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Research Paper

Memory test system for piston steady-state temperature measurement

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HIGHLIGHTS

- A memory test system has been developed.
- Signals are almost constant under a steady working condition.
- Memory test system has very high precision.
- Memory test system has been used for piston temperature measurement.
- Memory test system can reliably get piston temperature.

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ABSTRACT

Regarding the high thermal load of piston in engines, a novel apparatus, memory test system (MTS), was designed for steady-state temperature measurement of piston. By heating MTS up to 100 °C and 120 °C respectively, a test was carried out to verify the system and measure its error. Considering poor working conditions in engine, the readings of MTS and thermal plugs were compared with each other through an engine test to confirm the reliability of MTS. Moreover, MTS was used to measure piston temperature under multiple working conditions. The results show that MTS has very high precision and reliability and is competent in multi-condition test. MTS is an effective tool to measure piston temperature.

1. Introduction

Piston is one of the most important components in the engine. It often suffers from extremely high thermal load. Its temperature is not only a key factor to evaluate thermal load [1,2], but also an indispensable boundary condition for combustion and emission simulations [3–5]. Thus, measurement of piston temperature is quite meaningful. But lots of harsh conditions, such as high-speed reciprocating motion, narrow space under piston, oil mist with low visibility and complex electromagnetic environment, pose a great challenge to acquisition of piston temperature.

Currently, there are three methods widely used to measure piston temperature, respectively the thermal plug thermometry, the phosphor thermometry and the electric thermometry.

The thermal plug thermometry (referred to as 'templug' in following contents) determines the temperature according to the change in material properties of the templug. However, only the maximum temperature exerting on the templug can be acquired due to the irrecoverability of material change. Thus, this method is powerless in multi-condition test. Barna et al. [6] and Daniel et al. [7] respectively compared piston temperature measurement methods of templug and electric thermometry, and found that templug readings were often much higher than electric thermometry when templugs were installed at the top surface of piston.

The phosphor thermometry exploits the temperature-dependent feature of luminescent phosphor to indicate thermal field of surfaces. Phosphors are adhered to the surface of the piston head before engine test. A pulsed laser is used to excite the phosphor particles. Moreover, optical access often located on cylinder head is necessary for light access. So it costs quite much during the implementation of this approach. In spite of that, phosphor thermometry were widely used by engine researchers. Julian et al. [8] measured the temperature of combustion chamber surface on a single-cylinder diesel engine, and found that phosphorescence decay signal would be interfered by combustion luminosity. Husberg et al. [9] exploited phosphors and electric thermometry in a heavy-duty diesel engine, and found that phosphors reading fluctuation was much greater than electric thermometry and more seriously that soot deposits might lead unsuccessful measurement.

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In the pursuit of higher accuracy, attempts were made to utilize thermocouples or thermistors as sensors of electric thermometry in the piston temperature measurement. Whereas, how to send signals out from the engine is a fraught topic. One solution is to send the measured data out through wires mounted along the linkage mechanism. Shoichi and Enomoto [10] firstly developed this method. Then Assanis et al. [11,12], Kenninglry and Morgenstern [13] respectively developed similar devices. To improve the reliability of signal wires further, Jeon et al. [14] developed a twin linkage system. Generally, fatigue failure of signal wires frequently occurs in the linkage method. Thus, extra mechanism are utilized to prolong the system lifetime, which in return adds to the cost. Another method, the telemetry system, is also widely used, which sends data by means of wireless transmission technology. Barna et al. [6], Scott et al. [15,16] and Lee et al. [17] respectively used infrared, microwave and bluetooth telemetry system to transform data. In these systems, transmitters consume much power and increase the system volume. Moreover, wireless signals, such as microwaves and infrared lights, are interfered in the oil sump. The third method is to send signals out through electromagnetic loop, when receiver coil, installed on piston, approaches the resonator coil which is mounted on cylinder body. A map, such as temperature-voltage diagram, is indispensable to convert the received data into temperature. Kato et al. [18] developed an electromagnetic induction apparatus and provided a corresponding map for temperature calculating. Suzuki et al. [19] designed a similar apparatus. Then Lee et al. [20] verified the electromagnetic induction apparatus with a telemetry system. For this method, it is difficult to provide a proper map for temperature calculating and the improper installation of coils would bring great errors as well. In sum, these existing methods are not satisfactory, either unreliable or inefficient.

This article introduces a novel apparatus designed for electric thermometry, denoted the Memory Test System (MTS), which is hopeful to be both reliable and efficient. Functionally, the MTS mounted on piston-pin boss collects and stores signals from thermocouples. In the following contents, performance of the MTS will be inspected through out-of-engine error evaluation. Furthermore, simultaneous measurement results of the same piston utilizing MTS and templugs are compared to confirm its reliability in real engines. Finally, a series of multiple condition tests are conducted to measure piston temperatures with the help of MTS.

2. System principle

MTS adopts thermocouples as temperature sensors. It consists of two components, the data acquisition unit and the storage unit, as shown in Fig. 1. The data acquisition unit regulates signals from thermocouples and sends them to the storage unit in line. The storage unit stores these signals. After the experiment, data stored in the storage unit will be read out by the computer for post-processing.

2.1. Data acquisition unit

The data acquisition unit collects eight signals, $X_0 \sim X_7$, of which there are one drift signal (X_0), two cold-junction compensation signals (X_1, X_2) and five thermocouple signals ($X_3 \sim X_7$). To collect these signals, the data acquisition unit consists of three parts, compensation circuit, temperature-based triggering switch and analog switch circuit, as shown in Fig. 2.

2.1.1. Compensation circuit

The compensation circuit measures thermocouple cold-junction temperatures. A platinum resistor is used to measure the temperature near thermocouple cold-junctions, which is very close to cold-junction temperatures and regarded as it. To improve signal acquisition accuracy, a bridge is used to collect the voltage of platinum resistor, as shown in Fig. 3.

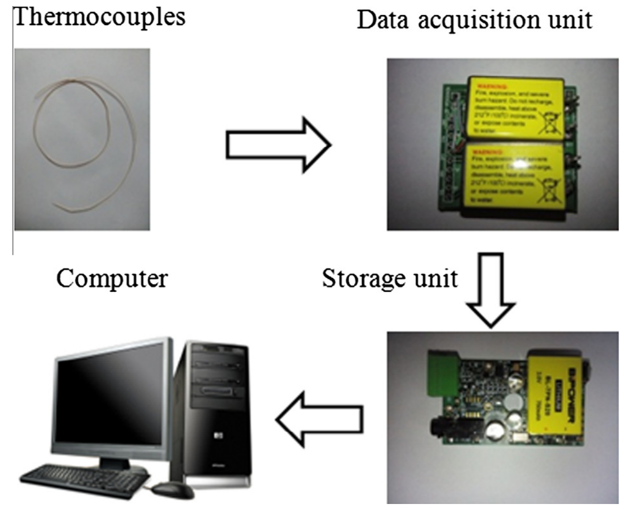

Fig. 1. Memory test system structure.

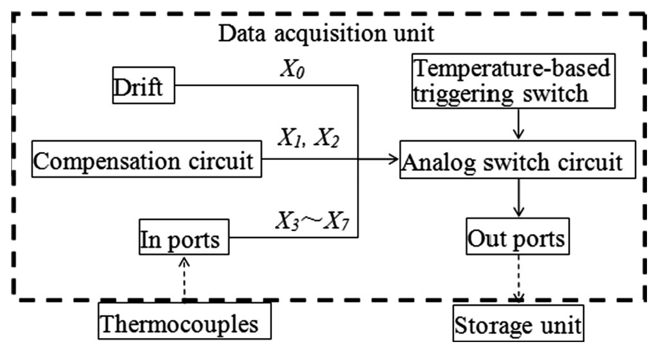

Fig. 2. Structure of data acquisition unit.

X_1 and X_2 stand for the voltages of R_7 and Pt_{1000} (the platinum resistor) of which the resistance value varies with temperature by 3.85 Ω/°C. Considering the drift of system, the cold-junction temperature, T_c, is calculated by Eq. (1).

$$T_c = (X_2 - X_1)/(X_1 - X_0) \times 260 \tag{1}$$

2.1.2. Temperature-based triggering switch

To reduce power consumption before experiments, the temperature-based triggering switch is designed to control the working state of analog switch circuit. A negative temperature thermistor is used to detect the environment temperature of system. Only when the environment temperature is more than 60 °C, would the temperature-based triggering switch awaken analog switch circuit. Otherwise, the analog switch circuit will be inactive and the system will consume little power. With the aid of

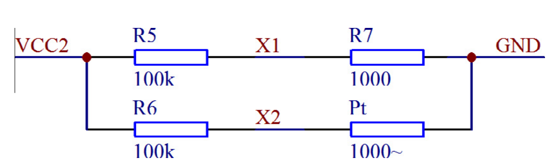

Fig. 3. Cold-junction temperature circuit.