Cooling system operation efficiency of locomotive diesel engine

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Abstract. A theoretical model for the calculation of the heat parameters of locomotive diesel engine cooling system in case of using heating agent bypass between the circuits is represented. The influence of the cooling fluid on the bypass from “hot” circuit to the “cold” circuit at different ambient air temperature is studied.

1. Introduction

Efficient operation diesel locomotive operation in many ways depends on the quality of the cooling system functioning which should provide the required heat sink, heating agent temperature stability, prevent working process compromise in the diesel engine cylinders, heating agent temperature drop or increase to the critical values, overheating of the diesel engine sleeve assembly parts, increase of power utilization for the refrigerator fan drive etc. [1–6].

One of the ways to meet the requirements above may be inter-circuit bypass of the heating agent in the locomotive diesel engine cooling system [2, 4].

The problem of the locomotive diesel engine cooling system operation efficiency improvement in case of using the heating agent (cooling fluid) bypass from the “hot” circuit to the “cold” one may be solved by means of accounting for the cooling fluid flow rate effect on the heat-engineering characteristics of the heat-exchangers and cooling system in general. The diesel locomotive engine cooling system parameters in inter-circuit bypass is discussed in the works [7 - 11] and a number of other authors.

This work provides results of the theoretical studies of the heating agent bypass effect on heat-engineering characteristics of dual-circuit cooling system as exemplified by SLET18DM diesel locomotive at fixed values of the refrigerator fan and crank shaft rotation speed for the diesel engine rated-power mode. Later it is planned to study the efficiency of the heating agent bypass in all operation modes of the diesel engine in different technical status of the heat-exchangers and determine the limits of the heating agent bypass flow rate.

The need of this study is also due to the mandatory observance of the requirement of the locomotive diesel operation in the driver controller low positions operation before the diesel engine shut-down to avoid the water boiling in the cylinder covers. The use of automatic heating agent bypass enables solving this problem.

Dependencies of the characteristics and parameters of the “hot” and “cold” circuits in SLET18DM locomotive cooling system for the rated-power mode at different ambient air temperature values and cooling agent bypass flow rate were obtained.

2. Experimental section

As the diesel locomotive design is improved, the requirements to the diesel locomotive cooling system grow.
The diesel locomotive cooling system operation efficiency may be improved using different methods [2–4, 8]:

– efficiency improvement of heat-dissipating capacity of the water/air radiators and reduction of their aerodynamic drag;

– fan unit capacity improvement with their cost-efficiency improvement;

– reduction of the related aerodynamic losses during the air flow in the shafts;

– use of special additives to the cooling water to reduce the pipeline scale;

– use of automatic bypass of the heating agents between the locomotive cooling system circuits.

In this work it is proposed to consider the heating agent bypass between the circuits to improve the cooling system efficiency. Design flow diagram of the cooling system with the heating agent bypass as exemplified by SLET18DM locomotive is proposed (figure 1).

The locomotive cooling system is designed for the regulation of the diesel engine heating operation mode and consists of:

– water and lubrication systems of the diesel engine;

– Diesel air-supply system;

– Water/oil heat-exchanger and supercharge air cooler designed to cool down the diesel engine oil and supercharge air with the intermediate heating agent (cooling fluid) before their entry to the diesel engine systems;

– lubricating oil and water pumps;

– cooling system radiator sections;

– three-way bypass valve and two points of the water mixing in the hot and cold circuits.

For the design determination of the heat-engineering characteristics of the locomotive diesel engine cooling system with the heating agent bypass it is necessary to identify the relation between the cooling system elements and determination of input and output coordinates of each element (figure 1) [3, 10].

Each element in the cooling system has its own input and output coordinates represented in figure 1.

Heating agent bypass between the circuits in the cooling system results in the redistribution of the heat sinks in the radiator sections and heat-exchangers acting, in this case, as both coolers and preheaters of the diesel engine heating agents.

The links between the input and output coordinates of the cooling system elements and circuits in general are described using respective static characteristics. To determine the static characteristics and parameters of the dual-circuit cooling system with the heating agent bypass between the circuits it is necessary to know the flow rate characteristics of the “hot” and “cold” circuits, heat-exchangers’ parameters as well as diesel engine heat emissions in different values of the diesel engine power and ambient air temperature.

At the model primary processing stage a number of admissions was made which exert a minor influence on the accuracy of the calculations of the cooling system characteristics accuracy but will enable substantial simplification of the calculation methodology [3, 12].

Based on the admissions made and equilibrium equation, heat transfer and mixing of uniform liquids the system describing the dual-circuit cooling system characteristics will look as follows:

\[ Q_B = G_B c_B (T_B^* - T_B^\prime); \]

\[ (G_B' - G_K) c_B (T_B^* - T_B^\prime) = G_{B3} c_{B3} (T_{B3}^* - T_{B3}^\prime); \]  \hspace{1cm} (2)

\[ G_{B3} c_{B3} (T_{B3}^* - T_{B3}^\prime) = k_B F_B \left( \frac{T_B^* + T_B^\prime}{2} - \frac{T_{B3}^* + T_{B3}^\prime}{2} \right); \]  \hspace{1cm} (3)

\[ Q_X = G_M c_M (T_M^* - T_M^\prime); \]

\[ Q_X = (G_{B3} + G_K) c_B - (T_{B3}^* - T_{B3}^\prime); \]  \hspace{1cm} (5)
\[ Q_X = k_W {OHE}_E F_W {OHE}_E \left( \frac{T_M' + T_M^*}{2} - \frac{T_{BS}^* + T_{BS}'}{2} \right); \]  

(6)

\[ Q_{HB} = G_{HB}\cdot c_{B3}\left( T_K - T_S \right); \]  

(7)

\[ Q_{HB} = \left( G_{BS} + G_K \right) c_B \cdot \left( T_B' - T_{BS}^* \right); \]  

(8)

\[ Q_{HB} = k_{SAC} F_{SAC} \left( \frac{T_K + T_S}{2} - \frac{T_{BS}^* + T_{BS}'}{2} \right); \]  

(9)

\[ G_{BS}^* c_B \left( T_{BS} - T_{BS}^* \right) = G_{BS}^* c_{B3} \left( T_B' - T_{BS}^* \right); \]  

(10)

\[ G_{B3}^* c_{B3} \left( T_B' - T_{BS}^* \right) = k_B^* F_B^* \left( \frac{T_{BS} + T_B^*}{2} - \frac{T_{BS}^* + T_{BS}'}{2} \right); \]  

(11)

\[ G_K c_B T_B' + c_B G_{BS} T_{BS}^* = \left( G_{BS} + G_K \right) c_B \cdot T_{BS}^*; \]  

(12)

\[ G_K c_B T_{BS}^* + \left( G_B^* - G_K \right) c_B \cdot T_B' = G_B^* c_B T_B'; \]  

(13)

where \( Q_X \), \( Q_M \), \( Q_{HB} \) is diesel engine heat-emission into the water, oil, heat-sink from the supercharge air, kW.

- \( Q_X \) – heat-sink from oil to water in the water/oil heat-exchanger, kW;
- \( c_B, c_M, c_{B3} \) – specific heat capacities of water, oil and air, kJ/(kg·K);
- \( G_B^* , G_{B3}^* , G_{BS} , G_M , G_{HB} , G_{B3}^* \) – mass flow rate of water and air through the cooler radiators in the hot circuit of water, oil, supercharge air and air through the cooler radiators in the cold circuit, kg/f;
- \( k_B^* , F_B^* , k_{W/OHE}_E , F_{W/OHE}_E , F_{SAC} , F_{SAC} , k_B^* , F_B^* \) – heat transfer and surface air factors of the hot circuit radiators, water/oil heat-exchanger, supercharge air cooler and cold circuit radiator sections, W/(m²·K);
- \( T_B', T_B^* \) – water temperature at the diesel engine outlet, diesel engine input and downstream the hot circuit radiator section, K;
- \( T_M', T_M^* \) – oil temperature at the diesel engine outlet, diesel engine input (downstream the water/oil heat-exchanger), K;
- \( T_K, T_S \) – supercharge air temperature at the turbine compressor outlet and diesel engine inlet, K;
- \( T_{BS}', T_{BS}^* , T_{BS}^* \) – water temperature at the inlet to the radiator section, outlet of the radiator section, inlet to the water/oil heat-exchanger, inlet to the supercharge air cooler, K;
- \( T_{BS}^* , T_{BS}^* , T_{BS}^* \) – temperature of the ambient air after the “hot” circuit cooler radiator sections and after the “cold” circuit radiator sections, K;
- \( G_K \) – water flow rate for the bypass from the hot circuit to the cold circuit and backwards, kg/s.
Figure 1. Design Diagram of Dual-Circuit Cooling System of SLET18DM Locomotive Diesel Engine

3. Results and discussion section
Based on the calculation data curves of the “hot” and “cold” circuit characteristics and parameters for the diesel engine rated-power mode and different ambient air temperature were built (figure 2 – figure 5).

The circuit characteristics are non-linear dependencies in the entire variation range $G_K$. 

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**Figure 2.** Dependency of the Water Temperature at the Cooling System Diesel Engine Radiator Section Inlet of SLET18DM Diesel Locomotive by the Control Action Variation $- G_K$ at $T_{BS}'' = 233$K

**Figure 3.** Dependency of the Water Temperature at the Diesel Engine Outlet with the Coupled Cooling System by the Control Action Variation $- G_K$ at $T_B'' = 233$K

**Figure 4.** Dependency of the Oil Temperature at the Cooling System Diesel Engine Radiator Section Outlet of Diesel Locomotive by the Control Action Variation $- G_K$ at $T_M'' = 233$K
Figure 5. Dependency of the Water Temperature at the Cooling System Diesel Engine Radiator Section Inlet of Diesel Locomotive by the Control Action Variation $- G_K$ at $T'_{B3} = 233K$

4. Conclusions
1. As a result of the theoretical studies it was found that:
- the temperature of the diesel engine heating agents at constant values of $n_D$, and $T'_{B3}$ as function of $G_K$ may vary in the wide range;
- $G_K$ increase results in the variation of all the heating agents’ temperature: “hot” circuit heating agent temperature decreases whereas the “cold” circuit heating agent temperature increases.
2. As a result of the studies data were obtained which enable analysis of the heating agent bypass efficiency in case of different technical state of the heat-exchangers and development of the joint operation algorithm of the inter-circuit bypass and diesel engine heating agent temperature automatic control system.

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