MODELING OF PASSENGER COMPARTMENT WARMING-UP

Grigoriy Nechaev, Michail Gribinichenko

Department of Transport Technologies, Faculty of Logistics, Volodymyr Dal East-Ukrainian National University, Lugansk, Ukraine

Summary. In the article theoretical bases of calculation of the mode of warming up of salon of car are improved.

Key words: salon of car, heating, temperature, warming up, heat-transfer,

INTRODUCTION

Operation of passenger compartment heating system starts with a warming-up mode, when the air temperature and the temperature of surfaces in the passenger compartment are equal to the outer temperature. According to requirements [1,2,3] at an outer temperature of up to 248 Kelvin, the heating system must provide a certain air temperature in the passenger compartment in 15 minutes after the start of the car motion. Before the motion start the windshield glass must be ice-free, requirements [1,2,3]. With the purpose of determination of rational parameters of the heater and fulfillment of the above-mentioned requirements one needs mathematical formulation of the passenger compartment warming-up mode and analysis of the influence of constructional and operating conditions of the heating system on the warming-up period. A solution of the mentioned problem consists in definition of dependence of the passenger compartment temperatures of air and walls upon the warming-up period, taking into constructional peculiarities of the heating system.

RESEARCH OBJECT

While conducting analytic description of the heating mode one accepts some assumptions, which allow simplifying calculation: the walls of the passenger compartment are considered to be flat and homogeneous, the heat-transfer process occurs only throughout the thickness, temperature distribution throughout the wall thickness is defined by linear dependence at every instant, the coefficients of walls heat conductivity are considered to be constant, the air in a cab is heated simultaneously throughout the whole volume, the temperature of air, which comes out of the passenger compartment via air outlets and clearances, is taken to be equal to the temperature of interior surfaces of opaque walls.

RESULTS OF THEORETICAL RESEARCHES

When heating system is operated at nonstationary heating mode of passenger compartment, the heat which is given away by the heater to passenger compartment goes to heating the passenger compartment, the walls and the seats. Part of the heat is lost with the air going out through ventilation outlets and by way of heat-transfer process via the passenger compartment walls. To take into account the heat incoming and outgoing in the passenger compartment we write down heat-balance equation of the passenger compartment, on the left side of equation we write down the heat, which is used to heating the air in the passenger compartment, and on the right side of equation we put down the difference between the heat, which comes into the passenger compartment from the car heating system and the heat, which is lost through the walls and with the outgoing air. While making calculation of passenger compartment warming-up, one should make a point of elimination of glasses ice-covering and their warming-up. Thus it is worthwhile to divide the heat flux, which passes through the walls of the passenger compartment, into two parts: one of which passes through the glass, and the other passes through the opaque walls. Then the heat-balance equation for nonstationary warming-up will be as follows [1]:

$$\rho_{2}c_{2}V_{s}\frac{dT_{2}}{d\tau} = c_{2}G_{2}(T_{2}'' - T_{2}) - \alpha_{2}S_{1}(T_{2} - T_{3}) - \alpha_{2}S_{2}(T_{2} - T_{4}) +$$

$$+ \sum Q - c_{2}G_{2}(T_{5} - T_{6}),$$
(1)

where: ρ_2 - air density in the passenger compartment, kg/m³,

 c_2 - volumetric heat capacity of air, J/(m³·K),

 V_s - inner void volume of the passenger compartment, m^3 ,

 T_2 – average air temperature in the passenger compartment, K,

τ.-time, s,

 G_2 - air consumption in the heating system, m³/s,

 T_2 - air temperature at an outlet from the heat exchanger, K,

 α_2 - heat-transfer coefficient to the inner walls of the passenger compartment, watt /(m^2 \cdot K),

 S_1 – area of the passenger compartment opaque walls, m^2 ,

 $T_{\rm 3}$ - temperature of the inner surfaces of the passenger compartment opaque walls, K,

 S_2 – glass area, m²,

T₄ - temperature of the inner surfaces of glass, K,

 $\underline{\ }Q$ - summarized heat incomings from electric accessories in the passenger compartment, the driver, passengers and the engine, watt,

 $T_{\rm 5}$ - temperature of surfaces having clearance, K,

T₆ - temperature of outer air, K.

In equation 1 the average air temperature in the passenger compartment T_2 , the temperatures of the inner surfaces of the opaque walls T_3 and glass T_4 are the time functions.

Heat power Q_1 , which is given away to the walls of the passenger compartment, can be written down as a sum of a heat power passing through the wall, and a heat power spent for wall heating:

$$Q_1 = \alpha_2 S_1 (T_2 - T_3) = Q_{11} + Q_{12}$$
, (2)

where: Q₁₁ - heat power, which passes through the wall and withdrawn to the environment, watt;

Q12 - heat power, which is spent for wall heating, watt.

Heat power, which is spent for cab wall heating:

$$Q_{12} = c_1 V_1 \frac{d\left(\frac{T_3 + T_7}{2}\right)}{d\tau},$$
 (3)

where: c_1 - volumetric heat capacity of the passenger compartment wall, J/($m^3 \cdot K$),

 V_1 - passenger compartment walls volume, m³,

T₇ - temperature of the outer surfaces of opaque walls, K.

Heat power, which passes through the walls:

$$Q_{11} = \frac{\lambda_1}{\delta_1} S_1(T_3 - T_7) = \alpha_3 S_1(T_7 - T_6), \qquad (4)$$

where: it follows that:

$$T_{7} = \frac{T_{3}}{\frac{\delta_{1}\alpha_{3}}{\lambda_{1}} + 1} + \frac{T_{6}}{1 + \frac{\lambda_{1}}{\delta_{1}\alpha_{3}}} = f(T_{3}), \qquad (5)$$

where: λ_1 - heat conductivity coefficient of the wall, watt /(m·K),

 α_3 - heat-transfer coefficient from the outer walls of the passenger compartment,

watt $/(m^2 \cdot K)$,

We shall plug 3 and 4 in the equation 2, then taking into consideration 5 we shall obtain:

$$\alpha_2 S_1(T_2 - T_3) = \frac{\lambda_1}{\delta_1} S_1[T_3 - f(T_3)] + c_1 V_1 d\left(\frac{1}{2}[T_3 + f(T_3)]\right) / d\tau.$$
(6)

While calculating warming-up of glass it's necessary to take into consideration the heat, which is spent for ice melting Q_3 :

$$Q_3 = \frac{c_3 m_3 (273, 15 - T_6) + \lambda_i m_i}{\tau_3},$$
(7)

where: c_3 - heat capacity of ice, J/(kg·K),

m_i - ice mass, kg,

 λ_i - heat of liquefaction of ice, J /kg,

 τ_3 -glass defrost time, s.

While cooling-down of the passenger compartment, the cooling rate of glasses is higher then the cooling rate of opaque walls, hereupon all the water steam is condensed just on them. Ice mass on the glass is calculated according to the formula:

$$m_3 = \frac{d_2 m_2}{1000},\tag{8}$$

where: d_2 - humidity rate, g/kg;

 m_2 – air mass in the passenger compartment, kg.

Humidity rate and the air mass in the passenger compartment are determined at $T_2 = 288$ K, which must be maintained according to the requirements [3] and relative humidity 70%.

Heat power, transferred to the glasses with regard for their defrosting:

$$\alpha_2 S_2(T_2 - T_4) = Q_3 + \frac{\lambda_2}{\delta_2} S_2[T_4 - f(T_4)] + c'_2 V_2 d\left(\frac{1}{2}[T_4 + f(T_4)]\right)/d\tau.$$
(9)

Equations 1, 6 and 9 form a system, which describes nonstationary heating mode of the passenger compartment:

$$\begin{aligned} \rho_{2}c_{2}V_{s}\frac{dT_{2}}{d\tau} &= c_{2}G_{2}(T_{2}^{''} - T_{2}) - \alpha_{2}S_{1}(T_{2} - T_{3}) - \alpha_{1}S_{2}(T_{2} - T_{4}) + \\ &+ \sum Q - c_{2}G_{2}(T_{5} - T_{6}); \\ \alpha_{1}S_{1}(T_{2} - T_{3}) &= \frac{\lambda_{1}}{\delta_{1}}S_{1}[T_{3} - f(T_{3})] + c_{1}V_{1}d\left(\frac{1}{2}[T_{3} + f(T_{3})]\right)/d\tau \\ \alpha_{1}S_{2}(T_{2} - T_{4}) &= \frac{\lambda_{2}}{\delta_{2}}S_{2}[T_{4} - f(T_{4})] + c_{2}'V_{2}d\left(\frac{1}{2}[T_{4} + f(T_{4})]\right)/d\tau + Q_{\pi} \end{aligned}$$
(10)

System of equations 10 consists of three differential equations of the first order and contains three unknown functions $T_2 = y_2(\tau)$, $T_3 = y_3(\tau)$, $T_4 = y_4(\tau)$. The system is solved by Rhunge-Kut method at initial conditions: $T_2 = T_3 = T_4 = T_6$ and boundary conditions: $T_4 \ge 0$; engine coolant temperature $T_1 = 313K$.

In order to estimate the adequacy of the cited mathematical model, a theoretical dependence of the average air temperature changes in the passenger compartment and the temperature of the inner surface of glass on the period of warming-up at $T_6 = 269$ K was obtained, which is used with the corresponding data of experimental results. Experimental value of F-ratio test is less then the tabular one, which confirms the adequacy of the mathematical model.

CONCLUSION

Thus, the cited theoretical researches allowed to develop a universal mathematical model, which adequately describes the operation of the heating system in the warming-up mode of the passenger compartment of any car on the parking lot or in motion, and a stationary operational mode as well. The task set – researches of the influence of changes of thermotechnical characteristics of the heater on the process of the passenger compartment is solved with the help of this mathematical model. This permits to choose the most rational constructional and operating parameters of the heating system operation.

REFERENCES

- Khohrjakov V. P. Ventilation, heating and dedusting of air in the cabs of the cars. M.: Machine-building, 1987. 152 p.
- 2. Technical requirements to the passenger cars. Losavno G.S., Butyryn N.N., Nosov D.P., Nagornyy E.G. M.: Transport, 1975. 24 p.;
- 3. GOST P 50993 96 Vehicles. Heating, ventilation and conditioning systems. Performance specifications and safety requirements.
- 4. Heating of booths of cars. Survey information. Khokhryakov V.P., M.: Niinavtoprom, 1986.—36 p.
- 5. Terekhov a.S., Kharin v.V., Kamnev m.A. Thermodynamics of salon of car // Announcer of Academy of transport of Russian Federation.— 1999.— №2.— p.23-27.
- Nagornyy E.G. Research of efficiency of the systems of heating of cars. Abstract of thesis of dissertation on the competition of graduate degree of candidate of engineerings sciences.— M.: Rotaprint of CBNTI Minavtotransa RSFSR, 1975.— 21 p.
- 7. Kutateladze S.S. Heat-transfer and hydrodynamic resistance: Certificate manual.— M.: Energoatomizdat, 1990.— 367 p.
- Isachenko V.P., Osipova V.A., Sukomel A.S. Heat-transfer: Textbook for the institutes of higher.— M.: Energoizdat, 1981.— 348 p.
- 9. Mikheev M.A., Mikheeva I.M. Bases of heat-transfer. A publ. 2th, stereotype.— M.: Energy, 1977. 342 p.
- Gebkhart B., Dzhaluriya Y. Svobodnokonvektivnye flows, heat- and mass-transfer: M: World, 1991.—478 p.

МОДЕЛИРОВАНИЕ ПРОГРЕВА САЛОНА АВТОМОБИЛЯ

Нечаев Г.И, Грибиниченко М.В.

Аннотация. В статье усовершенствованы теоретические основы расчета режима прогрева салона автомобиля.

Ключевые слова: салон автомобиля, отопление, температура, нагрев, теплопередача.