GAS PATH ELECTROSTATIC SENSOR MONITORING AND COMPARISON EXPERIMENT ON TURBOJET ENGINE

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Abstract: A monitoring and comparison experiment with two types of sensors on a turbojet engine is carried out. Compared with a probe-typed sensor, which is designed successfully before, signals are collected to verify the validity and better feasibility of the circular sensor. According to the signals monitored over 131 h, the typical signals of 125—129 phases are analyzed. The results show that the unusual exhaust particles are carbon depositions from fuel spray nozzle. Therefore, with the electrostatic sensor, early warning can be provided for initial fault condition, as well as real-time reference for the condition-based maintenance.

Key words: turbojet engine; gas monitoring; electrostatic sensor; carbon fault; condition-based maintenance

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INTRODUCTION

Aero-engine is the heart for military and civilian aircraft; obviously, its failure could lead to serious effects. It is an effective way for condition monitoring and fault diagnosis of aircraft engine to ensure flight safety and reduce support costs. Recently, there has been a further progress in state management technology to realize condition-based maintenance (CBM)[1]. The basis to realize CBM is condition monitoring as well as prognostics and health management (PHM)[2]. PHM has been applied in the logistical support of joint strike fighter (JSF) of U. S. Military, and it is an airborne system with advanced sensor integration to predict, monitor and manage the status of aircraft[3]. PHM does not mean to eliminate faults but to understand and predict faults when failure occurred. It has stressed the online, real-time and integrated monitoring technology[4]. Compared with the conventional engine monitoring technology, the gas path electrostatic monitoring technology can not only effectively monitor the state of charged particles but also sensitively detect the changes of engine condition[5].

1 PRINCIPLE OF GAS PATH ELECTROSTATIC MONITORING SENSOR

1.1 Particle generation mechanism

Under normal conditions, the main ingredients of aircraft engine emissions consist of water (H_2O), carbon monoxide (CO), carbon dioxide (CO_2), unburned hydrocarbons (UHC), nitrogen oxides (NO_x), and soot particle.

Besides of the soot particles formed in engine conditions, there are also two sources of particles in gas path, that is, foreign objects (FO) from the inlet port and fault products from gas components[6]. When particles are inhaled or sprayed with high-speed gas, there will be interactions, ablations, frictions, and rubbings in gas path, or these particles have already been charged in the

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forming process[7]. Once these faults happen, there will be different types and characteristics of particles, for instance, excessive soots would be emerged because of nozzle clogging, resulting in charged particle increased instantaneously.

1.2 Particle charge mechanism

Experiments have shown that pure gas will not be charged, because of solid or liquid particles suspended in gas. What's more, when these particles are sprayed with high-pressured gas, there will be interactions among them, or these particles have already been charged in the forming process, resulting in a high-pressure gas charged. There will be particles either formed from fuel combustion or FO or faults in engine parts, and these particles, which are charged in the process of formation, elimination and friction, are similar with powder-electricity. Powders are solid substances, so electrostatic process is followed by solid electrification. In addition, due to fuel combustion in the chamber and high temperature, there must be chemical ionizations and other physical ionizations in this region to enable the particles charged. Thus, the charged properties of the particles of gas path involving physical, chemical and other process are more complicated.

1.3 Electrostatic monitoring principle

When foreign objects with electrostatic charge (point-charge Q for example) pass along the sensor, parts of power lines formed by Q end at the surface of the sensor, and they will cause electronic redistribution inside the sensor to balance Q. Thus, current comes into being. Signal regulating circuit and acquisition system change the induced charge signal into voltage signal proportionally[8-9], as shown in Fig. 1.

2 EXPERIMENTAL APPARATUS AND METHOD

2.1 Experimental apparatus

This experiment is on an aviation turbojet engine test cell. Considering the exhaust airflow,

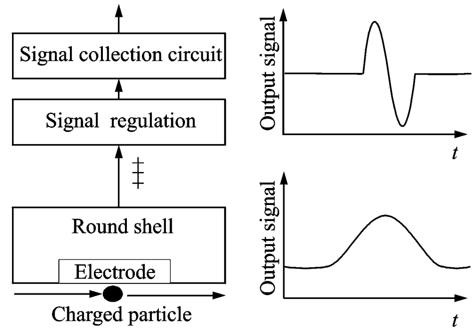

Fig. 1 Electrostatic monitoring principle

the circular electrostatic sensor is installed at the distance of 200 mm from the engine exhaust nozzle (the probe-typed sensor at the distance of 30 mm), as shown in Fig. 2. The electrostatic induction signals are collected by data acquisition card of NI-WLS9234, also, the data are saved into computer with collection procedures by Labview, 2 000 Hz.

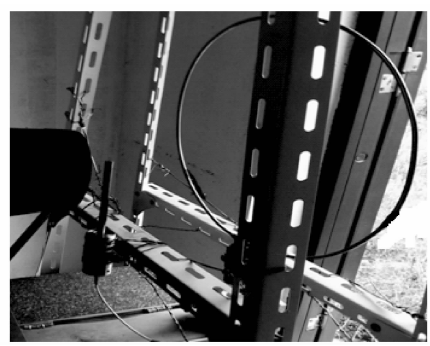

Fig. 2 Sensor installation

2.2 Circular electrostatic sensor

Electrostatic sensor consists of sensor electrodes, insulating medium, internal circuit and grounding shell. It is made into ring-shaped with its probe made of nickel-alloy stainless steel (axial diameter is 10 mm, and circle diameter 370 mm). Sensor covering is made by stainless steel for heat insulation and electromagnetic shielding while internal insulation material is microcrystalline-glass ceram that can stand up to 800 ℃ to protect the internal circuitry. Sensor equivalent circuit is shown in Fig. 3.

2.3 Experimental method

The experimental engine starts to test for 200 h life span, and the electrostatic monitoring experiments are carried out during the 200 h life

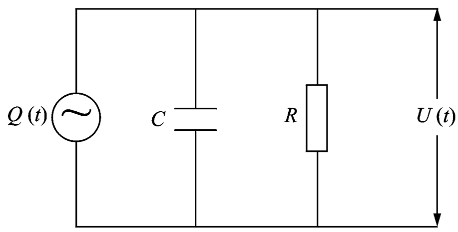

Fig. 3 Equivalent circuit of electrostatic monitoring

span test (there are an extra 40 h after 200 h, totally 240 h), taking each test for 1 h as a stage. Electrostatic signal acquisition begins with each stage and stops working when the rotor speed falling to zero. Limited by time, this electrostatic monitoring test goes on from stage 100 to stage 240, thus there are total 139 stages (collection line is connected at the ground for the first hour). Besides, there are 131 h effective data for circular sensor (circular electrostatic sensor begins from stage 110 monitoring) and 137 h effective data for probe-type sensor as well as the related parameters for later analysis.

3 EXPERIMENTAL RESULTS

This experiment is carried out using two types of electrostatic sensors for engine exhaust. The probe-type sensor has passed the verification experiments of turbo-shaft engine with successful 108 h exhaust static signal data[10]. The validity and feasibility of the circular sensor are judged by comparing the two monitoring signals between the sensors.

3.1 Background noise signals

At the phase of ignition, large amounts of positive and negative ions, which are produced in the pipe suddenly, make the induced voltage on both sensors changed sharply, as shown in Fig. 4. After about 5 s, the combustion gradually becomes stable and so is the induced voltage on both sensors, as shown in Fig. 5.

3.2 Typical signals

From engine condition, the background noise signals are in the millivolt-level (as shown in Fig. 5) while the abnormal pulse emerges within

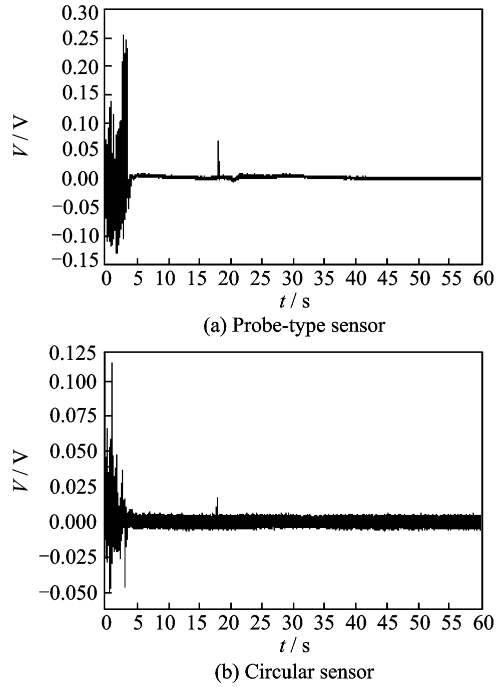

Fig. 4 Ignition phase signals

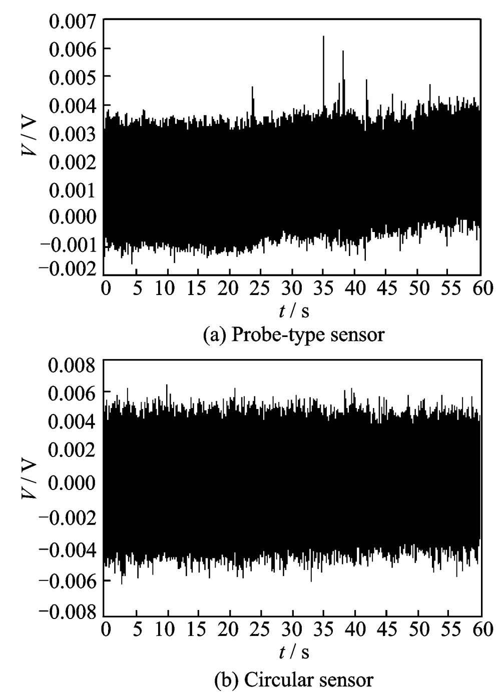

Fig. 5 Stable signals

125—129 h of test, or even there are volt-level signals (as shown in Fig. 6 and Table 1) with abnormal noise from engine. After inspection, engineers find there are large particles of carbon deposition in combustion chamber (as shown in Fig. 7). Therefore, this method can monitor realtime charge changing in gas path for early warning of initial fault.

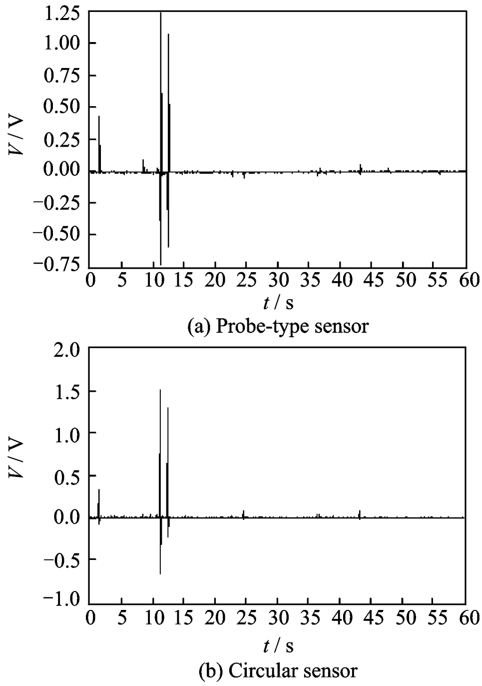

Fig. 6 Typical abnormal signals

Table 1 Abnormal signal amplitude

Data	Time	Probe-type sensor/V	Circular sensor/V
2011-11-04	09:11—09:12	0—2	0—2
2011-11-05	08:54—08:55	2—4	0—4
2011-11-05	14:17—14:18	0—2	0—1.5
2011-11-05	16:44—16:45	0—1	0—1.5
2011-11-06	09:09—09:10	0—0.3	0—0.6
2011-11-06	09:42—09:43	0—0.3	0—0.4
2011-11-06	09:43—09:44	0—0.2	0—0.1
2011-11-06	09:47—09:48	0—0.4	0—0.4
2011-11-06	09:52—09:53	−0.75—1.25	−0.5—1.5
2011-11-06	09:56—09:57	−0.5—2	−0.2—3
2011-11-06	09:58—09:59	0—0.15	0—0.3
2011-11-06	10:01—10:02	0—1.5	0—1.5

Fig. 7 Carbon deposition due to fuel spray

3.3 Comparison results

According to the collected data, there are high sensitivities on probe-type sensor and circular sensor, and both signals show the same background noise trend. Moreover, at the stage of condition changing, probe-type sensor has a little higher sensitivity on background noise while circular one covers wider range on abnormal signals, as shown in Fig. 8 and Table 1.

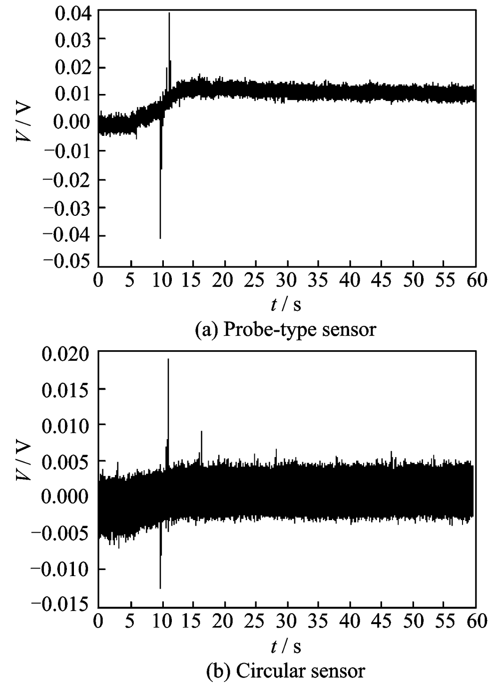

Fig. 8 Comparative signals

Due to the circular structure, the induced current is smaller in the center of the ring and larger when close to the ring, which leads to a little lower sensitivity than probe-type sensor. However, its sensing range is wider because of probe-type sensor fixed in a radial position.

4 CONCLUSIONS

Under engine working conditions, with electrostatic sensors on experiments, conclusions are drawn as followed:

(1) After frequency analysis, there are no frequency reasons matching to the rotational speed. Therefore, the abnormal particles, which cause changes in the engine exhaust electrostatic signals, are carbon deposition from fuel spray nozzle; meanwhile, it proves that there are large carbon particles after engineers taking apart the engine.

(2) Signals on circular sensor are similar to probe-type sensor with the same trend. Moreover, there is interference to exhaust stream as well as easily-worn structure for probe-type sensor. In addition, because of little contact between particulate solid flow and circular electrostatic

probe, the service life of electrode is increased to realize the nondestructive measurement of tail gas. Actually, exhaust particulate solids in pipeline are in the form of columnar streams with uneven velocity distribution, and the circular probe can balance the spatial effect and reduce the impact of phase or solid deposition. Therefore, circular sensor has little effects on exhaust flow with easier and wider applications.

(3) There are also some signals induced by metal particles in electrostatic monitoring with small amplitude occurred occasionally. The possible sources of these particles can be chipped from compressor blades or turbine blades, combustor materials-loss, and cavitations damage. The research needs later analysis from engine disassembling report, combining abnormal signal characteristics with faults, furthermore the typical failure characteristics can be proposed.

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