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INFLUENCE OF THE INITIAL STEAM PARAMETERS ON THE OPERATION EFFICIENCY OF THE SHIP UTILIZATION TURBINE

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ABSTRACT

The search for technical solutions aimed at improving the reliability of marine steam turbines (including exhaust-driven turbines), which have a part of the expansion process in the two-phase zone (wet steam), is an important issue in the operation of marine power plants. To date, not all practically important tasks of two-phase mechanical environments are fully resolved. Questions of optimization of lattices and shapes of flowing parts of the turbines working on water charged steam remain open. No less important in this regard is the correct choice of parameters and the distribution of heat differences by stages of the turbine. Research work in the field of water charged steam turbines shows the need to develop specific recommendations for the most efficient (in terms of energy loss and erosion wear of the blades) their operation. The purpose of this study is to develop recommendations for the optimal choice of parameters of the stages of steam turbines running on wet steam. The results of the analysis of the influence of the initial steam pressure in the last stages of wet-steam ship turbines allows to avoid unfavorable (in terms of final humidity) operating modes and thus increase their efficiency and erosion reliability. The most economical mode of operation for recycling steam turbines that use low-potential heat of exhaust gases and operate in the field of wet steam with a significant level of humidity is the mode in which the steam pressure at the inlet of the turbine is about 0.7 MPa. An increase of this pressure leads to a significant increase of humidity and, consequently, a decrease in efficiency. Reducing the pressure by less than 0.6 MPa significantly affects the efficiency of the turbine due to the reduction of the available heat transfer, which makes the use of exhaust-driven turbines impractical.

INTRODUCTION

Significant use of secondary energy resources on ships began to be paid attention to at the end of the twentieth century. At that time ships with an exhaust-driven turbine generators began to appear, which were powered up with a superheated steam from the composite boiler (CB), which received exhaust gases from the low RPM main diesel engine [1]. Currently, the temperature of the exhaust gases of the engine at full ahead is 350 – 400°C [2]. Further development of the low RPM main diesel engine was accompanied by an intensive increase in the pressure of the boost air charging, which increased its temperature after the turbocharger (TC) to 200°C and more.

Fig. 1 shows one of the possible schemes of the system of its deep utilization [2] in which the composite boiler (CB) and the compressed air cooler (CAC) act as the main elements for water vapor generation [2]. This scheme is characterized by the generation of a pair of three pressures: high (HP), medium (MP), low (LP), which determines the presence of three steam separators. Determination of the capacity of the exhaust-driven turbine (EDT), prevention of excessive humidity of steam in its last stages are connected with the processes of steam expansion, which are depicted in the coordinates "enthalpy - entropy" in Fig. 2. The steam pressure at the inlet of the turbine (1 MPa) is to some extent chosen arbitrarily. Note that the average pressure of 0.2 - 0.3MPa should be considered the minimum possible to prevent low-temperature sulfur corrosion in the last stages of EDT [3]. Also, note that the initial temperature before EDT is selected 220°C, which is determined by the level of exhaust gas temperature.

Research work in the field of wet-steam turbines [3,4,5] shows the need to develop specific recommendations for the most efficient (in terms of energy loss and erosion of the blades) their operation.

The purpose of this study is to develop a recommendation for the optimal choice of parameters of the stages of steam turbines operating on wet steam.

EXPOSITION

Exhaust-driven turbines of modern combined power plants operate at low potential heat, at a steam temperature not exceeding 200 – 250°C, while powerful steam turbines operate at temperatures above 400°C. At low inlet steam temperature and low parameters vapor pressure (0.6…1.5 MPa) curve of its condensation is quite high, and a

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significant part of the stages works on wet steam.

Studies conducted in experimental turbines [3, 4] have shown that the efficiency of stages decreases when working with wet steam. This is due to the following reasons:

− increase in energy losses in the lattice;

− energy losses for the acceleration of moisture in the gap due to the lower rate of steam flow, especially highly dispersed, and friction between the vapor and liquid phases;

− shock, braking action of fluid particles falling on the blades;

− additional losses in rotating work-grids.

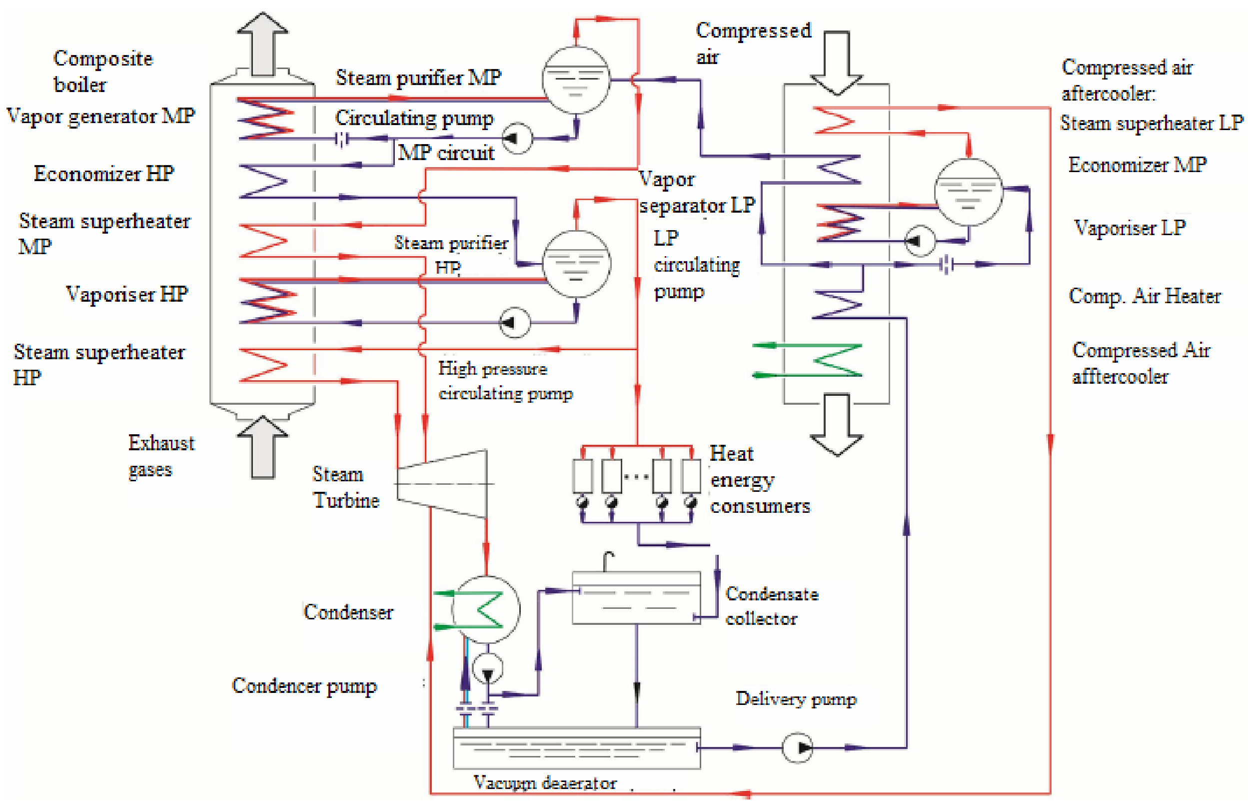

Fig. 1. Schematic diagram of exhaust disposal with a two-pressure boiler and a compressed air cooler

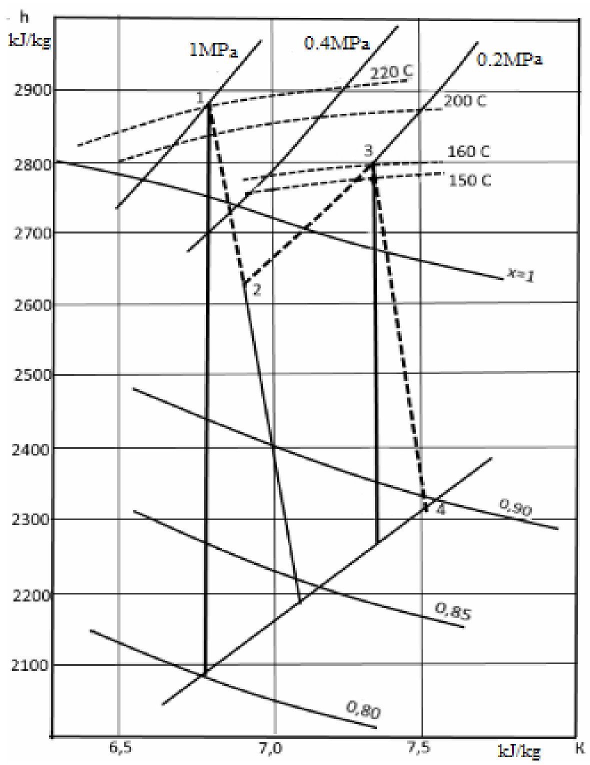

Fig. 2. Processes in the turbine with intermediate steam supply in the diagram h - K

The part of individual components of losses in the general decrease in efficiency when working with wet steam varies and depends on many physical and geometric factors. However, in most cases, in the levels of polystage turbines, the decisive factor is the loss of braking and acceleration of highly dispersed moisture.

Working on wet steam leads to wear of the blades. Fig. 3 shows the wear of the blade obtained in real conditions.

Despite the allegedly small percentage of wear, the figure shows that in the upper part of the wear area is threateningly close to the bank rod, which in the presence of oscillations should lead to the destruction of the blade long before its complete wear.

Analyzing the working processes (Fig. 2), we see that with an increase in the initial pressure from 0.2 to 1.0 MPa, the available heat difference of the turbine increases, and hence the efficiency. At the same time, the number of stages operating on wet steam increases, which leads to a reduction of service life. The turbine does not become less reliable. Thus, the choice of initial steam parameters (pressure and temperature) is a compromise between power, efficiency and reliability of the turbine.

From the point of view of efficiency of the turbine considered in work the best mode is an operating mode at p_0 = 1MPa (the located heat difference H_0 = 780 kJ/kg). However, please keep in mind that with humidity close to 12% (which is crucial) [6] an erosion wear greatly increases, which reduces the reliability of the turbine, and reduces its mean time between failures. Therefore, in case of need for increased resource or the reliability of the turbine is desirable to move to lower steam parameters, with an initial pressure p_0 = 0.6… 0.7MPa, at which the limit of allowable humidity - 12% is maintained [5, 6].

Prediction of erosion of the blade can be preliminarily determined based on computer simulations [7].

This tendency is described in detail in table 1, which shows the dependence of steam humidity on the last stages of the turbine and the blade efficiency of the turbine on the pressure at the inlet to the turbine p_0.

Table 1 shows the efficiency and reliability of the turbine at different initial steam pressures. Thus, p_0 from 1.5 to 1 MPa made it impossible for the turbine to operate at such pressures, because the last stages operate on steam with humidity greater than 12%. The mode p_0 from 1 to 0.8 MPa allows to use such initial pressure at which humidity is greater than 12%, but operating at these pressures last stages work at a humidity close to critical, which affects very negatively the reliability of the turbine. Mode p_0 from 0.7 to 0.6MPa shows the most favorable modes of operation of the turbine.

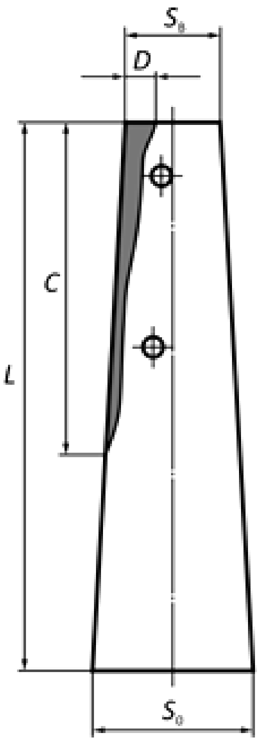

Fig. 3. Wear of the working blade in real conditions

Table 1 *Dependence of steam humidity on the last stage and relative efficiency from the initial pressure*

p_0, MPa	Humidity,%	η_{oi},%
1.5	14.0	68.54
1.4	13.6	68.95
1.3	13.1	69.32
1.2	12.6	69.65
1.1	12.1	69.93
1.0	11.5	70.14
0.9	10.9	70.30
0.8	10.2	70.28
0.7	9.4	70.02
0.6	8.5	69.60

However, the reduction of the initial steam pressure from the calculated (p_0 = 0.1 MPa) to 0.6 - 0.7MPa leads to a decrease in the existing heat drop of the turbine (and hence a decrease in its capacity) with H_{01} = 780 kJ/kg to H_{02} = 700 kJ/kg (at the same p_k = 0,006 mPa.)

If the thermal scheme of deep utilization does not allow reducing the initial parameters of steam at the inlet of the EDT to acceptable level in terms of erosion sustainability of the last stage. It is advisable to use a scheme with intermediate overheating of steam (Fig. 2). The steam after the second stage of the five-stage EDT (vol. 2, Fig. 2) is selected for intermediate overheating with the parameters p_{01} = 0.2 MPa and t_{01} = 160°C and then sent to the last stages of EDT. With such a scheme, it is possible to reduce the level of humidity at the last stage of EDT to the allowable 89 - 91%.

At the same time, the total heat difference increases (at the stage before steam extraction and on other stages after overheating, the process is 1-2-3-4, Fig. 2).

It can be assumed [1-3] that the efficiency of a stage of the turbine working in the on wet steam is defined by the formula [4].

$$\eta_{oi}^{вл} = \eta_{oi}^{n} - \xi_n - \xi_p - \xi_{уд} \qquad (4)$$

where:

η_{oi}^{n} - efficiency coefficient of the stage working on superheated steam;

ξ_n - energy losses in the stage of overcooling;

ξ_p - energy loss to accelerate the drops;

$\xi_{уд}$ - energy loss on the impact of drops on the blade .

Fig. 4 shows the dependence of the relative efficiency of the turbine on the initial steam pressure. It can be seen that the maximum efficiency corresponds to a pressure of about 0.85 MPa.

However, from the preliminary analysis (Fig. 4) it follows that at such a pressure at the last stages the humidity of the vapor exceeds 10%, which is close to the maximum allowable level of humidity (12%).

Thus, the most acceptable mode of operation corresponds to a vapor pressure of 0.6 ÷ 0.7 MPa, at which the decrease in relative efficiency does not exceed 0.5%. At the same time, the longevity of the turbine increases significantly. Similar to the previous table and figure, the inadmissible operating parameters, and a bold line indicates the most favorable ones.

ANALYSIS OF RESULTS AND CONCLUSIONS

The results of the analysis of the effect of initial steam pressure at the latest stages of wet steam marine turbines allow avoid disadvantageous modes (in terms of the final humidity) of operation and thereby increase their efficiency and erosion sustainability. The most economical mode of operation for the exhaust-driven turbines, which use the potential heat of exhaust gases, i.e. operating on wet steam with a significant level of humidity is the mode with vapor pressure at the inlet to the turbine of about 0.7 MPa. Increasing the pressure leads to a significant increase in humidity and reduced efficiency due to the humidity of the steam. Reducing the pressure less than 0.6 MPa significantly affects the efficiency of the turbine, in addition, rapidly reduces the heat drop, which makes the use of exhaust-driven turbine impractical. One way to increase the efficiency of EDT is a thermal scheme with intermediate superheating of steam.

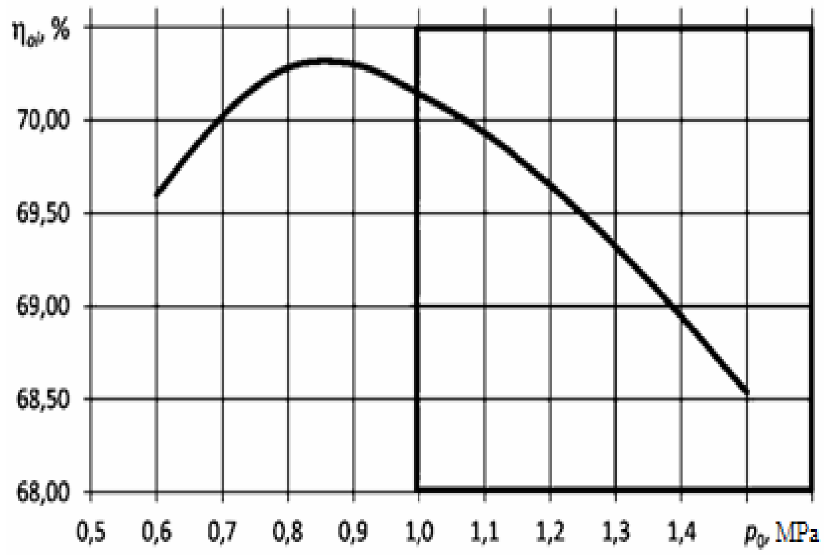

Fig. 4. Relationship of the internal relative efficiency of the turbine on the initial steam pressure

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