

Piston Temperature Measurement Technology for Actual HSDI Diesel Engines

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ABSTRACT

A new telemetry-based method for measuring piston temperatures in real time was introduced that is suited to the development of diesel engines, which are becoming higher output and using various types of combustion control in recent years. This method was used to measure temperature characteristics in engine bench tests and while cruising in an actual vehicle.

The new method uses a compact telemeter, and the amplifier and antenna can be mounted on the piston, facilitating both layout and work. This method was confirmed to provide measurement accuracy equivalent to that of the conventional linkage system and to have durability of 15 hours or more in diesel engines with an average piston speed of 14 m/s or more.

The new method was used to understand the effects of the diesel engine operation parameters on piston temperature. In addition, a piston temperature map was created that covers all operating conditions, and the contribution to fuel economy and emissions reduction was also investigated.

1. Introduction

Diesel engines for passenger cars are an effective means of reducing CO₂ emissions, but support for strict exhaust gas regulations is also demanded. For this reason, various types of combustion control are performed in recent diesel engines^{(1), (2)}. Increasing the power output density by turbocharging and downsizing should also be considered. Against this background, piston temperature measurement becomes an important technology for understanding combustion states and investigating the effects on durability.

Various temperature measurement methods have been proposed to date, but none are currently able to completely support recent development needs. Indirect methods that convert the reduction in material hardness to temperature require operation at a constant speed, which imposes time restrictions if various temperature measurements are to be taken. In the widely used linkage system, the parts of the sensing elements that bend experience fatigue failure in long-stroke engines and high-speed engines, so lifespan is limited, making it unsuited to measurement over long periods.

Compact methods using thermistors have also been developed as applications for high-speed engines such as those used in motorcycles and race cars⁽³⁾⁻⁽⁵⁾. However, due to the characteristics of the NTC thermistors mainly used in these methods, the resistance values do not change sufficiently in the diesel piston temperature range that can reach as high as 400°C, so temperature accuracy cannot be obtained.

The new measurement system uses a compact telemeter, and sheathed-type thermocouples as the temperature sensing elements. An additional feature is that the telemetry system is compact enough to fit inside the piston. This facilitates application to V-type engines and actual vehicles in which wired methods using a linkage system made layout a challenge.

The new measurement system enables measurement of piston temperatures both in engine bench tests and during actual vehicle operation. This paper reports the results of investigating durability compared to conventional methods, and the potential for enhanced fuel economy.

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2. Overview of Measurement System

Figure 1 shows the overall measurement system. The digital signal transmitted from the piston at the bottom dead center is D/A-converted inside the receiver, and output as an analog signal. This enables piston temperatures during actual operation to be understood in real time by converting the output analog signal to the temperature using a measuring device and a PC.

Figure 2 shows the signal transmission conditions. A sensor amplifier and a coil-shaped rotor antenna are mounted on the piston. Electric power and the measurement signal are transmitted and received when this rotor antenna and a rod-shaped antenna mounted on the cylinder block side approach each other near the bottom dead center. Electric power is supplied to the piston side by inductive coupling, and the sensor amplifier uses this supplied electric power to amplify the electromotive force of the thermocouple. Then, after A/D conversion the data is superposed onto a carrier wave and the measurement signal is transmitted to the rod antenna. The signal is transmitted by digital transmission, so it is highly resistant to noise.

The sensor amplifier mounted on the piston can measure up to six channels. Division into multiple channels by a multiplexer is supported, so ungrounded sheathed-type thermocouples need to be used for the temperature sensing elements.

Figure 3 shows the sensor amplifier and rotor antenna actually mounted on the piston.

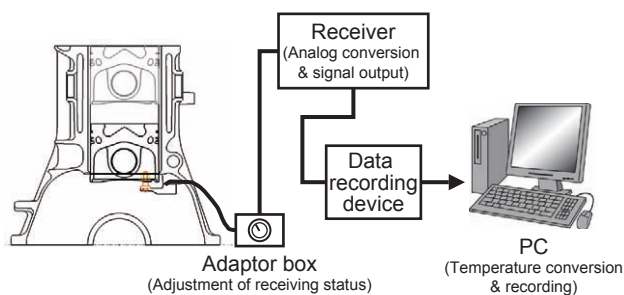


Fig. 1 Configuration of measurement system

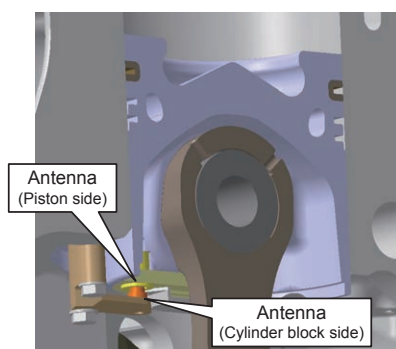


Fig. 2 Temperature measurement system

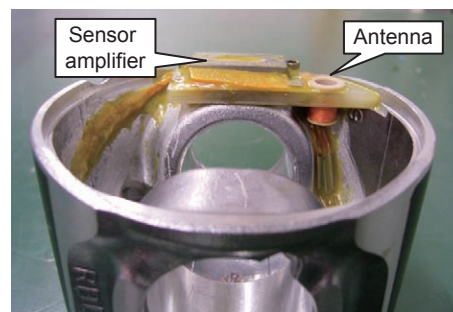


Fig. 3 Measurement piston mounted with new telemetry system

3. Measurement Performance

The measurement accuracy and durability of this measurement system were confirmed. Table 1 shows the specifications of the diesel engine used in this study. Basic performance was confirmed using a 2004 year model i-CTDI engine, and the measurement points were selected as shown in Fig. 4. The tips of the thermocouples at the points facing the combustion bowl were located 0.5 mm to the inside from the surface.

Accuracy was confirmed by locating a conventional exposed-type thermocouple and an ungrounded sheathed-type thermocouple next to each other on the pin boss area of the same piston, simultaneously measuring the former with the linkage system and the latter with the telemeter system, and comparing the results.

Figure 5 shows the results of verifying the temperature accuracy. The difference between the two methods was approximately 2°C regardless of the engine output power, which confirmed that the new measurement system using a telemeter has sufficient accuracy compared to the conventional method. The measurement values used the average values during steady-state operation one minute after the temperature stabilized at each operating condition.

Figure 6 compares the temperature transient characteristics. These results show that the new method exhibits good response, with the temperature rising and falling together with the torque in the same manner as the conventional linkage system.

Figure 7 shows the results of evaluating the measuring instrument durability during continuous operation. This test was conducted while confirming the effects of different operation parameters at high loads, and the lifespan exceeded 15 hours. This is sufficient durability in consideration of the fact that the high-speed test results for the linkage system were approximately 2 hours.

These results indicate that the new system has sufficient accuracy and durability performance as a measuring instrument.

Table 1 Specifications of test engine

Specification	04M/Y i-CTDI diesel engine	08M/Y i-DTEC diesel engine
Bore x Stroke (mm)	85 x 97.1	85 x 96.9
Displacement (cm ³)	2204	2197
Compression ratio	16.7	16.7
Max engine power (kW/rpm)	103/4000	110/4000
Max engine torque (Nm/rpm)	340/2000	350/2000
Max piston speed (m/s)	14.6	14.5

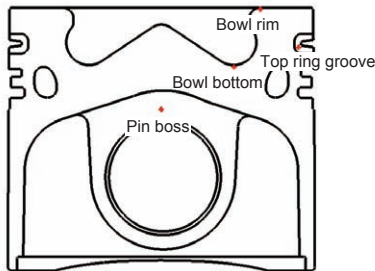


Fig. 4 Measurement points in thrust cross-section

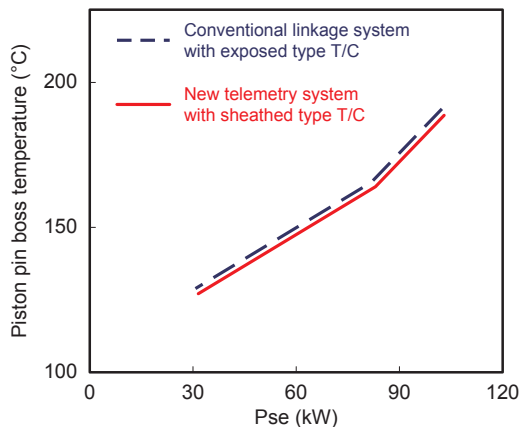


Fig. 5 Temperature correlation of both measurement systems

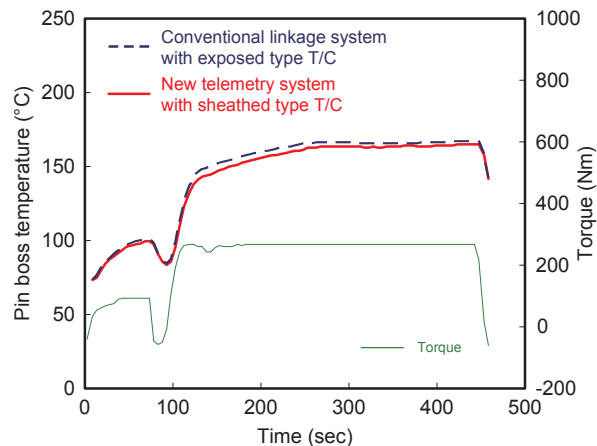


Fig. 6 Comparison of transient reaction of both systems

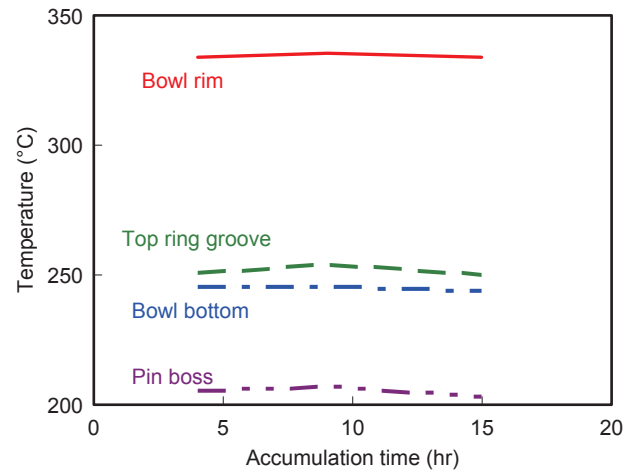


Fig. 7 Durability of telemetry system

4. Engine Bench Test Results

The new measurement system was used to confirm the effects of the diesel engine operation parameters on piston temperature. The results are as follows.

Figure 8 verifies the effects of water temperature and oil temperature on piston temperature. The operating conditions for all cases were 4000 rpm at full load, and the same indicated mean effective pressure and intake air temperature were also used from the standpoint of comparing temperatures. The horizontal axis shows the temperature of the oil discharged from the oil jets and the water temperature at the engine inlet, and the vertical axis shows the temperature at each piston location. The results showed that the piston temperature rose linearly in conjunction with the rise in oil and water temperatures, at all locations from near the combustion bowl to around the pin boss. In addition, arranging the slope by water temperature showed that the piston temperature rises by

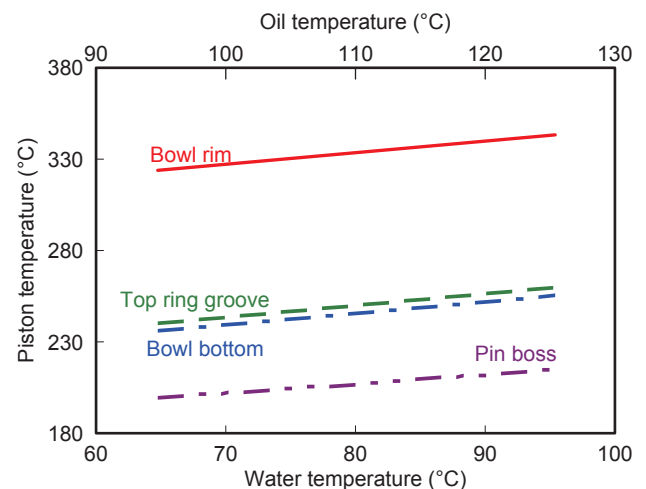


Fig. 8 Piston temperature against water and oil temperature

0.5°C to 0.6°C per 1°C of water temperature, with little difference between positions.

In turbocharged diesel engines, the heat resistance limit temperature of the turbocharger should also be taken into account, so the effects on exhaust gas temperature were also investigated. Figure 9 shows the relationship between exhaust gas temperature and piston temperature. In addition, the effects of cylinder pressure due to fluctuations in the turbocharged pressure are also shown. The operating conditions were the same 4000 rpm at full load as noted above, and the indicated mean effective pressure and intake air temperature were also the same.

Increasing the turbocharged pressure by 30 kPa produced a drop in the exhaust gas temperature of 100°C or more. The effect on the pistons was such that the temperature rise was limited to 4°C, but the cylinder pressure rose by 1.5 MPa.

These results indicate that the size and weight of each part can be further reduced by controlling the thermal and mechanical loads.

Figure 10 shows a temperature map created by measuring the piston temperature at the combustion bowl

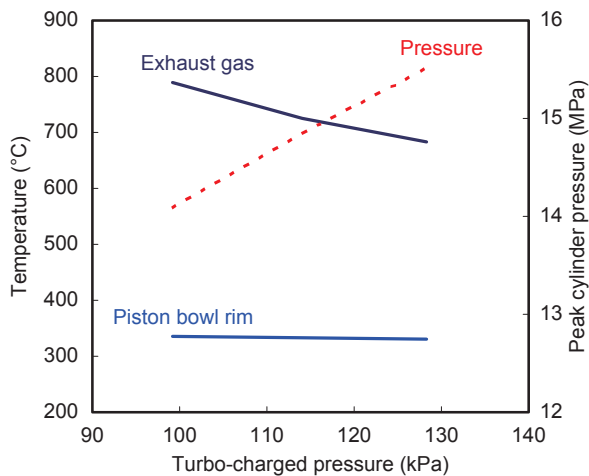


Fig. 9 Relation between piston temperature, exhaust temperature, cylinder pressure and turbo-charged pressure

rim over the entire operation conditions range using a 2008 year model i-DTEC engine⁽¹⁾. Conventional piston temperature measurement mainly aimed to evaluate durability, so measurement of the high load side was given priority. In addition to the conventional data, this study also obtained data for the low to medium load ranges, which is useful for future development.

The effects of piston temperature on fuel economy and emissions were also investigated using the i-DTEC engine. The piston temperature was controlled by varying the flow rate of the oil jet used to cool the piston. Figure 11 shows the results of confirming the correlation with the indicated specific fuel consumption (ISFC) when the piston temperature rises due to the load in the cruising mode range. Fuel consumption was confirmed to decrease as the piston temperature rises. This is because the thermal loss decreases as the piston wall surface temperature rises. Note that there was no change in NO_x, soot and pumping loss due to different piston temperatures at this time. Further investigation is needed to enhance fuel economy, but these results indicated the possibility that piston temperature control can contribute to enhancing fuel economy.

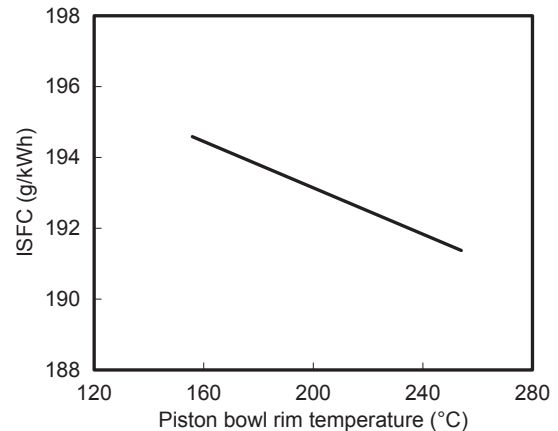


Fig. 11 Relation between fuel consumption and piston temperature

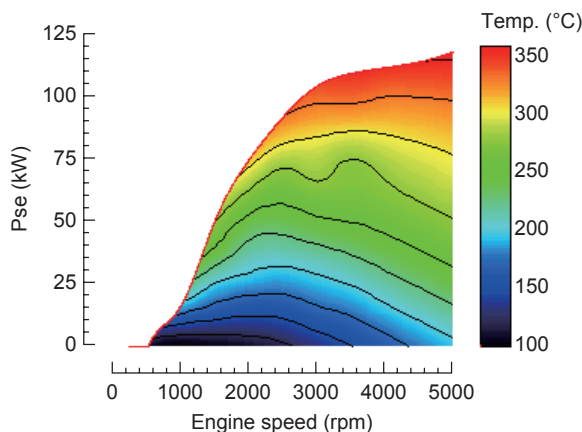


Fig. 10 Piston temperature map

5. Results of Temperature Measurement in an Actual Vehicle

An engine incorporating the new measurement system was mounted in a vehicle, and temperature measurement was performed to confirm the transient states in an actual vehicle and changes in temperature occurring in the actual operating condition. The cruising mode was the NEDC mode used to measure fuel economy and emissions in the EU region. In addition, a CR-V equipped with the i-CTDI engine was used in the tests. The test vehicle was equipped with both a diesel particulate filter (DPF) that captures the particulate matter (PM) generated by combustion, and a DPF regeneration function that combusts the collected PM

to help prevent filter plugging. This function generally sends non-combusted hydrocarbons to the DPF by post-injection within the cylinder, and then combusts the PM⁽²⁾. The effects of this regeneration function on piston temperature were confirmed.

Figure 12 compares the piston temperature in the normal NEDC cruising mode (without DPF regeneration control) and when DPF regeneration control, that is to say, post-injection, is performed while cruising. In both cases the temperature tended to rise sharply in response to vehicle acceleration, and then fall quickly at the approximate load ranges for maintaining the speed. In addition, the piston temperature rose during post-injection control compared to normal operation. The post-injected fuel should normally be input to the DPF as fuel used to combust the PM, but the piston temperature indicates that it is atomized and partially used for combustion inside the cylinder.

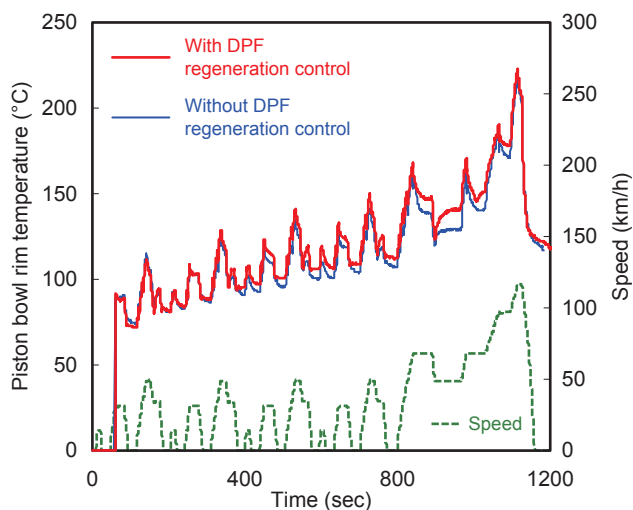


Fig. 12 Effect of regeneration control in NEDC mode on piston temperature

6. Conclusion

A telemetry-based temperature measurement system was introduced that is suited to measuring piston temperatures in a turbo-charged diesel engine. This compact measurement system was shown to have accuracy equivalent to that of the conventional linkage system, and durability that enables measurement over long periods in the high-speed range.

The new measurement system was used to measure piston temperatures in engine bench tests, and the effects of different operation parameters on piston temperature were quantitatively understood. In addition, a piston temperature map was created for engine operating conditions from low to high loads, and the results indicated the potential for piston temperature control to enhance fuel economy.

The new measurement system was mounted in an actual vehicle and used to measure and compare the fluctuation

in piston temperatures in NEDC mode, and temperatures during DPF regeneration.

The new measurement system features durability and ease of mounting, and use in the future is expected to increase overall vehicle efficiency including engine heat management.

References

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