Thermal efficiency improvement for a diesel engine achieved by high-heels heat release rate profile

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Achieving carbon neutrality for the total life cycle of automobiles by 2050 is regarded as not only a technical but also a social target. Since future renewable energy resources are all strictly limited in comparison with currently consumed fossil fuels, it should be much more effective to choose multiple technical routes eclectically from various combinations of powertrains and energy sources than to select only one technology. Especially in the consideration of massive energy stocks and resilient multiple delivery network, liquid fuels are advantageous by their handling easiness and existent infrastructures. That is to say, internal combustion engines operated by liquid fuels have been essential in the future, and accordingly further improvement in thermal efficiency of them is still one of the urgent issues.

The major technologies to increase thermal efficiency are considered to be ‘shortend combustion duration to approximate to the isochoric cycle’, ‘high compression ratio’ and ‘high excess air ratio’ from theory, whereas all these technologies are limited and/or in multiple trade-off relations by the mechanical constraints for the peak cylinder pressure. Since a degree of constant volume combustion as an index of ‘approximate to the isochoric cycle’ has reached almost 1.0 for the combustion of current heavy-duty engines, it was experimentally confirmed that further increase in degree of constant volume combustion, achieved by ‘shortened combustion duration’ and/or increased pressure ratio, could not always result in the increase of thermal efficiency by increased heat loss, but in the increase of peak cylinder pressure. Therefore, to achieve optimum combination of technologies for higher thermal efficiency under the peak cylinder pressure constraints, the heat release rate profile was re-examined.

To maximize the indicated work and to minimize the heat loss simultaneously under the peak cylinder pressure constraint, peak heat release is delayed from top-dead-center at where the piston is stood almost still to the timing when the in-cylinder volume change rate is increased. A novel heat release rate profile named ‘High heels’, which is formed by gradually increased heat release rate in two steps to retard the peak at the timing of higher volume-change rate, was proposed as a measure to practically maximize thermal efficiency of diesel combustion in lieu of the ideal thermodynamic cycles. To experimentally confirm the advantage of this heat release rate profile with a single-cylinder engine, a variable rate shaping fuel injection system was newly developed as shown the schematic in Figure 1. The system is composed of a high flow fuel injector and four pressure control valves connected in parallel to the upstream high pressure common rails. By controlling the switching timing of the control valves properly, injection rate shape was modified as shown in the figure. In comparison with the conventional rectangular injection rate profile with a common-rail injection system, the results indicated that significant reduction in cooling loss under the fixed excess air ratio condition, whereas the thermal efficiencies were slightly deteriorated with ‘High heels’ like heat release rate profile (see Figure 2). By increasing excess air ratio up to reaching peak cylinder pressure, ‘High heels’ like heat release rate profile achieved 0.5%pt higher thermal efficiency than the recutangular profile, as expected.

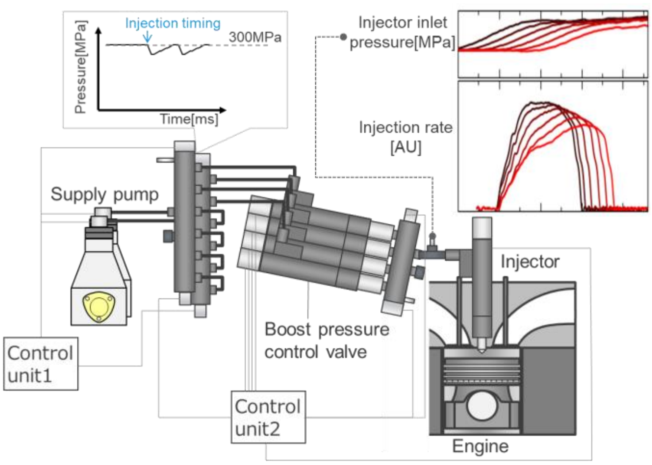

Fig.1 Schematic variable injection rate system

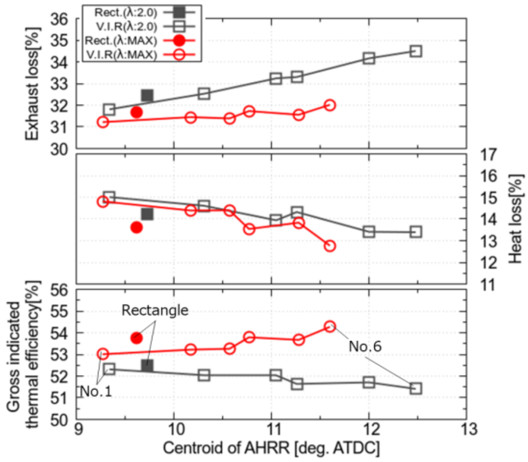

Fig.2 Comparison of heat balance between ‘High−heels’ and recutangular profile under fixed and maximum excess air ratio conditions