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TEMPERATURE FIELD OF SPARK PLUG IN THE SI ENGINE

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Abstract: *Spark plug is one of the most thermal loaded component in the cylinder of the SI (spark ignition) engine. The most exposed parts of the spark plug are the lowest part of the housing, centre and ground electrodes, which are inside of combustion chamber. The article shows the calculating field of temperature on spark plug and explains direct measuring of temperatures at spark plug housing. Process of calculating field of temperature on the spark plug through calibrated model was made for confirming efficiency of spark plugs housing design modifications of and the development of spark plug with integrated ignition chamber.*

Keywords: Spark Plug, Thermal Stress, Heat Flow, Thermal Field.

1. Introduction

The all walls of combustion space in the cylinder engine are affected by heat transfer from cylinder charge. The temperature field in the material of wall from the surfaces in the cylinder determines next to the heat flow (which has a decisive influence and in different locations of engine cylinder is different) and heat conduction in the wall material and the heat transfer from the outer side wall to another heat transfer environment (coolant, the other walls material, ...).

Mechanism of heat transfer into the walls of combustion chamber depends on several factors which influence appears from essential of molecular-kinetic gas theory or their variability in the procedure of power cycle of SI engine. Heat flow into to walls of combustion chamber in the engine (cylinder, piston, cylinder head etc.) is defined by Newton's equation:

$$\dot{Q}_S = \alpha_p \cdot S \cdot \left(T_p - T_s\right), \qquad (1)$$

where α_p is heat transfer coefficient, S is heat transfer surface, T_p is temperature of cylinder charge and T_s is temperature of the surface. The knowledge of heat transfer coefficient is very essential request for heat flow calculation. Heat transfer coefficient depends on lot of factors but most on the actual condition of cylinder charge (pressure, temperature, velocity of the fluid). The research tasks (theoretical, experimental) focused on solving of functional dependence of design and work conditions of heat transfer coefficient in cylinder of the engine are still actual and results into more accurate calculations.

One of the most uses the equation for calculation of heat transfer coefficient in cylinder of the engine is empiric Eichelberger's equation (year 1939). Equation for SI units:

$$\alpha_p = 2{,}485 \cdot \sqrt[3]{Z \cdot n} \cdot \sqrt{p \cdot T}\,. \qquad (2)$$

α_p [W m^{-2} K^{-1}], piston stroke Z [m], n engine revolutions [min^{-1}], p [MPa] a T [K] are immediate pressure and immediate temperature of cylinder charge. In the 1960s Woschni published the results of research work about heat transfer coefficient defined by characteristic numbers (Woschni, 1967). Calculation was based on description of heat transfer inside of tube with turbulent flow. Research works on the combustion engines in late 1990s (modern measuring and computational technique) allowed to get new knowledge which led to more accurate results of empiric equations for heat transfer coefficient and was

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more closer to values in the real engine. Newest empiric equation for heat transfer coefficient defined by Bargende (1990) is based on detailed explanation of condition in close proximity of walls (based on so-called wall function describes thermal boundary layer and different evaluations in cases of unburned mixture and burned gases). All equations referred above contains some differences (for each one different) of functional dependence of heat transfer coefficient in the engine depends on pressure and temperature of cylinder charge. Comparison of functional dependence of α_p according to various equations is on Fig. 1. Significant differences in values of heat transfer coefficient according to various equations are in the area of burning (particularly at Bargende's equation which includes the consequence of burned gas).

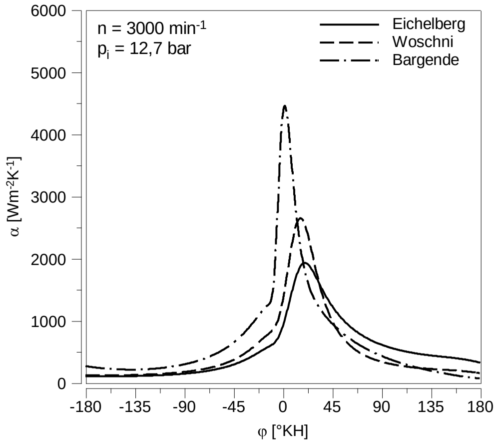


Fig. 1: Function of heat transfer coefficient calculated by various equations for vehicle atmospheric combustion engine.

2. Computational Model

Individual parts of computational model were based on description of thermal-mechanical process in cylinder of the engine. The basic is made by function dependence of gas pressure and temperature during operating cycle in cylinder of the engine for specific rating of the engine. Calculating of gas pressure and temperature was made in simple software which is long term used at workplace of authors. Result of calculating gas pressure and temperature is shown at Fig. 2.

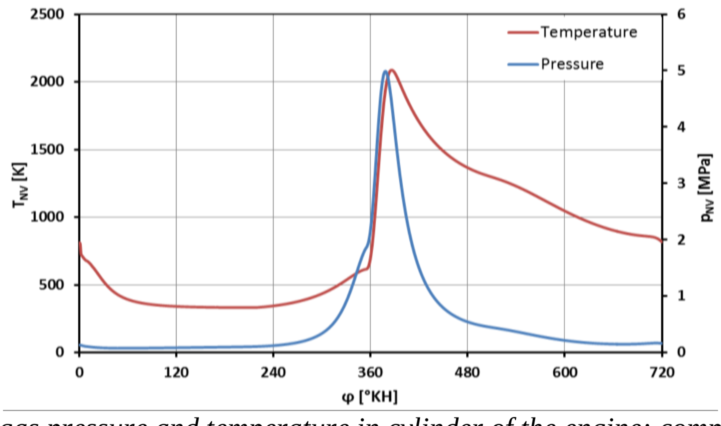
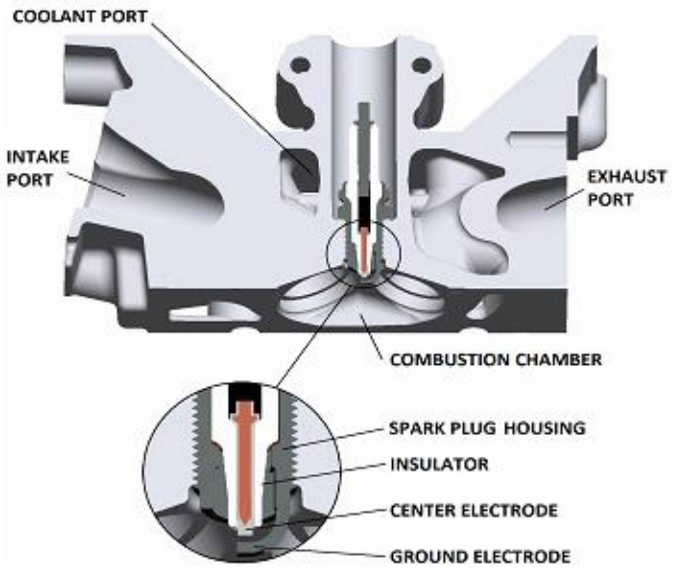


Fig. 2: Function of gas pressure and temperature in cylinder of the engine: computational model is verified by measured pressure cycle in cylinder (high pressure indication).

According to calculated function of gas pressure and temperature in cylinder of the engine have been calculated heat transfer coefficient according of Eichelberg equation. In the next step were computed dimensions of heat transfer surfaces which affect to thermal field of spark plug (cylinder head, lowest part of spark plugs housing, insulator, and center and ground electrode). Also was calculated heat flow into surfaces, for specific rating of the engine, referred above (heat flow for cylinder head and intake exhaust or cooling ports was made by same way).

Field of temperature was modelled by software Pro/ENGINEER Wildfire 4.0 in unit for finite elements method analysis called Pro/MECHANICA. Models of cylinder head and all parts of spark plug were created due to drawing documentation. Model respects the material aspect and attributes of each used part. On the all heat transfer surfaces of cylinder head and spark plug was used boundary condition of heat load named "HEAT LAOD". Heat flow values for heat transfer surfaces of cylinder head and spark plug was computed for n = 5000 min^{-1} a 100% engine load (Chiodi & Bargende, 2001).



Mesh of elements was generated by "AutoGEM" generator, in lowest part of spark plugs housing was used thickening of mesh for higher result precision (for mesh was used elements "tetra" with maximum size of element 1 mm for lowest part of housing should be presented as follows).

Fig. 3: Surfaces for boundary conditions.

Computed result of field of temperature in required spots was compared with result of direct measuring of temperatures on the housing of spark plug. Computational model was calibrated with correcting coefficient *K* (reference to Eichelberg equation), which changes values of heat flow into cylinder head and spark plug, to gain acceptable accordance with measured results.

3. Measuring Temperature of Spark Plugs Housing

In the spark plugs housing were drilled 2 holes of diameter 0.45 mm and depth until 0.45 mm from bottom of housing to put jacketed micro thermocouple (Ø 0.25 mm). One measured spot is above a welded ground electrode and the other one is on the opposite side of the housing. Third measured spot is at seat surface on outer spark plugs gasket. The scheme of measuring spark plug housing and results measured at engines speed characteristic shown at Fig. 4.

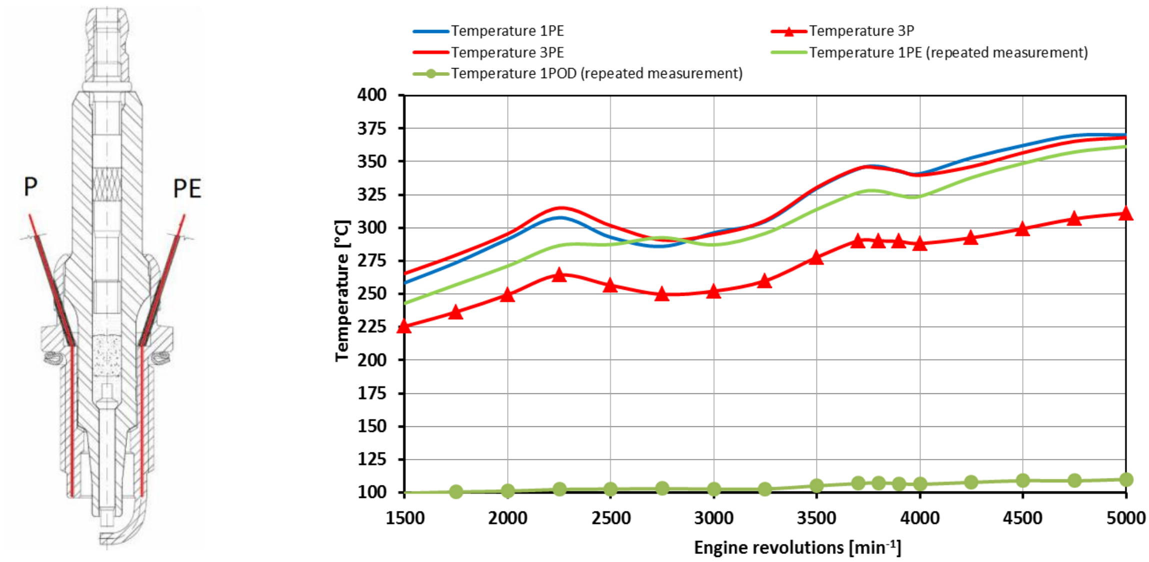


Fig. 4: Measuring spark plug with micro thermocouple inside of housing and results of measurement. For calibration were used measured temperatures at n = 5000 rpm and 100% engine load.

Note: Drilling of very small and depth holes into spark plugs housing was made by company SHD Zahrádky. Assembly of spark plug was made with cooperation of company BRISK Tábor. Assembly of micro thermocouple into holes with diameter 0.45 mm is made by using of thin walled pipes.

4. Calculating Field of Temperature for Spark Plug

Field of temperature on spark plug after calibration is shown at Fig. 5. To gain acceptable accordance with measured results in required spots was used correcting coefficient $K = 1.4$.

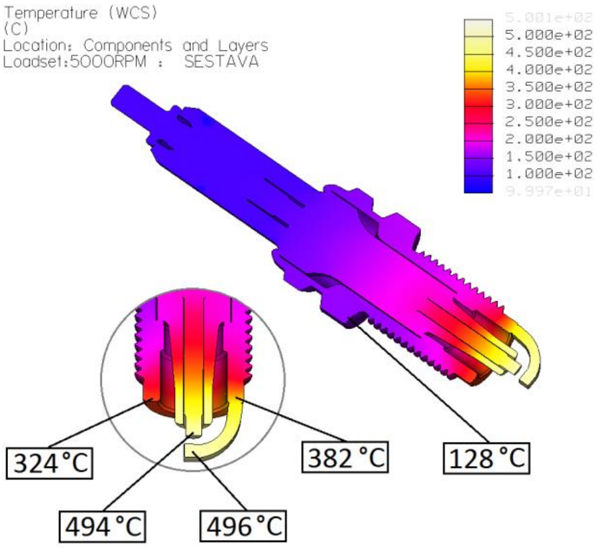


Fig. 5: Result of computed modelling of spark plugs temperature field.

Beside of knowledge of temperatures at lowest part of spark plug housing is very significant fact, that quite simple computational model is able to provide reliable results of temperatures at lowest part of spark plugs housing. The experiences from calculating of model or technically difficult measurement of temperatures of spark plug housing are very valuable for development of spark plug with integrated ignition chamber.

5. Conclusions

The results performed research works show the ability to solve the complicated problems by acceptable combination theoretic, computational and experimental procedures, which are found on reasonable simplification. Experimental program on spark plug with integrated ignition chamber cellule includes all procedures, which have been checked on classical spark plug.

All experimental works they are realized on a vehicle SI engine in Laboratory of driving units at Institute for nonmaterial, advanced technology and innovation on Technical University of Liberec. The results of research works contain first of all the criteria for complex evaluation (energy, power, emission and operation parameters) of the engine using the mixtures ignition by the spark plug with integrated ignition chamber. The investigation of the thermal load of new spark plug design (with ignition chamber, integrated to the housing of spark plug) has responsible position in this research works from standpoint of the functional reliability and durability of new spark plug design.

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