NUMERICAL OPTIMIZATION
OF THE IGNITION ANGLE OF SI ENGINE

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Summary. The paper presents the results of numerical optimization of ignition advance angle of the modernized test engine Andoria 1hc102 using AVL FIRE software. Modelling allows to find the optimal ignition advance angle of the test engine during the combustion of fuel mixture with an excess air factor $\lambda = 1.2$. The optimum value of the ignition angle was that which occurred at the maximum indicated pressure and indicated efficiency, and for which there was no combustion knock. Modelling results show that the test engine powered by the mixture of $\lambda = 1.2$, should work with the ignition advance angle equal to 10 deg before TDC.

At this ignition advance angle a knock occurred in the engine and it reached the indicated pressure and the indicated efficiency was equal to, respectively, 0.99 MPa and 41.47%.

Key words: internal combustion engine, modelling, ignition advance angle, indicated pressure, indicated efficiency.

INTRODUCTION

During recent years the numerical modelling research using more and more advanced mathematical models has been intensively developing. The development of numerical modelling is heightened by increasing computational power that allows modelling not only of flow processes but also combustion in 3D [1, 2, 3]. One of the more advanced numerical models used for combustion process in piston engines modelling is AVL FIRE [4]. In 2009 Institute of Internal Combustion Engines and Control Engineering at Częstochowa University of Technology began University Partnership Program with AVL Company and started using AVL FIRE software for modelling of the thermal cycle of IC engines [5,6,7].

The AVL FIRE software belongs to modern programs which are used for modelling of the thermal cycle of internal combustion engines. FIRE allows modelling flow and thermal processes occur in the intake manifold, in combustion chamber of IC engine and exhaust pipe with a catalyst and a particulate filter. This programme enables the calculation of transport phenomena, mixing, ignition and turbulent combustion in internal combustion engine. Homogeneous and not homogeneous combustion mixtures in spark ignition and compression ignition engine can also be modelled using this software. Kinetics of chemical reactions phenomena is described by combustion models

which take oxidation processes in high temperature into consideration. Several models apply to auto ignition processes. AVL FIRE allows for the modelling of the knock process which occurs in the combustion chamber of IC engine. This program allows for the creation of three-dimensional computational greed, characterized by boundary conditions of surfaces and initial conditions of simulation. The postprocessor makes it possible to visualize the results.

This paper presents results of numerical optimization of ignition advance angle in the modernized test engine Andoria 1hc102 using AVL FIRE software, during the combustion of fuel mixture with excess air factor $\lambda = 1.2$. The optimum value of the angle was that which occurred at the maximum indicated pressure p_i and indicated efficiency η_i, and for which there was no combustion knock.

The combustion knock is a type of abnormal combustion process, characterized by intensive pressure pulses in the engine combustion chamber. The knock is a type of abnormal combustion process, characterized by intense pressure pulsations in the combustion chamber, which are transferred to the block engine, generate a distinctive sound and could lead to engine damage. The source of combustion knock is auto-ignition of unburnt gases before the flame front (initiated by a spark plug) after a big increase in temperature and pressure [13, 15, 18, 19].

NUMERICAL MODEL

The test engine was constructed on the basis of a four-stroke compression-ignition engine 1hc102 manufactured by "ANDORIA" Diesel Engine Manufacturers of Andrychow. After some constructional changes, this engine was redesigned for the combustion of gasoline as a spark-ignition engine. For this reason, the engine was equipped with a new fuel supply system and an ignition installation. As a result of modernization the shape of the combustion chamber was changed and the compression ratio was reduced from 17 to 8.5. The engine is a stationary, two-valve unit with a horizontal cylinder configuration. The engine cooling system is the evaporation of the water jacket. Figure 1 shows the experimental modernized test engine Andoria 1hc102. On the basis of the real dimensions of the experimental engine, the three-dimensional mesh of combustion chamber of engine was built (Fig. 2).

Tab.1. The main engine parameters

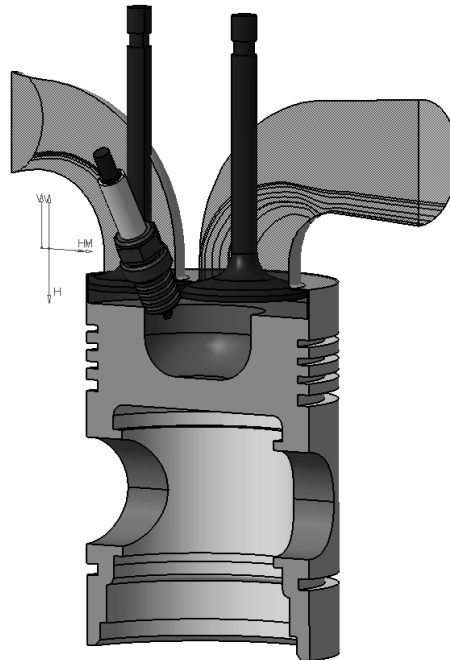| bore cylinder	100 mm
stroke piston	120 mm
connecting rod length	216 mm
direction of cylinders	horizontal
squish	11 mm
compression ratio	8.5
engine speed	1.5e+3 rpm
number of cylinders	1

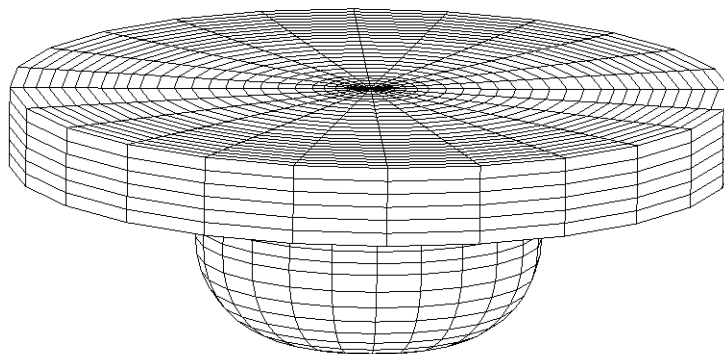Fig. 1. Experimental engine

Fig. 2. Geometric grid of combustion chamber
of model engine in TDC

COURSE OF CALCULATIONS

The calculation started at BDC at the beginning of compression stroke and finished at 360 deg since the end of engine power stroke. At the beginning of compression stroke, the lean mixture of excess air factor equal to 1.2 was in the chamber.

The modelling of combustion process was conducted for a range of ignition advance angle from 38 to 8 deg of crank angle before TDC in order to optimize the thermal cycle of the test engine. On the basis of the pressure data indicated pressure and indicated efficiency were calculated. They did not include many losses both in the combustion process and flow losses or blows. Using AVL FIRE software the computational analysis was conducted of the potential combustion knock.

Tab. 2. Chosen input parameters of the modelled process

ignition advance angle	8 ÷ 36 deg
ignition duration	10 deg
fuel	gasoline
temperature fuel injection	320 K
initial pressure	0.85e+5 Pa
initial temperature	365 K
excess air factor	1.2
density	1.19 kg/m^3
turbulence kinetic energy (180 deg before TDC)	0,1 J/m^3
turbulence length scale (180 deg before TDC)	1,12 cm

One of the parameters determining the performance of the combustion engine is the indicated pressure.

$$p_i = \frac{\sum_{180}^{540} \frac{p_n + p_{n+1}}{2}(V_{n+1} - V_n)}{V_s}, \tag{1}$$

where: p_n, p_{n+1} are instantaneous values of the pressure in the cylinder [MPa], V_n, V_{n+1} are instantaneous values of the cylinder volume [m^3], V_s is displacement volume [m^3].

The average value of the indicated efficiency, expressed in % is equal to:

$$\eta_i = \frac{p_i V_s}{Q} 100\%, \tag{2}$$

where: Q is the total heat supplied to the engine [MJ].

The heat supplied to the engine cylinder:

$$Q = \frac{V \rho W}{0.5 n t}, \tag{3}$$

where: V is volume of gasoline delivered to the engine cylinder [m^3], ρ is density of gasoline [kg/m^3], W is calorific value of gasoline [MJ/kg], n is speed engine [rpm], t is time consumption of gasoline delivered to the engine cylinder [min].

RESULTS OF CALCULATION

As a result of modelling the pressure courses were obtained as a function of crank angle for the whole analyzed range of the ignition advance angle (Fig. 3).
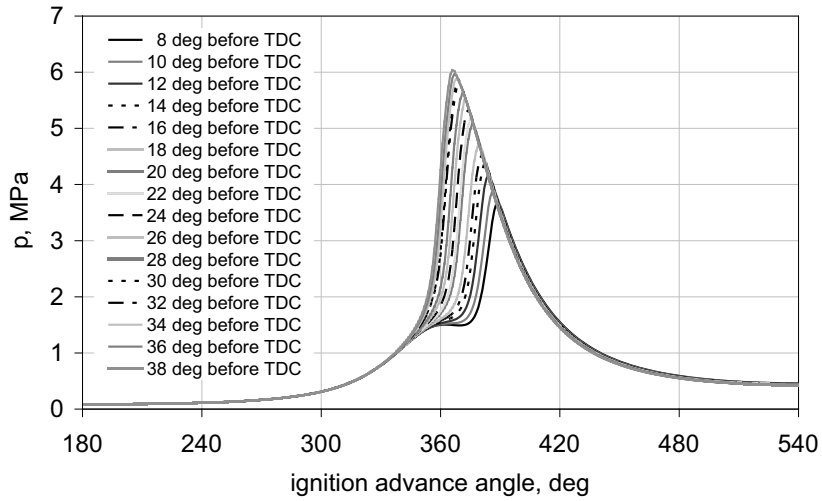
Fig. 3. Courses of pressure for the analyzed range of the ignition advance angle

Figure 4 shows the indication parameters of the engine model calculated on the basis of pressures.
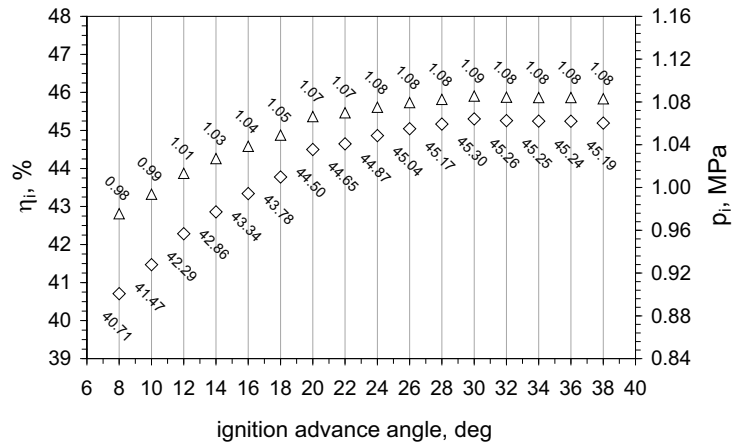

Fig. 4. The value of indicated pressure and indicated efficiency
for the analyzed range of the ignition advance angle

Figures 5 to 7 show the temperature distribution and location of the knock in the combustion chamber of test engine.
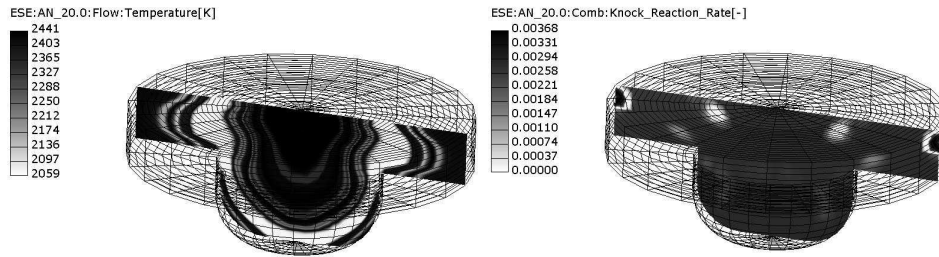

Fig. 5. Temperature distribution and location of the knock in combustion chamber
of model engine at 20 deg after TDC for ignition advance angle equal to 30 deg before TDC

Fig. 6. Temperature distribution and location of the knock in combustion chamber
of model engine at 52 deg after TDC for ignition advance angle equal to 12 deg before TDC
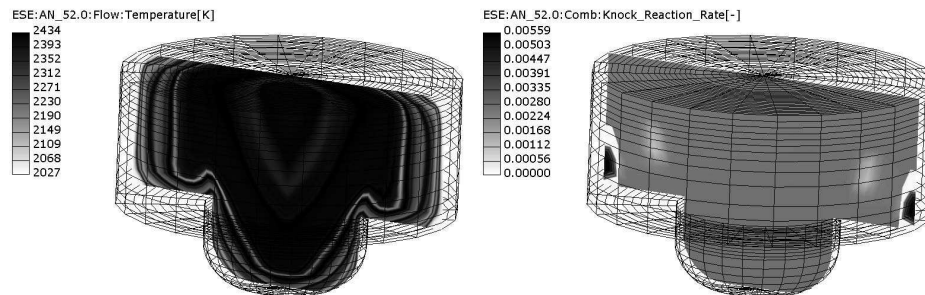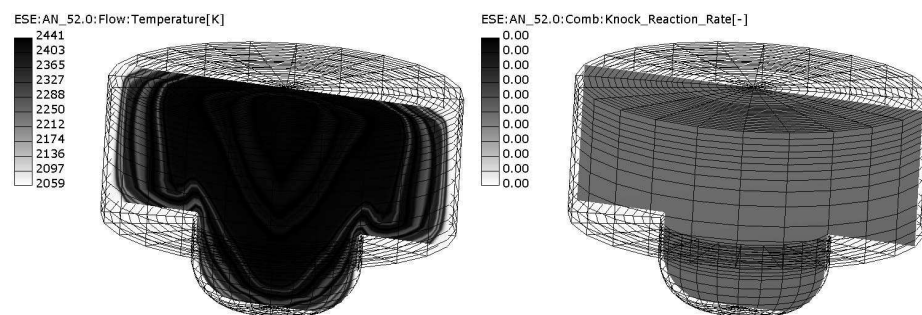

Fig. 7. Temperature distribution and location of the knock in combustion chamber
of model engine at 52 deg after TDC for ignition advance angle equal to 10 deg before TDC

The obtained results of modelling show that the angle of 30 deg before TDC is the most suitable ignition advance angle for the engine parameters. For this ignition angle the maximum indicated pressure achieved is 1.09 MPa and the highest indicated efficiency is 45.3%. Unfortunately, the consequence of using such a large ignition advance in the test engine causes the creation of combustion knock. The knock combustion process occurred also at smaller advance angles, at 12

deg before TDC. For this engine, the combustion process occurs normally to the ignition angle equal to10 deg before TDC. For the ignition angles larger than 10 deg BTDC knock occurs in the engine.

CONCLUSIONS

AVL FIRE program is a modern research tool that can be successfully used to model the thermal cycle of the internal combustion engine. The AVL FIRE up-to-date numerical code used during research made it possible to generate 3D geometric mesh of combustion chambers of the test engine and allowed to perform numerical calculations of processes occurring in this engine. Conducted simulations of combustion process have delivered information concerning spatial and time-dependent pressure and temperature distribution in the combustion chamber. This information would be extremely difficult to obtain by experimental methods. The ability to detect knock in the cylinder can identify the real engine operating parameters at the optimum settings. In the paper, using AVL Fire the optimal value of ignition advance angle was found for a modernized 1hc102 Andoria engine powered by a combustible mixture with excess air factor 1.2. The optimum value of the angle was that which occurred at the maximum indicated pressure and indicated efficiency, and for which there was no combustion knock. As a result of modelling it can be concluded that during combustion of the mixture of $\lambda = 1.2$, the engine should work with the ignition advance angle equal to 10 deg before TDC. At this ignition angle no undesirable symptoms such as combustion knock occurred in the engine and the obtained values of the indicated pressure and the indicated efficiency were equal to, respectively, 0.99 MPa and 41.47%.

Numerical modelling using the AVL FIRE can be used for preliminary determination of adjustable engine parameters such as ignition advance angle, without using a real engine on the testing stand. However, the use of numerical methods to optimize engine operation can and should be verified by experiments on the measuring stand.

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NUMERYCZNA OPTYMALIZACJA ZAPŁONU W SILNIKU SPALINOWYM ZI

Streszczenie. W ramach pracy w programie AVL FIRE przeprowadzono numeryczną optymalizację zapłonu w badawczym zmodernizowanym silniku Andoria 1hc102 o zapłonie iskrowym. Modelowanie umożliwiło znalezienie optymalnego kąta wyprzedzenia zapłonu silnika badawczego podczas spalania mieszanki palnej o współczynniku nadmiaru powietrza λ = 1.2. Optymalną wartością kąta była ta, przy której wystąpiło maksymalne ciśnienie indykowane oraz sprawność indykowana, i przy której nie zaobserwowano objawów spalania stukowego. W wyniku modelowania stwierdzono, że silnik badawczy spalając mieszankę o λ = 1.2, powinien

pracować z wyprzedzeniem zapłonu równym 10° przed GMP. Przy tym kącie wyprzedzenia zapłonu silnik nie wykazywał niepożądanych objawów spalania stukowego, a osiągnięte wartości ciśnienia indykowanego i sprawności indykowanej były równe odpowiednio 0.99 MPa i 41.47%.

Słowa kluczowe: silnik spalinowy, modelowanie, kąt wyprzedzenia zapłonu, ciśnienie indykowane, sprawność indykowana.