

# Design Modification of Marine Turning Gear Based on Spur Planetary Gear

Kun-Woo Kim\*, Jae-Wook Lee\*<sup>#</sup>, Jin-Seok Jang\*, Joo-Young Oh\*,  
Jong-Hae Hong\*\*, Kang-Jae Lee\*\*

\*Korea Institute of Industrial Technology, \*\*Yurim Industrial Co., LTD.

## 스퍼 유성감속기 기반 선박용 터닝기어의 설계 변경

김건우\*, 이재욱\*<sup>#</sup>, 장진석\*, 오주영\*, 홍종해\*\*, 이강재\*\*

\*한국생산기술연구원, \*\*(주)유림공업

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### ABSTRACT

A marine turning gear controls the position of the piston-crank mechanism by rotating the flywheel of the marine engine at a low speed, which is the main auxiliary machine that enables the disassembly and maintenance of the engine. In this study, the safety factor for surface durability and tooth bending strength was improved by the design modification of the marine turning gear based on the spur planetary gear. Angular velocity, torque, and efficiency of the turning gear were measured using a reliability evaluation tester, and a multibody dynamics model for analysis corresponding to the test results was developed. Finally, it was confirmed that the design improvements improved the tooth surface damage of the sun gear in the 3<sup>rd</sup> reduction stage.

**Keywords :** Marine Turning Gear(선박용 터닝기어), Spur Planetary Gear(스퍼 유성감속기), Design Modification(설계 변경), KISSsoft(키스소프트), RecurDyn(리커다인)

## 1. Introduction

A marine turning gear<sup>[1]</sup>, shown in Fig. 1 controls the position of the piston-crank mechanism by rotating the flywheel of the marine engine at a low speed, which is the main auxiliary machine that enables the disassembly and maintenance of the engine. It also plays a role in lubrication and in

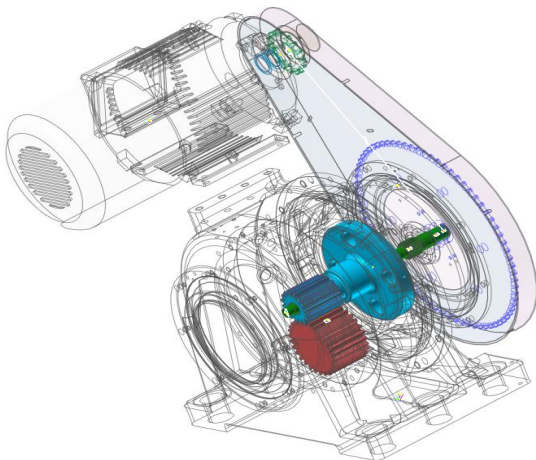
lowering the indicated horsepower before the marine engine is started. Therefore, its durability over the course of the life time of the engine should be guaranteed and reliability of its operation should be secured as the use time increases as the engine ages. Yurim Industrial Co., Ltd. has mainly produced marine turning gears and sold the products to domestic H and S companies and overseas M company, etc. It aims to supply excellent products to customers, lead the turning gear market, and increase its share in the overseas market beyond the Republic

# Corresponding Author : [jwlee@kitech.re.kr](mailto:jwlee@kitech.re.kr)  
Tel: +82-53-580-0186, Fax: +82-53-580-0140

of Korea by securing their own technologies through research and development, systemization, and advancement of technology. For spur gears with a zero helix angle, all geometric design values are determined by determining the number of teeth, module, pressure angle, profile shift coefficient, and face width involved<sup>[2]</sup>. Therefore, the spur gear design determines parameters such as the contact ratio, sliding ratio, surface durability, and tooth bending strength, by determining the five above mentioned values.



(a) Turning gear and flywheel



(a) Layout of turning gear

Fig. 1 Marine turning gear

This paper is organized as follows. In Chapter 2, the ability of design modification is reviewed through analysis of the conventional marine turning gear, and the safety factor for surface durability and tooth bending strength is calculated using the commercial software KISSsoft<sup>[3]</sup>. In Chapter 3, the safety factor for surface durability and tooth bending strength is improved by changing the number of teeth of the planetary gear and applying the profile shift coefficient. In addition, the measurement results obtained using the reliability evaluation tester owned by Yurim Industrial Co., Ltd. and the prediction achieved by the analysis using RecurDyn<sup>[4]</sup>, a multi-body dynamics software, were compared. An improved surface was visually confirmed by a photograph of the tooth surface of the conventional turning gear and the improved turning gear. In Chapter 4, the conclusion of this paper is eventually presented.

## 2. Analysis of an Conventional Marine Turning Gear

### 2.1 Design Analysis of Planetary Gear

The marine turning gear of this study consists of three stages, and the modules and number of teeth of each stage are shown in Table 1. It was equipped with a 7.5kW motor. The overall reduction ratio including the sprocket was 1/1196.2, and the output angular speed was 0.96rpm. The number of teeth in Table 1 was determined by Equation (1), which satisfies the equally distance condition wherein the idle gears can be arranged at regular intervals between the sun gear and the ring gear in three stages.

$$\frac{z_S}{N_I} = integer, \frac{z_R}{N_I} = integer \quad (1)$$

where  $z_S$  and  $z_R$  are the number of teeth in the sun gear and ring gear, respectively, and is the number of

idle gears. In addition, using Equation (2), it was confirmed that no overlap occurred between idle gears.

$$\frac{z_I + 2}{z_I + z_S N_I} < \sin \frac{\pi}{N_I} \quad (2)$$

where  $z_I$  is the number of teeth in the idle gear. However, as shown in Table 2, a common factor exists in the 3<sup>rd</sup> reduction stage, and it can be seen that it violates the sequential mesh condition. This means that it causes noise and vibrations by torsional vibration. In addition, the sun gear in the 3<sup>rd</sup> reduction stage needs to be adjusted since it corresponds to the number of teeth undercut theoretically.

**Table 1 Specification of turning gear**

	Number of teeth		
	Sun	Idle	Ring
1st stage	19	62	143
2 <sup>nd</sup> stage	19	37	93
3 <sup>rd</sup> stage	16	26	68
	Module		
	Sun	Idle	Ring
1 <sup>st</sup> stage		2.5	
2 <sup>nd</sup> stage		4.0	
3 <sup>rd</sup> stage		6.0	

**Table 2 Condition for the number of teeth of the conventional marine turning gear**

	Common factor		
	Sun	Idle	Ring
1st stage	X		X
2 <sup>nd</sup> stage	X		X
3 <sup>rd</sup> stage	O		O
	Sequential mesh condition		
	Sun	Idle	Ring
1 <sup>st</sup> stage	O		O
2 <sup>nd</sup> stage	O		O
3 <sup>rd</sup> stage	X		X

## 2.2 Surface Durability and Tooth Bending Strength

The surface durability and tooth bending strength were calculated based on specifications listed in Table 1 and the load conditions at each reduction section. The calculation was performed using KISSsoft, a commercial software, and the results are shown in Table 3. KISSsoft incorporates International Organization for Standardization(ISO)<sup>[5-10]</sup>, German Institute for Standardization(DIN)<sup>[11]</sup>, and American Gear Manufactures Association(AGMA)<sup>[12]</sup> standards for strength calculation. In this study, the ISO standard was used. The surface durability was calculated using Equation (3) based on ISO 6336-2<sup>[6]</sup>, and the tooth bending strength was calculated using Equation (4) based on ISO 6336-3<sup>[7]</sup>.

$$S_{H_{min}} = \frac{\sigma_{H_{lim}}}{\sqrt{\frac{F_t}{d_1 b} \frac{u+1}{u}}} f(K_H, Z) \quad (3)$$

$$S_{F_{min}} = \frac{\sigma_{F_{lim}}}{\frac{F_t}{b m_n}} f(K_F, Y) \quad (4)$$

where  $S_{H_{min}}$  and  $S_{F_{min}}$  are the surface durability and the tooth bending strength, respectively,  $\sigma_{H_{lim}}$  and  $\sigma_{F_{lim}}$  are the fatigue strength of a material against the surface pressure and bending, respectively.  $F_t$  is the nominal tangential load,  $d_1$  is the pitch diameter of a small gear,  $b$  is the face width,  $u$  is the reduction ratio, and  $m_n$  is the normal module. In addition, the safety factor of the surface durability and the tooth bending strength is determined by the coefficients  $K_H$ ,  $K_F$ ,  $Y$ , and  $Z$ .

As shown in Table 3, the surface durability at the second and third reduction stages is below 1. Since this factor is dominated by the effect of the applied load<sup>[13]</sup>, it is necessary to improve the safety factor.

**Table 3 Safety factor for surface durability and tooth strength of the marine turning gear**

Surface durability			
	Sun	Idle	Ring
1 <sup>st</sup> stage	1.04	1.18	1.30
2 <sup>nd</sup> stage	0.79	0.87	0.94
3 <sup>rd</sup> stage	0.48	0.53	0.79
Tooth bending strength			
	Sun	Idle	Ring
1 <sup>st</sup> stage	3.75	2.41	1.73
2 <sup>nd</sup> stage	2.27	1.75	1.48
3 <sup>rd</sup> stage	1.05	0.81	1.15

**Table 4 Specification of improved marine turning gear**

Number of teeth			
	Sun	Idle	Ring
1 <sup>st</sup> stage	17	64	145
2 <sup>nd</sup> stage	19	37	93
3 <sup>rd</sup> stage	19	23	65
Module			
	Sun	Idle	Ring
1 <sup>st</sup> stage	2.5		
2 <sup>nd</sup> stage	4.0		
3 <sup>rd</sup> stage	6.0		
Profile shift coefficient			
	Sun	Idle	Ring
1 <sup>st</sup> stage	0.4080	-0.4080	0.4080
2 <sup>nd</sup> stage	0.3400	-0.3400	0.3400
3 <sup>rd</sup> stage	0.0182	-0.0182	0.0182

### 3. Design Improvement of the Marine Turning Gear

#### 3.1 Design Improvement of Planetary Gear

Under the condition that the center distance is maintained, the number of teeth at the first and third reduction stages changed as shown in Table 4. In the case of the sun gear in the 3<sup>rd</sup> reduction stage, the number of teeth that undercut does not occur was

**Table 5 Condition for the number of teeth of the improved marine turning gear**

Common factor			
	Sun	Idle	Ring
1 <sup>st</sup> , 2 <sup>nd</sup> , and 3 <sup>rd</sup> stages	X		X
Sequential mesh condition			
	Sun	Idle	Ring
1 <sup>st</sup> , 2 <sup>nd</sup> , and 3 <sup>rd</sup> stages	O		O

**Table 6 Safety factor for surface durability and tooth bending strength of the improved marine turning gear**

Surface durability			
	Sun	Idle	Ring
1 <sup>st</sup> stage	1.02	1.08	1.32
2 <sup>nd</sup> stage	0.83	0.86	0.97
3 <sup>rd</sup> stage	0.61	0.65	0.77
Tooth bending strength			
	Sun	Idle	Ring
1 <sup>st</sup> stage	3.81	2.25	1.60
2 <sup>nd</sup> stage	2.56	1.53	1.44
3 <sup>rd</sup> stage	1.38	0.96	1.42

selected according to the gear theory, and the number of teeth of the sun gear was increased to 19. Therefore, the reduction ratio decreased to 1/1125.8 and the output angular velocity increased to 1.02rpm, but this was in line with the customer's requirements. The safety factor to ensure surface durability and a certain tooth bending strength of the sun gear was increased through the profile shift coefficient. In addition, as shown in Table 5, it was confirmed that the common factor did not exist at all reduction stages, and satisfied the sequential meshing condition.

#### 3.2 Surface Durability and Tooth Bending Strength

Table 6 shows the safety factors for guaranteeing surface durability and bending strength according to the improved design conditions. Looking at the sun gear in the 1<sup>st</sup> stage, although the number of teeth

had decreased, the safety factor for surface durability was not significantly different from the conventional value, and the safety factor for tooth bending strengths increased. It was seen that the safety factor of the sun gear at the 2<sup>nd</sup> stage increased simultaneously. This suggests that the profile shift coefficient can improve the safety factor. The sun gear of the 3<sup>rd</sup> reduction stage showed an improvement of 27% for the surface durability and 31% for the tooth bending strength on increasing the number of teeth and applying the profile shift coefficient. Considering that the load in the 3<sup>rd</sup> reduction stage is about 56 times of that of the load in the 1<sup>st</sup> reduction stage, it is necessary to improve the safety factor. The safety factor for surface durability was 0.61; this may be improved by increasing the module or by switching to a helical gear.

### 3.3 Reliability Evaluation

Reliability evaluation was performed for the improved marine turning gear. The reliability evaluation tester, shown in Fig. 2 and owned by Yurim Industrial Co., Ltd., could test a maximum torque of 250kNm through the speed increaser.

Reliability assessment tests were conducted according to the German FTA specification as shown in Table 7. This test guarantees a lifespan of 3,000 to 5,000 hours, and allows measurement of the efficiency and maximum torque. The maximum torque requirement for the marine turning gear for the customer according to this study was 105 kNm and, as shown in Fig. 3, the average value of the maximum torque was measured to be 106.2 kNm.

### 3.4 Development of Analysis Model for Multi-Body Dynamics

The marine turning gear is a multi-body system that combines gears, shafts, and bearings. Therefore, in this study, the commercial software RecurDyn was used. As shown in Fig. 4, an analytical model for determining the multi-body dynamics of the improved marine turning gear was constructed. The main information is presented in Table 8. The planetary gear was constructed using the Gear Toolkit of RecurDyn, and the stiffness and damping coefficients of the all stages of the two-dimensional contact were selected based on the applied load.

It is possible to measure the angular velocity,

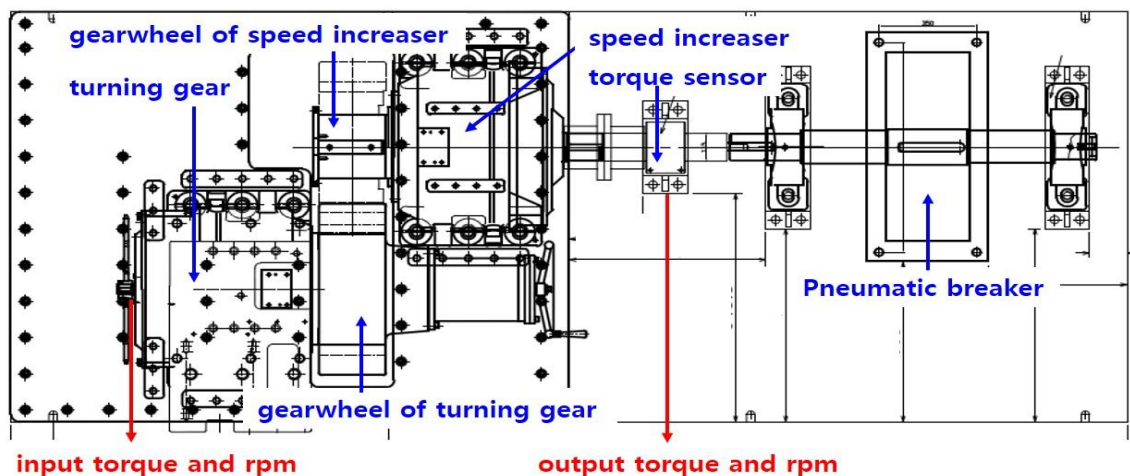


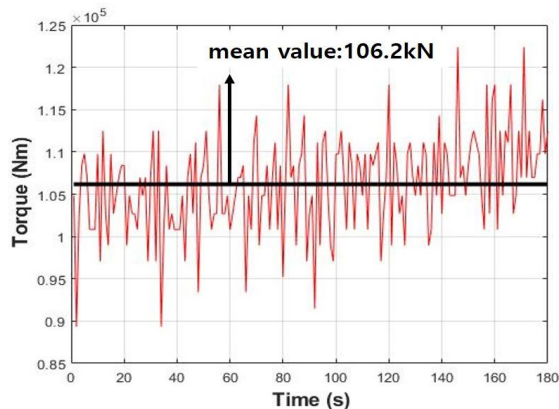
Fig. 2 Reliability evaluation tester

torque, power, and efficiency of the input and output through the reliability evaluation tester provided by Yurim Industrial Co., Ltd. Figs. 4 and 5 show the measurement results acquired using the tester and the prediction obtained through multi-body dynamics analysis, and the trends observed were similar.

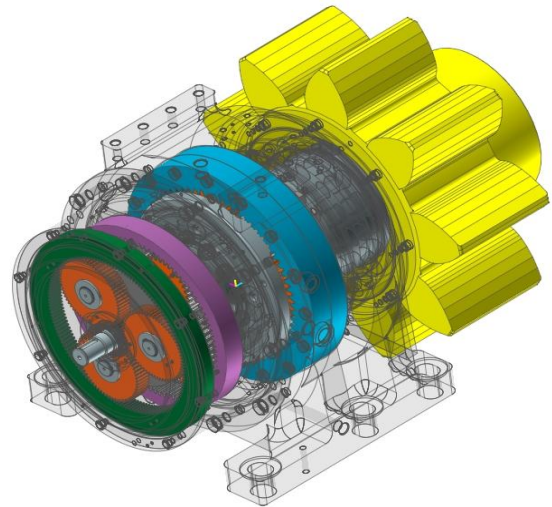
The efficiency of the improved marine turning gear, which drives the gearwheel from the electric motor through the sprocket and the 1<sup>st</sup> to 3<sup>rd</sup> reduction stages, was estimated to be 82%. As seen in Table 8, the input angular velocity corresponds to a driving constraint, and the output torque acts as a load.

**Table 7 MAN Ltd. FTA specification**

	Test	Method
1	Nominal load	1 set (2hr. / cw / ccw / 1min.) 1 set (4hr. / cw / ccw / 1hr.)
2	Full load	1 set (1hr. / cw / ccw / 5min.)
3	Output shaft blocked	10 start-up
4	Maximum torque	10 times
5	Chain slack	Less than twice the starting slack
6	Engaged / Disengaged	10 times with starting air system



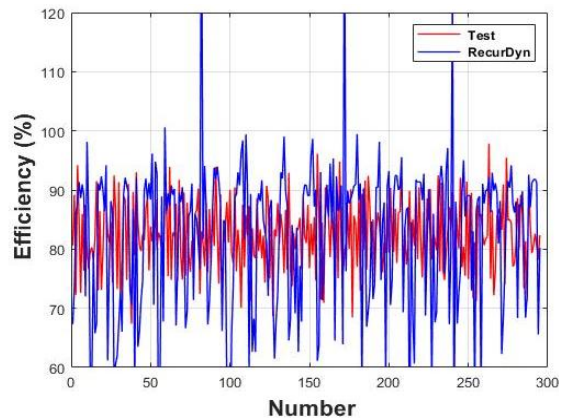
**Fig. 3 Mean value of maximum torque**



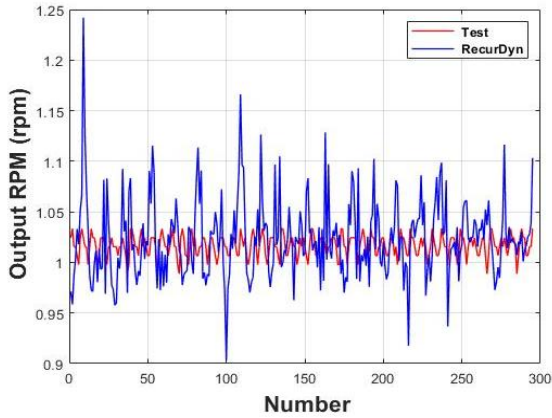
**Fig. 4 Multi-body dynamics model of the improved marine turning gear using RecurDyn**

**Table 8 RecurDyn model of the improved marine turning gear**

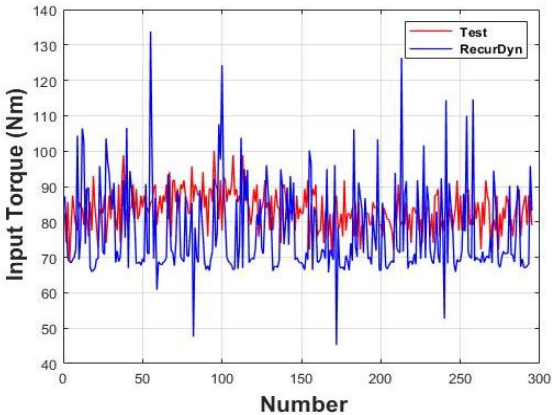
Degrees of freedom	14
Contact	curve to curve
Input rpm	1,150rpm
Output torque	69.580kNm



**Fig. 5 Efficiency of the improved marine turning gear**



(a) Output rpm

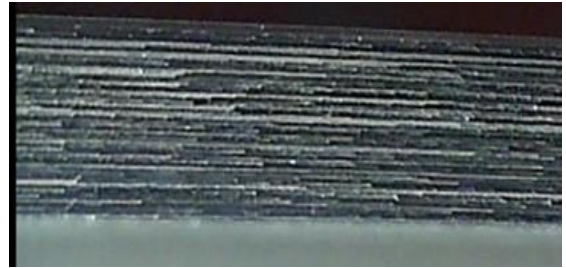


(b) Input torque

Fig. 6 Test and simulation results

### 3.5 Tooth Surface Damage

Fig. 6 shows the tooth surface of the conventional turning gear and the improved turning gear in the 3<sup>rd</sup> reduction stage. As shown in Tables 3 and 6, the safety factor for surface durability is not so large and it can be expected that tooth damage may occur. Nevertheless, as shown in Fig. 6, the design modification improved the damage. The main factors behind the improvement were the backlash accuracy, the number of teeth adjustments, and improvement in the surface durability by design of the profile shift gear.



(a) Conventional turning gear



(b) Improved turning gear

Fig. 6 Tooth surface of the sun gear in 3<sup>rd</sup> reduction stage

## 4. Conclusion

Yulim Industrial Co., Ltd. primarily produces marine turning gears. The marine turning gear is the main auxiliary machine that controls the position of the piston-crank mechanism by rotating the flywheel of the marine engine at a low speed, thereby enabling engine disassembly and maintenance. It also plays a role in lubrication and in lowering the indicated horsepower before starting the marine engine.

In this study, the design specifications of the existing marine turning gear and the safety factors for the surface durability and tooth bending strength based on ISO were verified through KISSsoft, a commercial software. Based on this, we selected the number of teeth to prevent the undercut and maintain the center distance, as well as the profile shift coefficient to improve the safety factor against surface

durability and the tooth bending strength. Through this, we achieved an improvement of about 27% for the surface durability and 31% for the tooth bending strength for the sun gear at the 3rd reduction stage improved, by increasing the number of teeth and applying the profile shift coefficient. Reliability evaluation of the improved turning gear through the tester provided by Yulim Industrial Co., Ltd. was performed by the MAN社 FTA test method. The reliability evaluation tester could test a maximum torque of 250kNm and measure the angular speed, torque, power, and efficiency of the input and output shafts. The customer's maximum torque requirement for marine turning gears was 105 kNm, and the average value of the maximum torque for the improved turning gear was 106.2 kNm. Next, a model for the improved turning gear was developed using RecurDyn, a multi-body dynamics analysis software, to compare the prediction with the measurements made in the test. The trends noted for the efficiency, output shaft angular velocity, and input shaft torque conditions were similar. Finally, the tooth surface of the sun gear in the 3<sup>rd</sup> reduction stage of the turning gear before and after the improvement was photographed, and the damage to the tooth surface was improved by increasing the safety factor against the surface durability.

In this study, an improvement was made in the design of the marine turning gear by improving the safety factor for surface durability and the tooth bending strength, as was confirmed by a reliability evaluation test, multi-body dynamics analysis model development, and tooth surface confirmation. We believe this will contribute to Yurim's technological advancement and market share, and it is necessary to develop a helical planetary gearbox-based turning gear in the future.

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