Analysis of anhysteretic demagnetisation procedure of under-water vehicles

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Abstract—Under-water vehicles such as submarine acquire permanent magnetism due to incessant exposure of earth’s magnetic field. These vehicles are periodically subjected to demagnetisation process to remove their permanent magnetism known as deperming. In this process, the entire vehicle is closely and tightly wrapped with copper wire in helical form. An alternate linearly decreasing current is passed through the coil known as Anhysteretic demagnetisation method. However, the subjected submarine shows nonlinear reduction of magnetic flux density due to their ferromagnetic nature. The analysis is done using finite element method in which hysteretic model is used to show the effect of stress under highly applied magnetic field. The paper also includes the study of finding accurate current values using some algorithm for solenoid coil supported by its mathematical modeling. At last, the idea of establishing concrete value of initial current shots is simulated. OPERA simulation of proposed deperming protocol has been shown considering one simplified test model of submarine inside cage structure.

Keywords—demagnetisation, FEM, magnetic field, under-water vehicles

I. INTRODUCTION

The naval vessels are deployed for the security and safety of a particular nation. The maintenance and manufacturing of these ships and submarines cost much higher than the magnetic mines. The vessels without the installation of effective demagnetisation system are always vulnerable to the threat by the magnetic mines which are underlying deep inside the ocean. Also, the designing of mines is becoming complex which detects deviation in Earth’s magnetic field at very small scale. Sea mines are effective, inexpensive and easy to deploy in large number[4]. Thus various methods are implemented to protect naval vessels against threat from these sea mines. It also discusses the drawbacks of some traditional ways of doing deperming and suggests the best method for the efficient protocol. There are many practical reasons where for not zero deperm signature cannot be achieved at the end of the deperming process.

This deviation is caused due to induced and permanent magnetic field signature produced by large submarines and ships [1]. The permanent magnetic signature depends on the constant exposure to earth’s field as well as magnetic history of the submarine. These signatures are large in magnitude mainly in horizontal direction [3]. The "permanent magnetization” is build up over many months due to constant exposure under earth background magnetic field. So, they are regularly subjected to a treatment to remove vessel’s permanent magnetization for optimal magnetic silencing. The demagnetization can be achieved using an alternating applied magnetic field. The amplitude of this field is slowly reduced to minimum value. This is practically attained by placing the object inside a long solenoid demagnetizing coil driven by an ac current source [5].

The process of demagnetizing ferromagnetic objects is important for various applications at different scales. In deperming, the vessel is tightly wrapped in horizontal direction by copper wire and alternative reducing magnetic field is applied to that coil [5]. The applied field changes the domain orientation until all domains of the object are randomly oriented and their average magnetisation approaches zero. However, the magnetised object is ferromagnetic in nature which shows nonlinear behaviour due to its hysteresis property. Thus the reduction in remanent magnetic flux density is nonlinear even though the applied earth magnetic field is linear. This makes the entire deperming process very time and power consuming [2]. This motivates us to propose the nonlinear deperming protocol over the traditional way of applying linear magnetic field. The paper also investigates how the deperming signature depends upon the physical and magnetic property of the model. This nonlinear deperming process presents an optimization technique for time and energy consumption during the demagnetisation of large vessel. The finite element analysis has been done for different size models placed inside solenoid coil using two hysteresis curves under different ambient earth background field. The
simulation and designing of model is done using OPERA FEM 3D DEMAG solver [6].

The organisation of this paper is as follows: After introduction of demagnetisation process of submarine in Section I, Section II presents the complete analytical study of anhysteretic demagnetisation process. Section III illustrates the effect of parameters on the magnitude of permanent magnetic field signature. Section IV details the finite element method based simulation which shows the contour effect of high magnetic field over the surface of small model submarine pressure hull. Conclusions are made in Section V where it is found out simulation results shows how the saturated magnetic field decides the magnitude of first current shot before the process starts.

II. METHODOLOGY FOR DEMAGNETISATION

This paper gives the overall understanding of deperming method. It includes the detailed study and implementation of most recent anhysteretic method used for removal of permanent signature.

A. Analysis of model by implementing Anhysteretic demagnetisation method

In present study, we have analyzed the deperming procedure assuming the ideal condition such as isotropy, simplified model of submarine hull. The above model is tested under different conditions to determine the actual magnitude of deperming signatures. It is observed that the magnitude of signatures varies with the variation of applied Earth’s magnetic field. The model of naval vessel can be ship or submarine that can be taken for analysis. Here a simplified capsule shaped submarine model of length 38m and 4m diameter is chosen for simulation in this study as shown in Fig. 1(a). The external demagnetizing coil is designed considering the various input variables like number of turns, length and radius of coil. Each input has its own importance in making the protocol achieve its goal of minimizing the permanent signature of ships and submarines. This model is placed inside solenoid coil which has well defined geometry and produces high degree of homogeneity required for deperming as shown in Fig. 1(b) [5]. The relation between magnetic field intensity $H_0$ and deperming current $I$ for the solenoid coil is computed using (1).

$$H = \frac{N \cdot V_x}{R \cdot L}$$

A very high current needs to be supplied to the coils for the deperming purpose. In this simulation submarine model is magnetized by applied very large transient earth magnetic field using half sinusoidal wave in two following steps as shown in Fig. 2.

Step 1: The material gets magnetized till the saturation level when increasing field is applied to the peak value

Step 2: The applied field is returned back to minimum or zero level and permanent magnetic flux density is recorded at this instant. This is the highest recorded value which eventually gets diminished after the application of magnetic field.

Step 3: The demagnetizing current is applied to the externally wrapped copper coil until flux density approaches minimum level.

B. Verification of B-H curve using component contour

The major requirement of the DEMAG solver for the calculation of deperming signature is uploading the required B-H curve. The hysteresis curve for material is obtained using lab setup of B-H curve measurement. Here the traditional method of obtaining B-H curve is replaced by fixed coil setup. The universal B-H curve tracer set up consists of fixed magnetizing coil system wherein different specimens can be inserted. Current owing through the magnetizing coil produces the potential difference across internally placed resistor R, which deflects the beam in X-direction. Thus, magnetizing field H can be calculated which is proportional to potential difference across the coil. It is given by the following relation shown by equation below:

$$H = \frac{N \cdot V_x}{R \cdot L}$$

where, `N` is the number of magnetizing coil winding, R the resistance in series with the coil, L is the coil length and $V_x$ is the voltage applied to the X-input of the CRO.

The magnetizing coil is driven by AC current supply which produces the magnetic flux density of the specimen inside the coil. The magnetic flux density is measured by specially
designed integrated circuit probe. The probe has the sensitivity of 5mV per gauss. Hence,

\[ B = 0.5V_y \]

where, \( V_y \) is the voltage applied to the Y input of the CRO.

The observed B-H curve on the screen of CRO corresponding to the sample material placed in the Universal B-H curve tracer setup is shown in figure 3 and figure 4.

![Universal B-H curve tracer experimental setup](image)

**Fig. 3.** Universal B-H curve tracer experimental setup

![CRO displaying B-H curve of different samples.](image)

**Fig. 4.** CRO displaying B-H curve of different samples.

To produce more accurate future prediction of permanent signature, hysteresis curve can be modeled using neural network as B-H curve is similar to S-shaped sigmoid curve.

In this paper, we have analyzed the effect of hysteresis property which is given to ferromagnetic material of the submarine model. Here the B-H curves have been taken using the device Universal B-H curve Tracer. This hysteresis curve is being used for simulation to measure the surface contour of magnetic flux density. As the applied field is increased the observed surface flux density value is also increased until it reaches its saturation value. 1\(^{\text{st}}\), 2\(^{\text{nd}}\) and 3\(^{\text{rd}}\) quadrant is given to Demag solver of OPERA software.

III. FEM BASED ANALYSIS OF DEPERMING SIGNATURE

The analysis of test model of submarine pressure hull generated different results under the effect of varying applied magnetic field. This analysis is applicable for ship as well as submarine model. In this analysis the results have been observed using linear current excitation process with fixed eight shot having 13% decrement factor. The test and acceptance criteria for shall justify the accuracy of the developed idea. However, the results will vary for real and complex models where many practical constraints need to be considered. The earth’s background field has been removed from the data while calculating permanent magnetization. The long deperming process can be repeated if the final magnetic state of the ship or submarine does not meet signature requirements.

The B-H curve used for simulation is verified using the component contour analysis. Here we have considered a hysteresis graph with very high applied magnetic field with coercive force \( H_c \), 4320A/m and residual flux density \( B_r \), 1.5T as shown in figure 5. This high magnetic field is applied along the longitudinal direction through the solenoid coil to magnetize the material above saturation level. The flux density is observed over the surface of the model when the applied magnetic field is returned to origin. Figure clearly shows the permanent longitudinal flux density of 1.5T after as a result of component contour analysis.

![Component contour analysis of model submarine](image)

**Fig. 6.** Component contour analysis of model submarine
We observe remanent magnetic flux density or deperming signature is 61 nT due to hysteresis property of the material. In third step, the model is gradually demagnetized with alternating decreasing field. Now the analysis for case 1 is done by varying the earth’s field. It is observed that remanent flux density increased from 61 nT to 1.5 μT as we scaled up the applied field from 85 A/m (106 μT) to 4250 A/m as shown in Table I. The observed results reveal that how permanent magnetic flux density signature rapidly increases with small variations of Earth’s background magnetic field.

<table>
<thead>
<tr>
<th>Scaling factor for applied magnetic field $H_a$ (A/m)</th>
<th>Residual flux density (Deperming signature) $B_r$ (nT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>71</td>
</tr>
<tr>
<td>5</td>
<td>340</td>
</tr>
<tr>
<td>10</td>
<td>650</td>
</tr>
<tr>
<td>20</td>
<td>940</td>
</tr>
<tr>
<td>50</td>
<td>1475</td>
</tr>
</tbody>
</table>

Thus the magnitude of first current shot is successfully simulated. The hit and trial initial current excitation function failed in achieving effective reduction of high range signatures. Thus the model has been analyzed under the effect of very high applied magnetic field where it attains value which is exact and equal to measured remanent flux density as shown in Fig. 7. The observed value after simulation also depicts the relation between magnetic material properties and the distance between submarine model and keel line where the signatures are measured.

IV. CONCLUSION

The different traditional demagnetisation process has been studied and a comparison has been performed based on the efficiency of different methods. The theoretical deperming methodology is tested with one small model object using hysteresis properties of material under different applied magnetic field. The method of testing real samples and using their hysteresis curve to calculate the parameters is simulated using OPERA. Thus, the reasons for change in magnetic signature are also investigated by analysing the model by using B-H curve taken by Universal B-H curve tracer. Therefore, an efficient DEMAG protocol for naval vessels is proposed where the value of first current shot can be figured out. Depending on the observations the test case may pass or fail and hence it can be figured out if the algorithm needs further improvement. Execution of all test cases as per expectation shall mark the success of development of DEMAG algorithm. Although the investigated deperming protocol on submarine model shows promising results in the simulation as far as permanent signature reduction and current profiles are concerned, but implementing this method on large complex real vessel is again a challenging job.

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