IOP Conf. Series: Materials Science and Engineering **157** (2016) 012010 doi:10.1088/1757-899X/157/1/012010

Design of wireless temperature measurement system for piston based on CC2530

Ge Rongyu[1,*], Wang Jin[1], Wu Yimin[2], Wu Guodong[2],

[1]School of Mechanical Engineering，University of Jinan, Jinan 250022, China
[2]Shandong Binzhou Bohai Piston Co., Ltd, Binzhou 256602, China

* me_gery@163.com

Abstract. Temperature measurement of piston is important to analysis its temperature field. Since it is difficult to extract the temperature signal in the piston by hard line, a multi-channel wireless measurement system of piston temperature is developed. The wireless SOC CC2530 is used. NTC thermistors with glass package are selected as temperature sensors. The realization of hardware and the design of software flowchart are explained in detail. The actual test demonstrates that the system has high measurement accuracy and strong practical value.

1. Introduction

The piston, as the key part of the internal combustion engine, is always running with the largest thermal load. As piston durability has an important influence on the lifetime, reliability, emission performance and economy of the internal combustion engine, piston temperatures are useful information for engine development. However, the current limitations of piston-temperature measurement systems make accurate measurements a difficult task. The difficulties are mainly due to piston revolution speeds over 6,000 r/m, accelerations over 2000g and temperatures in excess of 300 degrees Celsius[1].

The piston temperature can be measured in five ways: templugs, contact method, electromagnetic induction ,telemetry and optical method. Templug[2], a traditional measurement tool, has a short and simple preparation but the disadvantages are that it can only measure a maximum temperature and its error range is quite large. Contact method[3] can get most accurate temperature measurement but a disadvantage is that many engine parts need to be redesigned and a rather long preparation time is required. By the electromagnetic induction method[4], the signal transmission is not continuous and limited at the BDC. In addition, the number of measurement channels is limited. By the telemetry method[5], the electronic circuits connected to the temperature sensor are installed in the piston. In this method, signals are transferred via various media, such as infrared rays, radio frequency (RF), Bluetooth and so on. The method for optical measurement[6] is an innovative method, which works by detecting the thermal radiation emitted from the hot piston surface. It does not need any contact with the measured surface and can derive the surface temperature without temperature gradient. But it needs complicated preparation and special instruments. The emergence of wireless system-on-chip (SOC) provides a new solution to measure the piston temperature making the system simple and easy to develop. A wireless temperature measurement system for piston based on CC2530 is developed. This measurement system can be installed in the in real commercial engines and thus is small and compact.

2. General design of measurement system

The wireless temperature measurement system for piston, as shown in Figure 1, is mainly composed of power unit, temperature signal acquisition unit, wireless transmitting unit, wireless receiving unit and host computer.

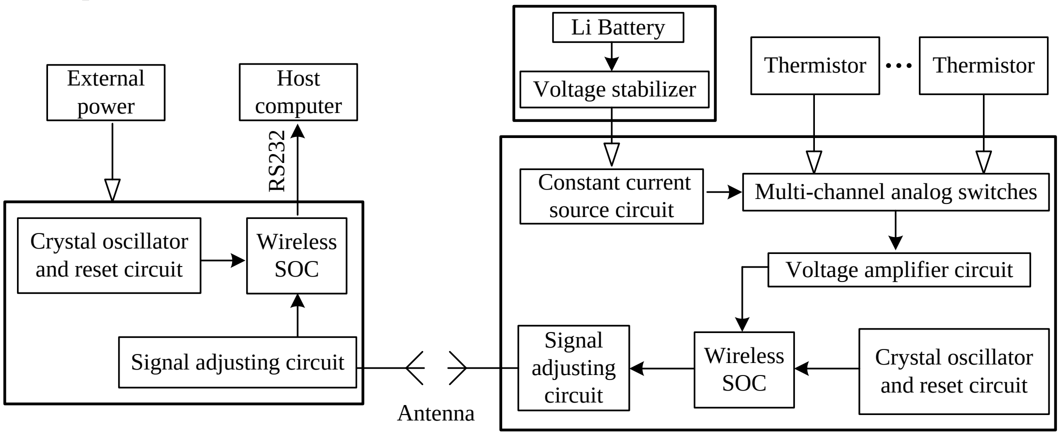

Figure 1. General design diagram of system

The power unit provides stable power for the whole system including Li battery and voltage stabilizer. The temperature signal acquisition unit is used to transfer the temperature signal in piston into voltage signal including temperature sensors, multi-channel analog switches, constant current source circuit and voltage amplifier circuit. Both the wireless transmitting and receiving unit use the wireless SOC CC2530. The voltage signal of piston temperature is adjusted with suitable level and connected to A/D pin of the master CC2530. After A/D transformation, the master CC2530 will transmit the numerical values to slave CC2530 with the point-to-point protocol. The slave CC2530 will sent the signals to host computer by the serial port. Eventually, the temperature valued will be arrived when the host computer gets and then processes the data with communication software.

3. Hardware design

3.1. Power unit design

The operating voltage is 3.3V for the whole system, so in this way it is avoided to convert different voltages and it have also some advantages such as low power consumption and easy development. As is shown in Fig.2, The system power is provided by Li battery with 3.6Voutput voltage and high temperature resistance. The stable 3.3V voltage can be output throughout the Power Management IC TPS63020.The TPS63020 is the industry's smallest and highest performance buck-boost converter with a 4-A switch and up to 96 percent efficiency, whose input voltage range is 1.8V to 5.5V, fit to manage the Li battery.

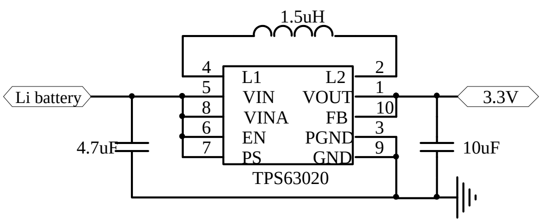

Figure 2. Schematic of power unit

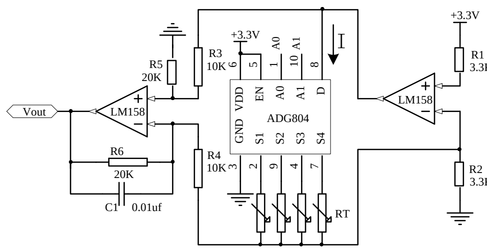

Figure 3. Schematic of temperature signal input unit

3.2. Temperature signal acquisition

3.2.1. Temperature sensor. There are three most widely-used temperature transducers: thermocouples, resistance temperature detectors (RTDs), and thermistors. A thermocouple produces a temperature-dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature. Thermocouples can measure a wide range of temperatures up to 1700°C, but the main limitation with thermocouples is bad accuracy and big volume. RTDs are made from a pure material, typically platinum. The material has a predictable change in resistance as the temperature changes and it is this predictable change that is used to determine temperature. RTDs have also a wide measurement range up to 800°C, but because of their big volume, they are not suitable to be assembled in pistons. Thermistors are similar to RTDs because they change resistance between their terminals with a change in temperature. However, they can be made with either a positive or negative temperature coefficient. The negative temperature coefficient (NTC) thermistor is widely used , which means that the resistance decreases with increasing temperature. Thermistors have small volume and are more sensitive and accuracy than RTDs but have a smaller temperature range up to 350°C. Since the assembling room is limited in piston and the maximum working temperature is less than 350°C, so NTC thermistors with glass encapsulated are used as the temperature sensors in this system. This kind of sensor with only 2mm diameter is easy to be assembled in piston and can also satisfy the temperature testing range of pistons.

The temperature inside pistons is close to the maximum test value of NTC and NTC has a much lower ratio of resistance change per ℃ in high temperature. Because the higher nominal resistance value, the higher ratio, so NTCs with 100K nominal resistance at 25℃, whose resistance is about 0.1KΩ with about 3Ω ratio of resistance change per ℃ at 300℃, are applied in this testing system.

3.2.2. Multi-channel analog switch Temperatures of many points inside piston need to be tested such as bottom of combustor, oil ring groove, skirt and pine hole. So method of time division multiple access is executed by applying the multi-channel analog switch IC ADG804, which decides voltages from all thermistors will be transited in turn to differential amplifier, as is shown in Fig.3. The ADG804 switches one of four inputs to a common output, as determined by the 2-bit binary address lines, A0 and A1.In this way, PCB of whole system has small volume and simple interface circuit. The inherent resistance of ADG804 is only 0.5Ω, almost no influence to the test results.

3.2.3. Make a Thermistor Measurement Because thermistors are resistive devices, you must supply them with an excitation source and then read the voltage across their terminals. This source must be constant and precise. Thermistors are usually made a measurement with either three-wire, four-wire or constant current source configurations. In order to improve the test accuracy and simply the design, constant current source supplied by a operational amplifier is adopted as depicted in Figure 3. The constant current can be derived as I=3.3/R2=1mA and R1 component is balance resistance. In this way, the resistance of thermistors can be transferred into voltage, and output voltage Vout derived after differential amplification is connected to A/D pin of CC2530.

The rang of piston temperature is 150℃ through 300℃ and during this range the change of thermistor resistance is from 1K to 1.5K and that of voltage is from 1V to 1.5V. So it works for A/D pin of CC2530 with twice of differential amplification. Because thermistors have a high nominal resistance, lead-wire resistance does not affect the accuracy of their measurements.

3.3. Wireless transmitting and receiving unit

Both the wireless transmitting and receiving unit have SOC CC2530 and its peripheral circuit and RF filter as shown in Fig.4. In addition, RS-232 communication interface between the wireless receive unit and host computer is needed to be designed so that the received data can be sent to the host computer.

3.3.1. SOC CC2530 CC2530 is a cost-effective, low-power and true system-on-chip (SOC) solution developed by TI. Its key features are described as extended operating temperature range from –40 to 125°C, less than 1μA current consumption in power down with sleep timer running, wide supply voltage range from 2 to 3.6V, which agree with the high working temperature and low consumption request of piston measurement system. There is a ADC in the CC2530 supporting analog-to-digital conversion with up to 12 effective number of bits. The effective resolution is 1.6mV for the reference voltage 3.3V, reaching requirement of test system of piston temperature. A 2.4-GHz IEEE 802.15.4

compliant RF transceiver is integrated in CC2530 to build Zigbee wireless net as well as communicate with point-to-point agreement.

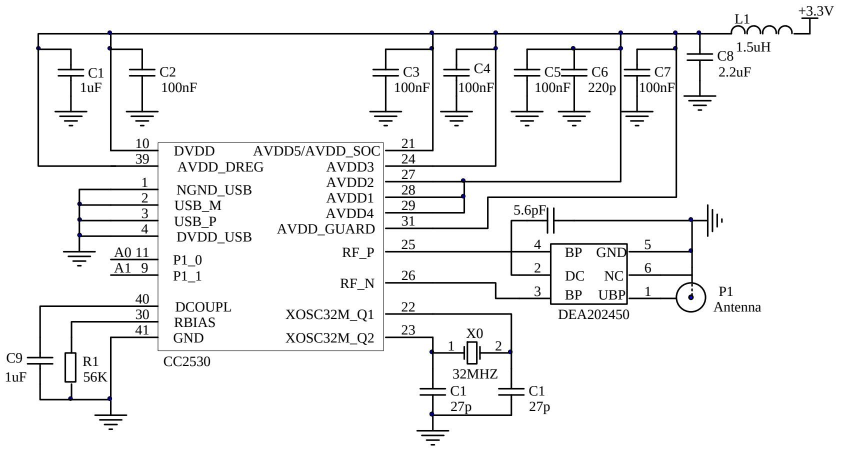

Figure 4. Schematic of wireless transmit unit

3.3.2. RF filter. The RF output of CC2530 is high impedance differential as seen from the RF ports (RF_P and RF_N), but the antenna is Single-Ended, so a balun convert between unbalanced and balanced signals is necessary. Balun circuit is usually composed of two capacitors and two resistances, but a integrating balance filter chip DEA202450 is used in the test system to reduce the peripheral design of CC2530, save the room of PCB and improve the RF performance.

4. Software design

The software design of the piston temperature measurement system accomplishes the program design of lower computer CC2530 on wireless transmitting unit and wireless receiving unit and the program design of the upper host computer as well.

4.1 Software design of wireless transmitting and receiving unit.

Wireless transmission unit mainly completes the wireless transmission of temperature data from all channels and the collection. The system collects and sends the temperature data every five minutes in order to reduce the power consumption and prolong the service life of the system and the rest of the time for CC2530 will work in sleeping mode. The wireless receiving unit mainly completes the data receiving and transmits them to the host computer through the serial port .

We will use the point-to-point communication mode when it receives and sends data, because the piston temperature testing system only comprises a sending end and a receiving end. And the program code is simple and clear by this mode. Besides, TI company provides ZigBee standard based on the protocol stack, and provides a series of API interface for the developer, so we need only to call the corresponding API function when we develop the wireless transceiver procedures. It is easy to editor program, because we should not set up ZigBee network.

4.2 Software design of host computer

The upper host computer mainly fulfills data processing, recording and displaying and so on, among which the data processing is most complex. On the one hand, we should calculate the resistance of the thermistor by the received voltage value Vout. On the other hand, we should determine the measured temperature by the R-T (resistance vs. temperature) tables thermistors.

5. Performance testing

It is put into the constant temperature furnace to carry out the simulation test in order to verify the testing precision of the system. Test results show that in the range of 150 degrees through 300 degrees, test accuracy of the piston wireless temperature measurement system is ±1℃, and it can fully meet the test requirements. On the power consumption, when we send the data of testing, the instantaneous working current of the wireless transmitting unit is 28mA, and the current is only 0.4uA in the sleeping mode. Thermistors are respectively buried in four tested points, which are the bottom of the piston combustion chamber, the first ring groove, the piston pin hole and the skirt. Then, the Li battery and the PCB are fixed on the inner cavity of the piston with high temperature glue. Assembly of the entire measurement system is shown in Fig.5. Finally we can proceed bench test and the real data of testing can meet the requirements.

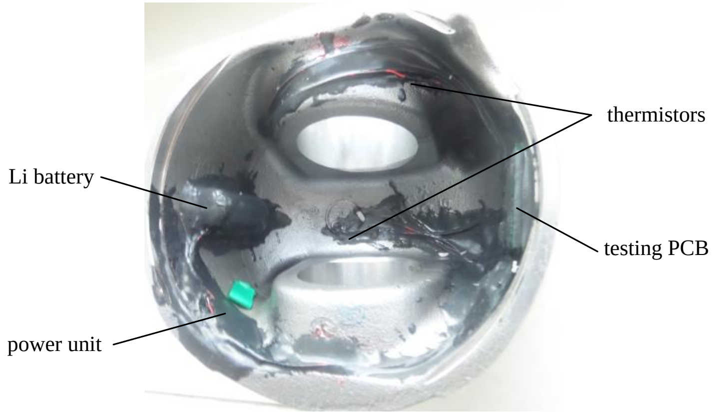

Figure 5. Assembly of entire measurement system

6. Conclusions

Temperatures inside the piston is difficult to measure because the temperature value is very high and installing room is limited as well as the reciprocating motion of piston with very high speed makes the signal get out hardly. A multi-channel wireless temperature measurement system for piston based on CC2530 is designed in this paper with the advantages such as low power consumption, compact PCB, small volume, high test accuracy and no lining out. This system can meet the dynamic test requirements under high temperature, high speed and small installing space, which has a good extensive application prospect in the engine measuring field.

References

[1] Wang Qingsheng, Liu Kun. Thermal analysis of piston in high-speed gasoline engines. *Journal of Hefei University of Technology(Natural Science),* 2008, 31(6): 839-842.
[2] Lo K H, Shek C H, Lai K L. Metallurgical Temperature Sensors. *Recent Patents on Mechanical Engineering,* 2008, (1):225–232.
[3] TAKAMATSU H. Piston temperature measurement method for high-speed gasoline engines. *JSAE Review*, 1999, 53(20): 259-261.
[4] Lee H H, Bang W, Kauh S K, et al. Piston-temperature measuring system using electromagnetic induction with verification by a telemetry system. *International Journal of Automotive Technology*, 2011, 12(3):351-358
[5] LEE H W, OH C H, KAUH S K. Development of a multipiston temperature telemetry system using bluetooth networks. *Journal of Automobile Engineering*, 2006, 220(2):127- 138.
[6] Husberg T, Gjirja S, Denbratt I. Piston Temperature Measurement by Use of Thermographic Phosphors and Thermocouples in a Heavy-Duty Diesel Engine Run Under Partly Premixed Conditions, *SAE paper,* 2005-01-1646.