Design and Research of Electrostatic Sensor Based on Aero-engine Airway Electrostatic Monitoring Technology

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Abstract. Aero-engine airway electrostatic monitoring technology is a new type of aero-engine airway fault monitoring technology, which has a good development prospect. The principle of this technology is to realize the acquisition of the electrostatic signal of solid charged particles in the engine tail nozzle through the electrostatic sensor, and to judge the fault degree of the engine air circuit through the analysis of the electrostatic signal. In this paper, the electrostatic sensor is designed and manufactured according to the principle of electrostatic induction, what’s more, the measurement circuit is designed and manufactured, and the noise and interference in the electrostatic signal are eliminated. The validity of the measurement circuit is verified by simulation test. Finally, according to the self-designed test platform of gas-path electrostatic monitoring based on small turbojet engine, the test of electrostatic sensor and measurement circuit was completed, and the electrostatic signal was collected, which preliminarily verified the feasibility and effectiveness of gas-path electrostatic detection method.

1. Introduction
Aviation engine is the heart of the aircraft, and is the core for its power. In order to improving the reliability and safety in the process of aircraft engine in the work, it need to have more advanced monitoring technology to real-time monitor the working condition of engine, and then it will realize the early warning of the engine fault and forecast service life, maintenance evaluation. In order to achieving these purposes, aero-engine aerosol electrostatic monitoring technology, as a real-time monitoring of aerosol electrostatic signal technology, has a broad application prospect[1]. Based on particle aero-engine gas path electrostatic monitoring technology as the breakthrough point, analysing the source of electrostatic particles in the air passage of aero - engine. The electrostatic sensor is designed based on the principle of electrostatic induction. Experiments are carried out to verify the feasibility of electrostatic sensor to collect the electrostatic induction signal of the electrostatic particles by using the gas-path particle simulation laboratory. These studies lay a foundation for the future experimental study on aero-engine aerosol particulate electrostatic monitoring[2].

2. Source of aero-engine gas-path charged particles and principle of electrostatic induction
During the operation of an aero-engine, fuel combustion mainly produces compounds chemical such as carbon dioxide, nitrogen oxide and so on, and it will also produce C particles under the condition of high temperature and hypoxia.

In general, pure gas is electrically neutral, but mixed particles or droplets in the gas appear to be electrically neutral. There are several ways for particles in gas to be charged. On the one hand, the gas is ejected at a high speed. During the flow process, the particles will have a large area of severe friction with the pipe wall, casing, blade and tail nozzle and thus become charged. On the other hand,
when the fuel burns in the combustion chamber, violent chemical reactions take place. Under the condition of high temperature and high pressure, chemical ionization and thermo ionization take place in these areas, and these processes are all particles with electrostatic charge. When the charged particles are close to the surface of the conductor, the surface of the conductor will generate an induced charge, but as the charged particles move away, the charge on the surface of the conductor will disappear. Lowered the sensors placed and tail nozzle exit, a continuous electrically charged particles through the agent very near, very electrostatic induction occur constantly, constantly internal charge redistribution transformation, so keep moving charge the induced current is formed within the ground pole, converting induced current through the circuit voltage, according to the change of voltage, for gas path fault monitoring.

3. Design and manufacture of electrostatic sensor

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In the use environment of electrostatic sensors, the induction sensitivity to electrostatic signals is determined by the length of electrostatic balance time achieved by the probe of electrostatic sensors. The induction sensitivity of conductors is only related to the conductivity of materials. The greater the conductivity, the shorter the time to achieve electrostatic balance, and vice versa. It has nothing to do with the shape, size and internal structure of the probe. Therefore, the greater the conductivity of the material selected for electrostatic sensor pole detection, the better.

Induction of the electrostatic sensor badly needed aircraft engine exhaust of electrostatic discharge by particles of electrostatic induction signal, the engine jet exhaust gas is high temperature and high pressure gas, due to the agent directly in the gas stream, in addition to the need to meet the requirements of sensitivity also need to tolerate high temperature environment, that can tolerate high temperature erosion and gas flushing. Therefore, the sensor pole detection needs to be isolated from the shell to avoid contact. The isolation material is similar to the working environment of the probe, and it is under the condition of high temperature gas scour. Therefore, the isolation material between the probe and the grounding shell needs to have good insulation, can't generate static electricity, can maintain its own structural characteristics under high temperature, and is not easy to be deformed or destroyed.

3.2. Measurement circuit design of electrostatic sensor

The concentration of electrostatic particles in the air circuit of an aero-engine is very low, and the induced electrostatic signal is also very weak. Moreover, the electrostatic sensor is usually placed in the tail nozzle and works under the environment of high temperature, big noise and serious interference. Therefore, high requirements are put forward for the pre-amplification stage of the sensor. The sensor needs to meet the following conditions[3]:

- input amplification stage shall have high input impedance and low output impedance
- the amplifier circuit has enough amplification factor to enlarge the signal to the extent that it can be collected and processed at the later stage;
- strong anti-interference ability.

The circuit design of electrostatic sensor is generally divided into two categories. One is to use resistance to collect inductive current signal. Weak inductive current flows through the resistance and generates voltage drop on the resistance. The other is to use operational amplifiers to convert the current signal into a voltage signal and connect the feedback resistance and capacitance in the feedback circuit to control the gain size and band width[4]. Therefore, according to figure 2, a circuit is built to collect signals.
3.2.1. Signal switching circuit. The first level of electrostatic sensor for signal conversion circuit, and the particle of aero-engine gas path electrostatic induction signal can be equivalent to become a source of alternating electric charge, which can be regarded it as a source of alternating current, so the role of the electrostatic sensor measurement circuit is having been converted the induced current signal to voltage signal[5]. Because the electrostatic induction signal is a low-frequency signal with minimal amplitude, it is necessary to amplify the signal. The integrated operational amplifier used in this paper is OPA129, as shown in the circuit in figure 3. The low bias current characteristic and high input impedance characteristic of this operational amplifier far exceed those of other operational amplifiers.

3.2.2. Instrument amplifier circuit. After the signal is collected and amplified by the signal conversion module, the amplitude is still very small. Therefore, in order to increase the gain of the circuit, the amplification module needs to be added. At the same time, in order not to introduce interference, the instrument amplifier circuit is used. The amplifier circuit is composed of two stages of amplification circuits. The first stage is two symmetrical codirectional input amplifiers. The second stage is a differential amplifier to achieve equal output of the signal[6].

Figure 1. Resistance to collect inductive current signals

Figure 2. Operational amplifiers convert signals

Figure 3. Signal switching circuit
Figure 4. Instrument amplifier circuit

As shown in the figure, U2 and U3 of the symmetrical phase amplifier constitute the first stage, and OP07 is the integrated operational amplifier selected for the second stage differential amplifier. When the resistance in the circuit satisfies the condition $R_2=R_6$, $R_7=R_8=R_9=R_{10}$, the gain of the circuit is

$$G_2 = 1 + \frac{2R_2}{R_5}.$$  

It can be seen from the above equation that the desired circuit gain can be obtained only by changing the resistors $R_2$ and $R_5$.

3.2.3. Filter circuit module. In the process of front stage acquisition and signal transmission, the signal will be subject to external interference or internal noise, which will make it difficult to identify the electrostatic signal. Therefore, a filter module should be added before the output of the measurement circuit to eliminate high-frequency noise and reduce interference[7]. Since the electrostatic signal is a low-frequency signal, the filter adopted is a low-pass filter, which allows the low-frequency signal to pass through and attenuates the high-frequency signal. This paper adopts the filter design software specially designed for Filter Pro Desktop. The design diagram of the filter is shown as follows:

Figure 5. Filter design schematic  
Figure 6. Filter baud diagram

3.3. Sensor circuit design

In order to verify the feasibility of the principle of electrostatic acquisition system, the software of Multisim 10 was used to simulate the measurement amplifier circuit of the sensor, and an alternating current source in series with a capacitor was used to simulate the signal source. In the alternating current source model, a current source of 5nA and 200 Hz is selected, and a capacitance of 100 pF is connected in series to simulate the electrostatic signal induced by the probe of the electrostatic sensor. The next two OPA129 are symmetrically connected to form an instrument amplification circuit, which is then connected to a complementary differential amplification circuit formed by a patch of OPA129, and finally to a low-frequency filter to output the signal[8]. Analog circuit lap is shown in the figure 7:
Figure 7. Simulation circuit diagram electrostatic sensor

Figure 8. The signal input is compared with the amplifier output

Figure 9. Amplifier output and filter output signal comparison

It can be seen from figure 8 and figure 9 that the designed amplifier circuit can effectively collect and amplify signals. According to the circuit designed by simulation, making the whole circuit into a printed circuit can greatly reduce the loss of signal and external interference. Figure 10 is the actual welded circuit board, and figure 11 is the physical picture of sensor pole detection.

Figure 10. Electrostatic sensor amplifies the circuit board

Figure 11. Physical picture of sensor pole detection

4. Performance test of electrostatic sensor

4.1. The establishment of the experimental platform
Test rig is developed by laboratory and designed specifically for small turbojet engine thrust test and provide the engine working gas device, in this experiment platform can realize simulation of engine gas path fault, including gas path components surface spalling or friction fault, external suction abnormal impurity particles, such as working conditions, it can be used to conducting electrostatic sensor signal feasibility verification experiments, which can be all kinds of fault gas path condition of engine was simulated. In the process of engine operation, carbon powder particles and iron powder particles can be injected by electrostatic duster to simulate different types of engine air circuit faults, or carbon powder particles and iron powder particles with static electricity can be injected into the nozzle simply by electrostatic duster.
4.2. Feasibility test of the sensor
Start the small turbojet engine, and when the engine reaches a stable state, place the sensor in the pole-probing mounting hole, and inject the starting motor and the vibration table to carry out rub experiment. The changes in the monitored signals during the experiment are shown in figure 13:

![Engine test run test phenomenon](figure13.png)

Through the experimental data, when, after the touch with electrostatic particles through electrostatic sensor, compared with not the touch experiments, circuit of the output voltage amplitude changed obviously, shows that electrostatic sensors that monitor electrostatic induction signal produced by electrostatic particles, electrostatic sensor design is feasible.

5. Work summary and outlook
In this paper, the characteristics of electrostatic signal generated by aero-engine electrostatic particles are studied, and a signal conversion circuit for electrostatic signal conversion is designed. And the model of conversion circuit is simulated. At the same time, the amplification circuit and low frequency filter circuit are built. The principle of sensor circuit was simulated theoretically. At last, altium designer software was used to draw the printed circuit board by itself, and finally the sensor signal processing circuit was produced. According to the designed sensor, the reliability test of the sensor is carried out through the test platform of small turbojet engine, and the generated electrostatic signal is
analyzed. It shows that the designed electrostatic sensor can effectively detect the fault signal, which provides a strong research foundation for the next step of establishing the engine recession model.

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