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Research of Engine Preheating using the Phase Transition Heat Accumulator

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Abstract:
The relevance of the study is conditioned by the complexity of ensuring of reliable engine starting in conditions of negative ambient temperatures. In this regard, this article is aimed at identifying the patterns of changes in the conditions of thermal preparation of the engine for starting, depending on the thermal fields of engine elements in contact with the constant thermal pressure of the coolant, and the place where the coolant is removed from the cooling jacket. The main research method was pumping the coolant through the cooling jacket according to various schemes, taking into account changes in the ambient temperature and the volume of the coolant. As a result of the study, the patterns of changes in the thermal fields of engine elements from the pumping circuit were revealed, a regression and calculation equation for the temperature of the engine elements was developed. The materials are of practical value for ensuring reliable engine starting in conditions of negative ambient temperatures.

Keywords: *thermal pre-operation, reliable starting, thermal fields, starting wear.*

I INTRODUCTION

The modern trends in the development of human civilization predetermine the necessity to use high-tech technical systems and mechanisms that can improve the work efficiency, reduce the of their production and operation cost.

One of these technical solutions is the internal combustion engine (ICE), which provides a drive for a large number of mechanisms. The most widespread ICE found in road transport and special power plants.

Starting properties of the internal combustion engine do not deteriorate and do not affect the reliable start of the engine at positive ambient temperatures, but in the winter period, which lasts from 6 to 8 months in Russia, they deteriorate significantly and this complicates the operating conditions of the car and increases the accompanying expenses.

The main way to ensure reliable starting of the engine in winter operating conditions is engine preheating, since inter-shift heating of vehicle components is economically unprofitable and

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technically inexpedient. However, the existing ICE preheating systems have significant drawbacks under these conditions, the most distinctive of which are: the need for an external source of energy (fuel, gas, electricity) and a long pre-operation time. In addition, the applied methods for determining the thermal performance of the source do not allow to establish with sufficient accuracy and unambiguity the rational amount of heat that will allow to warm qualitatively the engine before starting [1].

The aim of the study was to establish the patterns of change in the thermal fields of engine elements with various schemes for pumping the coolant through its cooling jacket.

II THEORY

The task of determining the required amount of heat for preheating the internal combustion engine is already being solved by more than one generation of specialists [2, 3, 4], but most of the solutions are suitable only for a narrow design group of engines and have large differences between them [5]. This is due to the fact that the engine elements reach for the set thermal fields in different periods of time. To the present day the heat currents distribution among engine elements and the influence of the coolant volume flow rate on the heat transfer process during the preheating of internal combustion engines are not taken into account, which leads to an increase in the total engine heating time. For cutting time of its thermal pre-operation for starting, it is necessary to distribute rationally the heat currents between the engine elements, so that the time of their readiness for starting becomes the same or commensurate with each other.

The most closely meeting the requirements is the methodology developed by F. G. Sidorov [5]. According to it, the engine is divided into individual elements directly involved in the preheating and if the necessary amount of this heat is taken as 100%, then the difference in the results of calculating this heat for preheating the engine, in comparison with other methods, will be: according to M. L. Minkin and A. N. Moseichik - 28%; according to P. F. Borisov - 81%; according to G A. Skvortsov - 127% and according to Yu. B. Sviridov - 226%. This is explained by the unsteady nature of heat transfer and the fact that various elements of the engine reach for the set thermal fields in different periods of time.

But the main drawback of these methods is that they do not take into account the influence of the coolant parameters on the final thermal fields of the engine elements, especially those that ensure reliable starting, after it is preheated.

At present, a large number of technical solutions have been developed to improve the starting qualities of ICE in conditions of negative ambient temperatures [6] and they are fixed in the design of both engines and stationary systems to ensure reliable starting, but this problem has not yet been completely solved.

Modern technologies and the proposed technical solutions have improved significantly the reliability and durability of all ICE systems and mechanisms, but still the specialists are trying to minimize the wear of friction pairs of ICE elements from cold friction and to ensure its reliable starting at the temperatures below zero, and this, in turn, reduces the engine lifetime despite the high-quality lubricants [7, 8, 9].

The special and technical literature provides more than a dozen ways and methods of preheating the cold engine elements using heated air, hot liquids or gases.

The most effective way to prepare an engine for starting at the temperatures below zero is to use heated parking (storage) places, but this requires significant costs and, as a rule, is expedient for emergency vehicles.

The analysis of sources [10, 11] showed that presently there are no unified approaches to solve the issue of commensurate thermal pre-operation of engine elements involved in the process of preheating. Even on the domestically-produced engines of various manufacturers, there are several patterns for the coolant flow in the cooling jacket. Almost all schemes are united by the inlet point of the coolant - this is the bottom point of the engine cooling jacket with its different location through the length of the engine. But there is no single solution with the outlet point of the coolant, and manufacturers use their design solutions [12]. The absence of single approaches to determining the regimen of the coolant flow along the engine cooling jacket during its thermal pre-operation for starting became the reason for this study. In parallel with the main studies, the work on study the dependence, the changes in the heating rate of engine elements was carried out using a source with a constant thermal head in which a phase transition heat accumulator (PTHA) can be used [13, 14].

Based on the purpose of the study, the following tasks were set:

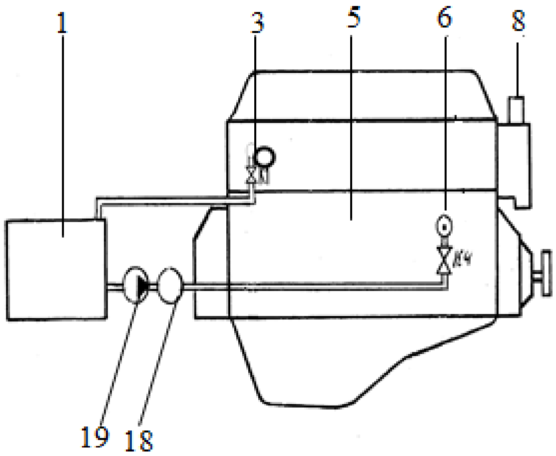
- determine the regimen for pumping the coolant through the cooling jacket of a four-cylinder in-line engine;

- establish the dependence of the thermal fields of the engine elements on the outlet point of the coolant from the cooling jacket;

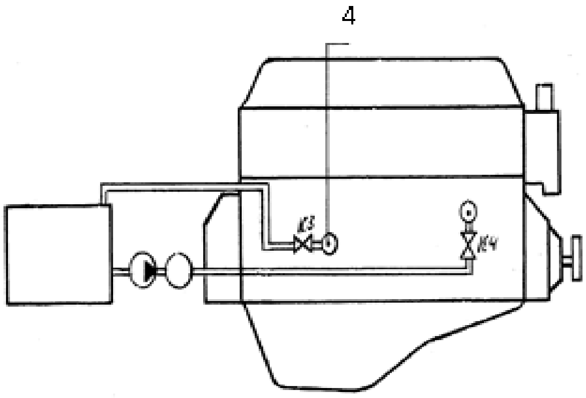
- determine the nature of the process of thermal pre-operation of engine elements when used PTHA as a heat source.

During the experimental study, two schemes of coolant pumping through the engine cooling jacket were used (Figure 1).

Common to both schemes was the coolant inlet into the cooling jacket - this is its bottom point within the first cylinder (K4). The the outlet point was carried out for scheme 1 from the cylinder head (3), and for scheme 2 - from the lower point of the cooling jacket within the fourth cylinder (4). The use of two schemes allowed to establish the dependence of the change in the thermal fields of engine elements depending on the ambient temperature, the coolant volume flow rate, and the heating time.



Scheme 1



Scheme 2

1 - PTHA; 3, 4, 6 - adapters; 5 - engine; 8 - thermostat; 18 - liquid flow meter; 19 - liquid pump; K1, K3, K4 - cranes

Fig.1. Schemes of engine preheating

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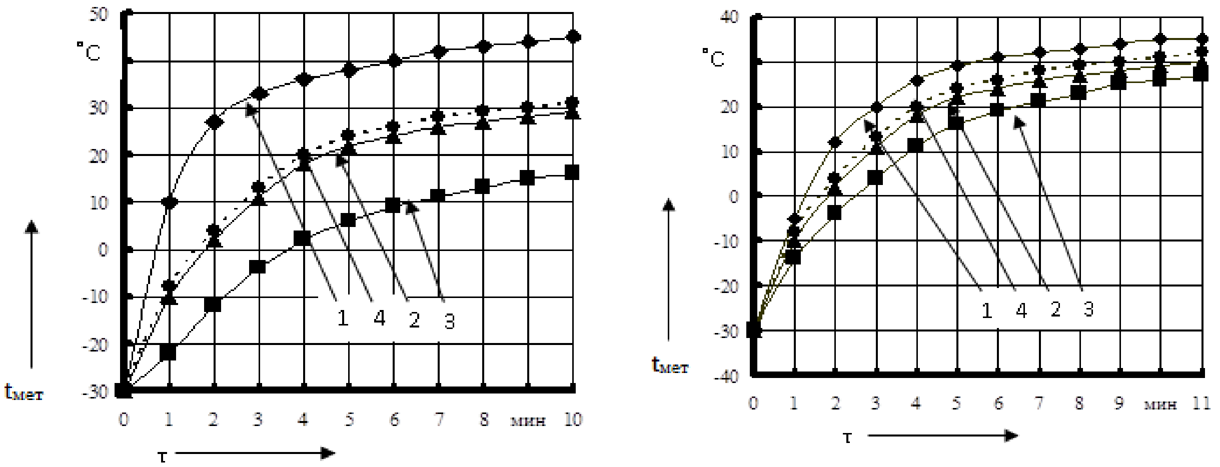
The thermal state of the engine elements, coolant) was measured with chromel-kopel thermocouples and recorded on the tape of a KSP-4 self-recording electronic potentiometer, the coolant temperature at the outlet of the cooling jacket was duplicated by an LT-2 mercury laboratory thermometer.

III RESULTS

The experimental studies allowed to collect a significant database in different temperature conditions, with different volumes of coolant flow, and Figure 2 shows the changes in thermal fields at an ambient temperature of 30 ° C below and a coolant volume flow of 0.08 l / s.



Scheme 1 Scheme 2

1 - cylinder head; 2 - the first cylinder; 3 - the fourth cylinder; 4 - average temperature

Fig. 2. The dependence of the temperature change of the engine elements

A comparative analysis of the temperature dependence of the engine elements shows that the coolant flow according to scheme 2 provides a reduction in temperature differences 2.5-3.0 times and practically equalizes the value of the thermal fields of the engine elements, which makes it possible to use the term "average temperature of the heated engine".

The obtained values of thermal fields are presented in table 1.

Table 1 Measurement results depending on the heating scheme

Scheme number	Engine element temperature, ° C					Temperature difference, ° C		
							heightwise	
	cylinder head	the first cylinder	the fourth cylinder	the average temperature	outlet pipe	endwise	the first cylinder zone	The fourth cylinder zone
1	42-46	13-17	28-31	29-30	minus 5-0	15-20	10-15	25-30
2	35-37	24-27	29-32	30-34	Minus 8	5-7	5	8-10

At the same time, the reduction of the cylinder head temperature when pumping the coolant according to Scheme 2 does not reduce significantly the temperature of the inlet pipe, but it

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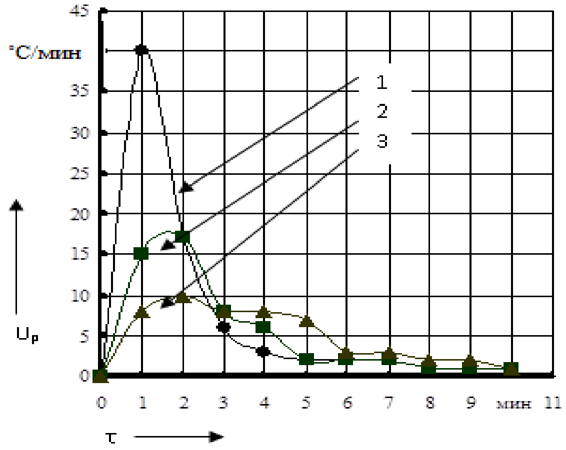
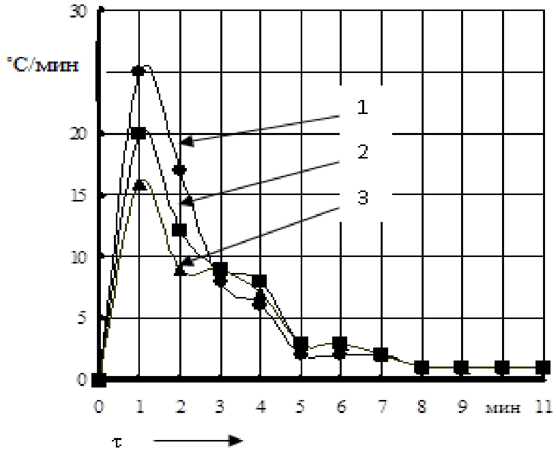
allows to reduce heat loss, since the cylinder head accounts for up to 30% of the total external surface of the engine, and it accumulates up to 40% of heat input.

Figure 3 shows a graphical change in the dynamics of the of engine elements heating rate using a source with constant temperature head.



Scheme 1



Scheme 2

1 - cylinder head; 2 - the first cylinder; 3 - the fourth cylinder

Fig. 3. Dynamics of engine elements heating using a source with constant temperature head

The analysis of the obtained dependences showed that the heating rate of the engine elements is sharply increasing in intensity, when in the first 2-3 minutes the input from 70 to 80% of the heat and the most intense heating of the engine elements happens. By 5-6 minutes it decreases to 1-2 ° C / min and slightly depends on the ambient temperature and the volume flow rate of the coolant. The temperature difference of the engine elements has the same dependency as in Figure 2. This nature of the process of the engine elements preheating indicates that this system is advisable to use for direct pre-heating of the engine and is not very effective for prolonged heating during the parking period.

Based on the results obtained, the dependency of the change in the thermal fields of the engine elements contacting with the cooling jacket was determined, depending on the volume flow rate of the coolant (V_{pr}) from 0.02 to 0.14 l / s, the preheating time (τ_{pr}) from 480 to 600 s, and the temperature ambient air (t_o) from 0 to minus 40 ° C. It varies according to linear law and can be described by a regression equation with a confidence coefficient of 0.95

$$t^{к}_{мем} = -10{,}893 + 357{,}125V_{np} + 0{,}065\tau_{np} + 0{,}573t_o - 0{,}147V_{np}\tau_{np} + 1{,}668V_{np}t_o + 10^{-5}\tau_{np}t_o - 0{,}0024V_{np}\tau_{np}t_o.$$

The data obtained in the course of the experimental study allowed to establish:

- the dependency of changes in the thermal fields of the four-cylinder in-line engine elements during preheating;

- a scheme that allows to get the most equal heating of the engine elements, in which the coolant inlet in the cooling jacket is within the zone of the first cylinder, and the output is within the zone of the fourth cylinder in the lowest point of the cooling jacket;

- the determinate variations in the intensity of heating of the engine elements contacting with the cooling jacket, when using a device with constant temperature head (PTHA) as a source;

- the phase transition heat accumulator (PTHA), transfers to the system from 70 to 80% of the heat accumulated during the first 2-3

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minutes of the heating process of the engine operation.

The processes in the constant temperature head source, which was the phase transition heat accumulator (PTHA), are not considered in this article.

IV IMPLEMENTATION

Based on the theoretical and experimental studies, a methodology for choosing the rational parameters of the engine pre-heating system was developed using the phase transition heat accumulator (PTHA) as the heat source [15].

A graphical implementation of the methodology for eight major brands of the domestically-produced engines is made in the form of a nomogram [15] according to which a rational amount of heat is set for pre-heating of engine elements contacting with the cooling jacket to a temperature of 30 ° C for a certain ambient temperature without additional calculations and experiments .

The most precise temperature values of the engine elements contacting with the cooling jacket can be calculated by the formula

$$t^{\text{к}}_{\text{мет}} = \frac{V'_{\text{пр}} \cdot \rho_{\text{ж}} \cdot \text{c}_{\text{ж}} \cdot \tau^{\text{к}}_{\text{пр}} \cdot t'_{\text{ж}1} + \left(\beta m_{\text{мет}} \cdot \text{c}_{\text{мет}} + m_{\text{ж}} \cdot \text{c}_{\text{ж}} + \alpha_2 \cdot F^{\text{н}}_{\text{дв}} \cdot \tau^{\text{к}}_{\text{пр}}\right) \cdot t_{\text{о}}}{\beta m_{\text{мет}} \cdot \text{c}_{\text{мет}} + \alpha_2 \cdot F^{\text{н}}_{\text{дв}} \cdot \tau^{\text{к}}_{\text{пр}}} - \frac{\left(V'_{\text{пр}} \cdot \rho_{\text{ж}} \cdot \text{c}_{\text{ж}} \cdot \tau^{\text{к}}_{\text{пр}} + m_{\text{ж}} \cdot \text{c}_{\text{ж}}\right) \cdot t'^{\text{к}}_{\text{ж}2}}{\beta m_{\text{мет}} \cdot \text{c}_{\text{мет}} + \alpha_2 \cdot F^{\text{н}}_{\text{дв}} \cdot \tau^{\text{к}}_{\text{пр}}}.$$

whereV_{pr} - volumetric flow rate of the coolant, m^3 / s; ρ^l - coolant density, kg / m3; s - mass specific heat, kJ / (kg · ˚C); τ - the time, s; t - the temperature, ° C; m - the mass of the element, kg; F^{ex} - external area, m^2; α - thermal transmittance value, W / (m2 · ° C), l - liquid heat carrier; met. - metal; o is oil; f - final; 1 - inlet to the system; 2 - outlet

In addition, when using this methodology and nomograms, it is possible to determine the total thermal capacity of the phase transition heat accumulator (PTHA) for the accepted brand of the engine and operating conditions through the average monthly isotherm of January.

V CONCLUSION

Thus, at the design stage of the engine pre-heating system, the presented materials will allow :

- to simulate the parameters of the process of pre-heating of engine elements depending on the ambient temperature, volume flow rate of the coolant, the engine brand and heating time;

- determine the optimal performance of the liquid electrically driven pump, which allows to provide the necessary temperature of the engine elements;

- determine the amount of heat required for pre-heating the engine, taking into account its technically unavoidable losses during the parking time of the car and the possibility of the cooling system by the amount of thermal energy to be cascaded;

- to evaluate the expediency of application of the proposed coolant flow scheme on the selected brand of engine.

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