Research Progress on Thermal Insulation Performance of Car Body of High-speed Train

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Abstract: Domestic research status and achievements heat insulation performance of car body of high-speed train is summarized. Test method and numerical simulation method are introduced and compared. Present problems about heat insulation performance of car body are analyzed. Future research direction is prospected.

Introduction

In recent years, Chinese high speed railway is in the period of high growth concentrating on investment and construction. In carriages of train, comfort level has became an important indicator of train design. Heat insulation performance, train air conditioning refrigeration and heating capacity are of great significance for comfort of train. Due to complexity of geographical environment in our country and the big gap between north and south climate, operation area and running environment of high-speed train is also changing. Heat insulation performance of car body of high-speed train directly affect load of air conditioning equipments, comfort of train compartment, and overall energy consumption of train operation. Effectively improving heat insulation performance car body of high-speed train is requirement of national energy saving and emission reduction and sustainable development policy. At the same time, superior heat insulation performance is an important indicator to measure comprehensive ability of design manufacture and installation of high-speed train.

Integrated Heat Transfer Coefficient of Car Body

When temperature of carriage inside and outside is not equal, heat from the hot air by convective heat transfer to high temperature side of body wall, then through thermal conductivity transfer to cold wall surface, finally through convective heat transfer to cold air.

Heat transfer process includes heat conduction in interior of car body and heat convective between internal and external environment. Because temperature distribution inside car and heat flow density distribution is directly affected by the main section of car body, characteristics of heat transfer of doors and Windows, hollow aluminum profile of car body, insulation performance of car body is directly affected heat doors and windows and insulation materials. While the existence of heat channel increased local heat transfer of thermal insulation wall, it causes local additional heat loss. So it is necessary for heat transfer analysis the main section of body, heat channel and doors and windows , in order to take measures to reduce heat loss as far as possible and achieve energy saving . When air conditioning system of train is designed, it is necessary to reduce integrated heat transfer coefficient of car body in order to reduce heat flow of train body and energy consumption. Integrated heat transfer coefficient of car body is embodiment of performance about overall heat transfer coefficient, It means that when difference of air temperature outside and inside is 1 k, heat flow pass by heat insulation wall car body per square meter. [1]

According to TB/T1674-1993 proposed by the ministry of railways in 2000, heat transfer coefficient of car body is generally: When trains still, overall heat transfer coefficient (K) of car body of single deck train is not more than 1.16 W/(m² · K), double deck train is not more than 1.45 W/(m² · K), train whose thermal insulation performance is strengthened is not more than 1.1
W/(m² · K). But due to the limitation of overall train design, under the premise of certain size, train load and traction, in reality, the integrated heat transfer coefficient of many high-speed train are not up to the standard.

**Research Methods of Heat Transfer of Car Body**

**Experimental Testing Method**

Experimental measurement method has been more mature, TB/T1674-1993 drafted by Ministry of Railways detailed rules on test method of train heat insulation performance. Train internal environment temperature is heated by electric heater. After establishment of thermal stable state, temperature of car body in test point for each section is measured. And K is determined by the following formula.

\[
K=\frac{P}{A \cdot \Delta t}
\]

In the formula: Heat transfer coefficient, K, W/ (m², K);

\(P\) - heating power, W;

\(A\) -total heat transfer area in test space, m²;

\(A_l\) - area of internal surface of car body in test space, m²;

\(A_e\) - area of outer surface of car body in test space, m²;

\(\Delta t\) - difference of mean air temperature inside and outside car, K.

By above formula, K which is obtained by experimental test method is calculated by difference of average air temperature inside and outside car, divided by heat from heat source inside car and surface area of car body. **[2]** But in fact, experimental test method also exist many problems which affect the accuracy of K. Heat transfer of car body involves a variety of ways and mechanism of heat transfer, not only contain heat conduction between solid materials inside car body, also convective heat transfer between internal or external surface and air, forced convective heat transfer inside air duct, and radiation heat transfer between car body and surrounding environment. Because of complexity of each part of body connection, insulating layer will be void. At the same time, the existence of heat channel makes heat transfer of car body nonuniform. And calculation of heat transfer area in test is based on the design layout and profile. Interior and exterior insulation wall of car body is treated as a smooth surface and local embossing, structure of the doors, windows and attachment connected to the body is ignored. On Steel plate of roof, calculation of thickness of insulation contains heat transfer area of boiler room and tea stove chamber counted. All of these factors influence accuracy and precision of experimental method to study heat insulation performance of car body. In addition, large investment and resources is required by thermal test method. these become main factors that restricted experimental test method. **[3]**

**Numerical Simulation Method**

With improvement of computer hardware and numerical theory and method, numerical simulation calculation is widely used in research. Heat conduction and convection heat transfer is simulated by numerical simulation software. Reasonable boundary conditions are set. Appropriate physical parameters based on experimental operating conditions are selected. Complete process of heat transfer of car body and overall heat transfer coefficient through Numerical simulation is more accurate and more convenient.

Compared with traditional heat transfer calculation method, in study about overall heat transfer coefficient of heat insulation wall car body, car body structure and heat transfer characteristics are must understand. At the same time, car body is must seen as structure of three-dimensional which is composed of multilayer materials. If according to one-dimensional model to deal with it, due to ignore obvious multidimensional characteristics in process of heat transfer, it causes large error of result. So calculation method of heat transfer based on simple one-dimensional steady-state multilayer flat wall cannot calculate heat transfer of car body accurately. And this problem can be solved effectively by numerical simulation whose results are in range of allowable error and reflect process of heat transfer of car body in detail. **[4]**
Research Results of Numerical Simulation Method

Domestic scholars have made a series of results on research of heat insulation performance of car body based on numerical simulation method. Heat transfer process of integral train is simulated and analyzed by Ji-hua Luo, Mei-chuan Yan, Southwest Jiao Tong university, using ANSYS software. Heat transfer of heat insulation wall was determined through change of air enthalpy value. Changes of car air temperature with time was simulated, and comprehensive heat transfer coefficient of car body of different materials and structure was analyzed.

Yu-jun Bao, Hong-zhen Yang, Chang Chun railway vehicle, [5] for CHR380B alpine emu car, by analysis of foreign alpine emu technology index, combined with use of Harbin to Dalian region environment, under the premise of no raising heating power, reduce heat insulation coefficient to solve technical problem of heat insulation of car body and heating capacity balance at 300 km/h speed when ambient temperature is lower, through optimization of heat insulation structure of car body.

Zhong-zan Wang, Hui Tian, Central South University, separated heat channel and car body main section points to calculate K using numerical simulation methods, for CRH2A train. According to the characteristics of wall structure car body, partition calculation method was used by them to divide body into different areas of basic unit. The heat which through each part of is calculated to get each unit of K using FLUENT software. Finally, heat flux of heat channel is attached vehicle K for calculating K of overall body. After proportion of heat flux in each part is analyzed in detail, ultimately, concrete measures improving thermal insulation properties of body have been proposed.

In view of distribution of heat flux of each body structure and K, the greatest influence on K is heat channel, accounts for about 40% to 45%, followed by heat flux of infrastructure (side wall, top, and floor), accounts for about 35% to 40. The rest are heat flux of doors and Windows, only 18% to 22%.

From the above four parts of car body structure to improve the insulation performance of vehicle, in addition to improving the insulation performance of side door is difficult, the thermal insulation properties of other structures can be greatly improved. In view of heat bridge of car body, the following several aspects generally can be considered: 1. Reduce the amount of heat bridge as far as possible. 2. To minimize contact area of heat channel and car body skeleton; 3. Minimize the contact area between fixed construction of heat channel and air. (Reduce the gap and space of fixed parts directly). Actually, the following measures can be adopted to improve heat insulation performance: Construction throughout vehicle plate and vehicle body skeleton is covered by heat insulating coating material as far as possible, such as rubber or plastic sleeve, in order to reduce contacted area between the direct heat transfer surrounding space and the contact area between heat channel and skeleton. Small gap between body and insulation material should be filled with insulating materials (gap in the body is filled with glue and insulation materials, and then find the flat cover it over compaction). The rubber pad should be used in the contact of fixed support and frame to reduce the area contacted with directly metal. After these measures are taken, insulation performance of vehicle can be improved about 6%-7%. Because area of door and window is small, the proportion of value is also small. Insulation performance of doors and windows possess great potential. For specific models, the use of glass of door and window with appropriate heat transfer coefficient can effectively reduce the proportion of heat flow of door and window.

The Existing Problems and Improving Measures

Experimental testing method mainly exist the following problems at present: 1. The test cycle is too long and too much manpower input. 2. Test method can test car body as a whole comprehensive numerical heat transfer, not test heat transfer process of parts of car body by quantitative in detail, especially analysis of local heat transfer of heat channel. In spite of proportion of heat flow of heat channel in K value is the largest, heat flux of heat channel is currently not to test effectively on limited experimental conditions. Test method, there is a "blind area", namely problems of hollow
Numerical simulation method mainly exist the following problems: in view of hardware conditions of numerical simulation computation, in previous simulation, heat channel and body main section are separated to calculate. First, the wall surface of vehicle as a whole is simulated. Secondly, heat channel is analyzed according to specific model of car body structure. Finally, local heat channel is a separate division to calculate thermal heat flux which is added to heat flux of vehicle to calculate $K$. In the domain of $K$, in fact, the boundary of each region is assumed to be adiabatic. However, due to heat flux in car is always flowing to the smaller thermal resistance, calculated $K$ have deviation with actual $K$.\[6\]

For above problems, Fist, it is necessary to improve hardware condition of numerical simulation and computing platform, establish heat channel vehicle model directly, and simulate Vehicle temperature field for calculating $K$. Secondly, research methods which combine numerical calculation with experiment test key body components and material is adopted. Through accurate and reliable experiments, main body profile, flooring material and insulation thermal conductivity is measured, so as to lay foundation for more accurate numerical simulation.

Conclusion and Prospect

At present, domestic research about heat insulation performance of high-speed train is developing rapidly. Numerical simulation method is most important, supplemented by test method. Especially, after improving computing hardware conditions, through simulation calculation of temperature field of whole vehicle, overall heat transfer coefficient which is calculated more accurate allow researchers to know characteristics of heat transfer of car body more comprehensive, full and accurate, and make optimized measures for thermal insulation performance of car body more targeted, so as to achieve energy saving.

The sense of heat insulation performance of car body of high-speed train and drop of overall heat transfer coefficient are symbol of manufacturing level of high-speed train. However, overall heat transfer coefficient only constitutes a part of energy consumption of air conditioning energy consumption (heat transfer of enclosure structure of car body). In addition, air conditioning energy consumption also includes solar radiation, personnel heat dissipation, equipment heat dissipation. At present, study about overall heat transfer coefficient, whether experimental testing method, or numerical simulation, are based on static running condition of train.

Therefore, future research on thermal insulation performance of train body, combined with actual conditions of meteorological parameters, load, speed and so on, considering solar radiation, personnel heat dissipation, equipment heat dissipation and variation of intensity of convective of heat transfer body outer wall with speed, will be gradually extended to calculation and analysis of real-time running energy consumption of train air-conditioning, and ultimately formation of energy consumption calculation, analysis method and database platform of air-conditioned on real-time running, in order to realize practical significance of energy-saving.

References


