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Magnetic Silencing of Naval Vessels Using Ridge Regression

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Abstract: To mask and conceal naval vessels are equipped with degaussing windings. With the development of degaussing technology, large number of degaussing coils are being adopted. In some of conventional methods for calibrating degaussing system If the prediction vectors are having similarity means multi-collinearity then the current values of individual coils will be too high which is difficult to implement on naval vessels. One of multiple regression methods, ridge regression gives optimum values of degaussing coil currents possible to implement it practically on warships and submarines. Taking some submarine model to apply proposed method and the optimized calibrating mathematical model and optimization results are given. Simulation results shows advantages of this algorithm over others, in terms of reduction of the vessels magnetic signature, and this method can be used to optimize parameters related to ship or submarine's magnetic signature, so the ship or submarine degaussing system is tuned to an excellent state, and the ship or submarine's magnetic silencing is done. Furthermore, this optimization algorithm has many advantages, such as less greedy, less calculation time etc.

I. INTRODUCTION

Recently to cancel out the magnetic signature of magnetic vessels, degaussing equipment is used to avoid the detection of vessel by magnetic mines or torpedoes and to protect from them. Degaussing is the most important process of hiding techniques of magnetic vessels. Magnetic signature has components in three directions i.e., the horizontal direction, the vertical direction, and the athwart ship direction. Degaussing coils are placed in each direction are made up of longitudinal windings, horizontal windings and athwart ship windings. And these three windings are orthogonal to each other used to cancel out the signature in respective directions [1] [2]. Fig. 1 shows the typical layout of degaussing coils. The coil which encircles the ship or submarine in a horizontal plane is main coil or called as M coil, beneath the waterline. The objective of this coil is to generate a magnetic field of equal magnitude and opposite direction that will nullify ship's vertical signature.

The coil with loops in vertical direction of ships plane are called as L coils or longitudinal coils. These coils are used to produce magnetic field of equal amount and opposite direction of longitudinal component of ships signature. The A coil or athwart ship coil, is formed with loops in vertical fore-and-aft planes. The objective of these coils is to produce magnetic field of equal amount and opposite direction of athwart ship component of magnetic signature. The whole system is

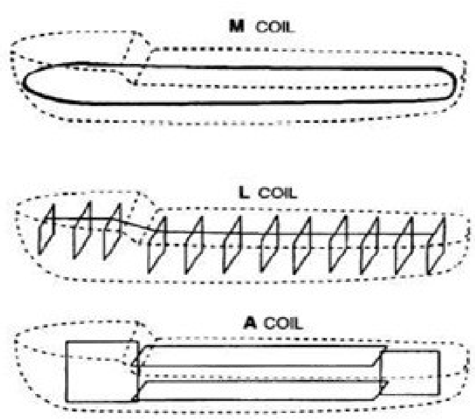

Fig. 1. Typical degaussing coil layout.

working for functions of detection of magnetic field, degaussing power and calculation of degaussing currents as shown in Fig. 2. This paper mainly focused to optimize decision-making of degaussing current. Previously peoples were using LSM (Least Square algorithm Method) to obtain degaussing current, but that method was based on the only objective of least root mean square error (RMSE). Few algorithms were used to find out optimum values of degaussing coil currents but the results showed disadvantages, i.e., long calculating time, complex programming and local optimization [3]. Ridge regression one of regularization methods is used to find out optimum values of degaussing coil currents with avoiding shortfalls mentioned above. The results compared with LSM e.g. ordinary least square method; the results showed the ascendancy of the method.

Results obtained in this method are better than ordinary least square method. The proposed method is less greedy and requires less computational time and gives best optimum values of degaussing coil currents.

II. THEORY OF VESSEL DEGAUSSING AND MODERN DEGAUSSING SYSTEM

Nowadays, the large naval vessels are formed with the heavy weight ferromagnetic substances, compared to the vessels

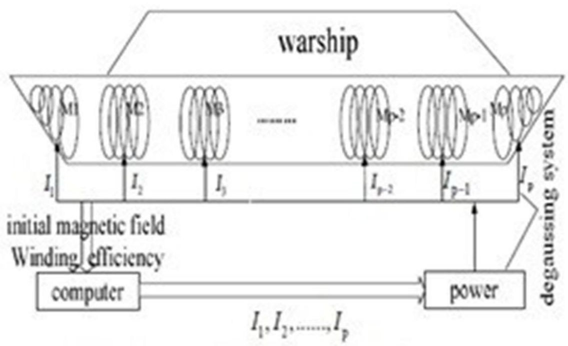

Fig. 2. Degaussing system of vessel.

build previously, which leads to the increase of value of magnetic signature, the complex distribution of magnetic field, and this leads to raise difficulties in designing, constructing and adjusting degaussing system. To solve these problems one way is to go with the subarea degaussing technique. Fig, 2 shows the graphical representation structure of degaussing system. The windings in p groups are placed on p subareas in a vessel. The degaussing system coils in other directions are similar to the vertical direction coils i.e. L coil. Before degaussing, the magnetic signature of the initial magnetic field B1 i.e. when the degaussing windings do not work (DG_off Signature) of the vessel obtained firstly, then through controlling the current values in all the windings and degaussing power reached to the optimum current values where B1 and B2 that is the total magnetic field formed by subareas windings are equal and their directions are opposite. The optimization will be stopped when the magnetic signature of field reduces to the prescribed limit. Adjusting the current in every winding and adjusting the number of turns in each winding is the objective of designing degaussing system. By passing unit current through each degaussing winding getting the degaussing capability of each winding. As shown in Fig. 3 the measurement system of magnetic field is designed where n magnetic sensors are used on b1,b2,,bn locations to measure magnetic flux.

Some of methods for adjusting vessel degaussing winding are introduced as below. Method 1: Look up degaussing handbooks, and choose the winding or winding combination that produces the magnetic field peak value closest to the present magnetic field peak value of the vessel and then adjust the current and number of turns to compensate and reduce the magnetic field peak value of the vessel. However, only one winding or a few windings can be adjusted at a time, and with the increase of degaussing winding under this method is increasingly difficult to implement. Method 2: In the past 20 years in the lab, LSM was used to fit degaussing winding effect of all models to the vessel magnetic signature. This method can better reduce the magnetic signature, because all winding effects of the degaussing system can be calculated and used. Lately, this method has been used to calibrate vessel degaussing windings and results show this method exceeds

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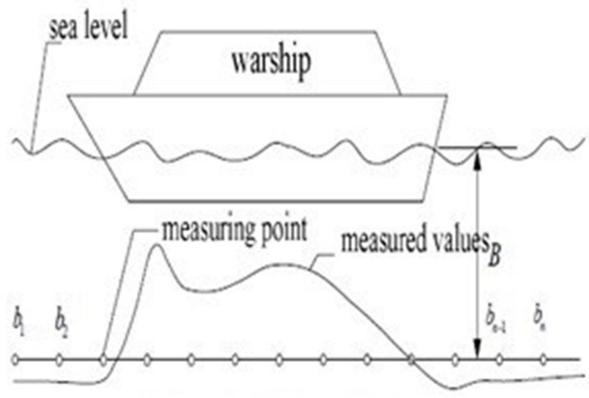

Fig. 3. Measurement of vessel magnetic field.

method1. But this method has a limitation that it only reduces the root mean square (RMS) error between the vessel magnetic signature and linear combination of winding effect (magnetic signature of the degaussing system), and other purpose, such as least residual magnetic field peak value, can not be achieved with it.

III. RIDGE REGRESSION ALGORITHM BASED ON MULTIPLE REGRESSION ANALYSIS

OLS (ordinary least square) models are BLUE - best linear unbiased estimators. But sometimes forcing unbiasedness causes other problems. In particular, if the independent variables are fairly collinear, then the variances of the parameter estimates will be huge and small differences in the input data can make huge differences in the parameter estimates. Hoerl and Kennard [4] introduced alternative method called ridge regression estimator. Ridge regression allows some bias in order to lower the variance i.e. by adding small degree of bias this method reduces the standard errors. Thus, getting the reliable values of the estimated coefficients.

A. Regression Models

The regression equation in usual notation is written as

$$Y = XB + e$$

where, Y is the dependent variable (overall signature of vessel),
X represents the independent variables (individual coil effects),
B is the regression coefficients (current coefficients to be estimated), and
e represent error(bias values).

B. Ridge Regression Basics

The regression coefficients in OLS are estimated using the following formula

$$\hat{B} = (X'X)^{-1}X'Y$$

Note that here the standardization of the variables is done with zero mean and unit variance, $X'X = R$ where R is the correlation matrix of independent variables. These estimates are unbiased so that the expected value of the estimates are the population values. That is,

$$E(\hat{B}) = B$$

The covariance matrix of the estimates is,

$$V(\hat{B}) = \sigma^2 R^{-1}$$

And we assumed that the variable matrix y is standardized,
$\sigma^2 = 1$. From the above, we find that

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remains constant. Note that increasing k will eventually drive the regression coefficients to zero.

Analytic k:

Hoerl and Kennard (1976)[4] proposed the method suggesting method for selecting k. This method is based on the formula

$k = \frac{p\sigma^2}{\widetilde{B}\,'\widetilde{B}}$ The first value of k is obtained using least square coefficients, giving the value of k. Using this new value of k, a new set of coefficients is formed, and so on.

$$V(\hat{b}_j) = r^{jj} = \frac{1}{1-R_j^2}$$

IV. RESULTS AND ANALYSIS

where, R^2_j is the R-squared value obtained from regression Xj on the other independent variables. In this case, this variance is the VIF (variance inflation factor). We see that as the R-squared in the denominator gets closer and closer to one, the variance (and thus VIF) will get larger and larger. The rule of thumb cut-off value for VIF is 10 [6]. Solving backwards, this translates into an R-squared value of 0.90. Hence, whenever the R-squared value between one independent variable and the rest is greater than or equal to 0.90, you will have to face multicollinearity.

Now, ridge regression proceeds by adding a small value, k, to the diagonal elements of the correlation matrix. (This is where ridge regression gets its name since the diagonal of ones in the correlation matrix may be thought of as a ridge.) That is,

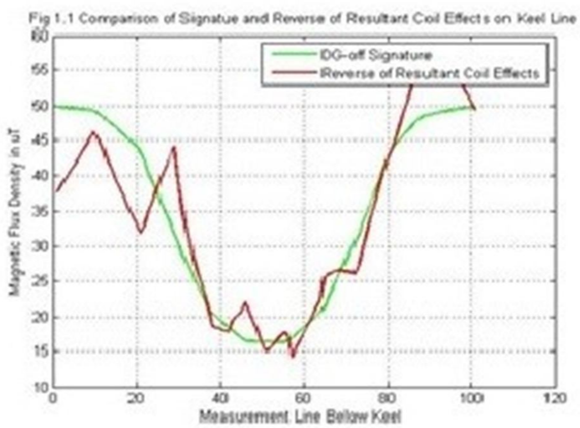

Fig. 4. ordinary least square method.

The following figures shows DG off signature (green line) which means magnetic signature of ship model in absence of coil currents. Reverse of resultant coil effect (red line) shows signature generated by passing currents through particular coils, which were calculated using ridge regression. The results of coil signature approximately same as of the DG-off signature.

A. Simulation result of ordinary least square method

k is usually less than 0.3 and value of k is positive quantity always. The amount of bias in this estimator is given by

$$E(\widetilde{B} - \hat{B}) = [\,(X'X + kI)^{-1}X'X - I]B$$

and the covariance matrix is given by

$$V(\widetilde{B}) = (X'X + kI)^{-1}X'X(X'X + kI)^{-1}$$

It can be shown that there exists a value of k for which the mean squared error (the variance plus the bias squared) of the ridge estimator is less than that of the least squares estimator.

$$\widetilde{B} = (X'X + kI)^{-1}X'Y$$

B. Ridge Trace

In ridge regression the concentration is mainly focused on selection of appropriate value of parameter k. Hoerl and Kennard (1970) [4], the inventors of ridge regression, suggested using a graphic which they called the ridge trace. In that plot they shown the ridge regression coefficient

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as function of parameter k. When viewing the ridge trace, the analyst picks a value of k for which the regression coefficients have stabilized. In general the value of regression coefficients will vary widely for small values of k and then gets stabilized. Choose the smallest value of k possible (which introduces the smallest bias) after which the value of regression coefficients

	DG-off signature	Generated signature
Max-value	50 µT	55.2 µT
Min-value	17 µT	13.8 µT

Percentage reduction in signature = 90.57.

C. Simulation result of ridge regression method

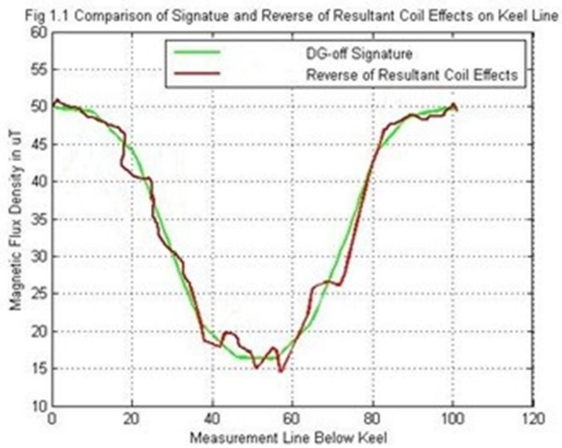

Fig. 5 Ridge regression method

	DG-off signature	Generated signature
Max-value	50 µT	51.9 µT
Min-value	17 µT	14.9 µT

Percentage reduction in signature = 96.33.

V. CONCLUSION

Ridge regression is new optimization technique used for reduction of magnetic signature to a prescribed limit by choosing the optimum value of coefficients of current in vessel degaussing systems. The algorithm has the advantages of exact calculations, easy programming and greatly reducing time to search optimization solution. Simulation results shown that the algorithm is suitable for both ships and submarines degaussing winding system optimization. The optimization algorithm ridge regression proposed in this paper can be used in many other similar optimization problems.

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