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An experimental study of fuel injection strategies in CAI gasoline engine

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Combustion of gasoline in a direct injection controlled auto-ignition (CAI) single-cylinder research engine was studied. CAI operation was achieved with the use of the negative valve overlap (NVO) technique and internal exhaust gas re-circulation (EGR). Experiments were performed at single injection and split injection, where some amount of fuel was injected close to top dead centre (TDC) during NVO interval, and the second injection was applied with variable timing. Additionally, combustion at variable fuel-rail pressure was examined.

Investigation showed that at fuel injection into recompressed exhaust fuel reforming took place. This process was identified via an analysis of the exhaust-fuel mixture composition after NVO interval. It was found that at single fuel injection in NVO phase, its advance determined the heat release rate and auto-ignition timing, and had a strong influence on NO_X emission. However, a delay of single injection to intake stroke resulted in deterioration of cycle-to-cycle variability. Application of split injection showed benefits of this strategy versus single injection. Examinations of different fuel mass split ratios and variable second injection timing resulted in further optimisation of mixture formation. At equal share of the fuel mass injected in the first injection during NVO and in the second injection at the beginning of compression, the lowest emission level and cyclic variability improvement were observed.

1. Introduction

A combustion system which utilizes auto-ignition of homogeneous in-cylinder charge is a combination of two well known basic principles of internal combustion engines operation. Feeding a cylinder with a homogeneous mixture, typical of spark ignition engines, and its compression ignition, typical of diesel engines, allowed the development of the third combustion system.

One of the first efforts in HCCI combustion implemented in a 2-stroke engine was reported by Onishi et al. [1]. Najt and Foster presented in 1983 [2] the first results of a 4-stroke gasoline HCCI engine. The application of this novel combustion technique resulted in an uncompromising improvement of the working cycle efficiency as well as reduction of the engine-out emissions of nitrogen oxides and particulates.

Compression ignition can initiate combustion of all commonly used fuels. Although each fuel has unique auto-ignition characteristics, in general they can be divided into two groups: single-stage and two-stage ignition fuels. In the case of two-stage ignition fuels, cold blue flames appear about 10–20 °CA prior to reaching the fast heat release stage. For such fuels, blue flames appear at temperatures of about 760–880 K [3]. Two-stage ignition occurs in diesel fuel combustion as well as in lighter fuels, such as naphtha [4]. For single-stage ignition fuels (e.g. gasoline, ethanol, natural gas), combustion reactions commence when the temperature of the in-cylinder load reaches 950–1050 K [5].

The energy required for auto-ignition can be provided by enthalpy of exhaust gases. The use of exhaust gases from the previous engine cycle for heating up the air–fuel mixture allows for gasoline auto-ignition at compression ratios typical of spark ignition engines. The most feasible method of internal energy elevation is exhaust trapping by negative valves overlap (NVO) and reduced lift of the valves. However, substantial dilution of the in-cylinder load by re-circulated exhaust provides reduction of volumetric efficiency, and therefore reduction of high load boundary in HCCI combustion mode [6].

In controlled auto-ignition (CAI) engines fuelled with gasoline, which use the NVO technique in order to obtain a homogeneous charge, fuel is most often introduced into the cylinder during recompression of exhaust gases. Temperatures during injection are much higher than the boiling point of the heaviest fuel fractions. It allows fast air–fuel mixture formation and reduces the possibility of piston impingement by the fuel stream. Moreover, the occurring reactions modify the fuel's molecular structure, thus improving its auto-ignition properties and increasing tolerance to air excess ratio and EGR rate [7]. The chemical changes of fuel composition at elevated temperatures and in the presence of water vapour as a catalyst are termed reformation [8–10]. This process

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