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An introduction to hydrogen internal combustion engine test systems

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Abstract

The hydrogen internal combustion engine is popular worldwide as a clean energy driven engine. Whether the internal combustion engine produces abnormal combustion affects whether the internal combustion engine can fully utilize its power and can reach a most efficient state, so abnormal combustion is a problem that needs to be taken seriously in the study of any type of internal combustion engine. If the highest combustion pressure in the cylinder and the maximum pressure rise rate is too large, it will cause a burst, when the burst is too violent, it will bring many effects on the internal combustion engine, such as increased negative compression work, efficiency decreases, spark plugs and pistons and other parts of the thermal load increases easily damaged and other serious. This paper mainly provides the detection of cylinder pressure, cylinder temperature, engine speed and power, hydrogen mass flow and emissions, and briefly describes the detection principle, providing a program option for the detection of abnormal combustion in hydrogen internal combustion engines.

Keywords: hydrogen; internal combustion engine; test system;

1. Introduction

The invention of the internal combustion engine during the second industrial revolution brought about a great change in the way people travelled, and it has been more than 130 years since the development of the automobile. Hydrogen has been welcomed as a clean energy source by various countries around the world. Hydrogen can be used as a fuel and is converted into power by the heat released through direct combustion in the cylinder. Hydrogen as a new energy source has many parameters to be measured during the study of its working process, which is used to check whether the cylinder is working properly. This paper studies the way in which some of the parameters of a hydrogen internal combustion engine are measured.

1. In-cylinder condition parameters

1.1 Measurement of pressure

Cylinder pressure test is an important test item of engine mechanical performance testing, which is also an important way to judge whether the mechanical part of the engine is good, there are many places on the hydrogen internal combustion engine with pressure measurement, but the main want to get and control is the cylinder pressure, in the theoretical cycle cylinder pressure is

the engine piston running to the compression stroke on the stop, when the engine cylinder pressure reaches the maximum pressure, but in practice, due to the limited speed of fuel combustion, the highest pressure often appears in the upper stop after 12 to 15 ° CA crankshaft angle. Normal cylinder pressure is an important guarantee for the normal operation of the engine. If the cylinder pressure is too low, it will lead to incomplete combustion, reduce fuel economy and aggravate emission pollutants; if the cylinder pressure is too high, it will lead to excessive piston working resistance and easily lead to the piston gas ring to stop working, so the cylinder pressure of a hydrogen internal combustion engine is an important influencing factor for the normal operation of a hydrogen internal combustion engine [1]. In addition to the maximum pressure also need to pay attention to the maximum pressure rise rate, these are the main parameters to determine the tendency of internal combustion engine burst occurrence, so the cylinder pressure is an essential measurement parameter.

Pressure sensors are devices or devices that can feel the pressure signal and convert the pressure signal into an output electrical signal according to certain laws. There are many kinds of pressure sensors, because the highest combustion pressure in the cylinder of hydrogen internal combustion engine can reach 4-6MPa, some pressure gauges do not have such a large measurement range, this paper chose the spring tube pressure gauge, single-turn spring tube pressure gauge structure is simple, easy to use, wide measurement range and other advantages, choose different materials to measure the pressure in the range of 0 ~ 1000MPa, according to the highest combustion pressure in the cylinder of hydrogen internal combustion engine The spring tube made of brass is selected according to the highest combustion pressure in the cylinder of hydrogen internal combustion engine, and the measuring range is from 0 to 20MPa.

This paper uses a sapphire pressure sensor, which utilizes the strain-resistive operating principle and uses silicon-sapphire as the semiconductor sensitive element, and has unparalleled characteristics for metering DX100T series high-temperature sensors. Sapphire is composed of single crystal insulator elements, which do not suffer from hysteresis, fatigue and creep; sapphire is stronger and harder than silicon, and is not afraid of deformation; sapphire has very good elasticity and insulation characteristics, therefore, the semiconductor sensitive element made of silicon-sapphire is not sensitive to temperature changes, and has very good working characteristics even under high temperature conditions; sapphire has very strong radiation resistance characteristics. In addition, silicon-sapphire semiconductor sensitive elements radically simplify the manufacturing process, improve repeatability, and ensure a high yield. Pressure sensors manufactured with silicon-sapphire semiconductor sensitive elements can operate properly under the harshest operating conditions with high reliability, good accuracy, minimal temperature error, and high cost performance.

The pressure transducer and transmitter consist of a double diaphragm: a titanium alloy measuring diaphragm and a titanium alloy receiving diaphragm. A thin sapphire sheet printed with a heterogeneous epitaxial strain-sensitive bridge circuit is welded to the titanium measuring diaphragm. The measured pressure is transmitted to the receiving diaphragm (the receiving diaphragm is firmly connected to the measuring diaphragm by a tie rod). In response to the pressure, the titanium receiver diaphragm is deformed, and this deformation is sensed by the silicon-sapphire sensitive element, which changes the bridge output by an amount proportional to the measured pressure.

The sensor's circuitry ensures power supply to the strain gauge bridge circuit and converts the out-of-balance signal from the strain gauge bridge into a unified electrical output. In absolute pressure sensors and transmitters, a thin sapphire sheet is connected to a ceramic-based glass

solder that acts as an elastic element to convert the measured pressure into strain gauge deformation for the purpose of pressure measurement.

1.2 Measurement of temperature

Each type of internal combustion engine has its specific operating temperature range, which is one of the important conditions to ensure the normal operation of the internal combustion engine. The temperature is too high or too low will cause serious harm to the internal combustion engine, so it must be given full attention, especially not to ignore the serious harm of low temperature on the internal combustion engine. To take practical measures to ensure that the internal combustion engine work in the normal temperature range. To make the internal combustion engine in a higher state of usability economy dynamics operation, to extend its service life [2]. The use of hydrogen internal combustion engines is no exception, as gasoline is similar to hydrogen in some aspects of its properties, so it is possible to convert gasoline engines into hydrogen internal combustion engines. A single-cylinder four-stroke Port Fuel Injection hydrogen engine was modified from a Jialing JH600 gasoline motorcycle as a base.

There are many ways to measure temperature, temperature measurement instruments according to its principle of action can be divided into: the use of liquid or solid heat expansion of the nature of the expansion thermometer, the use of a gas or liquid enclosed in a fixed volume of saturated vapor heat volume expansion or pressure changes in the nature of the pressure gauge thermometer, the use of conductors or semiconductors after heat resistance change in the nature of the RTD thermometer, the use of the object's thermoelectric properties Thermocouple thermometer and the use of the nature of the object heat amplitude radiation pyrometer, etc.

1.2.1 Principle of operation

In this article the thermocouple thermometer is chosen. The basic principle of thermocouple temperature measurement is that two conductors of different composition form a closed loop, when there is a temperature gradient at both ends, there will be a current through the loop, then there is an electric potential between the two ends - the thermoelectric potential, which is known as the See beck effect. Two homogeneous conductors of different composition are the hot electrodes, the higher temperature end being the working end and the lower temperature end being the free end, which is usually at a constant temperature. Based on the thermoelectric potential as a function of temperature, a thermocouple indexing table is made; the indexing table is obtained for the free end temperature at 0°C. Different thermocouples have different indexing tables [3].

Due to the high temperature and pressure in the cylinder of the internal combustion engine, while strong airflow movement, working conditions, to accurately measure the temperature of the cylinder there is a great trap, so high temperature thermocouple in addition to meet the general thermocouple performance, should also meet the following technical requirements: (1) high temperature resistance. Cylinder airflow temperature up to 2000 K or more, and temperature distribution is not uniform, temperature gradient, cannot use the contact method to measure temperature, the most difficult problem is to protect the shell of the high temperature problem. (2) compact structure. In the internal combustion engine cylinder head and cylinder body are arranged with many required parts, which brings many difficulties to install high temperature thermocouple, so in the design process should be minimized its damping area, for this reason to ensure the insulation at the same time require electric thermocouple compact structure. Based on the above considerations, the thermocouple chose a simple structure, using a new type of high temperature material - high temperature crystal silicon carbide composite silicon nitride to do the

thermocouple protection shell, this material has high temperature resistance, vibration and thermal shock resistance and good oxidation resistance characteristics.

2. Evaluation indicators

2.1 Measurement of dynamics

With the progress of the times, people are not satisfied with the low speed of the car, in the continuous pursuit of higher power performance, the power index of the car is mainly expressed by the maximum speed, acceleration ability and maximum climbing degree, these are the most basic and important performance in the use of the car performance. Generally speaking, power and torque are measured to determine the dynamics of an engine. The eddy current dynamometer of DW series is used in this paper. The eddy current dynamometer can be divided into inductor type and disk type, and the inductor type is chosen in this paper. The eddy current dynamometer has the following advantages: bi-directional testing and wide speed range; rapid response and convenient control; low starting torque and wide testing range; and not affected by the cooling water inlet pressure [4].

2.1.1 Principle of operation

The structure of eddy current dynamometer shows that the inductor is mainly composed of rotating parts and oscillating parts (armature and excitation coil). The inductor on the rotor shaft is shaped like a gear and is fixed with a DC excitation coil coaxially with the rotor. When there is a DC current flowing through the excitation winding, a magnetic field exists around it and a closed magnetic flux is generated around the excitation winding. Obviously, the receptor on the left side of the winding has one polarity and the right side has the opposite polarity. When rotating, eddy currents are generated due to periodic changes in magnetic flux. The magnetic field generated by this eddy current interacts with the magnetic field that generates it, thus generating a braking torque in the opposite direction of the test machine, causing the armature body to swing and transmitting the braking force to the measuring device through the force arm on the armature body. The vortex current makes the vortex ring hot, and the cooling water entering the vortex ring takes the heat away, realizing the energy exchange of power and heat balance. Since the rotational speed is required to measure the power, the rotational speed is measured using a non-contact magnetoelectric speed sensor and a 60-tooth tooth disc mounted on the spindle, which converts the speed signal into an electrical output [5].

Power Measurement

$$P=N\times n/10000(kW) \quad (1)$$

In equation 1

N—Load (N)

N—Rotational speed (r/min)

Torque measurement

$$M=N\times L \quad (2)$$

In equation 2

N—Load (N)

L—Calculated arm length is 0.95493m

2.2 Measurement of economy

The higher the engine power, the higher the fuel consumption rate, and not just the pursuit of power, some car companies will give up part of the power for better economy. Economy is generally evaluated by fuel consumption rate, and the measurement of economy is actually the measurement of hydrogen supply mass flow. In this paper, the WSAT-LK intelligent flow controller was chosen [6]

From the relationship between fuel consumption rate and fuel consumption B and power P, it is known that fuel consumption rate can be calculated by fuel consumption B and power P.

$$b_i = \frac{B}{P_i} \times 10^3 \text{ [g/（kw·/h）]} \quad (3)$$

In equation 3

B-fuel consumption (kg/h) can be obtained by the flow of hydrogen supply mass

P-Power (kw)

The WSAT-LK intelligent flow control meter was selected for this paper. The measurement of this flow meter differs in the calculation formula depending on the input signal. The input signal can be pressure difference, flow rate, frequency, in this paper the input signal is pressure difference. The mass flow rate calculation formula is as follows.

$$M = K \times \sqrt{\rho \times \Delta p} \quad (4)$$

$$K=3.995*\alpha*\varepsilon*d^2 \quad (5)$$

$$\alpha = \frac{C}{\sqrt{1-\left(\frac{d}{D}\right)^4}} \quad (6)$$

In equation 4

M—flow mass measurement

In equation 5

α—flow coefficient

ε—flow beam expansion coefficient

In equation 6

C—outflow coefficient

D—The diameter of the throttle hole or throat of the throttle member under working conditions throttle orifice plate opening diameter (mm)

d—upstream pipe inner diameter under working conditions

2.3 Measurement of Emissivity

In order for a car to be able to drive properly on the road, it must first of all meet the national emission standards. With the development of the economy, the awareness of environmental

protection has increased worldwide and the emission standards for cars are constantly being improved. The hydrogen internal combustion engine is fuelled by hydrogen, which as a clean energy source itself has only water as a product of combustion without any polluting gases. However, the gas inhaled during the combustion process is not pure oxygen, but natural air, which contains 78% nitrogen, and the temperature of hydrogen is very high when it is burned in the cylinder, and nitrogen reacts with oxygen under high temperature conditions to produce nitric oxide or nitrogen dioxide [7].

Since the amount of exhaust gas emitted from one hydrogen internal combustion engine test is not very large, the full volume sampling method can be used to collect all the exhaust gas generated from the test in a gas bag of sufficient volume, and the sample should be analyzed as soon as possible after completion to avoid oxidation of some products and reduce measurement errors. The exhaust gas emitted from the hydrogen internal combustion engine is mainly nitrogen oxides and a small amount of carbon oxides and hydrocarbons.

i) Non-dispersive light infrared analyzer (NDIR)

This method is mainly used to measure CO and CO_2 in exhaust gas. non-dispersive infrared analyzer, also known as non-diffusive infrared analyzer, is based on the principle that most asymmetric molecules have the ability to absorb infrared light at certain wavelengths in the infrared band, and the degree of absorption is related to the concentration of the gas being measured. Different gases have their specific wavelength absorption peak bands within the infrared band, such as CO absorbs infrared at 4.5-5um, CO_2 at 4-4.5pum, and HC at 2.3, 3.4, and 7.6pm [8].

ii) Hydrogen flame ion analyzer (FID)

The principle of FID is to use the organic hydrocarbon HC burning in the high temperature of hydrogen flame (2000C), some HC molecules or atoms will be ionized to generate free ions, while pure hydrogen flame almost does not produce free ions, if an electric field is applied, an ionic current will be formed to generate a weak current signal, the magnitude of the current and the number of carbon, specimen The magnitude of the current is proportional to the number of carbons, the flow rate and the concentration, and the output current is obtained by the current amplifier. This signal is related to the flow rate of the measured gas in the hydrogen flame and the concentration of HC, and is proportional to the number of carbon atoms in the HC. Therefore, the HC concentration measured by the FID is expressed as 10^{-6}C.

iii) Chemiluminescence Analyzer (CLA)

This method is mainly used to measure NO and NO_2 in exhaust gases, which can also be measured by NDIR and ultraviolet analyzer (NDUV) respectively, but neither has the advantages of CLA in terms of high sensitivity, fast response, and suitability for continuous analysis at low concentrations [9].The interaction of NO and excess O_3 produces certain radical NO_2* molecules, which decay to the ground state NO_2 then emits light quanta at wavelengths of 590-2500 nm h_v.

The reaction equation is as follows.

$$NO + O_3 \rightarrow NO_2^* + O_2$$
$$NO_2^* \rightarrow NO_2 + h_v$$

To increase the sensitivity of the CLA, the concentration of O_3 should be increased as much as possible and the concentration of other components should be reduced. O_3 generators are discharge devices and the efficiency of the O_3 generator needs to be checked frequently.

3. Conclusions

Hydrogen, as a very promising clean alternative fuel, is not yet well researched in China. The development of hydrogen internal combustion engine is not domestic mainstream at present, mainly because the power of hydrogen engine is not yet comparable to that of traditional fuel internal combustion engine, and the storage of hydrogen is difficult and the cost of making it is high. If hydrogen refueling stations can be popular like traditional gas stations, the development of hydrogen internal combustion engine will go further. The test system in this paper provides an idea for testing in the research of hydrogen internal combustion engine, which only contains temperature, pressure, torque, speed, power, emission and economy, and the concentration measurement of mixture in the cylinder and in the intake tract is not involved, which can be tested by PIV technology, and there are other uninvolved aspects need to continue to develop later.

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