Time-series Spectra Measurements from Initial Flame Kernel in a Spark-Ignition Engine

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Keywords: Fiber-optic spark plug, Time-series of spectra, Initial flame kernel, SI engine

Introduction

Mixture composition of the unburned charge fundamentally influences the combustion process in spark-ignition engines, especially direct-injection spark-ignition (DISI) engines. Evaluating the cycle-to-cycle fluctuation of combustion in direct-injection engines is desirable, as it is known that emission levels and thermal efficiency are related to fuel concentration in a spark-ignition engine. Cycle-to-cycle fluctuations of combustion in DISI engine are caused by inhomogeneity of fuel-air mixture around the spark plug, strong flow and higher turbulence inside cylinder, and much of exhaust gas recirculation (EGR) in engine cylinder. Therefore, it is important to investigate the relationship between local air/fuel ratio (AFR) around the spark plug and the initial flame kernel development from the spark plug. In this study, time-series of emission spectra from initial flame kernel were investigated in a spark-ignition engine. Spectral lines due to OH*, CH*, and C* are related to the AFR, and we chose to focus on the relative intensities of the spectral lines of these species. A spark plug sensor with an optical fiber was developed for SI engines, and the emission intensities of OH*, CH*, and C* radicals were investigated for several equivalence ratios and used to estimate the AFR from the ratios of the intensity of the different spectral lines. Time-series of emission spectra from initial kernel in a SI engine can be obtained by using the fiber-optic spark plug and the spectrometer with ICCD camera. Detected area obtained using the developed fiber-optic spark plug is investigated using high-speed visualization image from initial flame kernel development from the spark plug. Estimation of AFR measured by developed system is determined using homogeneous mixture in practical spark-ignition engine.

Experimental results

Figure 1 showed flame emission spectra at 2.73 and 4.10 ms after the spark timing and visualized flame images. Red circles in images showed the detected area in consideration with numerical aperture of optical fiber. At 2.73 ms after the spark timing, initial flame kernel arrived at the detected area of the developed fiber-optic spark plug. At 4.10 ms, premixed flame already passes through the detected area. Broadband emission spectra from 350 to 600 nm in wavelength is attributed to CO-O recombination [15], which occurs in the region of burned gas area due to final oxidation. Figure 2 shows the time-series of flame spectra of chemiluminescence in the practical SI engine. Experiments were done at an engine speed of 7,000 rpm, an A/F ratio of 14.7, and throttle position of 20%. The flame spectrum of OH*, CH* and C* could be detected around 0.5 ms after spark timing. These spectrum intensities increased with the CA and CH* and C* reached a peak around 0.8ms after spark timing. After these periods, the CO-O recombination spectrum at 300–600 nm was observed. The spark plug sensor with optical fiber can be applied to practical engine under the high engine speed of 7000 rpm and can observe flame kernel characteristics such as radicals emission of OH*, CH* and C*. Figure 3 shows the relationship between preset AFR and intensity ratio of C*/CH* from emission spectra of initial flame kernel. The ratio of the intensity of the C* spectral line to the intensity of the CH* spectral line decreased monotonically with the AFR, and so we can determine the AFR based on this metric by exploiting a time series of spectra.

Fig. 1 Simultaneous measurement of emission spectra and high-speed visualization of initial flame kernel

Fig. 2 Time-series of emission spectra of chemiluminescence in a spark-ignition engine

Fig.3 Relationship between preset AFR and intensity ratio of C*/CH*