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Development of control technology for abnormal combustion during high-speed operation

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It is predicted that the ratio of vehicles equipped with internal combustion engines, including HEVs, to EVs will be 50% in 2050, and it will continue to be important to improve the efficiency of internal combustion engines to realize a carbon-neutral society in 2050. To improve the efficiency of internal combustion engines, it is necessary to increase the compression ratio, increase the specific heat ratio (mixture dilution), and reduce various losses. However, with the recent trend toward higher compression ratios and thinner mixtures in improving the efficiency of internal combustion engines, abnormal combustion problems such as combustion variation and knocking have emerged as barriers to improving thermal efficiency. In knocking, the unburned mixture becomes locally hotter in the unburned region during flame propagation and auto-ignites. The chemical reaction of the unburned mixture rapidly proceeds behind the pressure wave generated by this auto-ignition, and the auto-ignition and pressure wave coincide. As the pressure wave travels at the speed of sound inside the cylinder, the amplitude of the wave increases near the wall because of phase inversion when it reflects off the wall. As a result, the pressure and temperature increase especially at the wall near where auto-ignition occurs and at the opposite wall, and heat transfer increases, resulting in abnormal combustion that can damage the piston, etc.

The conventional technologies to deal with abnormal combustion include: technologies to suppress knocking by the octane number and properties of fuel, methods to suppress knocking by slowing down combustion by introducing external EGR, increasing the fuel injection pressure in a direct injection engine to strengthen the turbulence in the cylinder caused by the injection, and the following In addition, many abnormal combustion response technologies have been reported, including technologies to avoid knocking by using machine learning and AI technologies, which have been applied in various fields with the development of computer technology in recent years.

In this report, we propose a system that predicts the occurrence of knocking based on features extracted from prior in-cylinder pressure measurements, and when knocking is predicted, injects additional fuel before knocking occurs in the same cycle to cool the cylinder and suppress knocking. Machine learning techniques with supervised data were used to predict knocking. Smoke, which is a concern due to fuel injection to suppress knocking, was evaluated experimentally.

When flame propagation progresses in a cylinder due to ignition, the flame is divided at a certain moment into the already burned region and the unburned region. At that moment, a region is created in the unburned region where the temperature is a certain level higher than the average temperature in the unburned region due to heat received from the exhaust valve, for example (hereinafter referred to as "hot spot"). This is the starting point for an autonomous and rapid chemical reaction within the unburned region (auto-ignition), and knocking occurs when the auto-ignition progresses in line with the pressure wave (abnormal combustion) (Figure 1). To capture signs of abnormal combustion based on hot spot generation, the in-cylinder pressure was measured in real time by an in-cylinder pressure sensor located in the combustion chamber, and 11 types of features were employed from the time series data of the in-cylinder pressure (Figure 2). In knocking prediction, it is necessary to determine the timing when the presence of abnormal combustion can be predicted as early as possible in the process from hot spot generation to abnormal combustion in order to reduce the harmful effects of smoke from additional fuel injection when knocking is predicted. The execution timing of the knocking prediction model was determined by considering the execution speed of the knocking prediction model and the preparation time of each device required for additional fuel injection to suppress abnormal combustion.

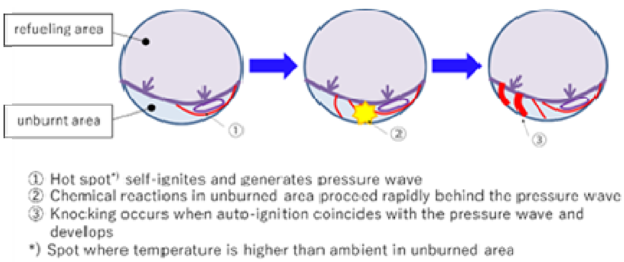

Fig.1 Knocking image

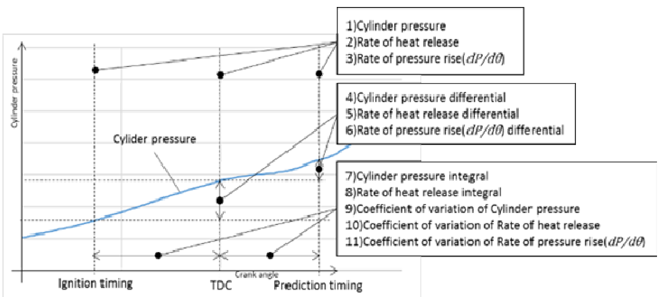

Fig.2 Feature based on in-cylinder pressure

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