A LOCKED-POSITION MONITOR FOR IMPROVING SAFETY OF RELEASE HOOKS IN ENCLOSED LIFEBOATS

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SUMMARY

Repeated casualties caused by inadvertent release of lifeboat release hooks during drills and inspections have attracted the attention of the International Maritime Organization, which correspondingly amends the Life-Saving Appliance (LSA) Code in the international convention for the Safety of Life at Sea. This study proposes novel installations of locked-position monitors on release hooks for monitoring and safety checks. With the installation of locked-position monitors near unsealed pull rod, upon lifting the lifeboat from the water, the sensors can initiatively detect whether the release hooks are in a locked position. If the release hooks are not in the locked position for any reason, audible alarms are activated, warning lifeboat operators to cease operations and wait for further inspection. The example provided in this research indicates that locked-position monitors can be implemented on lifeboats to reduce accidents resulting from malfunctioning lifeboat release hooks, thereby promoting a safer working environment for all seamen at sea.

1. INTRODUCTION

Lifesaving equipment on vessels is essential for ensuring the safety of lives at sea. Mandatory regulations stipulated in Chapter 3 of the International Convention for the Safety of Life at Sea (SOLAS), LSA Code and Res.MSC.81(70) [1-3] require vessels to be equipped with lifeboats and conduct regular inspections and drills to protect the lives and property of the crew. This demonstrates that lifeboat conditions and crew members' proficiency in launching and operating lifeboats is crucial for life saving. The inspections included in both Port State Control (PSC) and the Safety Management Certificate (SMC) programs are conducted by the Flag State Office of Maritime Administrations, thus highlighting the importance of lifeboat integrity and availability [4], as well as specific criteria for lifeboat maintenance, inspection, and operation.

The SOLAS Convention states that any enclosed lifeboats built after 1986 should be equipped with on-load release devices and amended by RES.MSC.317(89) [5] that has introduced SOLAS REG.III/1.5. During lifeboat drills, maintenance, or when crews must abandon vessels, the normal functioning of on-load release hooks is essential to ensuring the safety of lifeboat release and retrieval operations. Although on-load release hooks are vital for protecting the lives and safety of crews, the normal functioning of the actual devices is not guaranteed; thus, malfunction of the device cannot always be predicted, leading to lifeboat casualties, consequently, causing the incidence of crew accidents and casualties to be high. Most accidents occur because common on-load release hooks are poorly designed, causing hooks to open unexpectedly, resulting in injuries or deaths from falling into water [6]. It has been claimed as many of 16% of the seamen whom have been killed on merchant ships died, during lifeboat drills, and according to fatality reports, death due to failing of on-load release hooks accounts for 80% of the casualties [7]. Consequently, numerous fall preventer devices (FPDs) have been developed to prevent these accidents. A Lifeboat Fall Preventer Device can be used to minimize the possibility of an injury or fatality by providing a secondary alternate load path in the events of on-load hook failures or release mechanism malfunctions of accidental releases [8, 9]. FPDs (including resilient strops, continuous slings or locking pins) are difficult to break and thus can prevent lifeboat drill operators from falling into the water by compensating for any unexpected hook openings thus stabilizing the lifeboats. However, the durability of FPDs that protects people's lives can also pose a detrimental disadvantage. For example, lifeboat operators may be too nervous to locate appropriate tools to break FPDs during emergencies. Furthermore, due to the tension increase in FPDs when vessels are inclining, the difficulty of breaking these devices also increases. Thus, FPDs may result in release problem for emergency situations.

After numerous examinations and repairing various types of lifeboat release hooks, lifeboat engineers suggest that a monitor device should be employed to detect either incorrect hooks resets or hook displacements that caused by hooks mechanism broken. The purpose of this study is to increase the safety of on-load release hooks and the main mechanisms for enclosed lifeboat release systems by adding a locked-position monitor. The monitoring system could save the lives and property of passengers and crew. Current hook release systems of enclosed lifeboats comprise of release hooks affixed to the bow and stern, operating cables, release handle units, and hydrostatic interlock units and link cables. Release handle units are used to operate the release hooks located at both ends of the device through mechanical wire cables as shown in Figure 1. Because of the uncertainty regarding whether the hooks are correctly reset in position or whether the mechanism cannot support the lifeboat load because of displacements from device damages. Therefore a displacement monitor is required to verify the positioning of the device. One objective of this study was to implement displacement monitors to lifeboat release and retrieval systems.

The primary mission of the International Maritime Organization (IMO) is to ensure the safety of maritime operations and crew members. Although regulations mandate that all merchant and passenger vessels must be equipped with lifeboats, unexpected malfunctions of the release mechanism continue to cause casualties among crews. Thus, the amendments of the SOLAS Convention demand that evaluation of lifeboat release and retrieval systems (RRS), and all existing RRS are required to comply with MSC.1392 and SOLAS REG.III/1.5 [10, 11]. According to these provisions, not later than the first scheduled dry-docking after 1 July 2014, but not later than 1 July 2019, lifeboat on-load release mechanisms not complying with paragraphs 4.4.7.6.4 to 4.4.7.6.6 of the Code [12] shall be replaced with equipment for all ships. The primary purpose of this action is to prevent further accidental or premature openings of release hooks and reduce casualties. This study endeavours to design a safety-promoting device to enable early detection of the unexpected detachments of lifeboat release systems, non-simultaneous hook release and operating cable damages, in doing so, reducing maritime accidents.

2. PRINCIPLES OF RELEASE HOOK SENSORS

By analysing various types of sensors (e.g., Hall switches, reed switch, capacitive sensors, and inductive sensors) affixed to monitors [13] and based on numerous experiments, assessments, and observations of practical industrial cases, inductive sensors (i.e., inductive proximity switches) were selected for this study. According to electromagnetic theories, inductive sensors can detect non-electric metallic objects by using variation changes of magnetic resistances in the sensor coils. The mathematical model for inductive sensors is as followed [14]:

$$L = \frac{N^2 \mu S}{2\delta}$$

where L represents the inductance, N represents the number of turns per coil, μ represents the magnetic permeability of air gaps, S represents the sectional area of air gaps, and δ represents the air gap length. Inductive sensors are generally divided into two types, that is, variable air gap length sensors and variable area sensors. For variable air gap sensors, gap length δ and inductance L exhibit a nonlinear relationship (Equation 1). Let the air gap in the starting position be δ_0 and the corresponding initial inductance L_0. When the air gap is increased or decreased by $\Delta\delta$, the variance in inductance is ΔL (higher-order terms are neglected).

$$\frac{\Delta L}{L_0} = \frac{\Delta\delta}{\delta_0 \pm \Delta\delta} = \frac{\Delta\delta}{\delta_0}\left[\frac{1}{1 \pm \frac{\Delta\delta}{\delta_0}}\right]$$

Sensitivity

$$K_\delta = \frac{\Delta L}{\Delta\delta} = \frac{L_0}{\delta_0} = \frac{N^2 \mu S}{2\delta_0^2}$$

ΔL and $\Delta\delta$ exhibit a non-linear relationship, and linearity of the output characteristic contradicts the measurement range. The sensitivity of the variable air-gap inductive sensor K_δ is inversely proportional to the air gap thickness δ_0^2 . To achieve greater sensitivity, the measurement range must be limited.

For variable area inductive sensors, the coil inductance L varies with the area S in (1), exhibiting a linear relationship. Thus, the area variance in the magnetic circuit is set as ΔS, and

$$L + \Delta L = \frac{N^2 \mu}{2\delta}\left(S + \Delta S\right)$$

In (4), identified sensors can render N, μ, and δ constants. If the variance of the magnetic circuit area in sensor is ΔS, the inductance variance in the sensor is ΔL and converted into voltage or current through the measurement circuit. The linear relationship between output quantity and input quantity is the primary advantage of variable area inductive sensors. The type of inductive proximity sensor used in this study can detect horizontal metal displacements within approximately 8 mm or closer to the inductive sensor, and has a 3~4mm tolerance range within vertical distances, and execute "ON/OFF" switch functions. The battery of enclosed lifeboat provides all engine starting, radio and searchlight batteries.

3. RELEASE HOOKS SENSORS DESIGN AND INSTALLATION

As mentioned above, lifeboat engineers and distributors whom are responsible for various types of lifeboat inspections and maintenance determined that to improve inappropriate release hook designs, monitors should be employed to detect either incorrect hooks resets or hook displacements that caused by hooks mechanism broken. Mechatronics concepts can be adopted to effectively prevent accidents by monitoring and identifying the possible dysfunctions of release hooks.

Currently, most of lifeboats are equipped with two sets of 12 volt batteries that are recharged and maintained periodically. The annual inspections of batteries are compulsory and can be performed using a hook displacement detection system. Because hook release and resets are controlled manually using cables connected to pull rods, sensors that monitor the up/down position of the pull rods can be employed to determine whether the reset or open position of the release hooks is correct or not. A concept diagram of the proposed design is shown in Figure 1.

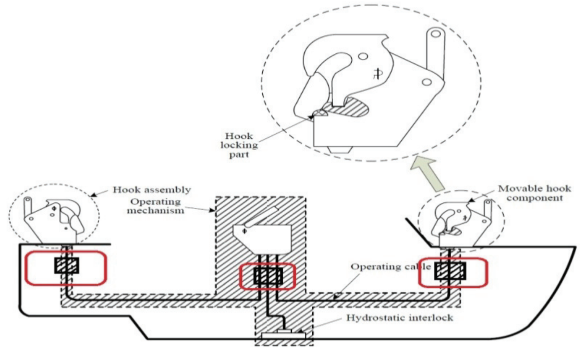

Figure 1. [Three sets of inductive proximity sensors affixed to an enclosed lifeboat]

The purpose of monitor installation in other engineering domains is to increase equipment safety. As shown in Figure 1, the pull rods that connect the release hook and the cables at the lifeboat bow and stern are the interlocks that drive the release and reset of the hook mechanism. Therefore, inductive sensors can be installed near unsealed pull rod to determine whether the hook mechanism is reset to the correct position. When lifeboat is waterborne and still connected to the davits wire falls, monitoring of the hook mechanism is not required; however, when lifeboats are out of water, constant monitoring is necessary. Consequently, three sets of inductive proximity sensors must be installed in this design. Monitors at the bow and stern are used to affix pull rods to iron rods, and proximity sensors with a detection distance ranging between 4 and 8 mm (depending on the brand of manufacturer) are used to detect the hook positions. Specifically, when hooks are reset (in locked position), the sensors detect whether their positioning is correct or not. When hooks are released, the iron rods connected to the pull rods are outside the detecting range; thus, the sensors detect that the hook is locked or unlocked. However, to distinguish normal lifeboat releases for launch from abnormal hook displacements, a reverse proximity sensor is installed on the hydrostatic interlock, when the lifeboat contacts the water surface or the hook is forcibly opened, the sensor is switched off to cease monitoring. When the lifeboat is out of water, the sensor initiatively detects incorrect positioning or displacement of the release hooks. If any release hook is determined to be in such conditions, in addition to a red flashing light, the sensor activates an audible alarm to instruct operators to terminate operations.

However, one concern regarding the proposed design is that the sensors may fail to detect the unexpected opening of the release hooks. Considering this issue regarding the release hook interlock mechanism, the following three interlock conditions can result in the accidental opening of hooks: (1) breakage of the operating cable generates abnormalities in the release/retrieval process or hook displacements. This issue occurs most commonly and is detected by the sensor most easily. (2) Breakage or bending of the pull-rod prevents the sensor from detecting normal operations. (3) Damage to the cam mechanism or inability of the mechanism to support the lifeboat load. Sensors can detect this abnormality within an approximate displacement of 3~4 mm. Should the cam break suddenly without warning due to rust or insufficient strength, although the sensor will activate an alarm, the lifeboat will not be prevented from falling since this is only a monitoring device. In summary, the proposed monitor satisfies the requirements of the design.

4. RESEARCH ACHIEVEMENTS

This study developed a lifeboat release hook locked-position monitor. This device was designed to automatically monitor hook displacements or incorrect positioning resulting from either internal or external factors of the hook devices (Regarding the mechanism, pull rods displacement indicates that the cam or similar mechanisms may have caused the release or partial opening of the hooks due to heavy load; however, if the monitor is installed at an exposed location on the hooks, erosion from sea climates is likely to happen, thus not suitable for external installation.). By using an alarm to warn operators of safety concerns associated with using lifeboats, the safety of lifeboat release and retrieval systems can be enhanced. The design and installation of the release hook locked-position monitor in lifeboats with unsealed pull rod is shown in Figure 2.

Figure 2 is a diagram showing the overall structure of the lifeboat release hook locked-position monitor. The device control panel is installed on the steering console for the operators to examine. Sensors located on the hooks of bow and stern and the hydrostatic interlocks transmit sensing signals via the circuit transmission lines to the control panel for display.

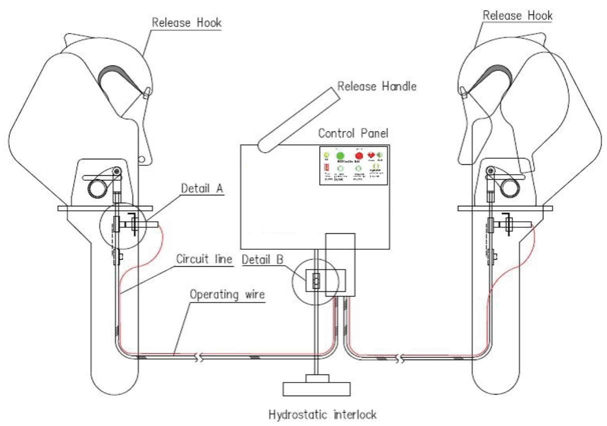

Figure 2. [Diagram of release hook locked-position monitor for the enclosed lifeboat with unsealed pull rods]

This study investigates the position of lifeboat release hooks, specifically, whether they are correctly locked or unlocked, or if hook displacements occur. The structure of release hook locked-position monitor comprises of three inductive proximity sensors, control circuit boards, and circuit lines. When an enclosed lifeboat is out of the water, the monitor continuously detects dangers related to the release hooks and warns operators by activating an alarm. Reset indicators by lifeboat manufacturers are typically used to passively determine whether lifeboat release hooks are correctly reset or positioned, in this approach, subjective judgment is employed to determine whether the hook is correctly positioned. However, gradual displacements are frequently caused by hook loads on broken operating cables and damaged cams. Accidental lifeboat releases because of gradual displacements typically result in numerous casualties.

To resolve these above issues, initiative monitoring was employed to determine whether the hooks are in the correct locked or released positions. The proposed monitor also facilitates the immediate detection of gradual displacements. Operators are notified of dangers using an alarm. The operating principles and design of the human-centred control panel, as well as its practical implementation, are shown in the following example.

Figure 3 is a schematic diagram of the release hook locked-position monitor control panel typically installed on the lifeboat steering console. Crew members who speak different languages can use the signal light schematic to understand whether release hooks are functioning normally. Three lights that marked in a rectangular box is focused. Green light means safe that release hooks are in locked position, whereas red light means lifeboat is on the water or RRS is in unlocked position and alarm is activated. The light positioned on the AFT hook (Figure 3, (1a)) is activated when the sensor and sensing metal are close to position 1a; conversely, the light is deactivated when the sensor and sensing metal are outside the detection area of 1b. The function of the light positioned on the FORE hook (Figure 3, (2a)) is similar to that of the AFT hook-position light. Specifically, the light is activated when the sensor and sensing metal are within the detection area of 2a; whereas, the light is deactivated when the sensor and sensing metal are outside the 2b detection area.

The light positioned on the hydrostatic interlock (Figure 3, (3a)) is deactivated when the sensor and sensing metal are near position 3a; in turn, the light is activated when the sensor and sensing metal are outside the 3b detection area. When lights positioned on the hooks are green (Figure 3, (4)), the FORE and AFT hook-position lights are activated and the hooks are in locked position. When the hook-position lights are red (Figure 3, (5)), either the AFT hook or the FORE hooks are unlocked. However, this does not indicate that the hooks present potential danger; instead, it may indicate hook releases because of forced on-load releases in various situations, or that the lifeboat is in water.

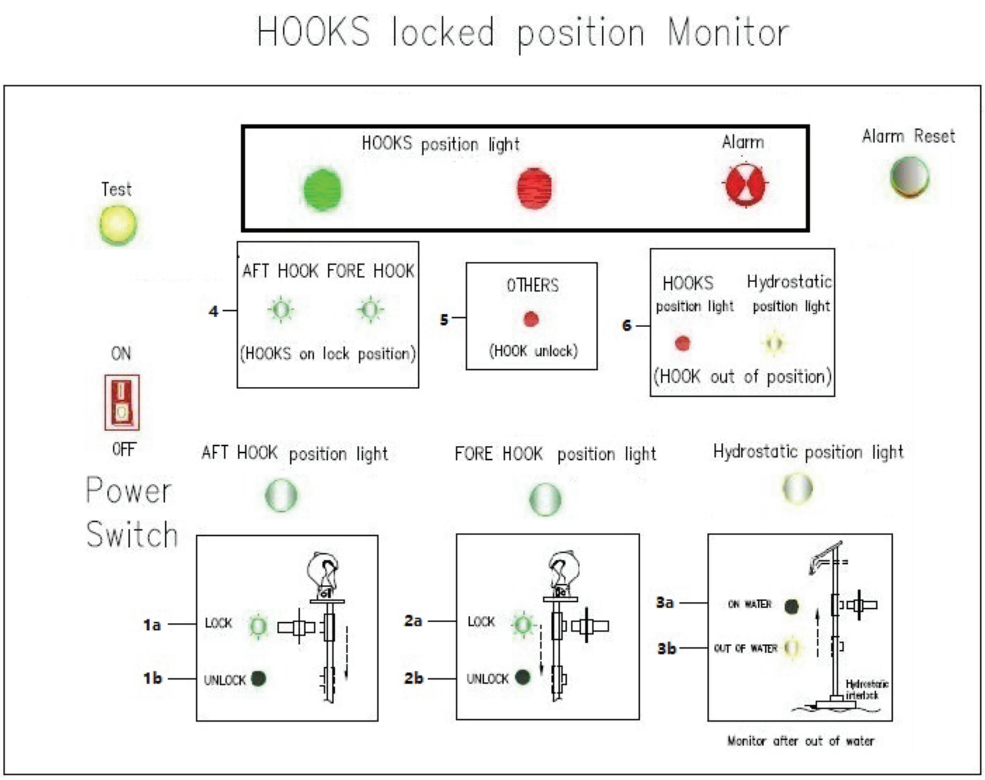

Figure 3. [Signal light schematic of the hooks locked-position monitor control panel]

Figure 3 (6) shows that when the hook-position light is red and the hydrostatic-interlock position light 3b is switched on, the alarm is activated and the red light flashes. This indicates that one of the hooks may be reset in a position incorrectly or displaced caused by mechanism damages. When the alarm is activated, pressing the alarm reset button silences the alarm; however, the red light will continue to flash. If another hook is displaced, the alarm will be once again activated. When the power is switched on, the test button is used to confirm normal operation of the signal lights and alarm sound systems. The force from the weight of the lifeboat or hook load can cause gradual displacements and can be easily detected with our device. Whether the hydrostatic interlock has reset upon removing the boat from the water can also be detected with our device. Thus one can see that our device complies with the LSA Code sections 4.4.7.6.4 to 4.4.7.6.6, regarding lifeboat hooks with the following three criteria approved by the IMO: (1) To provide hook stability, the release mechanism shall be designed so that, when it is fully in the closed position, the weight of the lifeboat does not cause any force to be transmitted to the operating mechanism. (2) Locking devices shall be designed so that they cannot turn to open due to forces from the hook load. (3) If a hydrostatic interlock is provided, it shall automatically reset upon lifting the boat from the water. Our devices also uses power saving LED lights, if the alarms are not activated it doesn't require too much resources for normal operations. With the above factors provided, the device is a suitable device for lifeboat monitoring.

With this on-board lifeboat monitoring concept, inspections of release hooks which were originally conducted by on-shore professional technicians can be replaced with remote monitoring using locked-position sensors. According to the NPT lifeboat brand [15] release hook tests, the results of their study indicates that all design requirements in our device satisfy with the LSA Codes. It is noted that in the above case that unlocked does not mean fully open and that some factors may cause the displacements for possible unexpected openings. The difference between locked and unlocked positions is defined by differences of about 3~4mm in the vertical distance for such sensor detectors, whereas locked and fully open conditions have differences of 60mm and above. Further information regarding the testing and operation of the release hook locked-position monitor is provided in the online-video available via the following link [16]:
https:// www.youtube.com/watch?v=ICJDYNb_iLg .

5. CONCLUSION AND DISCUSSION

A major achievement of this study is the development of the release hooks locked-position monitor for enclosed lifeboats that can enhance the safety of lifeboat RRS with unsealed pull rod. To control casualties resulting from the accidental openings of release hooks, the SOLAS Convention stipulates that either all enclosed lifeboat hook RRS be equipped with FPDs on lifeboat for exercise/ training/ maintenance/ inspection of the lifeboat. Although these devices prevent the unexpected opening of hooks, they also complicate the hook release process during emergency evacuations. For example, when crews attempt to release lifeboats in emergencies, FPDs may be too difficult to release or break, which can also lead to substantial casualties.

For all ships, not later than the first scheduled dry-docking after 1 July 2014, but not later than 1 July 2019, lifeboat on-load release mechanisms not complying with paragraphs 4.4.7.6.4 to 4.4.7.6.6 of the LSA Code shall be replaced with equipment that complies with the Code. The product developed in this study, that is, the release hook locked-position monitor for enclosed lifeboats, can assist whether or not the release hooks fulfil the three criteria of this code. During drills or inspections, the monitor can automatically detect whether the hooks are locked or unlocked and determine the current situation of the hydrostatic interlock.

The monitor device is available to unsealed pull rod only. Other limitations of the proposed device are as follows: (1) For situations where the launching appliance wire falls during release/retrieval, causing lifeboats to fall into water, the monitor is unable to detect abnormalities; this situation cannot also be prevented by FPDs (2) for sudden breakage of the hook release mechanism during lifeboat release/retrieval operations due to erosion or insufficient strength, the alarm is still activated, but without sufficient time to prevent lifeboats from falling into the water. However, for hook displacements caused by mechanical damage and possible subsequent hook releases, the monitor transmits an immediate warning. (3) The monitor only detects whether the release hooks are locked or unlocked, it cannot detect whether the hooks are affixed to the suspending rings. To detect whether the hooks are affixed to the suspending rings, video systems or other sensors must be employed. Furthermore, because lifeboats are placed on deck and exposed to sea conditions, the material selected for these components must be meet the requirement of MSC.Res.320 and MSC.Res.321 [17, 18]. In summary, despite the limitations, the proposed release hook locked-position monitors for unsealed pull rod can reduce potential incidents of accidental hook openings by more than 80% than uninstalled conditions.

The various types of enclosed lifeboat release hooks exhibit several design differences; examining these differences is an objective for the authors' subsequent research. Additionally, although freefall lifeboats do not result in crew casualties caused by accidental lifeboat releases, to ensure the safety of freefall lifeboats, their locking systems must also be investigated. But for some release cables, pull rod cannot be detected by sensor detector since it is in a sealed box. In summation, the release hook locked-position monitor increases the safety of release hooks, protects the lives of crews, and reduces crew members' concerns of safety issues during lifeboat drills. Therefore, if the SOLAS Convention can stipulate that lifeboats with unsealed release cables be equipped with the proposed monitors, the safety of lifeboat releases and retrieval operations can be increased. We hope that this concept of on-board monitoring can be applied in the near future by all lifeboat manufacturers, classification societies, and ship owners.

6. ACKNOWLEDGEMENTS

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