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Engine Exhaust Gas Data on Data Fusion

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Abstract: As China's energy demand continues to rise and the energy supply gap is increasing, engines are the main source of power for transportation vehicles, and the exhaust gas energy emitted from engines has a high recycling value, and it is important to use exhaust gas energy for power generation. This paper analyses engine exhaust data based on data fusion theory to address the problem of engine exhaust gas utilisation. This paper uses data fusion to filter and fuse multi-dimensional engine exhaust gas monitoring and sensing data, establish an engine exhaust gas power generation system, use exhaust gas turbocharging technology to utilise exhaust gas energy, and improve engine performance and exhaust gas emission characteristics through exhaust gas reforming and hydrogen recirculation.

1. Introduction

With the increasingly strict emission regulations of internal combustion engines and the contradiction between the supply and demand of petroleum resources, people have begun to explore alternative energy sources with more economical and cleaner emissions [1-2]. Under the background of energy saving and emission reduction, natural gas, as a vehicle fuel, is widely valued and promoted, and it is the third largest vehicle fuel after gasoline and diesel [3]. Engine exhaust gas contains a lot of available energy. With the increasing power load in transportation, using engine exhaust gas energy to generate electricity has become a new way to save energy and reduce emissions [4-5]. The recycle of hydrogen production from engine exhaust gas reforming is also of great significance for improving engine performance and emission characteristics [6].

With the increasingly prominent problems of energy and environmental pollution, a large number of researchers have made in-depth research on generator exhaust gas treatment and achieved good research results. For example, Nikolaev A V and other scholars have designed the turbocharger of the engine, optimized the structure of the intake manifold, and conducted a comparative experiment with the original model. The research shows that the fuel consumption of the whole vehicle is reduced by 5.18% after the turbocharger is installed while keeping the output power of the vehicle unchanged [7]. Abouel-Seoud S has designed a cylindrical thermoelectric generator. The exhaust gas of the engine circulates inside the cylinder and transfers heat to the surface of the pipeline. The thermoelectric module on the outer surface of the pipeline generates electric energy under the action of temperature difference. The research shows that the output power of the thermoelectric module increases with the increase of exhaust gas temperature and flow rate [8]. Through research, it is found that waste gas utilization is beneficial to the development of clean energy and environmental protection.

This paper analyzes the engine exhaust data based on data fusion, and the structure of this paper can be roughly divided into three parts: the first part is the system design part, mainly including the exhaust gas high-speed power generation system and exhaust gas turbocharging; The second part is the data processing of engine exhaust gas, which mainly analyzes and introduces the data fusion, the residual exhaust gas rate in the cylinder and the simulation conditions of hydrogen production from exhaust gas reforming. The third part is the analysis of engine exhaust gas data, including the influence of pipe wall temperature on hydrogen production characteristics of exhaust gas reforming and the analysis of output power of exhaust gas high-speed power generation system.

2. System Design

2.1. Waste Gas High-Speed Power Generation System

Engine is a kind of very important complex power mechanical system in modern machinery and manufacturing industry. Using the energy of engine exhaust to generate electricity is a new technology of engine energy saving and emission reduction. Engine exhaust high-speed power generation system mainly includes engine, power turbine, high-speed generator and rectifier circuit [9-10]. The overall structure of the power generation system is shown in Figure 1.

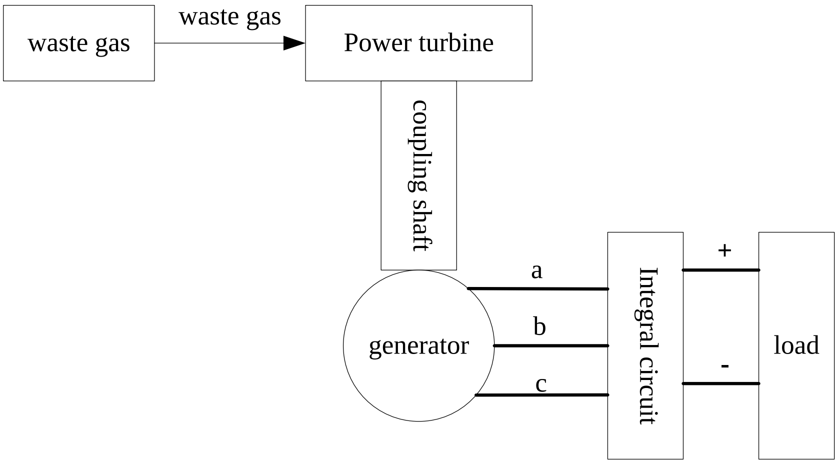

Figure 1. Overall structure of the exhaust gas power generation system

The working principle of the engine exhaust gas high speed power generation system is: when the engine is started, the exhaust gas produced by combustion in the cylinder will be discharged through the exhaust valve, the exhaust gas drives the power turbine and drives the coaxial generator to rotate to generate electricity, converting the exhaust gas energy into electrical energy, and converting the alternating current into direct current through the rectifier circuit to supply the load, thus realizing the recycling of exhaust gas energy [11-12].

2.2. Exhaust Gas Turbocharging

Exhaust gas turbocharging technology is an important strategic initiative to achieve energy saving and emission reduction back in the engine [13]. The engine can be matched to the optimum exhaust gas bypass valve opening for a defined operating condition [14]. The control objective of the bypass valve is to quickly establish its target boost pressure while keeping pressure fluctuations low, in addition to enabling the natural gas engine to have good power and economy during changes in engine operating conditions, while needing to ensure high mechanical efficiency of the turbocharger to prevent problems such as supercharger overspeed and engine popping [15]. In order to ensure the stability and timeliness of the control target boost pressure, an open-loop control model based on the exhaust gas bypass valve opening is used under transient conditions, and its control model structure is shown in Figure 2.

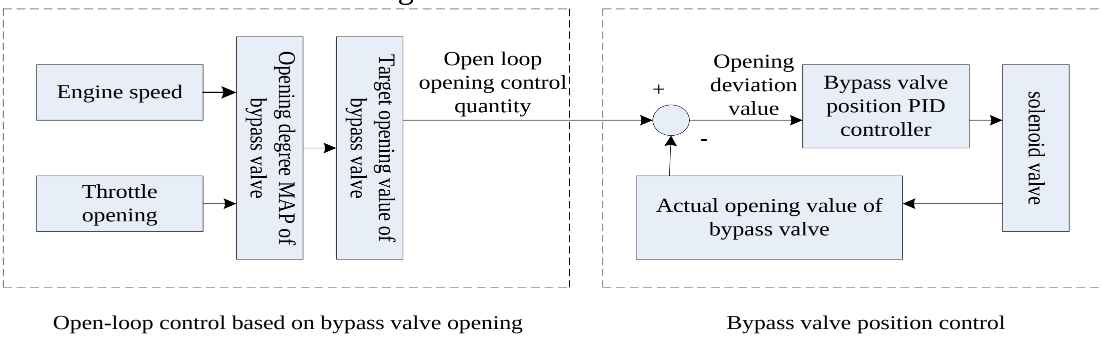

Figure 2. Block diagram of the single closed-loop control model

As can be seen from Figure 2, the entire control model consists of an open-loop feedforward control module based on the bypass valve opening and a bypass valve position control module combined into a single closed-loop control [16]. The target opening value of the bypass valve is obtained by querying the MAP diagram of engine speed and throttle opening, and then the deviation between the target value and the actual value of the bypass valve is used as the input of the PID controller in the bypass valve position control module, and finally the control quantity is converted into a duty cycle signal to control the solenoid valve and change the vortex front pressure to control the boost pressure [17].

3. Data Processing

3.1. Data Fusion

The many sensors of the engine collect and acquire multi-source monitoring data reflecting the engine exhaust gas, which is essentially a multi-dimensional data set, and each dimension is time series data, and effective methods need to be adopted to fuse these multi-dimensional data [18]. PCA, as one of the common data fusion methods, is simple in principle and can efficiently realize the mapping conversion of the data set from high-dimensional to low-dimensional, in line with the idea of fusing multi-dimensional data into The idea of low-dimensional data representation, therefore it was decided to use PCA to achieve the fusion of engine exhaust multi-source monitoring data.

In order to eliminate redundant information and simplify the analysis task, the engine sensing monitoring data was first initially screened to retain the monitoring quantities relevant to engine exhaust and remove the irrelevant ones. After data screening, the PCA method was used for data fusion and the maximum principal component was extracted as the exhaust gas monitoring index. The variance ratio of each dimensional principal component is shown in Figure 3, from which it can be found that the variance ratio of the first principal component, which was linearly combined by PCA data fusion, reached 74.3%, indicating that it contains most of the valid information of the original data.

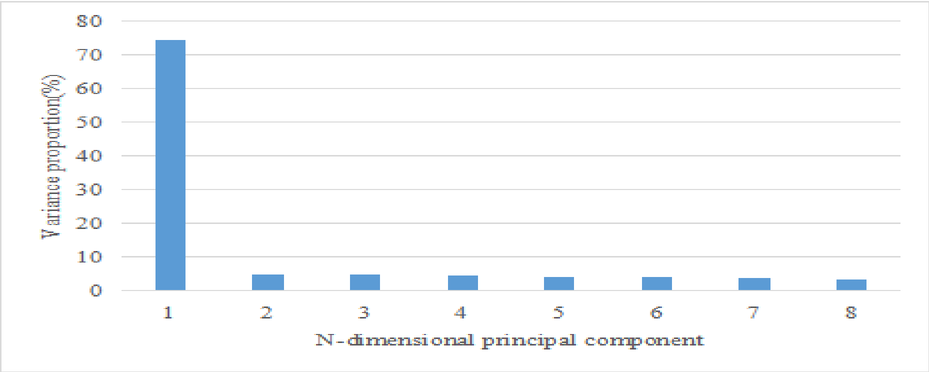

Figure 3. Percentage of variance of each dimensional principal component

3.2. In-cylinder Residual Exhaust Gas Rate

The real-time engine combustion analysis system has the ability to control the entire test rig, collect data and monitor the engine combustion status in real time. The parameters are adjusted online via the control panel to provide real-time feedback for engine testing. The engine combustion analysis system is also capable of off-line data post-processing analysis. Based on the collected real-time data, the combustion characteristics of the natural gas engine and the engine dynamics and economy indicators can be calculated. The residual in-cylinder exhaust gas rate is an important parameter for evaluating the engine combustion and controls the engine load. In actual engine operation, it is difficult to measure the in-cylinder residual exhaust gas rate by test means, therefore, the in-cylinder residual exhaust gas rate is calculated according to the following formula.

$$IEGR = \frac{L_1}{L_1 + l_1 + l_2} = \frac{e \bullet L_2}{e \bullet L_2 + l_1 + l_2} \tag{1}$$

Formula (1), l1 for the intake volume, l2 for the injection volume, L1 for the mass of residual exhaust gas in the cylinder, e for the total number of moles of residual exhaust gas in the cylinder, L2 for the average molecular mass of residual exhaust gas in the cylinder.

With the exhaust valve closed, the total number of moles of residual exhaust gas in the cylinder can be found from the ideal gas equation of state.

$$e = \frac{Q_{EVR} \bullet K_{EVR}}{R \bullet F_{EVR}} \tag{2}$$

3.3. Simulation Conditions of Hydrogen Production by Waste Gas Reforming

Engine exhaust emission test shows that the content and energy of exhaust gas components are different under different working conditions. This simulation selects the exhaust data of natural gas engine under different load conditions to carry out relevant simulation, and the reforming reaction needs to be supplemented with additional methane fuel as the reforming raw material. As this simulation mainly studies the hydrogen production reaction process of waste gas reforming in a single reforming reaction tube, without considering the heat exchange process between the waste gas outside the tube and the reforming mixer inside the tube, the following assumptions are put forward to simplify the simulation process:

(1) Under the same load condition, the flow rate and temperature of engine exhaust gas are kept constant, and the exhaust gas enters the reaction tube after being evenly mixed with additional fuel.

(2) The heat transfer process between the exhaust gas outside the tube and the reformed gas mixture inside the tube is simplified to a constant wall temperature boundary condition.

(3) The fluid is an ideal incompressible fluid, regardless of radiation heat transfer.

(4) The inlet temperature of waste gas-fuel mixture is the same as that of reformer tube wall.

4. Data Analysis

4.1. Influence of Tube Wall Temperature on Hydrogen Production Characteristics of Waste Gas Reforming

The heat exchange structure of the reformer and the changes of engine operating parameters directly affect the heat exchange process between the waste gas-fuel mixture gas and the waste gas used for heat exchange. In order to understand the corresponding characteristics of the waste gas-fuel reforming reaction conveniently and widely, Figure 4 shows the changing laws of methane reforming rate and hydrogen mole fraction at the outlet of the reforming reactor under different tube wall temperatures.

According to fig. 4, when the wall temperature is 700K, the reforming rate of methane is only 8%, and the molar fraction of hydrogen at the outlet of the reformer is 0.04. When the wall temperature increases to 1000K, the reforming rate of methane increases to 42%, while the molar fraction of hydrogen at the outlet of the reformer increases to 0.35. With the increase of the wall temperature, both the reforming rate of methane and the molar fraction of hydrogen at the outlet of the reformer increase exponentially, which is mainly due to the steam reforming reaction of methane. The reforming rate of methane is the result of the consumption of steam reforming reaction, oxidation reaction and carbon dioxide reforming reaction. Therefore, the selection of relevant operating parameters of the exhaust gas reformer needs to comprehensively consider the power and emission characteristics of the reformed gas mixture of the subsequent natural gas engine.

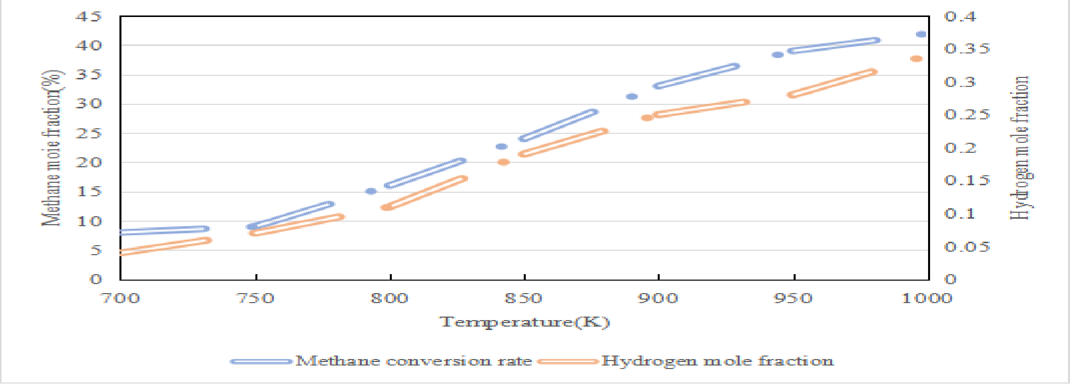

Figure 4. Exhaust gas-fuel reforming reaction characteristics at different tube wall temperatures

4.2. Output Power Analysis of the Exhaust Gas High-Speed Power Generation System

In order to investigate the relationship between the maximum output power of the exhaust gas high-speed power generation system and the engine operating conditions, a simulated gas source, a turbo generator, a three-phase synchronous rectifier circuit, and an electronic load were connected together and an overall experiment of the engine exhaust gas high-speed power generation system was conducted. A gas storage tank is used to reduce the pressure fluctuation of the high pressure gas during the experiment to ensure the smooth operation of the turbo generator and to keep the output AC power stable. The maximum output power of the power generation system is measured by first using the gas source to simulate the exhaust gas pressure of the engine under the working condition, then adjusting the resistance value of the electronic load and observing the change of the generator's rotational speed. The maximum output power of the system under this condition can be calculated by recording the voltage and current values of the load. Table 1 shows the maximum output power when a diode rectifier circuit is used, and Table 2 shows the maximum output power when a three-phase synchronous rectifier circuit is used.

Table 1. Maximum output power when diode rectifier (W)

Load(%) rotation speed	1600	2000	2400	2800	3200
25	93.47	312.46	367.15	389.42	423.46
50	124.68	415.77	488.62	499.35	501.37
75	234.52	476.28	643.74	672.69	701.33
100	296.71	543.93	682.16	723.56	763.41

Table 2. Maximum output power at synchronous rectification (W)

Load(%) rotation speed	1600	2000	2400	2800	3200
25	113.55	346.73	380.74	412.51	440.75
50	150.72	437.75	513.83	533.77	563.09
75	267.86	519.74	670.59	728.49	760.31
100	316.78	587.49	703.96	770.37	880.68

As can be seen from Table 1 and Table 2, compared with the diode rectifier circuit, the output power of the power generation system is increased under all working conditions with the increase of the output power of the power generation system, which can be increased from 763.41W to 880.68W at the highest, with an increase of 117.27W. In summary, the output power of the exhaust gas high-speed power generation system using a three-phase synchronous rectification circuit is greater than that using a diode rectification circuit, therefore, the power generation system should use synchronous rectification technology for power generation and use this technology to solve the efficiency problem of the power generation system.

5. Conclusion

Global warming, environmental pollution and energy security are threatening the survival of human beings and the development of society, and countries are seeking clean, efficient and safe ways to use energy. In this paper, the hydrogen production reaction characteristics of waste gas-fuel reforming are simulated, and the hydrogen production characteristics of waste gas reforming at different tube wall temperatures are analyzed, which reveal the hydrogen production reaction law of the reforming gas mixture in the tube. In this paper, a comparison between diode rectification circuits and synchronous rectification circuits is carried out to find that the use of synchronous rectification technology in waste gas power generation systems is beneficial in solving the problem of low efficiency of power generation systems.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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