한국기계가공학회지, 제19권, 제1호, pp.108～113(2020.01) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 19, No. 1, pp.108~113(2020.01) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2020.19.01.108

Optimization and Analysis of Output Pinion Design for Worm Gear Reducer

Seonghyun Cho*, Hyeonkyeong Kim*, Dongseon Kim*, Qin Zhen*, Sung-Ki Lyu*,#
*School of Mechanical & Aerospace Engineering(ReCAPT), Gyeongsang Nati. Univ.

워엄기어 감속기의 출력피니언 최적설계와 해석

조성현*, 김현경*, 김동선*, 진진*, 류성기*,#
*경상대학교 기계항공공학부,항공연

(Received 7 September 2019; received in revised form 8 October 2019; accepted 10 October 2019)

ABSTRACT

Pinions are generally heavy and integrated with a shaft. Thus, fabricating a pinion is a material- and machining-intensive task characterized by low productivity. Contact of the output pinion with a sliding surface or a cloud contact causes loss of power because of friction. Consequently, the output pinion undergoes considerable wear and tear at its ends, which adversely affects the overall transmission efficiency of decelerators. To improve transmission efficiency and extend gear life, an optimum output pinion design is required. To this end, in this study, an output pinion for worm gear decelerators was designed and optimized by means of product verification through prototyping and performance evaluation to improve gear life and productivity. The optimized design was validated and subjected to structural analysis.

Key Words : Reducer(감속기), Pinion Gear(피니언기어), Optimum Design(최적설계), Gearbox(기어박스), Micro Geometry(마이크로 지오메트리)

1. Introduction

Decelerators are widely used because of their excellent transmission efficiency and their ability to transfer and change torque and speed from the drive shaft to the driven shaft.[1-3] Typically, worm gear decelerators and planet decelerators are used for loads less than 5 tons and more than 5 tons, respectively. Worm gear decelerators allow for perpendicular transfer of power through the placement of axes at right angles to each other. They can achieve a large deceleration ratio of approximately 110 for the gears in one pair, have low levels of noise and vibration, and prevent reversals. However, they have many limitations, such as severe heat generation, high wear, and damage at the end of the pinion, which undergoes high-frequency heat treatment. Existing decelerators are heavy and difficult to assemble and repair. Pinions are generally heavy and integrated with the shaft, and as a result, their fabrication requires

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

considerable amounts of material and machining, which, in turn, lowers productivity. Contact of the output pinion with a sliding surface or a cloud contact causes loss of power owing to friction. Consequently, the output pinion undergoes considerable wear and tear at the ends, which adversely affects the overall transmission efficiency of decelerators.

To improve transmission efficiency and extend gear life, an optimum output pinion design is required. Therefore, this study aims to develop an output pinion for worm gear decelerators that is optimized by product verification through prototyping and performance evaluation to improve gear life and productivity.

2. Pinion gear modeling and optimization design

2.1 3D Modeling

In a reducer, different gears are used depending on the weight of the equipment to be handled. Each of the major types of gears and gearboxes, especially those with capacities higher than 5 tons, have been studied extensively. Many researchers have focused on worm gears and worm wheels. However, given that pinion gears play an important role in a gearbox, this study focused on the optimization of intermediate 5-ton class pinions. A three-dimensional model of an output pinion was designed using CATIA V5 (Dassault Systemès, France), a CAD/CAM software package, based on the result of output pinion and tooth profile modification (Fig. 1).

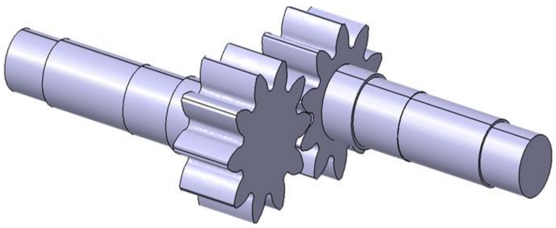


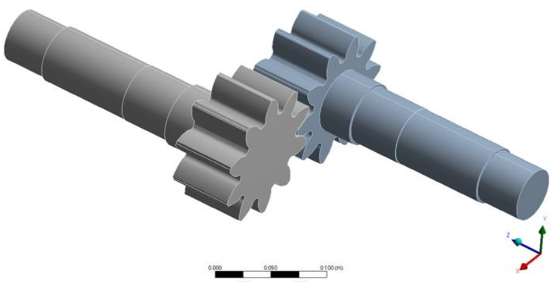
Fig. 1 3D modeling of output pinion

We designed and designed the CAD, CAD, and tooth profile of the module, pressure angle and number of teeth in the previous chapter.

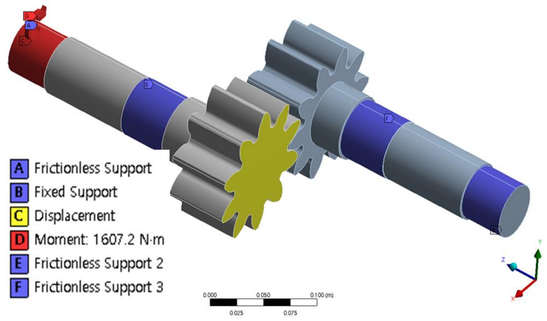
2.2 Structural Analysis

To examine the structural stability of the output pinion, structural analysis was performed using ANSYS (ANSYS, INC., PA, US), a structural analysis program. In the pinion analysis, two pins of the same pinion were brought into contact, and a rotational force was applied to investigate their deformation, stress, and strain rate. Fig. 2 (a) shows the model and the mesh of the pinion, and Fig. 2 (b) shows the boundary conditions of the pinion.

In the structural analysis, the power loss of the optimized output pinion, which is an important part of the power flow in a worm gear reducer, was minimized by modifying its tooth profile. A



(a) 3D modeling



(b) Boundary conditions

Fig. 2 Mesh analysis and deformation analysis

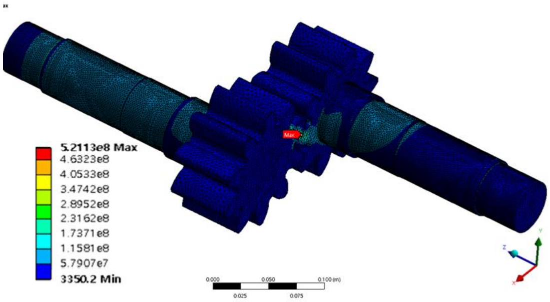


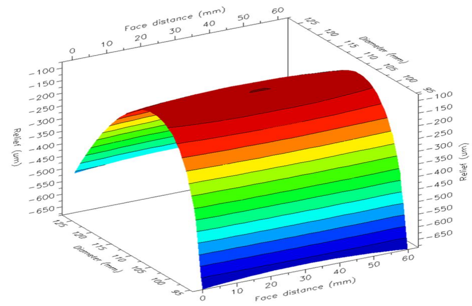
Fig. 3 Stress analysis

high-strength gear steel SCM420H was selected as the pinion material. Fig. 3 shows the analysis results of the output pinion modeled using ANSYS. [4-6]

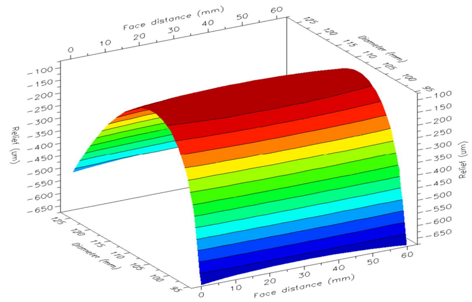
2.3 Gear Tooth Modification

The model designed herein was analyzed to find the optimized form of the gear. However, multiple interpretations are indispensable in designing the tooth profile with the most uniform load and minimized maximum stress. Therefore, tooth surface modification of the gears was performed along various directions. The correction applied to each gear was applied to the other engaging gear as well. Tooth modification was achieved through repeated modifications to the lead crown and lead slope. The lead crown and lead slope were set to 0 before correction, and the correction values were added to or subtracted from this value. Fig. 4 show the target geometry according to the micro geometry correction value and correction value of each gear.

The structural analysis, which involved identification of the optimum tooth profile modification by using ANSYS, confirmed improvements to the efficiency and structural safety of the output pinion. However, as mentioned above, in case of the output pinion of a worm gear reducer, abrasion and breakage occur mostly at the tip. Moreover, the analysis results obtained using ANSYS confirmed that the highest load was generated at the tip. Therefore, we designed the optimum pinion



(a) Input pinion flank



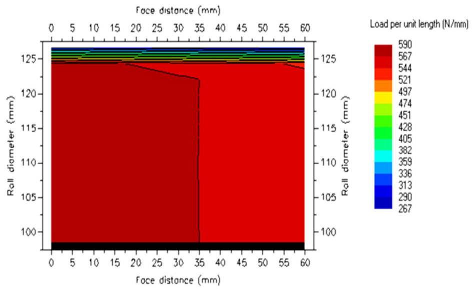
(b) Output pinion flank

Fig. 4 Gear flank form after modification

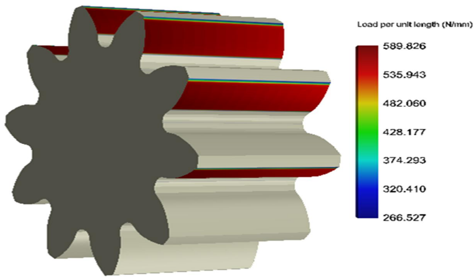
by using Romax Designer (Romax Technology, UK), a gear analysis program for optimizing output pinion designs.

The input values are shown in Fig. 5, and the results of the output pinion analysis are shown in Fig. 6. In this figure, we found the optimum design value by modifying a gear tooth. As shown in Fig. 6, design optimization was performed to improve gear life and efficiency through gentle dispersion of the load after optimizing the abrupt deformation of the transmission error of the contact interface. As shown in Fig. 5, a concentrated load occurred at the end before optimization. As shown in Fig. 6, the load was distributed at the center of the tooth profile. Fig. 7 shows the gear pair model used for analysis.

The drive reducer gears were optimized using Romax Designer, which corrected the profile and lead of the gears and performed simulations

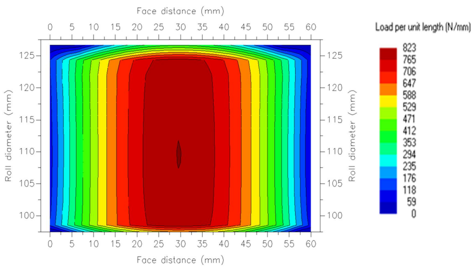


(a) 2D view of pinion gear

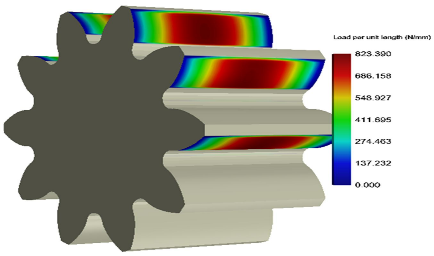


(b) 3D view of pinion gear

Fig. 5 Load distribution on meshing gear surface before micro geometry modification



(a) 2D view of pinion gear



(b) 3D view of pinion gear

Fig. 6 Load distribution on meshing gear surface after micro geometry modification

Fig. 7 Pinion product

repeatedly to determine the optimum gear correction value. In case of the gears, the load acting on the tooth surface before optimization of the stress distribution was concentrated at the gear tooth tip, while after optimization, the load was concentrated at the tooth center.

3. Pinion Gear Precision Test

The most important part of a gear is its tooth profile. A tooth profile is composed of a profile and a lead. Profile refers to the shape of the involute curve from the tooth root to the tooth tip, and lead refers to the lateral shape of the gear tooth on the pitch circle. In the measurement, the center of rotation of the gear was employed as a measurement standard by using a toothed measuring machine, and both the right and left tooth surfaces were measured for 1, 4, 7 and 10th. In KS B 1405, spur gears are classified into nine grades according to the purpose of use. The accuracy of the test gear is shown in Fig. 7. The gear test equipment (Model: UMM850, manufacturer: ZEISS, gear measurement: GEAR PRO involute). The dimensions of the gear were as follows: m (module) = 10 mm, z (number of teeth) = 10, D (pitch circle diameter) = 100 mm, and b (width) = 10.973 mm. The tooth profile measurement results of the five test gears are listed and shown in Table 1 and Fig. 8, respectively. The mean tooth tolerances of the test gears used in this study were 41.9 μm (left), 41.5 μm (right), 41.7 μm (average), which correspond to spur gears of grades superior to grade 4 according to KS B 1406. Lead error measurement results of the five test gears are listed and shown in Table 2 and Fig. 9, respectively. Lead error measurement results of the five test gears are listed and shown in Table 2 and Fig. 9, respectively.

Lead error measurement results of the five test gears are listed and shown in Table 2 and Fig. 9, respectively. The mean tooth tolerances of the test

Table 1 Profile error average of test gear

No.	1	2	3	4	5	Avg.
Left Tooth Profile(μm)	35	41.75	47.25	38	47.5	41.9
Right Tooth Profile(μm)	45.25	35.5	38	47.75	41	41.5
Avg. Profile(μm)	40.13	38.63	42.63	42.88	44.25	41.7

Table 2 Lead error average of test gear

No.	1	2	3	4	5	Avg.
Left Tooth Lead(μm)	15.5	22.75	20	24.75	23.75	21.35
Right Tooth Lead(μm)	20.25	21.5	19	22.5	18.25	20.3
Avg. Lead(μm)	17.88	22.13	19.5	23.63	21	20.83

Table 3 Runout error of test gear

No.	1	2	3	4	5	Avg.
Runout (μm)	39	49	25	62	25	40

Table 4 Pitch error of test gear

No.	1	2	3	4	5	Avg.
Left Tooth Pitch(μm)	15	19	14	22	12	16.4
Right Tooth Pitch(μm)	15	19	13	23	18	17.6
Avg. Pitch(μm)	15	19	13.5	22.5	15	17

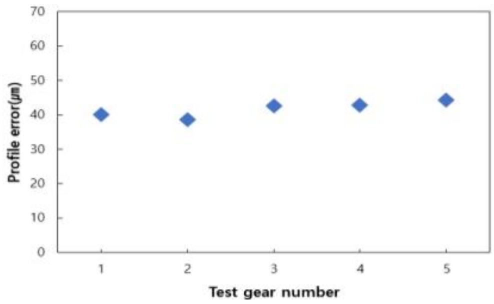


Fig. 8 Profile result of test gear

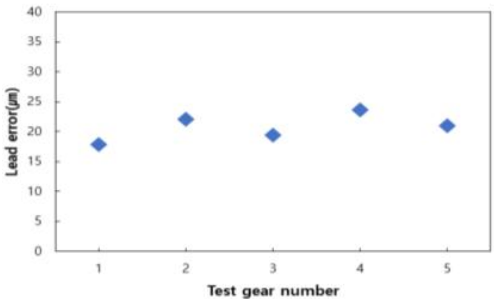


Fig. 9 Lead error of test gear

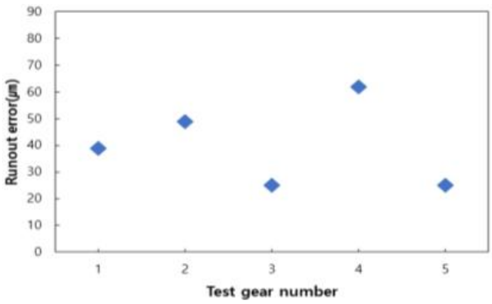


Fig. 10 Runout error of test gear

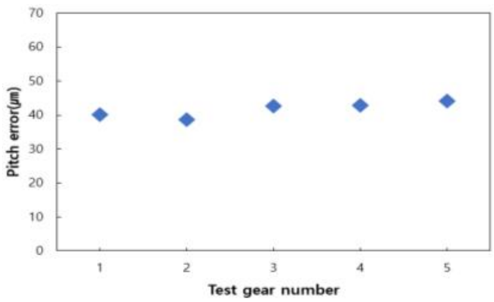


Fig. 11 Pitch error of test gear

gears used in this study were 21.35 µm (left), 20.3 µm (right), and 20.83 µm (average), which correspond to spur gears of grades superior to grade 3 according to KS B 1406. This is superior to the grade 4 spur gears of a typical pinion gear reducer.

Runout error measurement results of the five test gears are listed in Table 3 and shown in Fig. 10. The average runout error of the test gears used in this study was 40 µm (average), which corresponds to pinion gears of grades superior to grade 3 according to KS B 1406. This is superior to the grade 4 pinion gears typically used in worm gear reducers.

4. Conclusions

This study aimed to optimize and analyze the design of a 5-ton output pinion for use in special-purpose industrial machinery to increase transmission efficiency and gear life. To achieve the final objectives, geometry design and simulations, respectively, were performed in this study. The theoretical design of the 5-ton class pinion gear was optimized to verify the resulting performance improvement. The accuracy of the prototype was measured while optimizing the tooth surface load distribution by modifying the profile and lead tooth surface by using Romax Designer. The following conclusions were obtained.

1. The average profile error of the test gears was 44.375 µm, mean lead error was 17.875 µm, average pitch error was 15 µm, and mean runout error was 3.5 µm. The mean runout error of the test gear was 10.82 µm, and the average pitch errors on the left and right tooth surfaces were 9.38 µm and 7.8 µm, respectively.
2. As a result of the structural analysis, the maximum deformation, maximum strain, and maximum stress were found to be 2.9766 e-4 m, 3.3554 e-3 m/m, and 4.3029 e8 Pa, respectively.
3. As a result of structural analysis, the maximum deformation was 2.9766 e-4 m, maximum strain 3.3554 e-3 m/m, and maximum stress 4.3029 e8 Pa.

Acknowledgments

This work was supported by the Regional Leading Research Center of NRF and MOCIE(NRF-2019R1A5A808320111).

REFERENCES

1. Lyu, M. R. and Lee, C. M., “A Study on the Design Automation and Machining Technology of Spiroid Bevel Reduction Gear”, Journal of the Korean Society for Precision Engineering, Vol. 19, No. 7, pp. 141-146, 2002.
2. Lee, S., Lee, D. H., Hwang, S. C., and Lee, K. H., “Stress Analysis of Helical Gear for a Railway Reducer”, Journal of the Korean Society of Manufacturing Process Engineers, Vol. 11, No. 2, pp. 55-59, 2012.
3. Yeh, T. J. and Wu, F. K., “Modelling and Robust Control of Worm-gear Driven Systems”, Simulation Modelling Practice and Theory, Vol. 17, No. 5, pp. 767-777, 2009.
4. Simon, V. V., “Influence of Tooth Errors and Shaft Misalignments on Loaded Tooth contact in cylindrical Worm Gears”, Mechanism and Machine Theory, Vol. 41, No. 6, pp. 707-724, 2006.
5. Mohan, L. V., and Shung, M. S., “Geometrical Aspects of Double Enveloping Worm Gear Drive”, Mechanism and Machine Theory, Vol. 44, No. 11, pp. 2053-2065, 2009.
6. Shi, W., Qin, D., and Xu, W., “Meshing Control of the Double-enveloping Hourglass Worm Gearing under the Conditions of Existing the Errors and the Load”, Mechanism and Machine Theory, Vol. 39, No. 1, pp. 61-74, 2004.