Lead crown | 0 | 0 |
| | Lead slope | 0 | 0 |
| After modification (㎛) | Lead crown | -20.00 | 28.00 |
| | Lead slope | 0 | 0 |

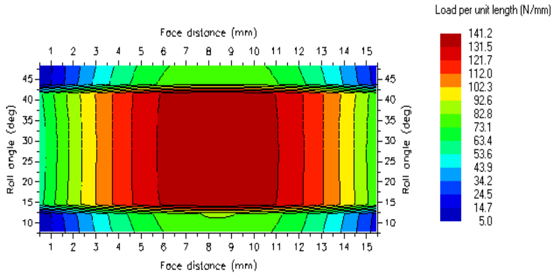



a) Planetary gear No. 1

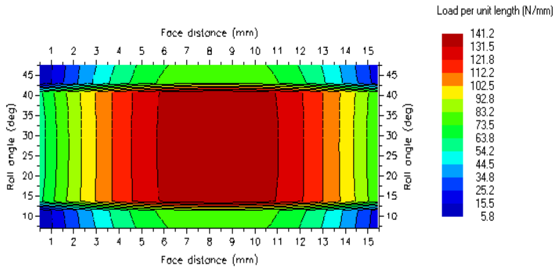



b) Planetary gear No. 2

**Fig. 5 Load distribution optimization of planetary gear in rear gear set**

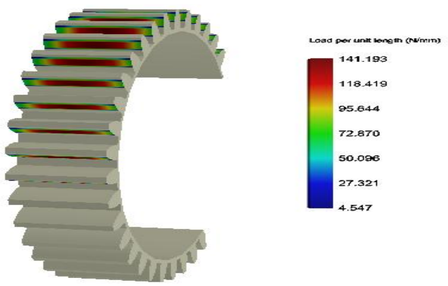



a) Sun gear No. 1

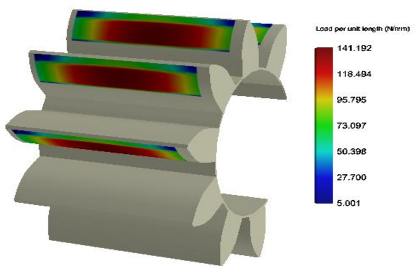



b) Sun gear No. 2

**Fig. 6 Load distribution optimization of sun gear in rear gear set**




a) Planetary gear




b) Sun gear

**Fig. 7 Load distribution optimization of gears in rear gear set (3D situation)**

As shown in the fig. 2 and fig. 3, before the tooth modification, the load received by the tooth surface is concentrated at the tip of the tooth, on the other hand, as shown in fig. 5 and fig. 6, after the tooth profile optimization, the load is concentrated in the center of the tooth, and the maximum load is lower than before optimization. Before optimization, the maximum load appeared at 144.8 ~ 175.5 N/mm for planetary gears and 144.7 ~ 175.3 N / mm for sun gears. After optimization, the maximum load appeared at 141.2 N/mm for planetary gears and 141.2 N/mm for sun gears.

Fig. 7 shows the load distribution at 3-dimensional situation after the optimization. Also, a graph of the compare results before and after optimizations is shown in Fig. 8 and Fig. 9.

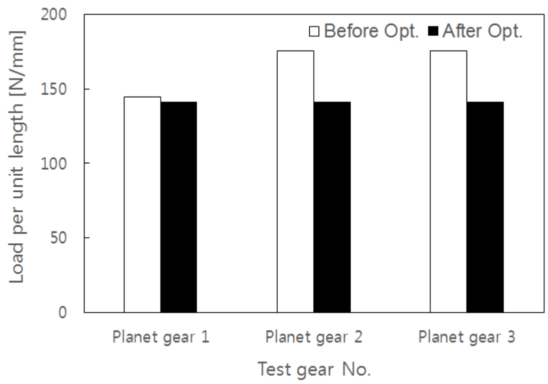



**Fig. 8 Optimization result of rear planet gear**

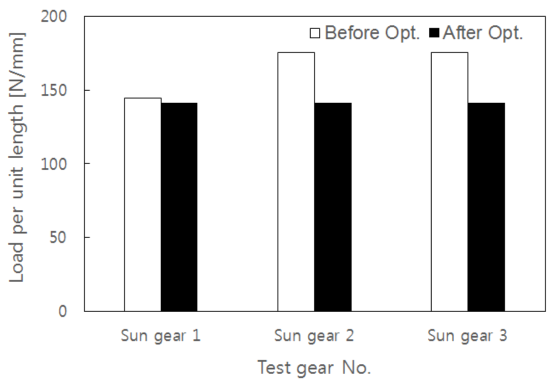



**Fig. 9 Optimization result of rear sun gear**

## 5. Conclusion

In this research, the optimization of gear tooth geometry of rear gear set of a 2-stage planetary gear reducer was studied, and came the following concluding observations.

1. Optimization of the rear gear tooth shape, the profile, and lead of the gear was modified and repeatedly simulated to obtain the optimal gear modified value.
2. Before the tooth modification, the load received by the tooth surface is concentrated at the tip of the tooth, and after the tooth profile optimization, the load is concentrated in the center of the tooth.
3. Through the optimization, the tooth profile, the maximum load of the rear planetary gears decreased from 144.6~175.5 to 141.2 N /mm.
4. Through the optimization the tooth profile, the maximum load of the rear sun gears decreased from 144.7~175.3 to 141.2 N/mm.

## Acknowledgment

This work (Grants No. C0490134) was supported by Business for R&D funded Korea Small and Medium Business Administration in 2017 & Romax Designer of Romax Technology.

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