Proceedings of Krylov Shipbuilding Research Institute

36(320)

A.M. Vishnevskiy, S.A. Kirillov, A.Y. Lapovok. **Application of the computer-aided technologies in design of the ship corrosion and electric protection.** Pp. 5–16.

The Krylov Shipbuilding Research Institute developed a software product designated STAR3D Electric for numerical analysis of potential and current in multi-electrode galvanic systems that is based on original modification of the boundary element method – equivalent current method.

One of the most perspective areas of application for this new software is design of the ship corrosion and electric protection. Process of designing these systems is inseparable from solving tasks of optimization, i.e. selection of the most rational parameters (anode arrangement, current regulation laws etc), which provide both meeting requirements to the ship electric field parameters and compliance with criteria of hull and propeller corrosion protection.

New methodology of numerical analysis has a variety of possibilities, which allow effective solving of tasks related to design and optimization of the corrosion and electric protection systems. The main are: application of special types of the boundary elements – thin bars and spheres with small radius to simulate elongated structures (cables, propeller shafts) and anodes, direct input of the cables with current (simulation of power sources of the corrosion and electric protection systems), accounting internal resistance between metallic structures.

The paper proposes generalized methodology for designing active systems of the ship corrosion and electric protection based on computer-aided simulations. Also it examines practical task of calculating current and potential distribution over ship underwater surface in case with cathode protection.

A.Y. Lapovok, N.L. Sudov. **Algorithms and software for calculating ship electromagnetic field in the radio frequency band.** Pp. 17–32.

For meeting the electromagnetic radiation requirements in the design of ship it is required to consider electromagnetic compatibility of the high-frequency electromagnetic fields generated by radio communication antennae. The main method of the antenna near field calculations considering the effect of upper deck metallic structures is the numerical method of moments.

A modification of the moment method is examined that is based on solving the integral equation of the electric field. It demonstrates that the use of Galerkin procedure reduces such integral equation to the system of linear algebraic equations that allow simple interpretation as Kirchhoff's law for electric circuit. Electric analogy allows easy consideration of loads as well as calculation of the input impedance and power input of the antennae.

Measurement data and calculation results of the input impedance for a rod antenna using NEC software are applied to validate calculation algorithm.

Calculation method is realized as software package, which includes, apart from calculation core, advanced pre- and post-processing tools to generate 3-D geometrical models and visual presentation of the calculation results as electric current distributions induced over surface of the ship structures, spatial distributions of the electromagnetic field and antenna directivity patterns.

G.A. Antipov, A.V. Mikhailov, N.L. Sudov. **Application of computer-aided technologies in studies of ship ELFE sources.** Pp. 33–44.

This paper examines functions of the EMSS software providing solutions for a wide range of tasks in ship electromagnetic protection and detection using its extremely low-frequency electromagnetic field (ELFE). To calculate ELFE, the EMSS software uses physical & mathematical models that describe all ELFE main sources: static magnetization and steady galvanic currents of the moving ship, electric equipment, current ripple in windings of the degaussing units, galvanic current modulations, magnetizations of the revolving propeller shafts, induction currents in the propeller blades, rolling and yawing of the ship in the terrestrial field, magnetoelastic phenomena due to underway vibrations.

The EMSS software includes advanced digital filtering of the ELFE calculations and measurements as well as their visual presentation as pass characteristics, spectra and spectrograms. These means are intended for detection of the actual ELFE sources based on comparison of calculation results and full-scale ship measurements.

A.Y. Lapovok, N.L. Sudov, A.G. Kalimov. **Estimation of ELFE screening coefficient for ship structures.** Pp. 45–51.

This paper demonstrates calculation and experimental data on screening of the low-frequency magnetic field by metal shells with gaps and holes. The screening effect of such structures is considerably less than in the case of closed shells and weakly depends on the width of gaps and on whether metal covers of holes are closed or open.

A.V. Mikhailov, N.L. Sudov. **Relative movement of sensor and ship in calculation of extreme low-frequency electromagnetic (ELFE) signature.** Pp. 52–65.

As a rule, in full-scale measurements of electromagnetic field (EMF) the field of moving ship is determined with a fixed sensor. On the other hand, EMF estimations are usually done using simple relativistic equations for the

case when the ship is fixed and the observer is moving. The electric dipole is used as an example to demonstrate that at low speeds (relative to light speed) the equivalence of the field source and observer movement is valid for homogenous medium (vacuum).

If the source is moving in non-homogeneous or piece-wise homogeneous medium, then the medium itself is moving in the source-fixed coordinate system. In this case, the conditions at the media interface are generally different from those for the media at rest, and the principle of the field source and observer movement equivalence is not valid. However, for many important practical applications (e.g., movement of a magnetized ship hull when the medium has practically no effect on the magnetic field) the fields of a moving source can still be calculated using simpler formulas for a moving observer.

M.M. Priemskiy. **Solutions for magnetization problem of thin-wall spheroid shell under effect of magnetic fields from Raleigh region within shell material.** Pp. 66–74.

This paper examines the magnetization problem of thin-wall spheroid shell in the external magnetic field under effect of magnetic field from Raleigh region within the shell material. It is demonstrated that the solution of this problem can be reduced to solving the infinite system of non-linear equations for the coefficients of Fourier series that represents shell magnetization averaged over the thickness of shell. An approximate solution of this system is obtained and calculation results are given for magnetization, dipole moment and Raleigh loop parameters of the hysteresis of the shell magnetization for a case, when shell material is ferromagnetic steel.

Y.V. Bolshakov. **On the use of one-axis magnetic hysteresis model in solving body magnetization problems.** Pp. 75–79.

The use of one-axis magnetic hysteresis models in solving 3-D problems as superposition of independent solutions in orthogonal directions leads to significant errors in calculations. By way of example these errors are estimated using Raleigh law. The simplest case of material magnetization in dynamically de-magnetized state by magnetic field of uniform direction is examined. It is demonstrated that the value of error in calculations of residual magnetization depends on the angles between direction of magnetizing field and assumed coordinate axes.

The relative error of residual magnetization calculations in solving 2-D problems as superposition of two independent solutions obtained through one-axis hysteresis model for orthogonal directions could lead to an error equal to $1-\sqrt{2}/2 \approx 0{,}29$. In the 3-D case, maximum error occurs at $H_x = H_y = H_z$ and it is equal to $1-\sqrt{3}/3 \approx 0{,}42$. Development and application of the magnetic hysteresis vector model are required to reduce error of calculations.

A.M. Vishnevskiy, D.A. Komarov, A.Y. Lapovok, N.L. Sudov. **Fast multi-pole method for solving large systems of boundary integral equations in calculations of static magnetic field for complex ship structures.** Pp. 80–92.

The paper examines solutions for magnetostatic problems of thin ferromagnetic shells based on the boundary element method (BEM).

Using conventional iterative algorithms for solving systems of linear algebraic equations required computational resourses with BEM are proportional to the square of the boundary element number. In this case, «spatial resolution» of the method for actual ships is 3–5 m that is insufficient in calculations of the winding magnetic field.

A special calculation method is used to increase efficiency of the BEM – the fast multipole method (FMM).

This paper examines conventional formulation of the FMM that is based on expansion of the function $1/r$ using spherical polynomials. An adaptive multi-level version of the FMM is used, when boundary elements are initially sorted by cubes embedded into each other. The largest cube covers all calculation area. In this case, the required memory and number of operations with floating point increase proportionally to the first degree of the element number. However, in multi-level version the accuracy and reliability of the method are highly dependent not only on the number of expansion components but also on stability of the original BEM, as well as on selection of criteria affacting the distribution of components over cubes.

The paper examines BEM based on the integro-differential equation for surface magnetisation. Efficiency of the FMM-acceleration for this formulation is validated through solving a test problem with calculation of magnetic field for the surface ship computer model, which contains more than 100 000 of boundary elements.

Fast multipole algorithm is included into the new version of the STAR3D Magnetic Software to calculate magnetic field of the thin-wall ferromagnetic structures with arbitrary shape.

A.M. Vishnevsky, A.A. Firsova. **Software for extrapolation of electric and magnetic field.** Pp. 93–106.

The software was developed on the basis of the Tikhonov regularization method for extrapolation of magnetic (RMF software) and electric (REF software) fields using the data measured underway. The software packages have similar functions and interface.

RMF software supports extrapolation of the magnetic field to different distances using measured vertical component or three components of the magnetic field vector.

REF software supports extrapolation of the electric field using measured electric potential. The results are extrapolated to different distances taking into account, among other things, the variations in depth and seabed conductivity.

A method is proposed for estimating the total calculation error (depending on the measurement error and procedure-related error including approximation and regularization errors) based on solutions of test problems simulating the measurement and extrapolation conditions. The structure of specified field sources in this case is selected to be as close as possible to those of the measured field.

A.M. Vishnevsky, A.A. Firsova. **Choice of regularization parameter in the problem of magnetic field extrapolation.** Pp. 107–121.

In a number of problems in ship electrodynamics it is required to estimate the spatial distribution of magnetic field (MF) generated by ships, vessels and other marine structures based on MF measurements taken at stay or underway. In both cases the results of measurements are defined as a limited set, and the field must be extrapolated to a broader area, e.g. to deeper or shallower depths.

The stable approximate solution is based on the A.N. Tikhonov regularization method and truncated singular value decomposition method. The key issue in this case is the choice of regularization parameter.

The methods of quasi-optimal choice of regularization parameter values are examined by solving a number of test problems. It is established that the known algorithms fail to provide the optimum regularization parameter. A new method for choosing the regularization parameter is proposed. Under this method it is not required to know the errors of initial data and approximations and it is efficient for solving the problems both by the method of equivalent sources and spectral method.

It is shown that the proposed method for quasi-optimal choice of regularization parameter can also be used in the truncated singular value decomposition method.

R.Y. Nizkiy, B.A. Panchenko. **Diffraction of the electromagnetic wave at thin weak-conductive shells.** Pp. 122–132.

This paper examines analytical solution of the task with diffraction of the plane electromagnetic wave at multi-layer sphere. Equations obtained by Stratton for task with diffraction of the plane wave at sphere are generalized for a case of spherical shell that consist of p concentric layers of dielectric or metallic materials. To calculate field for one particular layer, it is necessary to solve $2L$ systems of the linear equations of the order $2p + 2$, where L depends on the layer parameters, frequency and required accuracy, but does not depend on number of layers in the shell.

Obtained equations are used to calculate transmission coefficients of the electromagnetic field of the plane wave into the 1-m radius spherical shell, which consists of one layer with thickness of $8 \cdot 10^{-4}$ m. Electric permettivity of the environment and shell is assumed as equal to ε_0 and magnetic permeability is assumed as equal to μ_0. Dependence of transmission coefficient tran frequency is analyzed. There are 4 resonance frequencies within range below 700 MHz. Quality factor of the resonator is increasing with increase of the shell specific conductivity, at that resonance appears within all volume of the sphere.

A.Y. Lapovok, R.Y. Nizkiy, A.B. Razletova, N.L. Sudov, O.V. Grimalskiy. **Specific aspects of the high-frequency electromagnetic field calculations for ships with glass-fiber superstructures.** Pp. 133–141.

This paper describes calculation method for electromagnetic field at upper deck and in internal spaces of the ships with superstructures made of composite non-metallic materials.

Changes in the above-water hull architecture (upper hemisphere) of modern ships envisage a wide use of non-metallic materials and dielectric coatings in ship superstructure. Screening properties of such materials in the UHF band are reduced, when compared to screening properties of the metals. Increased level of electromagnetic radiation in the internal spaces, in which electronic hardware is located, could lead to numerous problems with the electromagnetic compatibility. When antenna deck is located directly on the superstructure top, exceeding of the hygienically acceptable levels of the electromagnetic fields and electromagnetic power density is possible.

It is proposed to use simplified calculation method to estimate levels of the electromagnetic fields generated inside internal spaces of the superstructures, i.e. numerical simulation of the electromagnetic field at upper deck is done using the moment method considering only metallic structures and the electromagnetic field reduction within ship superstructure is determined using analytical estimation of the transmission coefficient.

Practical application of this methodology is illustrated using computer model of the ship with composite superstructure containing a carbon fabric. It is demonstrated that presence of the carbon is sufficient to protect from short-wave electromagnetic radiation, if structures that form closed surface have reliable electric contact with each other.

This conclusion needs to be refined for the UHF band and radar antennae, since transmission coefficient of the electromagnetic field could dramatically increase at resonance frequencies of ship spaces.

A.Y. Lapovok, N.L. Sudov, O.V. Grimalskiy. **General approach to overcoming of low-frequency breakdown in electromagnetic calculations using the moment method.** Pp. 142–148.

This paper offers a solution for the well-known theoretical problem in computational electrodynamics – instability of the moment method in case of integral equation of the electric field at very low frequencies.

The mathematical tools of the graph theory is used to define in the space of basic functions for the electric current the closed currents with zero divergence generating only rotational electric field.

Unlike other methods used to overcome the low-frequency breakdown, the suggested method could be used to solve tasks with electromagnetic field diffraction at metal structures of any topology made up of arbitrary connected wires and surface components.

N.L. Sudov. **Electromagnetic properties of the threadlike metallic structures covered by isolation layer.** Pp. 149–157.

At present the wire antennae with dielectric coating are widely used on ships. Calculation of characteristics for such antennae are often used on numerical solution of the Poklington integral equation, in which coating is not considered at all or additional capacity and induction introduced by coating are determined basing on quasi-static approximation.

Regions of applicability of the Poklington equations could be extended through usage of impedance boundary conditions at external surface of the wire with coating. Parameters of the boundary conditions are obtained through analytical solution of the task with propagation of the electromagnetic field over multi-layer circular cylinder of infinite length.

Reliability of the results is validated by comparison of experimental and calculated characteristics of a monopole antenna with relatively thick coating layer.

A.V. Milaev, E.A. Shtager. **Determination of boundaries between coherent and non-coherent zones of radar reflections from marine objects in irregular seas.** Pp. 158–163.

The process of electromagnetic wave reflection from objects located near sea surface is characterized by a number of specific features. The sea surface is forming the structure of the field incident on object as well as the structure of the field reflected from object at the location of receiving/transmitting antenna. Depending on the grazing angle of radar wave over the sea surface we identify two zones of the reflected field – coherent (mirror) reflection zone and non-coherent zone.

The coherent and non-coherent zone boundaries are determined using the concept of critical grazing angle estimated on the basis of Raleigh criterion or statistic criterion.

Based on comparison of critical angle values with measured data it is shown that the statistic criterion provides more accurate results.

I.A. Shikhov, E.A. Shtager. **Configuration of zone with significant reflection of the electromagnetic waves from sea surface.** Pp. 164–171.

Areas with significant backscattering of the radio waves considerably differ in the cases when these waves propagate over smooth and statistically non-uniform surface. When electromagnetic waves propagate over sea surface, the latter is approximated by statistically non-uniform surface with smooth irregularities with typical dimensions significantly greater than the wavelength of the electromagnetic field. Substitution of dispersions for various angles of the sea wave slope into the equation derived for isotropic waves is applied to calculate configuration of the significant backscattering zone. Values of dispersions for the angles of irregularity slope are obtained from works of academician A.I. Kalmykov. The obtained results show that zones of significant backscattering are not elliptical at any ratio between heights of field sources and observation point. This situation is true for the sea waves propagating both along and across the propagation path of radio waves.

Yu. G. Stepanov. **Theoretical investigation of magnetic field effect on cavitation processes in marine environment.** Pp. 172–183.

The effect of magnetic field on dynamics of conducting medium containing a cylinder cavity filled with saturated water vapors is investigated as a study case to examine a possibility of applying magnetic fields to influence cavitation processes in marine environment for reducing cavitation-induced damage and noise.

The problem is solved based on magnetic-hydrodynamic approximation providing for separate solution of sets of hydrodynamic equations and Maxwell equations. Differential equations and their analytical solutions are derived where coordinates and velocities of fluid particles are related to the parameters of surface and volumetric forces. Also, the effect of magnetic field on cavitation process parameters is estimated.

Yu.G. Bryadov, O.E. Mendelson. **Calculations of electric parameters of degaussing devices with dedicated power supply sources for individual winding sections.** Pp. 184–186.

Relationships are considered for estimation of electric parameters of degaussing devices with dedicated power supply sources for individual winding sections. These relationships allow comparative evaluation of various degaussing systems and optimize their parameters in the design process.

Vl.A. Boushkovsky, A.Yu. Yakovlev. **Boundary elements method of axisymmetric bodies flow calculation.** Pp. 187–200.

The paper is devoted to calculation method development of ring wing and axisymmetric body flow. The flow is nonuniform and unsteady, fluid is inviscid and incompressible. The calculation method is based on solution of

Fredholm integral equation of sources strength on body surfaces. Additionally the mathematic model includes fixed vortexes inside the ring wing surfaces and free vortexes in the wake of thet. Vortex strengths are determined by Kutta-Jukovsky condition. The problem is reduced to solving the linear algebraic equations systems for each Fourie harmonics of required variables by angle coordinate and time.

Calculation accuracy of developed method is confirmed by comparison with experimental data and analytical solutions in case of uniform, nonuniform and unsteady ring wing flow.