Evaluation of fuel equipment operability of diesel locomotive engine with use of infrared receivers

S M Ovcharenko, O V Balagin, D V Balagin

Omsk State Transport University, 35, Marx Av., Omsk, 644046, Russia

E-mail: balagin@mail.ru

Abstract. This paper provides results of modelling the heat liberation in high-pressure pipeline of fuel equipment of diesel locomotive engines. Functional relationships between the technical state of fuel equipment and temperature of the outer surface of the high-pressure fuel pipeline are presented using the example of diesel locomotive engine 1-PD4D. The paper shows results of operational tests of the developed method for control of fuel equipment operability of diesel locomotive.

1. Introduction
One of the main areas to improve the reliability and economy of diesel locomotive engine operation is an application of technical diagnostics methods enabling one to detect the malfunction in a timely manner [1].

A solution of the problem can be provided by complex measures, including a wide range of issues related to sustainability of diesel locomotives and their systems. The diesel locomotive operation greatly depends on the reliability and efficiency of high-pressure fuel equipment (FE). The number of diesel locomotive failures on the Russian railways due to the diesel failure reaches 41% of the total number of diesel locomotive failures [2], including 12-13% of the total number of diesel failures due to the failure of fuel equipment.

A decrease in the number of fuel equipment operation of diesel locomotive engine can be reached as a result of introduction of the methods of in-place and non-contact diagnostics and detection of FE defects [3 – 5]. Development of a technique for monitoring the fuel equipment operability of diesel locomotives is an important component of technical measures aimed at increasing the efficiency of diesel locomotive operation.

The technique for evaluation of fuel equipment operability of diesel locomotive engine using infrared receivers was developed on the basis of set of the theoretical and experimental studies at Omsk State Transport University.

2. Research objectives
The research objective is to develop a mathematical model of the heat transfer process from surface of the high-pressure fuel pipeline of fuel equipment of diesel locomotive SLET18DM, that allows us to determine the fuel equipment operability (fuel injection pump (FIP), injector) based on a temperature of the outer surface of high-pressure fuel pipelines, taking into account the ambient air temperature.
3. Simulation of the heat release in the high-pressure fuel pipeline of diesels

The computational scheme of a fuel system with power transmission and delivery conduit (Figure 1) is proposed for mathematical simulation of the heat release in a high-pressure fuel pipeline of diesel locomotive engine [6].

At the first stage of the simulation, the process of heat release was conducted on the results of injection process calculation with the determination of nature of fuel pressure in per cycle with different technical state of the FE (FIP, injector).

![Figure 1. The computational scheme of a fuel system.](image)

**Modelling assumptions:**
- Elastic vibrations in the injection fuel line are not taken into account;
- Pressure across the entire high-pressure line is assumed to be the same and varies only in time.

Simulation of significant malfunctions is performed by setting different values of:
- cross-sectional area of the plunger ($f_{pl}$);
- cross-section of pressure valve ($f_v$);
- flow section under the cone of injector needle ($f_{n1}$);
- total flow area of nozzle hole ($f_{n2}$);
- discharge coefficient of flow section under the cone of valve ($\mu_v$);
- discharge coefficient of flow section under the cone of needle ($\mu_e$).

At the second stage of the study, the simulation results have allowed to introduce a parameter for assessing the technical state of the fuel equipment of diesel locomotives. This parameter is called temperature of the outer surface of high-pressure fuel pipelines, °C [7]:

$$t_{es}^{(h)} = t_f - \frac{Q_f \cdot R_w}{F},$$

where $t_f$ – fuel temperature in the high-pressure pipeline (after compression in the plunger space), °K;
$Q_f$ – number of heat transferred from fuel to air, W;
$R_w$ – thermal resistance of the wall, m$^2$·K/W;
$F$ – square of the outer surface of fuel pipeline, m$^2$. 
To automate and improve the calculating speed, a program was developed in the Delphi 7 programming language (Figure 2). The software package allows processing the results of thermography obtained from infrared receivers of different manufacturers (TESTO, FLIR, FLUKE, IRTIS-2000 ME).

Figure 2. Software package for controlling the technical state of fuel equipment of diesel locomotives using infrared receivers.

The temperature values on the outer surface of the high-pressure fuel pipelines depending on the technical state of the FE and ambient air temperature (from 0 °C to 30 °C) and a number of critical values in which further diesel operation leads to a deterioration of its power, economic and environmental characteristics were received as a result of the study.

Fragment of the simulation results is presented in Table 1.

Table 1. Simulation results of outer surface temperature of the high-pressure fuel pipeline in the case of serviceable and faulty FE (FIP, injector).

| Ambient air temperature, °C, \( t_{\text{sur}} \) | Outer surface temperature of the fuel pipeline, °C | \( \Delta \) = \( \frac{t_{c}(j(f) - t_{c}(j(p))}{t_{c}(j(f))} \), % | \( \Delta \) = \( \frac{t_{c}(j(f)) - t_{c}(j(n))}{t_{c}(j(f))} \), % |
|---|---|---|---|
| 25 | 51.6 | 45.9 | 47.1 | 11.0 | 8.7 |
| 26 | 52.7 | 47.1 | 48.8 | 10.6 | 7.4 |
| 27 | 53.9 | 47.8 | 49.8 | 11.3 | 7.6 |
| 28 | 55.2 | 48.9 | 52.0 | 11.4 | 5.8 |
| 29 | 56.9 | 51.0 | 52.6 | 10.4 | 7.6 |
| 30 | 58.1 | 51.9 | 54.3 | 10.7 | 6.5 |

Note: \( t_{c}(j(f)) \) – calculated normative value of pipeline surface temperature of serviceable fuel system at \( j \) temperature; \( t_{c}(j(p)) \) – calculated normative value of pipeline surface temperature of serviceable fuel system in case of faulty FIP at \( j \) temperature; \( t_{c}(j(n)) \) – calculated normative value of pipeline surface temperature of serviceable fuel system in case of faulty injector at \( j \) temperature.

Modelling has resulted in the critical values of pipeline temperature departure with faulty injector which is 5 % (minimal departure is 5.8 %, see Table 1), with faulty FIP which is 10 % (minimal departure is 10.4 %, see Table 1).

To verify the veracity of the simulation results, a series of experiments were performed using a portable infrared receiver (thermal imaging camera) [8] Testo 875i on operated diesel locomotives such as 1-PD4D. Comparison of results of processing thermograms (Figure 3) and results of theoretical studies confirms the sufficient accuracy of the developed mathematical model. Discrepancy
between the experimental and theoretical data does not exceed 4% (Table 2).

![Figure 3. Pressure pipes of 1st, 2nd, 3rd cylinders of diesel locomotive SLET18DM-770 (FIP of 3rd cylinder is faulty): a – thermogram; b – photo](image)

| № cylinder | Experiment №1 FE is «OK» | Experiment №2 Faulty FIP (wear of the plunger pair) | Experiment №3 Faulty injector (break of airtightness of locking cone of nozzle) |
|------------|--------------------------|-----------------------------------------------------|----------------------------------------------------------------------------|
|            | Experimental value       | Calculated value | Miscalculation Δ, % | Experimental value | Calculated value | Miscalculation Δ, % | Experimental value | Calculated value | Miscalculation Δ, % |
| 1          | 36.1                     | 3.7              | 36.2                | 37.5              | 3.5              | 33.4**             | 32.5              | 2.8              |
| 2          | 36.5                     | 2.7              | 36.5                | 37.5              | 2.7              | 36.5              | 37.5              | 2.7              |
| 3          | 36.2                     | 3.5              | 31.1*               | 30.5              | 2.0              | 36.3              | 37.5              | 3.2              |
| 4          | 37.1                     | 1.1              | 36.8                | 37.5              | 1.9              | 37.2              | 37.5              | 0.8              |
| 5          | 36.1                     | 3.7              | 36.5                | 37.5              | 2.7              | 37.1              | 37.5              | 1.1              |
| 6          | 38.1                     | 1.6              | 37.6                | 37.5              | 0.3              | 36.1              | 37.5              | 3.7              |

Note: * – faulty FIP of cylinder № 3; ** – faulty injector of cylinder № 1.

4. Conclusion
1. A relationship was established between temperature of the outer surface of the high-pressure fuel pipeline and technical state of fuel equipment (FIP, injector) and ambient air temperature.
2. Diagnostic parameter is proposed for control the technical state of the fuel equipment.
3. Boundary values of outer surface temperature of the high-pressure fuel pipeline, in which further diesel operation leads to a deterioration of its technical characteristics, to a possible failure in a route and to required unplanned repair, have been determined.
4. Operational tests of developed method for control of the technical state of fuel equipment of diesel locomotive 1-PD4D were conducted. The method enhances reliability of diesel locomotives in operation.

The results allow one to expand possibilities of the system of diesel locomotive technical diagnostics in operation and more effectively solve a problem of transition to repair the system on a technical state.

5. Acknowledgments

Researches are conducted according to the state budgetary research subject of Locomotive department of state registration 01.95.00 07235.

References

[1] Chetvergov V A 2003 *Reliability of the Locomotives* (Moscow: Marshrut) p 414
[2] Strategic directions of scientific and technical development of "Russian Railways" for the period until 2015 (Moscow: Russian Railways) p 54
[3] Alekseenko V M 2006 *Thermal diagnostics of rolling stock elements* (Moscow: Marshrut) p 398
[4] Shvalov D V 2005 *Diagnostics systems of rolling stock* (Moscow: Marshrut) p 268
[5] Golovash A N 2007 *Problems of repair and settings of diesel locomotive fuel equipment* (Moscow: Lokomotive Journal) 10, pp 30 – 33
[6] Volodin A I 1985 *Simulation of diesel locomotive operation on a computer* (Moscow: Transport) p 216
[7] Volodin A I 2008 Simulation of external non-stationary temperature fields of technical objects of complex configuration *Priority directions of science and technology development: Reports of All-Russian scientific-technical. conference* (Tula: Tula State University) pp 42 – 43
[8] Ovcharenko S M 2014 *Realization of a complex system of noncontact thermal control of diesel locomotive units* Trans-Siberian News: Scientific and Technical Journal / (Omsk: Omsk State Transport University) 4(20) 35-40