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Temperature Characteristics for PTC Material Heating Diesel Fuel

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ABSTRACT

This paper gives a way which utilizes the PTC (Positive Temperature Coefficient) material to preheat diesel fuel in the injector in order to improve the cold starting and emissions of engine. A new injector is also designed. In order to understand the preheating process in this new injector, a dynamic temperature testing system combined with the MSP430F149 data acquisition system is developed for PTC material heating diesel fuel. Especially, the corresponding software and hardware circuits are explained. The temperature of diesel fuel preheating by PTC ceramics is measured under different voltages and distances, which Curie point is 75 ^{o}C. Diesel fuel is heated by self-defined temperature around the Curie point of PTC ceramics. The diesel fuel temperature rises rapidly in 2 minutes of the beginning, then can reach 60 ^{o}C within 5 minutes as its distance is 5mm away from the surface of PTC ceramics. However, there are a lot of fundamental studies and technology to be resolved in order to apply PTC material in the injector successfully.

Keywords: Temperature, measurement, PTC, injector, MSP430F149

1. INTRODUCTION

The automobile rules have been stricter because of the stability augmentation of the vehicle fleet in the world. EuroIII, EuroIV and FTP-75 demand for testing the emissions of the cold starting at -7 ^{o}C since 50%~80% HC (Hydrocarbon) and CO (Carbon Monoxide) are generated during the cold starting[1]. Limits and measurement methods for emissions from light-duty vehicles (GB18352.3—2005) require to sample the exhaust gas after starting the engine immediately, measure the emissions of the HC and NOx (Nitrogen Oxides), moreover, gauge the THC (Total Hydrocarbons) and CO at -7 ^{o}C under the cold starting.

The HC and CO emissions are the main problem for the cold starting of the gasoline engine. Furthermore, for the diesel fuel engine, improving the cold starting capability is as important as minimizing emissions. People have studied the various methods to reduce the automobile emissions for a long time

2. MOTIVATION

Since 1990, the HC emissions of the internal combustion engine have been studied profoundly in the process of the cold starting[2,3]. Many factors have contributed to the cold starting emission and capability. In order to decrease the emissions during the cold starting, Yao Chun-dei finds that the HC emission has been decreased about 36% and the CO has been fallen by 13% via using the heat storage tank and raising the inlet gas temperature to 70 ^{o}C [4]. Qiao Xin-qi, et al. investigate the effects of oxygen-enriched intake air on the cold starting emissions from an spark-ignition engine, and find that the emissions of the HC and CO lessen notablely[5,6]. What's more, Zimmermann F. installs a heater in the injector. The fuel temperature can be heated to 65 ^{o}C within 5 seconds, and the steady state temperature is 70 ^{o}C to 90 ^{o}C,

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while the flow is 0.1g/s to 0.7g/s in the injector. On this condition, nearly 50% fuel change into gaseousness in the intake-tube, and the HC cut down by 20% after 20 seconds during the idle period[7]. Seoksu Moon considers that the jetting length is lowering, and the jetting width is increasing as the slit injector temperature rises, but the rule is opposite to the swirl injector. The PDA (Particle Dynamic Analyzer) testing results for these two injectors show that the spray grain diameter decreases with the injector temperature rising. The cold starting and warming process testing for the slit injector show that the THC cuts down with the injector temperature rising[8].

Rising the fuel or intake air temperature is an available way to decrease the cold starting emissions of the gasoline engine, and also improve the cold starting capability and emissions of the diesel engine. And the fuel quality is much less than the intake air quality. Consequently, it needs little thermal to raise the fuel temperature for improving the cold starting and warming-up of the engine. This paper gives a way which utilizes the PTC materials to preheat diesel fuel within the injector in order to improve the cold starting and emissions of engine[9].

A PTC material is characterized by a slight change in resistivity up to a certain temperature, the Curie temperature, and then its resistivity increases quickly by several orders of magnitude over a very small temperature range. Nowadays, the PTC materials have two types: the ceramic-based PTC material and the polymer-based PTC material. The ceramic-based PTC material has high resistance at the room temperature and relatively slow evolution of resistivity versus temperature above the Curie point. Furthermore, it’s expensive, fragile, and difficult to process and form[10]. The polymer-based PTC composite is a multiphase composite macromolecule conductor, which is obtained by blending an organic polymer matrix with some conductive filler like carbon black, graphite, or metal oxides. It has a good designability and a low-budget. In early 1980s, people utilized PTC materials to reduce the emissions of the motorcar[11]. Tan Hong-sheng, et al. adopt self-limited temperature heating material to produce the self-limited temperature heater for diesel vehicle[12]. Heating the fuel tank or pipe to elevating fuel temperature is the main application of the PTC materials. There are some defects like slow heating, large volume and much electric power consumption.

Otherwise, there are many advantages of installing the PTC material in the injector. Choosing different Curie point PTC materials ensure the self-limiting temperature heating in cold starting and warming with different fuels. Therefore, the fuel temperature must not exceed its boiling point avoiding the phase transition of fuel in the injector. Moreover, the PTC heater is small and heating rate is very fast because there is little fuel mass in the injector.

However, there are a lot of fundamental studies and technology to be resolved in order to apply PTC material in the injector successfully. This paper designs this new injector, and studies the preheating process in the injector. The results validate that the heating rate is very rapid by the PTC materials.

3. INJECTOR DESIGN

The new injector with PTC material is designed as Fig.1. This PTC injector includes the PTC ceramics, two thermal pipes and two insulation sheaths. The electric insulating coating is laid between the thermal pipe and PTC ceramics, but is easy to conduct heat. The PTC ceramics are manufactured as cylindrical tube and covered the thermal pipe, while the PTC ceramics are fixed in the insulation sheath. There are two PTC heating elements installed in the fuel inlet bolt and injector body respectively.

Before the diesel engine pump feeding fuel, the PTC ceramics in the fuel inlet bolt and injector body respectively heat the fuel to the Curie point, which is lower than the boiling point of diesel fuel. Then the heated diesel is injected into the engine cylinder in the cold starting. As a result, the emissions of the diesel engine are reduced and the capability of cold starting is improved.

4. TESTING EQUIPMENT

In order to understand the preheating process in this new injector, a dynamic temperature testing system combined with the MSP430F149 data acquisition system is developed for PTC material heating diesel fuel. This paper applies the ceramic-based PTC material as heating element, which Curie point is 75 ^{o}C.

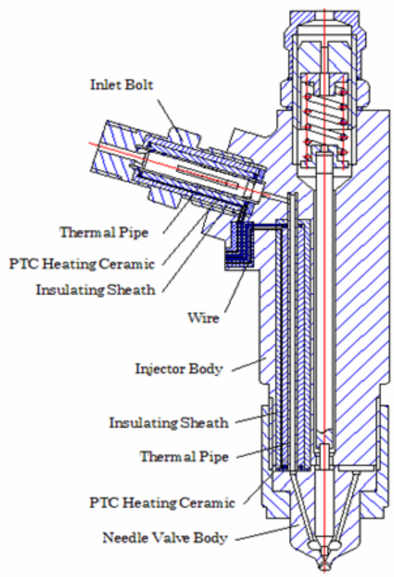

Fig.1: Schematic of injector with PTC material

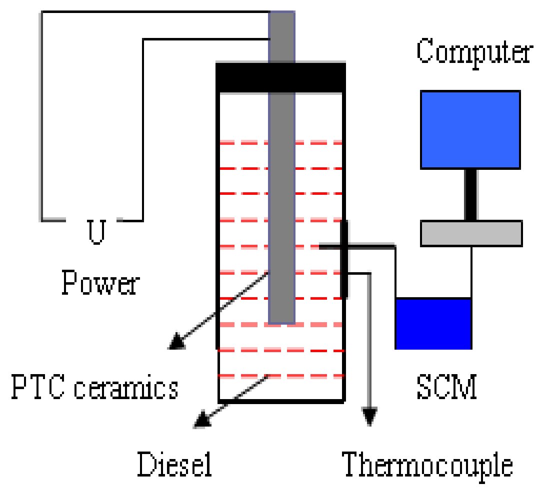

Fig.2: Schematic of experimental apparatus.

4.1 Testing equipment schematic

The diagram of testing equipment is shown as Fig.2. The measuring element is the K type thermocouple, and the heating media is 0# diesel fuel. The MSP430F149 is used to collect the data and translate it into computer to be processed.

4.2 Testing system

The dynamic temperature testing system comprises the PTC material, temperature sensor, amplification circuit, data acquisition system and display control module, etc.

4.2.1 Design of the hardware

The hardware of this system includes the PTC material, temperature sensor, amplification circuit and data acquisition system. The PTC material heats the diesel fuel at first. Then the temperature signals are converted into electric signals by the temperature sensor, and amplified by the amplification circuit. At last, the data acquisition system collects the amplified signals and transmits the A/D signals to the computer which analyses and processes the data. The INA118 and UA741 are served as main chip to amplifying signals, which are the central parts of data acquisition system. The testing voltage is 72V.

The main function of amplification circuit is to convert the weak analog signal to a strong signal which can be collected. The signal outputted from thermocouple is small as 2~3mV, therefore, many parameters need to be taken into consideration like anti-jamming, signal distortion, temperature drift and so on. In order to overcome these problems, the amplification is achieved through the INA118, which has the advantages of high-precision, low power, low temperature drift, high CMRR amplifier and high bandwidth. It can maintain a high bandwidth at a larger gain because of the special electric feedback structure (When the gain is 100, the bandwidth is 70kHz). The differential amplification structure of INA118 is made up of three operational amplifiers, and the over-voltage protection is built-in the INA118. The different gains (G=1+50000/Rg, G is the gain) can be obtained by setting different resistance. The stability of Rg and temperature drift have an effect on the gain, therefore, uses the metal film resistors which are high-precision and low noise to achieve a high gain. Rg is 250Ω in this design.

In order to avoid the data collect system turning into load, a voltage follower is connected between the amplification circuit and data acquisition system. The UA741 is used as voltage follower, which is single-supply op-amp and frequency compensation.

The MSP430F149 is a 16-bit ultra-low-power microcontroller, which has powerful processing capability, abundant module and maximum code efficiency[13]. The MSP430149 is a microcontroller configuration with two built-in 16-bit timers, a fast 12-bit A/D converter, two universal serial synchronous/asynchronous communication interfaces (USART), and 48 I/O pins. The A/D converter has 8 sampling channels, and its maximum sampling rate is 200kps. The MSP430F149 is the master chip in this system which works at the low-frequency crystal oscillator model and changes the sampling time via setting clock system control registers and A/D control registers. The analog signal which is amplified by INA118, converts into digit signal after the voltage follower elevating the load. Then, the related data is recorded by the computer. The reference temperature of thermocouple temperature sensor is 0 ^{o}C, but the environment temperature is the room temperature, therefore, the sampling signal inputted to the micro-controller has error. In order to solve this problem, the system applies the software to achieve temperature compensation and improves the sensor precision.

The temperature detector measures the temperature of sensor point. The micro-controller obtains the data through amplification circuit and acquisition system. The data is saved by the micro-controller. The sensor signal error acquires temperature compensation by executing the temperature error compensation program.

4.2.2 Design of the software

There is much development software for MSP430. This paper uses IAR Embedded Workbench from IAR Company and C – SPY debugger.

The analog signal from amplification circuit is converted to the digital signal using 12-bit A/D of MSP430 micro-controller. The program in this paper has two parts: main program and interrupt program. The main program has the following works: initialization, setting watchdog timer, enabled interruption and so on. The interrupt program checks the interruptible flag bit of A/D converter, if the sampling time detects the analog signal from amplification circuit, the program sets on interruptible flag to cause interruption. The interrupt program also stores the data from ADC12MEM to user-defined arrays with the purpose of intensifying data observability. The flow chart is shown as Fig.3.

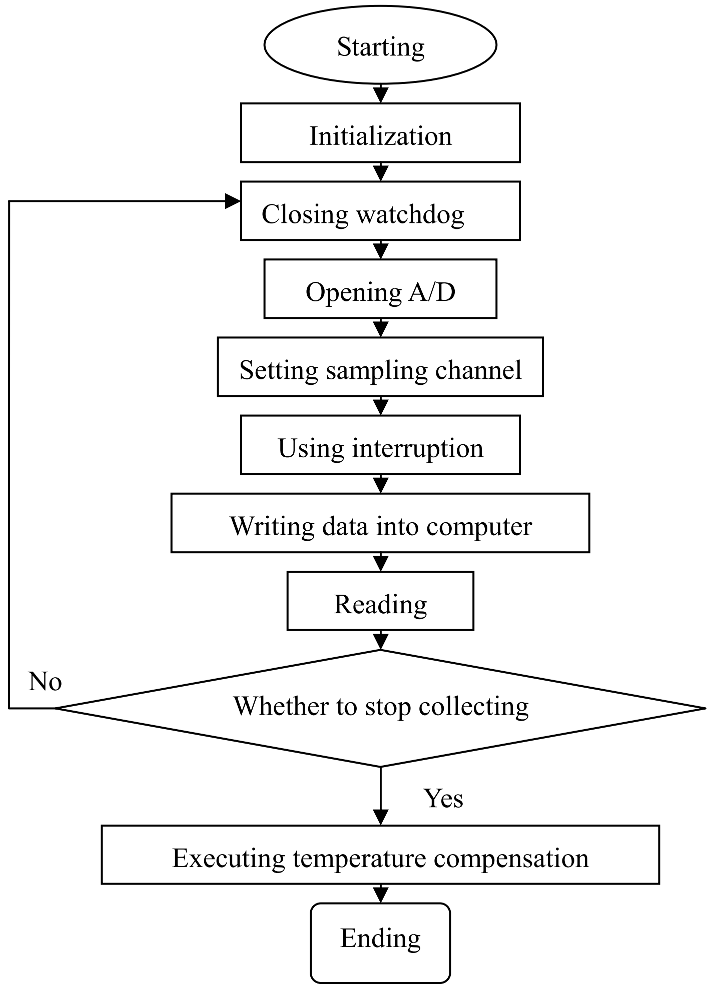

Fig.3: Main program flow chart.

5. RESULTS AND ANALYSIS

In order to understand the temperature variation of diesel fuel preheating by PTC ceramics under different voltages and distances, the air is utilized as the media at first, the voltages are 24V, 48V, 72V and 110V respectively, and the distances from the thermocouple to the surface of PTC ceramics are 0mm, 3mm, 5 mm and 8mm respectively. The testing results are shown in Fig.4 ~ Fig.7.

The Fig.4 shows that the temperature of PTC material surface increases slowly at 24V, but the temperature rising rate accelerates with the voltage building-up. At the voltage of 72V, the temperature increases to the Curie point in 2 minutes, furthermore, the time reduces to 1 minute at 110V. At different voltages, temperature variations from different disturbances of PTC heater are shown as Fig.5, Fig.6 and Fig.7. The Fig.8 and Fig.9 show the changes of diesel fuel preheating by PTC ceramics at 72V and 110V.

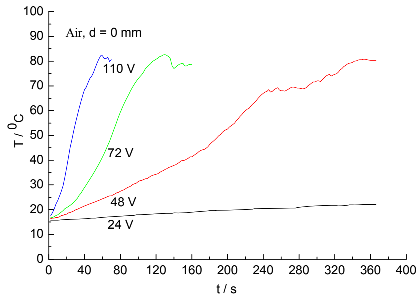

Fig.4: Surface temperature of PTC ceramics changing with time under different voltages.

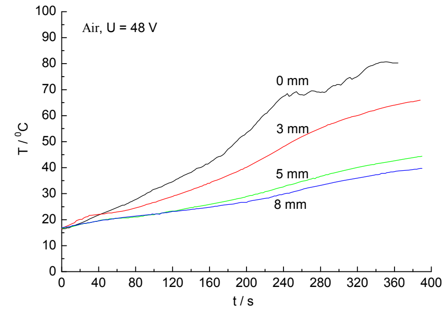

Fig.5: Heated air temperature above PTC ceramics changing with time under 48V voltage.

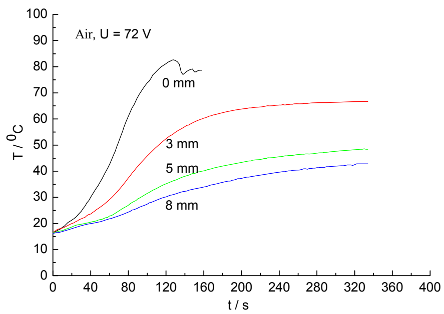

Fig.6: Heated air temperature above PTC ceramics changing with time under 72V voltage.

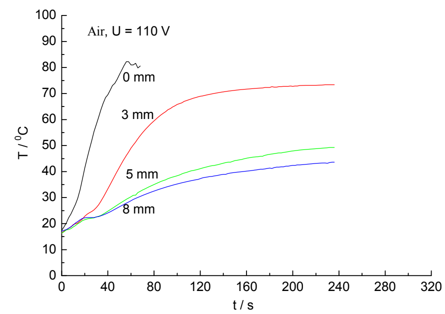

Fig.7: Heated air temperature above PTC ceramics changing with time under 110V voltage.

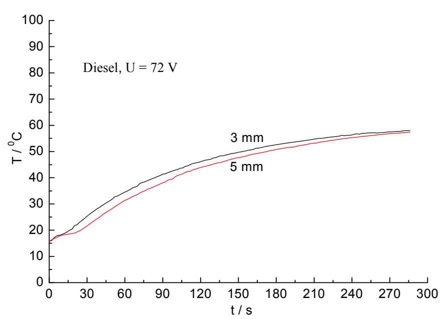

Fig.8: Heated diesel temperature above PTC ceramics changing with time under 72V voltage.

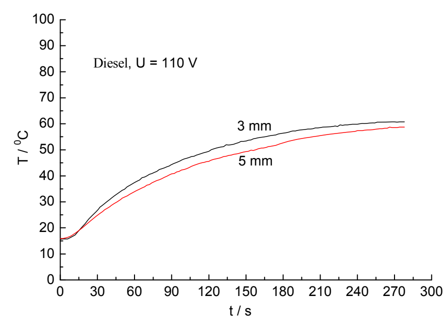

Fig.9: Heated diesel temperature above PTC ceramics changing with time under 110V voltage.

Fig.8 and Fig.9 present that the diesel fuel temperature rise rapidly in 2 minutes of the beginning, and can reach 60 ^{o}C within 5 minutes as its distance is 5mm away from the surface of PTC ceramics. All the data is measured under the static state, free connection heating transfer and the slow heat transmission (the Curie point is 75 ^{o}C). When PTC material is installed in the injector, fuel can be heated up to 60 ^{o}C within several minutes before starting the engine.

6. CONCLUSION

It's a good way to utilize the PTC material to preheat diesel fuel in the injector in order to improve the cold starting and emissions of engine. And this new injector is also designed. Based on the testing data, the diesel fuel can be heated to approximately the Curie point by the PTC material preheating.

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