한국기계가공학회지, 제16권, 제2호, pp.1～6(2017.04) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol.16, No.2, pp.1~6(2017.04) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2017.16.2.001

사이드 스러스터 설계 및 성능평가에 관한 연구

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A Study on the Design and Performance Test of Side Thruster

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(Received 8 March 2017; received in revised form 13 March 2017; accepted 18 March 2017)

ABSTRACT

In this paper, we present a study concerning the design of a 400 N class side thruster for small ships. The side thrusters used in Korea are imported from abroad. The performance and durability of the imported products employed in Korea are not adequate, therefore the side thrusters which will be suitable for Korean domestic needs to be re-designed.

The strength calculation of the side thruster was performed by KS standard. Strength calculation and design were made to meet design requirements. Structural analysis and safety factor analysis were carried out to confirm the validity of strength calculations and design. After manufacturing the bevel gear, a back lash test was conducted. We also conducted a no-load test, a rated load, and an overload test for a performance test and a durability test of the design while satisfying the design conditions.

Key Words : Side Thruster(사이드스러스터), Strength Calculations(강도계산), Structural Analysis(구조해석), Backlash Measurement(백래쉬 측정), Overload Test(과부하 시험)

1. Introduction

A side thruster is a mechanical device used as auxiliary power for entering and exiting ports which are installed at the bottom of the ship, in the case of small boats (fishing boats), all of these devices are imported from abroad. Since side thrusters are installed and used in small domestic vessels, users' request for improvement is increased, so our research continues.[1-5] The imported side thrusters are difficult to use in Korea in consideration of the price, performance and function. Users are demanding better performance and more variety choices. Korea users do not use the side thruster only when entering and exiting ports. Currently, the use of auxiliary equipment for operation and fishery work is universal, such as the role of ship grabbing a certain position by the ocean current when fishing and working by gradually moving the ship to the side. Along with changes in the size and working environment of small domestic vessels (fishing boats), we designed the side thruster with suitable thrust for the users'

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working condition. We set the validation test based on the technical design of the side thruster and performed the backlash test, rated output test and maximum output test to make the target value and considering if meet the design specification.

2. Design and Modeling of Side Thruster

The thrust class of the side thruster was chosen as 400N, and the side thruster configuration and development specification are shown in Fig. 1 and Table 1. The side thruster is made up of parts such as a hydraulic motor, a coupling which connects the hydraulic motor and the input shaft, input shaft, bevel gear, output shaft, power transmission source to the propeller, and case, case cover, tunnel, and protective cover and so on.

Table 2 shows the material and the minimum diameter for calculating the strength of the input and output shaft used in the design product. Shaft strength calculation was performed by selecting the most fragile part (minimum diameter).

The input shaft diameter (d_0) of the side thruster is calculated by equation (1) and must be greater than or equal to the calculated value.

$$d_0 = F \times K_1 \times \sqrt[5]{\frac{2 \times 30000}{\pi \times 100}} = 21.86 \text{ mm} \qquad (1)$$

P : Shaft output at the continuous maximum output of system [kW]
n : Rotating speed during continuous rotation of the shaft [rpm]
F : Coefficient according to the type of thruster
T_0 : Material design tensile strength [N/mm²]
K_1 : Coefficient of shaft design characteristics, the value stipulated by Korea Ship Safety Technology Authority(KST) was applied.[6-9]

Since the calculated input shaft minimum diameter is 32.0 mm, the calculated value is satisfied with the design specification because it is larger than the minimum diameter of the design input shaft.

Fig. 1 Configuration of side thruster

Table 1 Development specification

Specification	Content
Thrust	400 N
Tunnel size	ø400 mm
Propeller	Diameter : 390 mm Pitch : 330, Propeller : 1450 rpm
Motor	71.1 cc/rev
Pressure	170 ㎏/㎠ (16.6 MPa)
Gear and Shaft strength	Gear ratio : 1.19:1(25/21) Shaft of strength : KST and KR

Table 2 Shaft specification

Division	Input shaft	Output shaft
Material	SCM 440	STS 304
Heat treatment	Q . T	-
Minimum dia.	32	35

The diameter of the output shaft (d_P) is calculated by the formula (2) and must be not less than the calculated value.

$$d_0 = 100K_2 \sqrt[3]{\frac{H}{R} \cdot \frac{560}{T_p + 160} \cdot \frac{1}{1-(d_i/d_0)^4}} \qquad (2)$$

H : Shaft output at the continuous maximum output of system [kW]
R : Rotating speed at continuous maximum output of shaft [rpm]
d_i : Inner diameter of hollow shaft [mm]
d_o : Actual outer diameter of hollow shaft [mm]

T_p : Material design tensile strength [N/mm²]
K_2 : Coefficient of shaft design characteristics

Calculating the strength of output shaft by the equation (2), since the minimum diameter of the output shaft is 35.0 mm and larger than the calculated value, so the design condition is satisfied. As shown in Fig. 2, building the 3D modeling of the side thruster through the design such as side thruster input and output shaft strength calculation.

3. Structural Analysis and Discussion

Analysis data confirms the deformation of the side thruster system due to the thrust of the side thruster when the side thruster is mounted on the actual ship and confirms the deformation of the tunnel and the stability of the assembled bolt, proceeding structural analysis to prevent leakage of ships.

3.1 Material Selection

In Table 3, the physical property values of each material can be confirmed, and the physical properties of each material are entered into the modeling of parts. Since the physical property values which input to the simulation material may influence the analysis result greatly, so the real physical property values presented at Korea Standards Association were used. Moreover, for the tunnel, material property values provided by Hankuk Fiber were applied[10].

3.2 Load Condition

The load condition is the output thrust from the side thruster to the main body of the thruster and was calculated as 400N.

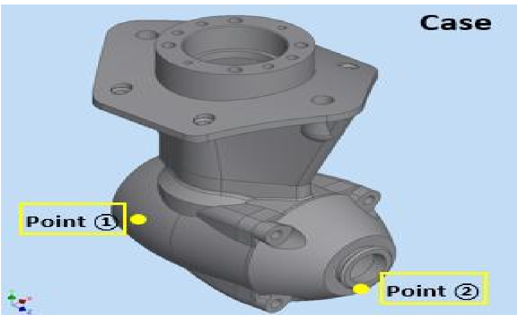

Fig. 2 3D modeling of the side thruster case

Table 3 List of the material properties

Application	Material	Young's modulus (GPa)	Poisson's ratio	Shear modulus (GPa)
Tunnel	FRP	22.3	0.16	9.612
Input shaft	SCM440	200	0.29	128.70
Output shaft, Bolt	STS304	193	0.30	86
Casing	CAC406	109.6	0.33	37

Table 4 Moment acting on the side thruster

	Force	Moment	Bolt Pretension
Case1	400 N	187 Nm Input Shaft	15961.2 N (M10, Stud Bolt) 65380 N (M16 Bolt)
Case2		223 Nm Propeller Shaft	

Also, the assessed moment values were given to two loads, one load which is received in shaft vertical direction and one load which is received in the rotation direction when the shaft rotated. Tabel 4 shows the calculated values of the moment which input to the load condition.

3.3 Results and Discussion

As shown in Table 5, the analysis result demonstrates the deformation at each part, and the load applied to each assembled bolt. Based on the analysis result, the deformation of the tunnel is within 1mm maximum, and the safty factor of assembled bolt is more than 1, so it is judged that there is no major problem in structural stability. Also, the maximum deformation among the tunnel, case, and bolt is 0.163 from the case, the minimum value of the safety factor is 1.41, so it is judged to meet the design standard.

Fig. 3 and Fig. 4 shows the displacement and safety factor by the site as a result of structural analysis. Analysis conditions and results are shown in the figure that can be easily confirmed. Since the thrust generated by the load direction of each assembled bolt, the rotation direction of the side thruster, and the rotation of the side thruster output part, input the load value which the side thruster main body received and confirm displacement and safety factor.

4. Test Results and Discussion

4.1 Backlash Test Results and Discussion

Measuring the cylindrical backlash to check the clearance occurs when the bevel gear assembled on the input and output shaft of side thruster, also for checking the interference between gears when meshing and rotating, and the space between tooth surfaces. Proceeding the test with the backlash measuring device as Fig. 5. First, fixing output shaft (a), using the measuring plate which in input shaft spline part (b) and indicator (c) to measure the three points at 120˚. The design standard of backlash was 0.2 ~ 0.3 mm. According to the test procedure and testing three specimens to confirm the backlash.

Table 6 summarizes the backlash test results, and the average of backlash was found to be 0.232 mm.

4.2 No Load Output Test Results and Discussion

The no-load output test is to check the output side rotation without any load of the hydraulic motor and the temperature variation of side thruster, comparing to the input flow rate of the hydraulic motor, measuring the rotation of output shaft and the surface temperature of thruster every 10 minutes. When inputting the rated flow rate of 122.7 ℓ/min, the thruster output rotation should be measured at 1,450 rpm.

Table 5 Structural analysis results of the side thruster

Structural analysis results of DSS 400 side thruster			
Tunnel	Stress (MPa)	Max.	13.75
	Displacement (mm)	Max.	0.073
	Safety Factor	Max.	15.0
Bolt	Stress (MPa)	M16 Bolt	174.9
		Stud Bolt	25.0
		M10 Bolt	42.5
	Safety Factor	M16 Bolt	1.43
		Stud Bolt	9.98
		M10 Bolt	5.89
Casing	Displacement (mm)	Max.	0.157
	Safety Factor	Max.	15.0

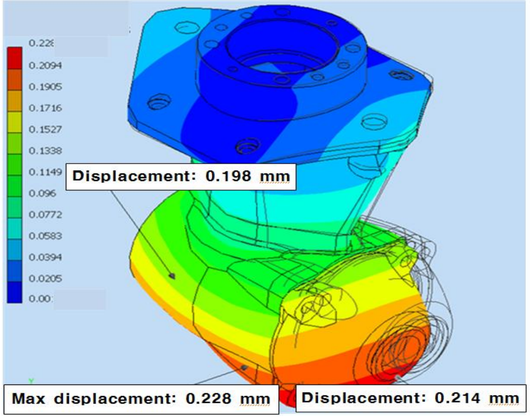

Fig. 3 Results of displacement for casing

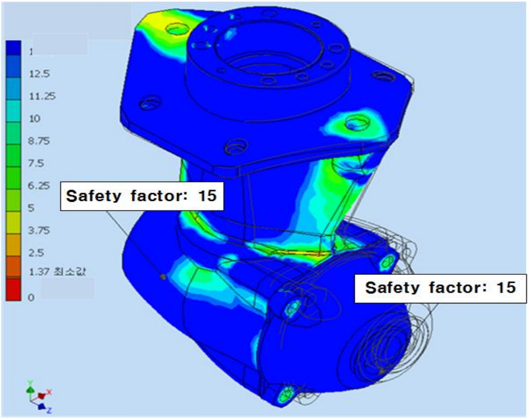

Fig. 4 Results of stress analysis for casing

Table 6 Backlash measurement test result

Angle	1	2	3	Average
0˚	0.25	0.23	0.24	0.24
120˚	0.24	0.24	0.23	0.237
240˚	0.22	0.23	0.21	0.22

Moreover, the temperature variation after 10 minutes should not be over 10 ℃. Fig. 6 is a test apparatus for the no load test, using the electric motor as the power source, rotate the hydraulic pump and input the required flow rate. The motor rotates according to the oil flows from the pump. When inputting a flow rate of 122.7 ℓ/min, the motor rotated at 1,726 rpm, and the output was 1,450 rpm due to the ratio of the bevel gear (1.19:1).

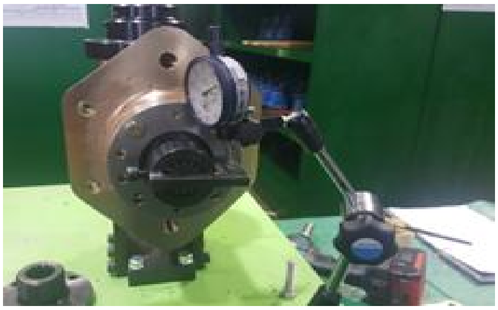

Fig. 5 Backlash measurement apparatus

Fig. 6 No-load test apparatus

Table 7 No-load test result

Division	1	2	3	4
Flow (ℓ/min)	30	70	90	122.7
rpm	345	795	1060	1400

Measuring the temperature of the side thruster during the no load test means that the frictional heat of the bearing and gear by press fitting when the side thruster rotates to be confirmed. Table 7 shows the results of the no load test, the rotation output was 1,400 rpm when inputting a 122.7 ℓ/min flow rate.

4.3 Rated Load Output Test Results and Discussion

In the rated load output test, when the side thruster is mounted on the actual ship and operates, the propeller receives a load while rotating, so that a charge corresponding to 100% of the load is artificially was added.

Table 8 Regular test results

Time (hour)	1	5	10	15	20	25
rpm	1428	1424	1426	1425	1426	1427
Temperature (℃)	25	25	26	26	27	26

Table 9 Overload test result

Time (hour)	1	5	10	15	20	25
rpm	1243	1251	1249	1245	1247	1250
Temperature (℃)	29	29	28	29	30	30

We confirmed that the problem and the target performance of 1,450 rpm rotation occurred on the output side and tested to see if there was an issue in the side thruster during 25 hours. So when 100% load is applied to the output shaft, confirm if the output rotation is meet the target performance. When the output shaft drives the side thruster, the hydraulic pump connected to the suction line which is attached to the output shaft applied a 10 MPa (100 kgf/cm^2) pressure.

Table 8 shows the results of rated output test with a testing side thruster. Through the trial, we found the output rotation is maintained at an average of 1,426 rpm, and confirmed there was no abnormality in the durability of side thruster.

4.4 Overload Output Test Results and Discussion

Overload test is a test to check the durability of the side thruster at the same rotation of rated load test by adding a 120% load on the output side. In this test, applying a 21 MPa (210 kgf/cm2) pressure to the output side and operating for 25 hours. At this time, whether the target performance of the production side was 1,450 rpm can be confirmed. The rated load test apparatus as shown in Fig. 6 also used in overload test.

Table 8 shows the results of overload output test with a testing side thruster. Through the trial, we found that the output rotation is maintained at an average of 1,247 rpm, and confirmed there was no abnormality in the durability of side thruster.

5. Conclusion

In this research, we conducted a test to demonstrate the target value based on the technical design of the 400N class side thruster. As a result of screening and considering the backlash, the rated output, and the maximum output, the following conclusions were obtained.

1. The strength calculation result of side thruster input and output shaft meet the design condition of KS standard.
2. Backlash appeared 0.24, 0.237, 0.22 mm at each of the three points according to the backlash test, and meet the design condition. As a result of analyzing the deformation and safety factor when applying rated thrust to thruster by structural analysis, it was judged to safe at a safety factor 15 maximum and 1.13 minimum.
3. The output rotational speed was 1,426 rpm when inputting a 122.7 ℓ/min flow rate via rated load test, and the output rotational speed was 1,247rpm when inputting a 122.7 ℓ/min flow rate via the overload test, so meet the design condition.

Acknowledgement

This work was financially supported by the Small and Medium Business Administration (Grant No: C0396466-2016-0553)

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