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Strength Analysis of the Internal Combustion Engine Elements by Using CAD/CAE-Systems

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Abstract: Internal Combustion Engine (ICE) working processes modeling method by using CAD/CAE Software is presented. Matters of gas dynamic and heat process modeling in 4-stroke engine by using ANSYS Fluent and ANSYS Steady-State Thermal Software which allows receiving main thermodynamic parameters fields are discussed. Especial attention is paid on the strength analysis method as well as its settings for solving of the task which are connected with internal combustion engine designing.

Key words: Internal combustion engine, ICE, ANSYS fluent, steady-state thermal, CAD/CAE Software, 3D model, mesh, gas dynamic calculation, thermal condition calculation, strength analysis

INTRODUCTION

Purpose of this research is a determination accuracy improvement of the loads which act on ICE Crank mechanism details by taking into account working cycle gas dynamic and thermal parameters non-uniformity. To accomplish this task, it is necessary to solve several problems:

- Numerical estimate of the gas temperature and pressure impact on crank mechanism elements in ANSYS fluent and ANSYS steady-state thermal
- Development of the Crank Mechanism Numerical Model for strength analysis based on acquired data

This task was accomplished by computer modeling based on finite elements method in the SolidWorks, ANSYS static structural, ANSYS steady-state thermal and ANSYS fluent.

Originality of this research is combined calculation method development with taking into account working cycle parameters (gas dynamics and heat transfer in cylinder) non-uniformity and design strength analysis.

Described method is suited for early stages project design optimization which in turn decreases output product cost, helps design departments to cut new product development cycle and minimizesthe amount of full-scale tests. This study contains:

- Gas dynamics calculation method for combustion chamber
- Thermal condition calculation method for Crank mechanism
- Strength analysis method for Crank mechanism

3D MODEL COMPOSITION OF THE CRANK MECHANISM ELEMENTS

3D model composition was made in the SolidWorks CAD Software. 3D model includes models of piston, wrist, connecting rod, connecting rod cap, hub and Crank shaft. After that assembling of elements was accomplished and its preparation for calculation (Ryazanov, 2014; Melentjev and Gvozdev, 2014) (Fig. 1).

ANSYS WORKBENCH PLATFORM

Numerical model calculation was carried out on the base of the ANSYS Workbench platform by using ANSYS fluent, ANSYS steady-state thermal and ANSYS static structural.

Fig. 1: 3D model of Crank mechanism

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The calculation was carried out in three stages. In the first stage, gas dynamic analysis of the combustion chamber was carried out in ANSYSFluent. In the second stage, piston thermal conditions was calculated for validation its operation in high temperature conditions. This calculation was carried out in the ANSYS steady-state thermal. Acquired temperature and pressure values were transferred to ANSYS static structural as boundary conditions. Results of the strength analysis which was carried out in the ANSYS static structural are equivalent stresses and factors of safety of the Crank mechanism.

GAS DYNAMIC PROCESSES MODELING IN THE INTERNAL COMBUSTION ENGINE CYLINDER

Preliminary created Mesh Model of the ICE combustion chamber volume was automatically loaded to the ANSYS fluent for gas dynamic processes calculation.

Unsteady modeling method with taking into account turbulence was selected for this task solving. Because of task complexity k-ε Turbulence Model was used. Energy equation was added for taking into account heat transfer. n-octane-airmixture was selected for combustion process modeling (Bochkarev *et al.*, 1993; Volobuev and Tolstonogov, 1997, 1987). The results of the calculation are thermal and pressure fields in the combustion chamber (Fig. 2).

The pressure maximum in the cylinder reached 6.21 MPa. Mean values of the combustion chamber volume are combustion pressure which is equal to 6.18 MPa and temperature at the end of combustion process which in turn equal to 2514 K. Acquired pressure data was transferred to ANSYS static structural for strength analysis as boundary condition (Biryuk *et al.*, 2014; Makaryants *et al.*, 2013; Shabliy *et al.*, 2014; Krivcov *et al.*, 2014).

PISTON THERMAL CONDITION CALCULATION DURING ENGINE'S OPERATION IN THE ANSYS STEADY-STATE THERMAL

Piston is the one of the most important parts of the ICE. It is affected by high mechanical and especially heat loads. During operation piston directly contacts incandescent gas and intensively absorbs heat from it. Heat dissipation from piston is difficult and directed to a cylinder wall through cylinder rings and particularly to the oil which is contained in the crank case (Falaleev and Vinogradov, 2006; Kuz'michev *et al.*, 2006).

For solving the thermal condition calculation task models of piston, wrist, cylinder rings and cylinder linerwas used. Meshing and setting of corresponded interfaces was carried out.

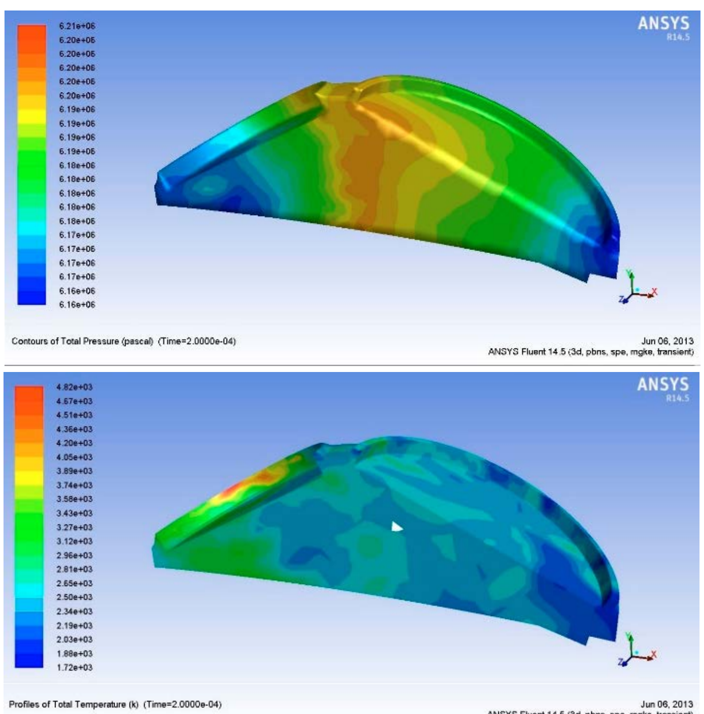

Fig. 2: Pressure and temperature distribution in combustion chamber

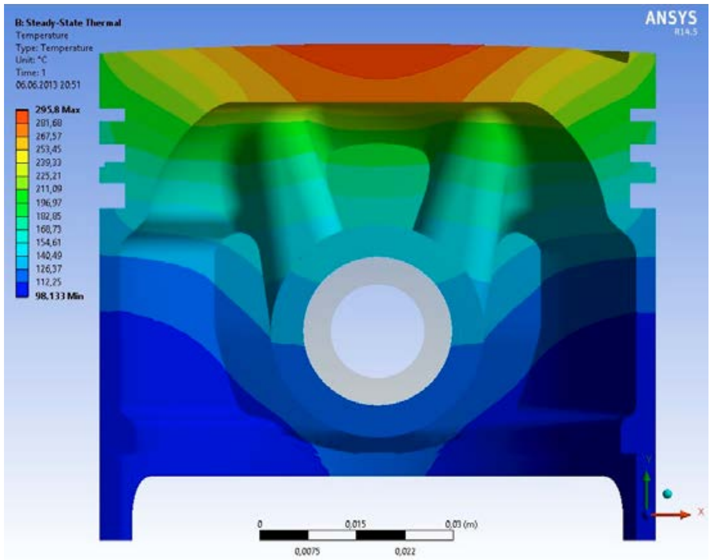

Fig. 3: Temperature distribution of piston

Heat transfer coefficient α and temperature T was selected as boundary conditions. Total heat transfer between piston top and gas is characterized by mean heat transfer coefficient α and final cycle temperature. These data was determined during calculation by ANSYS Fluent Software and was used as boundary condition on the top of piston during the calculation in the ANSYS steady-state thermal:

$$T_{mean} = 1063°C,\ \alpha_{mean} = 650\ W/m^2.°C$$

Piston thermal condition calculation in the engine steady state mode involves determination of its thermal field. Temperature of the first piston ring groove and piston top are accepted as standards of performance.

Groove temperature must not exceed 220°C and the piston top temperature must not exceed 350°C. Calculation results in piston temperature field (Fig. 3).

Maximum temperature of the piston is 296°C and first piston ring groove temperature is 200°C. Standards of performance are fulfilled. This thermal field was transferred to ANSYS static structural as boundary condition for strength analysis.

CRANK MECHANISM ELEMENTS STRENGTH ANALYSIS IN THE ANSYS STATIC STRUCTURAL

After completion of the gas dynamic and thermal condition calculations the next stage was accomplished in the ANSYS static structural.

For every element of the crank mechanism material with corresponding parameterswas selected, interfaces was set and meshing was carried out.

Calculation was carried out on the engine's mode with the heaviest conditions which includes maximum momentum of 3200 rpm when gas pressure in the cylinder reaches its maximum. This value was transferred from gas dynamic analysis which was carried out in the ANSYS Fluent Software and equal to 6.2 MPa when crank angle is equal to 10° after top dead centre (Popov *et al*., 2014a, b).

ANSYS Workbench platform allows transferring data from one calculation to another which allows evaluating the construction more accurate without parameters averaging. Gas pressure on the top of the piston was transferred from gas dynamic calculation to ANSYS static structural (Ivanushkin and Kolomin, 2014). Also, it allows seeing applied force direction and its value. Gas force spread visualization is shown in Fig. 4.

From preliminary completed thermal condition calculation in the ANSYS steady-state thermal heat loads data was transferred to strength analysis for calculation of the nonuniformly heated piston which is situated in elastic state (Table 1).

Crank shaft neck is fixed from displacement and rotation by contact surface of the cylinder with connecting rod bush.

After calculation completion stress and safety factor fields was displayed for every element of the model (Fig. 5).

Stress analysis shows that stress values of the every element are lower than its material yield point. As it can be seen all elements satisfy safety factor requirements. Entire model safety factor is selected as the lowest safety factor of all elements and equal to 2.16.

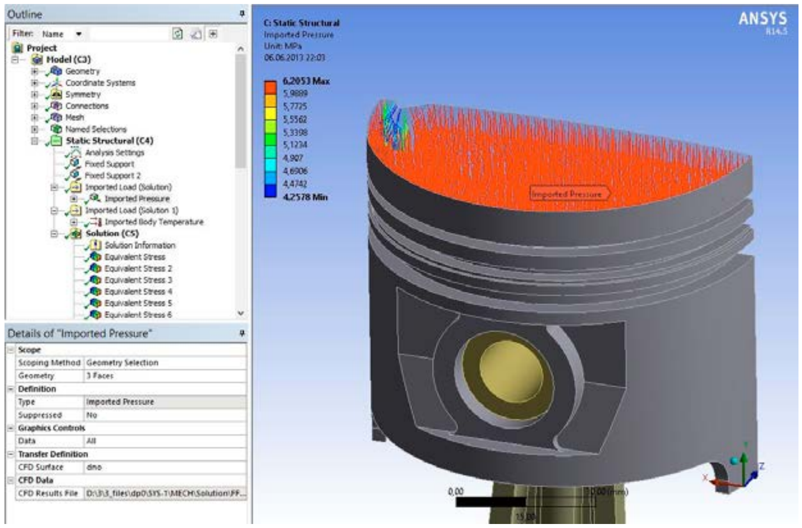

Fig. 4: Gas force epure

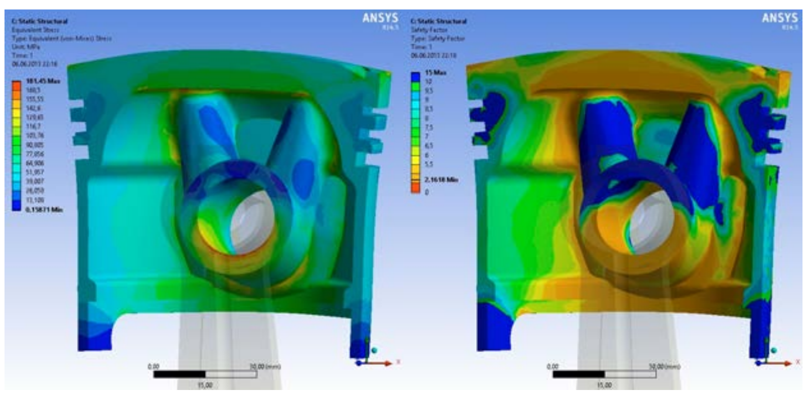

Fig. 5: Stress and safety factor fields of piston

Table 1: Calculation results

Elements	Stress (MPa)	Safety factor	Deformation (mm)
Piston	181	2.16	0.210
Wrist	295/77.2	3.4 /3	0.160
Hub	262	2.2	0.100
Connecting rod	337	2.9	0.100
Connecting rod bush	128	4.5	0.014
Crank	59	12.1	0.012

CONCLUSION

The results of this work are next:

- 3D model of the sleeve assembly is created
- Gas dynamics calculation method for combustion chamber is developed
- Thermal condition calculation method for Crank mechanism is developed
- Strength analysis method for crank mechanism is developed

Gas dynamic analysis shows that combustion chamber temperature at the end of combustion process is equal to 2514 K, pressure value reaches 6.18 MPa. Thermal condition analysis shows that piston temperature value during operation reaches 296°C, first piston ring groove temperature is not exceed 220°C. Standards of performance are fulfilled. Stress analysis shows that stress values of the every element are lower than its material yield point. As it can be seen all elements satisfy safety factor requirements. Entire model safety factor is selected as the lowest safety factor of all elements and equal to 2.16.

Using of these calculation methods allows receiving more accurate data by execution of the joint tasks which exception of the intermediate parameters averaging. This in turn decreases an amount of the full-scale testing which in turn decreases engine development cost and time.

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