MODELING THE IMPACT OF IRRATIONAL SHIP MANAGEMENT ON THE CONDITION OF SHIP TECHNICAL SYSTEMS

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Abstract

This thesis investigates the critical issue of human error in the context of ship management and its consequences on the technical systems and the safety of navigation. The focus is on analyzing and modeling the destabilizing impact of the navigator's actions, such as improper speed control, navigation errors, and deviations from the planned route, which can lead to wear or failure of the ship's technical systems.

Introduction

Human errors, specifically irrational ship management, can significantly affect the operating modes of the main engine, causing destabilization and wear of ship technical systems and complexes [1]. Considering this, the development of rational risk management strategies and monitoring of the crew's actions [2] becomes important. Given the problem mentioned, there arises the task of formal analysis and modeling of the impact of the operator-sailor factor on the energy processes of the ship's engine room.

The multifaceted nature of the human factor, starting from its psychophysiology and health status [3,4], undoubtedly affects its level of operation and is almost unpredictable. Thus, incorrect use or insufficient understanding of the functionality of navigational systems, such as GPS, radars, echo sounders, and Automatic Identification Systems (AIS), as well as engine and course control means, can lead to critical errors in determining the ship's position and avoiding obstacles [5].

Such errors increase the risk of maritime accidents, including collisions, grounding, or even receiving serious damage due to navigational errors. All this outlines a problem that requires a systematic and effective solution to ensure the safety of navigation as a whole.

Relevance of research

The relevance of researching the facts of irrational ship management, its impact on energy systems and equipment has significant theoretical and practical value, as it affects the safety of navigation, fuel efficiency, the lifespan of ship technical systems, as well as the environmental aspects of maritime transport. Directly irrational ship management, especially during maneuvers, significantly affects the efficiency of energy systems, in particular:

1. Prolonged use at minimal or maximal rotations can cause engine technical problems: wear of the cylinder group, accumulation of carbon deposit, and an overall decrease in efficiency. This not only increases fuel expenses but can also lead to costly repairs [6].

2. Choosing incorrect engine operating modes or ignoring the need for cooling system adjustments depending on operating conditions can lead to overheating. For instance, intensive engine operation without adequate cooling, especially in warm climates or under heavy load, can cause overheating of cylinders and pistons. This, in turn, can lead to a decrease in oil viscosity, an increase in internal friction in the engine, and, consequently, damage to these components [7].

3. Constant engine overload or operation at low rotations can lead to instability in the pressure and temperature of the exhaust gases feeding the turbocharger. These instabilities increase the risk of mechanical wear and thermal damage to the turbocharger, reducing its efficiency and reliability [8].

4. Incorrect choice of engine operating modes can lead to uneven fuel consumption, which, in turn, causes clogging of filters and fuel injectors. This can affect the optimal operation of the engine, reducing its performance and efficiency. Also, improper fuel consumption can lead to incomplete combustion, increasing emissions of harmful substances and fuel expenses [9].

5. Frequent overloading or incorrect distribution of load among generators can lead to their overheating and accelerated wear. Overheating can cause thermal damage to internal components, including insulation of windings, increasing the risk

of short circuits or generator failure. Irrational management of the ship's energy system can also lead to unnecessary wear of equipment, reducing its lifespan and reliability [10].

All mentioned directly holds significant importance for aspects such as:

Maritime Safety: The development and implementation of rational risk management strategies and monitoring of crew actions can significantly enhance maritime safety.

Fuel Efficiency: Optimizing engine management and increasing crew awareness of the importance of efficient fuel use are key to reducing operational expenses.

Lifespan of Ship Technical Systems: Understanding the impact of management decisions on equipment wear and developing measures for their optimization are important for extending the service life of ship systems.

Environmental Aspects: Effective management and optimization of operational procedures are crucial for reducing the environmental impact of maritime transport.

Therefore, the relevance of the research lies in the development and implementation of comprehensive models and approaches for optimizing ship management, which will help reduce risks to maritime safety.

Presentation of the main material

Let's describe the model taking into account the destabilizing influences of the navigator on the ship's movement:

1. Navigation error: incorrect course setting can lead to a change in the ship's direction.

2. Speed management error: incorrect speed estimation can result in the ship moving too fast or too slow.

3. Deviation from the planned route: unexpected deviations from the set route can cause destabilization.

We will define the navigator's main actions during maneuvers that can lead to a deterioration in the technical and operational condition of the ship's functional devices:

1. Excessive or improper use of the rudder: frequent or excessive maneuvering can lead to wear or breakage of the steering mechanism.

2. Incorrect speed management: constant changes in speed or abrupt transitions from full speed to sudden braking can increase the wear of the engine and other components of the power plant.

3. Ignoring or misinterpreting navigational data: negligent attitude towards information from navigation systems can lead to dangerous maneuvers that jeopardize the integrity of the ship and its systems.

Considering that the most complex and organized systems are the main engine and steering management systems, let's take a closer look at the processes of improper speed management on the ship (situation 2):

2.1. Sudden changes in speed: the navigator abruptly increases or decreases the ship's speed unnecessarily, for example, transitioning from full speed to sudden braking. This can happen due to an underestimation of the distance to other objects or due to an incorrect response to changes in navigation conditions.

2.2. Unstable speed: the lack of a constant speed, constant changes in speed without significant reasons. Such actions can be the result of uncertainty or insecurity in navigational decisions.

2.3. Speed mismatch to navigational conditions: the navigator maintains too high or too low a speed in conditions that require a different level of speed, for example, in dense traffic or in poor weather conditions.

The dependence of wear on the frequency of speed change:

$$V_{freq}(t) = \eta \cdot \sum_{i=1}^{n} \left| \Delta F_{thrust,i} \right|,$$

where: η – coefficient reflecting the influence of the frequency of speed changes on wear,
$\Delta F_{thrust,i}$ – change in engine thrust in the i-th time interval.

The effect of unstable speed on thermal wear:

$$W_{thermal}(t) = \theta \cdot \int_0^t \left| \Delta \dot{F}_{thrust}(t') \right|^2 dt,$$

where: θ - coefficient reflecting the impact of thermal load on wear.

Cumulative effect of wear:

$$V(t) = V_0 + V_{freq}(t) + W_{thermal}(t).$$

In such a representation, the model allows for a more accurate assessment of the impact of uncertainty in navigational decisions on the overall condition of the ship's power installations during maneuvers.

Considering the above, we will describe the dependence of wear of the ship's functional devices in general form in cases of improper speed management.

1. Sudden changes in speed:

$$W(t) = A_0 + \int_0^t \left(\xi \cdot \rho + \delta \cdot \Delta F_{thrust}(t') + \gamma \cdot V_{vib}(t') + \beta \cdot T_{heat}(t') \right) dt,$$

where: A_0 - initial wear of the ship's technical system,
ξ, ρ - coefficients reflecting the impact of abrupt changes in thrust and their absolute magnitude on wear,
δ - coefficient accounting for additional wear due to vibration change,
$V_{vib}(t')$ - vibration parameter at time t',
γ - coefficient of vibration impact on wear,
β - coefficient of heat dissipation impact on wear,
$T_{heat}(t')$ - heat dissipation parameter at time t'.

2. Unstable speed:

$$W_{\text{unstable}} = V_0 + \int_0^t \left(\lambda \cdot \sigma + \mu \cdot Var\left[F_{thrust}(t') \right]^2 + \nu \cdot R_{res}(t') \right) dt,$$

where V_0 - initial wear of the ship's technical system,
λ, σ - coefficients reflecting the impact of frequency and variation of speed changes on wear,
μ - efficient reflecting the impact of speed variation on wear,
ν - coefficient accounting for the impact of resonance on wear,
$R_{res}(t')$ - resonance parameter at time t'.

3. Speed mismatch to navigational conditions:

$$W_{\text{mismatch}} = W_0 + \int_0^t \kappa \cdot \Psi\left(F_{thrust}(t'), C(t') \right) dt',$$

where W_0 - initial degree of impact on the ship's technical system,
κ - coefficient of impact of speed mismatch,
Ψ - function of mismatch between actual and optimal speed.

Given the general analytical form of the equations presented, this section outlines approaches for determining the coefficients mentioned above.

To determine the coefficients ξ and ρ, reflecting the impact of abrupt changes in thrust and their absolute magnitude on wear, empirical data and engineering analysis should be used. These coefficients depend on the specific characteristics of the ship and its equipment but are generally determined as follows:

Coefficient ξ (impact of abrupt changes in thrust):

- Measured based on chronological data about equipment wear in situations with abrupt changes in thrust.

- May include analysis of the impact of acceleration/deceleration of the engine on its components.

Coefficient ρ (impact of the absolute magnitude of thrust change):

- Assessed based on changes in engine operating modes and their impact on the overall technical condition.

- Considers how large changes in thrust (e.g., transitioning from minimum to stop and to maximum) affect the engine and its systems.

These coefficients can be determined through technical trials, analysis of operational and maintenance data, and mathematical modeling of equipment wear over discrete time.

The proposed analysis aims to better understand how different ship management modes affect its durability and reliability.

For determining the coefficients λ and σ, reflecting the impact of frequency and variation of speed changes on wear, the following approaches are suggested:

Coefficient λ (impact of thrust change frequency):

- Can be determined based on analysis of equipment wear in response to frequent engine thrust changes.

- Measured through wear studies of mechanical and electrical components at various speeds change frequencies.

Coefficient σ (impact of speed modes):

- Determined based on the impact of various speed modes on component wear.

- May include analysis of discrete speed variation, such as standard deviations from the average speed, and their impact on the overall technical condition of the equipment.

Both coefficients are determined through technical analysis, empirical data on operation and maintenance, and through mathematical modeling and statistical analysis. This helps assess how frequent and varied speed changes affect the durability and reliability of the ship's power installations.

Coefficient κ (impact of speed mismatch):

- Determined based on analysis of the impact of deviations from the optimal speed on wear and safety.

- Can be determined through empirical studies measuring the impact of various speeds under different conditions on the overall condition of the ship.

The optimal speed can be determined based on navigational recommendations, safety standards, and specific sailing conditions. These parameters allow for a quantitative assessment of the impact of speed mismatch on the efficiency and safety of ship operations.

Additionally, stages for refining the generalized model and recommendations for its use should be specified.

Verification and calibration: Before use, the model requires empirical verification and calibration using real data to accurately adjust matrices and coefficients in wear functions.

Sensitivity analysis: Conducting a sensitivity analysis to determine the impact of each variable on the model's output parameters is recommended.

Scenario (situational) modeling: Applying the model for scenario modeling to assess potential wear and identify critical scenarios that could lead to ship destabilization.

Conclusions

Therefore, the study emphasizes the importance of developing and applying rational risk management strategies and crew action monitoring to enhance maritime safety, improve fuel efficiency, extend the service life of ship technical systems, and minimize the environmental impact of maritime transport.

A comprehensive approach is proposed, which includes formalizing the navigator's influence on energy processes in the ship's engine room, assessing the cumulative effect of wear, and developing analytical models that reflect the dependency of wear on various actions of the navigator.

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