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The influence of the engine load on value and temperature distribution in the piston of the turbocharged Diesel engine

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Analysis and modelling

ABSTRACT

Purpose: The determination of the temperature distribution in the piston in initial phase of the work of the turbocharged Diesel engine.
Design/methodology/approach: The results of calculations of the temperature distribution in the piston of the turbocharged Diesel engine in dependence from the engine loads were received by means of the two – zone combustion model and the finite element method.
Findings: The computations presented the possibility of use of the mathematical models of the combustion processes and the heat transfer on individual surfaces of the piston used by the variable values of the boundary conditions and temperature of the working medium in initial time of the work engine.
Research limitations/implications: The modeling of the heat loads was executed for analysis of the values and temperature distribution in the piston in initial phase of the work of the turbocharged Diesel engine until the moment of achievement quasi stabilized temperature values.
Originality/value: The results of numeric calculations of the heat loads of the piston displayed the possibility of the use of the original two-zone combustion model and finite elements method to analysis of values and temporary temperature distribution on individual surfaces of the piston.
Keywords: Numerical techniques; Heat loads; Piston; FEM

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1. Introduction

Modeling of the heat loads of the piston engine was conducted by use of III kind of the boundary conditions. These conditions describe the surface film conductance (Fig. 1) as well as the temperature of working medium. The temperature of the working medium (Fig. 2) was marked on basis of measured course of the indicated pressure (Fig. 3) by means of the two-zone of combustion process in the turbocharged Diesel engine [1-5]. The analysis of the heat loads in the piston engine for the engine speed n = 2000 [rpm] for two different engine loads which answered the excess air number $\lambda = 1.66$ as well as $\lambda = 3.08$ was carried out. The numeric computations were carried out by use of the finite element method (FEM) [6-7] in initial phase of the engine work from the moment when the temperature of the piston engine was equal the ambient temperature to the time in which the distribution of the temperature in the piston engine changed in small range. Further information about the material of the piston [8-10] and the heat loads of the other engine components can be found in ref. [11-16].

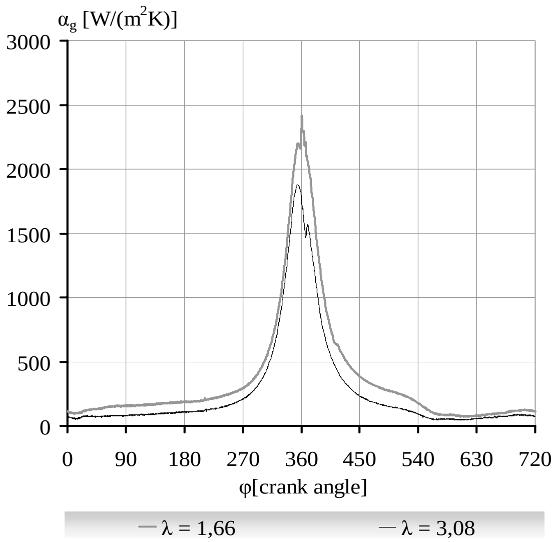

Fig. 1. The diagrams of total surface film conductance in function of crank angle for engine speed n = 2000 [rpm] and λ = 1.66 and λ = 3.08

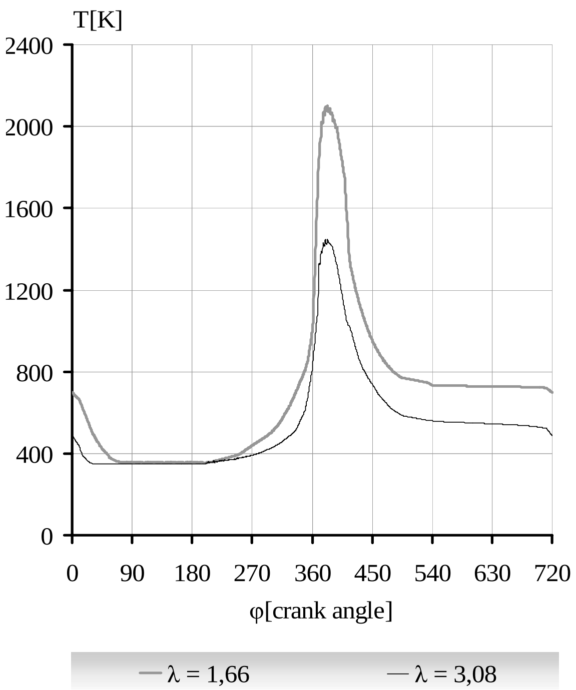

Fig. 2. The diagrams of the average temperature of the working medium for engine speed n=2000 [rpm] and λ = 1.66 and λ = 3.08

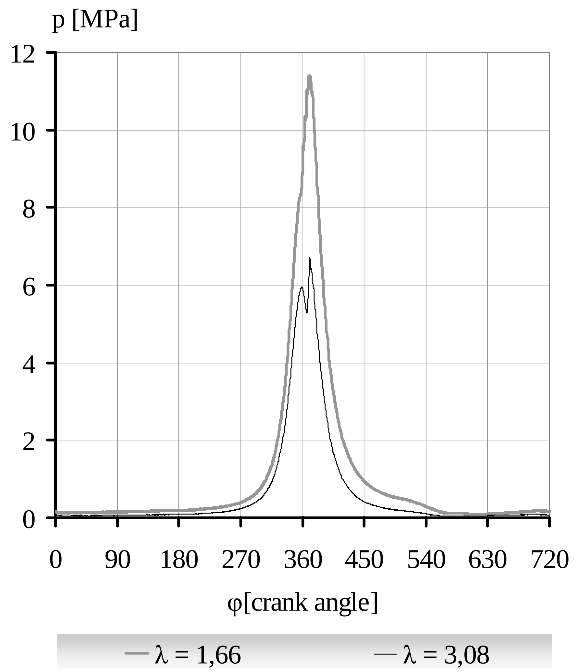

Fig. 3. The diagrams of the indicated pressure for the turbocharged Diesel engine about power rating N=85 [kW] and engine speed n=2000 [rpm] for λ = 1.66 and λ = 3.08

2. Geometrical model

The geometrical model of the piston (Fig. 4a) was executed with the help of the Geostar computer program COSMOS/M on basis of the real element (Fig. 4b). The order of his creating introduced as follows:

- was created the three-dimensional intersection of the piston engine;
- the intersection of the piston was divided with mesh of the finite elements;
- the mesh was based on the three-dimensional elements of tetrahedral solids (tetra 4) about 4 knots and dimensions 1.5 [mm].

a) b)

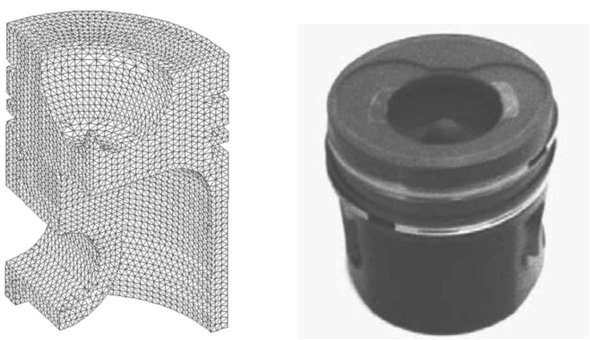

Fig. 4. The piston engine: a) discreet model, b) real element

3. Bonduary conditions

In the piston was distinguished 16 characteristic surfaces (Fig. 5) which the definite values of the III kind boundary conditions were attributed.

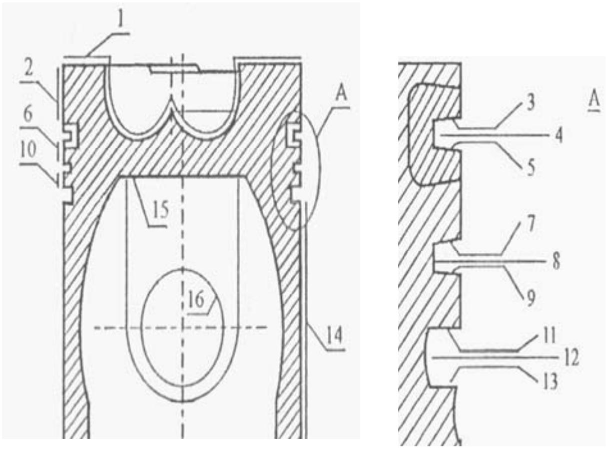

Fig. 5. Surfaces of the heat exchange of the piston; surface: 1 – piston head, 2 – flank piston over I ring, 3 – upper groove of I ring, 4 – bottom groove of I ring, 5 – under groove of I ring, 6 – between rings I-II, 7 – upper groove of II ring, 8 – bottom groove of II ring, 9 – under groove of II ring, 10 – between rings II-III, 11 – upper groove of III ring, 12 – bottom groove of III ring, 13 – under groove of III ring, 14 – skirt of the piston, 15 – internal of the piston, 16 – the point of contact of the piston pin with the piston engine

3.1. Surface of the piston head

In calculations whole surface of the piston head was accepted for equivalent heat conditions in combustion chamber engine for individual cycles its work:

$$\alpha_1(\varphi_i) = \alpha_g(\varphi_i) \quad \left[\frac{W}{m^2K}\right] \tag{1}$$

$$T_1(\varphi_i) = T(\varphi_i) \quad [K] \tag{2}$$

where:

$\alpha_g(\varphi_i)$ - coefficient of surface film conductance in crank angle function,

$T(\varphi_i)$ - temperature of engine working medium in crank angle function.

3.2. Surface side of the piston over I ring

However for side surface of piston the following conditions of the heat exchange were accepted [5]:

$$\alpha_2(\varphi_i) = \frac{1}{2}\alpha_g(\varphi_i) \quad \left[\frac{W}{m^2K}\right] \tag{3}$$

$$T_2(\varphi_i) = 0.8T(\varphi_i) \quad [K] \tag{4}$$

3.3. Upper surface of the groove of I, II, III ring

In case of upper surface of groove of I, II, III ring (3,7,11) the average substitute overall heat-transfer coefficient $\alpha_{z(3,7,11)}$ as well as temperature $T_{3,7,11}(\varphi_i)$ of medium surrounding the analyzed surfaces was accepted by work [2]:

$$\frac{1}{\alpha_{z(3,7,11)}} = \frac{1}{\alpha_{d(3,7,11)}} + \frac{l_{sr}}{\lambda_p} + \frac{1}{\alpha_{p\,tu}} \quad \left[\frac{m^2K}{W}\right] \tag{5}$$

$$T_{3,7,11}(\varphi_i) = T_x(\varphi_i) \quad [K] \tag{6}$$

where:

$\alpha_{z(3,7,11)}$ - average substitute overall heat- transfer coefficient in place of the contact of ring from upper surface of the groove,

$\alpha_{d(3,7,11)}$ - average coefficient of surface film conductance in place of the contact of ring from upper surface of the groove,

$\alpha_{p\,tu}$ - average coefficient of surface film conductance in the place of contact of the ring from the cylinder liner of the engine [6],

l_{sr} - the average road of the heat stream from the surface of the groove of the ring to the cylinder liner,

λ_p - coefficient thermal conductance of the ring,

$T_x(\varphi_i)$ - temperature of the internal surface of the cylinder liner represented the individual positions of the piston in function of crank angle engine.

3.4. Bottom surfaces of the groove of I, II, III ring

From regard on the gap among internal surface of I, II, III ring and the surface the bottom of groove (4,8,12) the heat exchange is very low on these surfaces. In calculations was assumed the fault of heat exchange from these surfaces (adiabate) [2].

$$\alpha_4 = \alpha_8 = \alpha_{12} = 0 \quad \left[\frac{W}{m^2K}\right] \tag{7}$$

$$T_{4,8,12}(\varphi_i) = T_x(\varphi_i) \quad [K] \tag{8}$$

3.5. Under surfaces of the groove of I, II, III ring

For under surface of the groove of I, II, III ring (5, 9, 13) the average substitute overall heat-transfer coefficient $\alpha_{z(5,9,13)}$ and temperature $T_{5,9,13}(\varphi_i)$ of medium surrounding the analyzed surfaces was accepted by work [2]:

$$\frac{1}{\alpha_{z(5,9,13)}}=\frac{1}{\alpha_{d(5,9,13)}}+\frac{l_{sr}}{\lambda_p}+\frac{1}{\alpha_{p\,tu}}\quad\left[\frac{m^2K}{W}\right] \tag{9}$$

$$T_{5,9,13}(\varphi_i)=T_x(\varphi_i)\quad[K] \tag{10}$$

where:

$\alpha_{z(5,9,13)}$ - average substitute overall heat- transfer coefficient in the place of contact of the ring from under surface of the groove,

$\alpha_{d(3,7,11)}$ - average coefficient of surface film conductance in the place of contact of the ring from under surface of the groove.

3.6. Flank surfaces between rings of the piston

For the flank surfaces between rings of the piston (6,10) as well as the leading surface (14) the coefficient of surface film conductance $\alpha_{6,10,14}(\varphi_i)$ and individual temperatures of medium surrounding the analyzed surfaces was described as follows [4,5,6]:

$$\alpha_{6,10,14}(\varphi_i)=\frac{\alpha_1(\varphi_i)}{3}\quad\left[\frac{W}{m^2K}\right] \tag{11}$$

$$T_6(\varphi_i)=0{,}665T_2(\varphi_i)\quad[K] \tag{12}$$

$$T_{10}(\varphi_i)=0{,}69T_2(\varphi_i)\quad[K] \tag{13}$$

$$T_{14}=348\quad[K] \tag{14}$$

3.7. Internal surface of the piston

However for internal surface of the piston following averages conditions of the heat exchange were accepted [2]:

$$\alpha_{15}=(60-90)\quad\left[\frac{W}{m^2K}\right] \tag{15}$$

$$T_{15}=(333-363)\quad[K] \tag{16}$$

3.8. Surface of point of contact of the piston pin with the engine piston

In case of the heat exchange of surface point of contact the pin from the piston the boundary conditions α_{16} and T_{16} were described by means of the following equations [2]:

$$\frac{1}{\alpha_{16}}=\frac{1}{\alpha_{ts}}+\frac{l_{st}}{\lambda_{sw}}+\frac{l_{sk}}{\lambda_{sw}}+\frac{1}{\alpha_{sp}}+ +\frac{1}{\alpha_{pk}}+\frac{s_p}{\lambda_p}+\frac{s_k}{\lambda_k}+\frac{1}{\alpha_{15}}\quad\left[\frac{m^2K}{W}\right] \tag{17}$$

$$T_{16}=(333-363)\quad[K] \tag{18}$$

where:

$\alpha_{ts}=\alpha_{sp}=\alpha_{pk}$ - average coefficient of surface film conductance in place of contact the piston pin; the piston pin – bearing bush, the bearing bush – connecting rod,

$\lambda_{sw},\lambda_p,\lambda_k$ - heat conductivity of the piston pin, the bearing bush and the connecting rod material,

S_p, S_k - thickness of wall of the bearing bush of the piston pin and the head connecting rod.

4. Calculations results

The comparative distributions of temperatures for two different engine loads on the surface of the piston head during 10, 20, 30, 40, 50 as well as 60 [s] the work of engine in Figures 6, 7 were introduced. However the diagrams of the maximum temperature which appear on the piston head as well as the minimum temperature on the surface of the skirt piston and the average temperature for the excess air number λ = 1.66 and λ = 3.08 were presented in Figures 8 and 9.

The comparison of the increase speed of the temperature of the piston head as well as course of maximum temperatures was introduced in Figures 10 and 11. In Figure 10 - “S” was appointed the increase speed of the temperature on the piston head [K / s].

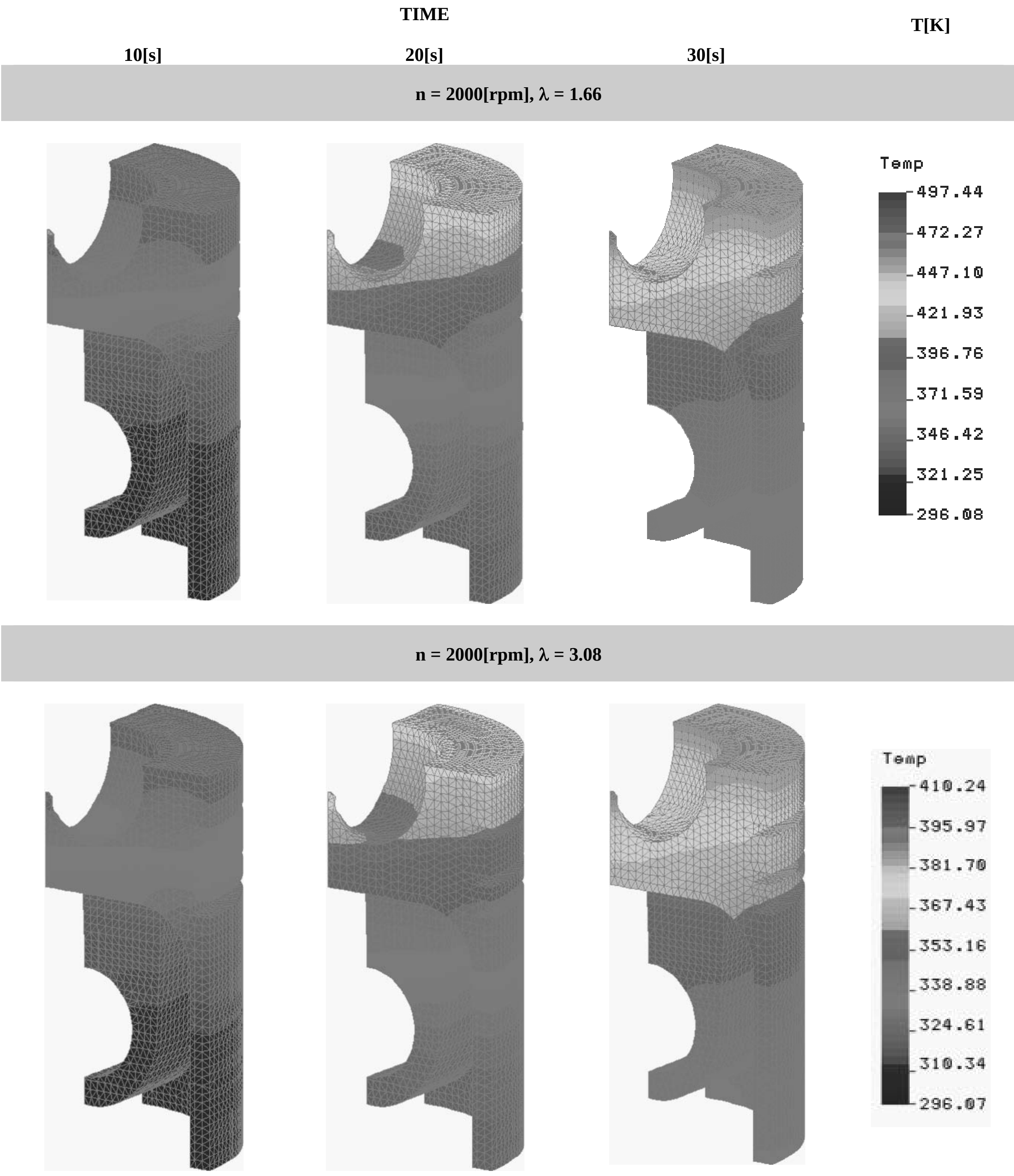

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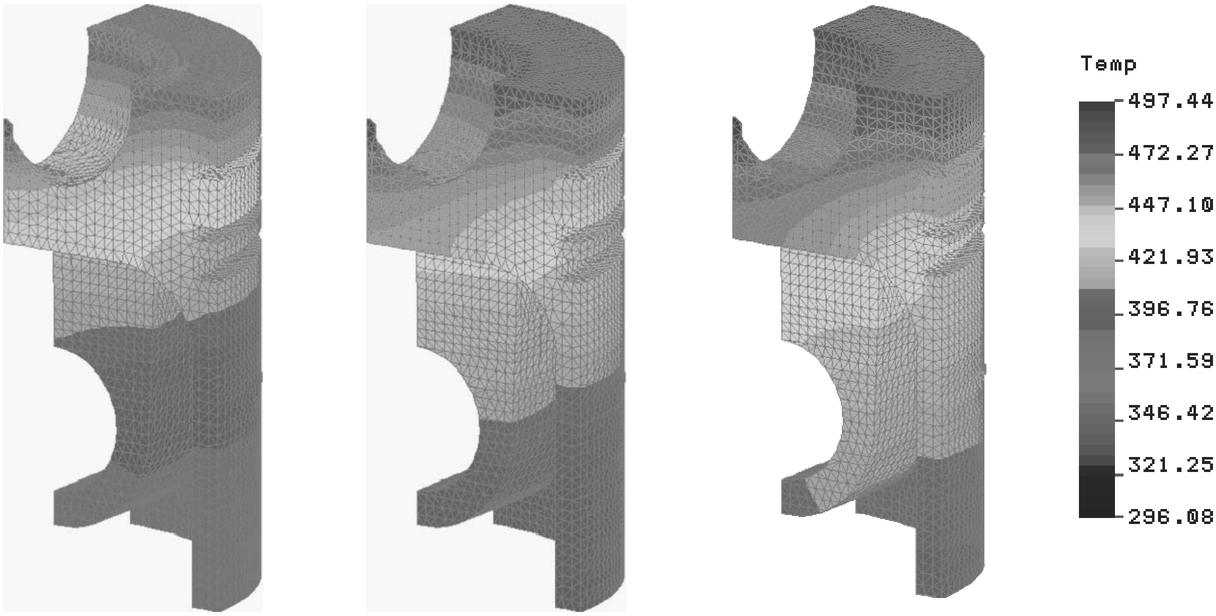
Fig. 6. The following phases warming up of the piston engine

T[K]

TIME

40[s]	50[s]	60[s]

n = 2000[rpm], λ = 1.66



n = 2000[rpm], λ = 3.08

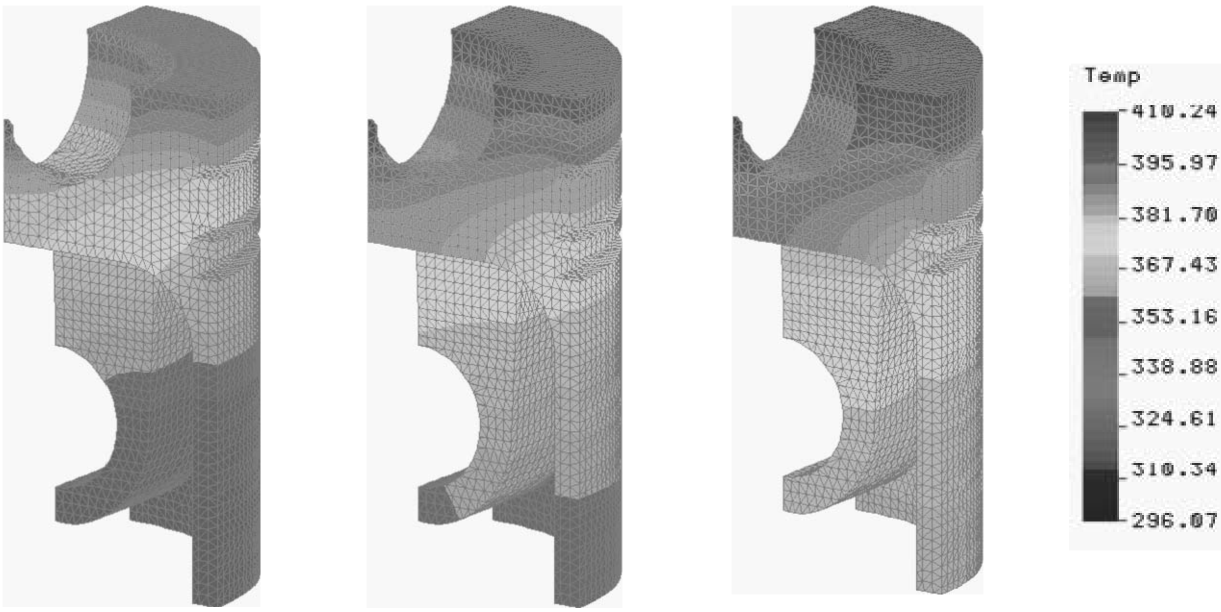


Fig. 7. The following phases warming up of the piston engine

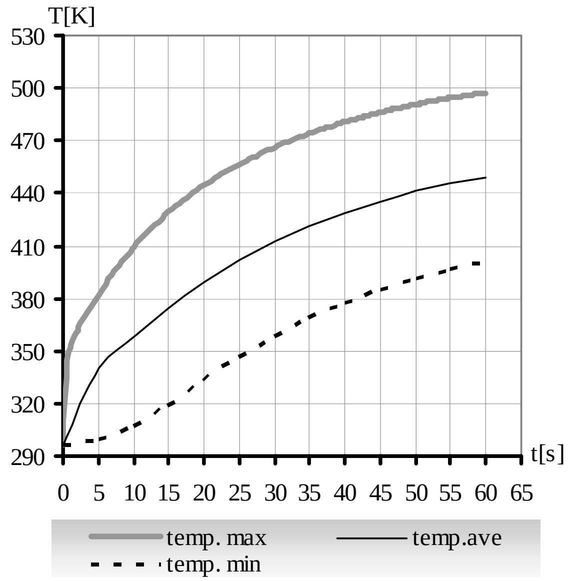


Fig. 8. The diagrams of the maximum, average and minimum values of temperatures of the piston for the λ = 1.66 during 60 seconds of the engine work

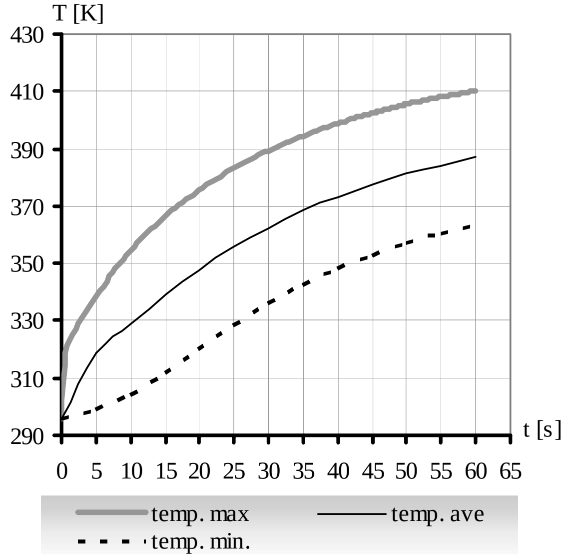


Fig. 9. The diagrams of the maximum, average and minimum values of temperatures of the piston for the λ = 3.08 during 60 seconds of the engine work

The diagram (Fig. 10) shows that the piston head most quickly warms in first 10 seconds. Together from outflow of time the speed of warming diminishes and aims to 0. The average value of the increase speed of the temperature since 0 to 10[s] carries out: 12 [K / s] for λ = 1.66 as well as 6 [K / s] for λ = 3.08.

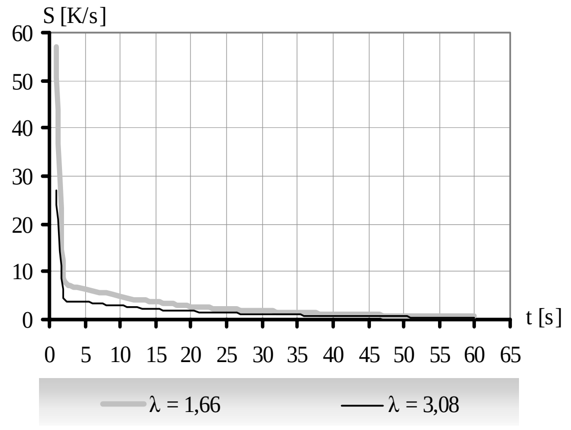


Fig. 10. The speed of the increase temperature of the piston head for two loads of engine during 60 seconds of its work

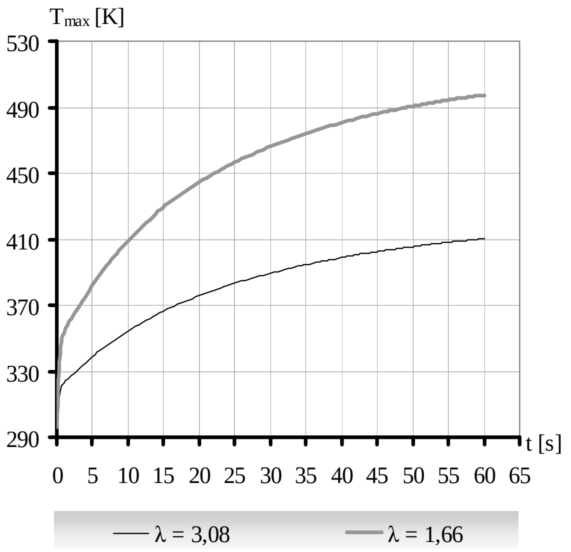


Fig. 11. The comparison of courses of maximum temperature for two loads of engine

The diagram (Fig. 11) presents that the maximum temperatures of the head of the piston for larger of load of the engine are higher in whole the time compartment. In 60 second of work of the engine the difference of temperatures carries out 87 [K]. In the time of warming up of the piston the temperatures were stabilized.

5. Summary

On the base of the performed numeric computations and diagrams it is possible deduce that the increase of the load in turbocharged Diesel engine causes the change of value and temperature distribution on the surface of the piston engine. For almost of double increase of the engine load the temperature of the combustion chamber and the edge of the piston, the most strongly warming up of the piston components, was enlarged about 17%. The heat most intensely flows from the surface of the piston head and the flank side above the compression rings into the deep of the piston material. For the largest of the heat load of the piston the temperature gradient carries out in approximation 2 [K/mm]. The most intensive warming up of the piston is visible during the first ten seconds of the engine work.

The conducted analysis doesn't permit fully to qualify the heat load of this engine element from regard on short time the carried out computations however give any picture about of the temperature distribution on its individual surfaces. Moreover the correctness of conducted calculations requires on the real piston of the turbo diesel engine use of the verifying researches which will be the object of more far investigations of authors

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