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INFLUENCE OF AERODYNAMIC CHARACTERISTICS ON THE HEAT EXCHANGING IN THE COOLING SYSTEM

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Summary. The adequate mathematical model of diesel locomotive cooling device is offered. The solution of this model is received by numerical method of calculation. The optimization criterion and the method of accounting the influence of aerodynamics on heat exchange process are offered.

Keywords: diesel locomotive, cooling system, heat exchanger, air flow, energy index, Prandtl criteria.

INTRODUCTION

Trouble-free and efficient operation of the locomotive is impossible without reliable and cost effective heat carrier’s cooling system. In the most advanced diesel engines by about 40% of the heat introduced with the fuel is converted into useful work, and the rest of the heat lost in exhaust gases for heating components and overcome the friction forces. Suffice it to say for example that the temperature of the lower piston diesel 10 D 100 at some points reaches 450 °C [3]. The temperature of the individual dots cylinder diesel engines covers 5 D 49 is only 50 - 100 °C below it.

If you do not take special measures, the hot gases come into contact with parts quickly overheat, their mechanical strength is reduced, the film lubrication between them will burn out. Dry friction is greatly impeding the movement of the wearing pieces and cause damage to work surfaces. To avoid this, the normal thermal state of the components of diesel supported by a special cooling system. There is an easy way of cooling. It's heat dissipation into the environment of the surfaces themselves parts. That’s how small capacity diesel engines do using air cooling. But for the powerful diesel engine this solution is unacceptable, since the sizes of surface of heated parts are negligible in comparison with the amount of heat that needs to deviate them to work properly. And to increase those dimensions directly in a diesel engine can not be due to the limited size of the locomotive [10].

THE FORMULATION OF THE TASK

Heat exchanger-cooler in locomotives designed to remove heat from the cooling, diesel oil, oil of hydraulic transmission, and dissipation of heat into the surroundings. Heat exchanging between the cooling medium (water and oil, diesel oil of hydraulic transmission) and the surrounding air is in the water-and water-oil cooler sections, representing a tubular structure with a transverse outer edges-plates. The fan is directly behind the front sections or water cooler. The tubes and plates are washed by the air that fan suck in. The rate of air passing through the section, up to 8 - 10 m/s [4]. The higher air velocity that goes through the sections, the more efficient the heat is transferred. The amount of heat given out sections depends on water temperature. To reduce the size of diesel refrigerator, the temperature of water that cools diesel increases to 80-95 °C, and closed cooling systems to 105-110 °C. Water supply to the sections and carried back to the diesel pumps.

This system provides heat transfer up to 12% of the total amount released by diesel engine, with a relatively small amount of water. Water systems in locomotives differ in the number of paths of circulation. They may be open or closed. In modern diesel engines, which provide oil cooling engine and charge air with water, as a rule, apply double-circuit system. Usually, the water system used in locomotives open - they are connected with the atmosphere. The water temperature in such systems should not exceed 90-95 °C. Closed systems are not connected with the atmosphere, the water in them is under surplus pressure and their temperature is about 100-120 °C [1] (high temperature cooling). Thus, water systems cooling include pumps for circulating water piping with fittings, devices for cooling water (radiator), fan, control and protection devices.

From the viewpoint of the cooling device's airflow aerodynamics in the mine it is important how rectifying apparatus, sections of the radiator and fan are relatively situated. On this basis the cooling device can be classified in order of placement of these units along the stream [7]. In existing designs of mine cooling devices are most often used the following scheme:

1. Louver apparatus - the radiator - the camera - the fan (2TE10L locomotive and its upgraded versions).
2. Louver apparatus - camera - the radiator - the camera - the fan (ТЭ109, ТЭП150 locomotives). To the same section of the classification can be attributed some of mine cooling devices locomotive with hydraulic transmission, such as ТГ16).
3. Louver apparatus - the radiator - the camera - the fan - the camera – the radiator (this mixed layout of blocks used in some foreign locomotives, such as "Century" (USA)).

This aerodynamic classification allows us to generalize the approach to modeling the flow of air inside the mine cooling device due to the possibility of setting up such boundary conditions.

As mentioned above, the cooling system should, on the one hand, provide optimal thermal conditions of the locomotive engine, on the other hand - to consume a minimum of energy to drive the fan. An important role in meeting these requirements has the aerodynamics of the shaft running cooler [5]. Its configuration defines the hydraulic resistance and, consequently, the consumption of the fan power. The velocity field defines the intensity of heat exchange between the cooling air and the cooling. To solve this problem, use mathematical simulation approach.

THE DECISION OF THE TASK

The object of mathematical simulations the mine of cooling device. Calculating the air flow without relative velocity of the incoming air is fully justified application; simplified two-dimensional model is allowed, as length of the radiator is several times greater than its height [17]. Besides, as the majority of constructions are symmetric, calculation scheme can be simplified and it is possible to consider only half of given cross section. This method has been used in our work.

A mathematical model of the process is a differential equation in partial derivatives. The exact solution of this equation, in general, does not exist. Therefore, to obtain the values of the velocities in the plane of the radiator have to resort to numerical methods for integrating differential equations. Among the numerical methods of finite element method is by far the most versatile method for numerical calculation of the fields. It is especially good for its flexibility, ease of programming, as well as those that it is well suited for the interpretation of physics of the phenomenon [12]. This method for solving air flow path in the air ventilation system was implemented in the application package MATLAB.

Executed calculations on "HydroGasDynamics" chair of Volodymyr Dahl East Ukrainian National University of aerodynamic characteristics of flowing part of ventilation system showed good conformity with experimental data. This allows recommending the methods of finite elements for researches of air flow in flowing part of ventilation constructions of different types.

Obtained adequate mathematical model used to study the characteristics of the locomotive system cooling in order to minimize hydraulic losses and increase the heat transfer coefficient. Hydraulic resistance of the mine is chosen in the capacity of optimization criterion. From Bernoulli's equation for the flow of real fluid, it follows that the decrease of pressure losses in the refrigerator, at equal power of fan that is installed at the end of the mine, the flow rate, washing radiator, will increase; therefore, will increase the value of Re [16]. The higher the value of Re is, the higher the heat transfer coefficient, and the quantity of hydraulic losses in the chamber cooling device is directly proportional to the coefficient of hydraulic resistance. Thus, this parameter determines the efficiency of the cooling system as a whole.

Optimization of the existing design flow of the locomotive, which is observed the formation of circulation zones, implemented in the following way:

Construction for the design scheme of the current lines are not solving the Navier-Stokes equations [15], and Laplace's equation, thus obtaining the model of the flow inside the computational domain an ideal fluid;

Then change the geometry of the existing structure so that the walls of the flow path cross-sectional repeated some of the current lines, obtained by integrating the Laplace equation.

The calculations have shown that it can reduce the pressure loss in the mine by 4% while maintaining air flow.

The cooling device as described above, are one of the complex and large-sized units. They consume up to 75% of the power consumed for own needs of locomotives. The development of rational design of cooling systems associated with the solution of complex problems of heat transfer, reducing aerodynamic drag, size and weight of large elements of the systems; to improve their layout in the back of the locomotive, to prevent ingress of the exhaust gases of diesel.

The literature presents methods to improve efficiency and reduce the size of the cooling device by changing the design of the radiator, the optimal choice of fans, as well as the layout of the nodes in the mine of locomotive cooling device. However, insufficiently sanctified remains the question of the influence of aerodynamic flow of the mine cooling device whose design determines the velocity distribution of cooling air at the inlet of the radiator, affects the heat exchange process.

Design calculations of heat transfer process are reduced to the simultaneous solution of the equation of heat balance:

$$Q = G_1 \Delta i_1 = G_2 \Delta i_2$$

and the equation of heat transfer:

$$Q = \alpha \Delta t F,$$

where: Q - the amount of heat transferred from one heat carrier to another;

G_1, G_2 - cooling flow rate sending and the receiving heat, $\Delta i_1, \Delta i_2 -$ enthalpy change heat transfer fluids, $\alpha -$ the average heat transfer coefficient, $\Delta t -$ the average temperature pressure, $F -$ the calculated surface of the radiator.

The main task in this case is to determine the average heat transfer coefficient. Radiators used in the locomotive, may be carried to the recuperative heat exchanger type, in which the transfer of heat from one fluid to another through a separating wall [2]. In this case, the heat transfer coefficient is determined by the Nuselt criterion:

$$Nu = \frac{\alpha l}{\lambda},$$

where: α - the coefficient of heat transfer; l - the typical geometric size; λ - the coefficient of thermal conductivity the cooling.

For different constructions of radiators coefficients that determine addiction are different, but the common feature most of the formulas is that the calculation of the number of criterion is the average value of the radiator at the front speed. This leads to the fact that the formulas derived for a specific type of radiator can give inaccurate results in case of changing flow conditions and changes in the velocity profile at the front of the radiator.

Dependences $Nu = f(Re)$ [1] are known for a number of different types of radiators at the different modes of liquid flow. In general, it is possible to present them in the form presented below, separating an aerodynamic component:

$$Nu = m \cdot Re^n,$$

where: $n = 0.45..0.84$.

The coefficient of m is the function of Prandtl criteria for liquid and gas, at the frictional-gravity mode the Grasgoff criteria is included [13].

Calculation in these dependences is carried out by average on front of radiator velocity. In general case it can result in the error of determination of coefficient of heat transfer.

Velocity distributing of cooling air on front of radiator can be executed on the basis of equations of mathematical model solution, showed above [4]. Then Nuselt criterion taking into account distributing of velocity

$$Nu_{d.s.} = \frac{\int_F Nu_i dF}{F}.$$

The relation of criterion value $Nu_{d.s}$ to his value, calculated at average velocity $Nu_{c.c}$, characterizes the calculation error of heat transfer coefficient.

Main influence on its value renders the index of degree of Reynolds number. We will show it on the example of calculation of heat transfer coefficient of TEP -150 diesel engines. Velocity distribution of cooling air on radiator inlet, got as a result of calculations and confirmed by experimental data is shown on fig. 1.

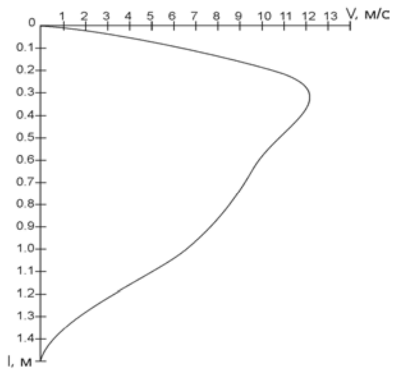

Fig. 1. Results of calculation and measuring of flow rate on front lateral jalousies of cooling chamber of ТЭП-150 diesel engine

The dependence of correction coefficient value k from the index of degree n is resulted on the fig. 2.

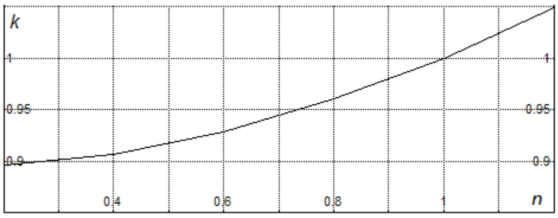

Fig.2. Dependence of correction coefficient k on parameter n

It is necessary to take into account correction coefficient to get $Nu_{\partial.c}$ value, calculated taking into account velocity distributing on radiator front

$$Nu_{d.s} = k \cdot Nu_{c.c}\,.$$

Thus, absence of account at the calculation of thermodynamics characteristics of mine of cooling device of velocity distributing results deflections of calculations from experimental data up to 10%.

Comparing estimation of efficiency of different charts of the cooling systems model and specific indexes, and also results of the unfolded technical and economical calculations are used.

To the number of actual parameters belong: quantity of heat, dissipated by cooling system; capacity, expended on functioning of the cooling system; gross weight of devices; expense of nonferrous materials; value of heat conveying surface of radiators; average annual expense of ferrous and nonferrous materials on cooling system repair; amount of heat exchangers (sections), repaired and changed during a year (average information), et cetera [22].

So-called specific indexes (energy, volumetric and gravimetric) got wide enough distribution at compounding cooling system in whole and, in particular case compounding separate heat exchangers [11]. Energy index

$$k_N = \frac{Q}{N\overline{\Delta t}} = \frac{kF}{N}\,,$$

where: Q is quantity of heat, transferrable in heat exchanger; N is power, expended on heat exchanger functioning; $\overline{\Delta t}$ is average difference of temperatures between the cooled and cooling liquids within the limits of the whole heat exchanger: ; k is coefficient of heat transfer; F is a calculation surface of heat transfer.

The index k_N is quantity of heat transferring in heat exchanger during one hour at $\overline{\Delta t} = 1°C$, being on unit of power, expended on heat exchanger functioning. Volumetric index

$$k_V = \frac{Q}{V\overline{\Delta t}} = \frac{kF}{V}\,,$$

where: V is volume, occupied by heat exchanger.

Gravimetric index

$$k_G = \frac{Q}{G\overline{\Delta t}} = \frac{kF}{G}\,,$$

where: G is heat exchanger mass.

For comparison of radiators (or sections) is used the index of thermal tension of front area

$$k_{F_{fp}} = \frac{kF}{F_{fp}}\,,$$

where: F_{fp} is frontal surface of radiator (or sections).

Specific indexes are more general comparing with full scale, because they allow conducting technical comparison of separate heat exchangers with different forms of surfaces, different values of conveying heat et cetera

Optimum heat exchanger, and the more so the optimum cooling system can not be chosen only on the basis of specific technical parameters, because they do not reflect many operating and economical factors. As basic technical and economical index, with sufficient plenitude of the characterizing the system cooling, accept the sum of the annual resulted charges, taken to heat dissipative ability of the system or to the measuring device of vehicular work [6]. The specific resulted annual charges in general case are

$$E'_P = \frac{1}{U}\left(E_H K + C\right)$$

where: E_H is normative coefficient of efficiency; K are capital costs on cooling device manufacturing; C are annual expenses on exploitation, depending on diesel engine cooling system; U – annual expenses parameter.

CONCLUSIONS

There are enough works devoted the calculation of running expenses and methods of comparative estimation of efficiency of the cooling systems [9], [10]. However all existing methods are based on the value of heat transfer coefficient α, at determination of which influence on the process of heat exchange of velocity distribution is not taken into account on the section of radiator, that reduces exactness of the calculations of efficiency and economy of the cooling systems.

In the presented work the main attention is paid on perfection of aerodynamic characteristics of flowing part of cooling device, their connections with the process of heat exchange on the basis of mathematical simulation of gas flow. The method of accounting the influence of aerodynamics on heat exchange process is offered.

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ВЛИЯНИЕ АЭРОДИНАМИЧЕСКИХ ХАРАКТЕРИСТИК ПОТОКА НА ТЕПЛООБМЕН В СИСТЕМЕ ОХЛАЖДЕНИЯ

Елизавета Гусенцова

Аннотация. Предложена адекватная математическая модель охлаждающего устройства тепловоза. Решение данной модели получено численным методом. Предложен критерий оптимизации и методика учета влияния аэродинамик на процесс теплообмена.

Ключевые слова: локомотив, охлаждающая система, теплообменник, течение воздуха, энергетический показатель, критерий Прандтля.