Design and Research of a Aero Engine Operating Status Monitoring System

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Abstract. A system for monitoring aero engine speed and discrete operating status signals from the engine is proposed in this paper. The system is mainly composed of MCU technology, sensor signal processing technology and serial communication technology, etc., which is used to monitor engine speed and discrete operating status signals from the engine. The system implements the following functions. On the one hand, the DC voltage signal outputted from the engine speed sensor and the DC voltage signal of the discrete working state of the engine output are collected, and the above information are processed and converted into a digital signal and transmitted to the master computer to obtain the data of engine speed and operating status; On the other hand, the output current signal is used to output a discrete alarm signal according to the detected signal. Aero engine operating status monitoring system has been tested and all parameters are in accordance with relevant regulations.

1. Introduction
Aero engine rotate speed, temperature, pressure, and oil quantity are important parameters for measuring the performance of an aero engine and the normal operation of the aircraft, which must be monitored. At present, The methods of engine speed monitoring include photoelectric code measuring method [1], magnetic flux velocity measuring method [2], flash speed measuring method [3], and speed measuring method of tachogenerator [4]. The fighter uses a speed measurement based on the speed measuring method of tachogenerator. The measured rotate speed signal is subjected to a signal conditioning circuit to obtain a specific rotate speed. Reasonable design of the signal conditioning circuit is essential for obtaining an accurate rotate speed. In addition, the working state of the engine is obtained by a temperature sensor, a pressure sensor, a fuel amount sensor, etc., subjected to a conditioning acquisition circuit, and then processed by the controlling chip to obtain a discrete alarm signal. In this paper, the engine conditioning acquisition circuit and the working state conditioning acquisition circuit are designed to obtain the rotate speed signal and the working status signal of the 10-way engine, which achieve monitoring of the operational status of this type of aircraft engine.

2. Overall design
The block diagram of the overall design scheme of the system is shown in Figure 1. The PIC18F8722 single-chip microcomputer is selected as the core. The signal output from the engine rotate speed sensor is collected and processed by the rotate speed signal conditioning circuit, and the discrete working state signal output by the engine working state acquisition circuit is used, realizing the output of the discrete alarm signal and the communication of the host computer. The engine working condition monitoring system directly connects the rotate speed sensor and each input and output switch through hard connection.
The analog signal outputted by the sensor is sampled, regulated and measured. The converted digital signal is transmitted to the upper computer through the RS-422 communication interface. After the completion of engineering design, high temperature test, low temperature test, vibration test, impact test, acceleration test, etc. are all normal, having practical engineering value.

![System overall design block diagram.](image)

3. System module design

This article is designed to two parts: system acquisition module and power module. The acquisition modules include a rotate speed signal conditioning circuit, an engine working state acquisition circuit, a single-chip MCU circuit, and a serial communication interface circuit. The following design gives the key circuits.

3.1. Engine rotate speed acquisition circuit design

The rotate speed sensor uses RE0110 DC voltage rotate speed measuring motor. Its output characteristic is DC voltage signal. The output voltage amplitude is proportional to the input rotate speed \[U(mv)=2n (rmp)\]. Since the rotate speed measurement range is -7000 to 7000r/min (positive and negative), so the corresponding voltage range is -14 to 14V. The AD7890 (which is 12-bit) has an input voltage range of -10 to 10V. Therefore, the input voltage of the rotate speed sensor is divided, considering the matching of the impedance, the divider resistance is 100KΩ/220KΩ and the precision is 1‰. The sampling voltage of the input AD7890 is about -9.625 to +9.625V, which satisfies the input voltage range of AD7890. OP07 has high common mode rejection, high open loop gain, low noise, low output temperature drift, low input offset voltage, and sufficient bandwidth to achieve ideal amplification. Therefore, OP07 is used to form the circuit. In order to prevent the voltage range of the speed measuring motor from fluctuating greatly, and to facilitate the sampling of the rear stage AD, the analog ground and the digital ground are respectively grounded through a single point of 0 Ω. In addition, a second-order low-pass Butterworth filter is applied to the front of the operational amplifier to pass the signal to the AD7890 converter. The AD7890 has fast conversion time, low power consumption, low total harmonic distortion, and built-in tracking/holding amplifier with high rotate speed and flexible serial interface. After the analog-to-digital conversion is completed, the processed speed signal is directly collected by using the PIC18F8722 [5], and the corresponding rotational speed is calculated according to the collected voltage value. The specific engine rotate speed acquisition circuit diagram is shown in Figure 2.

![Engine rotate speed acquisition circuit diagram.](image)
3.2. Engine working state acquisition circuit
The discrete operating state of the engine output has 10 signals (collecting 10 engine operating states), all of which are DC voltage signals of 28 VDC. Firstly, the acquisition circuit of the switch input signal uses optocoupler to do electrical isolation and level conversion. After being processed by the inverter, it is sent to the IO port of the acquisition MCU. The discrete acquisition circuit of the specific engine output is shown in Figure 3.

![Figure 3. Discrete output circuit of the engine output.](image)

3.3. Engine working state output signal drive circuit design
The engine working state output signal driving circuit is mainly composed of a processing single chip, an isolation circuit and an amplifying circuit. It is processed by the IO port of the processing chip to give the switching output signal, which is processed by the inverter circuit and then sent to the amplifier driving circuit to enhance the load capacity of the circuit. The specific engine operating state output signal driving circuit is shown in Figure 4.

![Figure 4. Engine operating state output signal drive circuit.](image)

3.4. Power module circuit design
The DC output voltage of the aviation power is 18-36V with a certain degree of fluctuation. In order to reduce the influence of voltage disturbance on the rear-stage circuit, ensure the reliability, and improve the electromagnetic compatibility of the system, Power module circuit add the fuse at its the input, filtering with the EMI module. The input voltage can be adjusted to a specific voltage by the DC-DC conversion module. Power module circuit has the advantages that are less peripheral circuits, stable output, and reliable operation. The stability of the power and the DC-DC switching generating pulse by itself will have an impact on the system performance. First, it will affect the noise level of the baseline, resulting in inaccurate acquisition of the engine state. On the other hand, it will affect the stability of the amplification parameters of the conditioning circuit. Therefore, on the basis of the pre-reserved filter, the DC-DC rear-stage matching power supply filter unit which is improved, and the matching capacitor is added at the power supply output stage.

The engine operating condition monitoring system requires 15V, -15V, and 5V DC power voltages. The DC/DC power module makes that the externally supplied 28 VDC power converts to the DC power supplying voltage during system operating. The specific power module circuit diagram is shown in Figure 5.

![Figure 5. Power module circuit diagram.](image)
4. Debugging data and analyzing results

The engine working condition monitoring system adopts a standard air box structure, and its internal structure mainly consists of a partition plate, a board mounting accessory, a circuit board assembly, a power module, a chassis box, and upper and lower covers.

The chassis adopts a frame structure, which is formed by splicing the front and rear covers, the left and right side plates, the front and rear partition plates and the motherboard reinforcement frame. The M3 countersunk screws are staggered and connected, and the components constituting the chassis frame are embedded with each other. It ensures structural stability. The chassis case and each circuit board assembly form a unitary structure that is effective against vibration and shock. When the chassis is assembled, the connections between the various parts are in the form of screw staggered connections and the chassis is subjected to vibration in various directions in a vibrating environment, the screws are always axially stressed to ensure the reliability of the connection. Metal frame with motherboard installed on the chassis, which can greatly improve the strength of the chassis and achieve the purpose of anti-vibration and impact. The physical object is shown in Figure 6.

4.1. Engine rotate speed acquisition circuit debugging

The maximum fluctuation of the sampling of the rotate speed signal conditioning circuit after processing by the Butterworth filter is about 5 bits, and the maximum rotate speed error is about 6.2 r/min. In order to further reduce the fluctuation, the control software is used to process the rotate speed sampling algorithm, and the filtering algorithm is combined with three filtering algorithms: limiting filtering, arithmetic averaging filtering and recursive averaging filtering. Although the filtering algorithm can filter out the interference and fluctuation signals, improper processing will also cause the real-time performance of the signal to deteriorate. Therefore, it is necessary to perform short-time accelerated sampling observation to judge its accelerated performance. The data point line diagram of the 5s acceleration sampling rotate speed bit value is shown in Figure 7. During the acceleration process, the figure shows that sample value rises smoothly and there is no data breakage, which proves that the speed sampling circuit is reliable.
5. Conclusion
The design and development of the aero-engine working condition monitoring system realizes the monitoring of the engine rotate speed and engine working state, monitors the aircraft's health status, and outputs the engine discrete alarm signal. The rotate speed signal module is tested and the test results are in compliance with relevant regulations. The application of this system to aero engines is of great significance, improving the safety and utility of aviation aircraft.

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