Summary of ship comprehensive degaussing

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Abstract: Improving the magnetic stealth capability of ships [7] is of great importance to the safety of ships. The comprehensive degaussing method is an important method of ship degaussing. This paper mainly introduces the principle, coil classification, key and difficult factors of the comprehensive degaussing method and its application prospect in China.

1. Introduction

In order to prevent the attack of magnetic weapons in water and improve their magnetic stealth capability [1], ships usually need to demagnetize. The magnetism of a ship is mainly composed of fixed magnetism and induction magnetism. In addition, ships also have some magnetic field caused by eddy magnetic field and stray magnetic field. But in addition to the submarine and other ships with higher magnetic protection requirements, other ships generally only need to consider their fixed magnetism and induction magnetism. Induced magnetism is generated by the ship under the action of the earth magnetic field, which is related to the geomagnetic field in the navigation latitude area, the ship's course, trim and sway. Generally, real-time compensation is required by the ship's degaussing system. This method is not within the scope of this paper. The fixed magnetism of ships usually needs to be eliminated regularly by fixed degaussing station (ship). At present, integrated degaussing method is the main method for fixed magnetism treatment of ships by fixed degaussing station (ship).

2. Degaussing mechanism of comprehensive degaussing method

According to the theory of ferromagnetism, there are a large number of magnetic domains in ferromagnetic materials [1], assuming that the magnetic moments within these domains are uniformly distributed, the substance is not magnetically significant at the macro level. If an external magnetic field is applied around the object and the magnetic field intensity is small, then its magnetization process is reversible and the magnetic intensity of the field is linear. When the magnetic field is removed, the magnetism will return. Geomagnetic field belongs to weak magnetic field relative to ship, and its magnetization to ship is linear reversible.

When the external magnetic field is strong, then the magnetic moment inside the magnetic domain of the ferromagnetic material will concentrate in a certain direction, making the object magnetic. If the magnetic field is removed, the magnetic moment in that direction will still exist and will not return to its original position. The substance also retains a portion of its magnetism, and this residual magnetism is called residual magnetization Br [8]. This magnetization process is called irreversible magnetization [8]. However, the ship will accumulate some residual magnetic field under the influence of external magnetic field during a long voyage, which is the origin of the fixed magnetic field of the ship.
If a ferromagnetic material is magnetized for a period of time by applying a magnetic field of sufficient amplitude in a non-magnetic environment, all the domains will be deflected in the direction of the external magnetic field. If you apply a slightly smaller field in the opposite direction over a longer period of time, most of the domains will revert back, with only a few remaining in the original direction. After that, the size and direction of the external magnetic field are changed repeatedly until the magnetic field reduces to zero, so that the magnetic domain inside the material presents a uniform distribution state and is not magnetic on the macro level. The process of eliminating remanence by using alternating attenuated magnetic field to overcome irreversible magnetization of ferromagnetic material is called hysteresis free demagnetization, which is also the theoretical basis of comprehensive demagnetization method.

To sum up, the comprehensive demagnetization of a ship is a process of non-hysteresis demagnetization of a ship without interference of external magnetic field by using positive and negative alternating, amplitude difference or attenuation current of equal ratio.

3. coil classification required by comprehensive demagnetization method

3.1 Classification of working coils

The working coil used in the comprehensive demagnetization method is mainly divided into two kinds: one is the longitudinal working coil, and the other is the vertical working coil. The longitudinal working coil generally adopts the solenoid type working coil, and its cable winding mode is shown in Figure 1. Its advantages include dense magnetic field distribution, good demagnetization effect, high working efficiency of the working coil, and large manual cable winding workload.

The vertical working coil is usually designed as a saddle, and is generally fixed on the support of the degaussing station (ship) or on the sea floor. Its advantage is that there is no need for manual cable winding, and the magnetic field of the ship after degaussing is stable. Its disadvantage is that the generated magnetic field is distributed in a divergence type and the required working current is large.

The single-turn vertical working coil is shown in Figure 2.
3.2 Classification of compensation coils
According to the principle of the integrated demagnetization method, the ship needs to be placed in an environment free from external magnetic field, which is the earth's magnetic field for the ship. In the ship coordinate system, the earth's magnetic field can be divided into three components: longitudinal, transverse and vertical. Three compensating coils are usually laid in stationary degaussing stations or ships to compensate the longitudinal, transverse and vertical components of the geomagnetic field.

The longitudinal compensation coil is usually solenoid type coil, and its winding way is the same as the longitudinal work coil.

The vertical compensation coil usually adopts geomagnetic simulation coil or saddle coil. The saddle compensation coil can be divided into two layers. The geomagnetic simulation coil is usually arranged as a coplanar double rectangular coil.

The layout is shown in Figure 3:

![Figure 3. Top view of geomagnetic simulation coil](image)

The laying mode of double-layer saddle coil is shown in Figure 4:

![Figure 4. Schematic diagram of double saddle coil](image)

When the degaussing station is built along the east-west direction of the geomagnetism, transverse compensation coil shall be laid. The common laying method of the transverse compensation coil is shown in Figure 5. The x direction is the bow direction.
4. The key and difficult factors of comprehensive demagnetization of naval ships and the present situation of domestic research

4.1 The influence of working current and its transition process on demagnetization

The operating current of the degaussing is required to be large enough because a strong magnetic field is needed to completely disrupt the domain distribution of the ship. But when the working current is large enough, it is worth studying whether the transition process of degaussing current [5] will affect the degaussing effect of ships and the influence of magnetic field stability of the ships after being degaussed. The transition process of demagnetization current usually refers to such parameters as rising time, falling time, duration time, etc.

In order to study the length of the degaussing current transition for ship degaussing effect and the effect on the stability of the ship results after degaussing magnetic field, 2011 Guoyou Zhang and others by theoretical analysis and mathematical equation using the same amplitude, rise time, fall time and duration are different 5 groups of current electricity for five of the same thickness of steel plate experiments, and to measure the magnetic field changes the amount of each plate, found that the curve of the magnetic field variation difference is very small. Subsequently, in order to verify the stability of the magnetic field after the demagnetization of the steel plate, a short period of pulse current was applied to each steel plate and the changes in the magnetic field at all measured points were measured. The final curve still showed little difference. According to the experimental results, Zhang guo-you et al. believe that the length of the current transition process has little influence on the magnetic field stability of the ship after degaussing and the degaussing effect under the condition that the degaussing power supply meets the requirements. This conclusion has some significance for degaussing engineers to make degaussing current decision.

4.2 Depth conversion of ship magnetic field

When a ship is degaussing comprehensively, the measuring surface of the ship's magnetic field is usually not on the standard measuring surface [4]. Therefore, it is necessary to convert the measured results to the standard measurement surface after measuring the magnetic field of the degaussing ship. The accuracy of magnetic field conversion is always a difficult problem in China. In 2007, Kui Yanlin et al. proposed a method to convert the surface ship magnetic field using a single component ellipsoid array [4]. To verify the feasibility of the method, Yanlin Kui et al. carried out magnetic field measurements using two different sizes of ship models in both the northward and the easterly directions, and the ship between calculated value and measured value of vertical magnetic field has carried on the error analysis, the maximum relative error between calculated and measured values under 5%, the relative mean square error below 2% [4]can basically meet the requirements of ship magnetic field measurement. Kui Yan Lin et al. found that the method had less error than the
conventional magnet simulation method and was universal [4]. It has a good applicability to the depth conversion of surface ships.

4.3 The laying scheme of compensation coil when the ship is degaussing comprehensively

Generally, three sets of longitudinal, vertical and horizontal compensation coils are required for degaussing in the east-west course, and two sets of longitudinal and vertical compensation coils are also required for degaussing in the south-north course.

In recent years, people have been studying whether the number of compensating coils can be reduced and the workload of compensating coils can be reduced. In 2013, Guoyou Zhang and Guohua Zhou et al. proposed a method to improve the compensation coil based on the comprehensive demagnetization theory. This method only requires a set of vertical compensation coils and a set of auxiliary power sources [6] to complete degaussing when degaussing north-south course, and a set of longitudinal compensation coils is subtracted. The demagnetization can be completed by subtracting a set of longitudinal compensation coils. However, the electrification mode of the method is changed, and the main and auxiliary currents need to be combined to electrify and its offset [6] should theoretically be equal to the calculated longitudinal compensation current. The difference between this method and the traditional integrated demagnetization is that the original working current in the interval period is zero, but now the interval period also needs to generate current, which is equivalent to sending an extra set of longitudinal compensation current to the ship, making up for the lack of longitudinal compensation coil. However, this method can control the power supply accurately [7]. It is very demanding and difficult to implement, so this method is not applied in practical demagnetization.

4.4 Accuracy of the measurement of the ship's induced magnetic field

A ship needs to process the measured data of its magnetic field after the degaussing station (ship) carries out electrification degaussing, which needs to use the measured value of the ship's induced magnetic field, and how to improve the precision of the measured value is always a difficult problem.

At present, fixed degaussing stations (ships) usually use geomagnetic simulation method or two-course method to obtain the ship's induced magnetic field. The course of changing course of two-course method is complicated and the error is large, and the accuracy of the induced magnetic field obtained by the geomagnetic simulation method is related to the uniformity of the simulated geomagnetic field.

At present, the magnetic field mapping method [2] based on integral equation is also in the development stage to calculate the induced magnetic field of ships. According to literature [7], LEG, a French company, has applied the integral equation method to the numerical modeling of the magnetic field of a ship's thin shell. As early as 2001, Associate Professor Chengbao Guo preliminarily verified the possibility of using integral equation method to calculate the induced magnetic field of ships. In 2019, Shengdao Liu, Hansi Chen and others improved the measurement accuracy of this method. This method mainly uses integral equation method to calculate the magnetic field mapping relationship between the volume element and the measuring point [2] and the components of the ship's induced magnetic field are calculated by establishing a mathematical model \( Z_{by} \). Then Shengdao Liu, Hansi Chen et al. carried out experimental research on the real ship and calculated the relative error of the method [2]. If the error is calculated with the accurate value measured by the two-place measurement method, then the RMS error of the induced magnetic field using the integral equation method is better than that of the traditional geomagnetic simulation method \( Z_{by} \). Therefore, they believe that this method of calculating the induced magnetic field is helpful to improve the measurement accuracy of the induced magnetic field during the comprehensive degaussing.

However, the integral equation method still has its limitations. For example, for large ships, considerable storage space is needed to store the elements of asymmetric matrix [7], higher requirements for computer performance. And for the ferromagnetic structure of the complex ship, its
coefficient matrix solution costs more time and memory, which also restricts the application of integral equation method.

5. Demagnetization by formula
In 2018, Associate Professor Chengbao Guo proposed a pass-through demagnetization based on the theory of comprehensive demagnetization [1] and Magship software was used to simulate and analyze it. The method utilizes horizontal coils laid on the seabed [1]. It can greatly shorten the demagnetization time of ships and allow ships to sail over the demagnetization coil [1] can complete demagnetization work. This method still belongs to the category of comprehensive demagnetization in terms of demagnetization mechanism. In August 2020, Chengbao Guo et al. proposed a new coil design scheme based on their simulation [1] and the demagnetization experiment is carried out by using the simple shrinkage model of the coil. In this experiment, longitudinal compensation coils were added to solve the longitudinal fixed magnetism of the ship model [1] big problems and achieved a certain effect. If this method is realized, it can effectively shorten the time of fixed magnetic treatment of ships and improve the working efficiency of de gaussing stations, and its application prospect will be very broad.

6. Conclusion
At present, the treatment of ship fixed magnetism is usually carried out by de gaussing station (ship). The comprehensive de gaussing method is a common method used in domestic de gaussing stations (ships). However, with the increase of ship size, higher requirements are put forward for the power of de gaussing main power supply and the working efficiency of de gaussing station. In the future, the construction of de gaussing station (ship) should focus on studying more efficient de gaussing working coil and compensation coil arrangement scheme and electrified equipment, so as to meet the demagnetization requirements of domestic ships.

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