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# A Study on the Fabrication and Performance Evaluation of Worm Gear Reducer

Dong Gyu Lee*, Qin Zhen*, Min Hyong Jeon*, Lae Sung Kim**, Sung-Ki Lyu*,#
*School of Mechanical & Aerospace Engineering(ReCAPT), Gyeongsang National University,
**Creative Aero-IT-Mech Convergence Eng. Program, Gyeongsang National University

# 웜기어 감속기 제작 및 성능평가에 관한 연구

이동규*, 진진*, 전민형*, 김래성**, 류성기*,#
*경상대학교 기계항공공학부(항공연), **경상대학교 창의적항공IT기계융합사업단

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## ABSTRACT

We aimed to develop a high quality 3.5 ton class swing reducer by studying the efficiency improvement of the reducer through the optimum design and performance evaluation of the assembled, high efficiency, lightweight 3.5 ton swing reducer. Based on the optimal design of the worm and worm wheel, the optimal manufacturing method of the worm wheel, the optimized casing design, and the optimum design of the output pinion, Respectively. Therefore, in this paper, to improve the efficiency of the worm gear reducer system, we will develop the manufacturing technology and verify the mass production by combining the manufacturing process design, processing and assembling technology according to the optimization design. We have conducted research to realize mass production by product verification such as product efficiency, reliability and durability according to optimal design of worm gear reducer.

**Key Words :** Swing Reducer(스윙감속기), Worm Gear Reducer System(웜기어 감속기 시스템), Performance Evaluation(성능평가), Optimum Design(최적설계)

## 1. Introduction

This study developed a high-quality 3.5 ton swing reducer by investigating the improvement of efficiency in reducers via optimal system manufacturing and performance evaluation and the optimal design of a lightweight 3.5 ton swing reducer with high assemblability and efficiency. We aimed to verify the efficiency of the product through system part manufacturing, assembly, and performance evaluation based on the optimal design of the worm and worm wheel, the optimal manufacturing method for the worm wheel, casing optimization, and the optimal design of the power pinion, which were our previous study results[1]. Thus, the purpose of this

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

study was to develop manufacturing technology and verify mass production by combining production process design, processing, and assembly technology and using optimal design to improve the efficiency of the worm gear reducer system. Two-dimensional (2D) drawings and three- dimensional (3D) modeling for optimized product manufacturing were fabricated and their optimal design was verified by assemblability verification utilizing 3D printing. This study then aimed to achieve mass production by verifying the efficiency, reliability, and durability of the product according to the optimal design of the worm gear reducer for specialized vehicle as a procedure development for performance evaluation.

## 2. Optimization modeling

### 2.1 Modeling of worm gear reducer system

This study verified the efficiency of the product by conducting performance evaluations after prototype production by reflecting the optimal design values in order to improve the efficiency by using an optimal design for the 3.5 ton worm gear reducer. For worms and worm gears, a power loss may occur in the power transmission in the input axis → worm → worm wheel → power pinion[2-5] process and an optimal design was proposed as a method to minimize this power loss. In addition, an optimized worm wheel was designed by combining a worm wheel made from AIBC2 material and a worm boss made from FC20 material as a separation type for improvements on transmission efficiency, weight reduction, and cost reduction.

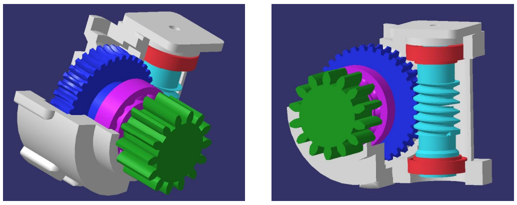


**Fig. 1 3D modeling of worm reducer system**

A worm was designed with SM45C, a relatively flexible material, in accordance with the optimized worm wheel. The optimization structure was designed for parts where power loss occurred and loads were applied by modifying the profile of the power pinion and the lead, which are important for power flow in the worm gear reducer[6-10]. SCM420H was selected as the material for the pinion. In addition, a forging process for manufacturing the power pinion was applied to improve profile strength and cost reduction as well as productivity improvements. Previously, two piece casing was used to manufacture 3.5 ton worm gear reducers, but an optimized three piece casing structure was used for its assemblablility, light weight and heat generation control benefits. Based on the optimized design data, the following 3D model was completed using CATIA V5. Fig. 1 shows the 3D model based on the optimized design values.

### 2.2 Manufacturing of worm gear reducer parts

The assemblability was verified by manufacturing the parts via 3D modeling was concluded. The equipment used was a 3D printer (manufacturer : Staratasys Fortus, model name : 900mc, mode : FDM) and the manufactured product is shown in Fig. 2. Based on the modeling data from CATIA V5, each of the parts was fabricated using 3D printing and their assemblability was investigated. The result of the investigation was good, and production drawings were made based on the optimized design data to fabricate optimized system parts, which are shown in Fig. 3.

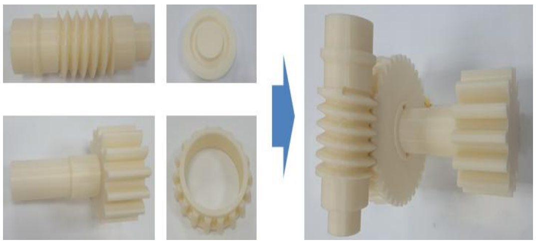


**Fig. 2 Prototype production using 3D printing**

(a) Worm

(b) Worm wheel

(c) Pinion


(d) Cover

(f) Casing & collar

**Fig. 3 Parts product of optimized worm gear**

## 2.3 Assembly of the reducer system

This study modified the worm, worm wheel and power pinion profile by selecting abrasion resistant materials and manufacturing worm gear reducer parts by designing high efficiency, abrasion resistant and high precision gear. The existing 3.5 ton swing reducer worm wheel was made completely of AIBC2 material.

**Fig. 4 Assembling of 3.5 ton class worm gear swing reducer**

This study configured the worm wheel by combining a worm boss made of FC20 material and a worm wheel made of AIBC2 material for weight reduction and cost reduction. To improve the wear property of the worm, the existing worm processing method, which only used cutting, was changed by following cutting with heat treatment and then grinding. The optimized reducer casing technology was developed to be light and with consideration for heat control and assemblability.

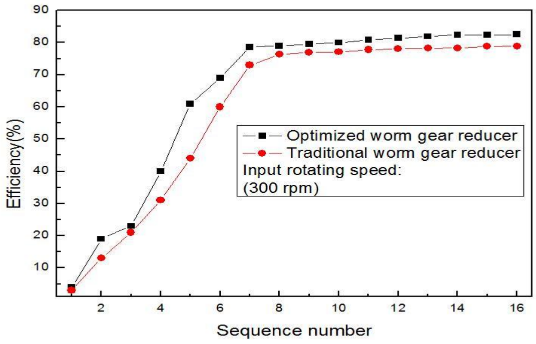
Though existing 3.5 ton swing reducers used two piece casing, the product proposed in this study was manufactured using three piece casing so that the weight can be reduced and heat generation can be controlled to consider assemblability. The power pinion was previously processed with high frequency heat treatment after whole processing but now uses the forging process to conduct metal forming of the pinion shape followed by profile processing.

Then, the optimal profile was designed to improve profile wear, and a study on carburizing heat treatment conditions where heat-treatment deformation was small and surface strength was good was conducted to apply the result to the pinion's manufacture. Fig. 7 shows the reducer system assembly after manufacturing the parts using the optimal manufacturing method and optimal designs for each part.

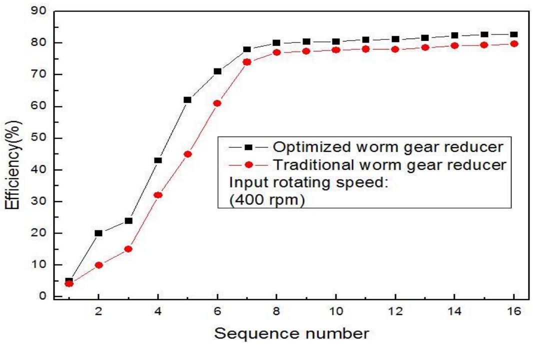
## 3. Performance test results and discussion

The performance test was conducted to verify the performance of the optimized product. In the performance test, transmission efficiency, precision, and gear surface roughness, durability, and noise were measured. The reducer in this study is a worm gear reducer specialized to be mounted in a vehicle. Thus, durability tests were conducted in accordance with KS R 1034: 2006 (vehicle part vibration testing method) and the noise measurement was conducted according to KS B 1410 (noise measurement method for gear devices)[11-13]. To measure transmission efficiency, it was composed of a hydraulic motor, torque sensor, worm reducer and electromagnetic brake. A motor (manufacturer : M+S HYDRAULIC, Model : SP125) was used. The measurement results are shown in Fig. 5. The measurements of gear precision and surface roughness were conducted using a 3D scanner (HEXAGEON) and a surface roughness tester (Model : SJ-301, manufacturer : Mitutoyo). The results are shown in Fig. 6. In addition, the surface roughness measurement results are presented in Table 1 and Fig. 7. The surface roughness of the worm wheel and pinion was less than Ra 1.6 μm and the surface roughness of the worm gear was Ra 1.85 μm. For durability testing, a large vibration tester (manufacturer : LDS Test and Measurement, model : LDS V8-440 LPT900 & SPA56K, controller : Dactron LASER, accelerometer : PCB Piezotronic 353b03) was used, and results are presented in Table 2. The vibration and durability test results showed that the resonance frequency (60.5 Hz) was detected in a horizontal range of 5 to 100 Hz in the resonant point. A resonance frequency (40.0 Hz) was detected in a vertical frequency range of 5 to 100 Hz, but no damage was found in the product.

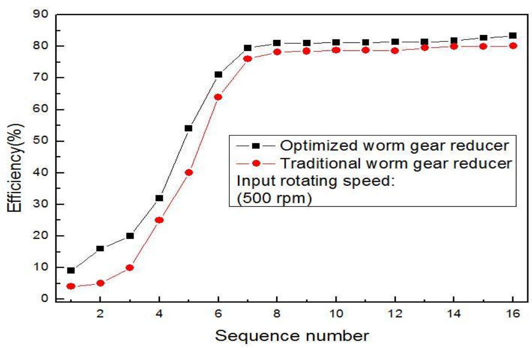
For noise measurement, a digital noise meter (manufacturer : Safa, model : NESM-105I) was used. The noise was measured in the four directions (left, right, front, and back) of the worm gear reducer from a 1,000 mm distance and the maximum value was selected. The measurement results are shown in Fig. 8 and show that the noise of the worm gear reducer prior to optimization was 75.10 dB and 71.04 dB after optimization an improvement of 5.7%.




**(a) 300 rpm**




**(b) 400 rpm**




**(c) 500 rpm**

**Fig. 5 Transmission efficiency of worm gear reducer**

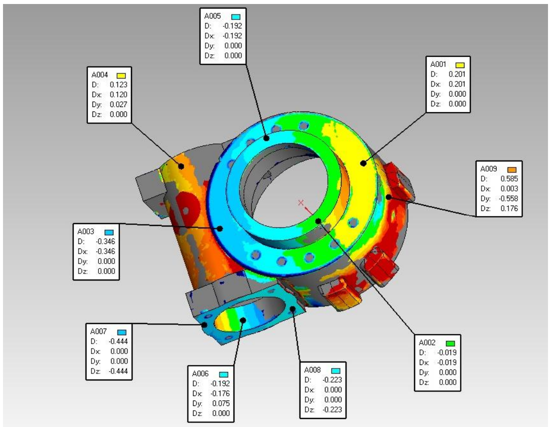
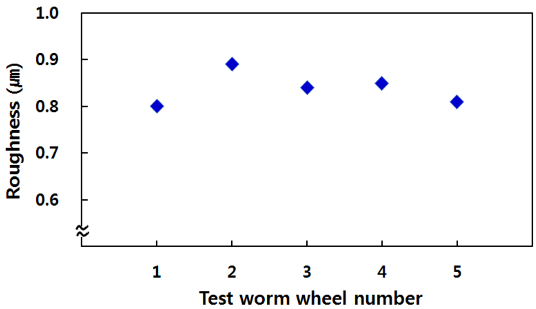


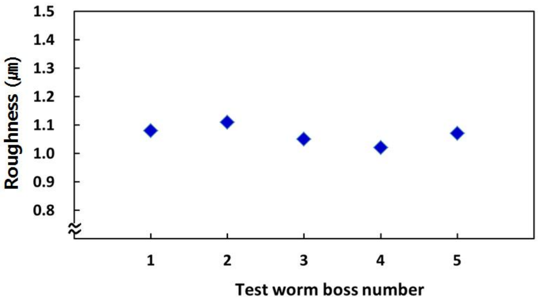
Fig. 6 Measurement using a 3D scanner

Table 1 Roughness test results

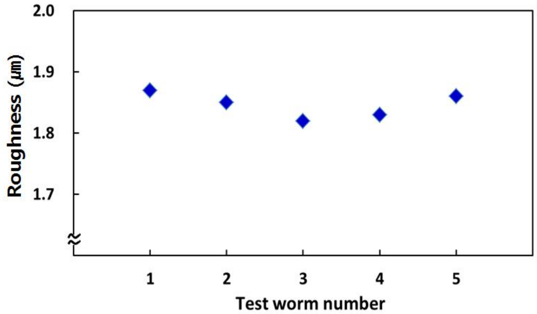
| Item | Unit | Drawing specifications | Inspection data |
|---|---|---|---|
| Worm wheel | μ m | 1.6 | 0.84 |
| Worm Boss | μ m | 6.3 | 1.07 |
| Worm | μ m | 6.3 | 1.85 |
| Pinion | μ m | 1.6 | 0.45 |



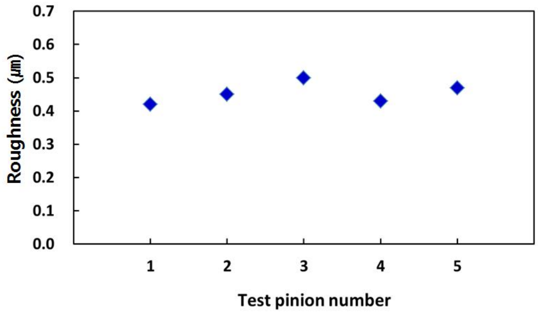

(a) Worm wheel



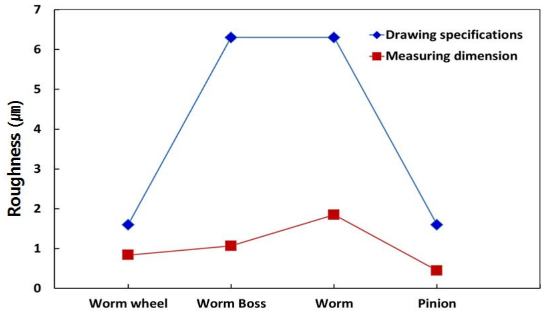

(b) Worm boss




(c) Worm




(d) Pinion




(e) Measurement average of drawing specification

Fig. 7 Measurement average of drawing specification

Table 2 Resonance search result

| Test direction | Frequency range(Hz) | Resonance frequency(Hz) |
|---|---|---|
| Back and Front | 5 ~ 100 | No resonance |
| Left and Right | 5 ~ 100 | 60.5 |
| Up and Down | 5 ~ 100 | 40.0 |

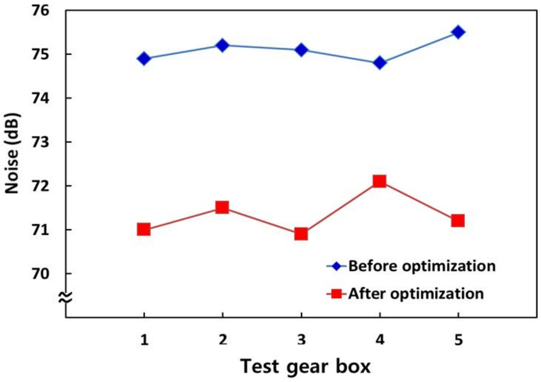



**Fig. 8 Noise tests results**

## 4. Conclusion

This paper optimized the design of parts for a 3.5 ton worm gear reducer meant for specialized vehicle in consideration of assemblability, light weight, and heat generation control as well as life improvements. The parts were manufactured and assembled to produce a system. A performance evaluation procedure was developed with regards to the optimized worm gear reducer assembly, and system and performance evaluation was conducted according to the developed procedure. The performance evaluation results were as follows:

1. The measurement results of transmission efficiency were 58.9% prior to optimization and 82.5% after optimization at 300 RPM, 79.8% prior to optimization and 82.7% after optimization at 400 RPM and 80.2% prior to optimization and 83.4% after optimization at 500 RPM.
2. The measurement results of surface roughness after gear processing showed that surface roughness of the worm wheel and pinion was less than 1.6 μm and Ra 1.85 μm for the worm gear.
3. The vibration and durability test results showed that a resonance frequency (60.5 Hz) was detected at a horizontal frequency range of 5 to 100 Hz and another (40.0 Hz) was detected at a vertical frequency range of 5 to 100 Hz in the resonance point, but no damage was found in the product
4. The measurement results of the noise of the product after vibration testing showed that the noise of the worm gear reducer prior to optimization was 75.10 dB and 71.04 dB after optimization, an improvement of 5.7%.

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