Research on In-situ Vibration Measurement Method of Rotor Supporting Structures under High Temperature Environment in Aero-engine

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Abstract: In engineering development, there is always an urgent need for in-situ vibration measurement of aero-engine rotor supporting structures. However, conventional vibration sensors can not be used under high temperature environment. A new type of Endevco high-temperature vibration sensor can withstand 482℃, and it can be used for research on in-situ vibration measurement of aero-engine rotor supporting structures. Firstly, the structural characteristic of the rotor supporting structures is analyzed and the test scheme is made.Then,the comparison and calibration of the high-temperature sensor principle test, and the analysis of the influence of temperature on the measurement accuracy, are completed and measured on the engine scale model test bench. Finally, the proposed test scheme can be applied to a core engine in the future.

Keywords: Aero-engine rotor supporting structures; In-situ vibration measurement; High-temperature vibration sensor

1 Introduction

As advanced aero-engines develop, it is urgent to measure its rotor supporting structures vibration directly. However, due to the fact that the aero-engine structure is complex, the temperature environment of rotor supporting structures are high (300-500 ℃), and the space is narrow, and it's hard to get rotor supporting structures vibration. In order to meet the demanding work requirements of intelligent high-performance aero-engines with high temperature, high vibration and high impact, a lot of researches had been carried out in the field of rotor supporting structures vibration at home and abroad[1-2]. Based on finite element analysis technology, Liu Zhansheng et

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 ISSN 2572-4975 (Print), 2572-4991 (Online)

al. [3] carried out the dynamic simulation analysis of the whole machine using the modal superposition method, and obtained the vibration response of the whole machine under the excitation of each bearing position, and then carried out the optimization analysis of the engine vibration sensor layout. Wang Meiling carried out research on the dynamic mechanism and vibration characteristics of rolling bearing misalignment and coupling misalignment, and obtained the lateral and axial vibration characteristics of the misaligned rotor system[4]. In literure[5], by a mean of the introduced evaluation method, the vibration relation between rotors and the main vibration measurement sections is analyzed. The rationality of theoretical results is sound verified by experiments on a designed pneumatic-driven double-rotor-casing test bench.The research results can provide a basis for the selection and optimization of vibration measurement locations and fault diagnosis in the aero-engine. Zhu Qingyu, et al.[6] proposed a laser linear scanning method to measure the modal shape of fiber-reinforced composite thin plate with high efficiency and precision. At present, it is only possible to measure the entire vibration of the engine in the external casing of the engine, and to analyze the vibration transfer characteristics of the rotor supporting structures, and it is impossible to grasp the real rotor supporting structures vibration. In the development of advanced aero-engines, it is urgent to develop in-situ vibration measurement of aero-engine rotor supporting structures.

In this study, Endevco 2248 high-temperature acceleration sensor is proposed to measure in-situ vibration of aeroengine rotor supporting structures.The working temperature of this sensor is up to 482 ℃, with high accuracy and small size, which can meet the requirements of in-situ vibration measurement of aviation aeroengine rotor supporting structures. In this article, the characteristics of the Endevco 2248 high-temperature sensor is firstly analyzed, and then a test plan is proposed, and finally comparison and calibration of the high- temperature sensor principle test is conducted.

2 Structural characteristics of aero-engine rotor supporting structures

In the development and use of high-end thermomechanical equipment represented by aero-engines, a large number of high-temperature sensors that can adapt to high-temperature environments and other harsh conditions are required to meet the needs of performance monitoring, including in-situ measurement of the state of the structural parts of the engine at high temperatures(above 400 ℃ to 800 ℃ -900 ℃) and even the temperature, pressure and vibration of the combustion chamber components(up to 1100 ℃ -1300 ℃). Typical engine temperature environment and sensing requirements are shown in Fig. 1 below.

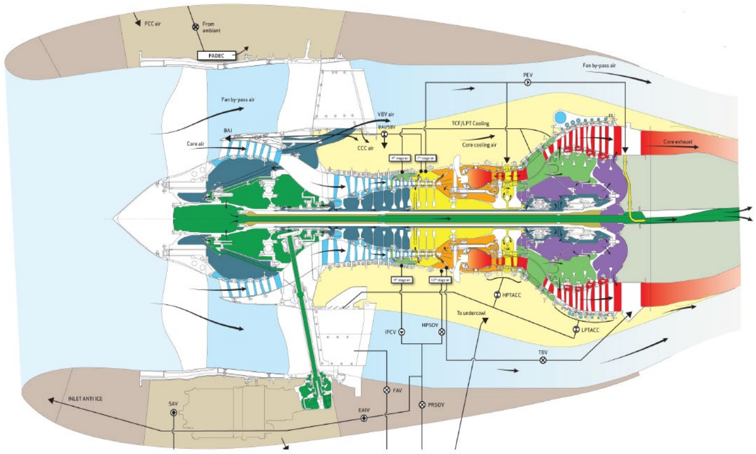


Fig.1 The temperature conditions and sensing requirements of an aeroengine

The high-pressure rotor and the low-pressure rotor have a total of 6 rotor supporting structures. The high-pressure rotor adopts the 1-0-1 two-point support scheme, and the back rotor supporting structures is the intermediate rotor supporting structures. The low-pressure rotor adopts the three-rotor supporting structures structure, that is, the 1-2-1 three-point support scheme. The fan rotor is supported at two rotor supporting structuress, and the low-pressure turbine rotor is also supported at two rotor supporting structuress. The transmission between the fan rotor and the low-pressure turbine rotor is sleeve gear.Generally, the assembly relationship between the bearing and the bearing seat is clearance fit. Too much load condition and long working period will cause deformation of the bearing seat, resulting in poor assembly reliability and abnormal structural vibration of the bearing and the bearing seat. For this reason, the outer ring of the rolling bearing in the elastic support structure of the aero-engine is often designed as an integrated structure with a flange mounting edge. One type of aero-engine 2 #, 4 # rotor supporting structures uses this flanged outer ring shaped bearing, and the outer flange of the bearing flange is connected to the supporting structure such as the squirrel cage and the bearing box by bolts, as shown in Fig. 2.

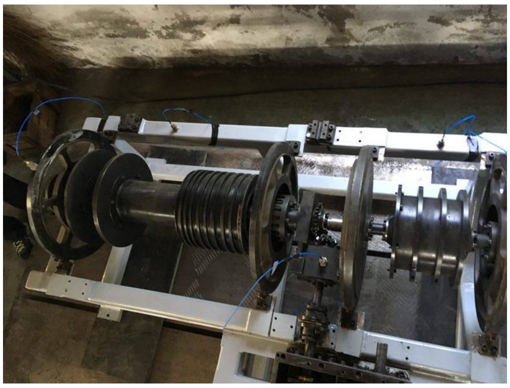


Fig.2 An aeroengine model and sensor arrangement

 ISSN 2572-4975 (Print), 2572-4991 (Online)

3 Test system for key measuring points of aero-engine rotor supporting structures

The test equipment for measuring the aero-engine rotor supporting structures vibration includes: an electromagnetic vibration table, which is used to apply sinusoidal excitation to the straight sample to be measured; a light vibration acceleration sensor and an Endevco high temperature sensor vibration acceleration sensor, each used to collect vibration signals; one industrial hot air blower and one hand-held infrared thermometer are used to heat and measure the sample respectively; a set of LMS test system is used for vibration signal collection and data analysis.

3.1 Features of Endevco sensors

American Endevco 2248 type acceleration sensor is a small piezoelectric acceleration sensor, specially designed for structural shock and vibration test in extremely high temperature environment and nuclear radiation environment, with reliability, nuclear radiation resistance.It can be used for vibration test of gas turbine and vibration monitoring of nuclear power plant.The sensor adopts endevco piezite P-14 sensor and endevco has a special base isolation structure, so that the sensor has a flat charge temperature response in the temperature range of - 55 ℃ ~ + 482 ℃. Piezite P-14 sensitive element has higher accuracy, lower thermal noise, and reduces the influence of temperature change. The base isolation structure makes the base not affected by the strain of the mounting surface. The sensor shell is made of Inconel alloy, and gas seal is achieved by integral welding and glass metal fusion at the joint.The sensor signal ground is in communication with the housing, it is equipped with a 10-32 output connector, and is equipped with a mounting flange. Piezoelectric acceleration sensor is a self-generated sensor without external power supply. Endevco 2248 high-temperature acceleration sensor uses Endevco Piezite P-14 type sensitive element. Fig. 3 is the physical picture of Endevco 2248 acceleration sensor.

Fig. 3 The physical picture of Endevco 2248 acceleration sensor

The Endevco 2248 high temperature sensor is fixed at the key measurement point of the aeroengine rotor supporting structures structure for picking up vibration signals, and the charge type vibration signal is transmitted to the Endevco 2771C-5 charge converter outside the casing through the 3075M6-120 high temperature cable. The charge converter converts the charge signal output by the sensor into a voltage signal, and collects, stores, and analyzes the vibration response signal through the LMS data acquisition instrument. Fig.4 shows the physical diagram of the test system.

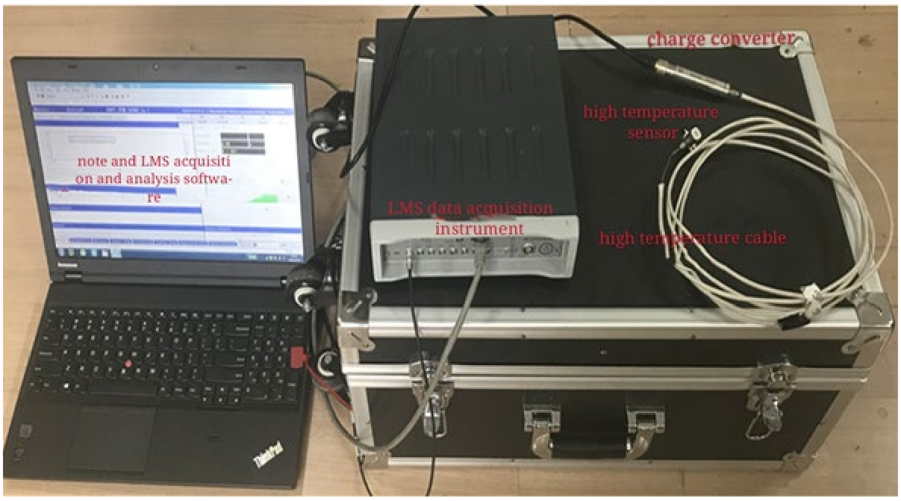


Fig.4 The physical diagram of the test system

Endevco 2248 high temperature acceleration sensor outputs the vibration signal of charge type, which needs to be used together with the charge converter. Endevco 2771c-5 remote charge converter (RRC) transforms the high impedance charge output of the sensor into a low impedance voltage output proportional to the charge of the sensor, because the signal output from RCC with low impedance is not easily affected by noise.

3.2 Testing scheme

The key test points of the structure of the rotor supporting structures of the aircraft are tested in the high temperature environment. In consideration of the need to protect the vibration table and the light vibration acceleration sensor, the vibration of a certain position of the straight plate prototype to be tested under the environment temperature and high temperature environment is measured successively for comparative analysis. The specific test site is shown in Fig.5. The test steps are as follows:

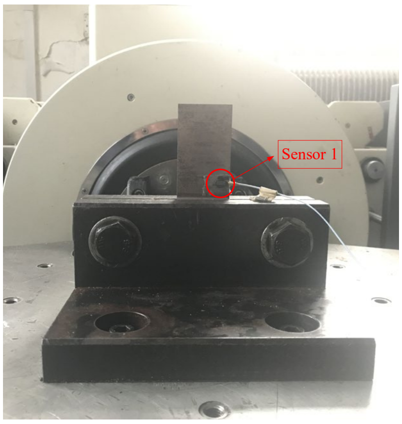
(1) Fasten the straight sample on the electromagnetic vibration table with a clamp;

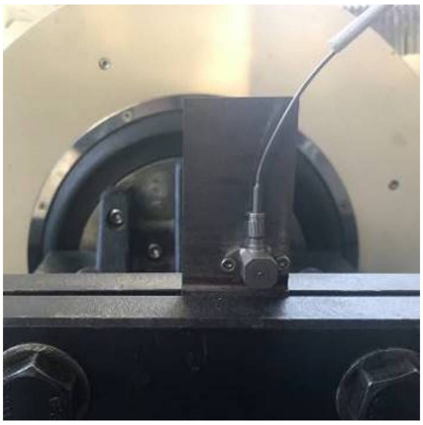
(2) Paste the light vibration acceleration sensor at the specified measuring point of the sample, start the electromagnetic vibration table, set the excitation frequency to 233Hz, and set the acceleration amplitude to 1g, 2g, 3g successively.After the signal is stable, collect and save the corresponding vibration signal;

(3) Paste the high temperature vibration acceleration sensor to be calibrated at the designated measuring point of the sample, start the electromagnetic vibration table, set the excitation frequency to 233hz, and set the acceleration amplitude to 1g, 2G, 3G successively. After the signal is stable, collect and save the corresponding vibration signal;

(4) Paste the high temperature vibration acceleration sensor to be calibrated at the designated measuring point of the sample, place the industrial heat blower on the back of the straight plate to heat the straight plate, use the hand-held infrared thermometer to measure the temperature of the measuring position, when the temperature is heated to 100 ℃, repeat the excitation methods in steps (2) and (3), collect and save the vibration signal at the corresponding temperature;

(5) Repeat step (4), heating to 150 ℃ and 200 ℃ successively, collecting and saving vibration signals at corresponding temperature.





(a) Light acceleration sensor (b) High-temperature vibration acceleration sensor

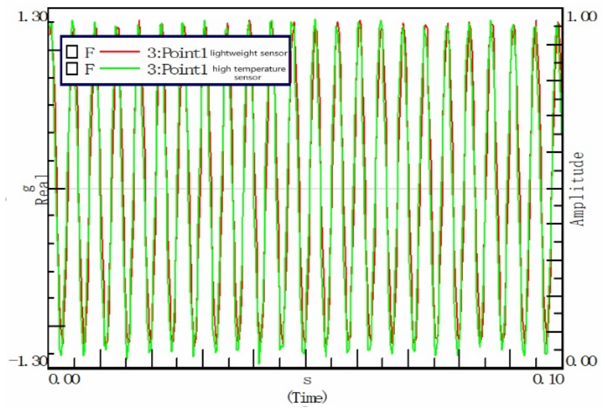
(c) Heating experiment

Fig. 5 The test site of the key measuring point of the aeroengine rotor supporting structures

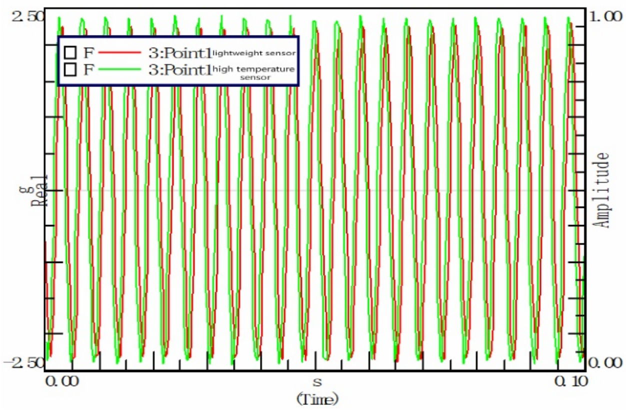
4 Vibration test and analysis of aero-engine rotor supporting structures

4.1 Comparison of measured acceleration of sensor at normal temperature

Set the excitation frequency to 233Hz, and set the acceleration amplitude to 1g, 2g, 3g successively. After the signal is stable, collected and saved the corresponding vibration signal. Fig.6(a), Fig.6(b), Fig.6(c) respectively provide the measured vibration response of the straight plate under the acceleration excitation of 1g, 2g, and 3g.

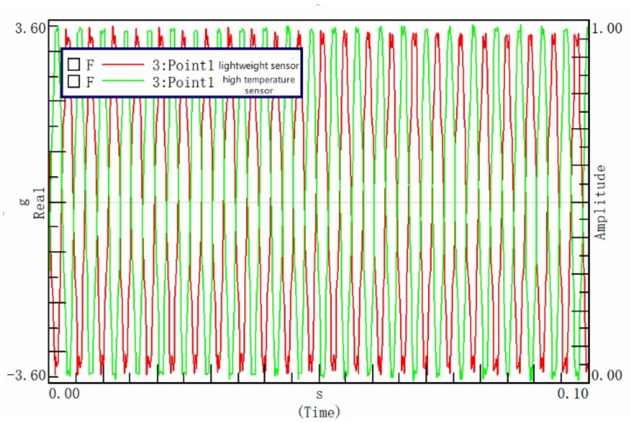


(a) 1g



(b) 2g

 ISSN 2572-4975 (Print), 2572-4991 (Online)



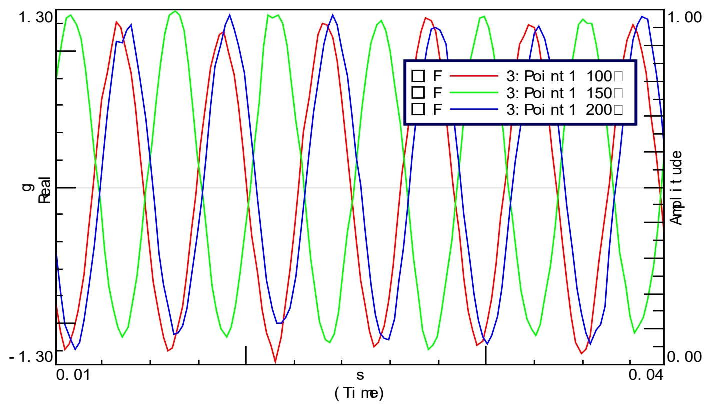
(c) 3g

Fig. 6 Vibration response of straight plate under different acceleration excitation

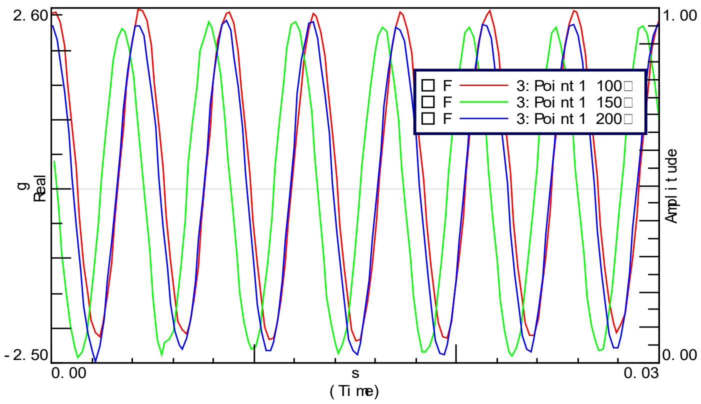
It is easy to see from Fig. 6 that under the acceleration of 1g, 2g, and 3g, the vibration response of the bar measured by the lightweight sensor and the high-temperature sensor to be calibrated is almost the same, which shows that the selected high-temperature vibration sensor has good accuracy and applicability.

4.2 Comparison of measured acceleration of sensors at high temperature

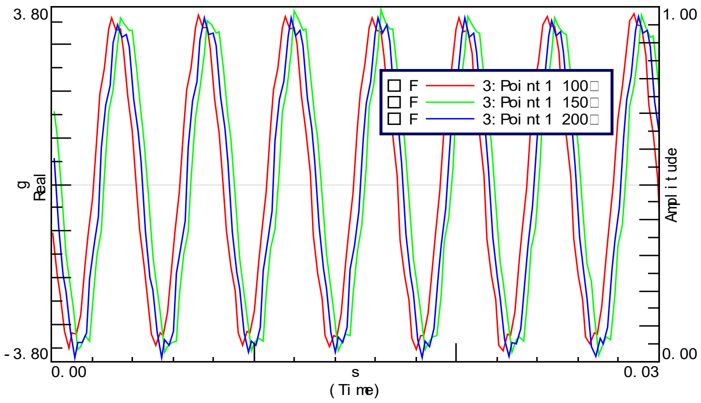
Endevco 2248 piezoelectric acceleration sensor adopts Endevco Piezite P-14 sensitive element, and Endevco has a base isolation structure, so that the sensor has a flat charge temperature response in the temperature range of -55 ℃ ~ + 482 ℃. In order to verify the reliability of the vibration measurement in the extreme temperature environment, the vibration response of the straight plate under the acceleration of 1g, 2g, and 3g at 100 ℃, 150 ℃, and 200 ℃ was measured respectively, and the results were compared with those measured in the normal temperature environment.



（a） 1g



（b） 2g



（c） 3g

Fig.7 Vibration response of a straight plate excited by different environment temperature and acceleration

It is easy to see from Fig.s (a), 7 (b) and 7 (c) that under the acceleration excitation of 1g, 2g and 3g respectively, the vibration response of the straight plate measured at 100 ℃, 150 ℃ and 200 ℃ is almost the same (the vibration amplitude is near 1.3g, 2.6g and 3.8g respectively), and the vibration response of the straight plate measured under the acceleration excitation corresponding to the normal temperature is also nearly the same, which shows that the selected high-temperature vibration sensor has a flat charge temperature response.

5 Conclusion

It is urgent to conduct the in-situ vibration measurement of aero-engine rotor supporting structures, however the conventional vibration sensor can not be used in high temperature environment. Endevco high temperature sensor has a flat charge temperature response in the temperature range of - 55 ℃ ~ + 482 ℃, which can meet

 ISSN 2572-4975 (Print), 2572-4991 (Online)

the requirements of in-situ vibration measurement of aeroengine rotor supporting structures.

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