VIBRATION MONITORING AND FAULT DIAGNOSIS OF INFLIGHT AIRCRAFT ENGINES

J. YI
Beijing Aeronautical Technology
Research Center, Beijing

Abstract

This paper presents mainly the new achievements inthe design of Airborne Vibration Monitoring (AVM) system and in the reaearch on method of vibration monitoring and fault diagnosis. We have measured and analyzedthe vibration signals of fifteen engines which includefaulty ones. The examples of application have proved that the system developed can work reliably and the methods proposed are effective for identifying engine vibration faults in flight.

I. Introduction

Airborne vibration monitoring and fault diagnosis of aircraft engine is one of the focal points in on-condition maintenance study. Since 1960's, advanced aircraft engines have been equipped with various AVM systems. Some of them are used to monitor the vibration of rotor using tracing filter, as shown in [1] [2]. Some record vibration signal of broad band in magnetic or semi-conductor memories in order to diagnose engine faults, as shown in [3] [4] . EDS (Engine Diagnostic System),only records the mass vibration value of engine without frequency information so as to judge whether the vibration strength exceeds the limit or not, as shown in[5] . These systems cannot well diagnose faults on in-flight engines, due to their poor system reliability, narrow frequency band, small memory capacity, or large system volume. In this paper, an improvement on the AVM system has been made and it has been successfully applied to the fighter, J-7.

Many specialists and scholars have done work on the vibration monitoring and fault diagnostic methods. They have theoretically discussed various mehtods, as demonstrated in [6], [7], [8] and so on. As FFT techniqueis developed perfectly day by day, spectrum analysis is widely adopted in vibration analysis, as shown in [9][10]. The diagnostic method in this paper is based onthe analysis of broad band spectrum. The process of airborne vibration monitoring and fault diagnosis, which have been applied to J-7, is that: < 1> . First, the sum of vibration acceleration (the dimension is g) and the sum of vibration velocity (the dimension is mm/s) on acertain frequency band, are used to monitor the vibration condition of engine; <2>. For the engine whose vibration exceeds the limit, the diagnostic method from the theory of spectral similarity is hence used to judge whether its operation is normal or not; <3>. For the faulty engine, the fault type is to be determined, and this analysis is performed on a computer.

The vibration on fifteen inflight engines have been measured in the paper, and their vibration characteristics has been studied in details. Finally, vibration limit values with high confidence level are determined. Using this AVM system and the diagnostic method, faults of several engines have been found out.

II. AVM and Fault Diagnostic System

Overall Design of System

The AVM and diagnostic system consist of airborne vibration data acquisition unit and ground analysis devices. A schematic of the AVM and diagnostic system is shown in Figure 1.

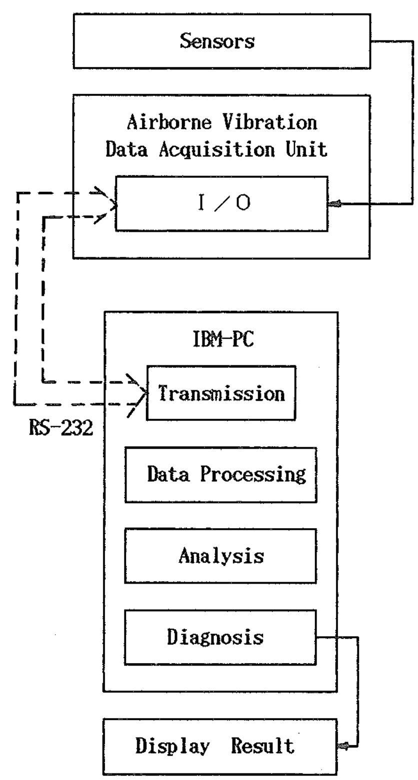


Figure 1. A Schematic of AVM and Diagnostic System

The airborne data acquisition unit can simultanously and synchronistically collect and store the vibration signals from three channels. The vibration signals, which are obtainted by double-terminal differential piezo-electric sensors, are transferred to charge transformators, signal modulators, anti-confusion filters and A/D converters with high sampling rate. The sampled data are memorized inside partitioned RAM in quasi-DMA fashion. The analog circuit also consists of bandpass filters, detection circuits and integration circuits, in order to obtain the sum of acceleration and velocity. A block diagram of the airborne data acquisition unit is shown in Figure 2.

Main Technical Features

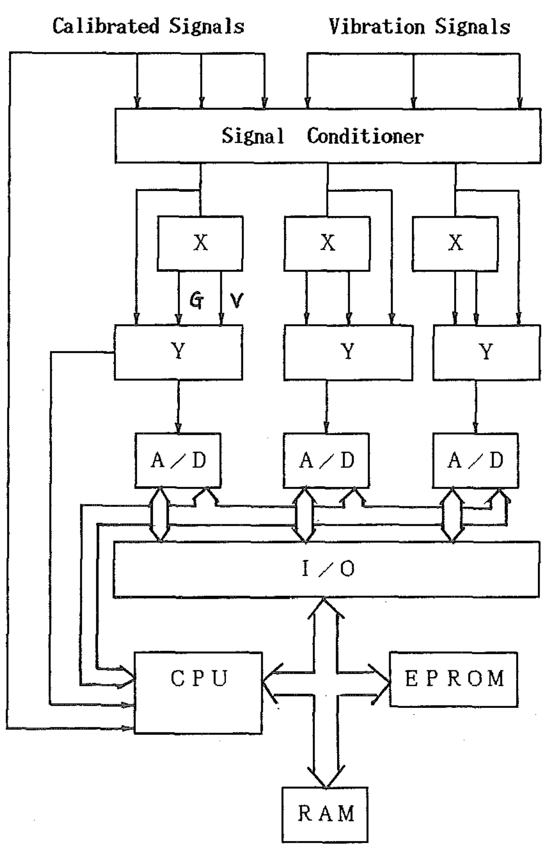
(1) . The airborne data acquisition unit, is controlled by a microcomputer, and memorizes the digital data in a memory board. It can record the broadband signals in flight in order that the engine vibration and faults can be analyzed.

(2) . This unit can be connected directly with a general purpose computer on the ground for processing and analyzing data on-line, without any special analog or decoded circuit.

(3). This unit possesses the advantages of small size, high sampling rate, large memory capacity and broad band, as listed below:

(a). Sampling rate: 1KHz or 25.6 KHz
(b). Total memory capacity: 192K or 1M bytes
(c). Frequency band of signal: 0-400Hz or 0-10KHz
(d). Volume: 220×140×70 (mm^3).

(4). The calibrated signals can be automatically generated and stored in the unit, so that the sum of vibration acceleration and the voltage in spectrum can be exactly converted into the dimension of g.

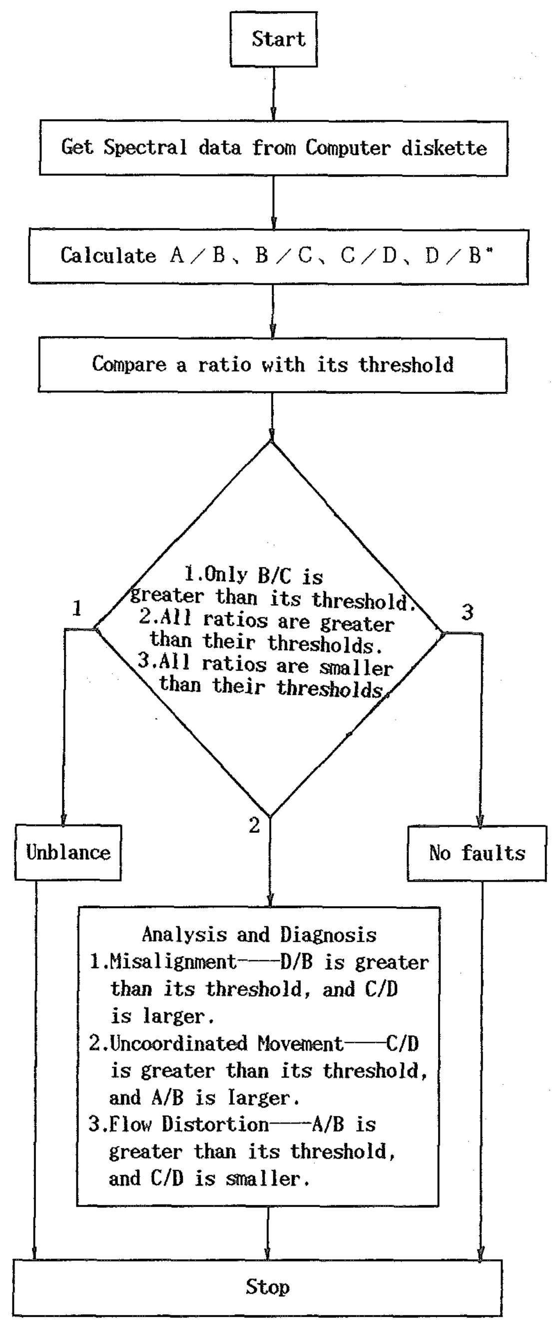


Note: X—Bandpass Filter, Detector and Integrator
Y—Analog Switch

Figure 2. A Block Diagram of Airborne Data Acquisution Unit

(5). A set of computer software for data processing and vibration analyzing is organized. The software includes data transfer and conversion program, digital data processing program, vibration monitoring and fault diagnostic program. The general flow chart of fault diagnostic program is given in Figure 3.

(6). The memory board fitted with batterys may be inserted in and pulled out from the unit in operation, and can itself keep the data for two months. When the unit is connected with a RS-232 interface, the data stored in the memory board can be transmitted to a computer diskette for long time keeping.



*See Table 2.

Figure 3. General Flow Chart

III. Methods For Vibration Monitoring and Fault Diagnosis

Vibration Monitoring

Vibration monitoring aims at evaluating the mass vibration strength of an engine and fast detecting the inflight engine vibration condition. To attain this goal, the sum of vibration on a certain band are taken as the evaluating parameter. The sum of vibration includes the sum of acceleration in terms of G and the sum of velocity V. G is a value which is obtained by the detector after the vibration signal from a sensor is transferred to 70 to 200Hz bandpass filter. The band of signal includes the fundamental frequency of engine rotor, its 1/2 harmonic and the frequencies of all " interfence signals" within the band of 70 to 200Hz. V is obtained by the detector after the signal from the bandpass filter is integrated.

After the vibration characteristics of in-flight engine have been deeply studied, G is used to monitor engine vibration in taking-off condition and V is for cruising condition. The limits of G and V are determined through probabilistic analysis of the actual measured data and have been corrected with reference to the vibration values of faulty engines.

Fault Diagnosis

Although vibration monitoring can promptly identify the engine in violent vibration, "false alarm" occurs occasionlly. In addation, it can not analyze the type and extent of engine fault. This can not meet the need for on-condition maintenance. In this case, the amplitude and frequency of broadband vibtation signal can be used to judge whether the engine's operation is normal or not, and then to determine the fault type. This paper presents a diagnostic method which is based on the theory of spectral similarity. The content of the method is as follows:

Power spectrum within 0 to 400Hz is divided into four bands, as shown in Table 1.

The fault type is judged in accordance with the ratios of the largest power spectrum on two bands. Through the theoretical analysis and experiment, the threshold values of all ratios and their corresponding fault types have been obtained. They are given in Table 2.

For the consideration of similarity between the spectra, the method of "ratio of the spectral peak values on two bands" is used to analyze the spectrum. Since aircraft engines possess the features of complex struture and multiple vibration sources, the spectra of the same kind aircraft engines in flight are much different[11]. So, it is quite difficult to detect the fault by directly comparing each spectrum with the standard spectrum. The theory of spectral similarity is based on the relative variation between the spectra, and this variation is used to diagnose engine fault. The fault diagnostic program has been developed.

Table 1. Frequency Band

Spectral Peak	A	B	C	D
Band (Hz)	45-100	150-200	225-300	305-400

IV. Application

Rotor Unbalance

There once was an airplane which was not permitted to fly due to the alerting of AVM system. During the process of taking-off, the sum of acceleration (G) of turbine outer ring was 4.5g, which exceeded the limit (4. 0g) . The diagnostic result given out by the computer shown that, the ratio of B to C was 3. 5, which was greater than the threshold (1.0), and the fault came from the turbine rotor unbalance . The engine was sent back to the factory to get repaired ahead of its schedule. The engine spectrum is shown in figure 4.

Misalignment

There was an engine whose inflight vibration value was larger than the limit. Its sum of velocity of front casing in cruising was 40mm/s, which exceeded the limit (35mm/s). The ratio of D to B was 3.9, which was greater than 1.5 in Table 2. It was considered that the fault of the engine came from the

Table 2. Ratio and Fault

Measurement Site	Ratio	Threshold	Fault Type	Fault Source
Front casing (Turbine outer ring)	B / C	3.0 (1.0)	Unbalance	Larger hot deformation. Uneven corrosion and rub.
	C / D	0.5 (0.1)	Uncoordinated movement of rotors	Low concentricity of rotors. Supporting rigidity decreasing.
	A / B	0.2	Flow distortion of air inlet	Self-excited vibration of airflow. Engine surge.
	D / B	1.5 (0.5)	Misalignment	Shaft flexure. Greater deviation of shaft coupling. Bearing fail.

misalignment. The report from the maintenance base proved that the intermidiate bearing was badly abraded and corroded, hence could not be used any longer. The engine spectrum is shown in Figure 5.

False Alarm

Once an AVM system installed on an airplane gave an alarm during flight. However, analyzing the engine vibration on the ground showed that none of the ratios shown in Table 2, exceeded its threshold value. Consequently, no fault can be concluded. Eventually, the engine worked until its lifetime scheduled.

Measurement Site:	Turbine Outer Ring
Engine Speed:	100%
Flight Condition:	Taking-Off
Flight Height:	10-500m

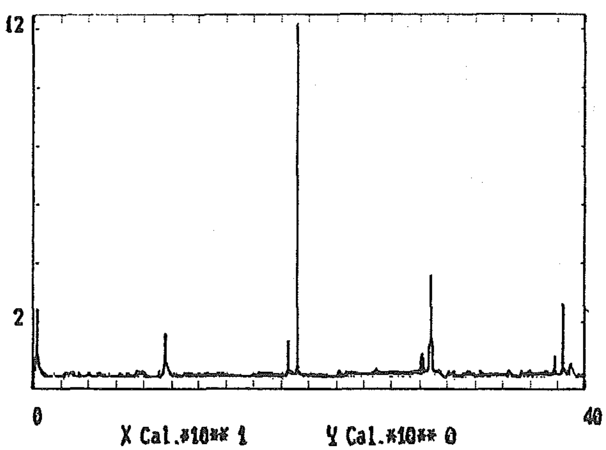


Figure 4. The Engine Spectrum

Measurement Site:	Front Casing
Engine Speed:	98%
Flight Condition:	Cruising
Flight Height:	6000m

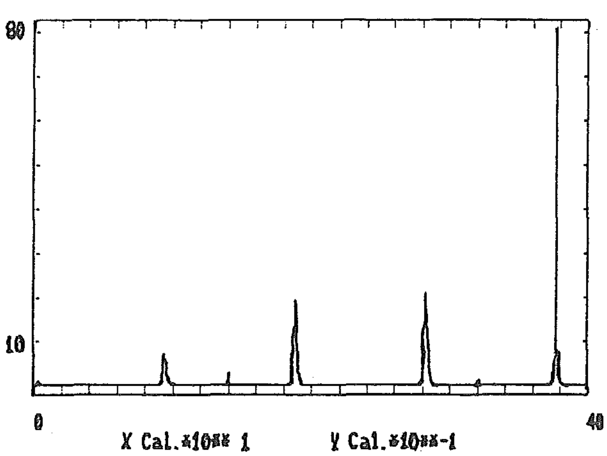


Figure 5. The Engine Spectrum

V. Conclusions

1. Broadband vibtation signals can be collected and stored on service fighter aircraft in flight.
2. Airborne microcomputer was successfully used to process fast-changing signals in complex aircraft environment. Sampled at high rate and stored in large capacity, multi-channel broadband signals in flight can be analyzed on the ground. The airborne data acquisition unit developed here is cheaper and more reliable than those using magnetic tape storage.
3. Frequency spectrum analysis technique is one of the effective tools used to diagnose the fault of machanical equipment. However, it is not sufficient to detect faults by simply using the spectrum graphalone directly. Processing for the spectrum is still required and the vibration characteristics related to faults are fully understood.
4. The method presented in this paper, which combines airborne vibration monitoring with the fault diagnosis on the ground, can efficiently monitor the vibration of inflight engines and diagnose their faults.

VI. REFERENCES

1. R. W. Greaves, "An Overview of Airborne Vibration Monitoring Systems", SAE Technical Paper Serives 871731.
2. P. Q. Hurry, "Modern Technology and Airborne Engine Vibration Monitoring System", AIAA-83-1240.
3. M. J. Angustin, "The V-22 Vibration, Structural Life and Engine Diagnostic System," SAE Technical Paper Serives.
4. R. G. Christophel, " A-10/TF34 Turbine Engine Monitoring System Evalution Systems Experiement", AIAA-81-1447.
5. "An Overview Of USAF Engine Diagnostic System", AIAA-86-1679.
6. "Aircraft Engine Vibration Analysis", ISABE Conference, 89-7068.
7. B. B. Aggarmal, " Knowledge-Based Systems For Rotordynamic Diagnostics", AIAA-86-1678.
8. "An Expert System for Gas Turbine Engine Diagnosis and More", SAE Technical Paper 87-1737.
9. ISA ASI 75293 74248.
10. "Engine Vibration in Flight", AIAA Aircraft Systems and Technology Conference 1987.
11. J. YI, "WP-7 Engine Vibration Frequency Spectra In Flight", Research Report