The Study of Turbo-Engine Early Fault Detection Technology Based PHM Sensor

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***Abstract*—The electrostatic sensor can measure the level of engine exhaust electrostatic charge ,based on electrostatic induction principle between the inducing charge and conductors. This paper proposes the basic design theory of the electrostatic sensor by building electrostatic sensor function and physical models. This study is significant for designing and manufacturing of a probe-type electrostatic sensor. In order to verify the effectiveness of the designed electrostatic sensor, there is a successful application in the aviation engine test process based on the aviation engine exhaust gas electrostatic monitoring principle and system. There were measured noise signals from electrostatic collection system, the electrostatic signals of an old engine starting process and a new engine for the first time test. These two types of signals reveal the basic form of the electrostatic signal changes and describe the levels of electrostatic charge in the Turbo-engine exhaust gas. The signal showed different characteristics conforming theoretical analysis for detecting early faults.**

Keywords—turbo engine; exhaust gas; electrostatic induction; sensor; experiment

I. INTRODUCTION

Turbo-engines are widely used in aircraft, whose abundant running state information can be collected with condition monitoring technology. The issue of establishing a complete PHM system becomes one of the hottest research topics**.** In recent years, more and more online monitoring technologies have been proposed and introduced to Turbo-engine condition monitoring in [1]. There is a new PHM sensor which can monitor the electrostatic level to get the condition information of Turbo-engine. Powrie [2][3]have made a great deal of research on electrostatic monitoring technology for monitoring turbojet engine exhaust gas. According to electrostatic induction principle, electrostatic sensor is designed to monitor the overall level of electrostatic charges. The research has been applied in the 5th generation fighter F-35, an aircraft having a new kind of technique for the engine condition monitoring that can support the maintenance of the engine by helping make decision appropriately. The studies of electrostatic monitoring technology include some researches, such as dust (including coal) flow velocity monitoring [4] [5] as well as monitoring of missile approaching in [6] [7]. Wen [8] [9] used the finite element method to study the sensing characteristics by simulating the exhaust electrostatic monitoring system. Therefore, considering the merits of electrostatic monitoring technology, it was promoted to the condition monitoring of Turbo-engine for collecting the running state data.

This paper proposes a design of an electrostatic monitoring sensor which is well applicable in high flow rate and high-temperature environment. Meanwhile, this paper establishes the function and physical model of the sensor. This probe-type electrostatic sensor has been successfully applied in testing of turbojet engine.

II. THE INDUCTING PRINCIPLE OF ELECTROSTATIC SENSOR

A. The theory of electrostatic inducting

When a charged object moves close to or away from an uncharged conductor, the conductor surface will appear the aggregation of induced charges. This phenomenon is called the electrostatic inducting, that a charged object generates an electric field in the space and the internal charges of the conductor will be redistributed according to the electric field. For example, if a charged object A moves close to a conductor B, the opposite charge will occur on the adjacent surface of B. A is referred as inducing charged Q and the charge on conductor B is called the induced charge Q_A. Since the interaction between the electric field generated by Q and the electric field generated by Q_A, conductor B will be in static equilibrium eventually. This process usually completes within a very short time (approximately 10^{-9} s) in [10]. B is always in equilibrium as a conductor in electrostatic field, but the balance is changing with time. According to the electrostatic field of Gauss theorem, conductor B has no extra charges internally and the induced charges only distribute on the surface of the conductor. When the charged object leaves away , the external electric field would be removed, as a result, positive and negative induced charges of conductors B will move rapidly and neutralize. The electrically isolated

conductor returns to its neutral state ,being ready to be induced once again in [11].

B. The principle of designing electrostatic sensor

Turbojet engine exhaust gas contains a large number of charged particles. When the charged particles go across the electrostatic sensor, induced charge will be formed on the electrostatic sensor surface for the electrostatic field. The electrostatic fields around the electrostatic sensor changes as particles move across the sensor. Thus, the constant fluctuant electrostatic charges will be inducted on the probe of the sensor in [8]. The principle is shown in Fig. 1.

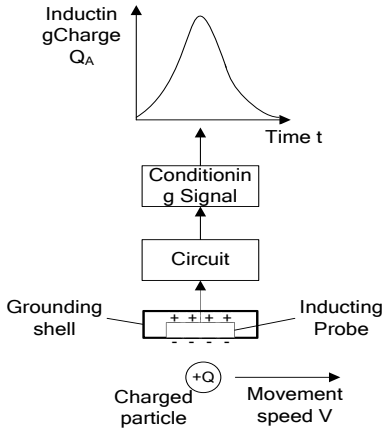

Fig1. The universal inducting principles of the electrostatic sensor probe

Electrostatic sensor mainly includes sensing probes, grounded enclosure, measuring circuit and other components. The principle of measuring circuit is illustrated in Fig.2.

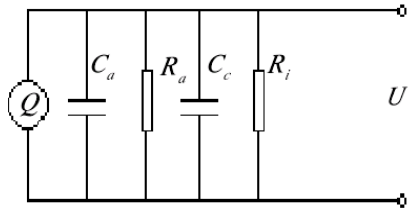

Fig2. The principle of measuring circuit in the electrostatic sensor

C_a is sensor capacitance to ground in the measuring circuit. R_a is ground leakage resistance. C_c is distributed capacitance of the cable. R_i is the input impedance of the measuring circuit. Assuming $Q(t)$ is the amount of induced charges on the sensor probe, $U(t)$ is measured output voltage. R is measuring the equivalent resistance circuit as $R = R_a R_i / (R_a + R_i)$. C is the equivalent capacitance of measuring circuit as $C = C_a + C_c$. Assuming initial state of the circuit is zero, the relation between the variations of the output voltage $U(s)$ and the variations of the inducing charge $Q(s)$ is as $U(s) = RsQ(s)/(RCs+1)$. When $RCs << 1$, the voltage is $U(t) = R\dfrac{dQ(t)}{dt}$, sensor output signal reflects the change of the amount of induced charges on sensor probe.

III. ELECTROSTATIC SENSOR FUNCTION AND PHYSICAL MODELS

A. Function model

The Electrostatic Sensor functional model is shown in Fig. 3. The components of the function model must respectively complete their assigned functions. They can guarantee the electrostatic sensor measuring the induced charges to achieve the charges in engine exhaust gas. The signal acquisition system reflects the induced charges on sensor probe by collecting the voltage signal.

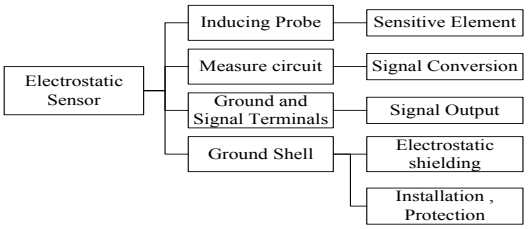

Fig3. The function model of the electrostatic sensor

B. Physical Model

The physical model of the electrostatic sensor is shown in Fig 4. The electrostatic sensor is applied in a high-speed airflow. There are the charged particles with many different sizes in high-speed air. The charged particles will be detected by the electrostatic sensor. In the detection process, the charge on electrostatic sensor probe is the result of all the charged particles in detecting space.

After the probe induces the signal by detection circuit module (measurement circuit), the sensor can output voltage signal through the signal cable. There is insulating material between the sensor probe and the ground shell. In order to avoid the induced charge impacting on the sensor probe, there is ground wire for the ground shell to timely eliminate the induced charge on the surface as shown in Fig.4.

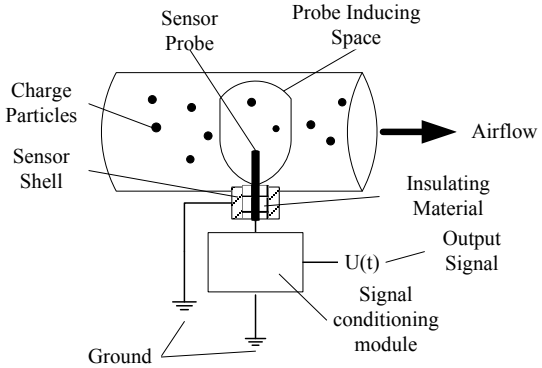

Fig4. The physical model of electrostatic sensor