講演番号	236

Development of a Hydrogen Engine for Light Commercial Vehicles

Ryosuke Matsui [1)] **Tomihisa Tsuchiya** [1)] **Michito Shirakawa** [1)] **Taketo Nagasaki** [1)]

Toru Sakuma [1)] **Satoshi Ido** [1)] **Yasuhiro Haruna** [1)] **Kazuya Nakata** [1)] **Akihiro Ando** [2)]

1) Toyota Motor Corporation
1 Toyota-cho, Toyota, Aichi, 471-8572, Japan (E-mail: ryosuke_matsui@mail.toyota.co.jp)
2) SOKEN Inc.
500-20 Minamiyama, Komenoki-cho, Nisshin, Aishi, 470-0111, Japan

KEY WORDS:**heat engine, hydrogen, spark ignition engine,** hardware reliability, abnormal combustion [A1]

A hydrogen-fueled spark-ignition engine for light commercial vehicles was developed as part of a multi−pathway approach toward carbon neutrality, aiming to expand hydrogen utilization beyond fuel cell electric vehicles. The engine was derived from a mass-produced 3.5 L turbocharged gasoline engine, retaining more than 95% of the base components to minimize additional investment and ensure manufacturability.

Lean combustion with an excess air ratio of $\lambda \geq 2.4$ was adopted across the entire operating range to suppress NOx formation. Direct hydrogen injection was employed to prevent backfire and improve mixture homogeneity, which is critical for suppressing abnormal combustion such as pre-ignition. Model-based development was used to optimize spray characteristics, injector layout, and piston crown geometry to enhance tumble flow while avoiding direct impingement on the spark plug, combustion chamber walls, or exhaust valves. The hydrogen injector was developed based on a conventional gasoline injector, with an injection pressure of 4.5 MPa selected as a balance between performance, driving range, and durability.

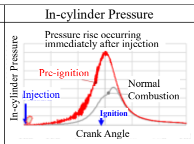
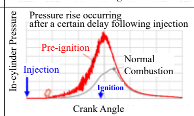
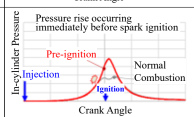
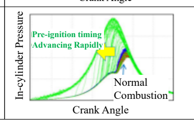
Hydrogen-specific reliability issues were comprehensively analyzed. Early pre-ignition, which poses a high risk of component damage due to extremely high in-cylinder pressure, was classified into injection-synchronized and injection-unsynchronized types. Injection-synchronized pre-ignition was traced to heat sources near the injector tip, including residual hydrogen combustion and exothermic reactions of injector insertion aid. These issues were resolved by reducing injector sac volume and changing to non-reactive insertion aid. Injection-unsynchronized pre-ignition caused by residual electrical charge in the ignition system was eliminated by adopting a newly developed ignition coil that suppresses unintended re-discharge. As a result, early pre-ignition was completely prevented.

Late pre-ignition, which occurs near the main ignition timing and increases during durability operation, was also investigated. Durability tests revealed that cylinders with frequent late pre-ignition exhibited higher levels of oil-derived deposits on intake valves and combustion chamber surfaces. Chemical analysis showed that these deposits contained calcium and zinc originating from engine oil additives. Further evaluation demonstrated that such deposits could react with hydrogen at relatively low temperatures, acting as localized ignition sources. These findings highlighted the importance of engine oil selection and oil consumption control to suppress deposit formation and ensure long-term reliability.

Additional hydrogen-specific challenges included water condensation and crankcase hydrogen accumulation. Hydrogen combustion generates significantly more water than gasoline combustion, leading to risks of oil emulsification and functional degradation, particularly under short-trip operation. A new estimation logic was developed to monitor water accumulation in the oil pan with high accuracy without additional sensors, enabling notifications to the driver to encourage warm-up driving. The PCV system was also redesigned with minimal added components to ensure sufficient crankcase ventilation under both naturally aspirated and boosted conditions, maintaining hydrogen concentration within safe limits while balancing oil consumption.

Engine bench tests demonstrated a maximum output of 120 kW and a peak thermal efficiency of 39.3%. Using a conventional diesel exhaust aftertreatment system consisting of OC and SCR, the engine met Euro 7–equivalent NOx limits in both steady-state and transient operation. Vehicle validation was conducted using a light commercial vehicle equipped with underfloor hydrogen tanks storing 6.2 kg of hydrogen. Public road demonstration tests totaling approximately 40,000 km were carried out over more than one year in diverse environments, confirming high functional reliability. Extending driving range is essential for commercialization. Therefore, we will advance the development of hydrogen engines that contribute to carbon neutrality, including powertrains that integrate HEV systems.

Table 1 Outline of Pre-ignition

Item		In-cylinder Pressure	Main Causes	Countermeasures
Early Pre-ignition	Injection-synchronized pre-ignition		1) After-burning of residual hydrogen near injector tip 2) Oxidation and exothermic reaction of injector insertion aid under high temperature	1) Reduce sac volume near injector tip 2) Change type of insertion aid
	Injection-unsynchronized pre-ignition		Unintended spark discharge of the spark plug	Adoption of an ignition coil that prevents re-discharge of residual charge
Late Pre-ignition			1) Residual high-temperature gas in spark plug tip pocket 2) Influence of oil-derived deposits suspended in combustion chamber	1) Reduce pocket volume 2) Suppress LOC (Lubricating Oil Consumption)
Runaway Pre-ignition			Maintaining elevated temperature due to prior abnormal combustion	Secure sufficient margin to runaway onset temperature