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MAGNETOMETRIC CONTROL SYSTEM OF MECHANICAL STRESSES OF THE SHIP'S HULL DURING CARGO AND BALLAST OPERATIONS

The global maritime community pays great attention to navigation safety, safety of life at sea and environmental protection. With the growth of navigation intensity and therefore the risk of accidents the International Maritime Organization (IMO) recommended to equip all large capacity vessels (deadweight of 20 thousand tons and more) with monitoring systems of general hull strength [1]. However, for various reasons, the shipowner avoids installation of such equipment and the modern history of merchant shipping replenished tragic cases carrying the death ships and people, loss of transported cargoes, pollution by oil products.

Even 20 – 25 years ago, good seamanship recommended to: all operations with ballast need to be completed before the ship is at sea. New conditions: the transfer of harmful aquatic organisms and pathogens (causing injury or damage to the environment, human health, property and resources) with the ballast water (biological invasion) changed the way – now the ships are forced to change ballast at sea. Really [2] it has been widely recognized that the uncontrolled discharge of ballast water and sediments from ships has led to the transfer of harmful organisms. In 2004 the International Convention for the Control and Management of Ships' Ballast Water and Sediments was adopted. According to the Convention it is recommended that, where possible, to change ballast on distance no closer than 200 nautical miles from the nearest shore at a sea depth of 200 meters.

During the cargo and ballast operations [3] it is quite difficult to control of general hull strength in real time. This is due to the impossibility of taking into account the influence of random factors (waves and swell), and during the intensive cargo operations – it is difficulty of taking into account of quickly changing loads on the ship's hull of the loaded/unloaded cargo. In some moments these loads can be exceed permissible loads that can entail permanent deformation, increased wear of the longitudinal hull constructions, torsion of hull or even to disruption or loss of ship's strength.

Based on the above, continuous monitoring of the general hull strength of large capacity vessels by measuring the mechanical stresses of ship's hull in real time is an important factor in ensuring of maritime safety and environmental protection.

Problem statement. Marine transport ship – is a complex engineering structure, which has a number of specific design features [4]. During the cargo and ballast operations on the still water the ship's hull is experiencing different kinds of loads, which are formed with loads in rough sea conditions [5]. Taking into account the above, the task of this research is to develop the structure of the magnetometric system of continuous monitoring of mechanical stresses of the ship's hull and to determine its basic components based on a fundamentally new magnetic method of control. And keep in mind that, as a rule, the ship is arbitrarily oriented in the Earth's magnetic field, the magnitude of which is superimposed on the measured magnetic field, while making a substantial measurement errors.

Review of the literature. According to these recommendations [1] monitoring system of ship's hull is designed to provide the captain and navigators of information about the parameters of pitching and mechanical stresses in the hull during the voyage, as well as during cargo and ballast operations. In accordance with [1] a simple monitoring system of ship's hull must contain: sensors for measuring mechanical stresses of bearing ship hull constructions (on both sides); accelerometer in the bow of the vessel to measure the vertical acceleration and two accelerometers amidships for measuring acceleration in the vertical and horizontal cross-rolling; microcontroller; display to represent information of sensors; a data storage device. The layout of the sensors of the ship's hull monitoring system recommended by the IMO is shown in Fig. 1.

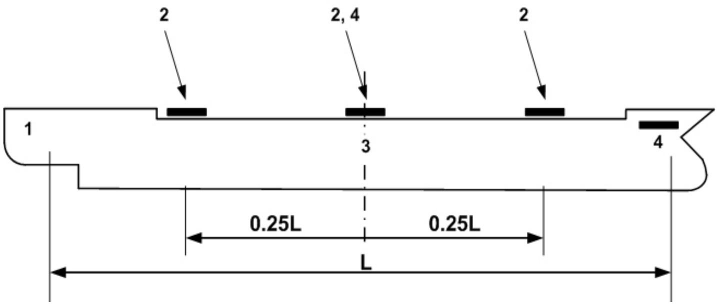

Fig. 1. The layout of the sensors of the ship's hull monitoring system recommended by the international maritime organization: 1 – ship's hull; 2 – strain sensors; 3 – midship; 4 – accelerometers; L – length of the vessel

Strain sensors should be placed [1, 6] on both sides in the area of each cargo hold and in the places of occurrence the maximum mechanical stresses at the common longitudinal bending of the ship's hull. Strain sensors should be installed in the middle part of the vessel (near midship) and in places that are ¼ the length of the ship from the forward and the aft perpendicular. Sensors of mechanical stresses are generally based on the use of classical strain control method. To increase its sensitivity a strain gauges with length from one meter are installed on deck, which leads to a considerable inconvenience during exploitation of the ship's hull by crew. The use of strain gauges or optical fiber strain gauges [7, 8] allows to determine the deformation of bearing element of the ship's hull only in the area of its location. This, and the need for continuous contact with the surface of the controlled object significantly limits their functionality and wide application. Other control devices of mechanical stresses included in the monitoring systems of ship's hulls have several disadvantages [9, 10]. Among them, the main ones are: the difficulty of operation, as well as the need for a preliminary physical impact using a transducer on the ship's construction and further study of its reaction to these effects.

Magnetometric method is one of the methods that do not require prior exposure to the metal of ship's hull any kind of physical field. The method allows to use the Earth's magnetic field in which there is marine vessel. It is found [11, 12] that the value of residual magnetization is dependent on the value of mechanical stresses in the metal (Fig. 2).

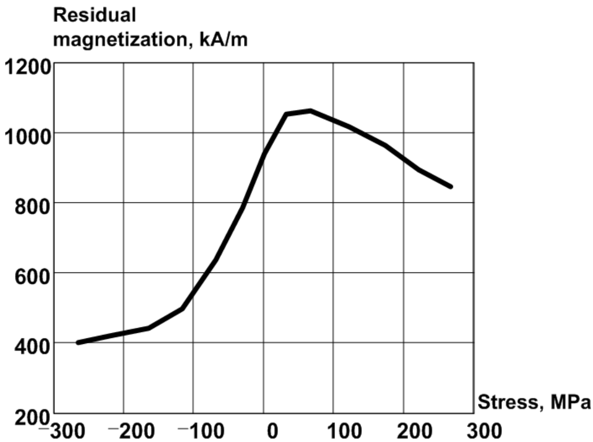

Fig. 2. The dependence of the residual magnetization from the tensile and compressive stresses in the elastic region for steel st3

Thus, by measuring the magnetic field on the ferromagnetic maintained strained steel structures and recalculating it in the residual magnetization can determine the value and the sign of the influence of mechanical stresses [12]. It should be noted that the required controlled object – hull – is in the

Earth's magnetic field and does not requires additional magnetization.

The flux gates are the most promising magnetic modulation transducers for measuring the residual magnetization on the surface of the ship's hull [13 – 17]. The proposed magnetometric method provides control of mechanical stresses in real time and uniquely connects these measured stresses with controlled parameter – the residual magnetization. At the same time a device realizing magnetometric method, built on the basis of the flux gate is simple and reliable in operation.

Materials and methods. The ship, as the object of control mechanical stresses, has a rather complex form [4, 18]. So the researched ship "river-sea" type has the following dimensions: length between perpendiculars – 128,43 m; breadth moulded – 15,63 m; depth moulded – 5,45 m. Despite the such dimensions in relation to the Earth's magnetic field, the vessel can be seen as an object of prismatic shape ("box-shape") with the appropriate dimensions. Before constructing the magnetometric system of continuous monitoring mechanical stresses of the ship's hull should be carried out an experimental research of elements of this system. During the experiments it is necessary to determine the correctness of the results of theoretical developments, to assess the metrological characteristics of the elements of the system [19]. The obtained results of experimental research will allow to develop and make experimental-industrial pattern of flux gate device for continuous monitoring of ship's hull mechanical stresses.

The experimental apparatus was developed on the basis of Helmholtz coils [19]. This coils are connected to the power supply B5-47, allows to regulate the current in increments of 0,01 A and an accuracy of 1,5 %. The flux gate is located in the center of the Helmholtz coils on the objective table, which is movable in height. The permalloy 79*NM* (Bs = 0,75 T, Hs = 2500 A/m) was used for flux gate cores. It was made annealing of this permalloy for stabilization its characteristics. Dimensions of the core: length – 0,1 m; width – $2 \cdot 10^{-3}$ m; thickness – $25 \cdot 10^{-6}$ m. The excitation winding having 667 coils is evenly wound on two cores. Additional excitation windings contain 227 coils and are located on the edges of the cores, wounding over the main winding. Output winding of the flux gate contains 667 coils and it is common to the two cores. The flux gate is excited by sinusoidal voltage of 100 kHz and an amplitude of 20 V. The obtained results of experimental investigations of magnetometric channel are shown [19] that its error from the external factors, primarily on the influence of the temperature range: -18 °C ... +40 °C, does not exceed 1.07 %. Registration the magnitude of the residual magnetization is carried out using the flux-gate magnetometer channel is made with a relative error of 3,4 %, which takes into account the error of recording devices.

Results. Control of mechanical stresses of the exploited ship's hull requires the creation a special magnetometric control system. This is due to a number of specific features of the design of the vessel, as well as its geometrical dimensions.

Control of residual magnetization is carried on the surface of ship's hatch coamings along its length. This is due to the fact that the hatch coamings [18] is one of the basic bearing elements of the vessel, extends along the entire upper deck of the ship and therefore it takes everything loads that act on the hull both outside and inside.

With a length of the vessel more than 150 m it is necessary to organize a local measurement of residual magnetization by placing marine magnetometers on coaming in areas experiencing the greatest mechanical loads during loading and unloading. Ship magnetometers provide measurement of two components of the magnetic field on the surface of the coaming and transfer the data to the control unit. Given the length of the ship, to organize transfer data and power of ship magnetometers along cable lines is rather difficult. Therefore, each magnetometer is self-powered and have the radio channel data transmission.

Flux gate excitation generator 11 (Fig. 3) is realized on the basis of microcontroller 14, which forms a signal with a pulse width modulation with a frequency f_1, which comes to the bandpass filter 13, where a signal of sinusoidal form is generated. This signal is amplified by amplifier 12 and comes to the excitation windings (3.1, 3.2) of flux gate 1.

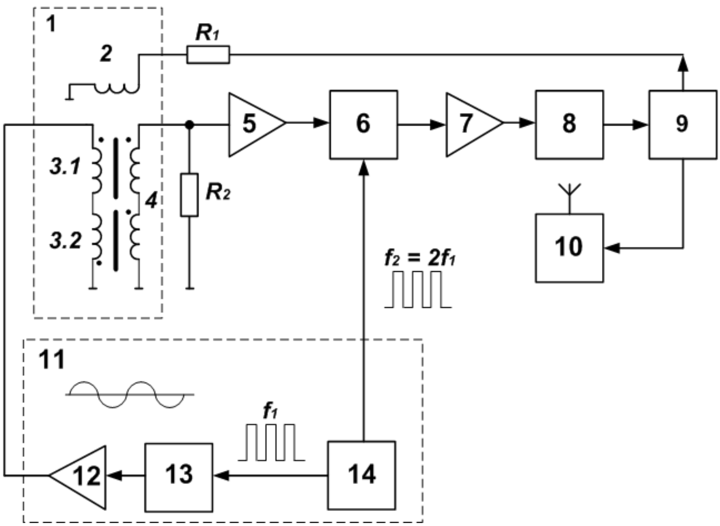

Fig. 3. A block diagram of a magnetometric channel

From output winding of flux gate 4, voltage, proportional to the measured magnetic field, is supplied to amplifier of alternating voltage 5, and then received to the synchronous detector 6. Reference signal from microcontroller with frequency f_2 is twice the frequency of flux gate excitation signal comes to the second input of the synchronous detector. The separated signal of the second harmonic is amplified by amplifier 7 and comes to an amplitude detector 8, and further, the detected signal is smoothed by the low pass filter 9. Low internal resistance of an amplitude detector and a low pass filter allowed to directly connect winding feedback 2 on the output of low pass filter. This schematic design (strengthening selected second-harmonic signal ac voltage and then its rectification) provides minimal drift channel dc voltage and high noise stability. From the output of low pass filter signal comes to transceiver, which transmits packet data on the display unit of ship magnetometer.

Exterior view of marine magnetometer (without cover) is shown in Fig. 4.

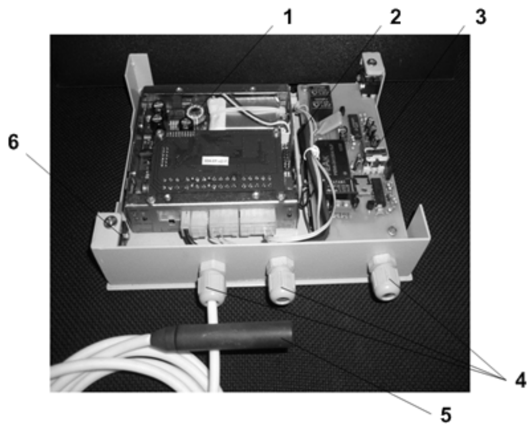

Fig. 4. Exterior view of marine magnetometer

The transceiver unit 1 together with the magnetic measuring channel is placed in a shielded case. They are powered by an alkaline battery with capacity of 2400 mA/h, which provides continuous power to the magnetometer for 5 – 6 days. Power saving mode is provided by periodicity of measurement and data transfer (1 time in 60 minutes). If magnetometer is registered deviation of residual magnetization more than 20 % from the previous measurement, then its activation period is reduced to 30 minutes and with a further change of the magnetic field intensity control period is 10 minutes. With the stabilization of the value of residual magnetization, the frequency of the survey is returned to its original state. On the board actuators 3 are located dc/dc voltage converters, connecting devices external circuits, and control elements of the battery 2. Through cable entry grommets 4 flux gates 5 and the antenna are connected to the magnetometer. To protect against unauthorized access to the magnetometer it is provided with two electronic seals 6 which are fixed together with a cover of the magnetometer. When opening the cover of the magnetometer on the display unit a signal is supplied which is recorded in non-volatile memory with fixing the date and time of opening. Thus, the objectivity of the control results is provided.

Two flux gates 3 (Fig. 5), which measure normal and tangential components of the magnetic stray field of the coaming of cargo holds of the vessel, are located in the control holder, made of brass 1. Flux gates fixed in the holder by retaining screws 2. The holder directly glued from below to the surface of the hatch coamings, in order not to create discomfort to the crew during the cargo and ballast operations and generally during exploitation of all the ship's hull.

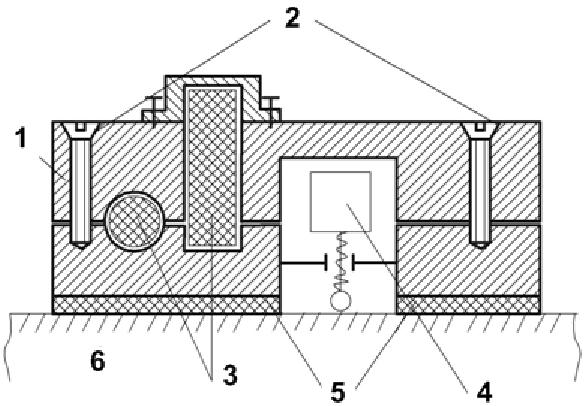

Fig. 5. The design of the control holder

As the adhesive, epoxy glue 5 are used, which provides a peel strength of 800 N/cm^2; shear resistance – 1600 N/cm^2 at a temperature of 80 °C. Such parameters of glue provides a reliable fixation of holder on the surface ship's coaming 6. However, to avoid producing false data when an emergency breakaway of the holder from the surface of controlled structure is provided in its breakaway sensor made of a limit switch 4. When isolation holder, the limit switch is triggered, and blocks the transfer of information from this magnetometer simultaneously signaling about emergency state of the magnetometer.

In six of ship magnetometers installed on the longitudinal cargo hatch coamings of portside and starboard side of the ship. To compensate for the Earth's field a magnetometer is installed on the platform of the radar antenna at a height of 11 meters from the control surface of the ship's coaming.

All information from the ship's magnetometers goes to the display unit (Fig. 6).

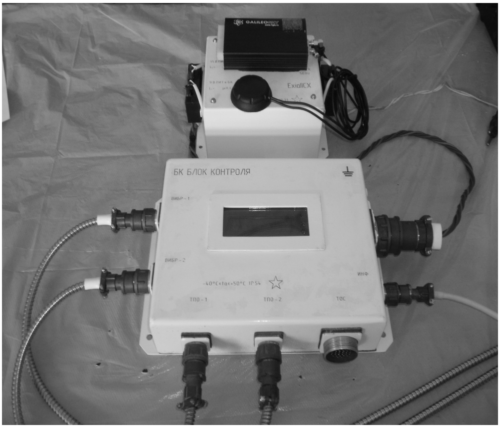

Fig. 6. Exterior view of the display unit of ship magnetic measuring complex

The display unit includes directly the display unit, power supply with backup battery and a transceiver. The screen display unit alternately is displayed readings of all magnetometers. When changing reading of the magnetometer by more than 20 %, the screen display unit is permanently displayed in a separate area its values and stored in non-volatile memory of the display unit. Non-volatile memory can store up to 8192 values with the date and time of measurement. Memory is built on a ring type and in excess of the allowable number of fixed events the first record is deleted and following record is written. The display unit has an output connecting it to computer. All current data, coming from the magnetometer, using the display unit are transmitted to a computer, where they are recalculated to the value of mechanical stresses. The information is presented separately for each board in the form of color histograms, allowing efficiently to control the mechanical stresses throughout ship's hull. The information from the non-volatile memory can be read only after entering the password. Thus, information is protected from unauthorized access, allowing objectively to evaluate the loads experienced by the ship's hull.

The display unit has a number of additional inputs for connecting other sources of information. During data transfer of magnetometers the coordinates of the vessel, the ambient temperature and the degree of heaving of the sea are fixed on the navigator. This information is required when the vessel is at sea.

Discussion. The experimental research of the elements magnetometric control system of mechanical stresses is carried out using experimental arrangement developed on the basis of Helmholtz coils. At this range of magnetic field strength measurements of the ship's hull within 50 - 5700 A/m, the obtained error of magnetometric channel allows to control the mechanical stresses in the ship's hull during cargo and ballast operations, taking into account the correlation dependence of the magnetic field strength from the mechanical stresses about 10 – 12 %. Based on the results carried out experiment it is designed and made the magnetometric control system of mechanical stresses of the ship's hull during loading and unloading operations, taking into account a number of specific features of the structure of the vessel, including its geometrical dimensions.

Conclusion. Developed magnetometric control system of mechanical stresses of the ship's hull took place sea trials on the ship "Siberian-2101" when loading 3300 tons of corn in the port of Azov (Rostov region. Russia). The obtained data allowed to estimate the value of the mechanical stresses acting on the ship's hull and the shipowner obtained information about strengthening areas of the hull at the planned repair. Sequence and intensity of ship's loading varied on the grounds of values of mechanical stresses that possible to obtain enough uniform stresses across the ship's hull. Thus the absence of local increasing stresses of the ship's hull provides safety of navigation and prolongs its term of operation. The application of the developed control system on board reduces the risk of pollution by oil products of marine environment that would be originated at disruption or loss of the general hull strength.

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