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A Study on Optimum Design of Worm Gear Reducer Output Pinion

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웜기어 감속기 출력 피니언의 최적설계에 관한 연구

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ABSTRACT

Reducer is a device to transmit and change torque and speed from drive shaft to driven shaft with excellent transmission efficiency, and it is widely used in many areas today. Reduction gear consists of two axes, gear, bearing supporting axes, and housing. The simplest method to transmit rotation or power to multiple axes is to attach circular plates to two axes and contact each other. However, in this case, if increasing number of rotations or if contact pressure is small, because of slipping, it cannot transmit power. For problems for the current reducer case, it is heavy and its assembling and repair is difficult. In addition, there are few studies about manufacturing and performance testing of worm gear reducer, causing lack of the foundation to improve the product competition and the performance.

Key Words : Swing Reducer(스윙감속기), Worm Gear(웜기어), Transmission Efficiency(전달효율), Optimum Design(최적설계)

1. Introduction

Worm reducers are often used for devices requiring swing exercises such as aerial work vehicles, elevators, various large propeller drives, industrial precision transmission equipment, various defense industrial machines, cutting machines, control transmissions, etc. A large reduction gear ratio can be obtained through one pair of gears. Comparing with other gears, it is possible to prevent reverse rotation with less noise and vibration cause its sliding motion, so much research was being studied.[1~5] Worm reducers are widely used in devices which need transmit power reliably with an accurate ratio. However, since the output pinion used for the worm gear is generally integrated with the shaft, the material cost and the processing cost is increased and the productivity is lowered. The contact of the output pinion includes not only the rolling contact but also the sliding contact, the transmission energy will be lost due to the frictional force under the sliding contact.[6,7] Wear and breakage phenomena often appears in the output pinion, which will affect the overall transmission efficiency of the

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speed reducer.[8,9] Many researches about gears have been carried out, but there are not many studies for output pinion of worm gear reducers.

This paper presents a manufacturing method to improve the durability of the pinion, and a effective way through the optimum design, tooth profile modification, structural analysis, performance evaluation to optimize the modulus, pressure angle, number of teeth of output pinion used for high precision worm gear swing reducer.

2. Optimum design of pinion

2.1 Modeling of Pinion

The pinion of the existing worm reducer uses a general spur gear. As shown in Fig. 1, many problems such as pinion wear, breakage and heat generation occurs in the worm gear reducer.[8]

Therefore, in this paper, in order to increase the abrasion resistance and to reduce the cost, we designed the forging mold and material by using the CATIA program as shown in Fig. 2. For application of the forging method, DEFORM was used to perform the forming analysis of the material. Then based on the characteristics analysis results of the output pinion and worm gear, the gear was designed by CAD / CAM. The basic specifications such as module, pressure angle, number of teeth of worm gear and pinion was designed by CAD, and then designed the tooth profile.

In consideration of the efficiency and productivity of the pinion, the high strength gear steel SCM420H was chosen as the pinion material. And to optimize the tooth shape, tooth form of gear's top part was modified.

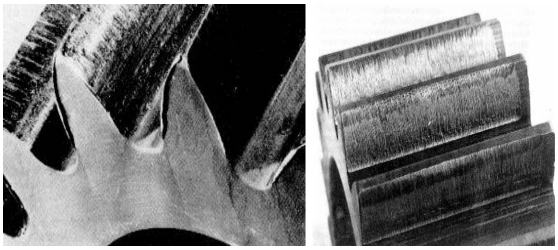
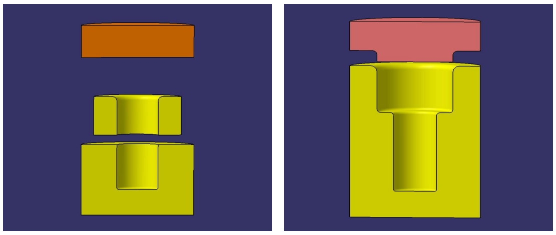
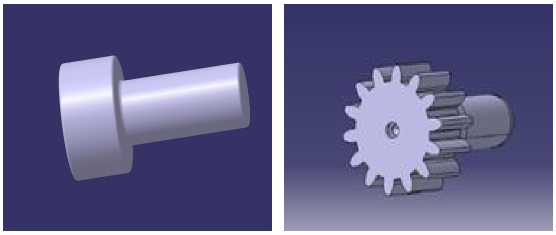


Fig. 1 Problem of pinion parts



(a) 1st mold (b) 2nd mold

Fig. 2 Forging analysis for pinion production



(a) 1st forging (b) Machining of pinion

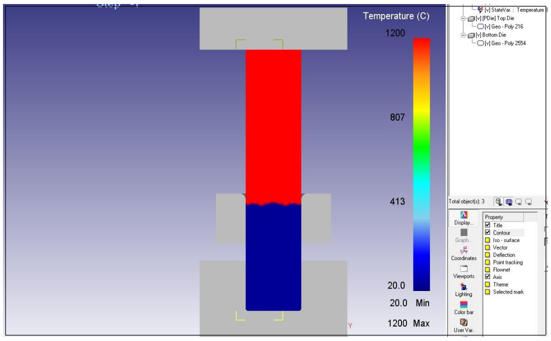
Fig. 3 3D modeling of pinion

The optimum tooth profile correction value was obtained via the gear analysis program Romax designer. Fig. 3 shows the three-dimensional model of the pinion which was modeled by CATIA V5.

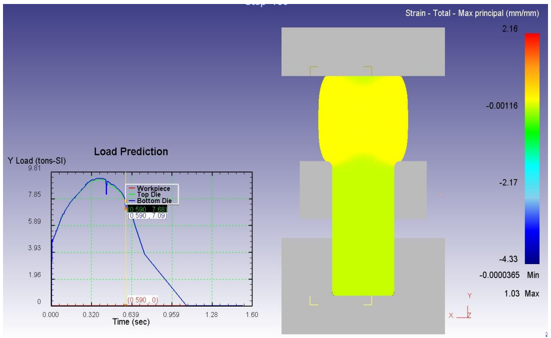
2.2 Analysis of Pinion

In this paper, the high strength gear steel SCM 420H was designed in three processes including 2 steps of forging process and 1 step of machining to reduce manufacturing cost and improve the productivity. 2 steps of forging processes were analyzed by DEFORM 3D, the forming analysis result is shown in Fig. 4. In order to improve deformation, the ductility and the brittleness of the material, only the gear shape portion was locally heated while the forming analysis was carried out. As a result, the load was 39 Ton in the first forming step, the maximum strain was 2.16 mm/mm, and the maximum stress was 99.1 MPa.

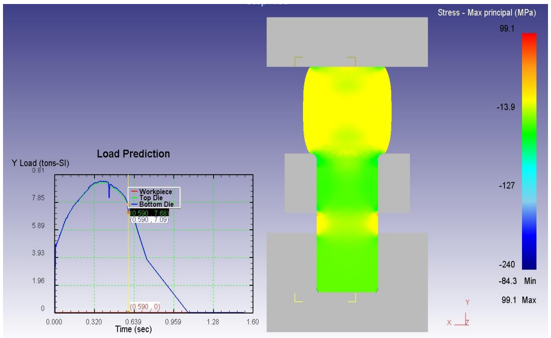
In the second forming step, the maximum load was 315.6 Ton, maximum strain was 1.04 mm/mm, maximum stress was 389 MPa. Wear and breakage of the output pinion occurred mostly in the end of tooth, and the maximum



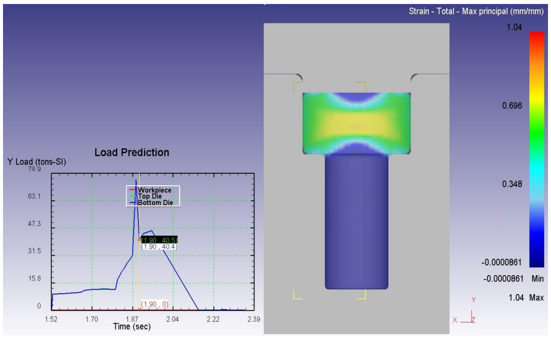
(a) Material set of pinion forging



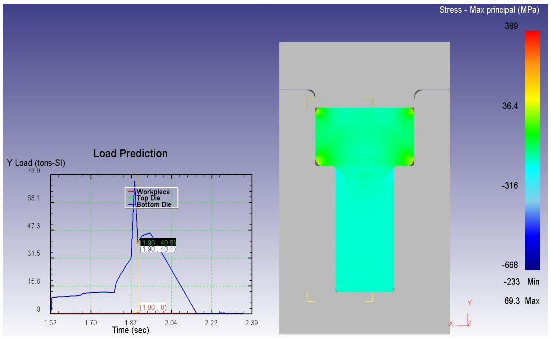
(b) Strain of pinion 1st forging



(c) Stress of pinion 1st forging



(d) Strain of pinion 2nd forging



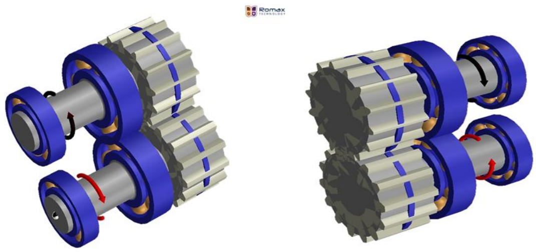
(e) Stress of pinion 2nd forging

Fig. 4 Forging analysis for pinion production

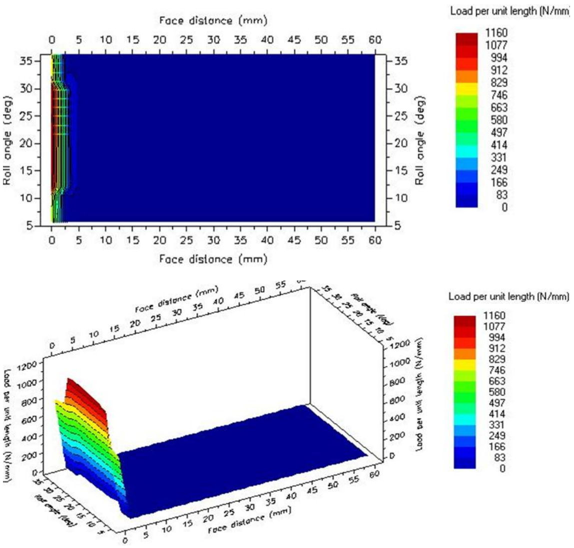
load of tooth profile analysis was appeared in the end part of tooth by using the analysis program Romax Designer. In order to improve this and optimize the gear strength, the modification value of lead and profile was obtained after repeated analysis.

It was confirmed that the load distribution before optimization was concentrated in the end of tooth, but after optimization the maximum load was distributed in the center of tooth. This indicates that in the case of the optimized pinion, the transmission error of the contact boundary surface was effectively improved. The tip of output pinion in this paper was modified as Ca.

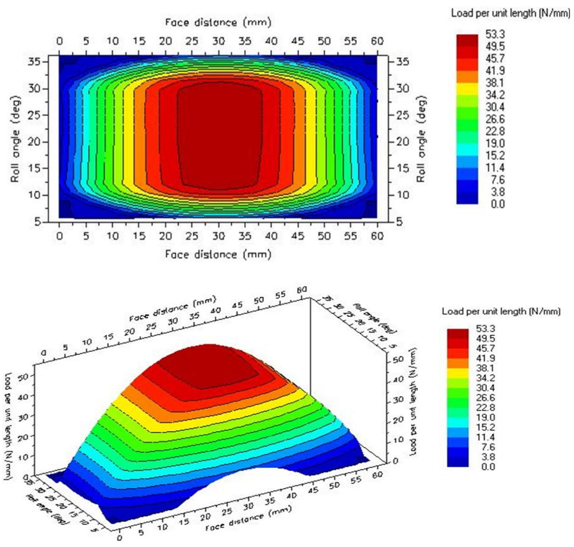
As the tooth profile Ca increases, the maximum deformation increases continuously, the optimal tooth profile can be confirmed as Ca = 1.5 mm. As a result of optimization, the maximum stress before modification was 1,160 N/mm in the end of tooth and the maximum stress was 53.3 N/mm in the center part of tooth after the optimization as shown in Fig. 5 and Fig. 6.



(a) 3D Modeling of pinion set

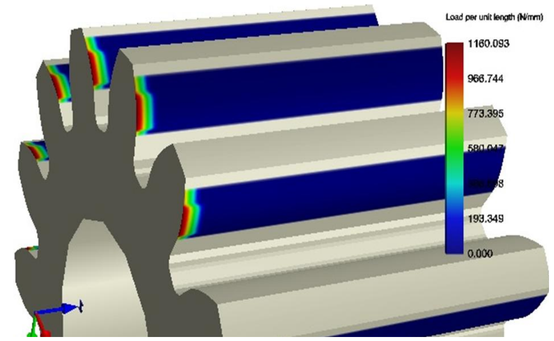


(b) Before modification

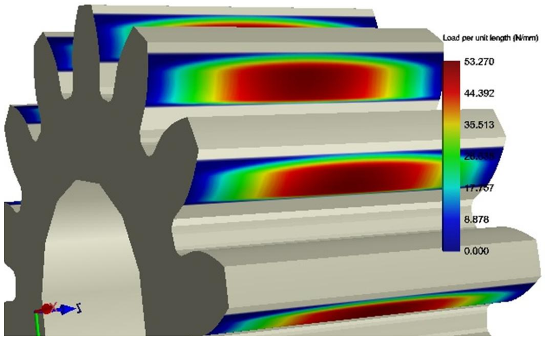


(c) After modification

Fig. 5 Analysis results of optimized pinion



(a) Before modification



(b) After modification

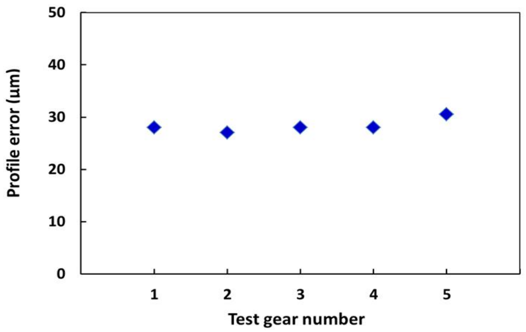
Fig. 6 Analysis results of optimized pinion

3. Evaluation of Performance test

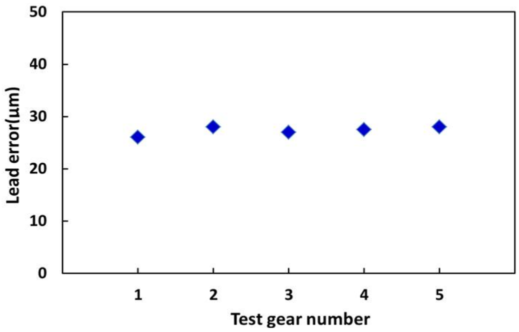
In order to evaluate the output pinion performance of the worm gear reducer manufactured based on the optimum design, the accuracy and hardness of the pinion were measured.

The precision of the pinion was measured by a gear measuring instrument (Manufacturer: KAL ZEISS, Model: UMM 850), the data of the test gear was measured with m(module) = 7 mm, z(number of teeth) = 14, D(pitch one diameter) = 98 mm, b(tooth width) = 60 mm.

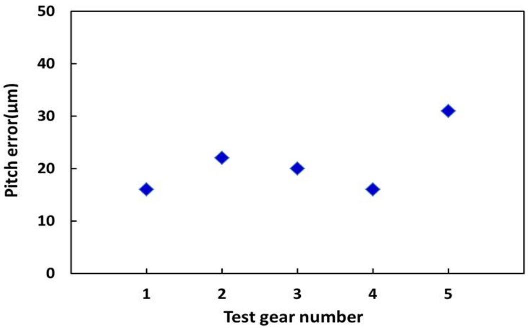
Using the tooth profile measuring device, and made the center of rotation of the gear as the measurement reference, measured the left and right tooth surfaces of 1, 4, 7, and 10th tooth. The results are shown in Table 1 and Fig. 7. As a result of the performance evaluation, the accuracy of the pinion was measured at the 3rd grade which was improved a grade than the 4th grade before optimization. Hardness was measured as HRC 63.3 as a result of carburizing heat treatment after shaping the tooth profile after forming the shape in the forging process of the output pinion gear, and the result is shown in Table 2 and Fig. 8.



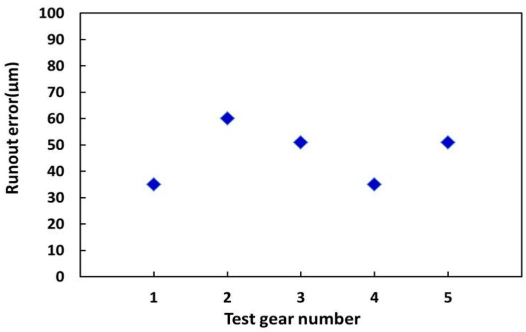
(a) Profile error



(b) Lead error



(c) Pitch error



(d) Runout error

Fig. 7 Gear precision measurement result of pinion

Table 1 Result of pinion test

Measure item	Unit	Result of test (Average)
Gear Profile	μm	29.75
Gear Lead	μm	28.10
Gear Pitch	μm	19.90
Gear Runout	μm	46.40

Table 2 Surface hardness of test gear

No.	1	2	3	4	5	Mean
Hardness before OP	60.7	61.0	61.4	61.1	60.9	61.02
Hardness after OP	63.5	63.2	63.5	63.0	63.7	63.38

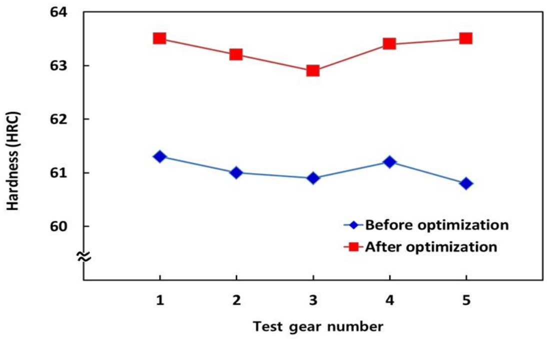


Fig. 8 Hardness of test pinion

4. Conclusions

In this paper, in order to optimally design the output pinion of high precision worm swing reduction gear used for special vehicles, design and manufacture an optimum output pinion while taking account of wear, breakage, and transmission errors occurring at the existing output pinion. As a result of performance test evaluation, the following conclusions were obtained.

1. The profile error of the test gear was 29.75 µm on average, the average error of the lead was 28.10 µm, the average pitch error was 19.9 µm, and the average runout error was 46.4 µm.

2. The result of hardness measurement showed HRC 61 in Shaft part and HRC 63.3 in tooth profile part.
3. The molding analysis revealed the 1st step forming load of 39 Ton, the maximum strain of 2.16 mm/mm, the maximum stress of 99.1 MPa; the 2nd step forming maximum load of 315.6 Ton, the maximum strain of 1.04 mm / mm and the maximum stress of 389 MPa.
4. The maximum stress of analysis result before gear optimum design was 1,160 N/mm, and the maximum stress after optimization was 53.3 N/mm.

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