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Mathematical formulation of the problem of designing a transport vessel, in the conditions of transition to a Blue Economy

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Abstract. When setting a task for designing a vessel, restrictions imposed by the customer, classification societies and requirements for the characteristics of ship structures are usually taken into account. In the current conditions, it also becomes necessary to ensure sufficient "sustainability" of the project. In this paper, a mathematical model describing these changes is given.

Keywords: Blue Economy, Mathematical Formulation, Ship Structure

1 Introduction

The task of designing a vessel is a complex task, as it is a complex system consisting of many subsystems. Due to the high degree of organization of the object, it seems very difficult to formalize the process of its design. However, the most appropriate in the scientific community is the iteration method or the method of successive approximations. In this paper, we will try to consider the design problem as an optimization problem with restrictions in the form of requirements for "sustainability" on the example of a transport vessel.

2 Methods

Consider the problem in two stages. In the first, we will solve the problem of optimizing the mass of the transported cargo and the speed of the vessel, based on the fact that the main task of operating a transport vessel is to deliver a given mass of cargo to a given point in a certain time. In the second, we will define the restrictions imposed by the conditions for the transition to the Blue Economy.

2.1 Optimization of the Mass of the Transported Cargo and the Speed of the Vessel Using the Conditional Gradient Method

It is most convenient to represent the method of successive approximations by the conditional gradient method [1][2]. Consider the problem as an optimization with respect to this criterion:

$$\max \frac{m_0 * v}{S}$$

where, S - cost of transportation. The constraint space is defined as follows:

$$m_{0min} \leq m_0 \leq m_{0max}$$
$$v_{min} \leq v \leq v_{max}$$

where, m_{0min} and m_{0max} – minimum and maximum weight of the transported cargo, respectively; v_{min} and v_{max} - minimum and maximum speed values.

Let's introduce the assumption of proportionality of displacement and cost through some coefficient k:

$$S = k * D,$$

where, D – displacement; k - cost of operation per tonne of displacement.

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Taking into account the above restriction , we will take the following criterion as an objective function:

$$\max \frac{m_0 * v}{D}$$

We will assume that displacement can be found from the three-term equation of mass:

$$AD + \frac{\overline{q_{pp}}}{C_w} v^3 D^{2/3} + m_0 + \sum_i m_i = D$$

Thus, in this case, the components of the desired vector X are m_0 and v_0 , a type of objective function F(X):

$$F(m_0, v) = \frac{m_0 v}{D(m_0, v)}$$

D(m_0, v) - solving the mass equation.

The set X' is a rectangle defined by constraints on v and m_0. The coefficients of the equation can be selected by analyzing the prototypes. If this is not possible, then the choice is made based on the researcher's assumption.

Then, we take the vector as the first approximation:

$$X^{(1)} = \begin{pmatrix} m_{01} \\ v_1 \end{pmatrix}$$

From the solution of the mass equation we find $D^{(1)}$ and $F^{(1)}$. Let's evaluate the vector grad F(X), to do this, it is necessary to calculate the value of F(X) at points $X^{(11)}$, $X^{(12)}$, which are close to $X^{(1)}$.

To calculate the values, we use approximate differential formulas:

$$D(11) = D(1) + \frac{\partial D}{\partial m_0} | X = X(1)\ \Delta m_0,$$
$$D(12) = D(1) + \frac{\partial D}{\partial v} | X = X(1)\ \Delta v,$$

where,

$$\frac{\partial D}{\partial m_0} = \frac{1}{1 - \mathrm{A} - \frac{2}{3}\frac{\overline{q_{pp}}}{C_w D^{1/3}} v^3}$$
$$\frac{\partial D}{\partial m_0} = \frac{\frac{\overline{q_{pp}}}{C_w} v^3 3D^{2/3}}{1 - \mathrm{A} - \frac{2}{3}\frac{\overline{q_{pp}}}{C_w D^{1/3}} v^3}$$

Having obtained $D^{(11)}$, $D^{(12)}$ and $F^{(11)}$,$F^{(12)}$ we obtain approximate stashes of the components of the vector grad F(X) at the point $X^{(1)}$

$$\frac{\partial \Phi}{\partial m_0} | X = X(1)\ and\ \frac{\partial \Phi}{\partial v} | X = X(1)$$

The problem is reduced to a linear:

$$\max_{m0,v} \left[m_0 \frac{\partial \Phi}{\partial m_0} \middle| X = X(1) + v \frac{\partial \Phi}{\partial v} \middle| X = X(1) \right]$$

The solution is a vector: X*

Next, we need to determine the coefficient α ∈ [0,1], to solve the problem[3]:

$$\Phi\left(X_{\alpha_1}^{(1)}\right) = \max_{\alpha} \Phi\left(X_{\alpha_1}^{(1)}\right)$$

where,

$$X_{\alpha}^{(1)} = \alpha X^{(1)} + (1 - \alpha) * X^{*(1)}$$

The solution of the above problem is obtained by the vector of the second approximation $X^{(2)} = X_{\alpha}^{(1)}$.

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Then we repeat the operations of the first approximation and get the following linear problem:

$$\max_{m_0,v} X^* gradF^{(2)}$$

The solution to this problem gives $X^{*(2)}$ and $D^{(2)}$, $F^{(2)}$
The next task to solve:

$$\max_{\alpha} F\ [\alpha X^{(2)} + (1-\alpha) * X^{*(2)}]$$

Further solution of the problem by successive approximations is difficult, because of the features of the function under consideration - the presence of a feature in the form of an ascending ridge [2]. Expressions describing the point of this ridge can be obtained by excluding the parameter D_0. If we neglect the attitude:

$$\frac{\sum_i m_i}{D_0}$$

then we get the following expressions:

$$v = 0{,}65 * (1-A)^{\frac{2}{9}} * (\frac{C_w}{q_{pp}})^{\frac{1}{3}} * m_0^{1/9}$$
$$m_0 = (1-A) * D_0 - \frac{q_{pp}}{C_w} v^3 D_0^{2/3}$$

Thus, the solution of this problem is located at the highest point of this ridge belonging to the permissible range of values

$$m_{0min} \le m_0 \le m_{0max}$$
$$v_{min} \le v \le v_{max}$$

2.1 Consideration of Additional Restrictions (Sustainability)

In this case, the solution of the problem, that is, finding the parameters of the vessel, can be written as follows:

$$opt\ Э(\mathrm{X}), \mathrm{X} \in \mathrm{X}',$$

Where Э - environmental compliance parameter (including recommendations of international and national associations).
The solution of the chosen task is X_{opt}, containing the selected parameters of the vessel.
The solution is obtained by searching for the maximum by some functional F':

$$\max_{\mathrm{X}\in \mathrm{X}'} F'[Э(X)]$$

As a result, it is necessary to obtain some subset X' in which, according to the principle, it is impossible to simultaneously satisfy all the indicators of Э. Then, we define the functional according to one of the principles[3][4]:

The principle of uniform optimization:

$$F(Э) = \min_i e_i\,;$$

The principle of average optimization:

$$F(Э) = \sum_{i=1}^{n} e_i;$$

The principle of fair compromise:

$$F(Э) = \sum_{i=1}^{n} log\, e_i$$

The above principles are valid only for the case of equivalence of particular indicators[6,]. Strictly speaking, it is necessary to normalize the vector e by the vector α [7,8,9], the components of which will be the weighting coefficients of the particular indicators e.

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$$\alpha = (\alpha_1, \dots, \alpha_n)$$
$$e = (e_1, \dots, e_n)$$
$$e_\alpha = (\alpha_1 e_1, \dots, \alpha_n e_n)$$

The desired functionality is transformed:

$$F(Э) = \sum_{i=1}^{n} \alpha_i e_i$$

The signs in the sum are set in accordance with the effect on the compliance parameter Э.

3 Result

The developed model allows you to quickly evaluate the main quantities associated with the operation of a cargo ship - displacement, cargo weight and speed**.** However, it must be taken into account that the presented model is highly dependent on the correct choice of the coefficients of the original equation (mass equation). This implies the importance of statistical processing of similar vessels before starting the actual design process. Separately, it is worth noting the lack of the possibility of a sufficiently accurate formalization of the parameter Э.

4 Conclusions

To design the dimensions of the heat exchanger it takes the value of the average temperature difference of the heat exchanger system of 29.72 ℃. From the difference temperature, it can be seen that the effective heat transfer surface area is 1.2 m2, with a planned tube length of 0.5 m and a tube diameter of 10 mm, the value of the number of tubes is 55 pieces. The tubes are designed in a staggered arrangement with a triangular pitch, so that the shell diameter is 0,121 m with a thickness of 5 mm. the system get 3 kg more heavy than previous design. And then after running the system by simulation on Software the cooling water temperature reach 52,3℃ before engine water jacket inlet.

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