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THE METHOD OF EXPERT ASSESSMENT OF THE TECHNICAL CONDITION OF AN AUTOMOBILE ENGINE AFTER OVERHEATING

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Abstract*. *Problem*.** *For expert studies of the technical condition of a car, a difficult task is to determine the causes and development of malfunction of engine mechanisms and systems. The paper proposes a model of engine malfunction during overheating, including in emergency mode caused by rapid loss of coolant. It has been established that thermal damage to the cylinder head is possible within 10 seconds after the cooling failure. The piston heats up more slowly and can only be damaged in the upper part and for a much longer time. According to the results of the study, it was found that in the event of an emergency loss of coolant, the driver does not have the technical ability to see the temperature rise, which may be important when investigating the causes of engine malfunctions associated with overheating.* ***Goal. *The goal is to investigate and reproduce the model of engine failure after overheating.* ***Methodology*.** *The theoretical calculated data are confirmed by real experimental studies of engine overheating failures.* ***Results.*** *It was calculated by calculation that in the absence of coolant, the temperature sensor, if it is located on the outlet pipe of the cylinder head, will not increase the temperature until the engine fails. A certain definite character of malfunction of parts of engine mechanisms during its sudden overheating is shown.* ***Originality.*** *On the basis of the developed models, a methodology was drawn up and the calculation of the thermal state of engine parts after overheating was performed.* ***Practical value.*** *The research carried out and the computational models compiled allow the expert to make a more objective assessment of the development of the engine malfunction mechanism when it overheats during the operation of the car.*

Key words: *internal combustion engine, coolant, failure, overheating.*

Introduction

It is known that various kinds of damage and failures can occur in various systems and units at all stages of operation of internal combustion engines [1, 2]. The failures in the cooling system often show themselves in the form of a serious disruption in the temperature conditions of the engine – overheating, and entail rather serious consequences for the engine up to a complete failure and non-maintainability [3, 4, 5]. According to the latest data [6], more than half of the total number of faults in operation is associated with the coolant, the loss of which through a damaged radiator, among other ways, among other ways, causes to breakdown of the cooling and emergency operation of the engine. As such cases pose the biggest danger to the engine, the research was focused on evaluating the quantitative patterns of processes as well as on comparing theoretical results with experimental data on the engine parts damage at coolant loss.

Analysis of publications

Despite the well-known phenomenon of engine overheating, a large number of works are still devoted to the study of the overheating features, the means of their diagnosis and the consequences for the engine [7, 8, 9]. At the same time, some design features of the cooling systems of the various engines can be the cause of the ambiguity of certain of the fault symptoms, even if there is a large amount of information about this type of fault.

An analysis of the sources, no matter how extensively it is conducted, shows that despite begin commonly known, these features are practically not discussed in well-known works on the study of the ICE cooling systems. Moreover, the results obtained in these works, as a rule, cannot be applied to the emergency cases of coolant loss, when all the thermal and hydrodynamic laws on the basis of which the cooling systems of known types are built are completely disrupted. In this case, we are talking about the engine operation features in the case of a failure in the cooling system, while well-known studies hardly pay attention to this emergency mode.

Indeed, not only in theory but also in operational practice, determination of the cause of an engine fault accompanied by overheating is usually difficul [10, 11]. For example, in the ICE operation it is far from always clear whether the driver could see an increase in the coolant temperature on the control panel indicator in order to take all the necessary measures in time to prevent engine failure (some cars do not have a temperature gauge, there is only an overheat warning indicator). As a result, a dispute might occur between the consumer (driver) and the seller, the service organization and even the manufacturer concerning the reasons and liability of the parties of the dispute for the engine damage due to overheating [2]. However, it is not possible to resolve such dispute within the framework of the well-known principles and the data on the cooling system operation.

Therefore, in addition to the characteristic symptoms of ICE overheating, when studying its causes, the knowledge of the additional patterns is needed to help determine the true cause of the fault. Such patterns have been first identified in the present study. Consequently, the objective of the work is to identify the patterns of time-varying thermal state of the combustion chamber walls, piston, and temperature sensor under the various operation modes of the cooling system caused by overheating, and first of all, in the emergency mode associated with the loss of coolant.

Purpose and objective

The purpose of the work is to investigate and recreate a model of an engine malfunction after overheating**.**

Work tasks:

– develop a model of the engine temperature change after an emergency loss of coolant;

– conduct expert studies of the technical condition of the engine after overheating.

Material collection

In automotive operation, there are various and very numerous causes of engine overheating [2, 3, 5, 10], which can conditionally be divided into 3 groups: 1) the faults that cause the disruption of the coolant circulation in the system, when the amount of coolant is normal (including the faults of the thermostat and the pump, radiator contamination from the inside, low pressure in the system, etc.); 2) the faults that disrupt heat removal from the system with normal amount of coolant (including the faults of sensors, fan, radiator contamination from the outside, etc.); and 3) the faults, caused by coolant leaks from the system (including those that occur due to damage to clamps, hoses, radiator, etc.).

In case of the first two groups of causes, the moment of the start of temperature increase in the system, the moment of the engine overheating, as well as its development in time can easily be controlled by the driver using the dashboard temperature gauge. The presence of a normal amount of coolant in the system is a sufficient condition for monitoring, under which the gauge will promptly show the temperature deviation from the norm for any fault included in these groups.

On the contrary, the 3rd group of causes is an emergency case when the coolant leaves the system [11]. This can significantly change the mode of the system operation up to a state where conventional control methods are not applicable. This mode is determined, first of all, by the combination of an extremely high temperature of those parts that have lost their contact with the coolant and a comparatively lower temperature of the parts that have not.

The features of the cooling system design and its operation when overheating

To begin with, it is necessary to clarify how the design of the engine itself can affect the results. This is an important factor since engine manufacturers use different cooling systems. It is clear that some processes can occur differently in different systems. However, some general patterns can be identified.

According to the experience of operation and repair of a large number of engines, the cooling system shown on Fig. 1 appears to be the most widespread in the design of passenger car engines [4, 5, 12, 13].

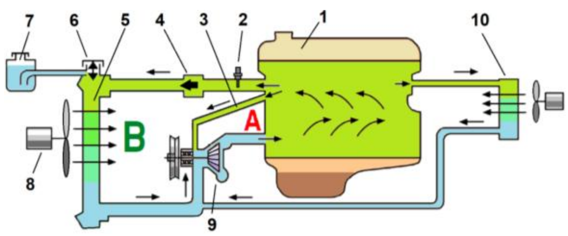


Fig. 1. Traditional cooling system with one-way thermostat and bypass channel: A – small circulation circle; B – large circulation circle, 1 – engine; 2 – temperature sensor; 3 – small circulation bypass channel; 4 – thermostat; 5 – radiator; 6 – cap; 7 – expansion tank; 8 – fan; 9 – pump; 10 – heater

Since the cooling system of this type is currently used in the most engines of mass-produced cars, it can conventionally be called the cooling system of traditional type. It is important to point out the most characteristic features of the application of the traditional scheme in many modern engines. One of them is a one-way thermostat that opens a large circle of circulation with a constantly open small circle (Fig. 1) that simplifies the cooling system and increases the reliability of its operation. The temperature sensor is installed in the channel (pipe) on the outlet of the cylinder head, since the coolant temperature is maximal there.

Analysis of the available data [2, 4] makes it possible to specify the main symptoms of strong and/or prolonged overheating of the engine in operation. The types of damage might be various from loosening of the cylinder head bolts, deformation of the surface of cylinder head, block and cylinders to scuffing on the pistons and cylinders, or melting of the cylinder head walls and pistons.

As practice shows [14, 15] only some of the symptoms indicated can be observed in operation and this depends on the amount of coolant in the system, the intensity of overheating, the engine operating mode and other conditions.

Features of the cooling system operation in emergency mode with a low coolant level

When the faults associated with a leak in the system including external leakage of coolant appear, the pressure in the system normally decreases [2, 3], which causes local to boil the coolant on the hot surfaces, which is dangerous for the engine.

To analyze the cooling system operation with low coolant level, it is necessary to take into account that a significant loss of coolant leads to a strong decrease in its level in the entire cooling system. In this case the engine and the radiator actually turn into two communicating vessels connected by the radiator lower hose (Fig. 2).

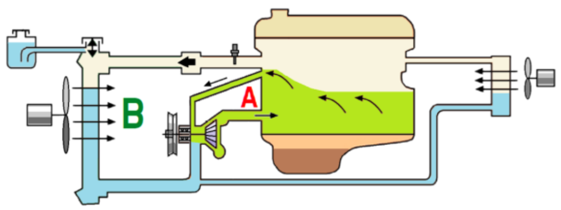


Fig. 2. The diagram of the cooling system operation in the event of coolant loss with continued circulation in a small circle (the designations of the diagram correspond to Fig. 1)

Obviously, with a decrease in the coolant level, the system elements located at the top of the system will either remain without the coolant or its flow will not be constant. According to the diagram of the traditional cooling system (Fig. 1), there are hoses at its upper level that connect the cylinder head to the radiator and the interior heater. Therefore, one of the main symptoms of a drop in the coolant level is usually the heater turning off [2, 3, 5], which is clearly noticeable in the cold season.

For this mode, it is important that if there is a bypass channel in the cooling system between the head and the cylinder block the coolant circulation in this channel will continue, since this channel is located below the outlet pipes of the cylinder head (Fig. 2).

In this state of the system and in this mode of operation, the radiator will be practically switched off from operation as soon as the coolant level in the system falls down below a certain critical value. According to the operating experience, typically a loss of 2–3 liters (or 30–40 % of the total) is a critical loss provided that the engine is operating at low or medium rpm [2].

Methodology

In order to determine the relationship between the parts heating and the readings of the temperature sensor in the emergency mode, it is necessary to calculate the change in their temperature over time. For this purpose, it is necessary to find a solution to the problem of unsteady heat transfer for the elements under consideration – the cylinder head and the piston, in the event when their cooling is disrupted.

Such problems are solved by modern methods, including the finite element method, which makes it possible to perform 3-D simulation of heat transfer processes. However, at this stage, it is more important to determine general principles, while the finite element method is more efficient when solving design problems. Under such conditions, the use of 3-D simulation at the beginning of the study would be unreasonable, and therefore, at this stage, the calculation method based on the general heat transfer theory and empirical dependencies was used.

Let us imagine a certain structural element of the engine heated on one side and cooled on the other (Fig. 3). When the engine is running, thermal equilibrium will be established when the amount of heat transferred by the working fluid (gas) into the element wall is equal to the heat amount transferred by the element to the coolant. Obviously, in this case, the temperature of the element will be constant over time.

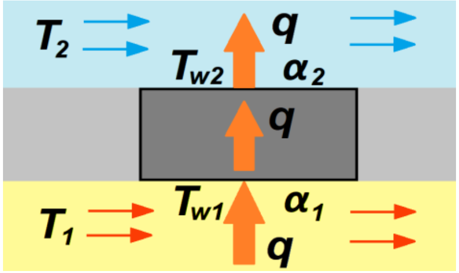


Fig. 3. The design scheme of the cooled engine element in the steady state heat condition

In the first approximation, thermal conductivity across the direction of heat propagation can be neglected, and the area of the wall through which the heat flux passes can be considered the same on the outside and on the inside.

Then for heat transfer from the side of the heat supply and removal we can compose the following equations for the specific heat flux q, equal to the amount of heat removed, referred to the wall cross-sectional area [16, 17]:

$$q = \alpha_1 (T_1 - T_{w1}) = \lambda \frac{(T_{w1} - T_{w2})}{\delta} = \\ = \alpha_2 (T_{w2} - T_2), \qquad (1)$$

where α_1 – is the heat transfer coefficient from gas to the wall;

T_1, T_2 are the gas and coolant temperatures, respectively;

T_{w1} is the wall temperature on the heat supply side;

T_{w2} is the wall temperature on cooling side;

λ is the coefficient thermal conductivity of the wall;

α_1 is the heat transfer coefficient from the wall to the coolant.

The equation for the heat flux through the wall with the thermal conductivity of the wall also taken into account [16, 17]:

$$q = \frac{(T_1 - T_2)}{\left(\frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}\right)}. \qquad (2)$$

Let us now assume that when operating in the steady state, the cooling of the wall has suddenly stopped due to the disruption of coolant supply (the heat removal with the coolant vapor in the 1st approximation is being neglected). This condition is equal to a sharp decrease of the heat transfer coefficient on the side of the element that is being cooled, for example, as a result of a sudden disappearance of the coolant. In this case, the equilibrium between heat supply and removal is disordered, therefore, equation (2), written for the steady state heat transfer, cannot be used to calculate the temperature change in this process.

For an approximate solution of the task with the heating of an element in case of a cooling failure, the heat balance equation written for the selected element [18] under the condition of complete absence of its cooling can be used (Fig. 4):

$$q \cdot F \cdot d\tau = C_w \cdot M \cdot dT, \qquad (3)$$

where F is the surface area of the contact with the working medium;

C_w is the specific heat of the metal;

M is the mass of the element;

$d\tau$ is the period of time it takes the temperature of the element T_w to increase by dT.

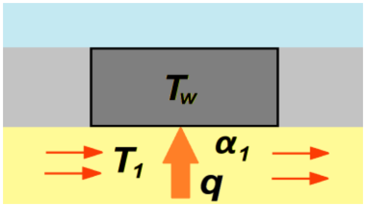


Fig. 4. The scheme of the engine element in case of cooling failure

Equation (3) shows the increase in the internal energy of the selected element when heat is supplied into it for a given time period at the absence of cooling and thermal conductivity across the heat flux direction (along the heated surface of the element).

Then it is easy to obtain the following simple equation from equation (3), if equation (1) is taken into account:

$$dT_w = (\alpha_1 \cdot F / C_w \cdot M)(T_1 - T_w) d\tau. \qquad (4)$$

Equation (4) approximately describes the process of the temperature time change of the element heated by hot gases after a sudden cooling failure. This corresponds in general to the emergency operation of the cooling system with rapid loss of coolant, provided that there is no thermal conductivity along the element surface and that the element is being cooled by the coolant vapor.

Calculation of the sensor temperature variation over time in case of cooling failure after coolant loss

Let us now consider the process of heat exchange of the temperature sensor flowed around by the coolant (during normal operation of the system and/or during engine overheating with normal coolant amount) and vapor (during overheating when emergency operation with coolant loss).

The sensitive part of the sensor is a cylinder mounted across the coolant flow (Fig. 5); the heat exchange of the cylinder with the flow is reliably described by the empirical equation [16]:

$$Nu = C \cdot Re^{m} \cdot Pr^{0.33}, \quad (5)$$

where Nu=α·d/λ is the Nusselt criterion (number);

α is the heat transfer coefficient;

d is the characteristic size of the process, which is taken as the diameter of the sensitive part of the sensor (d = 0.006 m);

λ is the thermal conductivity of the working medium (for coolant λ = 0.47 W/m·K [19], for vapor λ = 0.022 W/m·K).

Re is the Reynolds number (Re=v d/ν), v is the working medium velocity (in the 1st approximation, v = 1 m/s);

ν is the kinematic viscosity coefficient (for coolant ν = $0.24\cdot10^{-6}$ m^2/s, for vapor ν =$12\cdot10^{-6}$ m^2/s);

Pr is the Prandtl number (for coolant Pr = 2, for vapor Pr = 0.72).

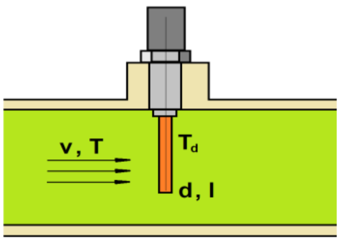


Fig. 5. Installation diagram of the coolant temperature sensor on the coolant system pipe

The empirical coefficients C and m are dependent on the type of the working medium and the flow mode [16]. So, for the turbulent mode of the coolant flow with Re = 4000–40000 the coefficients are C = 0.193, m = 0.618, for the vapor at Re = 40–4000 it is possible to accept C = 0.683, m = 0.466.

Substituting all the values into equation (5), we obtain the value of the heat transfer coefficient for the working medium flowing around the sensor: for the coolant α_f = $1.45\cdot10^4$ W/m^2 K, for the vapor α_v = 40.7 W/m^{2}K. The obtained difference of 350 times shows that the assumption made above that concerns neglecting the vapor cooling of the element after loss of coolant is quite acceptable with an error of less than 1 %.

To assess the inertia of the temperature sensor, it should also be assumed that the sensor heats only from the working medium (coolant or vapor), and there is no thermal conductivity between the wall and the sensor. This assumption is valid for the rapid occurrence of the overheating process, as well as in the case when the wall where the sensor is installed does not have the time to heat up due to heat conduction from hot parts of the cylinder head. It also corresponds to the situation when the sensor is located on the outlet pipe of the cylinder head and/or far from cylinder head.

Approximate calculation of the heating process of the combustion chamber wall and the piston head in case of cooling failure

In order to determine the temperature of the element of the combustion chamber, we can additionally take the following simplifying assumptions: the gas temperature is constant and equal to the average temperature in the combustion chamber T_1=1400 K (1137^{0}C), and the coolant temperature is constant and equal to T_2 = 363 K (90 ^{0}C).

The heat transfer coefficient of the gas, which is included in equation (4), can be approximately calculated using various equations, however, due to the approximate nature of the calculations, in the first approximation the Eichelberg equation was chosen [20]:

$$\alpha_1 = 7{,}8\, \sqrt[3]{c_m}\, \sqrt{p_1 \cdot T_1}, \quad (6)$$

where c_m is the average piston speed, m/s (c_m=$S\,n/30$);

n is the crankshaft rotation speed (at medium mode n = 3000 rpm);

p_1 is the engine average effective pressure (at medium mode p_1 = 0.4 MPa);

S is the piston stroke (it was accepted S = 0.09 m).

With this approximate data, equation (6) gives α_1 = 1.25·103 W/m^2·K.

According to [21], the heat transfer coefficient for the coolant in the ICE cooling jacket can be approximately taken equal to α_2 = 104 W/m^2·K. Substituting the indicated values into the formula (2), we obtain q = 1.08·10^6 W/m^2, whence the surface temperatures of the wall element for the steady state operation of the engine are:

$$T_{w1} = T_1 - q/\alpha_г = 536 \text{ K};$$
$$T_{w2} = T_2 + q/\alpha_в = 481 \text{ K}.$$

In addition, for the calculations, it will be necessary to know the parameter values included in equation (4): the specific heat of the material C_w = 1000 J/kg·K, the mass M of the wall element (with dimensions 10x10 mm and the thickness of 10 mm Mn = 0.0027 kg), and the wall surface area F = 0.0001 m^2.

Obviously, these data are sufficient for an approximate calculation of the heating process of the combustion chamber wall after cooling failure. According to the equation (4), the heating of the wall with no cooling will theoretically occur as long as there is a temperature difference. Therefore, it can be assumed that the end point of the calculation will be the strength loss of the wall material or even its melting (for an aluminum alloy, the initial melting point is 577^{0}C [22].

However, this condition in general does not fully correspond to the nature of the temperature change of the piston when overheating occurs. As is known [22], an increase in the temperature of the piston causes it to expand inside the cylinder. Then, the point of ultimate heating of the piston would not be the melting of the material but rather the scuffing, seizure and jamming due to excessive thermal expansion in the cylinder [2, 4].

In most modern engines, the cylinder is formed by a thin cast-iron sleeve embedded in an aluminum wall. The clearance between the piston and the cylinder in the area of the piston top land at normal temperature T_0 = 20 ^{0}C is usually equal to about 0.50 mm. If the piston crown is heated to temperature T_w, its diameter D_0 will increase in accordance with thermal expansion [23]:

$$D = D_0 + \alpha_a \cdot D_0 \left(T_w - T_0\right), \qquad (7)$$

where α_a is the coefficient of thermal expansion of the aluminum alloy (α_a = 20·10^{-6} K^{-1}).

Similarly, when expanding the cast iron cylinder liner during heating (α_c= 10·10^{-6} K^{-1}), the diameter of the liner D_c at the temperature T_w will be:

$$D_c = D_{0c} + \alpha_c \cdot D_{0c} \left(T_w - T_0\right),$$

where D_{0c} is the initial diameter of the cylinder liner at the temperature T_0.

In the event that the piston diameter becomes equal to the diameter of the liner, scuffing will occur. Then after equating the diameters:

$$D_0 + \alpha_a D_0 \left(T_w - T_0\right) = D_{0c} + \alpha_c D_{0c} \left(T_w - T_0\right),$$

it is possible to find the temperature at which this condition is met:

$$T_w = \frac{T_0 + \delta_0}{\left(D_0\ \alpha_a - D_{0c}\ \alpha_c\right)}. \qquad (8)$$

By substituting the diameter of the piston top land D_0 = 0.09 m, the initial clearance $\delta_0 = D_{0c} - D_0$ = 0.5 mm at temperature T_0 = 293K into equation (8), we obtain the maximum piston crown temperature T_w = 848K (t_w = 575^{0}C) that corresponds to the piston scuffing and seizure, which practically coincides with the start of the melting of the piston material. However, it should be noted that in reality scuffing normally occurs at less heat. Given that the piston top land during normal operation is heated to 300 ^{0}C, in the first approximation, the critical heating level of the piston to be chosen should be the one that exceeds this value by 180–200 ^{0}C.

In order to calculate the unsteady piston heating in the cylinder after a cooling failure, equation (4) can be applied. However, clarification for the mass included in this equation is required. Thus, for an approximate calculation, it can be assumed that only a relatively thick part (50 % of the mass) of the piston (the piston crown) and the part of the cylinder liner within the piston stroke are involved in this short-term process. The cylinder wall thickness is 0.01 m and its length is 0.1 m (we neglect the thickness of the cast-iron liner in the first approximation) while the estimated mass of the piston is 0.350 kg. Then the mass of the considered element of the part of the piston with the part of the cylinder should be approximately M = 1.0 kg with the piston area F = 0.00636 m^2.

The heat transfer coefficient α_c is calculated the same way as it was done above for the combustion chamber. After that, knowing the heat transfer coefficients, it is possible to calculate the temperature variation of all the elements according to the process time.

Results and discussion

Equation (4), which describes the heating of the element of the temperature sensor, the combustion chamber and the piston, is integrated for a given time interval with an initial temperature value corresponding to the normal cooling mode. Since this is an approximate estimate, it is quite sufficient to carry out numerical integration using the simple Euler method with a time step of 0.25 sec. In this case, the surface area of the sensitive part of the sensor $F = \pi\, d\, l$ (for l = 0.02 m and d = 0.006 m F = 3.7·10^{-4} m^2) is substituted into equation (4). The following values are also going to be required: C_w, which is the heat capacity of the sensor (for brass C_w = 400 J/kg·K), and M, which is the mass of the sensitive part of the sensor.

Let us now assume that the temperature of the working medium suddenly jumped up from 90 ^{0}C to 130 ^{0}C, i.e. by 40 ^{0}, which means that the engine has overheated. When all the values are substituted into equation (4), we shall get that the sensor, being in the coolant, will follow the coolant temperature with a delay of no more than 1–2 seconds (the temperature of the sensor in the liquid will increase by 40 ^{0}C per about 1 second). At the same time, the delay in the reaction of the temperature sensor for vapor will be extremely large, approximately 0.3 ^{0}C in 1 second or only 18 ^{0}C per minute (Fig. 6).

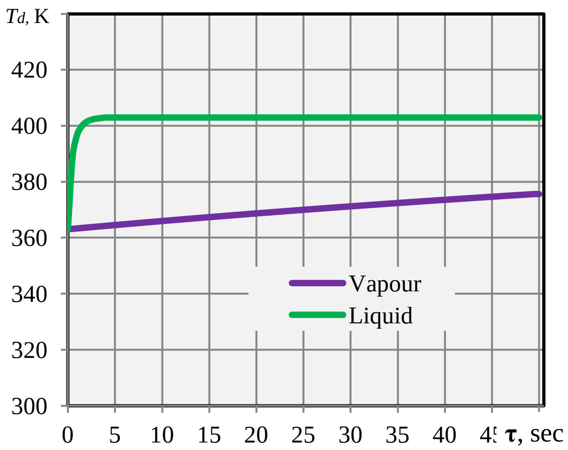


Fig. 6. The calculated nature of the temperature variation of the temperature sensor element from the point of the cooling failure with the sudden rise of the temperature from 90 ^{0}C to 130 ^{0}C (from 363 K to 403 K)

This result shows that with an abnormally rapid decrease in the coolant level in the cooling system or with its complete loss, the inertia of the temperature sensor increases by about 100 times. Under such a condition the sensor may be unable to track the temperature rise, while the entire time of the overheating process from loss of coolant to engine failure can be very small.

As follows from the calculation results (Fig. 7), in the event of a sudden and complete cooling failure, the combustion chamber wall can begin to melt already after about 10 seconds of engine operation in the nominal mode.

The piston crown heating in the event of a cylinder cooling failure occurs much more slowly than the heating at the cylinder head wall. That is why the appearance of scuffing on the piston top land should be expected in a period of time which is several times longer than the time of damage to the combustion chamber wall (Fig. 7).

For comparison, the diagram shows the temperature of the sensor element. The very small variation of this temperature during the accident up to engine failure allows us to conclude that the entire process of the engine damage before the melting of the parts (horizontal line corresponds to this temperature equal 850 K) can take place without informing the driver about the accident.

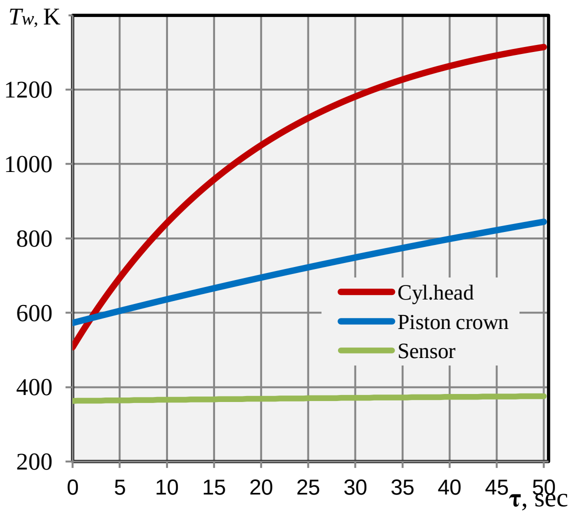


Fig. 7. The calculated nature of the temperature variation of the cylinder head, the piston crown and the temperature sensor over time from the moment of a cooling failure in the event of a sudden loss of coolant

Comparison of calculation results with experimental data

It is of interest to compare the calculation results with real-life investigations of the causes of engine failures in operation in the event of an emergency rapid loss of coolant. For an accurate comparison, it would be advisable to conduct a special experiment, however, due to the approximate nature of the calculations at this stage of the study, in the first approximation it was decided to use the already available experimental data on engine damage and to search mainly for qualitative confirmation of the results of the calculations performed.

The main cause of this type of failure is the damage to the cooling system radiator from various foreign objects tossed up from the road by passing or oncoming vehicles (Fig. 8). But the failures with similar consequences that occur due to the aging of the rubber or hose defects, including hose rupture, the tearing off of the hose from the pipe due to the loosening of the clamp, etc. are also quite common.

Practice shows [2, 4] that an engine with this kind of fault usually fails due to loss of compression in the cylinders as a result of significant thermal deformation of the mating surfaces of the cylinder block and the cylinder head, and the tightness loss of the cylinder head gasket. However, the damage is not limited to this deformation.

Fig. 9 shows the combustion chamber of a gasoline engine with traces of wall melting between the exhaust seats, what was the result of the fast coolant flow-out through the radiator damaged as a result of an impact of a foreign object.

As expected, the section of the combustion chamber wall located between the exhaust valve seats suffered the most damage, since this section is small but locally heated by hot gases on three sides at the same time (coming from the combustion chamber and both of the exhaust channels), while cooling acts on one side only.

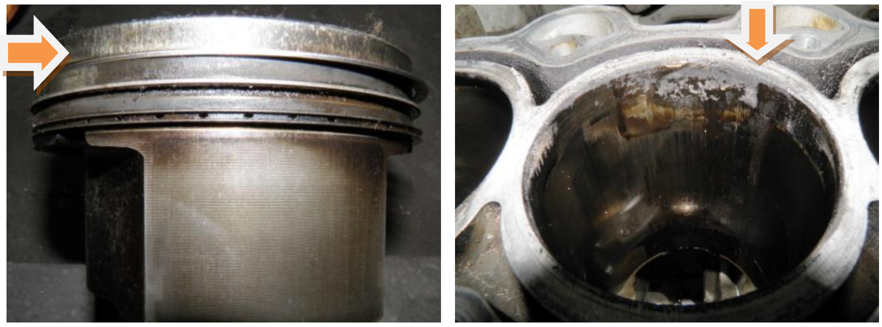
When the engine is working at low speeds and loads, the intensity of heating of the parts decreases and the process time increases. This causes the chamber wall temperature to balance, and instead of a local wall burnout between the seats, engine failure may occur due to the seats falling out from the cylinder head (Fig. 9). Typically, such failure occurs with an overall heating of the cylinder head above 200 ^{0}C.What these two considered cases have in common is the minimal damage to the cylinders and pistons, dealt only in the upper part, where due to thermal expansion of the top land the piston can jam in the cylinder with characteristic traces of scuffing and seizure (Fig. 10).

a b

Fig. 8. Typical radiator damage from foreign objects that causes rapid coolant loss: a – destruction of one of the radiator tubes; b – the edge of the lower radiator tank

a b

Fig. 9. Comparison of consequences of engines operating after loss of coolant: a – melting of the wall between the exhaust valves seats in the nominal mode of operation; b – and dropped valve seats of the cylinder head at idle speed operation



a b

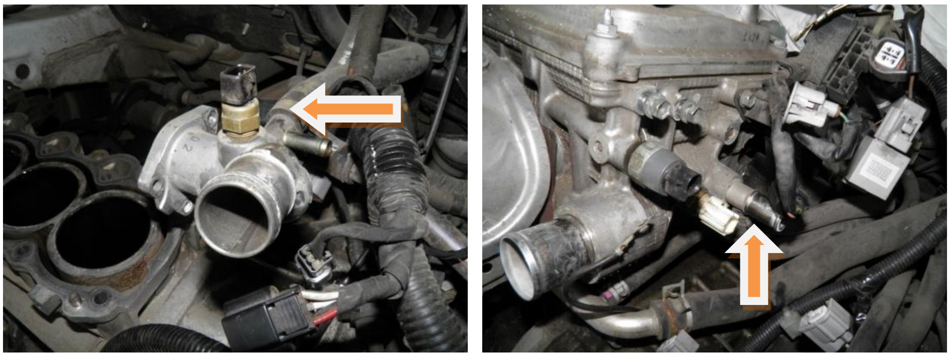
Fig. 10. A gasoline engine operation at an emergency loss of coolant: a – scuffing and seizure on the top land of the piston; b – the cylinder

Discussion of driver actions in case of engine failure due to overheating

Common to the considered cases of failure is lack of the driver's reaction to overheating and the continuation of the trip until the engine stops due to failure . This indirectly indicates the inoperability of the temperature sensor if it is installed on the outlet pipe of the cylinder head (Fig. 11).

As follows from the data obtained above, in the event of a sudden rapid loss of coolant, the inertia of the temperature sensor becomes extremely large if the sensor is installed on the outlet pipe far from the cylinder head.

In such conditions, the temperature at the pointer can increase noticeably for the driver only as late as a minute after the cooling system has completely failed, while an engine failure due to thermal deformation of the cylinder head occurs before the driver has a chance to see that the temperature of the engine has increased.



a b

Fig. 11. Features of the temperature sensor typical location on the outlet pipe of the cylinder head, made: a – as a separate part; b – as a structural part of the head

Conclusion

Internal combustion engines with traditional-type cooling systems that include a one-way thermostat and a bypass channel have a feature: as a result of a rapid emergency drop in the level of coolant the coolant will no longer circulate in the large circle. Even preliminary calculations show: the wall of the combustion chamber takes extremely serious thermal damage such as the melting and/or falling out of the valve seats which might occur only after a short period of operation in a matter of seconds. At the same time the pistons in the cylinders get minor thermal damage on the top land, and only after a much longer period of time after the accident has taken place. If the temperature sensor is placed on the outlet pipe of the cylinder head, then in the event of a rapid loss of coolant, due to the inertia of the sensor, it might fail to indicate not only the overheating of the engine, but even a mere increase in temperature. Due to these reasons, the driver actually does not have the technical ability to notice an increase in temperature in this type of the cooling system until the engine fails. This can be crucial in investigating the causes of engine failures that occur as a result of overheating in operation.

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Метод експертного оцінювання технічного стану автомобільного двигуна після його перегріву

Анотація. Проблема. *Для експертних досліджень технічного стану автомобіля непростим завданням є визначення причин та поширення несправності механізмів та систем двигуна. У роботі запропонована модель несправності двигуна в процесі перегрівання, зокрема в аварійному режимі, викликаному швидкою втратою охолоджувальної рідини. У двигунів легкових автомобілів із системами охолодження традиційного типу з одноходовим термостатом і байпасним каналом швидке аварійне падіння рівня рідини викликає припинення її циркуляції по великому колу. У цьому випадку камери згоряння отримують надзвичайно серйозні ушкодження у вигляді плавлення стінок і випадання сідл, тоді як поршні в циліндрах зазнають незначних термічних пошкоджень і тільки через значно більший час від початку руйнування камери згоряння. Установлено, що термічне ушкодження головки циліндра можливе вже через 10 с після порушення охолодження. Поршень нагрівається повільніше й може бути пошкоджений тільки у верхній частині* *й за значно більший час. За результатами дослідження встановлено, що за умови аварійної втрати охолоджувальної рідини водій не має технічної можливості бачити підвищення температури, що може мати значення в процесі виявлення причин несправності двигунів, пов'язаних із перегрівом.* ***Мета***. *Дослідити й відтворити модель несправності двигуна після його перегріву.* ***Методологія.*** *Теоретичні розрахункові результати підтверджені реальними експериментальними дослідженнями відмов двигунів у процесі перегрівання.* ***Наукова новизна.*** *На підставі розроблених моделей складена методика й виконаний розрахунок теплового стану деталей двигуна після його перегріву.* ***Результати.*** *Розрахунковим шляхом отримано, що за відсутності охолоджувальної рідини датчик температури, у разі його розташування на вихідному патрубку головки циліндра, не покаже підвищення температури аж до відмови двигуна. Визначений певний характер несправності деталей механізмів двигуна у випадку його раптового перегріву.* ***Практична значущість.*** *Проведені дослідження та складені розрахункові моделі дозволяють експерту зробити більш об'єктивне оцінювання розвитку механізму несправності двигуна за умови його перегріву в процесі експлуатації автомобіля.*

Ключові слова: *двигун внутрішнього згоряння, теплоносій, несправність, перегрів.*

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