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授 与 し た 学 位	博　士
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学位論文の題目	Mixture Formation Measurement of Transient Hydrogen Jet in Constant-Volume Vessel Using Spark Induced Breakdown Spectroscopy (SIBS) （定容容器内非定常水素噴流の火花誘起絶縁破壊分光(SIBS)による混合気形成の計測）
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学位論文内容の要旨

This thesis is divided into 6 chapters. Chapter 1 describes a previous work and gives motivation for the work performed in this thesis. The background discuss about the current fossil fuels, which leads to global problem such as emission of pollutants, greenhouse effect, ozone layer depletion etc. The answer to these problems is to replace and improve the current technologies with hydrogen fuels that have good performance and will not emit the carbon dioxide. However, the use of hydrogen in a direct-injection environment presents challenges must be overcome before it can be widely used. Chapter 2 discussed about the hydrogen properties and the benefit when it use in combustion. The techniques to measure equivalence ratio was describe as many technique such as Linear Raman scattering, Ion current, Laser-Induced fluorescent (LIF), Planar laser induced fluorescent (PLIF), Laser-induced breakdown spectroscopy and Spark-induced breakdown spectroscopy (SIBS) was used to study the fuel concentration. The techniques proposed by other researchers require changing in the engine combustion chamber design for optical access from outside and difficult to be applied to concentration measurements for practical SI engines. The main purpose of this study is to measure the fuel concentration near the spark plug. Therefore, the use of SIBS technique (developed SIBS sensor) for measuring the hydrogen jet concentration was proposed as a suitable technique that can measure the fuel concentration inside of the engine cylinder. Chapter 3 discussed about the apparatus and the methodology used in this study to measure the local fuel concentration. A constant-volume vessel equipped with a SIBS sensor was used, and a swirl-type direct-injection (DI) injector with a single orifice was installed at the top of the vessel. The local fuel concentration of the hydrogen jet was measured at several locations. The SIBS sensor was developed using a commercial spark plug with an optical fiber installed at the center. A spectrometer was used to analyses the light obtained from the optical fiber. A high-speed camera was used to visualize spark discharge fluctuations, and hydrogen jet concentration measurements were conducted simultaneously. Four types of filters were discussed. The quantity test experiment was discussed whereas the results of injection amount versus hydrogen injection duration, the relation between equivalence ratio and hydrogen injection duration can be calculated. Chapter 4 describes about the calibration technique with the SIBS sensor to obtain optimum results. The correlation between the hydrogen/nitrogen mixing ratio and atomic emission, and the post-processing procedure was discussed. Spectral calibration was carried out with a hydrogen/nitrogen mixture at pressures of 0.5, 1.0 and 1.5 MPa at room temperature. The spectra were determined for a range of the equivalence ratios from 0.3 to 5.0. Two clear emission peaks were observed in the wavelength range 450-700 nm; the peak at 656 nm corresponds to H_α while that at 501 nm to N(I). The intensity of the H_α peak increases as a function of the ambient pressure, P_{amb}. Various methods of data smoothing and filtering were discussed in order to remove noise from a contaminated signal. Moving average filters with two different numbers of points were applied to the emission spectral data. The atomic spectral lines were integrated and the background area was subtracted using the method originally reported by Shirley and later improved by Proctor and Sherwood to eliminate the effects of elastic scattering. An empirical formula for deriving the equivalence ratio for ambient pressure using the SIBS sensor was obtained. Chapter 5 focuses on the hydrogen jet concentration measurement. The injection of hydrogen with different ambient pressures visualized with a high-speed video camera was conducted to study the distribution pattern of hydrogen jet and to select the appropriate measurement points for the hydrogen concentration for optimal locations to carry out SIBS measurements. A high-speed camera was used to visualize spark discharge fluctuations. Direct visualization of the spark discharge provided useful information about the influence of spark discharge characteristics related to the spark timing. Local equivalence ratios for different spark timings were discussed and based on the results, the mixing process can be classified into three states, (i) initial unsteady state (HI at P_{amb}=1.0 and 1.5 MPa), (ii) quasi-steady state (HI at P_{amb}=0.5 MPa, CI and TI at P_{amb}= 0.5, 1.0, 1.5 MPa) and (iii) after-injection unsteady state (ATI in all conditions). Chapter 6 describes the conclusion arrived in this research work.

論文審査結果の要旨

本研究は，将来の燃料の一つとして有望とされる水素を熱機関で使用する場合の基礎的な研究として実施された．ここでは，定容容器内の窒素雰囲気中に水素を単発噴射したときの水素濃度を測定して，その混合気形成を調査することが目的である．安全のため，空気の代わりに窒素を使用した．また，その混合気形成に及ぼす雰囲気圧力の影響を調査した．さらに熱機関への実用化を考えて，測定のためのセンサとしては点火プラグ型として，火花放電をさせたときの点火プラグ近傍の水素濃度割合を測定することができるようにした．

火花放電によってガスにエネルギーが与えられ，そのとき誘起される絶縁破壊によって，ガスがプラズマ化される．そのとき，光が出る．その原子発光のスペクトルを観測することによって，特定の種類のガスがどの程度存在するかが分かる．ただし，毎回，発光の強さが変化するので絶対値の議論はし難いが，スペクトルの比をとることによって，たとえば，燃料と窒素の混合比が分かることになる．窒素の 501nm (NI) と水素の 656nm (H_α)の波長を選んで解析した．まず，所定の混合比の均一混合気を定容容器内に充填しておき，火花放電をさせて，そのプラズマのスペクトルを測定した．なお，実験で得られるスペクトルには，ノイズおよび広く背景光が存在するので，まず，これらの影響を除去する方法について，いろいろと検討した．次に，この２つのスペクトルの比に及ぼす雰囲気圧力の影響を調査して，実験式を得た．これらの準備をした上で，窒素を充填した定容容器内に，1 回だけ一定量の水素を噴射し，点火プラグ型のセンサによって，空間中の何点かで水素と窒素の混合比が時間的にどのように変化するかを調査した．水素噴流は，まず，最初，非定常に発達していき，ある程度時間が経過すると準定常となり，噴射終了後は減衰する．準定常期間においては，定常噴流理論に近いような濃度分布になる．また，雰囲気圧 0.5MPa から 1.5MPa と増加すると，噴流到達距離は抑えられ，噴霧角が大きくなり，混合気が均一になるのに時間を要する傾向にある．これらの知見は，熱機関内に水素を直接噴射するような場合の混合気形成過程を考える上で参考になり，さらに，この点火プラグ型センサを利用すれば，直接水素濃度割合を測定することも可能となるであろう．よって，本論文は，工学分野の学位に十分値すると認められる．