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Effects of Various Bore–Stroke Ratios on Hydrogen Direct Injection Spark Ignition Engines With Variable Valve Timing Under Low-Load Conditions

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Abstract
This study investigates the effects of various bore–stroke (S/B) ratios on the combustion characteristics, energy fractions, and performance of a hydrogen direct injection spark ignition engine equipped with a variable valve timing (VVT) system under low-load conditions. The experiments were conducted at S/B ratios of 1.0, 1.2, and 1.47 while maintaining a fixed displacement volume and compression ratio. The energy budget analysis focused on heat transfer loss, combustion loss, and exhaust loss to determine their effects on gross work. The results showed that as the S/B ratio increased, heat transfer loss increased due to enhanced piston speed and in-cylinder mixing, resulting in faster combustion. Combustion loss was highest at an S/B ratio 1.0 due to longer combustion duration. In contrast, exhaust loss did not show a clear trend with varying S/B ratios. The effects of fuel injection timing and excess air ratio on engine performance and emissions were investigated. The findings of this study suggest that optimizing the S/B ratio, fuel injection timing, and excess air ratio can significantly improve the thermal efficiency and emission characteristics of hydrogen engines, providing practical insights for the design and development of future hydrogen engine technologies.

Keywords Bore–stroke ratio(S/B ratio) · Hydrogen engine · Direct injection (DI) · Fuel injection timing · Spark ignition · Variable valve timing (VVT) · Excess air ratio (λ) · Energy fraction analysis

Abbreviations

CA	Crank angle
ECU	Engine control unit
HRR	Heat release rate
IMEP	Indicated mean effective pressure
MBT	Maximum brake torque timing
MFB	Mass fraction burned
MPRR	Maximum pressure rise rate
NOx	Nitrogen oxides
PFI	Port fuel injection
PMEP	Pumping mean effective pressure
S/B	Bore–stroke
TDC	Top dead center
VVT	Variable valve timing

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1 Introduction

The emissions of greenhouse gases, such as carbon dioxide and nitrogen oxides (NOx), have been identified as significant contributors to abnormal climate phenomena and climate change. Regulations on exhaust emissions are being enforced in the transportation sector to mitigate greenhouse gas emissions. As a result, the market for internal combustion engines based on conventional fossil fuels faces regulatory pressures, with numerous limitations and challenges remaining unresolved (Boxcar-admin, 2020).

Hydrogen is widely recognized as an energy storage and transport medium due to its carbon-free composition, high energy density, and wide flammability range. If used