Design of Online Monitoring System for Pulse Detonation Engine

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Abstract. The PDE monitoring equipment being applied is large in size, harsh in working conditions, unable to carry out outdoor experiments, limiting the flexibility of PDE’s original rational experiment. An online monitoring system was designed to meet needs of mobility, real-time, portability, none effect on PDE thrust test and so on. The paper introduces the whole scheme of the online monitoring system, the hardware design of each function module and the software design of the whole scheme. The experimental results show that the on-line monitoring system can realize the measurement of working parameters in the principle experiment of pulse detonation engine in time and accurately and improve the flexibility of operation.

1. Introduction

With the advantages of high thermal cycle efficiency and simple structure, pulse detonation engine (PDE) is recognized as the new aerospace vehicle power device of the 21st century[1-2]. Currently the basic laws of the PDE and various factors that affect its performance are mainly explored through principle tests and state monitoring is an important part of the principle test[3].

Figure 1. Structure of online monitoring system for PDE.

Several important parameters of PDE, such as detonation wave pressure, velocity, equivalence ratio and mixing time, need to be monitored constantly, which provides important basis for the analysis of engine working state and fault diagnosis. Unlike conventional engines, parameters of PDE vary with time periodically, which also raises higher requirements for the performance of the real-time monitoring.
system[4-5]. During the process of the principle test, pressure signal is collected by the pressure sensors mounted on the detonation chamber and is transmitted to the signal collector through the charge amplifier. The ion current signal of the detonation cavity is passed through the ion converter to the signal acquisition instrument. The testers must analyze the data collected by the acquisition instrument manually. However, due to the large size of the charge amplifier and ion converter, the long transmission distance between device and the PDE and the power supply voltage of the charge amplifier and the ion converter which needs to be AC220V, the flexibility of the principle tests have been greatly restricted. To simplify the outdoor experimental conditions, implement the real-time monitoring function in outdoor experiments and reduce the error caused by the outdoor test on the thrust test, this paper presents a high integration real-time monitoring system. This real-time device reduces the volume and weight of the device, greatly simplifies the system structure and improves experimental flexibility so that the PDE principle experiment can be carried out in a more complex and changeable environment. It also implements the function of monitoring parameters of PDE in each working cycle and improves the accuracy of the monitoring results, which is of great significance to PDE work mechanism research, fault diagnosis analysis and boundary condition exploration.

2. Design and performance requirements of PDE on-line monitoring system

2.1 Design scheme of PDE on-line monitoring system
The structure of online monitoring system for PDE is shown in Figure 1. It is mainly composed of working state monitoring unit, mixing time and equivalence ratio measuring unit and main control unit. During the experiment the engine controller controls the opening of fuel valve and oxidizer valve and ignition of spark plug during one ignition cycle to form detonation wave. During the ignition process the timing of ignition must be matched well with the filling time of the gas or it will cause fuel waste or reduce the intensity of detonation wave, and even lead to the failure of ignition[6]. The on-line monitoring system monitors the flow of fuel and oxidizing agent, timing of valve opening and spark plug ignition, changes of detonation chamber pressure and state of combustion in PDE working cycle, calculating PDE equivalent ratio and mixing time and obtaining the time sequence characteristic analysis of key parameters in PDE working cycle, which provides reference for the fault diagnosis and engine working mechanism exploration.

The main components and functions of each unit of the online monitoring system
(1) working state monitoring unit is composed of a detonation chamber pressure signal conditioning module and a flame ion current signal conditioning module to monitor the pressure change of the detonation chamber and calculate a flame propagation speed.
(2) mixing time and equivalence ratio measuring unit is composed of a high frequency flow collecting module and a control signal collecting module, monitoring the flow of fuel and oxidant and the engine controller ignition signals.
(3) main control unit is composed of a data processing module and a human-computer interaction module. The data processing module optimizes and calculates the data collected by the pressure signal conditioning module and the ion current signal conditioning module so that the system could calculate the exact equivalence ratio and mixing time through the mixing time and the equivalence ratio measuring unit and display the results on top of the human-computer interaction module.

2.2 Performance requirements for on-line monitoring systems
(1) Monitoring the detonation chamber pressure, ion current, fuel flow and oxidant flow state in each ignition cycle.
(2) Monitoring the change of valve control signal and spark plug control signal in each ignition cycle.
(3) Monitoring the equivalence ratio and mixing time in each ignition cycle.
(4) Monitoring the timing sequence of the ignition signal and the opening signal of the fuel and oxidizer valves in each ignition cycle.
(5) The Man-machine interface shows the engine ignition times and ignition success rate and the change of signals in each ignition time.
3. Hardware design of PDE on-line monitoring system

3.1 Hardware principle of on-line monitoring system

According to the performance requirement of PDE on-line monitoring system, the hardware principle of the monitoring system is designed as shown in Figure 2. It mainly includes six function modules, namely the control signal acquisition module, the high frequency flow collection module, the pressure signal conditioning module, the ion current conditioning module, the data processing module, the man-machine interaction module.

![Figure 2. Hardware principle of the monitoring system.](image)

3.2 Design of the data processing module and the man-machine interaction module

The on-line monitoring hardware system uses the STM32F4 of the ST Microelectronics company as the core processor, it takes the cortex M4 as the kernel, its main frequency reaches 168MHz, it has the 4-way UART to satisfy the communication demand, it has 12-bit ADC sampling channels to achieve high sampling accuracy. The data processing module includes STM32F4 microcontroller and its minimum system. STM32 minimum system is the smallest circuit which can make STM32 work normally, including STM32 microcontroller, Jtag download interface, clock circuit, starting circuit, power supply circuit and reset circuit. The working voltage of the STM32 is 5V, which can be supplied by the battery [7-9]. The Man-machine interaction module adopts RS232 Configuration screen, the screen has the following advantages: (1) Adopting CORTEX-M3+FPGA dual-core structure makes refresh speed fast (2) Excellent color difference performance, rich content of control, support touch operation, (3) ease of development, easy to debug[10]. The data processing module communicates with the Man-machine interaction module through the UART, the design is shown in Figure 3.

![Figure 3. Design of the data processing module and the man-machine interaction module](image)

3.3 Design of the ion current conditioning module

The ion current signal conditioning module adopts the spark plug as the ion current sensor. By adding biased voltage on the detonation chamber the ions produced by combustion are directed to move and produce ion current. The system figures out specific information of combustion by the intensity change of ion current. Ion current signal conditioning module principle as shown in Figure 4, the module uses high voltage silicon reactor as signal isolating element, bias voltage positive pole connects the Spark plug Center electrode while the negative pole connects the detonation chamber. The ion current signal is converted to the voltage signal by the resistor element, the adjusting sliding resistance causes the voltage signal to change within the appropriate voltage range. The voltage signal is amplified by the amplifier and
sent to the data processing module. The electrical components are connected by shielded cables to reduce the influence of the external interference on the ion current signal.

3.4 Design of the high frequency flow collection module and the pressure signal conditioning module
The pressure sensor is directly measured by pressure sensor, and the flow of fuel and oxidizer is measured directly by flowmeter. The pressure transducer and the flowmeter output signal are 4~20mA current signals. The current signal is converted to a voltage signal by a resistor element and transmitted to a data processing module through an ADC conversion module.

3.5 Design of the control signal acquisition module
The control signal should be of medium speed or high speed optocoupler to ensure that the signal is not delayed or deformed after optocoupler. In this paper, high speed optical coupling 6N137 is selected to control signal acquisition. The principle of the control signal acquisition module is shown in Figure 5. After the control signal is sent to the 6N137, the control signal is transmitted to the data processing module through the phase logic. To improve the system signal-to-noise ratio the control signal is isolated from the digital circuit and the power of the control signal is isolated from the power supply of the digital circuit.

4. Software design and implementation of PDE on-line monitoring system
Based on C language and firmware library that is provided by ST company and that is used for application development, the system uses Keil uVision integrated development environment to develop, which greatly improve the development efficiency. According to the concept of modular software design, the software system is divided into hardware initialization module, data acquisition module, business processing module and human-machine communication module. The hardware initialization module includes UART, Timer, AD, data initialization. data acquisition module including acquisition of AD output and control signal. The Man-machine interaction module is responsible for user setting parameters, obtaining status, etc. Combining the finite state machine model, the system divides the task into the editing mode and the view mode. System state parameters can be modified in edit mode and state parameters in view mode can only be displayed and cannot be modified. In this paper, the instruction issued by human-computer interaction module is used as the signal of triggering state switching, triggering the system state change. The program flowchart is shown in Figure 6.
After the system running, the related hardware module is initialized firstly, then the cycle of work is entered. In a work cycle, the system first processes the instructions issued by the human-computer interaction module, setting the system state and executing state tasks. After that, data acquisition and data processing are carried out, and finally the parameters are updated on the human-machine interaction interface.

5. Conclusion
The on-line monitoring system for PDE realizes real-time monitoring of detonation engine working condition in each ignition cycle and improves the accuracy and real-time of detection. It also has small size, light weight, portability, high integration, easy to operate, simple structure and other advantages, reducing the error caused by the device quality to the thrust measurement and simplifying the requirements for working environment, which makes the principle experiment can be carried out outdoors. The system accurately reflects the working state of the engine, which provides an important basis for the fault diagnosis and engine working principle exploration.

6. References
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