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CONTROL OF COOLING PARAMETERS DEPENDING ON THE ENGINE OPERATING MODE

***Abstract**: From an energy standpoint, heat transfer in the nucleate boiling regime is more efficient, as the high heat transfer coefficient enables intensive heat removal from cooled surfaces at relatively low coolant flow rates. Under maximum load or overload conditions, a transition from nucleate to film boiling may occur, leading to crack formation in highly heated components. This can be prevented by a modernized cooling system featuring a hermetically sealed expansion tank, in which the pressure at the liquid surface is regulated by a control unit receiving input from sensors installed on the engine. The pressure variation law programmed into the control unit ensures pressure regulation in response to changes in engine load.*

***Key words**: heat transfer; cooling; coolant; cylinder liner and head; temperature; pressure; load; operating mode; marine engine.*
***Language**: English*

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Introduction

The results of the conducted research indicate that the technical–economic and operational performance characteristics of an engine are strongly affected by the thermal state of its mechanisms and structural components [1, 2]. This thermal state is, in turn, governed by the effectiveness and reliability of the cooling system, which plays a critical role in maintaining optimal operating conditions.

The results of research on the effect of coolant temperature on the technical and economic performance indicators of the engine confirm the necessity of maintaining it at a defined optimal level. However, the coolant is considered an intermediate heat carrier between the surfaces to be cooled and the water of the outer loop [3]. Its temperature determines the thermal condition of the engine components. Therefore, it is more advisable to maintain the coolant temperature at the optimal level, not at the engine outlet, but at the surfaces of the most heavily heated components (cylinder liners and cylinder heads).

Basic part

Because the engine operates under partial load for a large portion of its operating time, during which it overcools, a significant economic benefit can be achieved by raising the coolant temperature when transitioning from nominal to partial load. In high-temperature cooling systems, special attention must be paid to the nature of heat transfer on the cooling surfaces of engine components to prevent film boiling, which sharply reduces heat transfer and can cause local overheating and engine failure [4, 5].

Our article [6] considers the influence of water-chemical parameters in a marine engine cooling system on the reliability of engine operation when various chemical additives are used.

The coolant parameters characterize the physicochemical and thermophysical properties of the heat-transfer medium within the cooling system. Reliable engine operation can be ensured if the cooling agent meets the following requirements: it must not cause surface corrosion and must remain stable over an extended period. These properties can be achieved through the appropriate chemical composition of the heat transfer medium and special treatment.

The transition to high-temperature cooling must proceed by improving the thermal state regulation of engine components.

Figure 1 illustrates the schematic diagram of a double-loop cooling system characteristic of marine engines.

In most existing systems, the Polzunov-Watt regulation principle is used, whose essence is to regulate the temperature of the cooling water at the engine outlet, with the regulatory action generated based on measurement of the regulated parameter (temperature). The following three main external factors act on the engine: crankshaft speed - ω, load - N, and air temperature at the intake stroke – T_{int}.

When analyzing automatic regulation processes, it is common to use functional diagrams of the system that show input and output parameters as well as external influences.

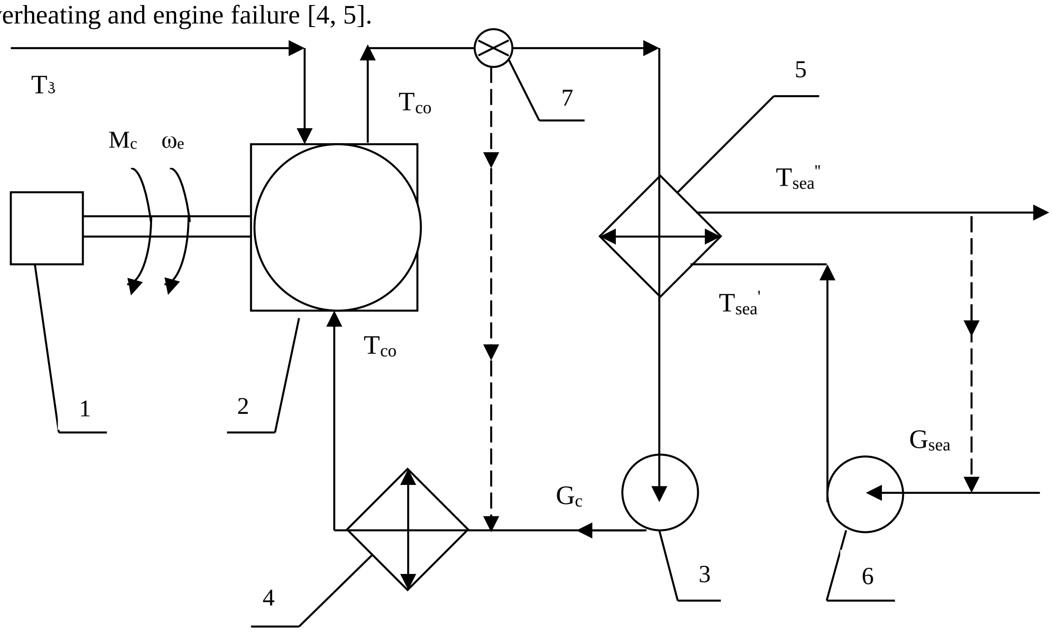
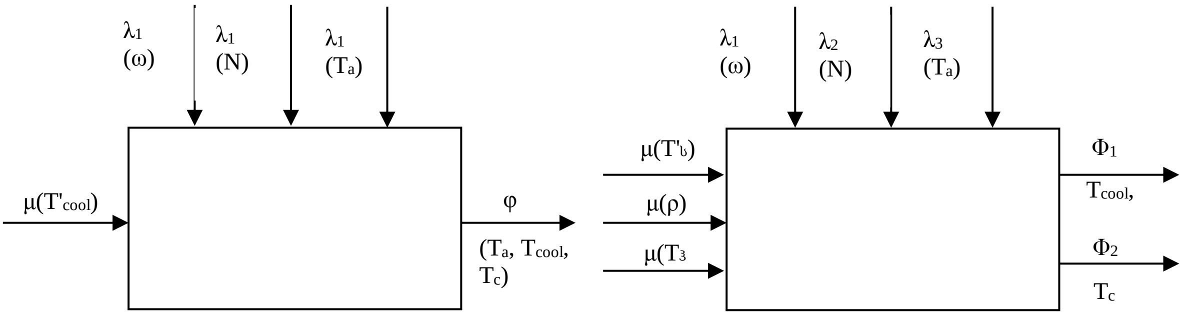


Fig. 1. The diagram of a double-loop cooling system.

1. Loading unit; 2 - piston assembly of the engine; 3 – inner loop circuit circulation pump; 4 – oil cooler; 5 – water cooler; 6 – outer loop circulation pump; 7 - thermostat; ωᵢ - crankshaft speed. M_1- engine torque; T_1 - air temperature at intake; $T^{I}_{cool}, T^{II}_{cool}$- the coolant temperatures at the engine inlet and outlet, respectively; T^{I}_{3}, T^{II}_{3} - the seawater temperatures at the cooler inlet and outlet, respectively; G_1, G_2 - the mass flow rate of the coolant in the inner loop and of the seawater.

Figure 2 illustrates the functional diagrams of the automatic control of the thermal state of a traditional double-loop cooling system. The most typical one-dimensional scheme of the functional diagrams of the automatic control of the thermal state is shown in Figure 2a, in which the coolant temperature is considered the controlled subject.

Preference is given to the multidimensional regulation system shown in Figure 2b, in which the output parameters are considered to be the temperature of heavily heated components -$T_{c,}$ the coolant temperature - $T_{cool,}$, and the engine oil temperature - T_{en}. The maintenance of the engine's optimal thermal state is achieved through combined control of the coolant temperature ($T_{cool,}$) and the temperatures of heavily heated components (T_c) . In this case, two regulatory actions must be implemented. One of these two actions may be a controlled pressure in the cooling system. Pressure-based control, depending on the operating mode, is proposed to be realized using the device described in [7].



a b

Fig. 2. Functional diagrams of the engine thermal state control system
a) one-dimensional; b) multi-dimensional.

Work [8] provides a detailed discussion of the static and dynamic characteristics of cooling systems with coolant temperature regulation. Cyclic temperature variations of the working medium induce 7–10 °C fluctuations at the cylinder's inner surface, extending to a depth of 2–4 mm [9]. The outer temperature of the cylinder liner remains practically unchanged, and the heat transfer process can be viewed as quasi-static.

The amount of heat transferred from the surfaces to be cooled to the liquid is determined by the Newton-Richmann equation.

$$Q = aF_c(T_c - T_{cool.av.}), \qquad (1)$$

where a – is a heat transfer coefficient;

F_p - the area of the surfaces to be cooled;

T_c, T_{av} - the average temperatures of the components and the coolant, respectively.

The resulting differential equation

$$T_c\frac{d\tau}{dt} + \Theta_i\varphi = \psi + \Theta_p\tau + \Theta_c\alpha_c \qquad (2)$$

can be used to perform a numerical experiment to determine how variations in cooling system pressure affect the temperature of highly heated components and the coolant, taking into account the use of a double loop cooling system.

Three methods of controlling the thermal state of an engine are known: throttling, transferring, and bypassing, which are implemented using various technical devices. Thermostats are the most common devices for controlling the thermal state. The drawback of the known control methods lies in their focus on maintaining a specified coolant temperature at the engine outlet, without considering heat transfer processes or the temperatures of the cooled surfaces. It is known that three types of heat exchange are possible in the engine cooling system: forced convection, heat exchange in a closed vessel during nucleate boiling, and heat exchange during film (layer) boiling.

From an energy perspective, heat transfer under nucleate boiling conditions is more favorable, as the high heat transfer coefficient enables efficient heat removal from the cooled surfaces at low coolant flow rates.

During engine operation in overload mode, under elevated ambient air and seawater temperatures, and when using additives that reduce the coolant's surface tension, a transition from nucleate boiling to film boiling may occur, leading to a significant reduction in the heat transfer coefficient. At this point, overheating of the cylinder group components occurs, leading to cracks in the cylinder liner and cylinder head. To prevent engine failure, the engine's thermal regulation system must be improved to ensure that, under maximum load, heat exchange occurs in the nucleate boiling regime without transitioning to film boiling. This can be achieved through a modernized cooling system.

A distinguishing feature of the proposed cooling system is that the expansion tank is hermetically sealed, and the pressure on the surface of the liquid contained within it can be adjusted based on information received from the control unit. The pressure level is regulated by means of a pressure-reducing valve, whose degree of opening, and consequently, the pressure level on the surface of the liquid in the tank and throughout the cooling system, is determined by a signal coming from the control unit. The latter is an electronic computing device that generates control impulses based on information received from sensors. These sensors are installed on the engine and characterize its operating condition.

Based on the information received, the pressure level is selected at which nucleate boiling mode will be ensured on the surfaces to be cooled. The pressure variation law, which is programmed into the control unit, must ensure the regulation of pressure in the cooling system in accordance with changes in the load on the engine.

Conclusions

Based on the results obtained, the following conclusions can be drawn:

- Increasing the pressure in the cooling system to 0.3 MPa, using the compressor of the forced induction system, raises the boiling point of water to 130 °C, thereby eliminating the possibility of film boiling in the engine cooling system.
- System pressure can also be regulated using a compressor with an independent drive, for example, one powered by an electric motor.
- To prevent saturation of the coolant with oxygen from the air, which may intensify corrosive degradation, the air cavity should be separated from the liquid by an impermeable elastic membrane.
- Modernization of the cooling system increases engine reliability through automated monitoring and adjustment of coolant properties.

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