

Effect of Streamer Discharge Assist on Combustion in a Supercharged HCCI Engine

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ABSTRACT

Homogeneous Charge Compression Ignition (HCCI) combustion has attracted widespread interest in recent years as a clean, high-efficiency combustion system. However, it is difficult to control the ignition timing in HCCI engines because they lack a physical means of inducing ignition. Another issue of HCCI engines is their narrow operating range because of misfiring that occurs at low loads and abnormal combustion at high loads. As a possible solution to these issues, this study focused on the application of a streamer discharge in the form of non-equilibrium plasma as a technique for assisting HCCI combustion. Experiments were conducted with a four-stroke single-cylinder engine fitted with an ignition electrode in the combustion chamber. A streamer discharge was continuously generated in the cylinder during a 720-degree interval from the intake stroke to the exhaust stroke. The results confirmed that the application of a streamer discharge to an HCCI engine enabled ignition under conditions where it would not ordinarily be possible. The effect on promoting combustion was obtained even for lean combustion and under the application of exhaust gas recirculation. However, that effect was diminished under a condition of a high boost pressure.

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INTRODUCTION

Homogeneous Charge Compression Ignition (HCCI) combustion is a highly efficient, clean combustion system in which a lean premixed mixture is inducted into the cylinder and autoignited under compression by the piston. This system makes it possible to achieve a level of lean combustion exceeding the ordinary limits of flame propagation. In addition, HCCI combustion also reduces both nitrogen oxide (NO_x) and particulate matter emissions simultaneously. However, it is difficult to control the ignition timing in an HCCI combustion system because it lacks a physical means of initiating combustion such as a spark plug or fuel injection. Moreover, because the mixture ignites at multiple locations simultaneously, it produces extremely rapid combustion in the high load region, giving rise to abnormal combustion and greater engine noise. For these reasons, one issue of HCCI engines is their narrow operating range. The results of a previous study revealed that supercharging and exhaust gas recirculation (EGR) make it possible to moderate the rapidity of combustion.⁽¹⁾ However, expanding the range of stable engine operation and controlling the ignition timing remain formidable issues to be resolved.

An attempt was made in this study to resolve these issues and expand the lean combustion limit by applying a streamer discharge assist in the form of non-equilibrium plasma. Combustion characteristics under this condition were investigated by in-cylinder pressure analysis and absorption spectroscopy.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

Experimental Equipment

The configuration of the experimental equipment used in this study is shown schematically in [Figure 1](#), and the specifications of the test engine are given in [Table 1](#). The test engine was a four-stroke single-cylinder engine with an overhead valve (OHV) system. The intake air temperature T_{in} [K] was adjusted with an intercooler and measured with a K-series thermocouple. A quartz crystal pressure transducer installed in the top of the cylinder head was used to measure the in-cylinder pressure P [MPa]. The heat release rate HRR [J/deg.] was calculated from the measured pressure signal.

Table 1. Specifications of test engine

4-stroke Air-cooled Single-cylinder Engine	
Bore × Stroke [mm]	76 × 66
Displacement [cm ³]	299
Engine Speed [rpm]	1400

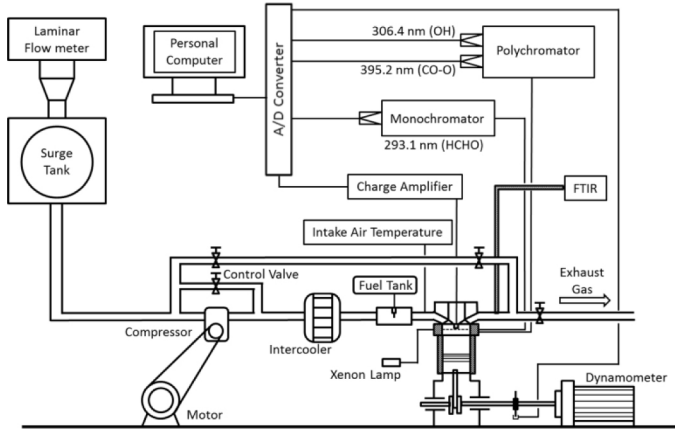


Figure 1. Experimental equipment

In order to measure the absorption of light by HCCI combustion, quartz observation windows were provided in the cylinder; light from a xenon lamp was irradiated in the bore direction and the transmitted light was sampled on the other side. The transmitted light was introduced into a monochromator via an optical fiber cable and separated at a wavelength of 293.1 nm (Figure 2). This wavelength is effective for capturing the behavior of formaldehyde (HCHO), which is a distinctive intermediate product of HCCI combustion. The intensity of the transmitted light E_A [A.U.] was detected with a photomultiplier tube and used to define absorbance $A_{293.1}$ [-] as shown in the equation below, where E_0 [A.U.] denotes the average value of the transmitted light intensity near bottom dead center.

$$A_{293.1} = \frac{E_0 - E_A}{E_0} \quad [-]$$

(1)

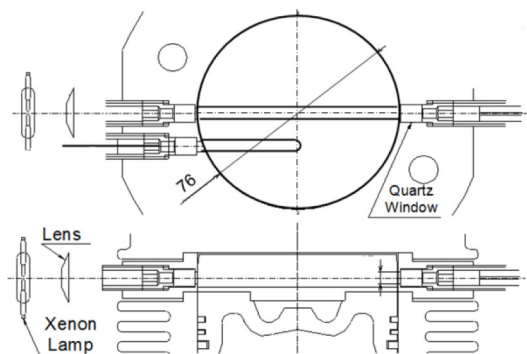


Figure 2. Configuration of spectroscopy system

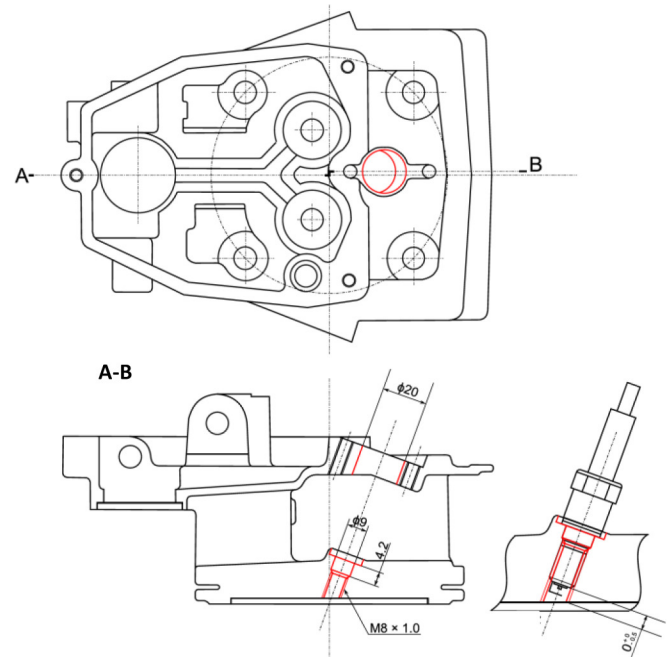
Generation of Streamer Discharge

To create a state with a streamer discharge (non-equilibrium plasma), it is necessary to apply a high voltage at a high frequency. A self-excited pulsed generator constructed with an inverter circuit was

used in this study to produce a high-voltage alternating current. A spark plug with the ground electrode removed was installed in the top of the cylinder for use as a discharge electrode having a frequency of approximately 20 kHz (Figure 3). This streamer-assisted ignition (SAI) system continuously generated low-temperature plasma from the streamer discharge. Observations were made of differences in the combustion state and ignition timing that were produced when the SAI system was either switched On or Off. It will be noted that in order to investigate the ignition and combustion characteristics obtained with the SAI system in an HCCI engine, experiments were conducted under conditions that would cause misfiring in normal HCCI combustion.

Test Fuels

The test fuels used were n-heptane and iso-octane. With an octane rating of 0 RON, n-heptane is a primary reference fuel that tends to autoignite easily, whereas iso-octane is a primary reference fuel with an octane rating of 100 RON and tends not to autoignite very readily. Under the experimental conditions in Case 1 (Table 2), n-heptane (PRF 0) was used as the test fuel. Under the experimental conditions in Cases 2 and 3, n-heptane and iso-octane were blended to make a test fuel with an octane rating of 90 (PRF 90).



a. Detailed view of the spark plug position

b. Spark plug for generating streamer discharge

Figure 3. Position and appearance of the spark plug