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Simulation of parameters of the vapor-liquid compression cooling system of power machines

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Abstract. The paper presents a mathematical model of the cooling system with vapor-liquid compression installation modified with an additional allowance for the effect of mass flow rate of ambient air on a heat transfer in the system's heat exchanger-condenser. Also the correction factors considering the difference between the mean log and the mean arithmetic temperature pressure are introduced. The results of numerical simulation showed that the efficiency of the proposed cooling system is 149% and 200% higher than the classical at the ambient temperature plus 10°C and 50°C respectively.

The resolution of the problem of qualitative improvement of cooling systems parameters of responsible for stabilization of the thermal state of power machines, the efficiency of which is largely determined by the external factor of seasonality due to the reduction of heat transfer of heat exchangers when increasing temperature of the environment, is considered by many authors [1, 2, 3, 4].

They offer the way of high-temperature cooling which can not be accepted for cooling systems as a part of the combined internal combustion engine with electric transmission because of the restriction of cooling liquid temperature on the entrance to traction electric motors and power converters [5], or for technological reasons.

In the work [6] it is proposed a method of cooling electrical machines using the liquid-vapor compression system (see figure 1). It gives a description of the design, the mathematical model used for calculations and dependencies of electrical machines exhaust thermal power when the mass flow and temperature of the ambient air circulating through the heat exchanger-condenser changes.

The proposed mathematical model [6] doesn't take into consideration the influence of mass flow air circulating changes of through the heat exchanger-condenser on heat transfer and the model was obtained using the expression for the arithmetic mean temperature pressure, which affects the precision of determined parameters.

Therefore, in this work we propose a modification of the mathematical model of the cooling system [6], taking into consideration the dependence of heat transfer from the dynamics of the air mass flow, and with correction factors $k_{t\_К}$ and $k_{t\_И}$ taking into consideration the difference between the arithmetic mean and mid-logarithmic temperature pressure in heat exchangers the evaporator and condenser respectively.

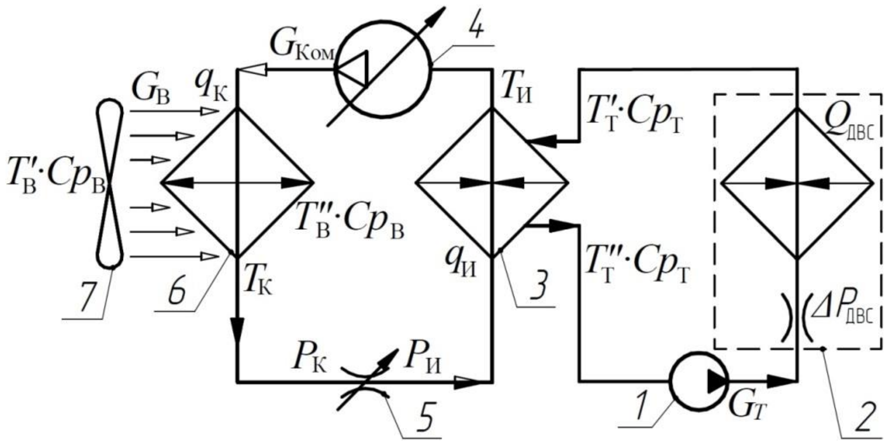


Figure 1 – Schematic diagram of the liquid-vapor compression cooling system 1 – coolant pump; 2 – cooling jacket of the energy machine (internal combustion engine); 3 – heat exchanger-evaporator; 4 – compressor of the working medium circuit; 5 – expansion device (throttle); 6 – heat exchanger-condenser; 7 – fan.

Modified mathematical model has the following form:

$$\begin{cases} Q_{И(i,j,k)} = \dfrac{G_Т \cdot c_{pТ} \cdot \left(T''_Т - T_И\right) + \left(x_k \cdot \dfrac{q_И}{q_К}\right) \cdot G_{В_i} \cdot c_{pВ} \cdot \left(T_К - T'_{В_j}\right)}{\dfrac{G_Т \cdot c_{pТ}}{k_{t\_И} \cdot k_И \cdot F_К} + \dfrac{G_{В_i} \cdot c_{pВ}}{k_{t\_К} \cdot k_{К_i} \cdot F_К}} \\ k_{К_i} = f\left(\alpha_В\left(G_{В_i}\right)\right) \\ 0 < x_k \le 1 \end{cases}, \tag{1}$$

where $k_{t\_И} = \Delta T_{И\_\log} / \Delta T_{И\_Л}$ and $k_{t\_К} \Delta T_{К\_\log} / \Delta T_{К\_Л}$ – dimensionless correction factors; x_k – the coefficient taking into consideration the energy cost of the compressor 4 (see Fig. 1) depending on the mass flow of the working medium.

Heat emission to ambient air was identified based on design features of the heat exchanger-condenser according to the equation of similarity [7]:

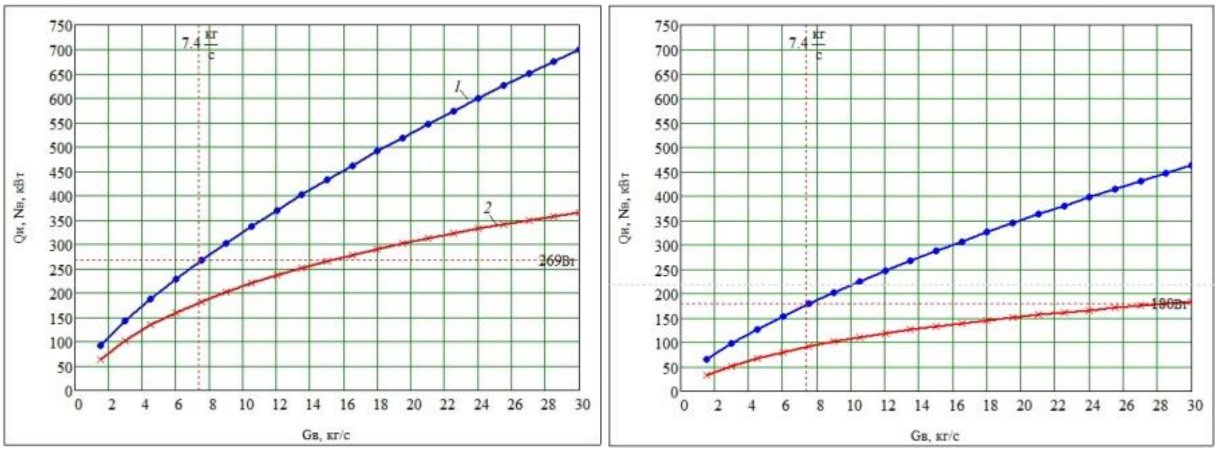
$$\alpha_В = C \cdot \frac{\lambda_В \cdot \mathrm{Re}_В{}^n}{L} \cdot \left(\frac{d_{К.н}}{b}\right)^{-0,54} \cdot \left(\frac{h}{b}\right)^{-0,14} \cdot \psi \cdot \varepsilon_С \cdot \varepsilon_Z\,, \tag{2}$$

Heat emission from the coolant to the working medium in the heat exchanger-evaporator was calculated taking into account design features of the equation of similarity:

$$\alpha_Т = C \cdot \frac{\lambda_В \cdot \mathrm{Re}_Т{}^n}{L} \cdot \mathrm{Pr}_Т^{0,36} \cdot \left(\frac{\mathrm{Pr}_Т}{\mathrm{Pr}_С}\right)^{0,25} \cdot \varepsilon_\varphi\,, \tag{3}$$

For calculation characteristics of the cooling system with vapor-liquid compression setting were made as numerical values of the parameters of the cycle and working medium similar in the work [6]: working medium freon-10, the condensing temperature $T_К$=127°C, evaporating temperature $T_И$=67°C, the coolant Tosol-65, which temperature at the outlet of the heat exchanger-evaporator was equal to $T_Т$=70°C and kept stationary, the heat transfer areas of the condenser $F_К$ and evaporator $F_И$ were obtained for the thermal power of the exhaust cooling system 180 kW at ambient temperature equal to 50°C and the air mass flow rate $G_В$=7.4 kg/s.

The result of numerical simulation is presented on the figure 2 a, b.



a) *b)*

*Figure 2 – Dependencies of the amount of heat dissipated by cooling systems when the temperature and mass flow rate of ambient air: **a** - at ambient temperature 10°C; **b** - at ambient temperature 50°C 1 – system with the liquid-vapor compression installation; 2 - a classical cooling system.*

The result of modeling showed that the thermal power which is taken away in the atmosphere in case of use of the cooling system with vapor-liquid compression installation at the same parameters of ambient temperature, mass flow rate the cooling air and identical stuffing of the heat exchanger-condenser (the heat exchanger for the classical cooling system), is much higher than the power taken away by a classical cooling system. So at the air mass flow rate of 7,4 kg/s and temperature of equal to 10°C heat emission of the classical cooling system is about 180 kW. The cooling system with vapor-liquid compression installation in the same conditions can take away 268 kW from the power machine that makes 149%.

With temperature increasing of ambient air to 50°C heat emission the classical cooling system decreases to 90 kW, and in the system offered the vapor-liquid cooling system to 180 kW, at the same time efficiency of cooling increases up to 200%.

Thus, the modified mathematical model allows to calculating performance cooling system characteristics with vapor-liquid compression installation taking into account all primary technical and thermal properties of system and environment. Implementation of vapor-liquid compression installation in the cooling system will allow to considerably increasing the average temperature differences due to increase in temperature of the working medium in the heat exchanger-condenser. The consequence of that will be increase of amount of the taken away heat to the atmosphere that in turn will ensure more effective functioning of the power machine at the increased ambient temperature, and will also improve weight and size characteristics of the system that is especially actual important for mobile equipment operated at high loads in harsh conditions.

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