BIO Web of Conferences **63**, 02004 (2023) https://doi.org/10.1051/bioconf/20236302004
ASE-2023

Mathematical Simulation in Traction Rolling Stock Systems Building

S. N. Bezdenezhnykh*, and *P. V.* Shepelin

Samara State Transport University, 1st Nameless lane, 18, 443066, Samara, Russia

Abstract. Modern design methods for both rolling stock and machinery aim to automate processes as much as possible. Cab engine driver should run the train, not be involved in its maintenance, and maintenance crew is required to know in advance all the failures on a particular cab. But in addition to standard train operation, there are a number of issues that affect the safety and reliability of operational equipment. These issues include heating of the rolling stock in low temperatures and related consumption of fuel and energy resources. The existing wide-patent database has a huge number of papers, but only a few are widely used on a rolling stock. Modern realities shape the principles and requirements of resource management, which over the years have made rigid and distinctive framework for designers and engineers, in particular — the workability of the system under the unknown parameters in advance. These requirements force to use principles based on adaptive systems.

1 Introduction

In the modern world, the designers of rolling stock design focus on the development of automated systems, much attention is paid to algorithms and planning accuracy. Not only traction systems and power units, but also auxiliary equipment are simulated. A striking example of such equipment is preheating systems, which have low reliability and increased consumption of energy resources.

When considering the statistics of fuel and energy resources consumption in winter, a one fifth of diesel fuel is spent on warming up and maintaining operating temperatures of the power plant. If we want to reduce consumption in areas of train traffic, first of all, we need to establish control over consumption for own needs, most of which is taken up by "hot" idle mode.

This is where mathematical models and adaptive systems adjusted to environmental conditions come into play.

2 Materials and Methods

Today, when designing the power units of rolling stock for winter conditions or conditions of the Far North, it is duly noted that starting the engine at subzero temperatures is difficult

*Corresponding author: sergeybezd@mail.ru

due to the increased viscosity of lubricants and poor combustion of diesel fuel. In order to reduce the influence of these factors, the diesel engine systems are equipped with devices, providing its preheating.

The simplest option is the use of third-party sources of heating without using the main power of the diesel plant. A striking example of such a system is a pre-start liquid heater DWB 300.59, installed on the rail bus RA-1 [7]. One of the disadvantages of this system is its low reliability and heavy consumption of fuel resources and low reliability. According to the data taken from Kanash motor depot, which performs major repairs of rail buses, the following data on the wear of the main elements of the preheater were obtained. The data is given in Table 1.

Table 1. Operational data for the preheater replacement of elements.

Unit name		Number of replaced units per year, units
“Ignition” unit		5
Fuel hoses	thin	6
	thick	6
Fuel pumps		5
Injectors		2
Electric motor		5
Layshaft bearing		10
Electric motor fuel pump driving gears		3
Flame sensor		6
electronic control unit of the engine starting heater (liquid)		21

Electric energy is an alternative to the consumption of diesel fuel. The main advantage of this type of energy was the high efficiency of electric devices, as well as the variability of the transmitted power with compact size.

A number of publications and patent developments were considered [2–6], while selecting a prototype of adaptive heating system for a rail bus. The most advanced today is the automated system of diesel locomotive warming up at hot idle developed by Tsikarev Yuri Borisovitch [8]. This system includes water circuits and heaters, which are connected one — to the cooling system, others to oil and fuel systems of the engine. Main advantage is the possibility of temperature control during diesel engine warm-up as well as transferring it into semi-automatic mode according to the marginal parameters. The disadvantages of this approach are the need to control the temperature of the diesel engine by operator, as well as increased consumption of diesel fuel.

The proposed solution makes it possible to create an adaptive model of the rail bus heating based on the flow heater installed "on board", thereby excluding the use of diesel fuel and replacing it with cheaper electric power taken from an external power source.

To describe the model of functioning of the proposed solution, let us show a number of its features. Since the temperature of the engine is monitored continuously during the operation of the rail bus, we can see its stable thermal state, regardless of the time of day. The nature of the appearance of thermal energy in the power plant is only due to the mode of its operation, and the region in which it is operated. The amount of heat released by the electric heater is conditioned only by the volume of heated fluid and the power of the heater itself, so the system is relatively simple. The estimated power of the electric heater required to heat the engine to a final temperature that is comfortable for normal starting is specified by the amount of heat required to heat the entire volume of coolant circulating through the power plant systems, the amount of heat required to heat the diesel engine casing and the amount of heat that is dissipated into the environment.

3 Research

Based on the data of the operational schedule, we obtain reduced time intervals for the warming up of the rail bus. The average standby time is no more than 4 hours. Then we get ambient temperature and the schedule of movement along the section. As a result, the total heating time in a day is 2.5 hours, taking into account the time of taking-over the rolling stock by the cab crew. In order to assess the thermal condition of the rail bus, a monitoring system of the ambient temperature, the temperature of the cooling circuit of the power plant on the inlet and outlet was applied. When on the move and during the "hot" idle period the system collects data on the state of the diesel engine and the rate of heating and cooling of its casing.

The aim is to develop an adaptive algorithm for the heating system, using an electric heater built into the circuit of the engine cooling system [9, 10].

The following expression is used to describe the heat loss of each power plant object:

$$dQ = kmC_p(t_2 - t_1) \tag{1}$$

where dQ is the change in the amount of heat per unit time, J;

k is heat transfer coefficient, W/(m2·K);

CP is specific heat capacity of air kJ/(kg·K);

t2and t1 are the cooling temperatures of the body and the environment, respectively, °C.

Heat loss occurs by convective exchange and by radiation, the expression describing this process is as follows:

$$\alpha Q = kF(t - t_0)d\tau \tag{2}$$

At the beginning of the heat exchange process plays a large role in the transfer of energy into the environment, which is proportional to the absolute temperature parameters to the fourth power, so the equation of heat exchange will look like this:

$$\alpha Q = kF(t - t_0)^n d\tau \tag{3}$$

Where F is the heat exchange surface, m 2;

k is heat transfer coefficient, W/(m2·K);

τ is time, s

tandt0 are the cooling temperatures of the body and the environment, respectively, °C.

Solving equations (1) and (2) with respect to temperature values, we get:

$$t = t_0 + \left(\frac{\tau_1}{\tau_2}\left(\left(\frac{t_2 - t_0}{t_1 - t_0}\right)^{1-n} - \left(1 - \frac{\tau_1}{\tau_2}\right)\right)^{\frac{1}{1-n}}\right) \tag{4}$$

We've conducted an experiment to describe the temperature characteristics of the diesel engine and its systems, in conditions of low temperatures. It implied monitoring and analysis of efficiency of the rail bus heating system from an external source of electric energy. This experiment was carried out on an operational section of the Gorky railroad between Kirov and Luza stations. In the course of the experiment the effectiveness of electric heater built into the cooling system was tested when the rail bus was hot idle, as well as the comparison with the ambient temperature data was carried out. Based on the data obtained during heating and cooling of the propulsion system and the main cooling system circuits, the final temperature and the time when the engine is heated or cooled depends on the heat capacity and own dimensions. With further cooling, the heat transfer rate will decrease and the ambient and engine temperatures will be approximately equal. The results of the experiment and generalization are shown in Figure 1.

Therefore, the heat balance equation can be used to describe the thermal state of the motor at hot idle using external electrical sources:

$$Q = Q_{zh} + Q_{rub} + Q_{pot} \tag{5}$$

where Q is the amount of heat required to heat the power plant of the rail bus to the calculated temperature;

Q zh is the amount of heat required to heat the entire coolant volume;

Q rub is amount of heat required to heat the diesel engine jacket;

Q pot is the amount of heat, which is dissipated into the environment through the walls of the pipes.

On the basis of dependence (5) it is possible to unambiguously describe the behavior of the rail bus heating system, leaving only two control parameters — the ambient temperature and the limit temperature of cooling liquid heating, to prevent its boiling.

4 Results and Discussions

Having collected a detailed picture of behavior of temperatures of a diesel engine it is possible to carry out "training" of mathematical model, on the basis of automatic work of heating analysis and monitoring system [11]. On the basis of the received model the experimental sample which has been tested on the rail bus which is operated on a range of the Gorky railroad in Kirov region where average monthly air temperatures fall below –20 °C has been made.

The basis of the automated system is its adaptability with the possibility of learning. Monitoring and parameter processing units provide minute-by-minute data collection on the temperature state of the rail bus cooling system, as well as on the current battery voltage. The system takes into account variation of time intervals in order to refine the control parameters. The equipment also includes actuators — contactor or a group of contactors, which start the heater after the control signal is given. In the process of learning the optimal algorithm is made to provide the maximum rate of the coolant liquid heating to the required temperatures, then the system switches to the long-term maintenance mode, providing for minimal fluctuations in thermal energy. Operational data collection sensors are mounted in the cooling system circuit. Some of the sensors can also be of a temporary. When forming the optimal algorithm of the heating system operation, it is allowed to leave only one sensor that collects data of the ambient temperature.

Figures 1 and 2 show statistically processed data on the diesel engine and ambient temperatures collected during operation of the prototype.

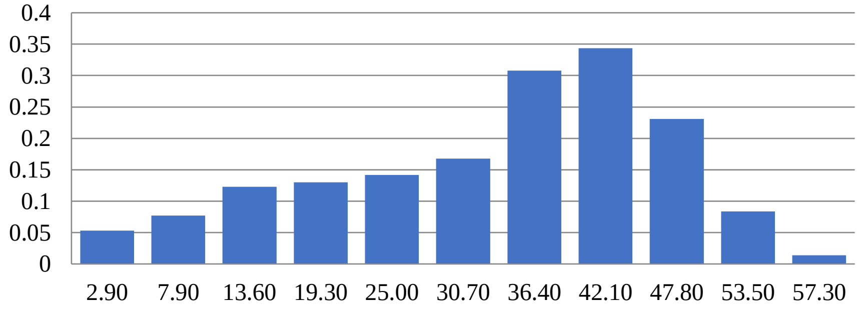

Fig. 1. Distribution of diesel engine temperatures at hot idle

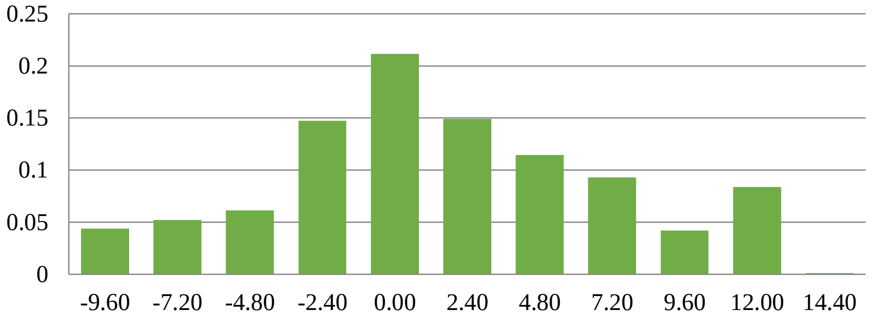

Fig. 2. Distribution of ambient temperatures

5 Conclusions

The study confirms the almost complete dependence of the temperature of the diesel engine, placed under the rail bus body on the ambient temperature and their minimal divergence.

The temperature indicators obtained during the operation of the rolling stock prototype model in the Kirov Region of the Gorky railroad were analyzed. According to the random distribution, the selected method of rail bus preheating proves its effectiveness.

Both the calculated and actually operational electric flow type heater can reach the target temperatures, due to the variation of heating time and power, even at low ambient temperatures.

The chosen preheating method is economical, both in terms of the use of diesel fuel and the service life of the power plant itself. When the procedure of preheating is performed, it is not required to start the diesel engine, the coolant circulates due to the use of two water pumps located in the bus preheating circuit, engaging only the energy from the battery, which can also be recharged when operating from an external source of rectified voltage.

This calculation is not only a theoretical proof of the model consistency, but also the basis for the design solution, in particular due to the physical properties and variability of the electric heater characteristics, there is a possibility of design development for different types of tasks, the main limitation in this case is an external voltage source, as well as the overall space under the car body. But in spite of the fact that any design for rolling stock takes place are conducted with marginal parameters taken into account, then we have an opportunity to create heaters, both for the forced commissioning of the rolling stock after a long standby period in conditions of low temperatures, as well as equal heating during the day.

References

1. N. V. Chertykovtseva, Improvement of shunting cab heating efficiency in winter time with the use of secondary energy carriers (2009).
2. Gazette International, No easy answers in the search for fuel economy Railway, **2**, 54 (1975).
3. V. A. Chetvergov, A. I. Volodin, V. T. Dankovtsev, Ways to decrease fuel consumption by diesel locomotives in the northern region, 57 (1991).
4. T. Sebesi, Convective heat transfer: transl. from English, 592 (1987).
5. M. Marcu, Independent installation to keep warm and economic operation of the locomotive diesel engine, MPK F02N 19/02 №PCT/R02014/000014 (2014).

6. Economic installation for keeping the diesel engine warm in diesel locomotives, 2013000110.
7. Rail bus RA-1. Service manual, 731.00.00.000 RE of ZAO METROVAGONMASH (2013).
8. Yu. B. Tsikarev, Automated heating system for diesel locomotives in hot idle mode, Russian Federation inventions, **2324826**, MPK: F01M 5/02 FO 2N17/04 (2006.01) (2008).
9. P. V. Shepelin, S. N. Bezdenezhnykh, A. A. Bulatov, Adaptive heating system for rail buses in winter period, Vestnik of transport of the Volga Region (2018).
10. V. N. Panchenko, S. N. Bezdenezhnykh, S. V. Glukhov, Reduction of power consumption at hot idle mode by modernization of a multiple-unit train (MU), Vestnik of Transport of the Volga Region (2017).
11. S. N. Bezdenezhnykh, A. S. Mikheev, Automated System of the Rail Bus, Materials of the All-Russian Scientific-Practical Conference with International Participation, Modern Research: trends and prospects (2020).