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Research paper

Temperature Deformation of Cylinder-Piston Group Parts of Uprated Diesels and Gas Engines for Kamaz Vehicles

D.A. Nikitin, G.D. Mezhetsky, A.S. Denisov *, V.N. Baskov *, V.V. Chekmarev

FSBEI of Higher Education "N.I. Vavilov Saratov State Agricultural University", Russia, 410012, Saratov, Teatralnaya sq. 1. Tel .: (845-2) 23-32-92, E- mail: nilppr@rambler.ru

**FSBEI of Higher Education "Yu. A. Gagarin Saratov State Technical University", Russia, 410054, Saratov, Politekhnicheskaya str., 77.*

Abstract

The paper describes the effect of temperature on the deformation of cylinder-piston group parts of uprated diesel engines and gas engines of the KAMAZ family. Based on the 3-D model with the use of the finite element method, the hypothesis proposed by the authors on the necessity to change a number of limiting dimensions of the cylinder-piston group parts is confirmed. The purpose is to ensure their performance at elevated temperatures in comparison with the basic engines. It is also shown that the design model is adequate to the actual operating conditions of the engines under consideration.

Keywords: *Cylinder piston group, piston ring, internal combustion engine, temperature deformation.*

1. Introduction

At present, there is a general tendency in engine building to increase the specific power of internal combustion engines (ICE), which is achieved by their uprating. One of the well-known and widely used methods of uprating is the use of turbo-supercharging [1]. In particular, for engines of the KAMAZ family, the engine power has been increased from 210 hp by means of uprating in the model 740.10 up to 440 hp in the model 740.75.440. At the same time, the cooling system of those engines did not undergo serious changes, what led to an increase in the thermal stress of the cylinder-piston group (CPG) parts [2 - 9].

In addition, in accordance with the global trend for the use of alternative fuel sources, many engine manufacturers, including KAMAZ, have mastered the production of gas engines (with respect to PAO KAMAZ - engine family 82.60). Taking into account that the combustion temperature of gas fuel is 2040 °C (instead of 1600 °C for diesel fuel), this also significantly affects the thermally stressed state of the cylinder-piston group parts.

As a result of these trends in the process of engine operation, failures caused by elevated temperatures under extreme operating conditions and previously uncommon to KAMAZ engines such as surface melting of pistons, burnout of exhaust valves, presence of deposits on pistons and cylinder head bottoms (Fig.1) begin to appear.


a)


(b)


(c)

Fig .(1). Previously atypical manifestations of faults in the KAMAZ family engines:
a - surface melting of pistons; b - burnout of discharge channels; c - deposits on pistons

These manifestations of failure clearly indicate the breakthrough of the working fluid into crankcases of the engines, what may result from the loss of sealing function by piston rings under the influence of an elevated temperature [10-14].

2. Materials and Methods of Research

When modeling the temperature deformations of the cylinder-piston group parts, 3D models of the main the cylinder-piston

group parts with the assembly model were constructed by the authors using the system of three-dimensional modeling KOMPAS 3-D, certified in the GOST-R system. Computing of temperature fields and deformations caused by them were performed by the finite element method using the ANSYS library. When dividing into finite elements (FEs), the authors have used a nonuniform grid with 4-node tetrahedrons and an element side of 1.5 mm, a fine grid factor of 5, and a coarse grid factor of 1.5.
A hypothesis was put forward at the initial stage of the research, in the analysis of the current situation. According to it, an abnormal performance of gas engines and uprated diesel engines under extreme operating conditions is due to the loss of serviceability of the piston rings (primarily the upper one) due to the temperature deformation caused by the increased operating temperature. This hypothesis is based on the fact that in the analysis of the upper compression rings of the engines operated, it showed: they all have a "hardening" in their lock, what indicates that thermal gap there is insufficient to compensate for the temperature deformation of the cylinder-piston group parts.
In addition, the analysis of the results of measuring the shape of the upper compression rings after operation showed that they have kinks caused by deformations that go beyond the plastic ones in the □□□□□□□□□□temperature□zone. This can be explained only by the insufficiency of the thermal gap value to compensate for the temperature deformation of the cylinder-piston group parts (Fig. 2).

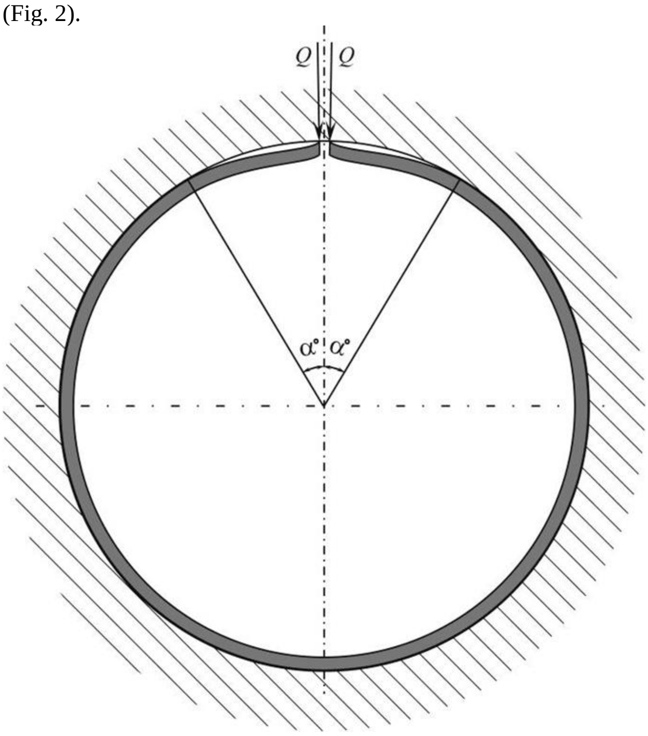

Fig .(2). Piston ring deformation model

The role of the computed determination of the temperature fields in the cylinder-piston group parts is particularly significant for engines with high average cycle indicator pressures. The reason is that the large heat flux densities that arise in this case can lead to local overheating and unacceptably high temperature gradients in the heat-stressed parts.
To assess the thermal state of the parts, it is necessary to have not average values of the heat flow densities per cycle for a given surface, but local values.
The general formulation of the temperature field problem in the cylinder-piston group part is as follows: let an elementary surface *dF* having the temperature T_W is flushed with a liquid which temperature is T_f, and $T_W > T_f$.
Under steady-state conditions, the temperature distribution in the body under consideration is described by the Laplace equation:

$$\frac{d^2T_W}{dx^2} + \frac{d^2T_W}{dy^2} + \frac{d^2T_W}{dz^2}, \qquad (1)$$

Where: T_W is current body temperature; x, y and z are the spatial coordinates, respectively.
To ensure the uniqueness of solution for the equation (1), it is necessary to specify the boundary conditions. There are several ways to set them.
T h e f i r s t m e t h o d (boundary conditions of the first kind) comes down to setting temperatures on the body surface. However, the surface temperature of a part is the required value, and it is impossible to determine it under the existing conditions. Therefore, setting the boundary conditions of the first kind for us is not possible.
T h e s e c o n d method (the boundary conditions of the 2nd kind) comes down to determination of the heat flux density *passing* through the body surface.
In the practice of calculating the temperature fields of the cylinder-piston group parts inside internal combustion engines, specifying boundary conditions of the second kind is as difficult as setting boundary conditions of the first kind. The thermal current density is a function of many parameters. It depends both on the conditions of heat exchange of the body surface and on its thermal resistance.
Accordingly, the temperature of cylinder-piston group parts is predetermined according to the first method based on the available data on KAMAZ 740.11-240 diesel engines in open information sources, taking into account the uprating degree for KAMAZ-740.354-450, KAMAZ-740.-50-360 and KAMAZ-740.14-300 diesels, and for the gas engine KAMAZ-820.73-300 - also taking into account the fact that the combustion temperature of the gas fuel is 2040 ° C (instead of 1600 ° C for diesel fuel).
In order to test the hypothesis, the authors carried out a preliminary computation of the strains in a sleeve and an upper piston ring at the maximum temperature loads. In this case, the sleeve temperature was adopted on the basis of thermometry carried out under experimental operation conditions.
During the research, a stationary thermal analysis was performed, which allows finding the system response (temperature deformations) to the steady-state thermal load.
In this case, the following equation was solved by the finite element method:

$$[C(T)]\{\dot{T}\} + [K(T)]\{T\} = \{Q(t,T)\} \qquad (2)$$

Where: t is the time, {T} is the temperature field, [C] is the specific heat matrix, [K] is the thermal conductivity matrix, {Q} is the heat generation rate vector in the system.
Calculations were carried out for a quasi-stationary (steady-state) thermal regime.

3. Results of Analytical Studies

In order to confirm (or reject) the hypothesis put forward, a computation was made for the most unfavorable combination of the dimensions of a sleeve, a cylinder block and an upper piston ring (the smallest diameter of the sleeve surface in the cylinder block, the largest limiting diameter of the upper setting rib of the sleeve and the smallest thermal gap size in an upper piston ring).
Figure 3 shows a graphical interpretation of temperature deformations in the sleeve.

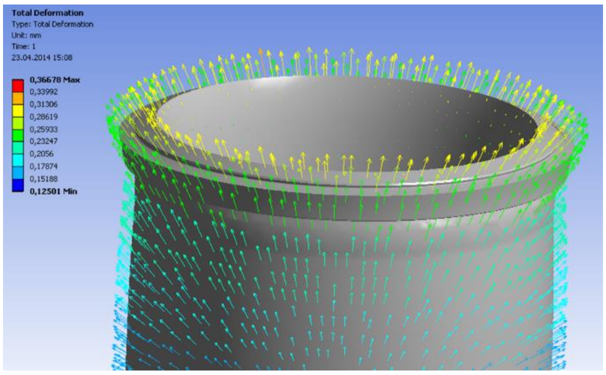

Fig .(3). Temperature deformation of the upper part of the sleeve.

As can be seen from this figure, when a sleeve is heated, its size increases, and this cannot lead to abnormal performance of the cylinder-piston group. However, this is true for a sleeve that is out of contact with the mating parts. Fig. 4 shows the deformation of the sleeve placed in the cylinder block.

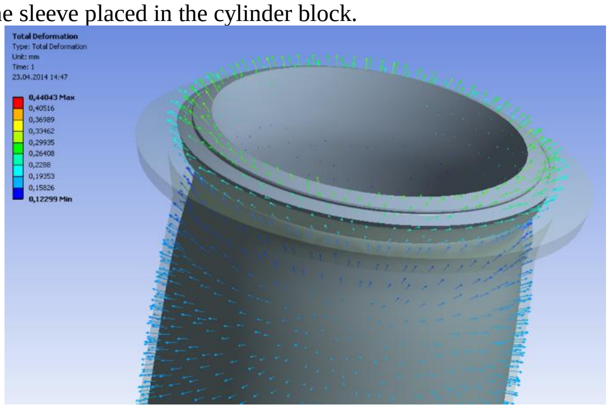

Fig .(4). Temperature deformation of the upper part of the sleeve placed in the cylinder block.

As can be seen from the presented figure, the effect of "bondage" over the setting rib is clearly represented, which does not allow the sleeve to expand freely and can cause a " joint " in the thermal gap of the upper piston ring.

Fig. 5 shows deformation of the ring in the top dead center position. As can be seen from this figure, indeed, as predicted in the proposed hypothesis, the temperature regime of the engine causes deformation of the cylinder-piston group parts that lead to the appearance of a "joint" in the thermal gap of the upper piston ring. This phenomenon leads to plastic (irreversible) deformation of a piston ring. This breaks the defined geometry and, consequently, the conformability, what disrupts the performance of the cylinder-piston group, at least in part of sealing of the cavities in the combustion chamber and in the crankcase.
The result is increased oil consumption through burning and phenomena associated with the breakthrough of gases.
It should be noted that the combination of the limiting sizes used in the presented calculation is unlikely.

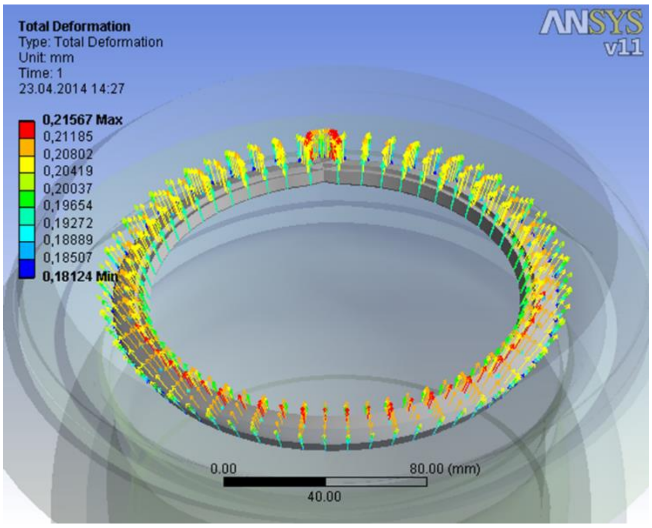

Fig .(5). Deformations in an upper piston ring.

In order to test the assumption of influence of the "bondage" effect in the interface "setting rib of the sleeve - cylinder block", a similar calculation was carried out for a sleeve and a ring not mated with the cylinder block. The calculation was carried out at the same temperatures. The results are shown in Fig. 6.
Analysis of this figure allows us to conclude that there is a significant influence of the "bondage" effect in the interfacing "setting rib of the sleeve - cylinder block". Therefore, in order to ensure the efficiency of the cylinder piston group under unfavorable temperature conditions, it is necessary to optimize the fit in the interfacing "setting rib of the sleeve - cylinder block" in such a way that there is no interference with the temperature expansion of the parts in the coupling.

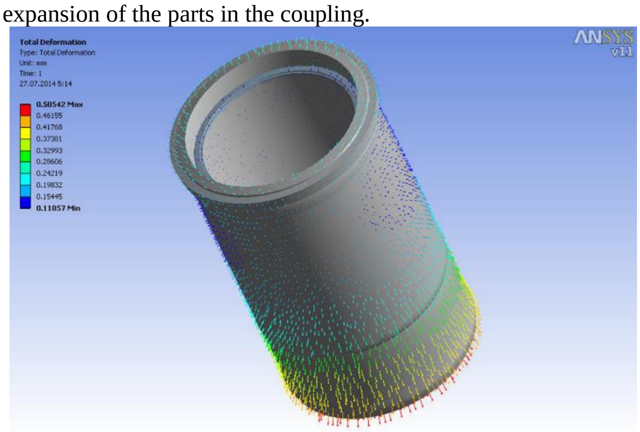

Fig .(5). Deformations of rings and sleeves caused by temperature

4. Discussion of the Results

As it was suggested by the hypothesis put forward by the authors, the results of the research showed that failures atypical for the KAMAZ family engines, visual manifestations of which are surface melting of pistons, burning-through of exhaust valves, and the presence of deposits on pistons and cylinder head bottoms, may be caused by elevated temperatures under extreme operating conditions in high-powered and gas engines. The reason is a more severe temperature regime.
In order to finalize the calculation results, increase the reliability of the boundary conditions and confirm the proposed model of gas breakthrough, oil consumption and deformation of the upper piston ring, and also for the formulation of final recommendations, it is necessary to conduct additional tests of engines with thermometry of cylinder sleeves. In spite of this, it is possible to recommend to the manufacturer to change the parameters of fitting a sleeve in a cylinder block in the region of the upper

setting rib. In existing engines this fit has the following parameters:

$$\varnothing 137{,}5^{+0{,}040}_{\substack{-0{,}050 \\ -0{,}090}}$$

i.e. the minimum possible clearance should be 0.05 mm. Given that the deformation of the sleeve in this region reaches 0.16 mm, it is obvious that they need to increase the minimum gap in the junction up to 0.2 mm.

Conflict of Interest

The authors confirm that the presented data do not involve a conflict of interest.

Acknowledgments

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