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Root cause analysis of the fracture of a sonar window caused by hydrostatic, hydrodynamic, and transient forces around a ship

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ABSTRACT

Sonar systems are installed in naval vessels to inspect objects in the sea. When the system is installed at the bulbous bow of the ship, it can be vulnerable to fractures in rough seas due to hydrostatic and hydrodynamic forces, such as fluid-induced forces, and transient forces, such as slamming and collision with submerged foreign objects. In this paper, root causes analysis (RCA) of the fracture of a sonar window of a typical naval vessel was performed. To identify the root causes of the fracture, a numerical analysis was performed of the stress distribution on a sonar window under various extreme conditions. The results of the analysis, together with hypotheses of the causes of the fracture, are presented. The results of the analysis were verified by measuring the stress on the sonar window under typical sailing conditions of ships. The RCA demonstrated that buckling in response to the hydrostatic forces applied under the typical operating conditions of a water management system (WMS), in addition to excessive slamming, can cause a sonar window to fracture. Based on this RCA, corrective actions to prevent sonar window fractures include changing the material of the window and the operating conditions of the WMS.

1. Introduction

The sonar system of naval vessels is important to confer stealth capability. Recently, these systems have been installed at the bulbous bow of frigates. The bulbous bow is exposed to hydrodynamic forces, such as drag, in addition to slamming and impact forces caused by submerged foreign objects. Fig. 1 shows a sonar window installed to protect against these kinds of transient forces.

The application of high-density, high-strength material to the sonar window would decrease the detection capability of a sonar system because it would result in high transmission loss. Therefore, low-density, high-strength materials, such as glass reinforced plastic (GRP) and carbon fiber reinforced plastic (CRP), are widely used for sonar windows. Many studies have been performed to investigate their fracture patterns and strength. Carlos et al. [1] researched the relationship between the geometry and the damage sequence under tensile loads using textile-reinforced composite material. They found that this type of material, which is composed of mat fabrics, is vulnerable to sudden and catastrophic fracture when the first signification sign of damage appeared without exhibiting a previous progressive failure along the sample. Therefore, it is very

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difficult to detect the development of cracks in this kind of material. Mahmet et al. [2] used the Charpy impact test to determine the fracture toughness of filament-wound basalt fiber-reinforced (BFR) and glass fiber-reinforced (GFR) arc-shaped specimens and reported the impact energy and fracture toughness of these composite materials.

As high-strength material, such as steel, cannot be used for sonar windows, the windows can be fractured when exposed to impact forces caused by slamming and submerged foreign objects. Hence, many studies are investigating designs capable of enduring these kinds of impact forces. Kang [3] investigated the ability of a sonar window to withstand the impact of a floating object crashing into it while the ship was sailing. Based on a numerical analysis, Kang suggested that the ultimate tensile strength of the sonar window should be more than 700 MPa to enable it to withstand a collision with a log (diameter of 0.2 m and length of 2 m) when the ship was sailing at 32 knots. In addition to damage caused by collisions with submerged objects, the impact of slamming into the bow of a high-speed vessel in rough seas can cause the sonar window to fracture [4]. To define the slamming pressure, analytic and experimental studies have been performed. To define the slamming force for a real ship, Lee and Wilson [5] and Shin et al. [6] measured the slamming pressure on a model scale ship in a drop test with a pressure transducer, an accelerometer, and a force transducer. Lee et al. [7] measured the slamming pressure in a real voyage through the North Pacific Ocean. Based on various studies of slamming forces, ship resisters in many countries suggest the design criteria to endure slamming pressure [8–10].

In this paper, RCA of the fracture of a sonar window of a typical naval vessel was performed. Through the visual investigation, it can be estimated that the fracture was caused by the external force. This fracture of the sonar window occurred when the ship was sailing in a rough sea and found out it when the ship had returned to the harbor. To identify the root causes of the sonar window fracture, the material and mechanical properties of a fractured sonar window were first investigated. A numerical analysis was then performed to identify the distribution of the stress on the sonar window under various extreme conditions. Hypotheses for the causes of the fracture are presented. The results of the analysis were verified by measuring the stress on the sonar window under typical sailing conditions of ships. Finally, based on this RCA, methods to prevent sonar window fractures are suggested.

2. Investigation of the fracture

To investigate the root cause of the fracture, the RCA was conducted in accordance with the guidelines of VDI 3822 [14]. The resulting RCA logical tree is shown in Fig. 2.

The fractured sonar window was composed of a sandwich panel with GRP and NBR rubber, as shown in Fig. 3. As show in Table 1, the density, Young's modulus, and ultimate tensile stress (UTS) were measured according to DIN EN 14125 [12] to determine the mechanical properties of the panel. In Table 1, the ultimate tensile stress (UTS) is 214 MPa, which is sufficiently over (111.3%) the allowable limit (192 MPa) suggested by the manufacturer, although the Young's modulus is only 85% of the value suggested by the manufacturer. Based on the test results of the mechanical properties of the sonar window, the low mechanical strength of the material does not appear to be a cause of the fracture.

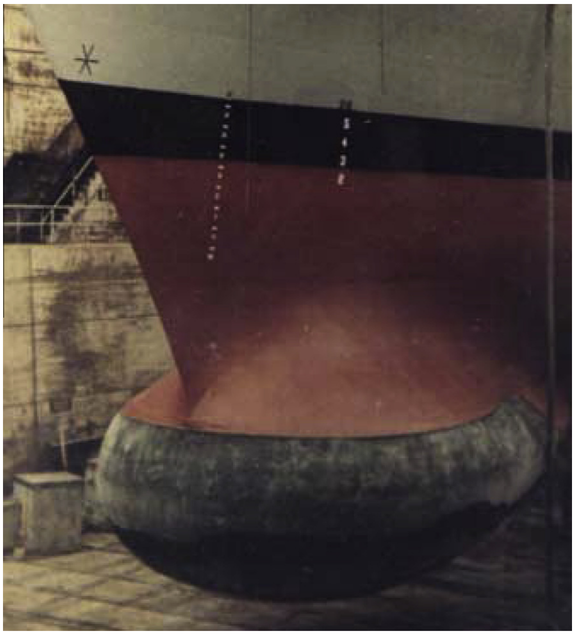

Fig. 1. Example of the sonar dome window.