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An Investigation on Combustion Cycle-by-cycle Variations Affected by Spark Discharge Behavior under High EGR Ratio

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Spark ignition engines have a fateful event that enhancing EGR ratio makes cycle-by-cycle variations, and then ends up its combustion limit. To unveil this event, spark discharge images were shot with a high-speed video camera, and spark discharge electric current and voltage, in-cylinder pressure were measured at the same time under high EGR ratio combustion. The relations between spark discharge behaviors and combustion characteristics were investigated. It is discussed here how initial combustion speed variations, which caused by differences of spark discharge behavior among cycles, affects the combustion cycle-by-cycle variations.

Fig.1 shows the ignition circuit. Electric current and voltage are measured around the spark plug. The measured current and voltage have significant noises on their lines. These noises are removed with a smoothing method. And discharge path lengths (l_{path}) are estimated using Equation (1) which is modified from the equation(1) made by KIM et al.. This procedure is shown is in Fig.2.

$$l_{path}(t) = \frac{e(t) \cdot i(t)^{0.32}}{40.46p^{0.51}} \qquad (1)$$

Here, e is voltage [V], i is current [A], p is pressure [bar], t is time.

Fig.3 shows maximum discharge path length and maximum cylinder pressure in continuous 60 cycles. They have cycle-by-cycle variations. The cylinder pressures are changed like the graphs in the figure. Fig.4 shows T0-2 and T0-90 combustion periods for maximum discharge path length. The T0-2 period has a strong relation with the maximum discharge path length. It can be said that longer discharge path promotes the flame kernel growing in the early stage of combustion in cases of high EGR ratio combustion. On the other hand, the relation between the T0-90% period and the maximum discharge path length is considerably weak. Therefore the other factors that make cycle-by-cycle variations must be larger than this factor.

Fig.5 shows a visualized electric discharge path with its ignition discharge characteristic. Equation (1) was validated with this visualization.

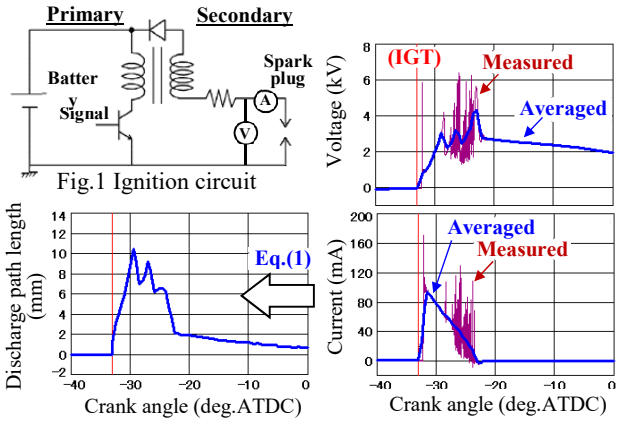


Fig.1 Ignition circuit

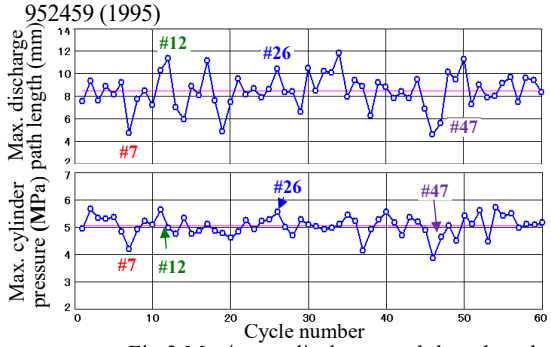
Fig.2 Discharge path length estimation

Reference

(1) J.Kim,R.W.Anderson, Spark Anemometry of Bulk Gas Velocity at the Plug Gap of a Firing Engine, SAE paper 952459 (1995)

Table 1 Engine specification and test condition

Bore	85 mm
Stroke	110 mm
Compression ratio	12.9
Engine speed	2000 rpm
IMEP	0.64 MPa
External EGR ratio	25 %
Ignition timing (ATDC)	-33deg.



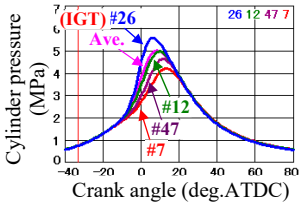


Fig.3 Maximum discharge path length and maximum cylinder pressure

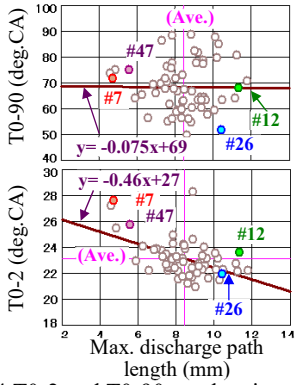


Fig.4 T0-2 and T0-90 combustion periods for maximum discharge path length

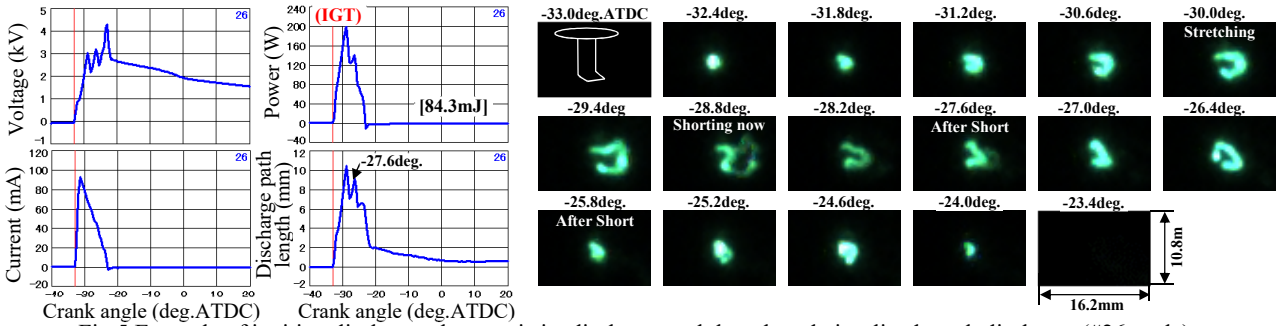


Fig.5 Example of ignition discharge characteristic, discharge path length and visualized spark discharge (#26 cycle)