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A Comprehensive Approach to Structural Integrity Analysis and Maintenance Strategy for Ship's Hull

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ABSTRACT

The structural integrity of the ship's hull is an important aspect of ensuring safety of navigation. The ship's hull is its main element and is vital for the safety of the ship and its crew. During ship operation, the hull is exposed to various factors, such as mechanical loads, corrosion, material fatigue and other actions that can lead to a violation of its structural integrity. One of the ways to ensure the structural integrity of the ship's hull is to maintain it regularly, including inspection, maintenance and repair. This article presents a comprehensive approach for analyzing the structural integrity of ship hulls and developing an effective maintenance strategy. The study encompasses various principles, formulas, and risk assessment techniques to evaluate the hull's condition, probability of damage, potential losses, and associated costs. The analysis incorporates factors such as corrosion rate, probability of damage occurrence, potential damages, and the cost of maintenance. By utilizing these calculations, informed decisions can be made regarding maintenance prioritization, resource allocation, and the development of a robust maintenance plan. The proposed approach aims to enhance the longevity and reliability of ship hulls, ensuring safe and efficient maritime operations.

1. Introduction.

Despite the development of hull maintenance technologies, shipowners still face problems related to hull damage, which can lead to accidents and loss of the vessel. Insufficient attention to the condition of the hull and lack of regular maintenance are also factors that increase the likelihood of accidents. Therefore, the condition of the hull is an important maintenance step that helps to identify problems and prevent possible accidents.

The structural integrity of a vessel's hull is one of the key characteristics that affects its operational safety and service life. Damage to the hull structure can lead to serious consequences, including ship sinking. An analysis of the literature allowed us to synthesize the necessary information and create a comprehensive overview of the topic of structural integrity of the ship's hull. In particular, article [1] discusses methods and models for assessing the strength and reliability of ship hulls, as well as problems associated with damage and loss of strength. Paper [2] discusses the basic principles of assessing the strength and reliability of ship hulls, as well as the methods used to study them. Paper [3] is devoted to the methodology for assessing the strength of a ship's hull when damaged. Papers [4-6] discuss the principles and methods of hull design, as well as structural integrity control and deformation monitoring. A general overview of the design and construction of the ship's hull is provided, including consideration of the most important components and their functions, methods and tools for monitoring structural deformations, including ship structures and practical aspects of ship hull design and construction, as well as assess-

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ment of its strength and reliability. Paper [7] also discusses methods and tools for monitoring the structural integrity of the ship's hull, including non-destructive testing methods. Scientific work [8] is devoted to the mechanical properties of materials used for the construction of the ship's hull, as well as methods for assessing their strength and reliability. The study [9] investigates the relationship between global ship accidents and ocean swell-related sea states, providing insights into the impact of sea conditions on ship safety. Article [10] presents a navigational safety assessment method using a Markov-model approach, offering a framework for analyzing and improving ship safety during navigation. Study [11] focuses on the development of an underwater robotics complex for laser cleaning of ships from biofouling, highlighting experimental results and the potential application of laser technology in hull maintenance. The paper [12, 14] explores the antifouling potential of Subtilisin A immobilized onto maleic anhydride copolymer thin films, contributing to the understanding of effective strategies to combat biofouling on ship hulls. The study also focuses on the development of advanced technologies for maintaining the integrity of ship hulls. In [13] discussed advanced nanostructures developed within the EU Integrated Project AMBIO for controlling biofouling, providing insights into innovative approaches for managing fouling organisms on ship surfaces. Paper [15] discuss the use of advanced nanostructures for the control of biofouling. The study explores the FP6 EU Integrated Project AMBIO and its contribution to preventing and managing biofouling on marine surfaces. In [16] investigated the settlement behavior of zoospores of Ulva linza during surface selection using digital holographic microscopy. The study provides insights into the colonization process of marine organisms on different surfaces. Paper [17] examined the antifouling potential of Subtilisin A immobilized onto maleic anhydride copolymer thin films. The study explores the use of enzymatic coatings to inhibit the adhesion of marine fouling organisms. In [18] presented an integral approach to vulnerability assessment focusing on ship's critical equipment and systems. The study aims to enhance the safety of maritime transportation through the application of probabilistic models. The concept of autonomous ships and the application of mathematical models in their steering process control discussed in [19]. In [20] presented a modeling approach for the dynamics of project portfolio structure in organizations, considering the resistance of information entropy. The study focuses on managing and optimizing project portfolios. Paper [21] proposed a stereoscopic approach for three-dimensional tracking of marine biofouling microorganisms. The study aims to enhance the understanding of the behavior and movement patterns of biofouling organisms. The application of imaging surface plasmon resonance for in situ studies of surface exploration by marine organisms demonstrated in [22]. The study provides insights into the interaction between marine organisms and different surfaces. The settlement and adhesion of algal cells on self-assembled monolayers with systematically changed wetting properties investigated in [23]. The study focuses on understanding the factors influencing the attachment of marine organisms. In [24] utilized digital in-line holography as a three-dimensional tool to study motile marine organisms during their exploration of surfaces. The study provides valuable information about the behavior and interactions of marine organisms on different surfaces. Articles [25, 26] propose an acoustic method for estimating the parameters of marine low-speed engine turbochargers. The study focuses on the development of non-intrusive techniques for engine performance evaluation. In [27, 28], the authors investigate the environmental efficiency of ship operations concerning the effectiveness and safety of freight transportation provision. In [29] presented a comprehensive multicriteria approach for determining the optimal composition of technical means and equipment. The paper [30] explored modeling of organizational energy and entropy creation, focusing on the complex dynamics of energy and entropy in organizational systems.

In addition, important information about the structural integrity of the ship's hull is provided by the standards and recommendations of international organizations, in particular the International Maritime Organization (IMO), the International Association of Classification (IACS), and the American Society of Mechanical Engineers (ASME). These documents contain requirements for the design and construction of the ship's hull, as well as methods for monitoring structural integrity. Therefore, the analysis of condition monitoring methods and methods for assessing the structural integrity of the ship's hull, studying the basic principles of ship hull maintenance to develop strategies and ensure the safety of ship operation is of a certain degree of relevance.

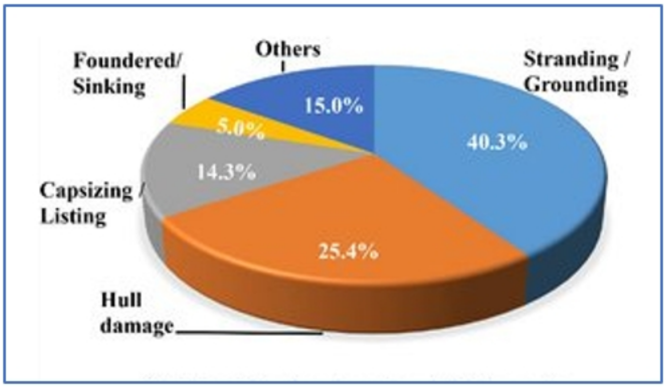
2. Materials and methods.

According to the International Maritime Organization (IMO), in 2019 alone, there were 2256 ship hull-related accidents. This amounted to 34.5% of the total number of accidents in the world's maritime transport. A year earlier, according to a report by the US Bureau of Labor Statistics, there were 59 fatal accidents on US-flagged vessels. Of these, 18 cases were related to ship hull causes. According to a report by Lloyd's Register, a ship classification society, there were 378 ship hull-related accidents over the past decade, including 17 ship losses.

This data shows that damage to the hull can lead to serious accidents and mishaps, and emphasizes the importance of regular maintenance and inspection of the hull for safety at sea (Fig.1).

The hull is the most important part of any seagoing or river vessel, as it provides the necessary strength and rigidity required for safe and efficient navigation. However, due to various factors, such as mechanical damage, corrosion, physical and chemical environmental influences, the hull can lose its structural integrity and strength. This can lead to serious consequences, such as accidents at sea and loss of life. Therefore, ensuring the structural integrity of the ship's hull is one of the most important tasks that requires constant monitoring and periodic maintenance. In this context, it is important to have a proper understanding of the technologies and methods for monitoring the structural integrity of the ship's hull, as well as to use the most modern methods of maintenance to ensure the safety and efficiency of the vessel's movement. The condition of a

Figure 1: Weather-related ship accidents based on initial events.



Source: Authors.

ship's hull can be damaged by various factors that can affect it individually or in combination, some of them presented in Table 1:

Table 1: Factors Affecting the Condition of a Ship's Hull.

Factors	Impact on the ship's hull
Impact of the marine environment	The marine environment, including salt water, sea air, and tides, can adversely affect the hull. This can lead to corrosion, warping and other types of damage;
Adverse weather conditions	Adverse weather conditions, such as storms and strong winds, can cause damage to the hull, such as cracks, tears, and deformations;
Intense	Maneuvers, such as collisions with other vessels, can cause damage to the hull;
Maneuvering	Errors in the operation of the vessel, such as overloading or improper use of the control system, can lead to hull damage;
Errors during vessel operation	The time the vessel has been in service may cause the hull to wear naturally, which may result in damage or loss;
Service life of the vessel	Failure to regularly maintain and repair the hull may result in the accumulation of damage and deformation that may adversely affect its structural integrity;
Lack of regular maintenance	Certain species of animals and vegetation, such as crayfish and algae, can cause damage to the hull, especially if the vessel is left in one place for a long time;

Source: Authors.

To prevent damage and ensure the safety of the ship's hull, it is crucial to take appropriate measures for regular maintenance, repair, and protection. This includes conducting periodic inspections, applying protective coatings to prevent corrosion, addressing identified damages through timely repairs, implementing cathodic protection systems, and implementing effective cleaning and fouling control measures. By implementing these measures, ship owners can maintain the structural integrity of the hull, extend its lifespan, and enhance the overall safety and performance of the vessel.

Undoubtedly, underwater inspection of the ship's hull is a critical procedure for ensuring safe operation of the vessel. It allows to identify potential problems, such as hull damage, corrosion coating integrity, hidden defects and other causes that may lead to a shipwreck. Underwater inspection is carried out with the help of special equipment, such as unmanned underwater vehicles (UAVs) and cleaning robots, which can visually inspect the hull and collect data on the condition of its surface (Fig.2).

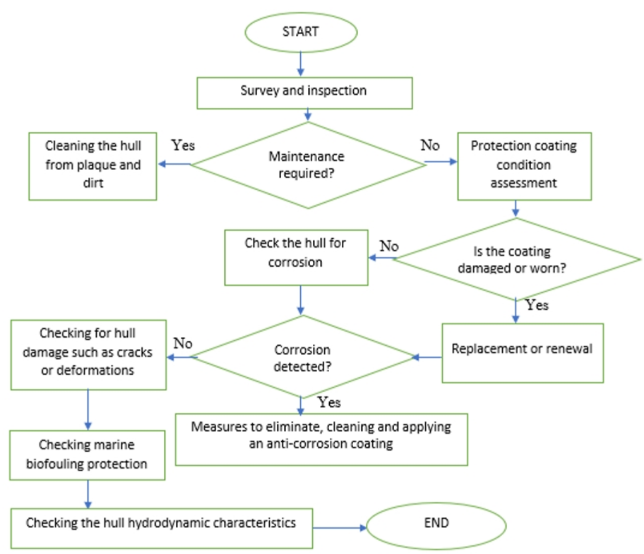
Figure 2: Condition of the outer shell of the ship's hull.

Source: Authors.

This data is then analyzed by specialists to determine the extent of wear and tear and potential issues that may require repair. The importance of underwater inspection is emphasized by the fact that hull defects can lead to extremely dangerous situations, such as loss of vessel stability, leakage of fuel or other harmful substances, water penetration into the internal compartments of the vessel, and other serious consequences. Therefore, regular underwater inspection is an important part of hull maintenance and guarantees safe operation.

The ship's hull maintenance algorithm may include the following steps (Fig.3):

Figure 3: Algorithm of ship hull maintenance.



Source: Authors.

Visually inspect the case for defects and damage. Cleaning the housing from plaque and dirt. Various methods can be used for this purpose, for example, mechanical cleaning, chemical treatment, waterjet cleaning, etc. Assess the condition of the protective coating. If the coating is damaged or worn, it should be replaced or renewed. Check the body for corrosion. If corrosion is detected, measures must be taken to eliminate it, for example, by cleaning and applying an anti-corrosion coating. Checks for damage to the hull, such as cracks or deformation. Check the marine biofouling protection system and take corrective action if it is not working properly. Check and replace fasteners such as bolts, nuts, rods, etc. Inspection and replacement of trim elements, if necessary. Check and adjust the ballast tank system. Checking the state of hydrodynamic characteristics of the hull, such as surface smoothness and coating thickness, and taking the necessary measures to improve these characteristics. The hull maintenance algorithm can be supplemented or modified depending on the type and characteristics of the vessel, its operating conditions and the presence of specific hull problems.

Figure 4: Traditional Underwater Hull Cleaning Methods.

Source: Authors.

Some general principles used for analyzing the structural integrity of a ship's hull include (Table 2):

Table 2: Principles of analyzing the structural integrity of a ship's hull.

Principle/Analysis Method	Description/Details
Strength Analysis	This involves assessing the strength and stability of the hull structure under various loads and conditions, such as static, dynamic, and environmental loads. It considers factors such as material properties, structural design, and load distribution
Fatigue Analysis	Fatigue refers to the degradation of material and structural integrity due to repetitive loading over time. Fatigue analysis involves evaluating the hull's resistance to fatigue failure and predicting the fatigue life of critical components, considering factors such as cyclic loads, stress concentrations, and material properties
Buckling Analysis	Buckling is the sudden and catastrophic failure of a structural element due to compressive loads. Buckling analysis assesses the stability of the hull structure against buckling, considering factors such as geometric imperfections, material properties, and applied loads
Hydrodynamic Analysis	This involves studying the interaction between the hull and water, considering factors such as wave loads, hydrodynamic forces, and fluid-structure interaction. It helps assess the hull's resistance to wave-induced loads and its hydrodynamic performance
Non-Destructive Testing (NDT)	NDT techniques, such as ultrasonic testing, magnetic particle inspection, and visual inspection, are used to detect and assess any defects, cracks, or corrosion in the hull structure. NDT plays a crucial role in identifying potential structural issues and ensuring the integrity of the hull

Source: Authors.

These are just a few examples of the principles used in the analysis of a ship's hull structural integrity. The specific methods and techniques employed may vary depending on the type of vessel, its operating conditions, and applicable industry standards and regulations. Main principles used for analyzing the structural integrity of a ship's hull include:

1. Stress (σ) and Strain (ε) based on the Hooke's Law:

$$\sigma = E \cdot \varepsilon \quad (1)$$

where E - modulus of elasticity of the material.

2. Bending Stress (σ_b): Bending Moment Formula:

$$M = \sigma_b \cdot S \quad (2)$$

where M is the bending moment, and S is the moment of inertia of the cross-section.

3. Strength Criteria (e.g., von Mises criterion) based on von Mises Criterion Formula:

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \leq \sigma_{yield}^2 \quad (3)$$

where σ_1 , σ_2, σ_3 are the principal stresses, and σ_{yield} - the strength of the material.

3. Results and discussion.

The following steps can be taken to develop a maintenance strategy and conduct a hull condition assessment and risk assessment using the available calculations:

- Calculation of corrosion rate;
- Estimation of damage probability;
- Evaluation of potential losses;
- Calculation of maintenance costs.

Once the calculations for the level of corrosion, probability of damage, potential losses, and associated costs have been performed, it is essential to analyze the results to make informed decisions regarding the maintenance strategy. By considering these factors, such as the extent of corrosion, likelihood of damage, potential losses, and the associated costs, maintenance activities can be prioritized, resources can be allocated efficiently, and a comprehensive maintenance plan can be developed for the ship's hull. This analysis allows for a proactive approach to address critical issues, optimize maintenance efforts, and mitigate risks to ensure the long-term structural integrity and operational efficiency of the vessel.

1. Calculation of corrosion rate:

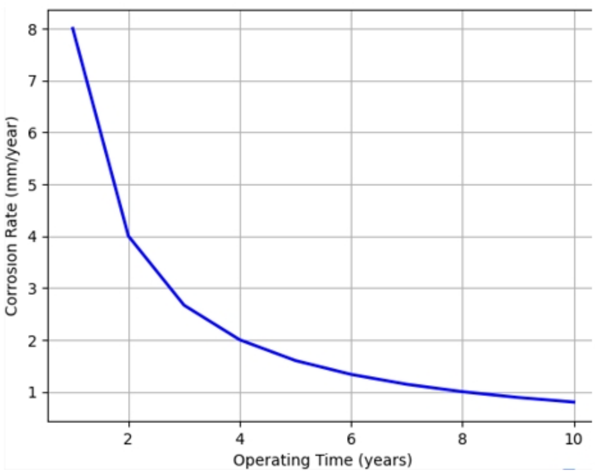
$$K_S = \left(\frac{K_1 \times K_2 \times K_3 \times Z \times A}{T}\right) \times \left(1 - e^{-K_4 \times T}\right) \quad (4)$$

Where: K_S is the corrosion rate (mm/year), K_1, K_2, K_3, and K_4 are coefficients that depend on various factors influencing corrosion, Z - coefficient accounting for the condition of the hull surface, A - the surface area of the hull (m^2), T - time of ship operation (years), *exp*- exponential function.

The coefficient K_4 determines the rate at which the corrosion rate approaches a maximum value over time. This can represent phenomena such as the development of a protective layer or a saturation effect in the corrosion process. It's important to note that the specific values for the coefficients K_1, K_2, K_3, K_4, and Z would depend on the specific conditions and materials being considered. These values would typically be determined through experimental data, expert knowledge, or published corrosion rate guidelines for the particular ship or material.

Suppose: $K = 0.1$ (coefficient for this type of corrosion), $Z = 0.8$ (coefficient that considers the condition of the hull surface), $A = 100$ (hull surface area, in m^2), $T = 10$ (time of operation of the ship, in years). Thus, in this example, the corrosion rate is 0.8 mm/year. This rate can be used to predict the decrease in the thickness of the hull walls during the year (Fig.5).

Figure 5: Relationship between corrosion rate and the ship operating time.



Source: Authors.

2. Estimation of damage probability:

$$P = \frac{N \times F \times S}{T \times R} \quad (5)$$

where: P - probability of damage occurrence, N - number of ship operation cycles, F - frequency of damage occurrence per one cycle, S - coefficient considering the influence of additional factors (for example, operation conditions, maintenance, ship age), T - time of ship operation, R - coefficient taking into account the risk of damage occurrence.

Above formula allows to consider not only the number of operating cycles and the frequency of damage occurrence, but also additional factors that may influence the probability of damage occurrence. The S and R coefficients can be determined based on data analysis, expert estimates or statistical methods. It is important to note that the specific values for S and R factors will depend on the specific conditions and factors you are considering. They can be determined by analyzing the raw data or by applying appropriate industry standards and guidelines.

$$P = 1 - e^{-\lambda T} \quad (6)$$

where: P is the probability of damage occurrence, λ is the intensity of a random event (e.g., the intensity of damage occurrence per unit time), T is the operating time of the vessel.

This formula is based on an exponential distribution and assumes that the probability of damage decreases exponentially with time. The intensity λ can be determined on the basis of statistical data, studies or expert evaluations. More sophisticated statistical analysis or modeling techniques can be used to more accurately estimate the probability of damage occurrence depending on the ship's operational time. One possible approach is to use Monte Carlo simulation. The Monte Carlo simulation generates random events of damage occurrence with specified probabilities and distributions. The results are then analyzed to estimate the probability. This code implements a Monte Carlo method to estimate the probability of damage occurrence vs. the lifetime of the ship. In this example, a large number of simulations are performed where damage events are randomly generated for each cycle of operation. The results of the simulation are analyzed to estimate the probability of occurrence of damage as a function of the ship's time of operation (Fig.6).

Figure 6: Estimation of Probability of Damage Occurrence.

Source: Authors.

3. Evaluation of potential losses:

$$U = P \times C \quad (7)$$

where: U - potential damage; P - probability of problems; C - cost of fixing the problem.

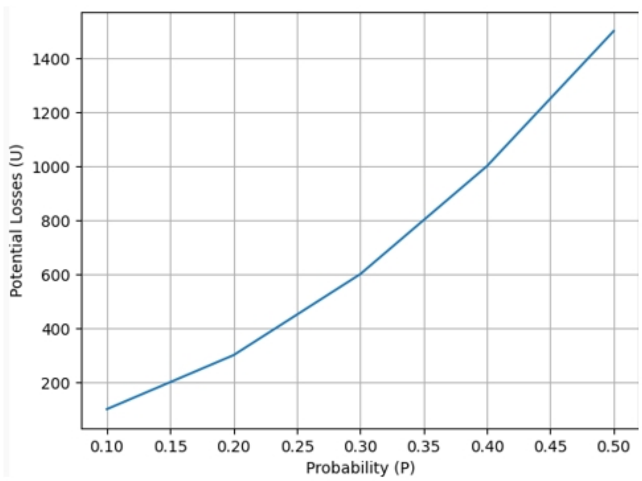
For example, let's assume the following values:

P = [0.1, 0.2, 0.3, 0.4, 0.5] # probabilities of problem occurrence;

C = [1000, 1500, 2000, 2500, 3000] # costs of problem resolution.

In the given example, we utilize the lists P and C to represent the values of probability and cost, respectively. By using a function, we compute the potential losses U by multiplying the corresponding elements of P and C. The resulting values of potential losses are then plotted on a graph, allowing us to visualize the relationship between potential losses and probability. This graphical representation enables us to analyze the impact of probability on the magnitude of potential losses, providing valuable insights for decision-making and risk assessment in various scenarios (Fig.7).

Figure 7: Relationship between the probability of problem occurrence and the potential losses.



Source: Authors.

From the graph, we can observe the relationship between the probability of problem occurrence (P) and the potential losses (U). As the probability of problem occurrence increases, the potential losses also tend to increase. This indicates that a higher likelihood of problems occurring can result in greater potential financial losses. The graph shows a linear relationship, suggesting that the potential losses are directly proportional to the probability of problem occurrence. This implies that the impact of the probability on the potential losses is consistent and predictable. The slope of the line represents the cost per unit probability. A steeper slope indicates a higher cost for each incremental increase in probability, while a shallower slope indicates a lower cost. By analyzing the graph, decision-makers can assess the potential financial risks associated with different probabilities and make informed decisions regarding risk mitigation strategies or resource allocation.

4. Calculation of maintenance costs:

$$M? = C_1 + C_2 + C_3 + \ldots + C_n \tag{8}$$

where: M_C – maintenance cost; C_1, C_2, C_3 - cost of each individual service measure; n – number of service measures.

In general, a maintenance strategy should be a comprehensive approach that includes assessing the condition of the hull, identifying risks, developing a maintenance plan, and monitoring the effectiveness of the measures taken. optimal maintenance interval:

$$I_{\text{opt}} = \frac{C_p}{C_f + (C_h \cdot (1 - \exp(-r \cdot T))) + C_m} \tag{9}$$

In the given formula, additional complexity is introduced through the inclusion of an exponential term and a rate parameter (r) that represents the rate of deterioration over time. The term $(1 - exp(-r \cdot T)$ accounts for the accumulated damage or deterioration of the hull over the maintenance interval *(T)*. The numerator C_p - represents the cost of preventive measures to reduce the probability of hull failure. The denominator consists of three components: C_f which represents the cost of hull failure, C_h - represents the cost of downtime during repairs, and C_m - represents the cost of routine maintenance.

By incorporating the exponential term and rate parameter, the formula considers the accumulation of damage over time and adjusts the cost of downtime accordingly. This allows for a more accurate estimation of the optimal maintenance interval that balances preventive measures, repair costs, and routine maintenance.

Thus, the optimal hull maintenance interval is defined as the inverse of the root value of the product of coefficients characterizing various aspects of ship operation. These coefficients should be determined based on the analysis of a particular situation and the specific characteristics of the ship's hull.

The process of ensuring the structural integrity of a ship's hull can include mathematical models that allow analyzing and predicting the behavior of the hull under various conditions. One of the main models used in this field is the Finite Element Model (FEM). A finite element model divides a ship's hull into a finite number of elements, called finite elements. Each finite element has certain mathematical characteristics such as geometry, material, and properties. The model then uses mathematical equations and numerical analysis techniques to solve these equations and predict the behavior of the ship's hull under various loads and conditions. The finite element model allows the analysis of stresses, deformations, stability and other parameters that affect the structural integrity of the ship's hull. The model can be used for determination of optimum hull design, optimization of material and component distribution as well as for prediction of hull behavior under operating conditions. From the calculation results it is possible to draw stress or strain diagrams in the ship hull, which help to visualize stress distribution and identify critical areas or points with high stresses.

Ship hull insurance is one of the most important aspects of ensuring maritime safety. Hull insurance protects the shipowner from financial losses related to damage or loss of the ship's hull. The main types of hull insurance are hull insurance and marine insurance. Hull insurance provides protection against financial losses associated with damage to or loss of the ship's hull as a result of collision, fire, explosion, pirate attack and other similar events.

Maritime insurance provides protection against financial losses related to damage or loss of the vessel's hull as a result of adverse weather conditions, flooding, cargo accidents and other similar events. It is worth noting that the terms and conditions of hull insurance may vary significantly depending on the type of vessel, its technical characteristics, operating conditions and other factors.

Therefore, when choosing insurance coverage, it is necessary to consider all the features of the vessel. In general, hull insurance is an important tool for ensuring safe navigation and protecting the interests of shipowners. In this case, it is necessary to choose the optimal insurance coverage, considering all the features of a particular vessel and its operating conditions.

New technologies in hull maintenance include various innovations and methods that help improve efficiency, safety and cost-effectiveness. Some of them may include inspection of the ship's hull without the need for divers to dive, which reduces labor costs and risks to human life, automatically cleaning the hull from algae, sea shells and other unwanted formations. This helps to reduce hull drag and improve hydrodynamics, which in turn can reduce fuel consumption helps to improve hydrodynamics and reduce fuel consumption and extend the life of the ship's hull.

For example, unmanned underwater vehicles that have recently gained popularity can operate without human intervention and be used for various tasks, including inspection and survey of the ship's hull, and are equipped with a high-quality camera and other sensors, such as thermal cameras and laser scanners, which can detect damage, corrosion and other problems that may not be visible to the naked eye. This allows for surveys to be carried out without risking human life, as there is no need for divers to dive. Drones can be used to search for and detect hull damage, inspect inaccessible areas, and monitor the hull cleaning process. They can operate in a variety of conditions, including at depths of up to several thousand meters, which allows them to be used to inspect both large ships and small boats and yachts. The use of marine drones in ship hull maintenance has a number of advantages. Firstly, it reduces the cost of surveys and reduces the time required for work. Secondly, it improves work safety, as there is no need to dive into dangerous areas to inspect the hull. Thirdly, it provides more accurate and complete information about the condition of the ship's hull, which helps prevent problems and damage in the future.

Nano- and micro-coatings are technologies used to protect the surface of a ship's hull from various types of contamination and corrosion. These coatings are applied to the surface of the ship's hull in the form of thin films and have micro- and nanoscale structures that can reduce water resistance and corrosion resistance. Nanoshells are thin coatings composed of nanoparticles that can change surface properties such as hydrophobicity (water repellency) or hydrophilicity (water attraction). This can help reduce water resistance, which in turn can reduce the energy consumption of the vessel. In addition, nanoshells can have anti-corrosion properties, protecting the hull of a ship from rust and other types of corrosion.

Microshells are thin films that have microstructures on the surface, creating thousands of microscopic air pockets. This can help reduce water resistance and improve the hydrodynamic properties of the ship's hull. Microshells can also prevent the formation of algae, shells and other marine organisms on the surface of the ship's hull. They can also reduce the operating costs of ships by improving their energy efficiency and reducing the need for frequent hull cleaning.

Figure 8: Navigator drone built by a team of engineers from Rutgers University.

Source: Rutgers University.

Robotic cleaners are automatic devices that can clean the hull of a ship from algae, shells, microorganisms, and other deposits that can reduce the speed and maneuverability of a vessel. These robots are used for hull maintenance and can operate both on the surface and underwater. The cleaning robots are equipped with different types of brushes that can clean the hull of the ship from different types of deposits. They can also use a water jet to remove deposits that are difficult to remove with a brush. In addition, some robotic cleaners are equipped with vacuum cleaning systems that can collect deposits from the surface of the ship's hull.

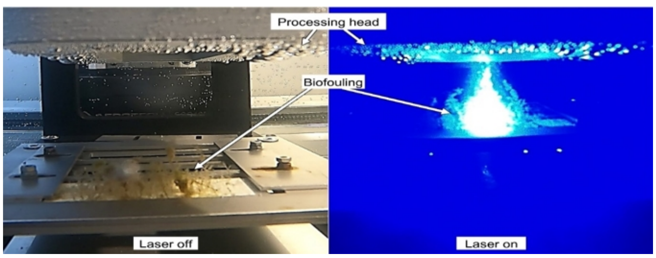
There are several advantages to cleaning the hull with robotic cleaners. Firstly, it reduces the cost of ship maintenance, as there is no need to involve a large number of workers in cleaning. Secondly, it improves the quality of cleaning, as robotic cleaners can work more accurately and efficiently than humans. Thirdly, it reduces the risk of injuries and other problems associated with working in water, as there is no need to immerse oneself in water to perform cleaning. Robotic cleaners are used in a variety of fields, including shipbuilding, marine industry, fishing, and other areas where hull maintenance is required.

Figure 9: The developed ROV device for the remote inspection and laser cleaning of ship hulls.

Source: Lasersystemseurope.com.

Laser radiation has emerged as a promising technology for effectively removing marine fouling from the underwater surfaces of ship hulls without causing damage to the underlying coating. Scientists at LZH (Laser Zentrum Hannover) have developed a process that utilizes laser radiation to selectively damage the cells of the fouling organisms, leading to their demise. The damaged fouling is subsequently dislodged and washed away by the natural flow of water over time. This innovative approach offers a potentially environmentally-friendly and efficient solution for maintaining clean hulls and optimizing the performance of ships, while minimizing the need for more invasive and environmentally harmful fouling removal methods.

Figure 10: The underwater laser process in side view.



Source: LZH.

There is no doubt that service life is one of the most important factors affecting the condition of a ship's hull. Each material has its own service life, which is determined not only by the quality of the material, but also by the operating modes, operating conditions and maintenance. In general, the service life of a ship's hull can vary from a few years to decades, depending on the materials, operating conditions and maintenance. There are several factors that affect the service life of a ship's hull, including: materials, operating conditions, maintenance, operating mode, lack of regular maintenance.

Ship hulls are made of various materials, such as steel, aluminum, composites, etc. Each material has its own characteristics and service life, which may vary depending on the operating conditions. Operating conditions such as exposure to salt water, corrosion, impacts, etc. can shorten the service life of a ship's hull. Regular maintenance can extend the life of the hull and reveal hidden defects. Improper operating conditions, such as overloading or improper handling of the vessel, can shorten the life of the hull. Lack of regular maintenance is one of the factors that can negatively affect the condition of the hull. Regular maintenance includes checking the hull for defects, cleaning it from plaque and contaminants, and repairing damage.

If the vessel does not undergo regular maintenance, its hull may develop defects and damage that can lead to serious consequences. For example, corrosion of metal surfaces can lead to a loss of structural strength of the hull, which can lead to accidents. The accumulation of plaque and contaminants on the hull surface can also lead to a decrease in the speed and maneuverability of the vessel, which can affect its safety. Therefore, regular hull maintenance is an important element of maintaining its condition and safety of operation. It allows for early detection and repair of defects and damage, which reduces the likelihood of accidents and extends the life of the hull.

Conclusions.

In conclusion, it is important to develop effective strategies for maintaining the structural integrity of the ship's hull. Various factors such as corrosion, fatigue, and hydrodynamic forces can affect the condition of a ship's hull. Using techniques such as strength analysis, fatigue analysis, buckling analysis, hydrodynamic analysis, and nondestructive testing, structural integrity can be assessed, potential problems identified, and an effective maintenance strategy developed. In addition, the use of advanced technologies, such as laser light to remove marine contamination, promises to maintain the integrity of the hull without damaging the main coating. Considering factors such as corrosion rates, likelihood of damage, potential losses and associated costs, informed decisions can be made about prioritizing maintenance activities and allocating resources. Ultimately, a comprehensive maintenance plan and regular evaluations are critical to ensure the long-term safety and performance of the ship's hull.

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