Study on Improvement of Mixture Formation in Hydrogen Direct-Injection Engines Using Air Injection

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The promotion of mixing between hydrogen and air is effective for improvement of thermal efficiency of hydrogen direct injection engines. In order to improve the mixing characteristics of hydrogen and air in Hydrogen internal Combustion Engines, the authors propose an engine system that injects air into the combustion chamber.

To achieve air injection, a six-stroke engine was adopted. This adds two strokes for generating compressed air for injection to the four strokes—intake, compression, expansion, and exhaust—currently standard in mainstream engines. This compressed air is then injected into another combustion chamber with a phase shift of half a cycle via the valves and tubes which connected to another chamber.

Then, a zero-dimensional simulation was performed to calculate how much kinetic energy due to jet contributes to mixture formation via air injection compared to the hydrogen jet, as described in the aforementioned proposed system. Furthermore, since thermal efficiency losses occur during the process of compressing air for air injection, this was also evaluated.

A spatially zero-dimensional tank-tube model was used for the air jet calculations. Throughout all calculations, adiabatic changes are assumed, and cooling losses, mechanical losses, pumping losses due to normal intake and exhaust strokes, and friction loss are not considered. For engine specifications, the bore × stroke was set to 80 mm × 93.67 mm, displacement per cylinder to 471 cc, compression ratio to 17, valve diameter for air injection to 20 mm, and engine speed to 2000 rpm. In addition, equivalence ratio was set to 1. The governing equations consist of the equation of state, the mass conservation equation, and the enthalpy conservation equation. Furthermore, considering the compressibility of air, the energy of the air jet was calculated using the equation for isentropic flow equations for a convergent nozzle.

This calculation revealed that the kinetic energy of the air jet contributing to mixing is several times greater than that of the hydrogen jet. It was also found that thermal efficiency losses occur when generating compressed air, creating a trade-off relationship with the kinetic energy of the air jet obtained. Optimization of the valve opening timing is required for the improvement of thermal efficiency in the proposed system.

Finaly, CFD analysis on the air and hydrogen jets into the quiescent constant volume cylinder chamber were performed with ANSYS Fluent in order to compere the mixing ability between air jet and hydrogen jet for making same amount of stoichiometric air/hydrogen mixture. Specifically, the distribution of the equivalence ratio and turbulent kinetic energy was compared for both hydrogen injection and air injection. In the calculation, quadrilateral elements were adopted, with a mesh size ranging from 0.1 mm to 1 mm. This is a transient calculation using a density-based solver that accounts for compressibility, employing the RNG k-ε model as the turbulence model. For both hydrogen and air injections, the conditions of the resulting mixture were standardized for comparison. Specifically, the mixture was set to 0.1 MPa and 300 K at a stoichiometric ratio. The injection pressure is 70 MPa for hydrogen injection and 0.25 MPa for air injection, with nozzle diameters of 0.346 mm and 17.6 mm, respectively.

Figure 1 shows the contour plot of the equivalence ratio at each time. For both cases, mixing progresses as time goes from 3ms immediately after injection termination, causing the region near the equivalence ratio of 1 (light green area) to expand. However, it can be seen that the air injection case has a larger region near the equivalence ratio of 1.

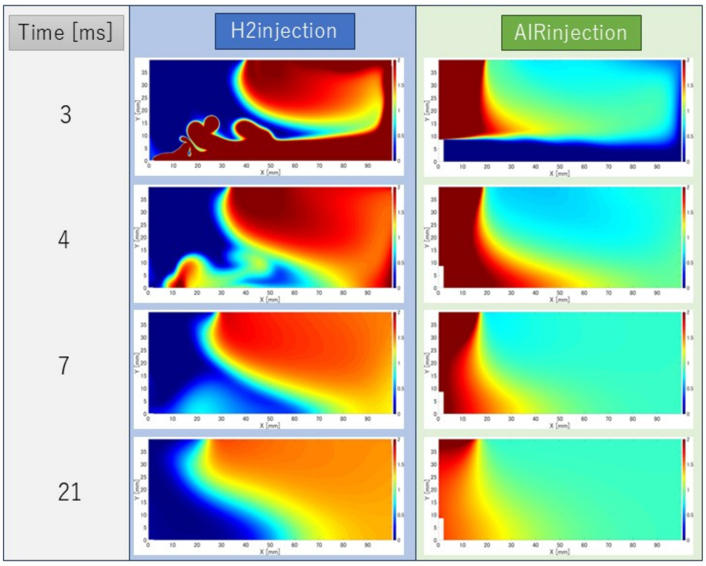

Fig.1 Contour plots of equivalence ratio

Regarding the kinetic energy of turbulence, the air injection also demonstrated superiority by the time history of the average of the turbulent kinetic energy.

These evaluations demonstrated that injecting air into hydrogen allows for the formation of a mixture in a shorter period of time and at lower injection pressures than injecting hydrogen into air.

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