Magnetic Signature Prediction of Submarine Considering Mechanical Stress by Water Pressure

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This paper predicts the change of induced magnetic field during the underwater operation of structures – the magnetic field analysis of submarines. For the FEM analysis, the pressure hull of the submarine was modeled and the strain of the pressure hull was calculated through a structure-magnetic field analysis. To copy magnetic properties according to water pressure change, ferromagnetic properties were measured through the experiment. The magnetic properties of the pressure hull were such that the B-H initial curve measured in the experiment according to the strain calculated in the structural analysis was inputted. The magnitude of the input magnetic field was 31,000nT and applied horizontally. As a result, the submarine increased its inductive magnetic field magnitude in the same geomagnetic field during operation underwater.

Index Terms—Submarine, B-H curve, Stress, Degaussing, through the mechanical

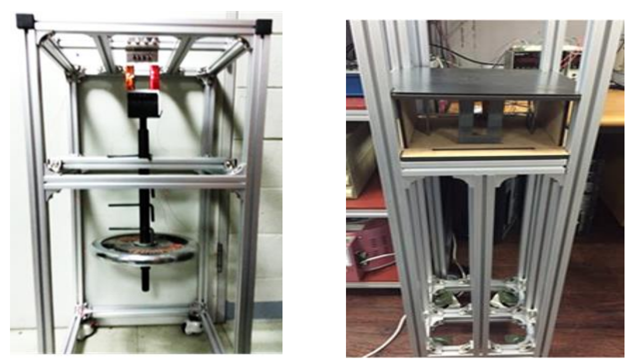
I. Introduction

THIS PAPER discusses submersible magnetic field reduction technology, a stealth technology. Submarines operate under water. In the ocean, magnetic field by submarines are easy to detect because there are few metals except for submarines. Degaussing, which is one of the underwater magnetic field reduction techniques, is a method of reducing the induced magnetic field generated by the earth's magnetic field [1].

Degaussing is a method of minimizing the induced magnetic field generated in a submarine by winding a coil in three axial directions inside the submarine to form a magnetic field in the opposite direction of the induced magnetic field of the submarine, which is induced by the earth's magnetic field. Degaussing calculates the value of the current of the coil in the three axis direction by predicting the induced magnetization of the submarine with respect to the direction of the earth's magnetic field, based on the data measured in the magnetic processing facility. However, as a submarine is deformed due to water pressure during a voyage, magnetic properties of the ferromagnetic substance are changed. This results in a variation in the magnitude of the induced magnetic field in the case of a submarine which consists of a ferromagnetic substance. Therefore, it is difficult to calculate the degaussing current due to the variation of magnetic properties during operation. The degaussing current should be calculated in consideration of the magnetic properties of the submarine under water pressure [2].

II. Magnetic property variation measurement system

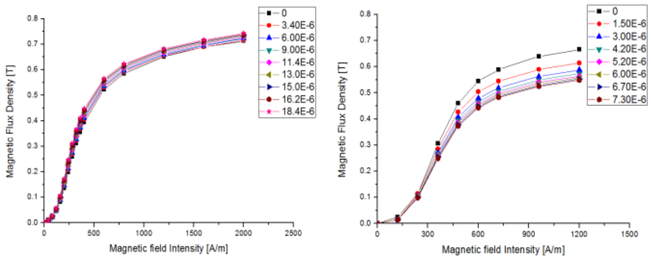
The buckling behavior of the pressure hull caused by water pressure refers to the deformation caused by the force of bending when it is made of beam. At this time, compressive stress is generated on the upper side to produce a shrinking effect, and a tension stress is generated on the lower portion, so that an elongated portion is generated. The horizontal plane, without stretching between the top and bottom, is called the neutral plane. Therefore, in order to simulate the behavior of buckling in this study, the experimental equipment is designed by dividing the tensile stress and the compressive stress based on the neutral plane. Also, a system to measure the magnetic properties of a ferromagnetic substance according to strain and magnetic field strength was developed and constructed from a data base. Based on this, a magnetic signature of the properties' variation according to water pressure variation through mechanical-magnetic coupling analysis was developed [3]. Fig. 1 shows tensile and compressive stress devices.



(a) (b)

Fig. 1. Stress device. (a) Tensile stress device. (b) Compressive stress device.

Each stress application device applied a force using a weight. The tensile stress device was basically applied with a 3 kg weight hanging table, which was always attached, and it was increased up to 83 kg. The compressive stress device weighed up to a total of 70 kg and the specimens were balanced using two identical specimens. The average strains and magnetic properties of each weight were compared. The relationship between stress and strain was nonlinear. The reason is that it was difficult to apply a uniform stress to the specimen. A B-H curve tracer was used for measuring the magnetic properties. Strain gauge and Wheatstone bridges were used for strain measuring. The material of the specimen was SS400. Fig. 2 shows the initial B-H curve according to each strain of the tensile stress device and compression stress device.

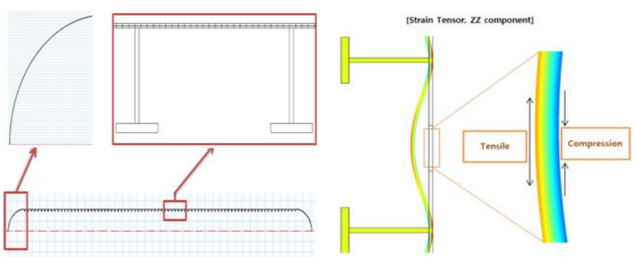


(a) (b)

Fig. 2. Initial B-H curve, according to each strain of the stress device. (a) Measurement results of tensile stress device. (b) Measurement results of compression stress device.

III. Mechanical-Magnetic Coupling Analysis

A FEM analysis was performed using a commercial analysis program. For structural analysis, the submarine modeled only the pressure hull, which had the most underwater pressure. Figure 3 shows the axial symmetry model and the structural analysis results of the pressure hull. The length of the cylindrical shell was 3,6 m, the diameter was 4.4 m, and the thickness was 0.018 m.



(a) (b)

Fig. 3. Modeling and structural analysis result. (a) 2D axial symmetry model of pressure hull. (b) Structural analysis result.

In the structural analysis, the strain of the pressure hull during underwater operation was calculated. For the ring frame supporting the shell, a fixed boundary condition was entered, so that the pressure would not be affected. In order to apply the magnetic properties measured in the experiment, material characteristics of SS400 was applied to the submarine's pressure hull. In order to apply the magnetic properties according to the strain measured in the experiment, the water pressure was set at 10,000 Pa (10 m depth). The shell between the ring frames was divided into 25 zones and the average strain per zone was calculated.

In the magnetic analysis, the strain of the pressure hull during underwater operation was calculated. It was assumed that there was no residual magnetization of the pressure hull, and only the induced magnetic field due to the geomagnetic field was considered. The relative permeability of the pressure hull was such that the initial B-H curve measured in the experiment was according to the strain calculated in the structural analysis which was inputted. The measurement position of the induced magnetic field was measured at 4.4 m, which was the length of the submarine width from the bottom of the submarine. The magnitude of the input magnetic field was 31,000 nT and applied horizontally. Fig. 4 shows the variation in induced magnetic field with hydraulic pressure.

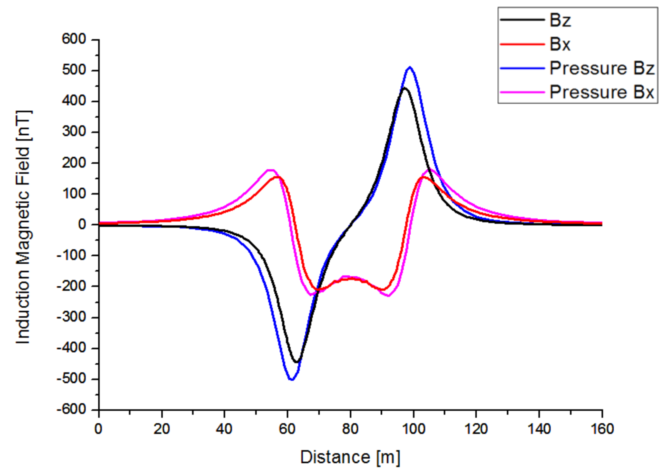


Fig. 4. Induced magnetic field according to water pressure.

Before applying water pressure, the Bz magnetic field of the submarine pressure hull was 447.3 nT, at maximum, and after the application of water pressure, the Bz magnetic field of the submarine's pressure hull was up to 510.8 nT, a 12.4% increase. Before applying water pressure, the Bx magnetic field of the submarine pressure hull was 157 nT at maximum and after the application of water pressure, the Bx magnetic field of the submarine's pressure hull was up to 181.6 nT, a 13.5% increase. Therefore, for water pressure of 10,000 Pa, the induced magnetic field of the submarine becomes larger.

IV. Conclusion

This paper presents a method to predict the change of the induced magnetic field from water pressure through underwater magnetic field reduction technology. The method used magnetic properties change according to external pressure measurement experiments and a structure - magnetic field coupling analysis.

As the submarine operated, the magnitude of the induced magnetic field increased within the same range as the earth's magnetic field. Therefore, it is necessary to calculate the degaussing current considering the magnetic properties of the submarine under water pressure. However, the ferromagnetic material used in this paper is SS400. SS400 is not used as submarine material. Therefore, in order to apply these findings to an actual submarine, a strain value due to a larger weight is required by using a material which is used for submarines. These results are expected to contribute to the improvement of domestic underwater magnetic field reduction techniques.

References

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