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MODELING THE HEAT EXCHANGE PROCESS BETWEEN THE MAIN UNITS OF MODERN WHEELED ARMORED TROOP-CARRIER ON THE BASIS OF FINITE ELEMENT MODELING METHODS

In the article, the authors analyzed the existing designs of wheeled armored personnel carriers based on the methods of finite element modeling of physical processes, in particular, heat transfer processes in the cooling system of modern samples of domestic military equipment BTR-4A, BTR-4V and BTR-4E-2. When calculating the options for the layout of the engine-transmission compartment, hydropneumatic suspension and fan cooling system of the power plant, the presented mathematical model of heat fluxes allows with sufficient accuracy to determine the effectiveness of the proposed promising samples.

Keywords: engine-transmission compartment, hydraulics, ventilation system, wheeled armored personnel carrier.

STATEMENT OF THE PROBLEM

Over the past decade in the State Enterprise «KDBM» named after O.O. Morozova, prototypes of wheeled armored personnel carriers (APCs) were designed and manufactured, equipped with modern weapons systems of domestic production, as well as engines, automatic transmissions (AKP), elements of hydropneumatic suspension, both foreign and Ukrainian. When carrying out design developments of power plants, wheel suspension of armored personnel carriers, special attention was paid to their ability to perform combat missions in hot climates typical for states - potential customers, especially at ambient temperatures up to + 55 °C in the shade.

To achieve this goal, two types of cooling systems (CS) were designed: traditional for «KDBM» ejection cooling systems used on BTR-60M, BTR-70M, BTR-3E, BTR-4E and providing cooling of radiators by ejection of ambient air due to the use of the energy of the engine exhaust gases at the outlet of the receiver nozzles; and fan cooling systems in which the radiators are cooled by the air flow generated by the fans (on the BTR-3DA, BTR-3E1, BTR-4A, BTR-4V and BTR-4E-2). But if in specific given ejection cooling systems the radiators are cooled by air from the atmosphere, and the engine-transmission unit (ETU) is separated from the penetration of air flows passing through the radiators, then in the developed fan cooling systems the air flows pass through the engine-transmission compartment (ETC), however, there are two types of constructs that have advantages and disadvantages.

In the first version, the fans suck in cold atmospheric air into the radiators, after which it heats up, blows over the ETU and is thrown out through the exit louvers (BTR-4A, BTR-4V and BTR-4E-2). On the positive side, the radiators are cooled by air from the atmosphere, on the negative side, there is a significant heating of the air inside the ETC, which reduces the performance of the hydraulic systems located there and increases the temperature in the habitable compartments, creating uncomfortable conditions for the crew members.

In the second version, the fans take the air already warmed up by the engine and power units from the ETU compartment and send it to the radiators of the cooling system, after which it goes outside (BTR-3DA and BTR-3E1). At the same time, it is positive that the engine, transmission, fuel and oil tanks, hydraulic systems located in the ETC are not additionally heated by hot air and comfortable conditions for the crew are maintained, and negative - the efficiency of the cooling system decreases, because the air already heated in the ETC enters the entrance to the radiators.

Purpose of the article. Evaluation of the currently used transmission designs in terms of determining the optimal layout of the fan cooling system for its operation with greater efficiency at the same power consumption, which is further necessary for the design of promising armored personnel carriers.

MAIN PART. In this article, we will analyze the existing structures using the methods of finite element modeling of physical processes, in particular, the processes of heat exchange in the cooling system of modern samples of military equipment of domestic production, BTR-4A, BTR-4V and BTR-4E-2. Based on this analysis, it is also possible to evaluate the efficiency of the most promising layout of the cooling system, when atmospheric air is sucked through the radiators through a separate air duct with the help of fans and is thrown back into the atmosphere without getting into the ETC. Such modeling will allow you to correctly evaluate and select the cooling scheme for armored personnel carriers.

In fig. 1 as an example of a design in which cold air from the atmosphere is sucked by fans through the radiators and enters already heated in the ETC and to the hydraulic elements, a simplified schematic diagram of the BTR-4V fan cooling system is shown.

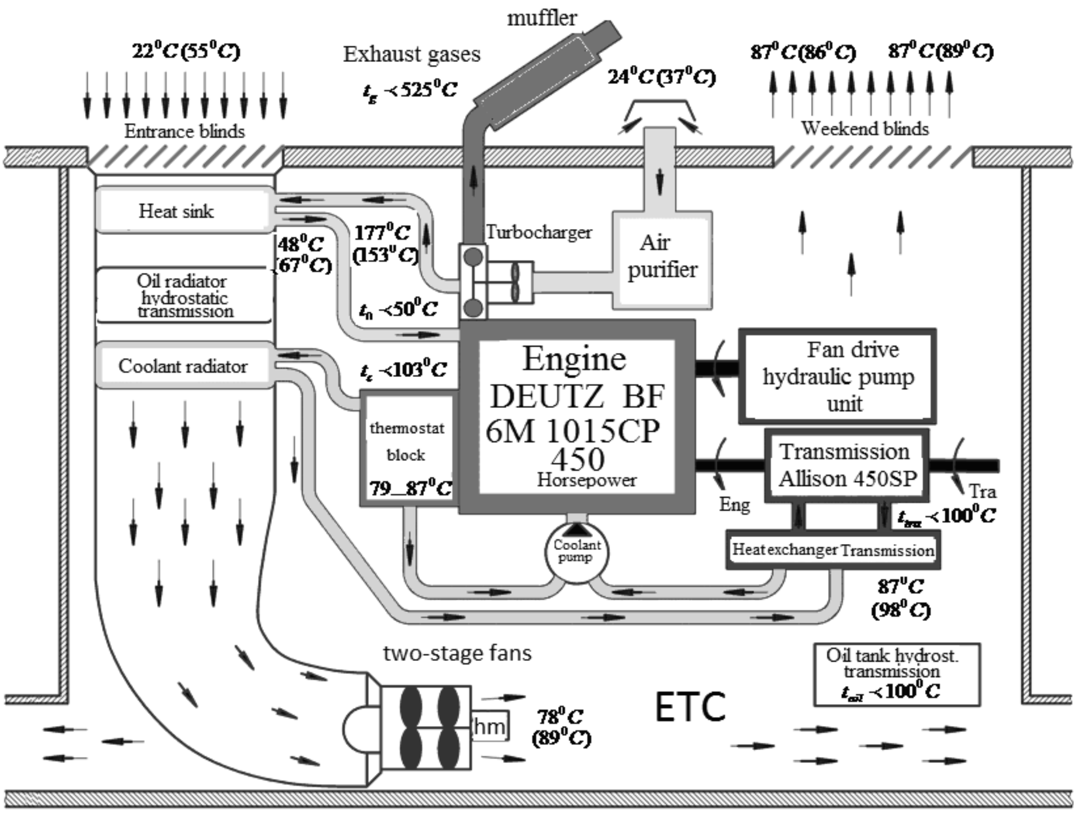

Figure: 1 Schematic diagram of the BTR-4V fan cooling system, air supply and gas removal systems of the power plant with a DEUTZ engine (in brackets are the values of air and coolant temperatures when air heated to + 55 °C is supplied to the radiators).

In this diagram, arrows show the movement of air and coolant (coolant) flows, and also show the values of their temperatures obtained during tests. So, for example, at an air temperature at the inlet to the radiators of 22 °C at the outlet from the fans (after the radiators), it enters the ETC heated to 78 °C, after which it heats up and at the exit from the compartment its temperature is already 87 °C.

At an ambient temperature of 55 °C, the air heated to 89 °C (values in brackets) comes from the fans into the ETC, and at the exit from the exit louvers its temperature is 86 ... 89 °C. Thus, heating the air inside the ETC BTR-4V to a temperature of 80 ... 90 °C negatively affects the operation of hydraulic systems, and in the event of a leak, the ETC creates uncomfortable working conditions for the crew members.

Based on the experimental data, when fans blow the surface of the radiators, the turbulent air flow has a wave pulsating character (Fig. 2).

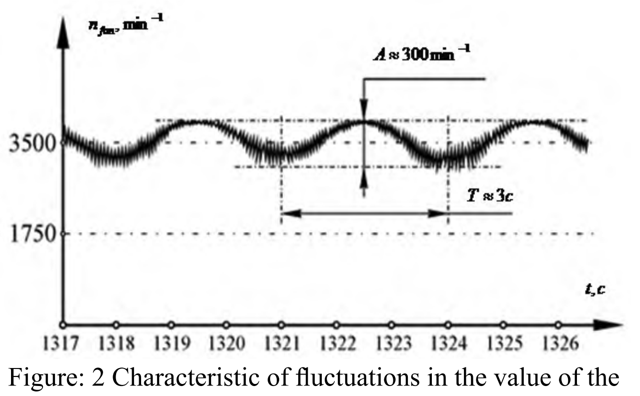

Figure: 2 Characteristic of fluctuations in the value of the rotor speed of the fan of a typical cooling system.

Therefore, when testing various designs of the casing, along which the turbulent air flow moves, the velocity pulsations were concentrated in one direction. Having experimental data on the pulsation characteristics of a turbulent flow, it is possible to simulate the movement of air at each point of the flow region from the fan outlet to the front surface of the radiator, if the fan works for blowing, and vice versa, when working for suction, from the front surface to the fan inlet [1].

Atmospheric air **d** is sucked in through the radiator block e under the action of a vacuum generated by a fan mounted on the flange **h** behind the radiator block and is straightened by the casing in front of the fan inlet; this is how the radiators are blown off (Fig. 3).

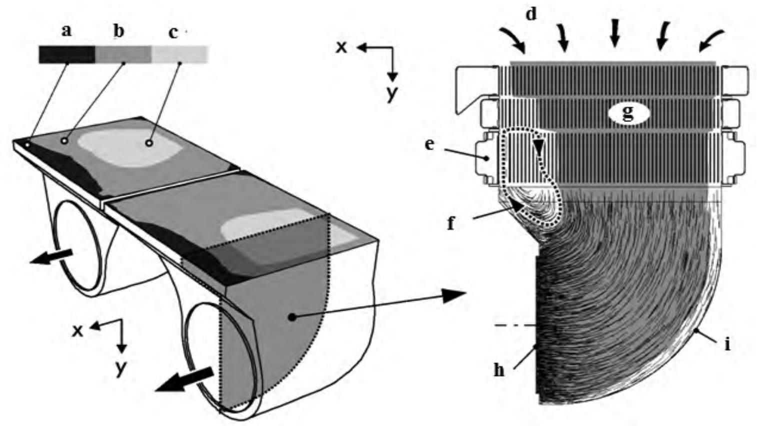

Figure: 3 Diagram of the flow of cooling air in the cooling system of the BTR-4V armored personnel carrier in the section from the entrance to the fan unit.

The calculation showed that the distribution of the velocity field, as expected, is far from uniform. The air flow has a core **c** (Fig. 3), the flow velocity in which exceeds the calculated one, which is associated with a reduced average flow velocity in zone **b** at a constant initial flow rate of atmospheric air [1]. Also inevitably there is a stagnant zone **a**, consisting of attached vortices [3], for example, vortex **f**.

Obviously, such a picture is quite different from the calculated one, in which the velocity field over the cross section of the radiator core has a uniform distribution, and the narrowing of the real equivalent flow diameter is not taken into account. Obviously, the introduction of a coefficient that takes into account a decrease in the heat transfer coefficient in case of incomplete washing of the heat transfer surfaces of the radiator **δ**, as suggested in [2, 3].

As can be seen from the experimental data, group formations appear in transient and turbulent flow regimes, which leads to a new kinetic theory to generalize the definition of entropy for nonuniform and inhomogeneous flows. This generalization shows that the formation of groups of molecules in the gas flow increases the entropy, which indicates a more probable state of the gas with turbulent moles.

Based on this analysis, a theory is needed to construct turbulence in a more rigorous approximation, considering laminar flows as stabilized and revealing a number of other phenomena.

When constructing a turbulence model, it is necessary to average the hydrodynamic characteristics of a turbulent flow by the flow parameters, taking into account that in a laminar flow the process of leveling the fields of velocity $\boldsymbol{u}$ and, temperature **T**, and flux density **ρ** is carried out due to the chaotic movement of molecules with an average speed and medium u_{surr} and an average path length λ.

In turbulent flow, the process of equalizing the flow parameters involves not only individual molecules, but entire groups of molecules - moles, which have the same speed and temperature, after which they mix with the main flow, changing the speed.

The appearance of mole molecules in transient and turbulent flows was confirmed by Filippov [4].

In addition, proceeding from the principles of mechanics and the theory of probability, in the works of Struminsky [5, 6] it is shown that at large Reynolds numbers, stable groups of molecules appear.

If you look at fig. 2, it can be seen that the unstable region **ci> 0**, and also that two adjacent amplitudes have opposite directions of the pulsation velocity and forming groups with opposite directions of the flow velocities. In such flows, the mixing process will proceed much more intensively than in laminar flow regimes. Therefore, when determining the stability boundaries of laminar flow regimes, where the Reynolds numbers are small, it is necessary to determine the onset of turbulence pulsations, where a stable group of molecules appears. In the work of Struminsky [5], it is shown that the group functions satisfy the system of kinetic equations:

$$\frac{df_s}{dt} = \sum_{\tau=1}^{M} \iiint (f_s^{/} - f_{\tau}^{/} - f_s f_\tau) g_{\rho\tau} bdbd \quad d\epsilon \; dU_\tau, \quad (1)$$

where: $\boldsymbol{M}$ - is the number of groups in the system; $\boldsymbol{fs}$ - is the distribution function of groups of molecules of the system; $\boldsymbol{f}_\tau$ - is the distribution function of the friction stress of the turbulent flow of the system; $\boldsymbol{g\rho\tau}$ - is the system recovery function depending on the density and friction stress; $\boldsymbol{b}$ $\boldsymbol{d}$ - zones of limitation of the system; $\boldsymbol{dU\tau}$ is the differential of the pulsating velocity of turbulent stresses; $\boldsymbol{d\epsilon}$ - total system flow turbulence.

The solution of this system by the Struminsky method led to a system of hydra-dynamic equations, different from the Navier-Stokes equations [6].

In this regard, when generalizing the kinetic theory, due to significant inhomogeneous nonequilibrium processes caused by pulsations of the temperature flow, a shock wave with a boundary layer, accelerating motion in a flow where there is a sufficiently large number of groups of molecules, the energy can change with a change in flow regimes. This kinetic theory has great possibilities in analytical form to solve the problems of changing the structure along the motion of a turbulent flow by the modeling method, using the experimental values of the wall heat transfer coefficient, and makes it possible to study thermal processes not only on the entire surface of the streamlined body, but also on the investigating part.

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$$S_S = -kH_S, \tag{2}$$

where S_s - is the entropy of the system; k - is the Boltzmann constant; H_S - is the distribution function introduced by Boltzmann.

$$H = \iiint f_1 \ln f_1 \, dV . \tag{3}$$

We differentiate equation (2) in time and obtain:

$$\frac{\partial S_s}{\partial t} = -k \iiint 1 + \ln F_s \frac{\partial F_s}{\partial t} dV_s \tag{4}$$

or $$\frac{\partial S_S}{\partial t} = -k \sum_{\tau=1}^{M} \iiint 1 + \ln F_s \, J(F_s F_\tau) dV_s , \tag{5}$$

where $J(F_s F_\tau)$ - is the distribution function of the turbulent flow passing through the surface region Vs per unit time.

Performing integration over the V_S region, we determine the state of the entire substance contained in a given volume while taking into account that:

- the V_s region is parallel to the Oz axis and does not lie on the boundary of the S region;

- the whole area V_s is projected onto the Oxy area of S;
- any part of the region Vs is parallel to any of the planes (Oxy, Oxz, Oyz).

$$\frac{\partial S_S}{\partial t} = \frac{8k}{m} \sum_{\tau=1}^{M} \frac{\rho_\tau \rho_s \Omega_{s\tau}^{1,1}}{T_S} \left[(T_\tau - T_s) + \frac{2mT_s}{T_\tau + T_s} (u_\tau - u_s)^2 \right], \tag{6}$$

where $\Omega_{s\tau}^{1,1}$ – is the parameter of microstates of the friction coefficient of the turbulent boundary layer; m – is the boundary layer constant.

From the obtained expression (6), it can be seen that the entropy of groups of molecules increases, and this is the result of the quadratic term of the velocity pulsation $(u_\tau - u_s)^2$, the linear term $(T_\tau - T_s)$ at $T_\tau > T_s$ entropy $\partial S_s/\partial t > 0$, of the group molecules are positive and cool the S region; and at $T_\tau < T_s$ the entropy $\partial S_s/\partial t < 0$, the groups of molecules are negative and heat the region S.

This expression describes the internal entropy, the rate of change in the external entropy and the temperature of the exchanging energy of groups of molecules with different input and output parameters that are usually different from each other.

Thus, the analysis performed shows that the formation of molecular groups in a turbulent flow leads to an increase in its entropy, and characterizes the structure of the system as capable of the appearance of more probable states.

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Thus, the analysis performed shows that the formation of molecular groups in a turbulent flow leads to an increase in its entropy, and characterizes the structure of the system as capable of the appearance of more probable states.

Entropy can be determined using two equivalent approaches - statistical and thermodynamic. The statistical definition is based on the idea that irreversible processes in thermodynamics are caused by a transition to a more probable state, so entropy can be related to the probability of events.

With an increase in entropy, a phenomenon takes place when the entropy of the system changes due to the flow of heat during heating. In this case, the system is increasingly moving away from the previous state of equilibrium. This can be seen from expression (6) for the statistical definition of entropy, when the increase in entropy is accompanied by an increase in the thermodynamic probability of the macroscopic state of the system. However, in the presence of a significant field energy, corrections for the entropy of the fields should be introduced into expression (6). At the moment, experimental studies, confirmed by the results of calculations, should be given great attention, and this is acquiring a clear scientific explanation.

At the same time, by composing new hydrodynamic equations, it is possible to predict with high accuracy the onset of the onset of instability in the system associated with a huge number of groups of molecules, some of which deviate from a uniform distribution. The state parameters do not remain strictly constant, but experience large fluctuations within their equilibrium states.

Therefore, we can emphasize that, within the framework of the theory, when taking into account the appearance of groups of molecules and various perturbations in the system created by them inside the boundary layer (as can be seen in Figs. 3 and 5), small steps lead to additional changes in the function of components that create additional disturbances in the system itself, which leads to an increase in the critical Reynolds number.

As can be seen, in the unstable region, where groups of molecules of the turbulent flow regime appear, the kinematics of the entire system can be calculated using formulas.

In terms of improving the design of the ETC layout, aimed at changing the direction of air flows inside the compartment, let us consider the schematic diagram of the improved fan cooling system of the BTR-4V, shown in Fig. 4. In this case, atmospheric air, for example, at a temperature of 36 °C, enters the ETC, where, as a result of the existing heat release from the engine, transmission elements and other operating units, it heats up to 52 °C. With such a temperature, the air is forced by fans into the radiators of the cooling system and exits them into the atmosphere heated to a temperature of 93...98 °C. In this case, the air entering the ETC contributes to the cooling of the outer surfaces of the operating ETC units, but it enters the entrance to the radiators already heated with a temperature of 16 °C higher than its temperature at the entrance louvers, which in general reduces the efficiency of the cooling system for this the layout of the ETC. It should be noted that the ones shown in Fig. 4 temperature values were obtained during thermal engineering tests of the BTR-4A power plant with an IVECO Cursor 10C10ENTC engine with a power of 430 hp. with a similar ETC layout and with fans of the same performance.

CONCLUSIONS. The considered options for the layout of the ETC with a fan cooling system of the power plant of the armored personnel carrier are not sufficiently acceptable to meet all the requirements for the temperature conditions for the placement of hydraulic systems, other components and assemblies inside the ETC, the efficiency of the cooling system of the power plant and the habitability of the compartments. The analysis of the measurement results allows us to assert that the most promising in terms of minimizing the existing problems of the considered ETC layouts is the third option - when the fan compartment with radiators is hermetically sealed and separated from the ETC volume, that is, the air is taken from the atmosphere by fans, cools the radiators and the heated one is thrown back into the atmosphere, and ETC ventilation is provided by other devices.

When calculating this variant of the ETC layout with a fan cooling system of the power plant, the created mathematical model of heat fluxes makes it possible to determine the effectiveness of the proposed measures with sufficient accuracy.

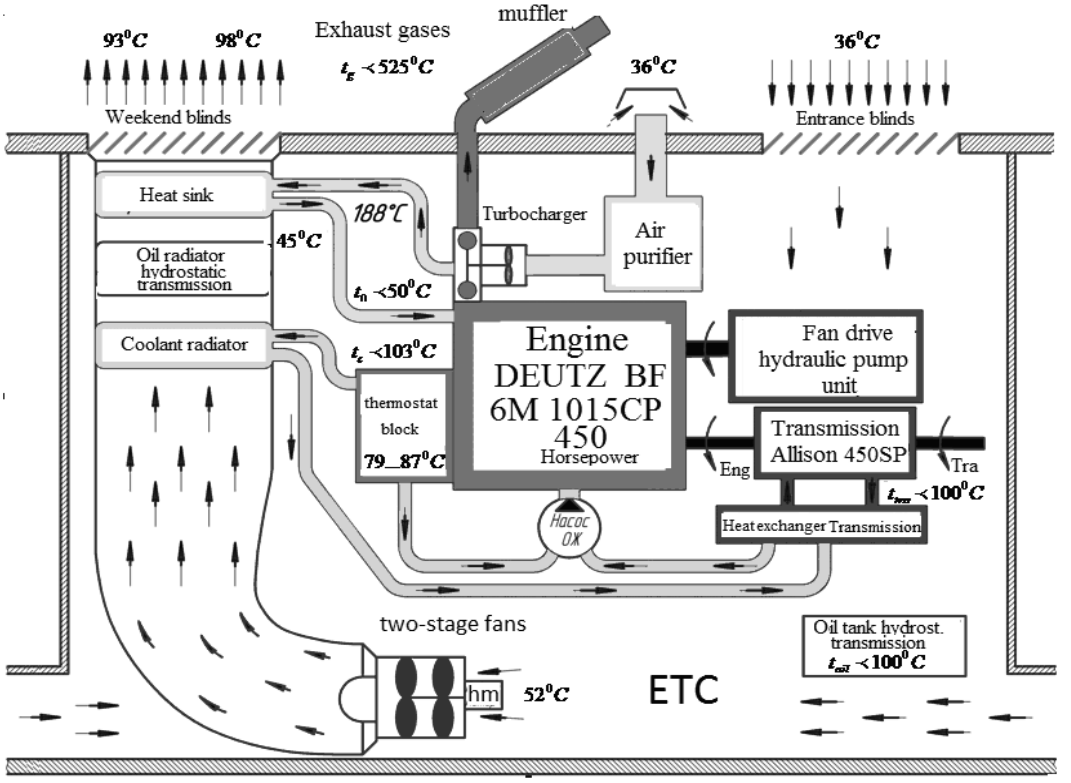

Figure: 4 Schematic diagram of the improved fan cooling system of the BTR-4V and air supply and gas exhaust systems of the power plant with a DEUTZ engine.

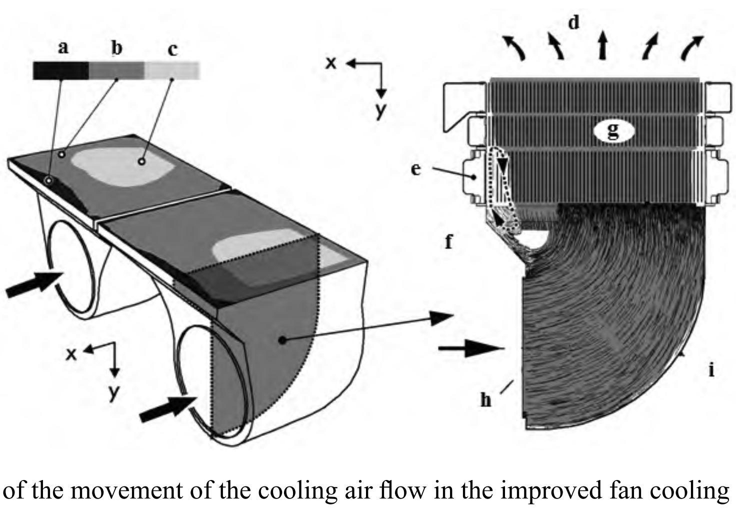

Figure: 5 Diagram of the movement of the cooling air flow in the improved fan cooling system of the BTR-4V armored personnel carrier in the section from the entrance to the fan unit.

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МОДЕЛЮВАННЯ ПРОЦЕСУ ТЕПЛООБМІНУ МІЖ ОСНОВНИМИ АГРЕГАТАМИ СУЧАСНИХ КОЛІСНИХ БРОНЕТРАНСПОРТЕРІВ НА БАЗІ МЕТОДІВ КІНЦЕВООЕЛЕМЕНТНОГО МОДЕЛЮВАННЯ

В статті на основі математичних розрахунків та отриманих експериментальним шляхом даних проведено дослідження компонувальних рішень моторно-трансмісійного відділення (МТВ), гідросистем бронетранспортера з вентиляторною системою охолодження. Ці матеріали мають практичну цінність і повинні використовуватися на початкових етапах проєктування систем охолодження основних елементів бронетранспортера з метою їх оптимізації та поліпшення характеристик.

В статті авторами проаналізовано існуючі конструкції колісних бронетранспортерів на базі методів кінцевоелементного моделювання фізичних процесів, зокрема, процесів теплообміну в системі охолодження сучасних зразків військової техніки вітчизняного виробництва БТР-4А, БТР-4В і БТР-4Е-2. При попередніх оцінках варіантів компонування моторно-трансмісійного відсіку, гідропневматичною підвіски і вентиляторної системи охолодження силової установки представлена математична модель теплових потоків дозволяє з достатньою точністю визначити ефективність пропонованих перспективних зразків.

Ключові слова: моторно-трансмісійний відсік, гідравліка, вентиляційна система, колісний БТР.

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