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The Fault Diagnosis Method of Automotive Engine Ignition System Based on Multi-body Dynamics

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Abstract: The ignition system is an important part of a gasoline engine and its operation directly affects the performance of the engine. Fault detection and diagnosis of the ignition system is an important means to keep the engine running well. The purpose of this paper is to study the fault diagnosis method of the ignition system of an automobile engine based on multi-body dynamics. The ignition system of a model engine is used as a specific research object to carry out a series of simulation and analysis work, with multi-body system dynamics as the theoretical basis. The fault of the ignition system is diagnosed through gas force calculation, and the detection system and analysis and processing system are built by using LabVIEW and VC++ software. The test results show that the system developed in this paper can identify the faults of the ignition system quickly and easily.

1. Introduction

How to accurately and efficiently diagnose faults in electronically controlled engine control systems in cars is a problem that many car mechanics must now overcome. Automotive engines can be damaged due to long life, high mileage and deviations from standards [1]. The ignition system consists of a battery and generator that provide low voltage current, a switch and ignition coil that converts low voltage current into high voltage current, and a distributor that connects high voltage current to each cylinder head at a specific time [2]. The role of the ignition system is to ensure that the in-cylinder compression mixture is charged for a specified period of time [3-4].

Engine ignition systems often fail, but traditional methods do not easily locate the type of fault. kuka uses an optimised BP neural network algorithm to analyse the voltage waveform data associated with ignition system faults and safely locate the type of ignition system fault. In contrast, the BP neural network optimised by the BBO algorithm has more advantages in terms of convergence speed and stability. It can meet the system fault finding requirements [5]. Based on Reddy's analysis of the working principle of the ignition system of a Toyota faw 1.6l GL car, engine vibrations and fault lights during vehicle deceleration were eliminated. The troubleshooting process, circuit system and mechanical parts were judged reasonably well to finally identify a bent piston connecting rod fault, resulting in insufficient cylinder pressure and cylinder fire. Code and motor fluctuations provide a reference for rapid diagnosis and repair of such faults [6]. Zavos proposes a new multi-body dynamics simulation framework that can effectively handle large dimensional and complementary multi-contact conditions. Typical contact simulation methods perform contact pulse-level fixed-point iteration (IL-FPI), which has high time complexity due to large-scale matrix inversion and multiplication, and is susceptible to pathological contact conditions. To avoid this, they propose a new framework based on velocity-level fixed-point iteration (VL-FPI) that allows not only inter-contact decoupling but also inter-axis decoupling (i.e. contact diagonalisation) by exploiting some kind of agent dynamics and contact nodalisation (with virtual nodes). This allows them to solve the contact problem during each VL-FPI iteration cycle in one go/in parallel [7]. Therefore, there is a need for a fast, accurate and easy diagnostic method to determine the technical condition of the engine ignition system.

In this paper, an engine ignition fault diagnosis system is designed and constructed to acquire two analogue signals simultaneously through a data acquisition card. According to the technical requirements and functions of the system, the main hardware in the development process is selected, and anti-interference measures are taken to improve signal recognition. According to the requirements of the test system, various functions provided by the LabVlEW program development environment are fully utilized, and combined with the VC++ language, the designed test system has a simple and clear front panel, which is convenient for the experimenters to operate.

2. Research on the Fault Diagnosis Method of Automotive Engine Ignition System Based on Multi-body Dynamics

2.1. Theory of Multi-body System Dynamics

(1) Multi-body system dynamics

The theory of multi-body system dynamics has undergone the development of rigid body system dynamics and flexible multi-body system mechanics theory [8-9]. Most construction machinery systems consist of many components. When studying these complex systems, it is often possible to reduce the system components to rigid bodies connected by "hinges" to obtain a multi-rigid system [10-11]. Not only are there many differential equations of motion, but also many non-linear concepts. Analytical solutions are often difficult to obtain and must be computed by computer [12].

(2) Dynamics of multi-flexible systems

A multi-flexible system is often understood as a system of multiple flexible bodies connected by hinges (also called hinges). Two neighbouring flexible nodes may have relatively rigid displacements [13-14]. Structures in the traditional sense are supposed to be geometrically uneven, that is to say, they are supposed to be geometrically uneven. The degrees of freedom of a fixed structure therefore depend only on its elastic displacements. If the structure can be moved, degrees of freedom need to be added to the possible global movements. But a multi-flexible system is completely different: in addition to the freedom of movement of each flexibody, there is also the freedom of movement between two flexibodies. In the case of a flexible multi-body system, the displacement of its conglomerate and the elastic displacement always occur simultaneously and in relation to each other, most of them under controlled conditions. Therefore, it can be said that flexible multi-view systems are in fact engineering systems that move under controlled conditions. For such non-structural engineering systems, the traditional structural dynamics theory and dynamics analysis are not sufficient, so the dynamics of flexible multi-view systems are designed

[15-16].

2.2. Engine Ignition System

(1) The function of the ignition system

The automotive ignition system is the key to the strength of the engine. The fuel and air mixture in the cylinder is ignited by an electric spark at the end of the compression stroke [17-18]. The basic function of the ignition system is to produce an in-cylinder electric spark in a timely, accurate and reliable manner under different engine operating conditions and to ignite the fuel mixture to run the petrol engine.

(2) Ignition system main components function and common failures

Spark plug: Ignition energy is injected into the combustion chamber in the form of an electric arc between electrodes to make the mixture burn in the combustion chamber. The most common errors are carbon build-up in the spark plug, too small or too large an electrode gap, electrode ablation, fouling or power loss.

High voltage wire: The function of the high voltage wire is to provide a high voltage line. Errors often occur with high resistance, broken circuits, short circuits and other faults over a long period of time.

Distributor: supplies high voltage to the cylinder spark plug in the correct sequence and at the correct time. The main defects are cracked cases and excessive or insufficient contact gaps.

Ignition coil: converts the low-voltage current output from the battery or generator into a high-voltage current to produce a spark of sufficient strength in the spark plug. The most common error is the deterioration of the ignition coil, resulting in the ignition coil turning on or off and deteriorating the ignition performance, as shown in Figure 1.

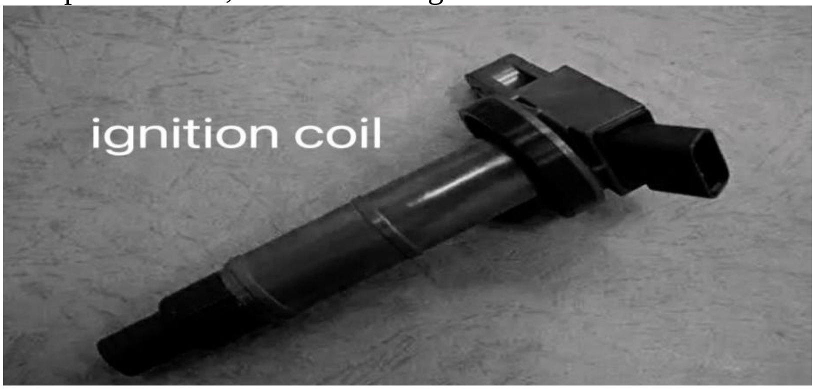

Figure 1. Ignition coil

All of the above causes can lead to engine failure such as failure to start, unstable idling, poor acceleration, stalling or excessive emissions, which can cause great inconvenience to daily driving.

3. Investigation and Study of Fault Diagnosis Methods for Automotive Engine Ignition Systems Based on Multi-body Dynamics

3.1. System Software Development

The design of this system involves more complex work such as data acquisition and processing. In order to shorten the development cycle and simplify the design process, LabVIEW and

VisualC++ are chosen as the languages for the test system software. The main body of the system is developed using the LabVIEW platform and the driver is developed using the VisualC++ language, and a dynamic link library is generated for LabVIEW to call.

3.2. Data Acquisition Card

The system uses the existing HY-8021A multi-functional data acquisition panel in the laboratory to collect the reference cylinder ignition high voltage signal and combustion voltage signal in real time through two A/D channels. The A/D conversion circuit is started by software, the A/D query is converted to completion bit and the result data comes from the node. the HY-8021A acquisition panel is equipped with a 12-bit A/D/A resolution converter, 8-mode input channels/ The A/D converter can be selected from a range of ±5 V, ±10 V analogue input signals. The 0-5V input range has been selected to ensure the accuracy of the data acquisition in this topic. The system resolution is 12 bits (4096), the start mixing time is 150 ps, the system measurement accuracy is 0.05% (g<1000) and the system pass rate is 50 kHz (software start).

3.3. Gas Force Calculation

The gas burst pressure of the work stroke, Pg(X), acts on the upper end of the piston and is obtained either by means of the output of the internal combustion engine work simulation calculation software or by means of tests on the engine to obtain a work graph. The gas force Fg(N) is:

$$F_g = \frac{\pi D^2}{4}(p_g - p') \tag{1}$$

Where, D is the cylinder diameter (mm); Pg is the absolute pressure in the cylinder (MPa); P' is the piston back pressure (MPa).

Piston on the role of force F not only on the connecting rod AB have a pull pressure F1, but also on the cylinder wall lateral force Fc, the size of:

$$F_c = F \tan \beta \tag{2}$$

Where β is the angle of swing of the connecting rod.

When the gas pressure Fg in the cylinder acts on the top of the piston at the same time. The same size but in the opposite direction of the force - Fg acts on the cylinder head.

4. Analysis and Research on the Fault Diagnosis Method of Automotive Engine Ignition System Based on Multi-body Dynamics

4.1. Calling the DLL in LabVIEW

According to the overall design plan of the system, the computer needs to collect two signals at the same time. The first signal is the ignition voltage of the reference cylinder, and the second is the combustion voltage. The first signal is used as the trigger condition of the second signal, and when the ignition voltage exceeds the threshold value, it means that the piston of the reference cylinder is in the position of the compression upper stop of the working stroke, at which time the combustion voltage signal is collected. And stored as a text file for off-line analysis and processing use.

According to the requirements of the system design, the ignition parameters are collected mainly for the purpose of triggering the combustion voltage signal collection, while no quantitative requirements are made for the specific values. This responds to the consistency of the spark plugs in each cylinder and the air-fuel ratio situation, if the mixture air-fuel ratio is too low, the combustion voltage will be lower than normal. Due to the limitations of the sampling rate and system resources, it is not possible to display the ignition parameters in real time, but rather to store the parameters and then use the software system for offline playback. The program block to implement the data acquisition control is shown in Figure 2.

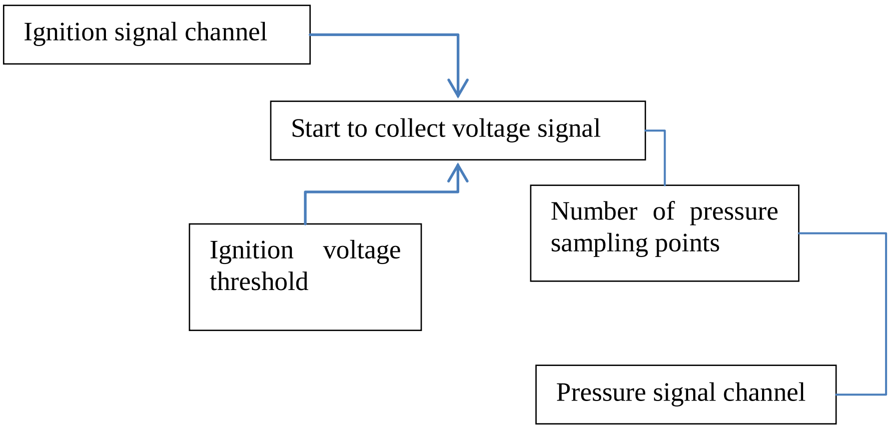

Figure 2. Block diagram of data acquisition control program

The F23A3 engine of the Honda Accord car is the subject of this paper. The ignition system of this engine is an electronic ignition system utilising an inductive magnetic ignition generator distributor ignition control module. This engine is highly representative of the vehicles in which it is used. The parameters of the ignition system of the F23A3 engine of the Honda Accord vehicle are shown in Table 1 below.

Table 1. Parameters of ignition system of Honda Accord F23A3 engine

Overhaul items	Normal value
Resistance of central high-voltage conductor	26
Ignition signal generation induction coil resistance	360
Ignition timing angle	10
Ignition coil primary winding	0.54
Ignition coil secondary winding	24.5

The idle speed of this engine is 770 r/min. As the value of the secondary ignition voltage waveform parameter varies under various speed conditions, a complete blockage test of the injector and a cut-off test were carried out at 900 rpm, and the measured test data are shown below:

Table 2. Data of complete blockage test and cut-off test

Time (s)	Completely blocked	Fire cutoff
0.1	182000	175000
0.15	196000	198000
0.2	183000	184000
0.25	190000	201000
0.3	187000	185700
0.35	196000	197000
0.4	184000	179000
0.45	190500	198000
0.5	187000	182000

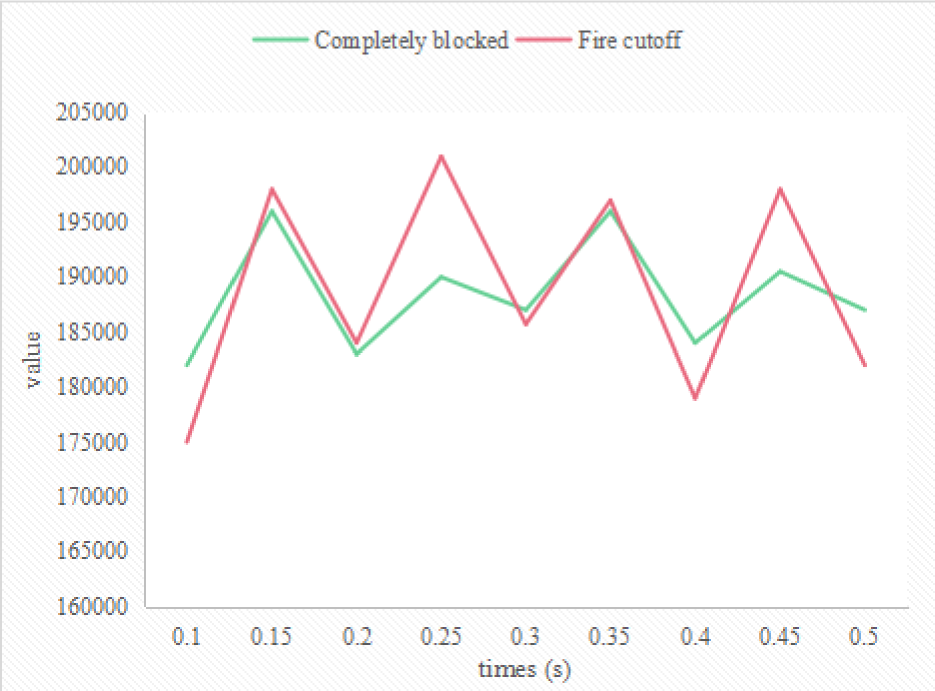

Figure 3. Time domain of pressure waveform

Analysis of the results: If the ignition system is faulty, the engine misfires causing unstable speed and affecting the vacuum fluctuations in the intake pipe, the time domain of the pressure waveform is shown in Figure 3 and Table 2.

The test results show that by detecting pressure fluctuations, it is possible to quickly and easily detect possible ignition system faults when individual cylinders of the engine are not working properly, and the fault characteristics are significant.

5. Conclusion

Along with the rapid development of the automotive industry and the strict increase and improvement of various automotive regulations, the demand for automotive quality indicators has become increasingly important for the testing and diagnosis of the technical performance of vehicles. As the heart of a car, engine failure directly affects its power, economy, durability and operational reliability. Therefore, a correct understanding of the causes of engine failures and basic prevention methods is of great importance to extend engine life. This paper focuses on the development of a system for fault diagnosis of automotive engine ignition systems. In addition to relying on LabVIEW software for multi-body dynamics calculations, other discrete methods based on flexible bodies can also be used to establish the dynamics equations of the multi-body system, relying on self-programming to realise the rigid-flexible coupling dynamics calculations of the ignition system.

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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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