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A study of the abnormal combustion mechanism at high engine speed and high load in high compression ratio engine

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Infrequent abnormal combustion with high pressure oscillation such as detonation is the major issue of high compression ratio engines with operating conditions of high speed and high load. It is known that detonation is generated depending on a temperature and pressure condition in unburned gas region when self-ignition occurs with a part of an end gas. A reason why an end gas self-ignites is existence of a “hot spot” in which gas is easy to ignite. However, it is not clear how a hot spot is created. In this study, the creation mechanism of a hot spot was investigated using the CFD calculation result that high pressure waves propagate in cylinder starting from a self-ignition point.

First, calculations were performed simulating with operating conditions of high speed and high load. (1) It was confirmed that the pressure amplitude increased with a slight difference in ignition timing. (2) Self-ignition occurs with a part of an end gas. This region was a hot spot, because the reaction was progressing locally. (3) It was confirmed that high pressure region was generated by the self-ignition of the hot spot. And The pressure then propagated into the combustion chamber. (Fig.1) From the results of (1) ~ (3), we were able to reproduce the creating hot spot and the combustion with high pressure oscillation caused by the hot spot.

Next, the trajectory of the hot spot was traced back in the combustion chamber. (Fig.2) As a result, it was found that the hot spot leading to self-ignition were widely distributed in combustino chamb at the latter half of the compression processer and remained near the exhaust valve about TDC timing, when the flow weakened. In this study, we defined and visualized the region with a large difference from the average gas temperature of the unburned gas as hot spot. Comparison of this region with the trace line revealed that unburned gas moving in the combustion chamber stagnates near the exhaust valve about TDC, creating a hot spot.

Finally, the factors that created hotspot were investigated. Hot spots are caused by reactions and temperature effects. In order to isolate these factors, a non-combustion calculation (combustion calculation stopped after intake valve close) was performed. Based on the results, exhaust valve temperature reduction (exhaust valve temperature 600 K after intake valve close) was calculated. As a result, it was confirmed that heat transfer from the exhaust valve is the dominant cause of creating hot spot. It was also found that hot spot formation could be suppressed by reducing the exhaust valve temperature.

From these results, it is clear that the mechanism of hot spot generation is (1) a portion of unburned gas stagnates near the exhaust valve and (2) a localized reaction proceeds due to the heat received from the exhaust valve. In addition, it is considered effective to prevent the gas from stagnating in order to eliminate hot spots. The validity of this idea was confirmed changing the flow near the exhaust valve by swirl. As a result, it was confirmed that the swirl flow eliminated the hot spots, although region with higher temperatures than the ambient temperature were generated.

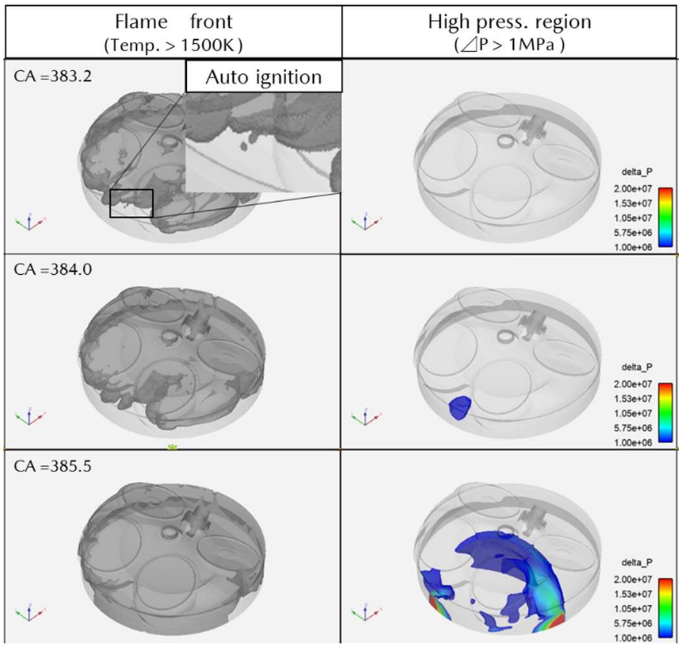

Fig.1 Flame front and high pressure region ($\angle P=P-P_{average}$)

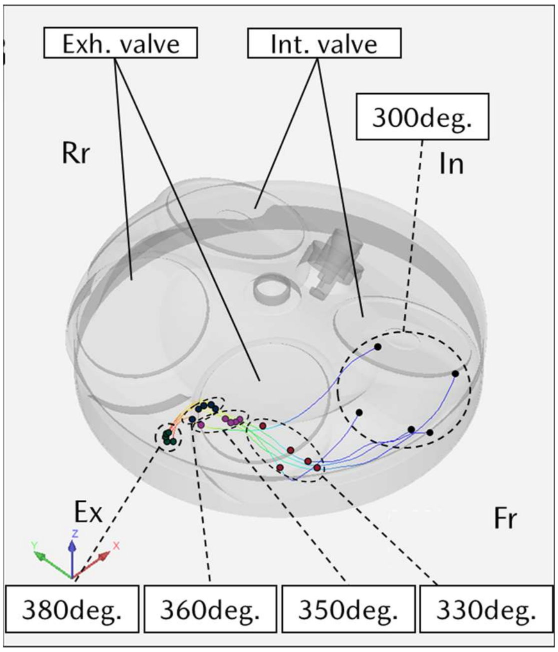

Fig.2 streamline for hot spot