講演番号	093

Elucidation of In-Cylinder Abnormal Combustion Phenomena by Simultaneous Dual-Direction In-Cylinder Direct Imaging in a Direct-Injection Hydrogen Engine for Motorcycles

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KEY WORDS:**Heat engine, Hydrogen, Combustion analysis,** Abnormal combustion, Visualization [A1]

Hydrogen engines offer advantages such as a wide flammability range and high flame propagation speed; however, their low ignition energy makes them susceptible to abnormal combustion phenomena, including pre-ignition and knocking. In particular, motorcycle engines are compact and operate at high rotational speeds with high specific output, and abnormal combustion phenomena specific to hydrogen fuel under such conditions have not yet been sufficiently investigated using actual engines.

In this study, pre-ignition occurring under high-speed operation in a direct-injection hydrogen engine for motorcycles was investigated using a simultaneous dual-direction in-cylinder direct imaging technique. To observe a wide region within the combustion chamber, two optical access windows were installed on the intake- and exhaust-valve sides of the cylinder head, enabling simultaneous capture of ultraviolet chemiluminescence from OH radicals using high-speed cameras.

Under an engine speed of 10,000 min^{-1} and an excess air ratio of $\lambda = 1.5$, pre-ignition was intentionally induced. The results revealed that pre-ignition originated near the outer edge of the piston on the intake side and propagated toward the exhaust side (Fig. 1). Geometric comparison of visualization images from both viewing directions with a three-dimensional spherical flame model enabled identification of the pre-ignition origin with high spatial reliability (Fig. 2).

In addition, factor analysis combining in-cylinder wall temperature measurements, exhaust carbon dioxide concentration measurements, and knocking intensity evaluation suggests that lubricating oil intrusion, localized wall temperature elevation in the inter-bore region, and knocking-induced hot spot formation collectively contributed to the onset of pre-ignition. Enriching the mixture reduced knocking frequency and effectively suppressed pre-ignition.

This study clarifies the three-dimensional origin of pre-ignition in a high-speed hydrogen engine under actual operating conditions and provides insight into the mechanisms governing abnormal combustion in motorcycle hydrogen engines..

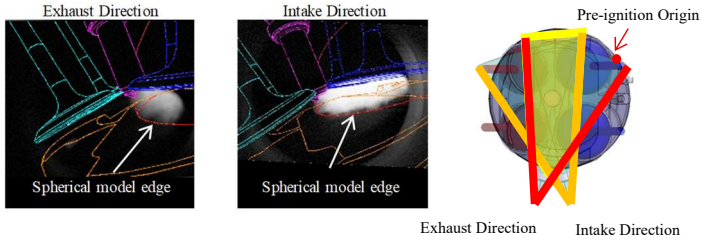

Fig.2 Estimation of pre-ignition origin by dual-direction imaging

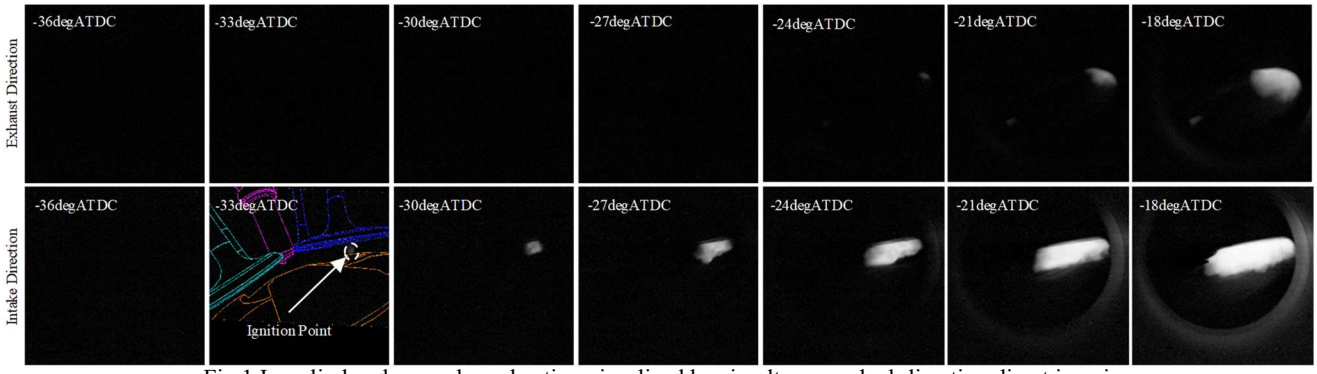

Fig.1 In-cylinder abnormal combustion visualized by simultaneous dual-direction direct imaging