

РУХОМИЙ СКЛАД ЗАЛІЗНИЦЬ І ТЯГА ПОЇЗДІВ

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WAYS TO MANAGE HEATING INERTIA

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Purpose. The research paper proposes to estimate the effect of heat inertia of the water heating system, in transient operation modes, on the temperature condition in the passenger car, as well as to offer technical solutions intended to reduce the heating system inertia effect and to maintain a stable temperature condition in the passenger car premises in transitional modes of the heating system. **Methodology.** The author developed the method for controlling the heat transfer of heating system pipes with the help of regulating casings. To control the heating system and the heat transfer of heating pipes, two types of temperature control sensors were used in the passenger car: certain sensors interacted with regulatory casings, while the others interacted with high-voltage tubular heating element control devices. To assess the efficiency of heat interchange regulation of heating pipes and the heating system control, with installed regulating casings, the operation of the heating system with regulating casings and two types of sensors was mathematically modelled. Mathematical modelling used the experimental test data. The results of experimental tests and mathematical modelling were compared. **Findings.** Currently in operated passenger cars, control of heating appliances is not constructively provided. Automatic maintenance of the set temperature in a passenger car is limited to switching on and off of high-voltage tubular heating elements. The use of regulating casings on heating pipes allows reducing the effects of heat inertia and maintaining stable thermal conditions in a passenger car, using the heating system as a heat accumulator, and also provides the opportunity to realize an individual control of air temperature in the compartment. **Originality.** For the first time, the paper studied the alternative ways of regulating the temperature condition in a passenger car. Using of the heating system as a heat accumulator. **Practical value.** The regulation of the heat transfers of the heating pipes by regulating casings allows reducing the effect of thermal inertia of the heating system on the temperature condition in a passenger car, implementing individual adjustment of air temperature in a compartment within 40% of the power of the heating pipe section, using the heating system as a heat accumulator.

Keywords: heating of passenger cars; free convection; heat transfer; heat accumulator

Introduction

During operation, it is practically impossible to maintain the required heat transfer fluid temperature in the passenger car boiler. This is due to the shutdown of high-voltage electric heating tubes of the heating system. The reasons for the shutdown are different during moving and standing with subsequent heating, resulting in transient heating modes that cause temperature fluctuations in passenger cars. This process is compounded by the fact that during moving and standing of a passenger car the required heating capacity of the heating

system is different, the higher the speed of the car, the more the required heating capacity of the heating system increases, this is confirmed by the results of the study [4], Fig. 1.

Transitional modes are compounded by the large heat inertia of the heating system. The installed high-voltage heating tubes also have heat inertia, which also affects the inertia of the heating system. The installed sensors for monitoring the temperature in the car have no correction for the inertia of the heating system.

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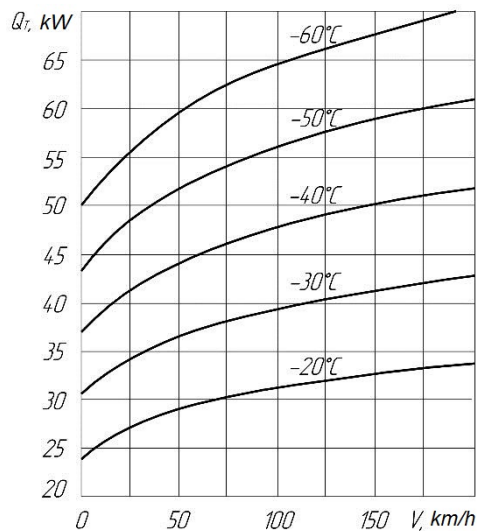


Fig. 1. Required heating capacity of the passenger car heating system in relation to traffic at various outdoor temperatures

Since 2004, all types of cars are equipped with air-conditioning units [2]. The water heating system with smooth regulation of the boiler's heat output in the range of loads from «0» to 48.0 kW is proposed. For this purpose, the boiler is equipped with three groups of electric heating: I group – 24.0 kW, 3 kV, II group – 12.0 kW, 3 kV, III group – 12.0 kW, 380 V. The third group of the boiler is connected to the air conditioner converter circuit through the appropriate switching devices. The converter provides for smooth regulation of the output power from «0» to P_{nom} (12 ÷ 17 kW). Therefore, the III group of the boiler will have smooth power regulation from «0» to $P_{nom} = 12$ kW. As a result, the entire range of heat output of the boiler will be with smooth regulation.

The disadvantage of the proposed system is that the system can work qualitatively when heating the boiler only with electricity.

The work [2] considers the water heating system with smooth regulation of heating output of heating pipes at boiler combined heating. The system is designed for smooth regulation and stabilization of the heat transfer fluid temperature at the inlet to the heating devices, respectively, at transient and steady-state modes, stabilizing the air temperatures inside the car during cycling of high-voltage heating groups of the boiler, and also when the boiler is operated with solid fuel.

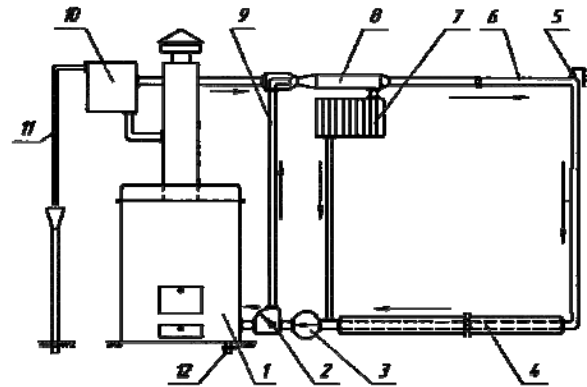


Fig. 2. Layout of water heating with separation of flows: 1 – boiler; 2 – divisor; 3 – circulating pump; 4 – heating pipes; 5 – air line; 6 – feeding pipe; 7 – air heater; 8 – mixer; 9 – bypass pipe; 10 – expander; 11 – overflow pipe; 12 – drain plug

The principle of operation of the system, whose layout is shown in Fig. 2, consists in the separation of the heat transfer fluid flow at the inlet to the boiler into two adjustable parts by the divider 2 with an electric drive. One part of the flow returns to the boiler 1, and the second one through the bypass pipe 9, passing the boiler, goes to the mixer 8. The movement of the heat transfer fluid through the system is carried out by a circulation pump 3. Depending on the required heating output of the system, a heat transfer fluid with the required temperature is fed into the heating devices through the mixer 8. In this case, there is no need for strict maintenance of any value of the heat transfer fluid temperature at the outlet from the boiler.

This system can only work when the circulation pump is on, which reduces its reliability.

The work [8] proposes to use the heating system as a cold and heat accumulator; the selection of accumulated, cold or heat is assumed only through the water heater, without additional conversion of the heating system. Using a heating system as a cold accumulator is possible, but as a heat accumulator without additional conversion is impossible, since the heating system will work in the usual heating mode. The publication of specialists [1] is devoted to the interaction of heating and ventilation systems; the work proposes to automate the operation of the water heater to maintain the set temperature, the outer air heated in the heater and fed by the ventilation system. Improvement of the operation of refrigerating

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equipment of passenger cars in transitional modes was considered in [11].

The study [14] is aimed at reducing the energy costs of modern light rail system Luas operating in Dublin, Ireland, through the optimization of the heating and ventilation system. The work [12] studied the Swiss railroad vehicles of Swiss Rhaetian Railway (RhB). The research is aimed at improving the energy efficiency of life-support systems for railway vehicles, by reducing the consumption of outside air by way of controlling CO₂ content in the air. The publications [5, 9, 13] are devoted to the improvement of air conditioning systems of modern passenger cars. Problems of increasing the comfort of passenger transportation are also examined in the scientific works of other researchers [7, 10], but they consider other aspects of comfort, which are associated more with the improvement of the dynamic characteristics of passenger rolling stock.

Proceeding from the foregoing, it follows that along with comparatively large volumes of research on improving the design of passenger car heating systems [1, 2, 4, 8, 11, 12, 14], the tasks of ensuring the maintenance of a stable temperature condition in passenger premises are practically not considered and require more effective solutions. Therefore, the direction of research related to improving the efficiency of the operation of heating units for passenger cars is an urgent scientific and applied task.

Purpose

The purpose of this study is to develop technical solutions to improve the design of the water heating system, in order to ensure a stable temperature condition in the passenger car premises in transitional modes of the heating system

Methodology

To carry out the research it was necessary to solve the following tasks:

- Analyse the shared participation of convective and radiant heat exchange on the surface of heating pipes;
- Evaluate the heat transfer efficiency of heating pipes, when installing the regulating casing.

On the heating pipe surface there is the

convective heat exchange with the internal air and the radiant heat exchange with the walls and internal equipment of the car. The intensity of such heat exchange is estimated by the heat transfer coefficient α , W/(m²·K), [6]:

$$\alpha = \alpha_r + \alpha_c \quad (1)$$

where α_r – radiant heat-transfer coefficient, W/(m²·K); α_c – convection coefficient, W/(m²·K).

For different bodies the radiation factor is different [3]. Its value is determined by the nature of the body, its surface state and temperature. This law establishes the dependence of the density E_0 of the body integral radiation flux on its temperature. For an absolutely blackbody:

$$E_0 = \sigma_0 T^4, \quad (2)$$

where σ_0 – Stefan-Boltzmann constant $\sigma_0 = 5.67 \cdot 10^{-8}$ W/(m²·K).

In technical calculations, this law is applied in the more convenient form:

$$E_0 = c_0 \left(\frac{T}{100} \right)^4, \quad (3)$$

where c_0 – blackbody coefficient.

$$c_0 = \sigma_0 \cdot 10^{-8} = 5.67 \cdot 10^{-8} \text{ W}/(\text{m}^2 \cdot \text{K}).$$

Consequently, the radiation energy of the absolutely black body is proportional to the fourth power of the absolute temperature.

This law can be applied to real bodies. In this case, it takes the form:

$$E = c \left(\frac{T}{100} \right)^4. \quad (4)$$

Here c is the radiation factor of various bodies. It varies from 0 to 5.67.

Comparing the flux density of the body's self-radiation with the radiation flux density of an absolutely black body at the same temperature, we obtain another characteristic of the body, which is called the emissivity factor ε .

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$$\varepsilon = \frac{E}{E_o} = \frac{c}{c_o}. \quad (5)$$

The value of ε varies from 0 to 1, which is convenient.

In this case we have for a real body:

$$E = \varepsilon E_o = \varepsilon c_o \left(\frac{T}{100} \right)^4. \quad (6)$$

The flux of radiant heat exchange between two grey surfaces in an enclosed space, when one of the surfaces with the area F_2 flows around the other with the area F_1 , is calculated by the formula:

$$Q = \varepsilon_n c_o F_1 \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right], \quad (7)$$

Where the expression:

$$\varepsilon_n = \frac{1}{\frac{1}{\varepsilon_2} + \frac{F_2}{F_1} \left(\frac{1}{\varepsilon_1} - 1 \right)}, \quad (8)$$

is called the reduced blackbody emissivity factor.

With regard to heating pipes:

F_1 – surface of the surrounding object (i.e., surface of the walls and the internal equipment of the car);
 F_2 – surface of heating pipes.

If we consider the last formula (8) with respect to the heat transfer on the unit of the heat-sensing wall surface, the specific heat flux of the radiation will be:

$$q_r = \varepsilon_n c_o \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right]. \quad (9)$$

Taking into account that the specific heat flux by convection is determined by the formula:

$$q_c = \alpha_c (t_p - t_n), \quad (10)$$

where t_p – pipe temperature, °C; t_n – air temperature, °C,

And the total heat flux q , by convection and radiation is as follows:

$$q = q_r + q_c. \quad (11)$$

Taking into account the expression (11), we obtain a formula for calculating the radiation heat transfer coefficient:

$$\alpha_r = 0.04 \varepsilon_n c_o \left(\frac{T_m}{100} \right)^3. \quad (12)$$

In formula (12) $T_m = 0.5 \cdot (T_1 + T_2)$ is the average temperature of bodies exchanging radiant heat.

With respect to the heat exchange between the heating pipes and air in the car, index 1 refers to the surface of the pipes, index 2 refers to the car inner equipment surrounding the pipe.

To determine the convective heat transfer coefficient, we use the criteria for the dependence of the Nusselt number N_u on the Grashof number G_r and the Prandtl number P_r :

$$N_u = c(G_r \cdot P_r)^n. \quad (13)$$

Having determined N_u , we calculate the value of the convective heat transfer coefficient:

$$\alpha_c = \frac{Nu\lambda}{d}, \quad (14)$$

where λ – air thermal conductivity coefficient, W/(m²·K); d – determining dimension, here the pipe diameter, m.

The value of the coefficients c and n , as well as the product G_r and P_r in the formula (13) is determined by the data of the table given in [3].

Having determined the value of heat transfer coefficient α , we calculate the heat transfer of the heating pipes Q_T , W;

$$Q_T = \alpha F (t_a - t_n). \quad (15)$$

Calculations of the heat transfer fluid temperature at various points along the pipe are made using the formula:

$$t = t_n + (t^0 - t_n) e^{-\alpha l}. \quad (16)$$

Let us analyse the share of convective heat transfer on the heating pipes of the heating system, the calculation results are summarized in Table 1.

Table 1

Heat transfer of the radiator from horizontal metal pipes at free convection

Initial data		Notation	Values	Units
1	Radiator pipe diameter	$D =$	76	mm
2	Radiator length (one pipe)	$L =$	22	m
3	Number of pipes in radiator	$N =$	2	pcs.
4	Water temperature at the beginning of the pipe	$t_n =$	85	°C
5	Water temperature at the end of the pipe	$t_0 =$	65	°C
6	Indoor air temperature	$t_a =$	22	°C
7	Type of pipe outer surface	Grey paint		
8	The Stefan-Boltzmann constant	$C_0 =$	5.67	W/(m ² ·K ⁴)
9	Acceleration of gravity	$g =$	9.80665	m/c ²
10	Emissivity factor of pipe surface	$e =$	0.900	–
11	Average temperature of pipe walls	$t_{cm} =$	75.0	°C
12	Temperature drop	$dt =$	53.0	°C
13	Air volume expansion coefficient	$b =$	0.00339	1/K
14	Kinematic viscosity of air	$n =$	0.0000133	m ² /c
15	Prandtl number	$P_r =$	0.7035	–
16	Air thermal conductivity	$\lambda =$	0.026119	W/(m·K)
17	Radiator surface area	$A =$	10.5055	m ²
18	Heat flux	$Q_u =$	3 536	W
19	Radiation heat transfer coefficient	$\alpha_u =$	6.4	W/(m ² ·K)
20	Grashof number	$G_r =$	3314599.8	–
21	Nusselt number	$N_u =$	19.5387	–
22	<u>Convective heat flow</u>	$Q_c =$	3477	W
23	Convective heat transfer coefficient	$\alpha_c =$	6.2	W/(m ² ·K)
24	Full power of radiator heat flow	$Q_T =$	7.013	kW
			6.030	kcal /h
25	Radiator heat transfer coefficient	$k \approx \alpha =$	12.6	W/(m ² ·K)
			10.8	kcal / (h·m ² ·K)

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As can be seen from the calculation results in Table 1, the share of convective heat transfer is 46–40% of the total heat transfer, the variations depend on dt of the temperature drop.

Free (natural) motion arises under the action of heat exchange near the surface due to the difference in the densities of air layers having different temperatures: lighter heated layers are forced upward by heavier cold layers.

In view of the foregoing, it can be proposed to control the heat transfer of heating pipes due to free convection, reducing or increasing the degree of convective heat transfer on the surface of the heating pipes. This can be achieved by installing regulating casings on the heating pipes. The closed space is formed with holes for convective heat transfer, while the area of the holes for convective heat transfer must be adjustable, which will allow increasing or decreasing the degree of convective heat transfer on the surface of the heating pipes.

Direct regulators can be used for automatic regulation. The principle of operation of a direct-acting thermostat is based on the phenomenon of liquid volume change due its temperature change. That will allow to more accurately react to changes in air temperature in the car, increasing or decreasing the degree of convective heat transfer on the heating pipes, thereby controlling the heat transfer of the heating pipes.

In this case, two types of air temperature sensors will be installed in the car, some will interact with the regulating casings, and others will interact with the control devices of the high-voltage tubular heating elements. The interaction between sensors for monitoring the air temperature in the car should be as follows: the high-voltage tubular heating elements can be switched off only after full closing of the regulating casings holes; they can be switched on only after full opening of the regulating casings holes. The principle of the system operation: when the car air temperature increases to 20 °C, the area of the holes on the regulating casings becomes smaller, and with an increase in the car air temperature their area decreases; when the car air temperature reaches 22 °C, the holes are completely closed, only then the sensors of high-voltage tubular heating element control devices are activated, and the heating elements can only be switched on when the regulating casings holes are

fully open. Thus, the heating system will accumulate thermal energy and will function as a heat accumulator. This gives advantages: the accumulated heat in the heating system will always be available almost instantly, when opening the holes, i.e. increasing the free convection increases the pipe heat transfer. Thus, it will be possible to maintain a stable temperature condition in cars, as well as to adjust individually the air temperature in the compartment.

To assess the efficiency of heat transfer regulation of heating pipes, with installed regulating casings, the operation of the heating system with regulating casings was mathematically modelled. During mathematical modelling we used the formulas (1), (12), (14)–(16), the car air temperature can be determined by the formula:

$$t_I = \frac{Q_T - Q_F + Q_V + \alpha_1 F_1 t_1 + \alpha_2 F_2 t_2 + c_p G_O t_O}{\alpha_1 F_1 + \alpha_2 F_2 + c_p G_O}, \quad (17)$$

where Q_F – heat loss through the car windows; Q_V – heat emission of the fan; Q_T – heating capacity of heating pipes; α_1, α_2 – heat transfer coefficients respectively on the inner surfaces of the enclosing structures of the body and the internal equipment of the car; F_1, F_2 – inner surface of the enclosing structures and the surface of the internal equipment; t_1 – average temperature of inner surfaces of enclosing structures; t_2 – average temperature of the surfaces of the internal equipment.

Mathematical modelling was carried out for the all-metal passenger car of model 61–826 built by the Tver Carriage Works (TVZ). We used the initial data given in [2] in Fig. 12. Graphs of temperatures of the heat transfer fluid and air, namely: 1- t_{out} , 2- t_{in} – temperature of the heat transfer fluid at the input and output of the boiler; 7- t_O – outdoor air temperature, 5- t_I – indoor air temperature of the car, 8 – switching on of high-voltage tubular heating elements. The initial data are summarized in Table 2.

The results of mathematical modelling are shown in Fig. 3.

Table 2

	Initial date										
T, h	1	2	3	4	5	6	7	8	9	10	11
$t_{in}, ^\circ C$	45	65	91	63	56	87	60	45	55	65	55
$t_{out}, ^\circ C$	32	42	63	44	32	62	53	32	39	45	37
$t_j, ^\circ C$	20	18	24	24	17	24	24	22	20	23	22
$t_o, ^\circ C$	-12	-14	-11	-19	-18	-17	-9	-12	-9	-6	-3

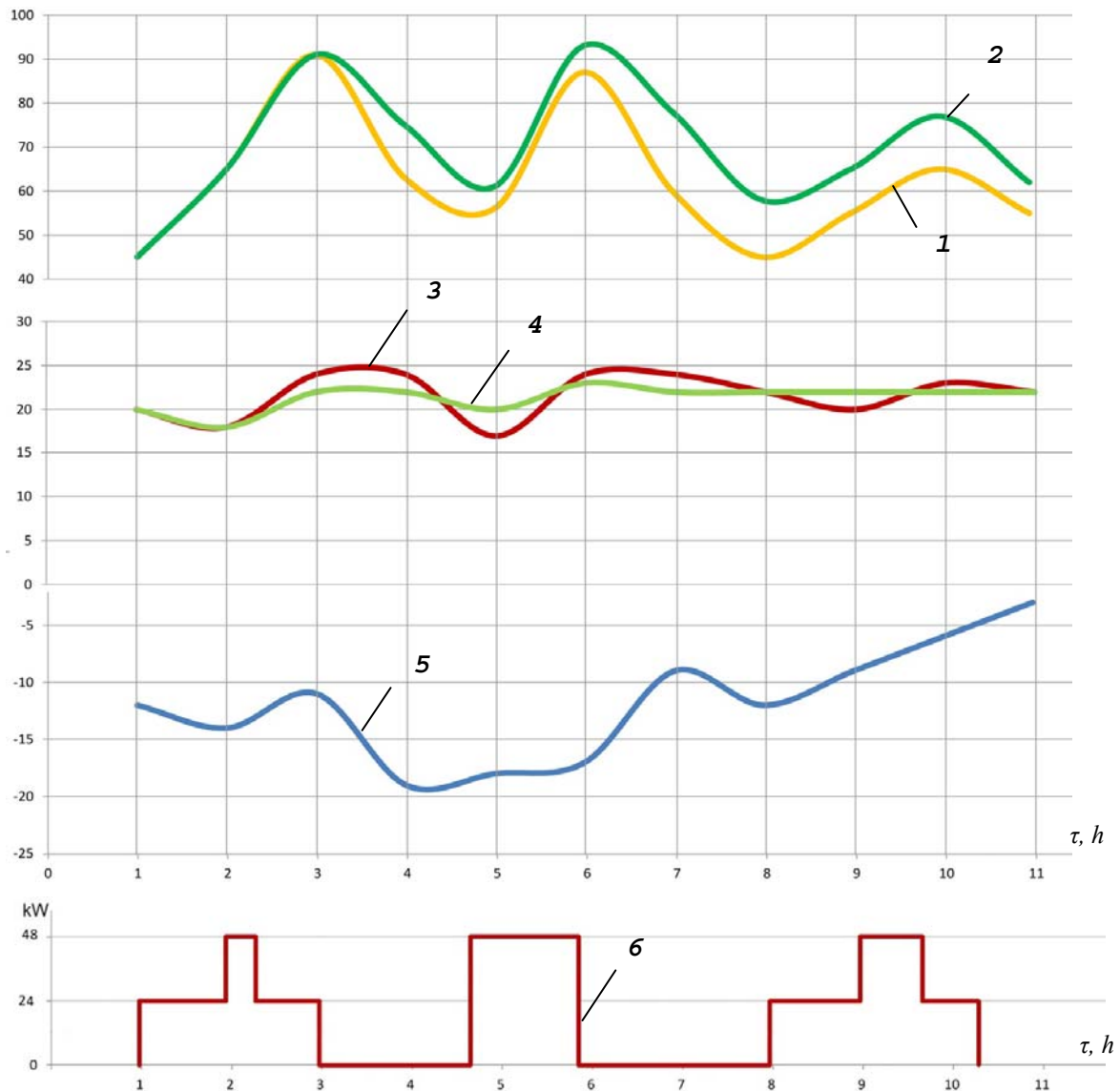


Fig. 3. Diagrams of air and water temperature in boiler, switching on and off of high-voltage tubular heating elements:
 1 – water temperature in boiler, 2 – water temperature in boiler with regulating casings, 3 – air temperature in a car,
 4 – air temperature in a car with regulating casings, 5 – outdoor air temperature, 6 – switching on of high-voltage tubular heating elements

Findings

As follows from the data of the diagram 3 shown in Fig. 3, fluctuations in the car air temperature within the limits of $17 \div 25$ °C are caused by the switching off of high-voltage tubular heating elements, drop of the outdoor air temperature, thermal inertia of the internal equipment of the car, and thermal inertia of the heating system. The process of differences occurs as follows: when the car air temperature drops to 18 °C, the control equipment switches on the high-voltage tubular heating elements; during the time of overcoming the inertia (heating) of the heating system, the car heat loss continues and the car temperature drops; when the system is heated the air temperature rises; upon reaching 22 °C, the control equipment switches off the high-voltage tubular heating elements, but in view of the large heating system inertia, the car air continues to heat up to equality between the car heat loss and thermal output of heating tubes, whereby the car air temperature ranged between $17 \div 25$ °C.

When using the regulating casings of heating pipes (diagram 4, Fig. 3), the car air temperature fluctuated within $20 \div 23$ °C. This is due to the fact that when the air temperature in the car reached 22 °C, the regulating casings decreased the heat transfer of the heating pipes, when the car air temperature was below 22 °C, the heat transfer of the heating pipes increased, resulting in reduced effect of thermal inertia of the heating system. Comparing the diagrams 1 and 2 in Fig. 3 of water temperature in boiler, it can be seen that with regulating casings, diagram 2, the water temperature in boiler is higher than that without the regulating casings, diagram 1, under the same conditions of the system heating and the car heat loss. This leads to the conclusion that the heating system, while performing their functions, can act as a heat accumulator.

The use of regulating casings on heating pipes allows reducing the effects of heat inertia and maintaining stable thermal conditions in a passenger car, using the heating system as a heat accumulator, and also provides the opportunity to realize an individual control of air temperature in the compartment.

Originality and practical value

For the first time, the paper studied the alternative ways of regulating the temperature condition in a passenger car. Using of the heating system as a heat accumulator. The regulation of the heat transfer of the heating pipes by regulating casings allows reducing the effect of thermal inertia of the heating system on the temperature condition in a passenger car, implementing individual adjustment of air temperature in a compartment within 40% of the power of the heating pipe section.

Conclusions

Analysis of the study, control of the heating system inertia in the passenger cars, made it possible to single out one of the problems in the operation of the heating system, the unstable temperature condition caused by the large thermal inertia of the heating system.

Currently in operated passenger cars, control of heating appliances is not constructively provided. The heating pipe performance can be controlled only by the temperature of the heat transfer fluid in the heating system, into which the heating pipes enter as a heater. Automatic maintenance of the set temperature in a passenger car is limited to switching on and off of high-voltage tubular heating elements.

The paper proposes and examines the issue of automatic maintaining a stable temperature condition in a passenger car by installing regulating casings on heating pipes. The mode of operation and interaction of air temperature sensors in the car is proposed.

This method of pipe heat transfer regulation will allow reducing the effect of thermal inertia of the heating system on the temperature condition in a passenger car, implementing individual adjustment of air temperature in a compartment within 40% of the power of heating pipes passing through the compartment. Using a heating system as a heat accumulator will allow a maintaining a regulated temperature condition in the car for the longer period, for example, at the marshalling or turnaround stations. The operating mode and interaction of sensors for monitoring the car air temperature will allow maintaining a stable temperature condition in the car.

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In addition, the results of research can be used to modernize heating units in the cars of the not only for the construction of new cars, but also to operating park, in depot conditions.

LIST OF REFERENCE LINKS

1. Белошицкий, Э. В. Повышение эффективности отопительно-вентиляционных систем / Э. В. Белошицкий, Ю. В. Кебал // Вагонный парк. – 2017. – № 1. – С. 32–35.
2. Жариков, В. А. Климатические системы пассажирских вагонов / В. А. Жариков. – Москва : Трансинфо, 2006. – 135 с.
3. Зигель, Р. Теплообмен излучением / Р. Зигель, Дж. Хауэл. – Москва : Мир, 1975. – 935 с.
4. Китаев, Б. Н. Повышение эффективности теплообменных процессов в пассажирских вагонах / Б. Н. Китаев, В. А. Жариков. – Москва : Транспорт, 1995. – 53 с.
5. Кукса, Ю. Я. Перспективы модернизации пассажирских вагонов при проведении капитально-восстановительного ремонта / Ю. Я. Кукса, П. М. Мустафа, И. Ю. Хоменко // Залізничний транспорт України. – 2010. – № 2. – С. 28–30.
6. Михеев, М. А. Основы теплопередачи / М. А. Михеев, И. М. Михеева. – Москва : Энергия, 1977. – 344 с.
7. Мямлин, С. В. Новые технологии в проектировании дизель-поездов / С. В. Мямлин, А. В. Кивишева // Локомотив-інформ. – 2013. – № 11. – С. 4–5.
8. Пат. 61021 Україна, МПК В 61 D 27/00. Застосування системи опалення пасажирського вагона з водоповітряним калорифером, розташованим у напірному повітропроводі, як акумулятора холоду (тепла) / Хоменко Ірина Юріївна ; заявник та патентовласник Хоменко Ірина Юріївна. – № u201013475 ; заявл. 15.11.2010 ; опубл. 11.07.2011, Бюл. № 13. – 2 с.
9. Попередні випробування систем життєзабезпечення пасажирського плацкартного вагона, дообладнаного системою кондиціонування / О. Г. Дуганов, В. Т. Вислогузов, Ю. В. Кебал [та ін.] // Інтеграція України в междунар. трансп. систему : тез. І Междунар. науч.-практ. конф. (21.05–22.05.2009) / М-во трансп. і зв'язи України, Днепропетр. нац. ун-т ж.-д. трансп. ім. акад. В. Лазаряна. – Днепропетровск, 2009. – С. 22–23.
10. Приходько, В. И. Научные основы создания пассажирских вагонов для скоростных перевозок : монография / В. И. Приходько, С. В. Мямлин. – Днепропетровск : Маковецкий, 2011. – 355 с.
11. Хоменко, І. Ю. Удосконалення системи енергетичного та холодильного обладнання пасажирських вагонів при капітальних ремонтах : дис. ... канд. тех. наук : 05.22.07 / Хоменко Ірина Юріївна ; Дніпропетр. нац. ун-т заліз. трансп. ім. акад. В. Лазаряна. – Дніпропетровськ, 2014. – 125 с.
12. Energy efficiency of railway vehicles / N. Vetterli, U.-P. Menti, F. Sidler, E. Thaler, G. Zweife // CISBAT 2015 : International Scientific Conference (9.09–11.09.2015). – Lausanne, Switzerland, 2015. – P. 955–960.
13. Khomenko, I. Yu. Mathematical modeling of unsteady heat exchange in a passenger car / I. Yu. Khomenko // Наука та прогрес транспорту. – 2013. – № 6 (48). – С. 147–155. doi: 10.15802/stp/2013/19762.
14. Sweeney, E. Modification of Luas heating and ventilation systems to reduce energy consumption [Електронний ресурс] / E. Sweeney, J. Brunton // Conference papers (5–6th September) / Dublin Institute of Technology. – Dublin, 2013. – Режим доступа: <http://arrow.dit.ie/engschmecccon/62/>. – Загл. с экрана. – Проверено : 03.06.2017.

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СПОСОБИ УПРАВЛІННЯ ІНЕРТНІСТЮ ОПАЛЕННЯ

Мета. У науковій роботі передбачається оцінити вплив теплової інертності водяної системи опалення (при перехідних режимах роботи) на температурний режим у пасажирському вагоні. А також запропонувати технічні рішення, спрямовані на зниження впливу теплової інертності системи опалення та підтримання сталого температурного режиму в приміщеннях вагона на перехідних режимах системи опалення. **Методика.** Розроблено спосіб керування тепловіддачею обігрівальних труб системи опалення за допомогою регулюючих кожухів. Для управління системою опалення та тепловіддачею обігрівальних труб використані

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два типи датчиків контролю температури повітря в вагоні: одні взаємодіяли з регулюючими кожухами, а інші – з приладами автоматики управління (нагрівальними високовольтними ТЕНами). Для оцінки ефективності регулювання тепловіддачі опалювальних труб та управління системою опалення з встановленими регулюючими кожухами математично змодельована робота системи опалення з регулювальними кожухами, з використанням двох типів датчиків. Для математичного моделювання використані дані експериментальних випробувань. Проведено порівняння результатів експериментальних випробувань та математичного моделювання. **Результати.** На даний час в експлуатованих пасажирських вагонах управління приладами опалення конструктивно не передбачено. Автоматична підтримка заданої температури в пасажирському вагоні зводиться до включення і виключення високовольтних ТЕНів. Застосування регулюючих кожухів обігрівальних труб дозволяє знизити вплив теплової інертності опалення для підтримки стійкого теплового режиму в пасажирському вагоні, використовувати систему опалення як тепловий акумулятор, а також дає можливість реалізувати індивідуальне регулювання температури повітря в купе. **Наукова новизна.** Автором вперше досліджені альтернативні способи регулювання температурного режиму в вагоні. Використані системи опалення як акумулятори тепла. **Практична значимість.** Стабілізація тепловіддачі опалювальних труб регулюючими кожухами дозволяє знизити вплив теплової інертності системи опалення на температурний режим повітря в вагоні, реалізувати індивідуальне регулювання температури повітря в купе в межах 40 % від потужності ділянки обігрівальних труб, а також використовувати систему опалення як акумулятор тепла.

Ключові слова: опалення пасажирських вагонів; природна конвекція; тепловіддача; акумулятор тепла

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СПОСОБЫ УПРАВЛЕНИЯ ИНЕРТНОСТЬЮ ОТОПЛЕНИЯ

Цель. В научной работе предполагается оценить влияние тепловой инертности водяной системы отопления (при переходных режимах работы) на температурный режим в пассажирском вагоне. А также необходимо предложить технические решения, направленные на снижение влияния тепловой инертности системы отопления и поддержание устойчивого температурного режима в помещениях вагона на переходных режимах системы отопления. **Методика.** Разработан способ управления теплоотдачей обогревательных труб системы отопления с помощью регулирующих кожухов. Для управления системой отопления и теплоотдачей обогревательных труб использованы два типа датчиков контроля температуры воздуха в вагоне: одни взаимодействовали с регулируемыми кожухами, а другие – с приборами автоматики управления (нагревательными высоковольтными ТЭНами). Для оценки эффективности регулирования теплоотдачи отопительных труб и управления системой отопления с установленными регулируемыми кожухами математически смоделирована работа системы отопления с регулируемыми кожухами, с использованием двух типов датчиков. Для математического моделирования использованы данные экспериментальных испытаний. Проведено сравнение результатов экспериментальных испытаний и математического моделирования. **Результаты.** В настоящее время в эксплуатируемых пассажирских вагонах управление приборами отопления конструктивно не предусмотрено. Автоматическое поддержание заданной температуры в пассажирском вагоне сводится к включению и выключению высоковольтных ТЭНов. Применение регулирующих кожухов обогревательных труб позволяет снизить влияние тепловой инертности отопления для поддержания устойчивого теплового режима в пассажирском вагоне, использовать систему отопления как тепловой аккумулятор, а также дает возможность реализовать индивидуальное регулирование температуры воздуха в купе. **Научная новизна.** Автором впервые исследованы альтернативные способы регулирования температурного режима в вагоне. Используются системы отопления как аккумулятор тепла. **Практическая значимость.** Стабилизация теплоотдачи обогревательных труб регулируемыми кожухами позволяет снизить влияние тепловой инертности системы отопления на температурный режим воздуха в вагоне, реализовать индивидуальное корректирование температуры воздуха в купе в пределах 40 % от мощности участка обогревательных труб, а также использовать систему отопления как аккумулятор тепла.

Ключевые слова: отопление пассажирских вагонов; естественная конвекция; теплоотдача; аккумулятор тепла

REFERENCES

1. Biloshytskyi, E. V., & Kebal, Y. V. (2017). Povysheniye effektivnosti otopitelno-ventilyatsionnykh sistem. *Car Fleet*, 1, 32-35.
2. Zharikov, V. A. (2006). *Klimaticheskiye sistemy passazhirskikh vagonov*. Moscow: Transinfo.
3. Siegel, R., & Howell, J. (1975). *Thermal radiation heat transfer*. Moscow: Mir.
4. Kitaev, B. N., & Zharikov, V. A. (1995). *Povysheniye effektivnosti teploobmennykh protsessov ekspluatatsii vagonov v passazhirskikh vagonakh*. Moscow: Transport.
5. Kuksa, J. Y., Mustafa, P. M., & Khomenko, I. Y. (2010). Perspektivy modernizatsii passazhirskikh vagonov pri provedenii kapitalno-vosstanovitel'nogo remonta. *Railway Transport of Ukraine*, 2, 28-30.
6. Mikheev, M. A., & Mikheeva, I. M. (1977). *Osnovy Teploperedachi*. Moscow: Energy.
7. Myamlin, S. V., & Kivisheva A. V. (2013). Novyye tekhnologii v proyektirovanii dizel-poyezdov. *Lokomotyv-Inform*, 11, 4-5.
8. Khomenko, I. Y. (2011). *UA Patent No. 61021*. Ukrainian Intellectual Property Institute (UKRPATENT). Retrieved from <http://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=161080>
9. Duhanov, O. H., Vyslohuzov, V. T., Kebal, Y. V., Furmanova, A. V., Khomenko, I. Y., Shapoval, A. V., ... Rechkalov, S. D. (2009). Poperedni vyprobuvannia system zhyttiezabezpechennia pasazhyrskoho platskartnoho vahona, doobladnannoho systemoiu kondytsionuvannia. *Proceedings of the 1st International Conference Integration of Ukraine into the International Transport Network, May 21-22, 2009, Dnipropetrovsk*. 22-23. Dnipropetrovsk: Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan.
10. Prikhodko, V. I., & Myamlin, S. V. (2011). *Nauchnyye osnovy sozdaniya passazhirskikh vagonov dlya skorostnykh perevozok* [Monograph]. Dnipropetrovsk: Makovetsky.
11. Khomenko, I. Y. (2014). *Power Supply and Air Conditioner Systems of Passenger Cars Improvement During the Thorough Overhaul* (PhD thesis). Available from Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Dnipropetrovsk.
12. Vetterli, N., Menti, U.-P., Sidler, F., Thaler, E., & Zweife, G. (2015). Energy efficiency of railway vehicles. *Proceedings of the International Scientific Conference CISBAT 2015, September 9-11, 2015, Lausanne, Switzerland*. 955-960. Retrieved from https://infoscience.epfl.ch/record/213444/files/9_VETTERLI.pdf
13. Khomenko, I. Y. (2013). Mathematical modeling of unsteady heat exchange in a passenger car. *Science and Transport Progress*, 6 (48), 147-155. doi:10.15802/stp2013/19762
14. Sweeney E., & Brunton J. (2013). Modification of Luas heating and ventilation systems to reduce energy consumption. *Irish Transport Research Network Conference, Trinity College Dublin, Dublin, Ireland, 5-6 September, 2013*. Retrieved from <http://arrow.dit.ie/engschmecon/62/>

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