Using material science tools to monitor the qualitative condition of hull steel of ships and vessels

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Abstract.
The article discusses two methods for monitoring the structural state of steel in ship hulls. The first method is based on the use of fragments extracted from the longitudinal stiffeners of the deck. The second method of monitoring of the technical condition of the ship's hull involves using overhead sheets as "surveillance specimens" of structural damage to the hull steel, contacting (jointly) working with the hull structures, in which the highest stresses from the transported goods and waves are developed. The total number of surveillance specimens should be so that it is possible to organize systematic monitoring of the structural damage that gradually accumulates in the hull steel throughout the entire operational period of the vessel. During the operation of a ship or a vessel, hull steel is exposed to time-varying wave loads and degrades. This is reflected in the growth of structural damage to the hull steel, the steel gradually loses, and its quality state is changed.

1. Introduction
According to Wikipedia [10], many experts suggest that most of the Arctic water space will be completely free of ice in the 21st century summer, and this opens up new perspectives for sea transportation of goods. Intensive operation of ships and vessels in this and other areas is a real prospect that causes increased attention to issues in the design, manufacture, operation of ships and vessels, including ice class soon. From this point of view, the future practical application, as well as the subsequent study of such issues, has reason to be considered as very important and highly demanded. The state of our environment is of great importance for the Earth's climate system. Its pollution can contribute to the development of very serious negative consequences. Therefore, the ice of the Arctic reflects the sun's rays and thus prevents the planet from overheating. They play a large role in the systems of water circulation in the oceans, but the area of ice cover has been rapidly decreasing in recent years. The operation of ships and vessels, other structures with the danger of large scale pollution should not enhance the dynamics of these processes.

2. Methods and tools for monitoring of the technical condition of steel hulls
An unambiguous relationship between the structure of a material and its resistance to fracture has been proven [1, 2]. Therefore, when the total and the residual resources of the ship's hull and its structures are forecasted, it is necessary to have appropriate ideas about the structural damage and the structure of the hull steel.
In [1], two methods of monitoring of the structural state of steel in ship hulls are considered. The first method is based on using fragments extracted from the longitudinal ribs of the deck stiffness,
participating in the general buckling of the ship's hull and providing its longitudinal strength. The removed fragments are replaced with new ones, which are painted in bright light colors: white or yellow, indicating the date of the control fragment removal for the diagnosis of the structural state by metallography methods.

The second method of monitoring of the technical condition of the ship's hull involves using overhead sheets as "surveillance specimens" of structural damage to the hull steel, contacting (jointly) working with the hull structures, in which the highest stresses from the transported goods and waves are developed. In the appointment of the sizes of "surveillance specimens", their peculiarities of working under load as part of the ship's hull and during fatigue tests, as well as the possibility of making specimens for metallographic studies and static tensile tests, are taken into account. Places of installation of surveillance specimens in the ship's hull are structures located in the middle part of the ship's hull, sheer strake, deck stringer, cargo hatch coamings (Fig. 1) [1, 8].

The total number of surveillance specimens should be so that it is possible to organize systematic monitoring of the structural damage that gradually accumulates in the hull steel throughout the entire operational period of the vessel. The frequency of checks of changes in the structural state of the hull steel every 5 years predetermines the number of surveillance specimens of 4 - 6, depending on the selected order of diagnostics, placed symmetrically on the left and right sides of the ship.

![Figure 1. Installation places of surveillance specimens of structural damage to the steel of the ship's hull symmetrically for each side, depending on the chosen order of diagnostics.](image)

Specially prepared schedules set the required dimensions of shell doubler, working as surveillance specimens of structural damage to the shell plate, with longitudinal and transverse set systems.

To service ships, the hulls of which include surveillance specimens, special research centers should be created in the east and west of our country, studying, through surveillance specimens, the quality condition or the degree of degradation of the hull steel of ships and vessels.

The proposed methods relate to practical methods for investigating the reliability and forecasting the technical state of a ship's hull for ships with a length of 80 meters or more using non-destructive diagnostics based on a systematic study of structural damage to hull steel caused by material fatigue. In the practice of operating ships and vessels, they are not used yet. The lack of the necessary information support for navigators, technical services for the fleet operation does not allow making informed decisions; conditions for catastrophic accidents are created [4].

During operation, the ship's hull experiences a cyclic action of wave loads, and changes in the structural damage of the hull steel are caused by the manifestation of material fatigue. These changes are difficult to track and quantify, despite new acoustic, electronic methods have appeared opening up wider possibilities in technical diagnostics. By tracking fatigue structural damages over time, a selective function of these damages is obtained, the consideration of which makes it possible to describe the process of accumulation and development of structural damages in hull steel at different stages of its operation. Ensuring the safe operation of ship hulls should be determined by the permissible level of structural damage to the hull steel, this requires appropriate technical control and diagnostics. At the same time, it can be said that now they are not only far from perfect, but practically absent.
3. Improving quality control tools for ship hulls and vessels

Fatigue failures of materials in structures, especially material-intensive ones, predetermined the creation of new diagnostic tools in the form of special devices [6] of portable devices [5]. These devices include the electronic small-sized portable TEMP-2, designed for Express measurement of the hardness of steels, alloys, and their welded joints on the Brinell (HB), Rockwell (HRC), shore (HSD), Vickers (HV) scales, as well as determining the tensile strength (kgf/mm\(^2\)) according to GOST 22761-77 for carbon steels of the perlite class.

The control of the structural steel state of ships and vessels using materials science and, in particular, metallography is supplemented by classical methods of coercive force [3]. To carry out such studies, a portable coercimeter and a metallographic microscope are used [5].

The main advantage of such approaches in improving the tools for monitoring of the technical condition of the ships and vessels' hulls is the possibility of an operational assessment of the mechanical characteristics of steel without putting the ship out of action and without cutting out specimens from its hull. Thus, the unification of diagnostic measurements and their output to a new level of efficiency is realized.

The appearance of non-contact mine and torpedo weapons, and then magnetic detectors (magnetometers) of submarines in a submerged position, reacting to the magnetic field of the ship, led to the development and creation of methods and tools for protecting ships. The main method of passive protection is ship demagnetization.

Demagnetization is performed in two different ways - winding and without winding. These names should be understood as conventional, since the demagnetization of ships is performed by one or the other method using windings supplied with current (Fig. 2).

![Figure 2. Demagnetization with windings temporarily applied to the ship.](image-url)

In the first case, the windings are applied to the ship's hull temporarily, only for the period of demagnetization, or they are generally placed outside the ship, on the ground. When the second method
is used, the windings are permanently mounted on the ship and turned on while traveling through hazardous areas.

The essence of demagnetization or electromagnetic processing (EMO) is to create in a certain way a magnetic field, opposite in sign to the ship's field. The process of such an artificial decrease in the magnetic field of the ship gives an idea of the tension or coercive force, which increases with the exhaustion of the metal resource or its degradation.

Coercimetric diagnostics [3], as well as diagnostics using overhead sheets [1, 2] performing the functions of “surveillance specimens”, are carried out on existing structures. The magnitude of the coercive force of the controlled metal depends on its current state. Therefore, the methods under consideration of all non-destructive testing ones closely reflect the mechanical state of the material of a real structure. Corrections in strength calculations based on these methods will make such calculations most adequate to the true current state of the hull steel.

Currently, calculated dependencies have been obtained that determine the endurance limit for some characteristics of the metal, including the characteristics of its structural damage and structural state [1, 2].

The well-known classical fatigue tests [9] (Fig. 3) allow simulating these processes and preparing them for use in practice.

In the test scheme for circular bending of a cantilevered specimen (Fig. 4), the head of a cylindrical specimen is fixed in a cartridge. At the other free end of the specimen, there is a ball bearing suspension that creates a vertical load. The bending moment will be distributed unevenly (in the form of a shaded triangle), and the maximum value of the moment is reached at the base of the console (Fig. 3, section a—a). The greatest alternating stress $\sigma_{\text{max}}$ in this section is obtained by the formula

$$\sigma_{\text{max}} = \frac{Pl}{W} = \frac{32Pl}{\pi d^3} \quad (1)$$

where $P$ — vertical load; $l,d$ — shoulder and a cross-sectional diameter of the specimen; $W$ — a moment of resistance to bending of the specimen section.

Hardness measurements in this case are considered as preferable ones, since they directly depend on the degree of loosening of the steel.

Alternating stresses in this test are achieved by rotating the specimen around its axis together with the chuck. Rotation provides a sinusoidal voltage change from $E$ to $-E$ for each complete revolution of the specimen with a constant vertical load $P$. The level of alternating stresses varies along the length of the specimen from $E$ to the right of the loading bearing to the maximum at the base of the console. The structural damage of the metal specimen will change accordingly. If the degradation of the hull steel of ships and vessels is studied, the specimen is made from it.

When test results are processed, the specimen is divided into cylinders of small height, they are numbered, preferably from the free end of the specimen, the number indicates the position of the cylinder in the specimen during testing. Each such a part of the specimen is subjected to metallographic studies, measurements with a coercimeter, and a hardness tester.

According to the metallographic parameter of structural damage of 3% the probability is $l_{3\%}$, the results of measurements with a hardness tester are set according to the formulas [1, 2], the corresponding fatigue limits. All results of measurements, calculations are displayed graphically: $l_{3\%}$ is plotted along the horizontal axis, together with the number of hardness and coercive force, they are grouped for each selected part of the specimen; vertical axis fatigue limits.
4. Conclusion

During the operation of a ship or a vessel, hull steel is exposed to time-varying wave loads and degrades. This is reflected in the growth of structural damage to the hull steel, the steel gradually loosens, and its quality state is changed. Such qualitative changes in the hull steel determine the technical condition of the ship's hull and require system control to ensure its reliability and survivability.

The combination of metallography in the control of the quality state of the hull steel of ships and vessels match the values of the coercive force, hardness numbers with the endurance limit, metallographic characteristics of the metal, including the characteristics of its structural damage and structural state.

The effectiveness of the informative parameters of the devices allows supplementing and automating the classical diagnostics of the technical condition of the ships and vessels’ hulls. A real opportunity is created to move to a strategy of reasonable and timely repair measures, corrections of operating conditions.

The operability rises and the cost of diagnostics decreases by reducing the volume of flaw detection, increasing the accuracy of conclusions about the current technical condition of the ships and vessels’ hulls, and the forecast of the development of this state.

The economic effect is achieved by the prevention of fatigue accidents of hull structures, which are practically inevitable today because of the lack of monitoring of the technical condition of the steel hulls of ships and vessels by fatigue type.
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