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SHIP'S DE-PERMING PROCESS USING COILS LYING ON SEABED

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Abstract

A ship built from ferromagnetic steel disturbs the uniformity of the Earth's magnetic field. Changes of ship's signature are due to the magneto-mechanical interaction of the hull with the Earth's magnetic field. The ship's magnetic field can be detected by a magnetic naval mine. For this reason, the vessel has to be demagnetized. There are several methods of ship's de-perming. The results of experimental and computer simulations of the ship's de-perming process using coils lying on the seabed are presented in this paper. The simulation of the de-perming process with a hysteresis model of ship's steel was carried out in Opera-3d 18R2. The laboratory experiments were carried out using a physical ship's model, several Helmholtz coils, magneto-resistive sensors, etc. The experiments and computer simulations have shown that ship's de-perming with coils lying on the seabed is possible. The values of coil currents are over dozen times greater than those used in the standard method.

Keywords: magnetic field, ship, de-perming, energy de-perming.

1. Introduction

A ferromagnetic ship disturbs the Earth's magnetic field in its surrounding. This disturbance bears the name of ship's magnetic signature. Each ferromagnetic vessel contains permanent and induced magnetization [1, 3–11, 17, 18, 22–24]. The permanent magnetization of a ship changes due to the magneto-mechanical interaction of the hull with the Earth's magnetic field. The ship's magnetic field can be detected by a magnetic naval mine. Therefore, for the safety of the naval ships not only their reliability and dynamics in the automatic determination of changes of the path are required, but what is also necessary is a periodic de-perming procedure [13,14]. The de-perming procedure is also used for other devices [19–21]. The magnetic signature must be lower than mine's threshold sensitivity. For this reason, the vessel has to be demagnetized [5, 6, 8, 12]. This procedure is repeated once every period to maintain the desired magnetic signature of the ship. There are several methods of ship's de-perming [1, 2]. An example of the classical de-perming method is shown in Fig. 1 [7].

Fig. 1. Admiral Gorshkov-class frigate during demagnetization [7].

The method of ship's demagnetization using coils lying on the seabed has a great advantage, because the de-perming time is shorter than that in the classical method. The simulation of the ship's de-perming process enables to analyse and improve it. This paper presents computer and experimental results of de-perming a submarine model with coils lying under the model. It should be noted that some quantities in the system are not directly measured but can be determined indirectly as a result of mathematical calculations [15]. In the examined case the distribution of magnetic flux density within the entire volume of the ship's side is not directly determinable with experimental methods but only with an indirect method employing a model of the object (the ship) [12, 15, 16]. The computer simulations were carried out in Opera- 3d 18R2.

2. Simulation research

2.1. Numerical model

A simple model of submarine was designed in Opera-3d (Fig. 2). The diameter and length of the model are respectively D and $L = 11D$. There are no bulkheads inside the model. The *West–East* (WE) magnetic direction of the submarine model was assumed in the deperming process. In this case the submarine magnetization along the longitudinal axis is minimal. The demagnetization coils lying under the model are shown in Fig. 2. The length and width of the median coil are respectively $15D$ and $10D$, while the corresponding dimensions of the lateral coils are $5D$ and $10D$, respectively. The central coil generates the demagnetizing field and the side coils enable to decrease magnetization of the submarine along the longitudinal axis (Fig. 3).

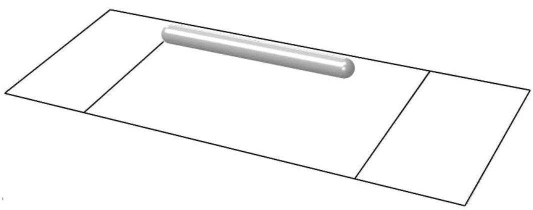

Fig. 2. Submarine model with demagnetization coils.

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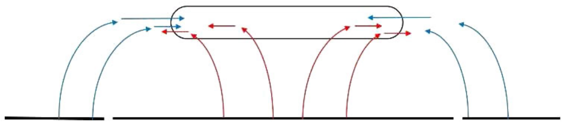

Fig. 3. Decreasing the submarine magnetization along the longitudinal axis.

The FEM grid of the submarine model is shown in Fig. 4. The ship's hull is divided into four layers. The de-perming process requires a nonlinear solution of the magnetic field with a hysteresis model of steel [5]. The magnetization curve of ship's steel assumed in the simulations is shown in Fig. 5. The coercive field intensity assumed in the calculations was equal to $H_c = 10$ A/m.

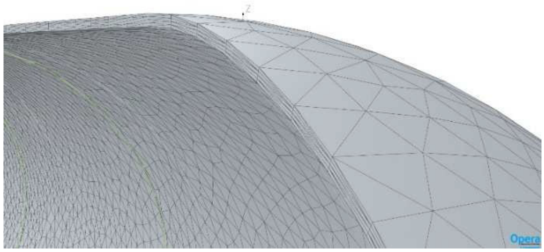

Fig. 4. FEM grid of the submarine model with four layers.

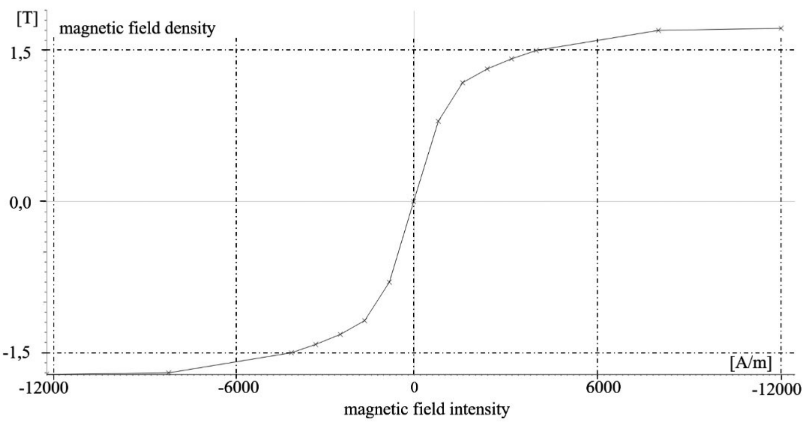

Fig. 5. Magnetization curve assumed in calculations.

The initial magnetization curve is shifted to the left side in the model of hysteresis loop. This shift is equal to the magnetic field intensity (Fig. 6). The computer simulations of the deperming process were divided into three steps:

– magnetization of the submarine model;
– demagnetization of the submarine model;
– calculation of the disturbed magnetic field of the submarine model in four directions of the Earth's magnetic field.

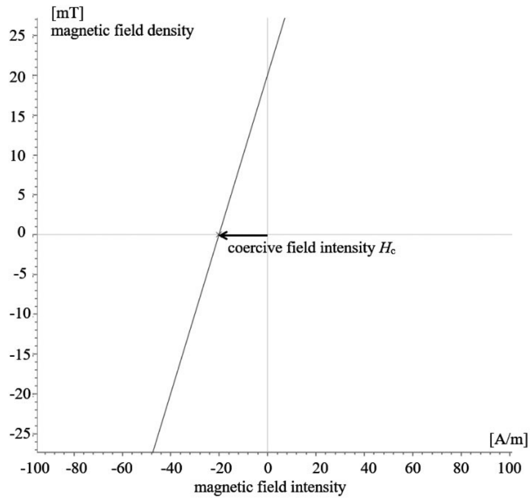

Fig. 6. Offset of the initial magnetization curve.

In the simulations, the change of permanent submarine magnetization, which by nature changes as a result of the magneto-mechanical interaction of the hull with the Earth's magnetic field, was replaced by an artificial change of the Earth's magnetic field. During the magnetization process (first step), the value of this field increases from zero up to eight times the value of the vertical component of the Earth's magnetic field (Fig. 7):

$$B_z = k_{\mathrm{Ez}}\ 50\ \mu\mathrm{T}. \tag{1}$$

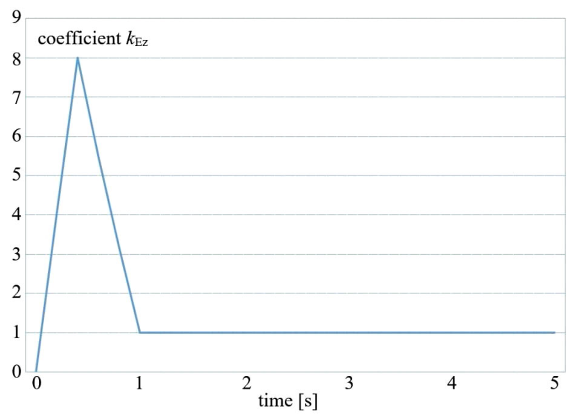

Fig. 7. Changes of coefficient k_{Ez}.

The demagnetization process (second step) starts after the magnetization. During the demagnetization process, the Earth's magnetic field does not change ($B_{\mathrm{Ez}} = 50\ \mu\mathrm{T}$, $B_{\mathrm{Ey}} = 17\ \mu\mathrm{T}$). The density of the magnetic field generated by the coils changes proportionally to a demagnetization coefficient k_d (Fig. 8):

$$B = k_{\mathrm{d}}\ 500\ \mu\mathrm{T} \tag{2}$$

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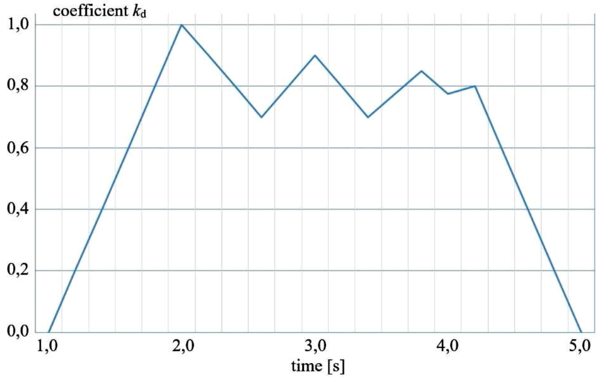

Fig. 8. Changes of coefficient k_{d}.

The signatures of the submarine model were calculated in four directions after completing the demagnetization process (third step). The ship direction change was simulated by using two large solenoid coils (Fig. 9). The currents of these coils changed in time, according to changes of two coefficients (k_{Ex}, k_{Ey} – Fig. 10).

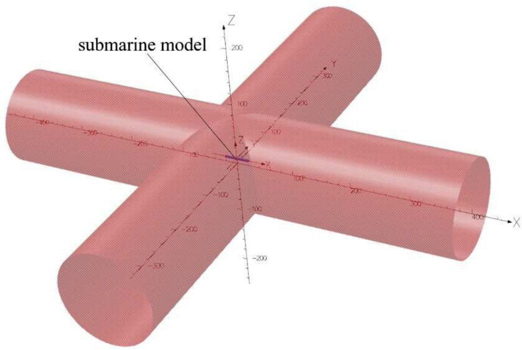

Fig. 9. Two solenoidal coils.

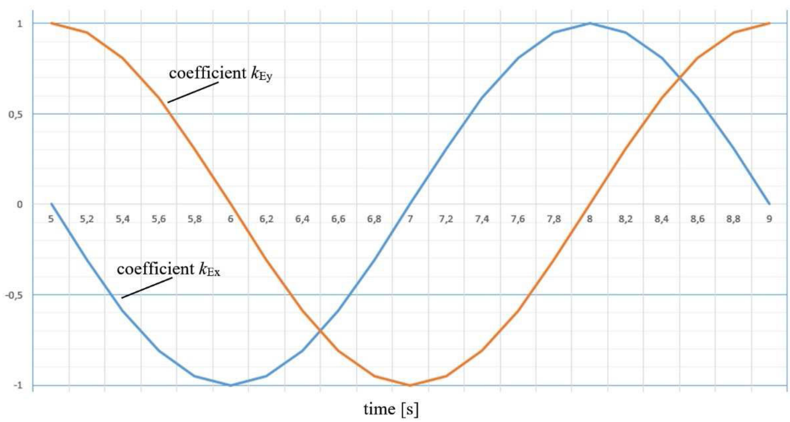

Fig. 10. Changes of coil coefficients.

2.2. Numerical results

The magnetization and demagnetization processes were simulated for WE direction of the submarine model. The vertical component of magnetic flux density at the distance D during the de-perming process is shown in Fig. 11. The vertical components of magnetic field at a distance $2D$ below the model after magnetization and after the de-perming process are shown in Fig. 12 and Fig. 13, respectively.

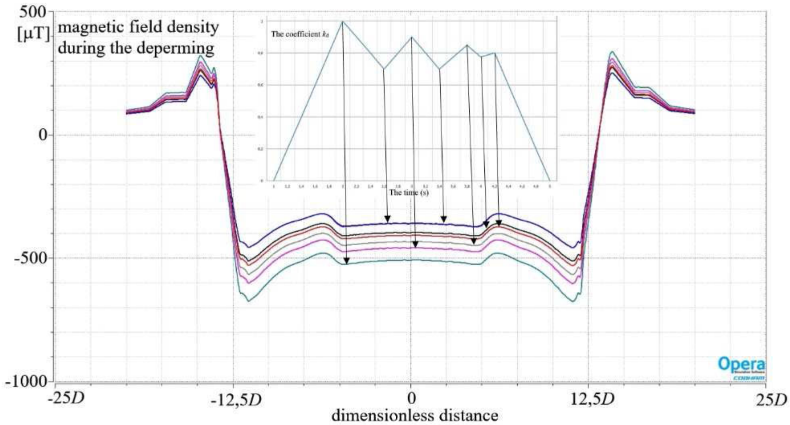

Fig. 11. Vertical component of submarine's magnetic flux density during de-perming process at distance D below the model.

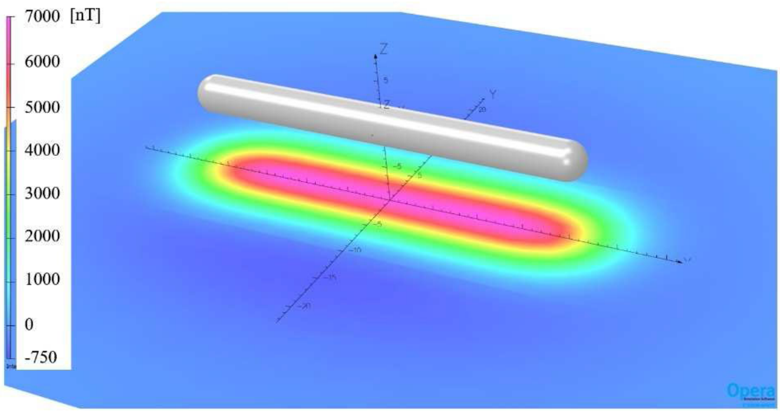

Fig. 12. Vertical component of submarine's magnetic field after magnetization.

After magnetization, the maximum value p-p of the submarine's magnetic flux density is 7750 nT, and after the de-perming process it decreases to 3000 nT. Fig. 14 shows distributions of the vertical component of submarine's magnetic field along the keel after magnetization and after demagnetization (four directions), and for the model without permanent magnetization.

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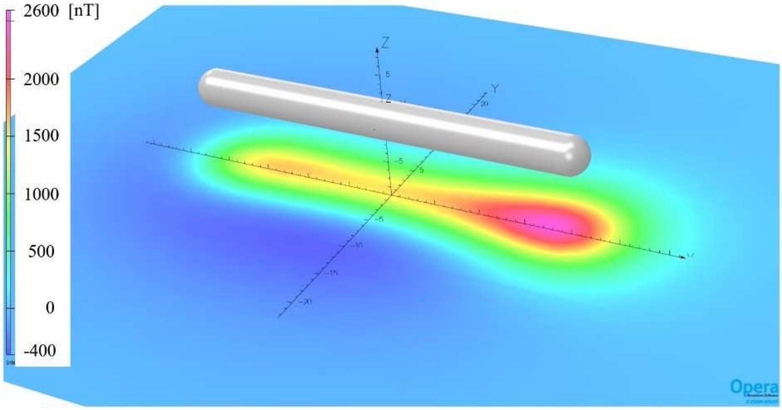

Fig. 13. Vertical component of submarine's magnetic field after de-perming process – direction NS.

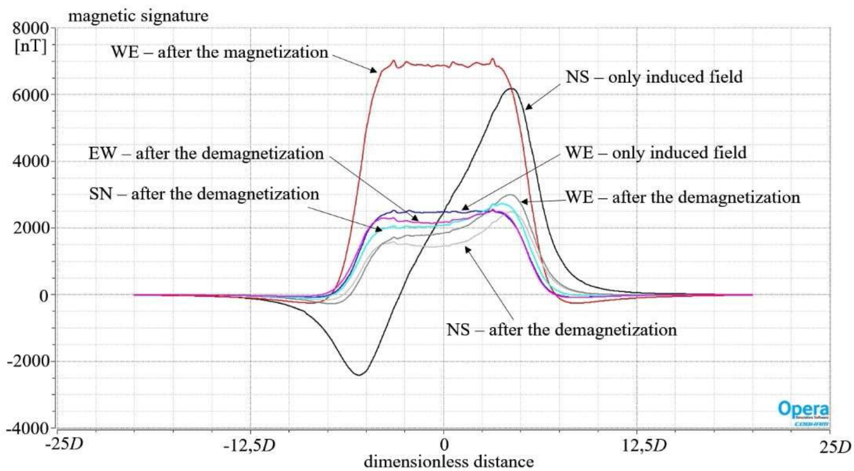

Fig. 14. Magnetic signatures along the keel.

2.3. Power consumption

The power consumption of the de-perming system is huge. All three coils generate a relatively large magnetic field. The power of each coil can be calculated from the following formula:

$$P = \left(\frac{\theta}{n}\right)^2 R_c n, \tag{3}$$

where: θ is the current value for one turn; n is the number of turns, and R_c is the resistance of one turn.

The power of each coil depends on the number of turns and the diameter of the conductor. The power consumption of each coil is shown in Fig. 15.

The conductor diameters were assumed as: $D_1 = 1$ cm, $D_2 = 3$ cm, $D_3 = 5$ cm.

The power consumption for $D_1 = 1$ cm and $n = 20$ turns is equal to 5.68 MW, while for $D_3 = 5$ cm and $n = 20$ turns it is equal to 0.227 MW. We can see that the degaussing system's

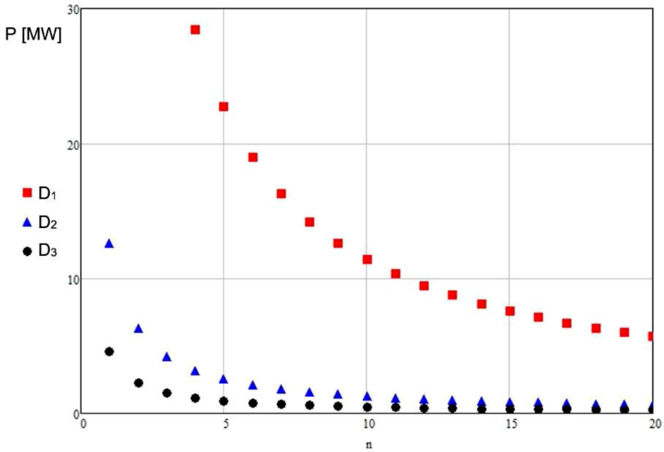

Fig. 15. Power consumption of each coil.

power is large and depends on the number of coils and the conductor diameter. It pays to invest in an expensive system to reduce the energy consumption. In the real degaussing system, in order to decrease the influence of eddy currents generated in ship's steel, the duration of the de-perming process should be greater than that assumed in the simulations. If we assume that this process will take one minute for the number of turns equal to 20 and the conductor diameter equal to 1 cm, then the consumed degaussing energy will approximately amount to 0.208 MWh.

3. Experimental research

3.1. Physical mode

The method of ship's de-perming with coils lying on the seabed was examined using a physical submarine model (Fig. 16) [10]. The proper ship steel with a thickness of 1 mm was used to

Fig. 16. A photo of submarine model [10].

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build the ship's model. The dimensions of the ship model were taken in a scale of 1:15. The research stand consisted of the submarine model, several Helmholtz coils, a moving platform with nine magneto-resistive HMR2300 magnetometers, demagnetization coils, computer control current sources, and a computer. One magnetometer was used as the reference sensor, in order to decrease industrial interferences of the magnetic field. The HMR 2300 magnetometer is a three-axis digital magnetometer with resolution of 7 nT and field range of ±200 μT. The magnetic flux density of the ship model is equal to several thousand μT. Therefore, the resolution of the used magnetometers was sufficient. The magnetometers were moved on the platform under the submarine model. The Helmholtz coils were used for generating four magnetic directions, which made possible to measure the ship's magnetic signature in four directions (NS, EW, WE, SN). The magnetic backgrounds were measured for four magnetic directions without the ship model and were subtracted from the magnetic fields recorded in the presence of the ship. In this way, the non-uniform magnetic field of the laboratory was minimized.

3.2. Experimental results

The magnetization and demagnetization processes were examined experimentally for WE direction of the submarine model. At the beginning of each experiment, the magnetization process of the ship model was carried out. In this process the same coil was used as in the demagnetization process. After magnetization of the ship, the de-perming process was started. The dimensionless results of magnetization and demagnetization processes of a physical model of submarine are shown in Fig. 17.

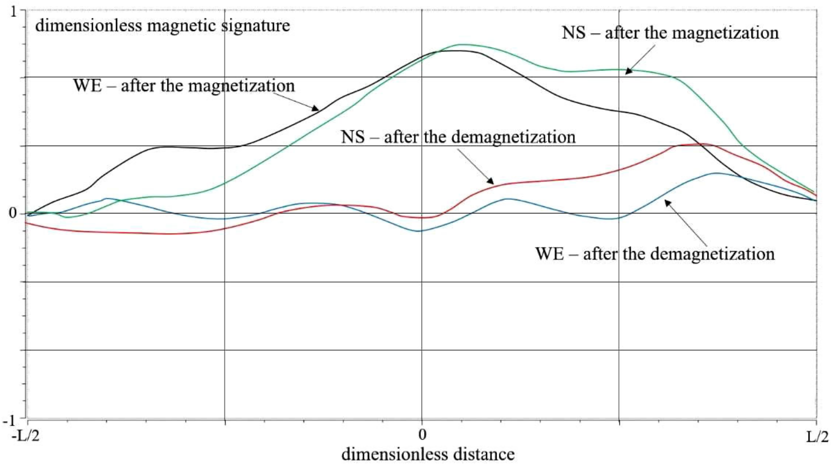

Fig. 17. Dimensionless results of magnetization and demagnetization processes of physical model of submarine [10].

4. Conclusions

As computer simulations have shown, de-perming of the ship with coils lying on the seabed is possible. The values of coil currents are several dozen times greater than those used in the standard method (coils wrapped on the ship). This disadvantage is compensated by a significantly shorter de-perming time, compared with the standard process. The level of ship demagnetization available in the designed technique in relation to the detection thresholds specified for typical naval magnetic mines is the same as in the typical demagnetization method. The power consumption of the de-perming system with 20 turns in each coil and the conductor diameter equal to 5 cm amounted to about 0.5 MW. The experimental studies have confirmed the applicability of the presented method to demagnetizing of a vessel.

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