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NUMERICAL STUDIES ON MODELING THE TEMPERATURE STRESS-STRAIN STATE OF CYLINDER HEADS OF THE D49 DIESEL LOCOMOTIVE

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ABSTRACT

The article presents the results of numerical modeling of the stress-strain state under temperature effects on the cylinder heads of diesel locomotives; the numerical studies were carried out in the MATHCAD 15 programming environment.

ЧИСЛЕННЫЕ ИССЛЕДОВАНИЯ ПО МОДЕЛИРОВАНИЮ ТЕМПЕРАТУРНОГО НАПРЯЖЕННО-ДЕФОРМИРОВАННОГО СОСТОЯНИЯ КРЫШЕК ЦИЛИНДРОВ ТЕПЛОВОЗНОГО ДИЗЕЛЯ Д49

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ABSTRACT

В статье представлены результаты численного моделирования напряженно-деформированного состояния при температурных воздействиях на

Дизели тепловозов, головки цилиндров дизелей тепловозов, численное моделирование напряженно-деформированного состояния при температурных воздействиях на крышки цилиндров дизелей тепловозов, алгоритм, программа для среды программирования MATHCAD 15.

крышки цилиндров тепловозных дизелей, численные исследования проведены в среде программирования MATHCAD 15.

The cylinder head of a diesel locomotive engine is one of the most complex engine components. This is due to the fact that it performs several different functions: it closes the cylinder block's power circuit, ensures the required gas exchange parameters and the appropriate charge swirl level (which is essential in large engines), and transfers some heat from the combustion chamber to the cooling system. Therefore, improving calculation methods and performance evaluation criteria under conditions of increasing specific loads on the cylinder head of a diesel locomotive engine is of significant interest [1÷5].

The cylinder head of the D49 diesel engine is cast from alloyed cast iron with nodular graphite. It houses two inlet and two outlet valves and an injector [1,2]. The valves are made of heat-resistant steel. The temperature state of the cylinder head bottom according to thermometry data in the mode P_e = 1,2 MPa at an exhaust gas temperature t_r = 510°C is as follows: t_{max}= 315°C in the zone between the exhaust valves, at the periphery of the bottom the temperature decreases to 230°C. The maximum temperature gradient across the thickness of the cover of 70°C/cm characterizes the average level of bending stresses.

Studies have shown that with a 2.5-fold increase in P_e boost, the temperatures and thermal stresses of the bottom increase by 2 times. A 1 mm reduction in the bottom thickness causes a 15-20°C decrease in the temperature difference in boosted diesel engines [1,2,3,4,5]. In this regard, the thickness of the bottom of the D49 diesel engine covers is reduced by milling in the area of the exhaust valves and a 3 mm groove around the injector.

At a temperature difference of t = 100°C, the thermal stresses in the bridges of the cover connected to the suspended cylinder liner increased by 8÷27% compared to a cover unconnected to the cylinder liner. During diesel engine operation, even with careful adherence to water treatment regimes, scale deposits form on the bottom of the cover, leading to a significant increase in temperature (approximately 100÷150°C) and, consequently, to a thermal stress at the bottom of the covers. Methods for increasing the efficiency of cover cooling with increasing boost levels can be observed in a number of designs.

One of the most important aspects of modeling the stress-strain state (SSS) of a cylinder head is determining the boundary conditions, which can be separated into separate computational problems for estimating the cylinder head temperature field and fluid hydrodynamics in the cooling cavities.

The cylinder heads of diesel engines house the intake and exhaust valves, fuel injectors, and, together with the cylinder liner and piston crown, form the working volume of the cylinder. During diesel operation, the head experiences high pressure (up to 12 MPa) and high thermal stresses arising from uneven heating and the varying thicknesses of individual components. To reduce thermal stresses, the internal cavities of the head are water-cooled [1,2].

Diesel locomotive cylinder heads are typically cast from high-strength cast iron grade SCh24-44, with a specific pressure of no more than 80 MPa [1]. They contain channels for air flow to the intake valves, exhaust gas outlet, and cavities for cooling the bottom and exhaust tract.

To study the occurrence of mechanical stress in diesel locomotive cylinder heads due to heating, a finite-difference model in the MATHCAD 15 programming environment was used. The average gas temperature per cycle and the average total heat transfer coefficient α_Σ per cycle were used to study the temperature and mechanical stress fields. For example, the average fire surface temperature per cycle was between 300 and 350°C.

To solve the problem numerically, a piecewise linear approximation method is used in the MATHCAD 15 programming environment. The temperature-dependent variable values of heat capacity, heat transfer coefficient, and density of cylinder head components of diesel locomotives are, respectively, made constant for each selected fixed temperature value (every 1°C). Since all variable values are then made constant, the three-dimensional heat conduction equation in cylindrical coordinates r and z, according to [6,7], can be used to evaluate the patterns of temperature field change in the following form

$$\nabla^2 T - F(T)\cdot\frac{\partial T}{\partial t} = F_1(T)\cdot\Phi(r,t), \tag{1}$$

where indicated

$$\nabla^2 T = \frac{1}{r}\cdot\frac{\partial}{\partial t}\left(r\cdot\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\cdot\frac{\partial^2 T}{\partial\varphi^2} + \frac{\partial^2 T}{\partial Z^2}, \tag{2}$$

with the initial condition in the form

$$\mathrm{T}(r,\varphi,Z,0) = T_{cp\mathrm{H}}\,;\; 0 \le \varphi \le \varphi_{max}\,;\; 0 \le r \le \frac{D}{2} \tag{3}$$

and boundary conditions by analogy with the work [6,7].

Let us find the eigenfunctions for equation (2) using the Fourier method under the assumption $T = U(\varphi)\cdot V(Z)\cdot W(r)$, (4)

in the form of cylindrical harmonics of the form

$$T_{\pm Km}(r,\varphi,Z) = e^{\pm KZ}\cdot Z_m(Kr)\cdot(\alpha\cdot COS(m\varphi) + \beta\cdot SIN(m\varphi))\,, \tag{5}$$

$$T_{\pm K0}(r,\varphi,Z)=e^{\pm KZ_0}\cdot(Kr)\cdot(\alpha+\beta\cdot\varphi), \qquad (6)$$

$$T_{0m}(r,\varphi,Z)=(a+b\cdot Z)\cdot((A\cdot r^m+\frac{B}{r^m})\cdot(\alpha\cdot COS(m\varphi)+\beta\cdot SIN(m\varphi))$$

(7)

$$T_{00}(r,\varphi,Z)=(a+b\cdot Z)\cdot(A+B\cdot\ell n\cdot r)\cdot(\alpha+\beta\cdot\varphi), \qquad (8)$$

where $Z_m(\xi)$ is a cylindrical function; in particular, in our case, when the solution T is bounded for $r=0$, $Z_m(\xi)$ is the Bessel function of the first kind - $I_m(\xi)$.

As a result of the numerical solution, the system of three nonlinear equations of the form

$$\frac{d^2U(\varphi)}{d\varphi^2}+m^2\cdot U(\varphi)=0, \qquad (9)$$

$$\frac{d^2V(Z)}{dZ^2}-K^2\cdot V(Z)=0, \qquad (10)$$

$$\frac{d^2W(r)}{dr^2}+\frac{1}{r}\cdot\frac{d}{dr}W(r)+(k^2-\frac{m^2}{r^2})\cdot W(r)=0. \qquad (11)$$

The functions $F(T)$ and $F_1(T)$ in the nonlinear equation (1) are taken according to the experimental data obtained by the authors [3,4] and have the form:

$$F(T)=\frac{C_H(T)\cdot\rho_H(T)}{K_H(T)} \qquad (12)$$

$$F_1(T)=\frac{\alpha}{C_H(T)\cdot\rho_H(T)} \qquad (13)$$

where the designations $C_H(T)$, $K_H(T)$, $\rho_H(T)$ are introduced - variable values of heat capacity, thermal conductivity coefficient and density of the reinforcing lining, depending on temperature.

Figure 1 shows the compressive stress diagrams calculated for the cylinder head fire surface in the cross-section between the valves, caused by heating of the D49 diesel locomotive's cylinder head.

The following assumptions were made in the numerical calculation:

- head material – ductile iron; elastic modulus $E = 1,75\cdot105$ MPa; coefficient of linear expansion $\alpha = 1,15\cdot10^{-5}$ ºC; transverse deformation coefficient $\mu = 0,3$;
- temperature at the fire surface of the head bottom – 300ºC; at the cooled bottom surface – 90ºC; at the outer surfaces of the head – 50ºC.

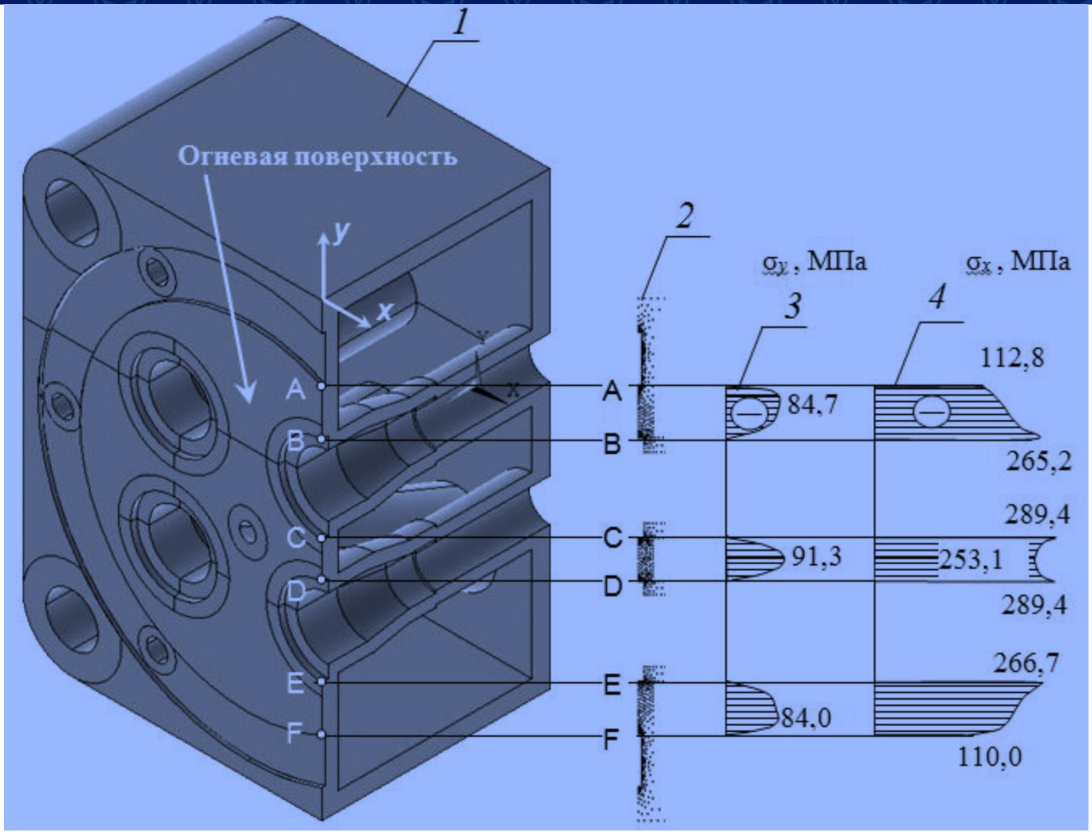

Figure 1. Stresses on the fire surface of the cylinder head bottom of the D49 diesel locomotive at a temperature of 3000°C:
1 - part of the cylinder head model cut off by a plane passing through the valves; 2 - finite element nodes in the bottom cross-section;
3, 4 - stress diagrams in the vertical and horizontal directions.

Figure 1 shows that the thermal stresses arising on the fire surface of the cylinder head bottom of the D49 diesel locomotive at a temperature of 300^{0}C are significantly higher than the stresses arising from mechanical action:

- stresses arising from mechanical action during bending and torsional vibrations of the interval bridge of the cylinder head of the 1A-5D49 diesel engine with pulsations of the steam gas pressure in the cylinder $q_P(X,Y)$ do not exceed $\sigma_{\text{MEX}} \ll$ 91,3 MPa;

- under thermal action on the fire surface of the cylinder head bottom at a temperature of 300^{0}C (Figure 1), stresses range from 110 MPa to 253,1 MPa for various points on the surface;

- in general, the total stresses σ_SUM on the fire surface of the cylinder head bottom at a temperature of 300^{0}C (Figure 1) range from 265,2 MPa to 289,4 MPa for different points on the surface.

This article develops a comprehensive numerical method for studying of the stress-strain state under temperature effects on the cylinder heads of diesel locomotives. We have developed a methodology for engineering calculations of the stress state of locomotive diesel cylinder heads under thermal and mechanical stress and vapor pressure pulsations in the cylinder, with the selection of rational parameters for rolling stock based on theoretical, experimental, and design work based on previously completed scientific research [8÷11].

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