

A Study on the Development of Hall Effect Sensor for Hydraulic Locking Alarm in Ship's Steering Gear

Jung-Min Lee*, Won-Jee Chung**,#, Dong-Jae Lim**, Kyung-Shin Choi***

*FLUTEK.Ltd., **Changwon National University, ***Lloyds Register.

선박용조타기의 Hydraulic Locking Alarm용 Hall Effect Sensor 개발에 관한 연구

이정민*, 정원지**,#, 임동재**, 최경신***

*홀루테크, **창원대학교, ***로이드선급

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ABSTRACT

The LVDT (Linear Variable Displacement Transducer) type sensor used for the existing ship's steering gear is simple on / off that does not perform proportional control operation to the control & unloading device. When the main spool is located at both extremes, It is reflected in the price by using an expensive sensor for import. In this paper, the Hall Effect Sensor is applied to Hydraulic Locking Alarm to analyze classification rules, structure, characteristics and operation principle of valves, and research on localization development in terms of cost reduction. The comparative analysis of the existing prototypes and the cause analysis of the problems were carried out, and the structural analysis showed satisfactory results within the allowable stress range. In addition, it was verified through experiments that the actual operation is realized by applying the actual developed product, and it was confirmed that the load on the maximum value exceeds the allowable maximum load even in the case of the universal tensile test in preparation for the departure of the rod casing.

Key Words : Hydraulic Locking Alarm(유압 잠금 장치 알람), Hall Effect Sensor(홀 효과 센서),
Ship's Steering Gear(선박 조타 기어), Sensor(센서)

1. Introduction

Ships are always exposed to various floating debris or ship collisions during voyages in their lifetime and must consider many unexpected environmental variables. Ships have sunk due to various variables, but the lack of any feedback

system for steering gear is an example of the urgent need for research on ship control for ship automation and safe navigation.^[1-2] Most of the mechanical machines that make up the ships depend on imports and the ships are being built with expensive imports because the research and development of these machines have not been performed properly. In particular, (Linear Variable Displacement Transducer (LVDT)-type sensors used in the steering gear are simple on/off

Corresponding Author : wjchung@chanwon.ac.kr

Tel: +82-55-213-3624, Fax: +82-55-263-5221

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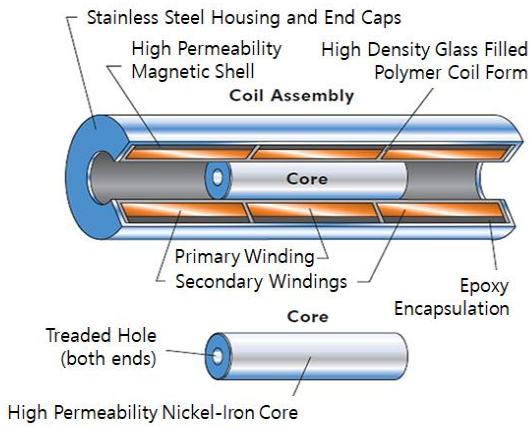


Fig. 1 Configuration of LVDT

sensors that do not perform proportional control operations for the control & uploading device and only send detection signals to check whether the main pool is fixated when it is located at either end. Nevertheless, expensive imported LVDT sensors are used, which are reflected in ship price. This study examines the classification rules and the structure, characteristics, and operation principles of valves by applying a Hall Effect sensor to the hydraulic locking alarm and investigates localization development of the sensor for cost reduction.

2. Hydraulic Locking Alarm

2.1 Outline of hydraulic locking alarms

The accurate name for an alarm generated in auto pilot is a “control motor fail alarm.” A control motor fail alarm is output to the Auto Monitoring System (AMS) and sent to the Voyage Data Recorder (VDR). The AMS captures alarms mainly coming from the power systems, which are monitored on the Engine Control Console (ECC) and records the data related to navigation in the VDR. It can maintain the records for some time,

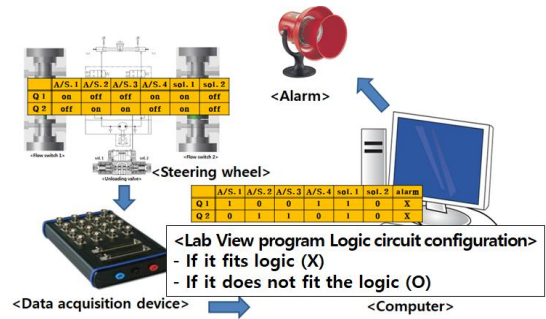


Fig. 2 Operation sequence for hydraulic locking alarm

even during block out and power failure. Ship position, speed, course, bridge worker’s voice, communicator voice, radar data, water depth, and rudder usage details are mandatory records according to Solas regulations. The classification societies have acknowledged hydraulic alarms. Fig. 2 shows the operating process of the hydraulic locking alarms.

When an electric switching signal enters the directional switching valve in the steering gear, the waiting pilot pressure moves to the chamber on the constant direction port-side and moves the spool. The sensors inserted in either end of the spool generate output signals, which are sent to the computer through a data collector. The Lab View Program determines if the steering gear is operating in the commanded direction based on the configured logic and signals an alarm when it is not. In other words, if the Lab View Program matches the logic, the alarm does not sound and it is judged that the rudder is operating normally.

2.2 Common matters of classification societies

Considering the characteristics of the rudder, when the tolerance of deviation between rudder command and response is exceeded, visual and audible alarms must be generated on the navigation bridge. These

alarms are hydraulic locking alarms. As a result of analyzing the regulations of various classification societies such as KR (Korean classification society), ABS (US classification society), BV (French classification society), LR (UK classification society), NK (Japanese classification society), RINA (Italian classification society), DNV/GL (Norwegian/German classification society), and Common Structural Rules (CSR), the following common conclusions were derived.^[3-5] When more than one hydraulic circuit is activated, the generation of a hydraulic locking alarm must be considered. The alarms must be systematized to enable immediate distinction at the bridge. The hydraulic locking alarm must be designed for avoidance. Furthermore, the alarms must be mutually independent and receive power from an emergency power supply, and there must be no overcurrent protection except short-circuit protection.

3. Major Components and Designs

3.1 Position of sensors in steering gear

Fig. 3 shows the positions of assemblies of major components and rod casing assembled at both ends of the spool.

3.2 Rod casing design

Pipes that have a pressure relief valve or an overpressure prevention device are tested by the following minimum breaking pressure, P_b for the parts that are subject to the pressure of the following working fluid of the pressure rudder actuator, such as the adjustment pressure of the pressure relief valve or an overpressure prevention device. If it is confirmed that the pipe endures it, the detailed stress analysis specified in (2) may be omitted. However, the detailed stress analysis specified in (2) may not be omitted if the structure

Table 1 Types of components

COMPONENTS	TYPE
MOTOR	One way / continuous
PUMP	Piston / Fixed
CONTROL	SOLENOID VALVE
Additional circuit	RELIEF REGENERATION
HYD. LOCKING	VALVE POSITION

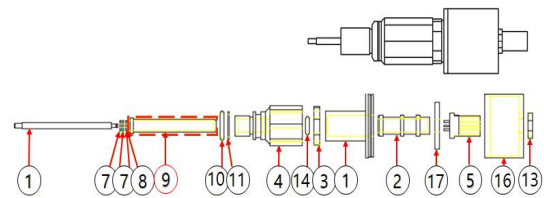


Fig. 3 Position of sensor for RV steering gear

or production method is special.^[5-6] Regarding the classification rules for the allowable pressure of the valve body, the sensor receives a pilot pressure of 60 bar.

A structural analysis was performed for the developed model of rod casing in accordance with the design conditions of the classification rules. The part marked in red in Fig. 4 is the high-pressure part of 250 bar from the main power pack, and the part marked in blue is the low pressure part of 60 bar pilot pressure. The high-pressure part is excluded from analysis because it has no direct effect on the rod casing in which the sensors are inserted, as shown in this figure. Furthermore, the blue low-pressure part was included in the region of structural analysis because it has sensors.^[7-9]

As shown in Fig. 5, the maximum principal stress was 39N/mm² at 60 bar. This is much lower than the allowable tensile load. The analysis result shows that the rod with sensors is not affected at all.

Fig. 6 shows that the maximum total deformation at 60 bar was 0.002291 mm, suggesting that there is almost no deformation.

Fig. 7 shows that the safety factor at 60 bar was 5.2 or higher, although the application scope is generally different when dynamic problems are handled. Thus, it can be seen that the safety factor is more than 5 times the simple safety factor of 1.

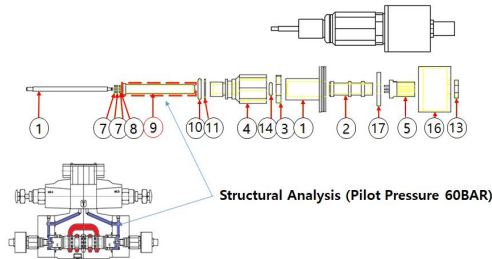


Fig. 4 Position of rod casing for finite element analysis

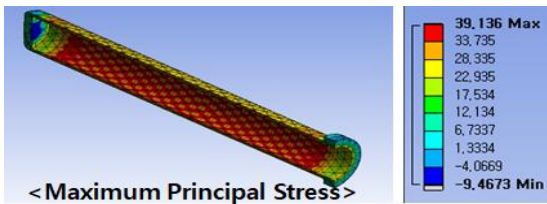


Fig. 5 Maximum principal stress of 60 bar

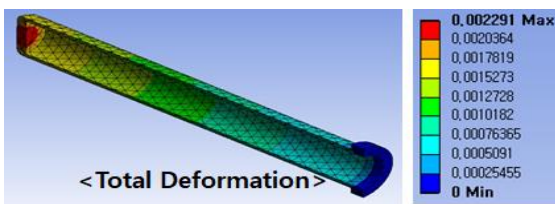


Fig. 6 Total deformation of 60 bar

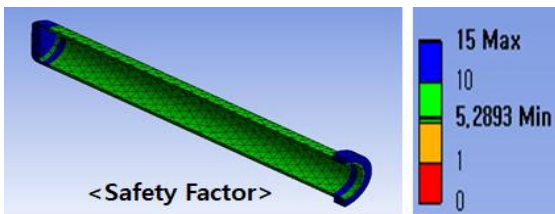


Fig. 7 Safety factor of 60 bar

4. Product Tests and Results

4.1 Performance test for hydraulic locking alarm sensor (switching durability test)

The performance test (switching durability test) was conducted according to the following procedure. Sol. a. is energized for 5 s by supplying DC 24V. When the RELAY(MY4N) connected to N.C. of Sensor #1 is energized, a value is received from output terminal 1, 2, 3 or 4 of RELAY and COUNTER is checked. Sol. a. is blocked from the supply of DC 24V for 2 s. Sol. b. is energized for 5 s by supplying DC 24V. When the RELAY(MY4N) connected to N.C. of Sensor #2 is energized, a value is received from output terminal 1, 2, 3 or 4 of RELAY and COUNTER is checked.

Fig. 8 shows the dimensional changes measured with Vernier calipers when the rod is pulled out by impact during switching in the performance test for sensor output. The open test was performed one million times, but the values did not change at all. Fig. 9 shows the operating method for sign detection in the performance test. First, while the switch is on in the distribution board, the main power switch is turned on as shown in ①, and the operation mode button in ② is switched to automatic. Then, as shown in ③, solenoid valve no. 2 is switched to “Start” and then to “Stop”. Finally, as shown in ①, the main power is switched to Off and the distribution board switch is turned down. Furthermore, the normal operation of the recording of the switching count is recorded as ① and ② through the controller, as shown in Fig. 10. In the end, regarding the sensor operation, the output for the switching relay of Solenoid Valve A was performed more than 1 million times, and the sensor part was operated more than 1 million times. They were confirmed to operate normally.



Fig. 8 Test 1. Pressure test 5mm

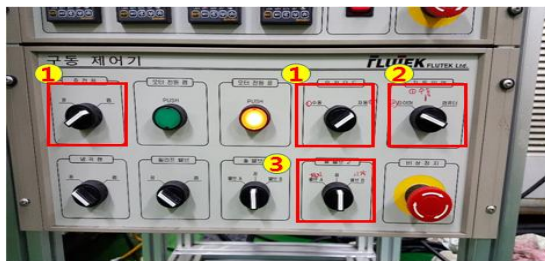


Fig. 9 Test 2. Heat insert test 5mm



Fig. 10 Machine of universal tension test

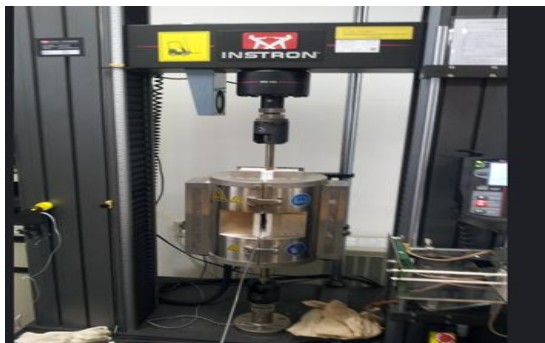


Fig. 11 Universal testing machine

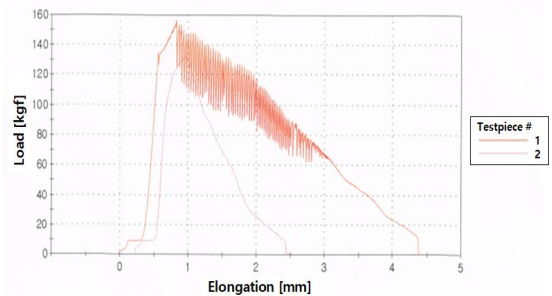


Fig. 12 Graph result of tension test

4.2 Tensile test

The rod inserted into the spool may be detached due to impact, and abnormal sensor detection and valve malfunction may occur while the spool of the solenoid valve switches to either side. Thus, to examine the possibility of detachment of the inserted rod, tensile strength tests were performed with two specimens. First, specimen 1 was for 5-mm indentation. After the spool was fixed in a tightening frame, a rod was inserted into the hole and then indented with a hammer. Specimen 2 was for shrink fitting. The spool was fixed in the tightening frame, heated with a torch, and then shrink-fitted for 5 mm. In addition, the jig spool and rod were assembled and tested with a universal tensile testing machine (INSTRON 5900).

The tensile test results for each specimen are summarized in Fig. 12 and Table 2. For specimen 1 for 5-mm indentation, the maximum load was measured at 156.32kgf and the fracture/elongation was measured at 4.39 mm. For specimen 2 for 5-mm shrink fitting, the maximum load was measured at 132.2kgf and the fracture/elongation was measured at 2.31 mm. During the shrink fitting, the rod insertion length in the hole was less than 5 mm due to thermal deformation, and the elongation was low, as the hardness of the rod increased due to thermal deformation.

Table 2 Comparison of specification for sensors

Specimen label	Maximum load(kgf)	Fracture /elongation(mm)
Specimen 1. press fitting 5mm	156.32	4.39
Specimen 2. shrinkage fitting 5mm	132.20	2.31

5. Conclusions

In this study, the classification rules were analyzed and the structure, characteristics, and working principles of the valves were examined and researched by applying Hall Effect sensors for hydraulic locking alarms to ships. They were analyzed in comparison with existing prototypes, and the causes of problems were analyzed. The structural analysis produced satisfactory results within the allowable stress range. Furthermore, normal operation was confirmed through experiments with actually developed products. In addition, the results of universal tensile tests in preparation for the detachment of rod casing showed that the maximum load was higher than the allowable maximum load.

Due to the provisions of the classification rule that the sensors for hydraulic locking alarm must be possible to check in auto pilot, the directional switching valve is currently used to detect sensor malfunction. However, if the sensor itself has a problem, the detection of the problem is judged only by sensor malfunction, even though the steering gear is operating normally in auto pilot. Thus, it is necessary to develop a sensor that can trigger an alarm immediately without going through the directional switching valve when there is a problem such as a sudden change due to an actual movement of the steering gear. Therefore, future

research should develop an operating flow direction detection sensor in addition to existing and developed sensors.

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