REDUCING THE LEVEL OF THERMOELASTIC STRESSES IN THE PISTON OF A VEHICLE DIESEL ENGINE BY AFFECTING THE ENGINE CYCLE

СНИЖЕНИЕ УРОВНЯ ТЕРМОУПРУГИХ НАПРЯЖЕНИЙ ПОРШНЯ ТРАНСПОРТНОГО ДИЗЕЛЬНОГО ДВИГАТЕЛЯ ПУТЕМ ВОЗДЕЙСТВИЯ НА РАБОЧИЙ ПРОЦЕСС

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Abstract: *Given are the results of a comparative design analysis of the operating cycle and thermal stressed state of a piston in diesel engine 2F10,5/12 under rated power conditions. To reduce the thermoelastic stresses in the piston, the paper suggests using the modern method of managing the operating cycle – homogeneous mixing and combustion. Such an operating cycle reduces the maximum local temperature in the combustion chamber and the temperature gradients, thereby reducing the thermal load on the piston.*

KEYWORDS: DIESEL ENGINE, THERMOELASTIC STRESSES, TEMPERATURE, OPERATING PROCESS.

1. Introduction

As is known, the life of a piston engine depends, primarily, on the life of the piston. The piston operates in very rigorous conditions, and is affected by thermal and mechanical loads. Reducing the maximum temperature of the piston and the temperature gradients in the combustion chamber is one of the priority methods of improving piston operating conditions.

2. Preconditions and means for resolving the problem

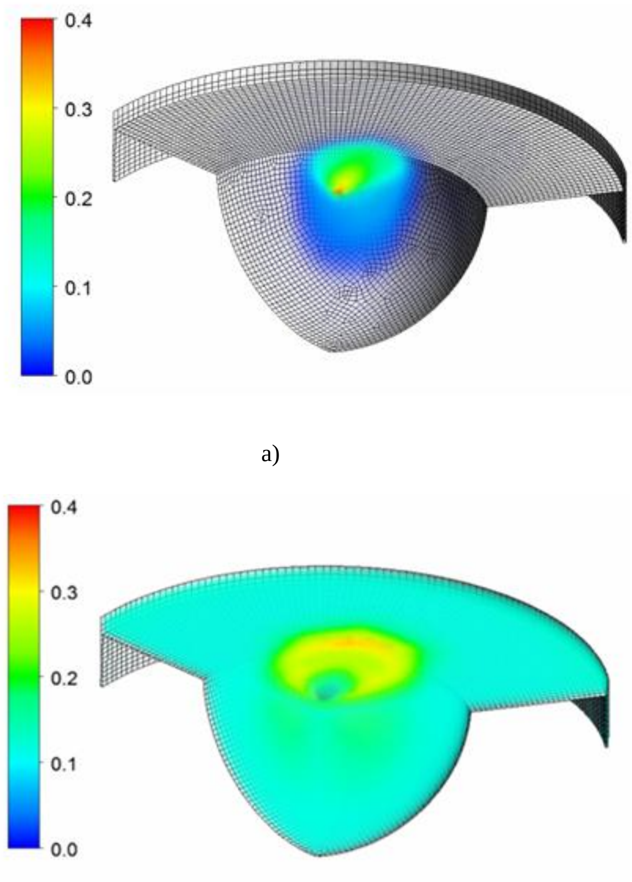
Advanced program packages are used for evaluating analytically the economic, ecological and life indicators of an ICE as early as at the design stage. This enables reducing dramatically the development lead time of a new modification of an engine with superior economic and life indicators. Managing the operating cycle of a diesel engine with Homogeneous Charge Compression Ignition (HCCI) improves the engine's ecological indicators and reduces the maximum local temperatures in the combustion chamber. The burn processes in HCCI engines were investigated by such scientists as Prof. Rolf D. Reitz (U.S.A.), J. Chauvin (France) [1-7] and other researchers. In their research, these authors focused on issues related to managing the operating cycle of an HCCI engine and choosing effective adjustments of fuel injection equipment, whereas issues related to evaluating the impact of the HCCI cycle on thermal stressed state of a piston were studied insufficiently.

3. Solving the problem

Advanced design methods were used for numerical simulation of the operating cycle of diesel engine 2 F 10,5/12 (the reference design engine and HCCI). In the reference design engine, the fuel is injected over 20 degrees of crankshaft rotation (c.r.) to the top dead centre (TDC). In the HCCI variant – 4 injections: 1st – 130 deg. c.r. to TDC; 2nd – 100 deg. c.r. to TDC; 3rd – 40 deg. c.r. to TDC; 4th – 2 deg. c.r. to TDC, each with an interval of 20 deg. c.r.). This enabled filling the combustion chamber space with a virtually homogeneous air-and-fuel mixture. This, along with adding prepared exhaust gases to a fresh charge, provided appropriate conditions for self-ignition at the proper time instant.

4. Results and discussions

Fig. 1 shows the distribution of the fuel volume fraction in the combustion chamber of the Diesel cycle engine 2 F 10,5/12 and with the HCCI process at the instant of self-ignition of the air-and-fuel mixture at the crankshaft rotation angle of φ =352.5 deg. c.r.



a)

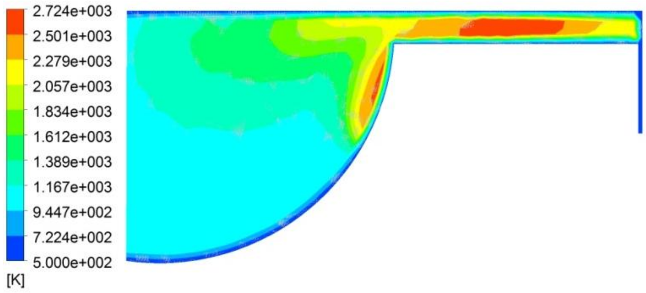
b)

***Fig. 1.** Distribution of the fuel volume fraction in the combustion chamber of Diesel cycle engine 2 F 10,5/12 (a) and with the HCCI process (b)*

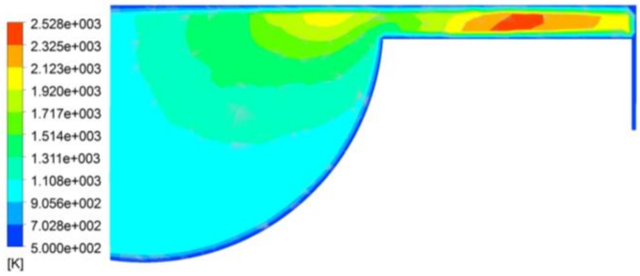
Next are the results of numerical modelling of the operating cycle. Fig. 2 shows the distribution of local gas and flame temperatures in the combustion chamber.

The results show that the maximum flame temperature in a Diesel cycle engine reaches 2,724 K (Fig. 1 a), and in the HCCI engine, the flame temperature reaches 2,528 K (Fig. 2 b). Such a substantial local temperature drop is attributed to formation of a homogeneous air-and-fuel mixture and the presence in the fresh charge of prepared exhaust gases. However, further movement of the piston and the air-and-fuel mixture, the near-wall effects close to the combustion chamber walls, and gas and flame turbulence localise the combustion processes.

Fig. 3 shows a comparison of indicator diagrams for engine 2 F 10,5/12.



a)



b)

Fig. 2. *Distribution of local gas and flame temperatures in the combustion chamber (φ =375 deg. c.r.): a – Diesel cycle; b – HCCI engine*

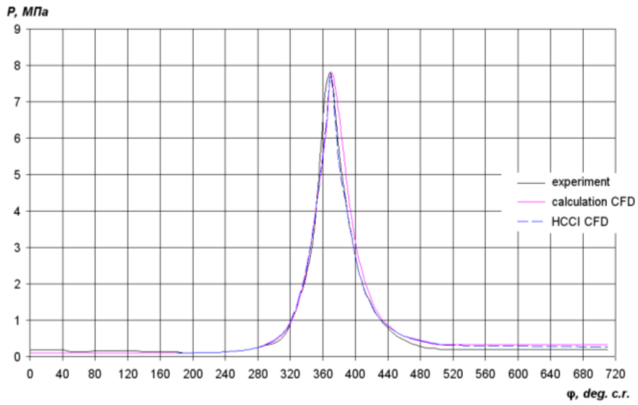
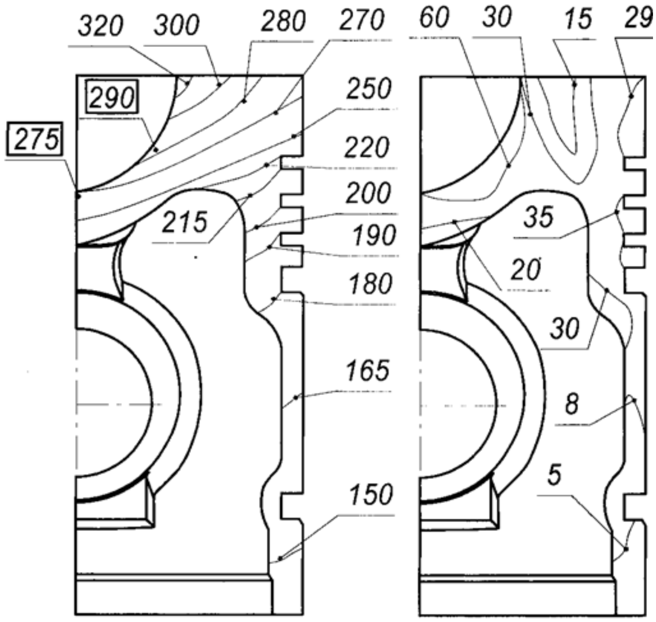


Fig. 3. *Comparison of indicator diagrams of engine 2 F 10,5/12 (rated power conditions at n = 1,800 min^{-1}, N_e = 18.4 kW)*

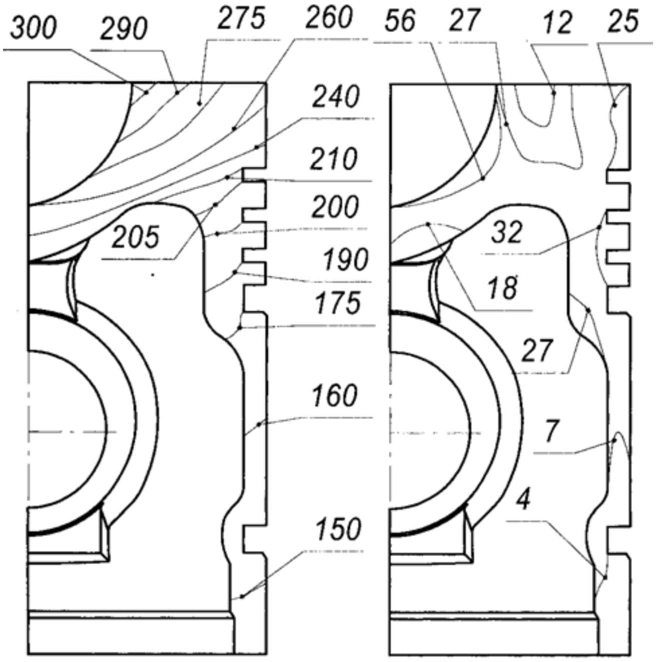
The results in Fig. 3 show that the design indicator diagram differs from the experimental one (averaged, with sampling of 120 cycles) in admissible limits, testifying to the correctness of the problem posed and validity of results. At rated power conditions, the maximum combustion pressure Pz (for experimental data) is 7.84 MPa, and that yielded by numerical modelling is 7.8 MPa.

The HCCI engine shows an insignificant pressure drop Pz = 7.7 MPa. This is attributed to the peculiarities of the processes of combustion of a homogenised air-and-fuel mixture.

The temperature fields and the fields of thermoelastic stresses in the piston of engine 2 F 10,5/12 for design variants: a, b – standard, c, d – HCCI engine, in the meridional section perpendicular to the piston pin axis are shown in Fig. 4.



a) b)



c) d)

Fig. 4. *Temperature fields (a – standard, c – HCCI engine), °C and fields of thermoelastic stresses (b – standard, d – HCCI engine), MPa in the piston of engine 2 F 10,5/12*

The rectangles show the results of thermal measurements in piston reference points. The results (Fig. 4 a) show that the piston temperature field of the piston was recreated with adequate accuracy. For the standard variant, the maximum piston temperature is 330 ºC near the combustion chamber edge in the piston (not shown in Fig.). Near the annular groove for the first compression ring, the temperature is within 220 ºC. Over the piston height, the temperature changes from 200 ºC to 150 ºC (Fig. 4 a). The thermoelastic stresses are 60 MPa in the piston combustion chamber, and over the piston height they change from 35 MPa to 5 MPa. An HCCI engine demonstrates an average piston temperature drop of 15-20 ºC (Fig. 4 c), with a positive effect on the level of thermoelastic stresses, which decrease by 3-5% (Fig. 4 d). Reducing the temperatures and thermoelastic stresses in the piston of an HCCI engine will facilitate piston operating conditions and have a positive effect on engine running as a whole.

5. Conclusions

The research conducted has demonstrated that the HCCI cycle offers the following benefits:

- Reduces the maximum local temperatures in the combustion chamber and the temperature gradients, on the average, by 15-20%;
- Reduces the maximum piston temperature in the fireside by 20 °C;
- Reduces thermoelastic stresses in the piston, on the average, by 5-7%. This increases the diesel engine boosting level without degrading the piston life indicators.

6. Literature

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