Daxili yanma mühərriklərinin istilik balansı və istilik itkilərinin azaldılması üsulları

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Xülasə

Məqalədə əsas diqqət daxili yanma mühərrikləri sisteminin istilik balansına, istilik enerjisinin yüklənməsi və onu azaldılması üsullarına yönəldilib. Mühərrikin məsul detallarının enerji yüklənməsinə təsir göstərən amillər: istilik mübadiləsi proseslərində iştirak edən donuq və cilalanmış səthlərin sahələrinin nisbəti, detallarda metalın tərkibi və onların materiallarının istilik keçiriciliyi əmsallarına diqqət yetirilib. Çox qatlı müqavimət sistemində istilik ötürmə əmsalının təsiri, başqa sözlə: istilik tutumu, istilik keçiriciliyi və istilik ötürülməsi müəyyən edilib. Mühərrikin enerji rejiminin seçimi detalların istilik möhkəmliyi prosesinin optimal yerinə yetirilməsi şərtləri ilə müəyyən olunub və buna görə də mühərrikin həm qızması, həm də həddindən artıq soyuması diqqət mərkəzində olmalıdır.

Açar sözlər: daxili yanma mühərriki, mühərriklər sistemi, müqaviməti, istilik tutumu, istilik keçiriciliyi, istilik ötürülməsi.

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Тепловой баланс двигателей внутреннего сгорания и способы снижения тепловых потерь

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Аннотация

Основное внимание в статье уделяется тепловому балансу систем двигателей внутреннего сгорания, загрузке тепловой энергии и способам ее снижения. Выделены факторы, влияющие на энергетическую нагрузку ответственных деталей двигателя: соотношение площадей матовых и полированных поверхностей, принимающих участие в процессах теплообмена, содержание металла в деталях и коэффициенты теплопроводности их материалов. Устанавливается влияние коэффициента теплопередачи в многослойной системе сопротивления: теплоемкость, теплопроводность и теплопередача. Выбор энергетического режима двигателя диктуется условиями оптимального выполнения рабочего процесса тепловой прочности деталей, и поэтому необходимо избегать как перегрева, так и переохлаждения двигателя.

Ключевые слова: двигатель внутреннего сгорания, системы двигателей, сопротивление, теплоемкость, теплопроводность, теплопередача.

Introduction

The problems of modern piston engine construction depend on: increased engine power and speed; quality of combustible mixtures and multilayering, taking into account toxicity and harmful emissions; start-up (diesel) and fuel injection systems; mechanical and thermal stress reduction.

Work is under way to improve the performance of internal combustion engines and their systems: fuel feed, combustion, lubrication, air supply and cooling.

Analysis of literary sources and the state of the problem

The processes, phenomena and effects observed in internal combustion engine systems are interrelated and occur in a strict sequence.

It follows from the analysis of the operating principle of internal combustion engines [1-5] that the mechanical movement of its components is to a large extent determined by the kinematics of the crank mechanism, the mechanics of the fluid movement in the channels, and also by the more complex forms of motion: chemical and thermal motion, i.e., processes of heat extraction and transmission to the working body in the engine cylinder. Thermodynamic and heat transfer [6-8] is an important system in the engine

The nature of the processes in this system has a decisive influence on the processes in the mechanical and hydraulic circuits, and thus on the operation of the engine as a whole.

Thermodynamics determine the amount of heat (Q), the parameters of the gas (temperature, pressure and specific volume) and the specific heat flux (q). Heat transfer includes free and forced convective heat exchange, as well as conductive and radiation heat exchange. The main methods used are heat conductivity and heat transfer coefficients, leaving aside the heat transfer coefficient. Moreover, researchers [8-12] do not pay attention to the thermal resistance of heat exchange types and gas-liquid boundary layers.

Problem Statement

The mechanical and thermal performance of the engine should be addressed. The main issues of the article are: thermal balance and energy load of engine parts, ways to reduce the energy load of engine systems.

The objective of the work

Improvement of mechanical and thermal loading of main engine parts.

Engine heat balance

According to the ideal heat message cycle at $V = const$ and its equivalent Carnot cycle, a formula for thermal efficiency is obtained:

$$\eta_T = \frac{T_1 - T_2}{T_1} = 1 - \frac{T_2}{T_1}, \tag{1}$$

where T_1 and T_2 - the equivalent average temperatures at which the ideal gas is conducted and separated from it heat Q_1 and Q_2.

Since temperatures T_1 and T_2 are almost always limited, thermal efficiency cannot be equal to one, that is, only a fraction of the heat input Q_1 can be used for mechanical work.

This provision is one of the manifestations of the second law of thermodynamics.

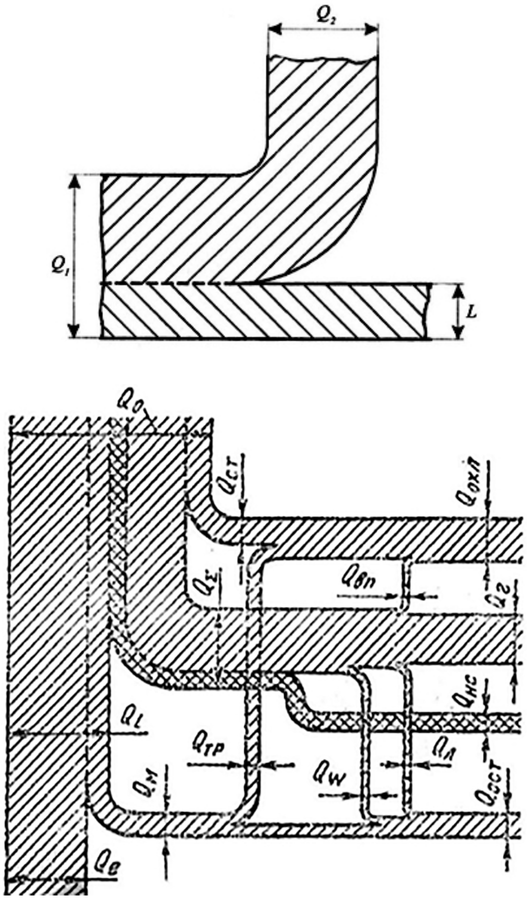

Figure 1 – Schemes: partial (a) and complete (b) thermal balance of the engine: Q_1, Q_2 – heat supplied and removed from the ideal gas; L= Q_1 - Q_2 - mechanical work;
Q_0(I) – heat obtained from the combustion of the fuel injected into the engine cylinder; Q_0(II) is the heat equivalent to the engine's tracer performance; Q_e(III) is the heat equivalent to the efficient operation of the engine; Q_{CT}(IV) is the heat transferred to the walls limiting the internal volume; $Q_{0XЛ}$(V) is the heat given to the cooling medium; Q_Σ(VI) is the total heat contained in the exhaust gases; Q_M*(VII)* is the heat equivalent to the friction work and the drive of the auxiliary mechanisms; Q_{TP}*(VIII)* is the heat transmitted to the cooling medium by the friction of the piston and the rings; Q_{HC}*(IX)* is the part of the heat of the fuel lost due to the chemical incompleteness of the combustion; Q_{OCT}*(X)* - residual heat; Q_w*(XI)* - corresponding to the kinetic energy of the exhaust gases; $Q_Л$*(XII)* - the heat lost due to radiation by polished and matte surfaces; $Q_{BП}$*(XIII)* is the heat released by the exhaust gases into the cooled system in the exhaust pipe; $Q_Г$*(XIV)* - the heat transferred from the exhaust engine.

In the engine thermal balance diagram (Fig. 1.b), heat Q_2 is the loss of heat to a cold source caused by the second law of thermodynamics.

$$Q_2 = (1 - \eta_T) \cdot Q_1, \qquad (2)$$

This loss can be reduced in principle according to the thermal efficiency equation of the Carnot cycle, only by a decrease in temperature $\frac{T_2}{T_1}$.

The analysis of the components of the engine heat balance showed the following:
– Chemical - I, VI, IX, XI, XIII and XIV;
– Turning heat into work - II, III and VII;
– Different types of heat exchange of parts with surrounding medium IV, V, VI, VIII, IX, X, XI, XII.

Let's focus on the latter as they relate to the energy load of the engine parts. The modern trend in the development of high-speed engines is characterized by the desire to speed them according to speed mode and average effective pressure. This direction of development leads to an increase in mechanical and thermal loads. The latter mainly determine the limit of engine acceleration.

The thermal tension of the engine characterizes the level of energy loading of the main parts of the engine and determines the thermal load for the materials used, which is allowed by the strength conditions of the applied materials. Thermal tension also characterizes the working conditions of friction pairs.

The furnaces of the cylinder block head and the piston, whose temperature fields are very uneven in different zones, are under the most difficult conditions of energy consumption. The surface temperature of these parts, and especially the piston, significantly affects the engine operating conditions and reliability. Overheating of the piston, if the adjoining parts are not sufficiently well lubricated, causes rings coking, obstruction of the working surface of the piston and casing, and other defects. Due to the uneven field of temperatures in the bottom of the piston and the head, they are deformed and the degree of thermal tension in the zones with different temperature gradients differs, resulting in microfractures and burning at the specified locations.

The optimum conditions for the energetic loading of the forced engine are determined by the rational design of the heat-absorbing parts, the cooling cavities and the parameters of the units of the cooling system.

The correct ratio between the amount of heat transferred to the engine cooling medium and the amount removed from the exhaust cylinder is also important. Especially in the case of gas turbine inflation, the rational distribution of the heat is conducive to increased heat use and hence to the acceleration of the engine.

Therefore, the study of the factors influencing thermal tension is important for its reliable operation.

In an internal combustion engine, the heat stress of the main components is determined by the size and nature of the heat fluxes.

The structural complexity of the parts, the difference in the conditions for the forced cooling of the surfaces of the parts, the heterogeneity of the thermodynamic parameters of the working medium according to the volume of the combustion chamber result in the conditions for the heat transfer of the surfaces of the parts limiting the internal volume, are uneven.

As a result, heat flows through different parts of the heat transfer surface differ. During the cycle, the heat transfer surface changes.

The above-mentioned and other factors associated with the course of individual stages of the cycle (swirling gas flow, hydrodynamic processes during intake and discharge, changes in the state of the working body during combustion, etc.) significantly influence the nature of the heat fluxes.

Specific heat flux in W/m^2:

$$q = \frac{Q}{F_1}, \tag{3}$$

where Q is the amount of heat passing through the explored surface of the component, W; F is the surface area considered, m^2.

Heat flux and engine are highly unsteady (fig. 2).

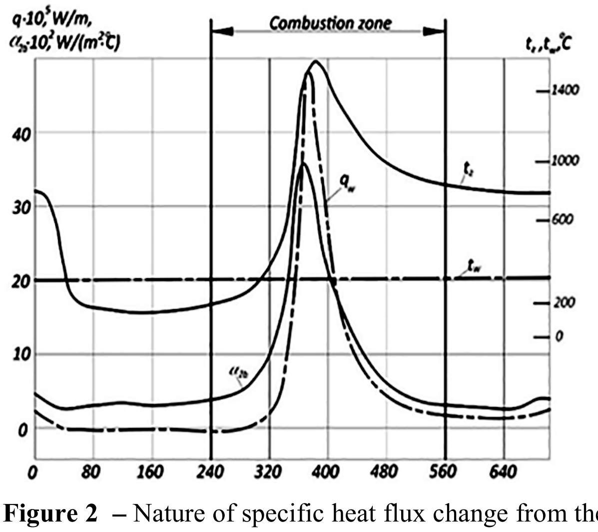

Figure 2 – Nature of specific heat flux change from the working body to the bottom of the head of the diesel cylinder block: n=2100 min^{-1}; $P_к$ = 0.175 MPa; air abundance coefficient α=1.55; heat flux q_W = 64.0·10^5 W/m^2 at α_b = 950 W/(m^2·°C)

Figure 3 shows the bottom temperature of the YMZ-238 piston. The temperature field relative to the cylinder axis is almost symmetrical. Studies have shown a significant influence on t_ω of the heads and pistons of the change in the angle of advance of fuel injection.

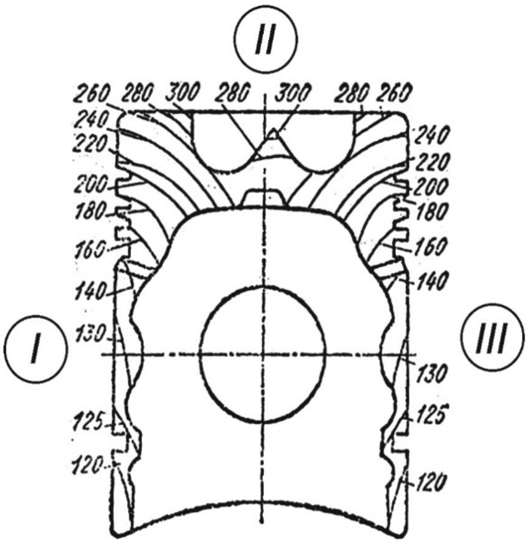

Figure 3 – Temperature distribution (°C) by piston surfaces YMZ-238 diesel engine

As the angle increases, the temperatures in all the zones studied rise. If you increase from 20 to 40° in individual zones, the head increases linearly by about 70° and the piston by 60°.

In zone I the maximum temperature gradient was 260-120=140 °C, in zone III - 240-120=120 °C, and in zone II - only 300-260=40 °C.

In the heat absorbing aluminium-based gasoline engine parts, the temperatures in various zones are lower than in diesel. According to ZIL, the temperature of the base of the aluminium head of the unit which does not have the scale crust is 150 °C in the plane of adjoining the head to the block of cylinders in the maximum power mode (N_e = 110 kW), n = 3200 min^{-1} at the temperature of the coolant $t_в = 90\ ^oC$, and the boss opening for attaching the head to the block is 170°C. If you have a large amount of scale crust compared to the head, not having scale at the boss openings the temperature increases to 50 °C.

Increased thermal stresses in the bottom of the piston of gasoline engines occur during abnormal detonation combustion or potassium ignition.

In diesel due to the relatively longer duration of the combustion process, the heat is partially transmitted by radiation. In this case, the heat is transferred less to the sides of the cylinder casing, and more to the bottom of the piston and the head.

Compared to the carburetor engine, a higher heat flow passes through the above-mentioned surfaces and especially through the bottom of the piston. This is also facilitated by the higher density of charge in diesel due to higher compression and pressure.

Studies have shown that heat transfer by radiation significantly influences the thermal stress of individual areas of the heat-absorbing surfaces of the engine. This particularly applies to the conditions for the transfer of heat in the central zone of the head of the diesel engine and for the transfer of heat by the edges of the piston thereof.

Ways to reduce the energy load on parts of internal combustion engines

Of the factors influencing the energy supply of the responsible parts of the engine, the following are of great influence:

- the ratio of areas of matte and polished parts;
- the metal content of the parts and the heat conductivity factors of their materials;
- nano-liquids with their physico-chemical properties.

With the surfaces (matte and polished) of the metallic elements of the engines, the heat output is carried out by radiating the evaporating heat carrier.

According to the Stefan-Boltzmann Law [6], the coefficient of heat transfer by radiating is determined by the expression:

$$\alpha_{Л} = \frac{c_{Л}\left[\left(\frac{t_H}{100}\right)^4 - \left(\frac{t_O}{100}\right)^4\right]}{t_H - t_O}, \qquad (4)$$

where $c_{Л}$ is the coefficient of radiance, t_H, t_O the temperatures of the surface of the parts and the environment.

Air, gas and liquid act as the ambient medium.

It has been established that the ratio of the radiation coefficients of matte (C_M) and polished ($C_{П}$) surfaces should be equal to the ratio of the area of cooled F_O and heated F_H surfaces of engines with air and liquid cooling of their parts. The ratio is as follows:

$$\frac{C_M}{C_{П}} = \frac{F_O}{F_H}, \qquad (5)$$

When the ratio $C_M / C_{П} = 3,3$ for engines with air $F_O / F_H = 3,2$ and liquid $F_O / F_H = 3,0$ cooling, in most general case the heat is transferred to the surface of the components of the engine cooling system via a boundary layer, which first absorbs a part of the heat, as it has a thermal capacity, i.e., heat-absorbent resistance

$$R_C = c' \cdot \rho' \cdot \delta, \qquad (6)$$

where $c'\rho'$ is the heat-carrying capacity and density of the heat-transfer agent;

δ is the thickness of the boundary layer and, secondly, lowers (puts out) the heat flow, which at the same time has thermal resistance to heat transfer.

The presence of a layer at the surface of the body which simultaneously exhibits resistance of heat-intensive and thermal heat transfer leads to a scheme of a two-layer body at which a boundary condition of the type IV occurs.

With this the boundary layer has:

- the thermal resistance of the heat transfer and the heat-absorbent resistance equals zero $R_C = 0$;
- the thermal resistance of the heat transfer is zero $\alpha_i^{-1} = 0$;
- thermal resistance of heat transfer $(\alpha_i^{-1} > 0;\ R_C = 0)$ and heat-absorbent resistance $(R_C > 0;\ \alpha_i^{-1} = 0)$ i.e. consists of two parts and is combined.

The framework of the internal heat tank of the engine (Fig. 1 a) consists of longitudinal and transverse elements of different thickness. The latter forms the thermal resistance of thermal conductivity (ratio of thickness δ to coefficient of thermal conductivity λ). The coefficient of thermal conductivity remained constant in all cases.

When the thickness of one of the elements of the thermal balance framework (Fig. 1 b) is increased by 2.00-4.00 mm, the thermal resistance of the thermal conductivity is increased by 2-4 times.

When the walls of the frame are washed on one side by gas and on the other side by liquid, the coefficient of heat transfer is:

$$K^{-3} = \alpha_1^{-1} + \left(\delta_i / \lambda_i\right)^{-1} + \alpha_2^{-1}, \qquad (7)$$

where α_1^{-1}, α_2^{-1} are the thermal resistance coefficients of the heat transfer with different media.

Dependence (7) implies that an increase in thermal coefficients of heat transfer and heat conductivity can increase the coefficient of heat transfer by 15-20%.

Conclusion

An important function of engine building is to organize efficient heat transfer from engine elements such as piston, cylinder head and mirror. The following has been done:

- linear relationships between resistance (heat-capacitance, thermal conductivity and heat\transfer) and the thickness of boundary layers have been established;
- the coefficient of heat transfer is a fictitious parameter which significantly affects the value of the heat flow;
- the application of heat transfer coefficients in the calculations.

An alternative method of increasing the heat transfer coefficient is the use of the predicted bubble boiling in the cylinder head coolant jacket. In bubble boiling, the heat transfer coefficient is much higher than in single-phase convection and increases with the wall temperature. Bubble boiling occurs in the most heated zones, which makes it possible to achieve a more even distribution of temperatures in the part and to reduce heat voltages. It shall not be possible to switch to volumetric or film boiling regimes, which are extraordinary and may lead to an emergency. The presence of stall zones of cooled liquids, especially when located in areas of high thermal fluxes, can contribute to the appearance of film-like boiling.

In recent years, a number of new, non-traditional designs, axial piston engines [12] have been proposed, which are largely free of the mentioned disadvantages and combine the advantages as engines with crankshaft mechanisms (possibility of use of high compression degrees, simplicity of structural forms of the main elements) as well as of shaftless engines (absence of crankshaft, connecting rods, parts performing complex flat-parallel motion), including free-piston engines.

The main and essential difference of the proposed schemes of axial piston engines is the possibility of converting reciprocating motion into rotational motion by the piston. It is this fact that informs such engines of a number of important qualities: good economy, complete equilibrium (in designs with opposing pistons as well as with oppositely positioned cylinders) and significantly better specific capacity and mass dimensions.

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