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NUMERICAL ANALYSIS OF SOME PARAMETERS OF SI INTERNAL COMBUSTION ENGINE WITH EXHAUST GAS RECIRCULATION

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Summary. The paper presents results of modelling of the thermal cycle of SI test engine using AVL FIRE software. The results are presented of the influence of exhaust gas recirculation on some engine parameters e.g. indicated thermal efficiency and mean indicated pressure. The knock phenomenon was taken into account. The engine parameters were limited by knock combustion process. It turned out that several percent of exhaust gases turned back into the cylinder which is beneficial not only for NO concentration but also has a favorable impact on knock combustion limit.

Key words: internal combustion engine, combustion, knock, exhaust gas recirculation

INTRODUCTION

Contemporary engines are designed to minimize exhaust emissions while maximizing power and economy. One of possible methods of doing this is exhaust gas recirculation. A fraction of the engine exhaust gases is recycled to the intake to dilute fresh mixture for control of NO_x emission [6]. This method is called exhaust gas recirculation, in short EGR. The recycled gases reduce the in-cylinder temperature and cause a decrease in knocking tendency.

Amr and Saiful[1] experimentally investigated the use of the stoichiometric air–fuel mixture with exhaust gas recirculation technique in a spark-ignition natural gas engine. Engine performance and NO emissions were studied for both atmospheric and supercharged inlet conditions. It was found that the use of EGR has a significant effect on NO emissions. NO emissions decreased by about 50% when EGR dilution increased from zero with an inlet pressure of 101 kPa to close to the misfire limit with an inlet pressure of 113 kPa. In addition, the use of EGR effectively suppressed abnormal combustion which occurred at higher inlet pressure. The use of higher inlet pressure in the presence of EGR improved engine performance significantly. NO emissions decreased by about 12% when 5% of EGR dilution was employed with an inlet pressure of 113 kPa compared to using undiluted stoichiometric inlet mixture with an inlet pressure of 101 kPa [1]. In recent years an increase is observed in the petroleum price. It has led to more interest in alternative fuels like DME. Wang and Zhou [2] confirmed that the properties of DME provide a potential for a large EGR ratio in an engine. Their experimental results indicate that NO_x emission can be reduced by about 40% at a large EGR share without visible smoke and deterioration in thermal efficiency of DME engine. However, CO emission increases with the rise of EGR share. A commercial oxidation catalytic converter was used to investigate its influence on CO emission. Additionally, they prove that DME vehicle engine can meet stricter emission regulations with an EGR integrated system and oxidation catalytic after treatment [2]. Bin Huang and co-workers [3] have investigated the cycle-by-cycle variations in a spark ignition engine fueled with natural gas–hydrogen blends combined with exhaust gas recirculation. The effects of EGR ratio and hydrogen fraction on an engine's cycle-by-cycle variations were analyzed. The results showed that the cylinder peak pressure, the maximum rate of pressure rise and the indicated mean effective pressure decrease and the cycle-by-cycle variations increase with the increase of EGR ratio. A slight influence of EGR ratio on indicated mean effective pressure was observed at low EGR ratios while large influence of EGR ratio on indicated mean effective pressure was demonstrated at high EGR ratios [3]. Pradeepa and Sharma have taken into account the renewable fuel JBD suitable for diesel engines [4]. Diesel engines running on JBD were found to emit higher nitrogen oxides, NO_x. Hot EGR, a low cost technique of exhaust gas recirculation, was effectively used in that work to overcome this environmental penalty. Practical problems faced while using a cooled EGR system were avoided with hot EGR. Results indicated higher nitric oxide emissions when a single cylinder diesel engine was fuelled with JBD, without EGR. NO emissions were reduced when the engine was operated under hot EGR levels of 5–25%. However, EGR level was optimized as 15% based on adequate reduction in NO emissions, minimum possible smoke, CO, HC emissions and reasonable brake thermal efficiency. Smoke emissions of JBD in the higher load region were lower than diesel, irrespective of the EGR levels. However, smoke emission was higher in the lower load region. CO and HC emissions were found to be lower for JBD irrespective of EGR levels. Combustion parameters were found to be comparable for both fuels [4]. Erjiang and coworkers [5] have conducted an experimental investigation on the influence of different hydrogen fractions and EGR rates on the performance and emissions of a spark-ignition engine. The results showed that massive EGR introduction decreases the engine power output. However, hydrogen addition can increase the power output at large EGR operation. Effective thermal efficiency showed an increasing trend at small EGR rate and a decreasing trend with further increase of EGR rate [5]. For a specified hydrogen fraction, NO_x concentration was decreased with the increase of EGR rate and this effectiveness becomes more obvious at high hydrogen fraction. HC emission was increased with the increase of EGR rate and it decreased with the increase of hydrogen fraction. CO and CO_2 emissions showed little variations with EGR rate, but they decreased with the increase of hydrogen fraction. The study showed that natural gas–hydrogen blend combining with EGR can result in high-efficiency and low-emission spark-ignition engine [5]. Shizuo and all [7] investigeted an effect of EGR on direct injection gasoline engine. They confirmed that an appropriate volume of EGR improves fuel economy and HC emission. This phenomenon is presumably due to the intake temperature increase by EGR, which improves the flame propagation in the relatively lean area of the air-fuel mixture, which is not uniformly distributed [7]. Abd-Alla in his work presented a summary of the possibility of using exhaust gas recirculation in a spark ignition engine. He confirmed that in spark ignition engines, substantial reductions in NO concentrations are achieved with 10–25% EGR. However, EGR also reduces the combustion rate, which makes stable combustion more difficult to achieve. At constant burn duration and brake mean affective pressure, the brake specific fuel consumption decreases with increasing EGR [8].

MODELLING RESULTS

Modelling of the thermal cycle of the test spark ignition engine in the AVL FIRE program was carried out. The object of investigation was a spark ignition S320ER internal combustion engine fed with gasoline. The engine was operated at a constant speed of 1000 rpm. Exhaust gas recirculation was taken into account. An influence was analyzed of EGR on engine operating parameters, NO concentration in the exhaust gases and reduction of engine knocking phenomena. The paper presents the thermal cycle parameters for the conditions of constant ignition advance and the optimized angles.

The percentage of exhaust gases recycled back to the engine intake (%EGR) was calculated as a percentage of the total inlet mass flow rate. Geometric mesh of combustion chamber of modeled test engine is presented in the paper "Numerical analysis of the impact of EGR on the knock limit in SI test engine". The verification results and modelling parameters are also presented in the above-mentioned paper. Figure 1 shows changes in the indicated thermal efficiency and mean indicated pressure for the modeled engine depending on the EGR ratio. It turned out that small exhaust gas content in a fresh load causes an increase in engine efficiency. For modeled engine 2.5% EGR ratio caused an increase in the efficiency. The maximum obtained efficiency was 34.7%. Of course, with increasing participation of EGR in the fresh charge the value of mean indicated pressure decreased. With the increasing EGR there was a higher than 2.5% decline in engine efficiency.

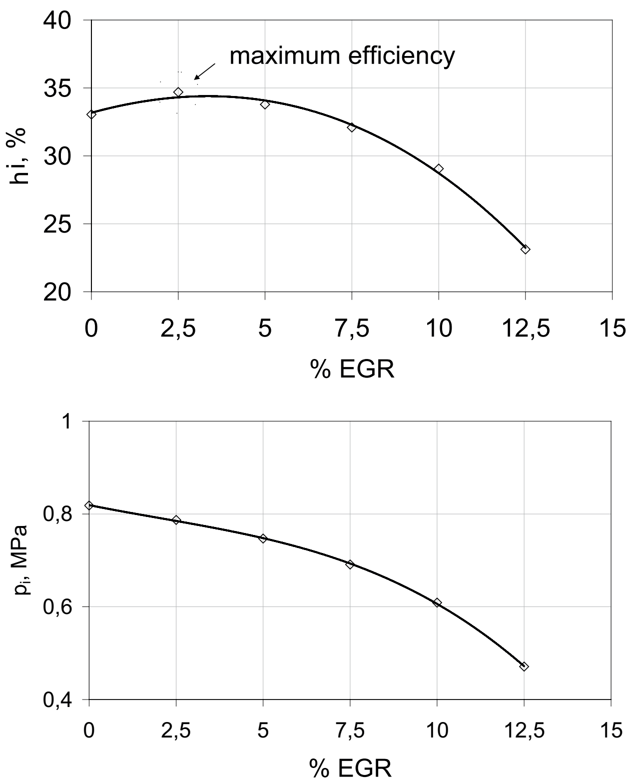

Fig. 1. Courses of indicated thermal efficiency and mean indicated pressure for constant spark advance timing equal to 10 deg before TDC

Figure 2 shows the value of mean indicated pressure for a fixed advance angle and the optimized conditions. It turns out that it is appropriate to increase the advance angle for increased participation of recycled gases in the fresh charge. For 12.5% increase of EGR the ignition advance angle allowed for an increase of mean indicated pressure by over 35 % from 0.47 MPa to 0.74 MPa

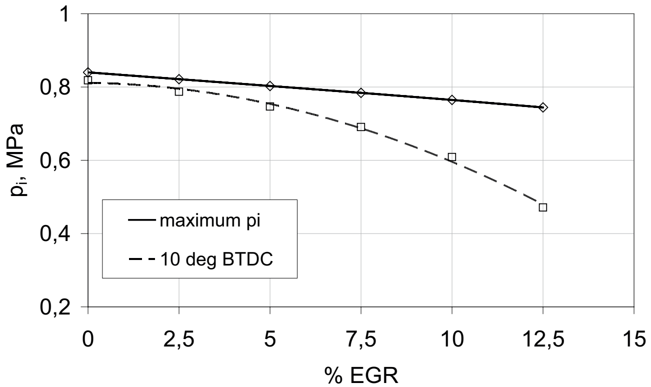

Fig. 2. Mean indicated pressure for constant ignition angle 10 deg before TDC and for optimized conditions at different shares of EGR, λ=1.2

Engine running without EGR reached the indicated efficiency equal to 33%. For 12.5% EGR ratio the indicated thermal efficiency dropped to 23%. Results were obtained for the test engine running with a constant angle of ignition advance.

The solid line in Fig. 3 represents the maximum pressure obtained for the conditions in which there was no knock combustion.

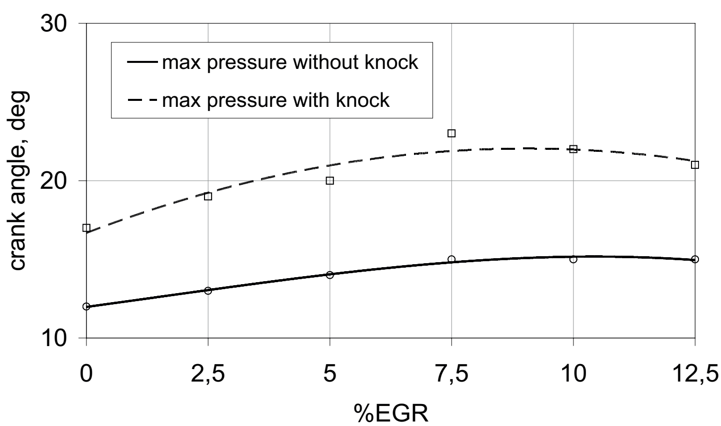

Fig. 3. The angle of the maximum combustion pressure for the conditions with and without knocking for different EGR shares

The dashed line represents the hypothetical value of the maximum pressure obtainable in the research engine, the limitation is the occurrence knock process.

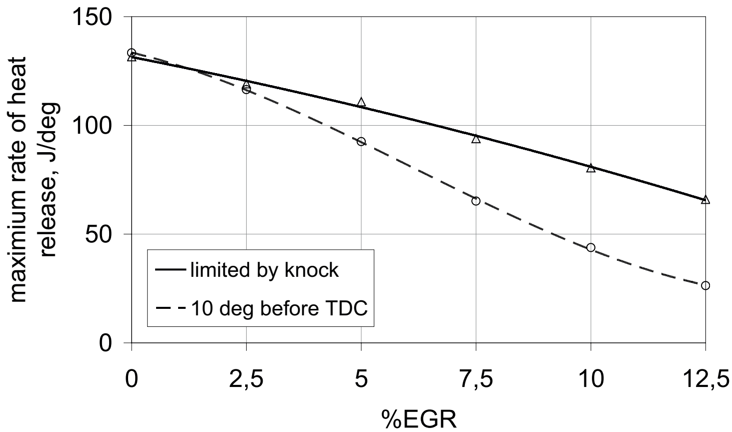

Fig. 4. Maximum rate of heat release for condition limited by knock onset and for constant ignition advance equal to 10 deg before TDC

Fig. 4 shows the dependence of rate of heat release to the conditions of constant advance angle and the optimized conditions. From Fig. 3 it can be concluded that the maximum heat release rate decreases with the increase of percentage EGR share. The increase of EGR dilution in the mixture decreases the in-cylinder oxygen concentration and, consequently, it reduces the heat release rate.

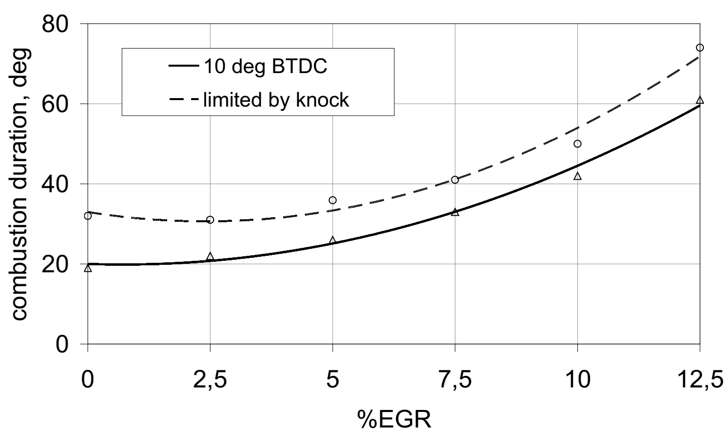

Fig. 5. Effect of EGR on the combustion duration angle for conditions: ignition advance equal to 10 degrees before TDC and the conditions for optimum ignition angle restricted by knock combustion onset

The combustion duration was calculated as the crank angle interval from the spark ignition to the end of combustion where the heat release reaches its maximum [1]. The increase of EGR share decreases the oxygen concentration which slowed down the combustion rate and increased combustion duration.

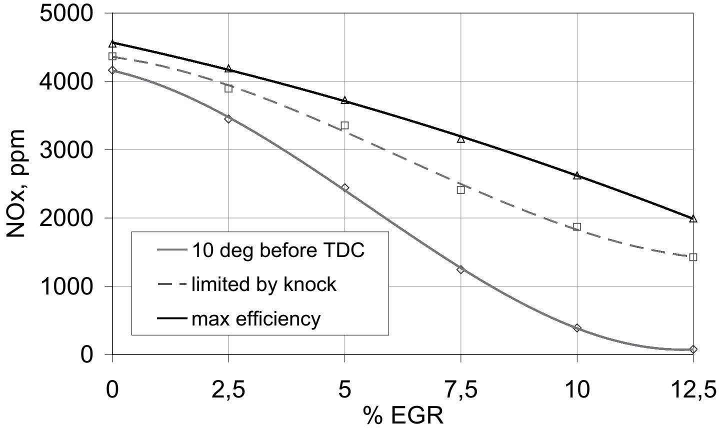

Fig. 6. Curves of NOx concentration depending on EGR percentage share

Figure 6 shows the impact of EGR ratio on NO content in the exhaust gases. With the increase in the share of exhaust gases in a fresh load it causes an decrease of NO in the exhaust gases. For the test engine NO concentration in the exhaust gas can be reduced by using 12.5% of EGR and the ignition angle about 50 deg before TDC. Under these conditions the drop of NO concentration from 4450 ppm to 1460 ppm can be achieved.

Due to the concentration of NO in the exhaust gas it is preferable not to make changes in the value of ignition angle, but it involves a significant deterioration in the thermodynamic parameters of engine cycle. For optimal conditions, without knock combustion, 12.5% of EGR reduced NO in the exhaust by more than 65%.

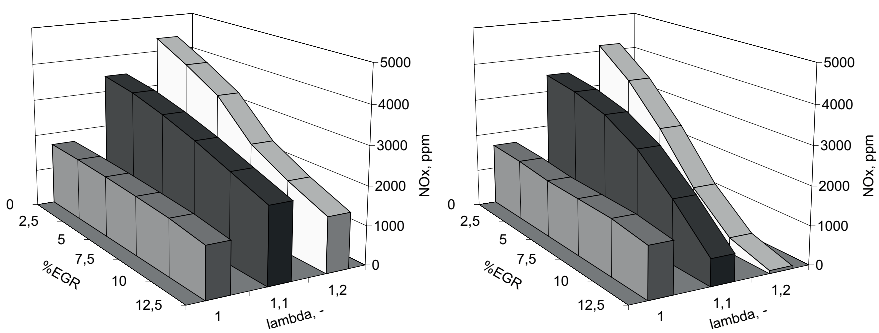

Fig. 7. NO concentration: a) in optimized conditions (max p_i and η_i),
b) constant ignition angle equal to 10 deg BTDC

Fig. 7 shows the NO concentration in the exhaust gases for different coefficients of excess air. Without optimizing the thermal cycle engine by changing the angle of advance a significant reduction of nitrogen oxides was achieved using EGR. On the other hand, a decrease followed of thermodynamic parameters of the engine cycle (Fig. 7b). Optimizing the thermal cycle of an engine with EGR in conditions of angle advance caused a smaller reduction of NO in the exhaust. However, it had a beneficial effect on the engine performance. This is the most evident for the excess air ratio equal to 1.2.

CONCLUSION

The paper presents the problem of optimizing the thermal cycle of a piston engine with exhaust gas recirculation. Achieving maximum thermodynamic parameters of the test engine cycle is limited by the occurrence of knock phenomenon. Maximum mean indicated pressure equal to 0.83 MPa was obtained for the test engine, without EGR. In the case of 12.5% EGR the maximum value of p_i reached a value 0.74MPa with more than 60% decrease in NO content. Exhaust gas recirculation is beneficial not only in reducing the toxicity of exhaust gases but also by effectively shifting the formation of the knock limit.

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ANALIZA NUMERYCZNA WYBRANYCH PARAMETRÓW PRACY SILNIKA ZI Z RECYRKULACJĄ SPALIN

W pracy przedstawiono wyniki modelowania obiegu cieplnego tłokowego silnika spalinowego o zapłonie iskrowym z uwzględnieniem recyrkulcaji spalin. Modelowanie przeprowadzono z wykorzystaniem propgramu FIRE. Analizowano wpływ EGR na tokyczność spalin z uwzględnieniem granicy spalania stukowego. Określono wpływ recyrkulacji spalin na długość procesu spalania.