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COMPUTER AIDED ANALYSIS OF COMPLEX VIBRATION SIGNATURE OF TURBOJET ENGINES

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ABSTRACT

With the advent of computer's technique there has been a rapid growth in the use of microcomputers in all engineering activities. This paper outlines the important role played by a general purpose microcomputer in the analysis of the extremely complex vibration signals of the turbojet engines.

The proposed system consists of an FFT analyzer and a 64 k micro computer Basically, through proper interface and specialized software, the microcomputer converts the constant bandwidth spectrum to a constant percentage bandwidth spectrum for overcoming small fluctuations in turbojet engine speed. Direct comparison of any two spectra, and comparison with predefined reference mask may be performed. The results of these comparisons are automatically printed in the fault detection program output.

The paper includes practical examples illustrating, in detail, the main benefits of using the micro-computer in this domain. All the vibration spectra presented in this paper are measured on real turbojet engines mounted on the test stand.

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INTRODUCTION

In recent years, the desktop microcomputer systems are finding increasing popularity in the scientific domain. The low-cost microcomputer provides on-the-spot answers in an interactive on-line fashion to various scientific problems which were usually solved by the help of large computer systems (main-frames) with long turn-around delays. The increasing use of microcomputers in scientific and engineering applications stems partly from their low price and partly from their easy use and programming (particularly in high level languages). Also, the use of graphics capabilities has proved to be of considerable importance in the design and analysis. In addition, many microcomputers interface easily to a variety of scientific instruments which are important in many laboratory applications. In fact, the microcomputer revolution is rapidly changing the profile of laboratory research and of measurements and control techniques. Scientific and engineering application packages are now very common and cover a wide range of interest for engineers and scientists. For example, reference [1] describes the main software tools used in the mechanical engineering field.

An important field where the microcomputers can play a significant role is the vibration signature analysis of high-speed rotating machines [2] . In particular, the extremely complex vibration signature of the turbojet engine requires an efficient data acquisition and diagnostic system. Economical desktop microcomputers with suitable programmes can do an excellent job of data reduction and analysis, in just a few seconds, to provide hard copy plots of dynamic information for on-line or recorded vibration data of turbojet engines. This is the corner stone for establishing "on condition maintenance "and fault diagnosis technique.

The present paper deals with the successful application of a general purpose micro computer in the analysis of the measured vibration signatures of turbojet engines. The constant band width spectra of the FFT analyzer are reprocessed by the microcomputer to constant percentage bandwidth spectrum. This facilitates digitized spectra comparison and automatic fault detection. Example of the application of fault detection program to a tested turbojet engine with a defected first stage compressor blades is included. The paper outlines the various advantages of using the micro computer in this domain throughout some examples from real turbojet engines mounted on test stand.

PROPOSED SYSTEM FOR TURBOJET ENGINE VIBRATION SIGNATURE ANALYSIS

Fig. 1. depicts the proposed system for the analysis of turbojet engine vibration signatures. It consists of the following instruments:

- A four channel F-M recorder with high signal to noise ratio type B&K 7005.
- Real time FFT analyzer type B&K 2033
- X-Y plotter type B&K 2308
- Microcomputer type HP 9826 with soft ware package No. WW9034/WH1224 of B&K.
- Printer type HP 2671G

Description of the main features of these instruments is given in [3] .

SIGNAL IMPORVEMENT

The vibration signal of a turbojet engine, measured using the vibration measuring system described in [3] , is shown in Fig.2, where the variation of the peak-to peak amplitude of the acceleration level with time is illustrated. Obviously, nomuch information, other than the overall vibration level, can be gained from a signature in this form of presentation. Processing of such signal in the FFT analyzer results in the instantaneous spectrum as shown in Fig.3. The latter figure depicts the variation of vibration level against the frequency. However, due to the relatively large level of the baseline random noise, improvement of the signature in frequency domain is done through averaging process of several spectra . The result is that the baseline noise has been considerably reduced and the main frequency components are more easily detected in the averaged spectrum. From the present experiments, it is found that averaging of 32 spectra of turbojet engine vibration signatures is sufficient to improve the signal without too much increase in the time and length of record. As for example Fig.4 depicts the averaged spectrum of the same signal shown in Fig.3.

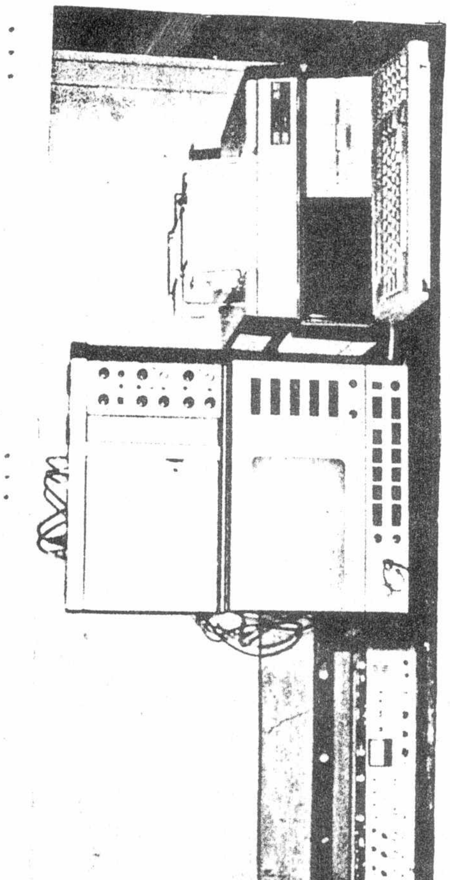

Fig.1. Vibration Signature Analysis System

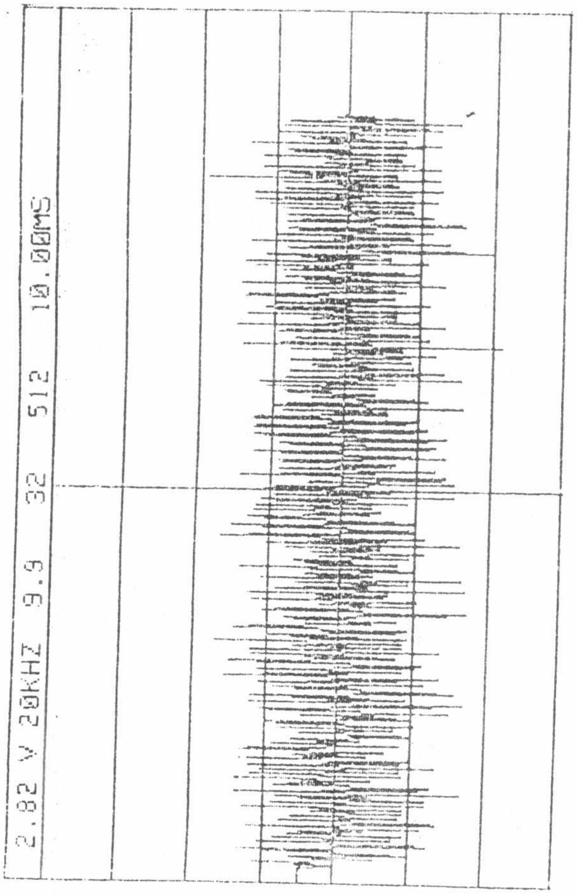

Fig.2. Turbojet Engine Vibration Signal in Time Domain

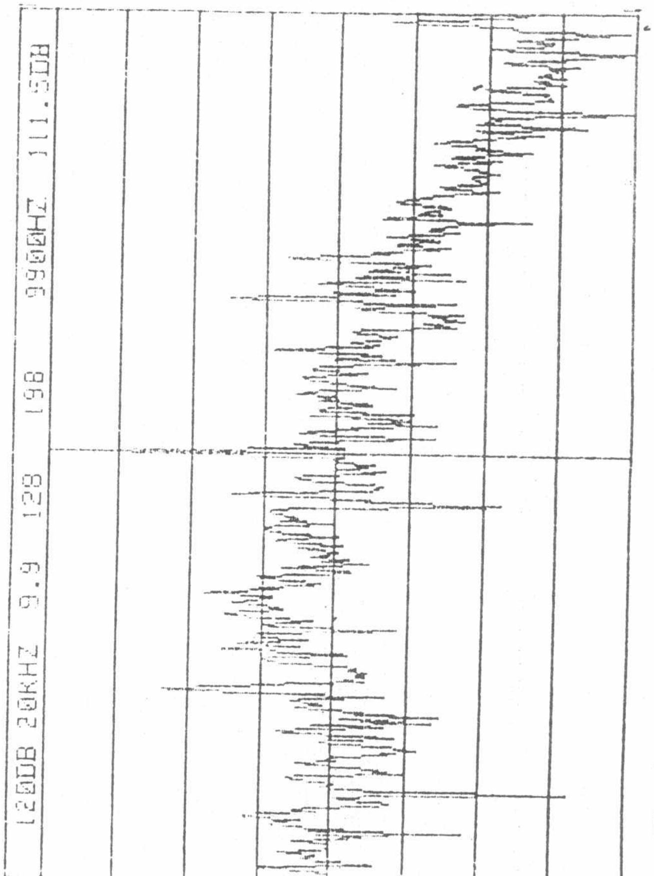

Fig.3. Instanteneous Spectrum of a Turbojet Engine

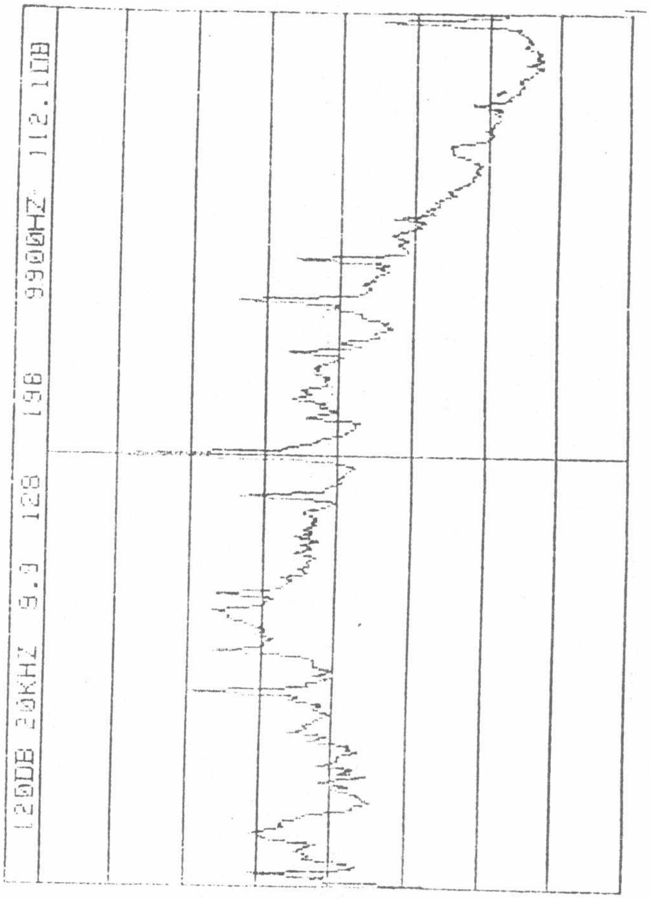

Fig.4. Averaged Spectrum of a Turbojet Engine

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COMPARISON OF DIGITISED SPECTRA

The successful applications of vibration measurement and analysis in turbojet engine fault detection requires the ability of correct and rapid comparison of digitised spectra for detection of significant changes. Although the narrow band frequency analyzer gives digital value of the amplitude for each of the 400 frequency components, it is usually not sufficient to compare two spectra by simply subtracting their digitized values [4] . In fact, direct subtraction of two spectra will lead to completely meaningless misleading results in case of turbojet engines for two main reasons:

* Even very slight speed variations ($< 0,25$ %) can mean that the same vibration component falls in two different locations in the two spectra.

* Digital sampling of the spectrum is very sensitive to steeply sloping flanks of discrete frequency components.

It is here that the micro computer plays its major role in overcoming the difficulties of digitised spectra comparison by transforming the constant band width spectrum to a constant percentage bandwidth spectrum of broadened width of peaks.

The conversion of the spectra to a logarithmic frequency axis with constant percentage bandwidth makes a lateral shift sufficient to eliminate the effect of the speed changes. Simultaneously, the logarithmic frequency axis enables a wide frequency range to be covered in one spectrum. This feature is extremely important in the case of turbojet engines where a large frequency range, extending from low engine order frequency components to high blade passing frequencies, should be covered for fault diagnosis. The lateral shift for speed change compensation is carried out in accordance with the same reference speed in both of the two compared spectra. Usually, reference speed is taken as the first engine order since it can be easily identified in future spectra of the same turbojet engine.

The constant percentage bandwidth spectrum shown in Fig.5, has been produced by the micro computer using three individual linear spectra from the analyzer each separated by a decade in frequency i.e. with full scale frequencies of 200 Hz, 2 kHz and 20 kHz, respectively. The constant bandwidth used in Fig.5. is 1/3 Octave (or 23%) resulting in 10 channels per decade, which is the

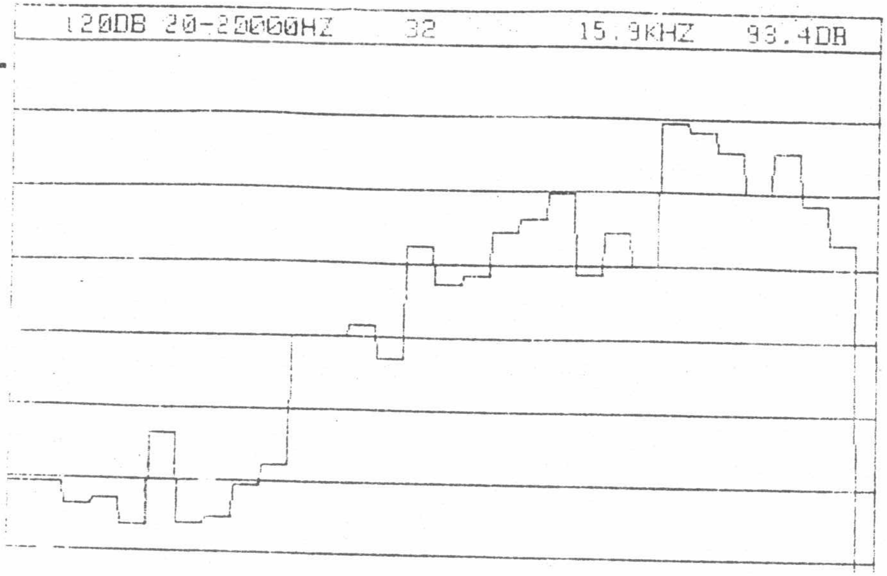

Fig.5.Constant Percentage Band width Spectrum with 10 channels / decade

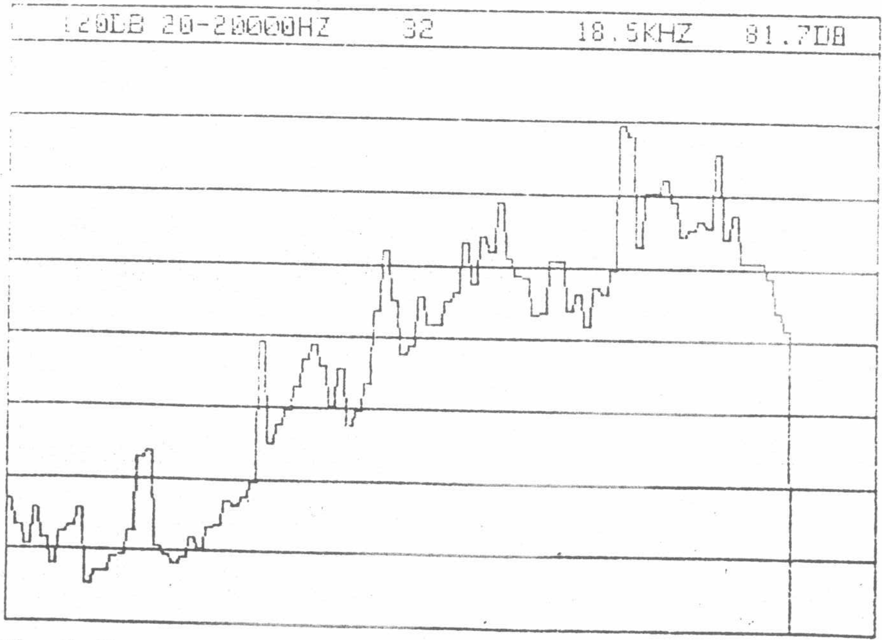

Fig.6.Constant Percentage Band width Spectrum with 30 channels/decade.

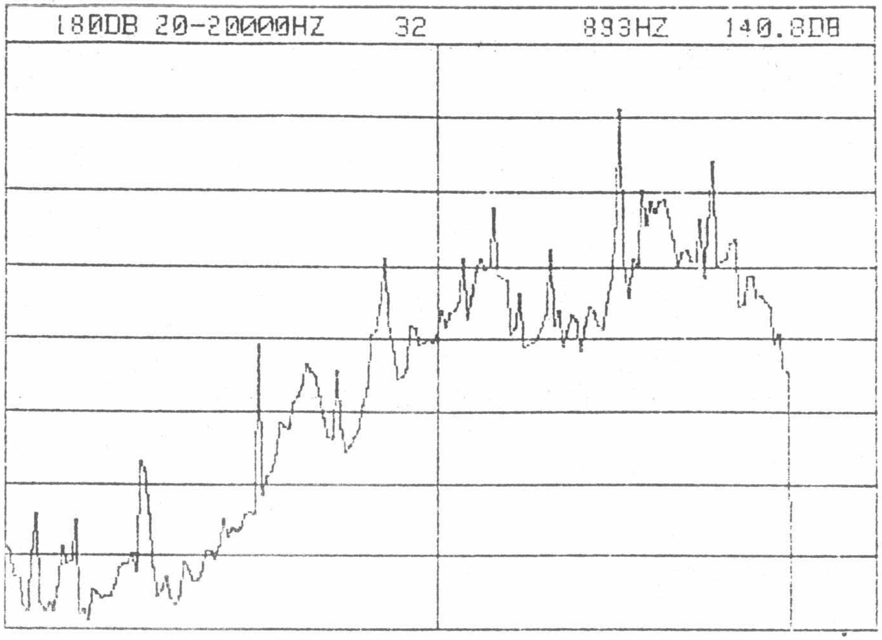

Fig.7.Constant Percentage Band width Spectrum with 60 channels/decade.

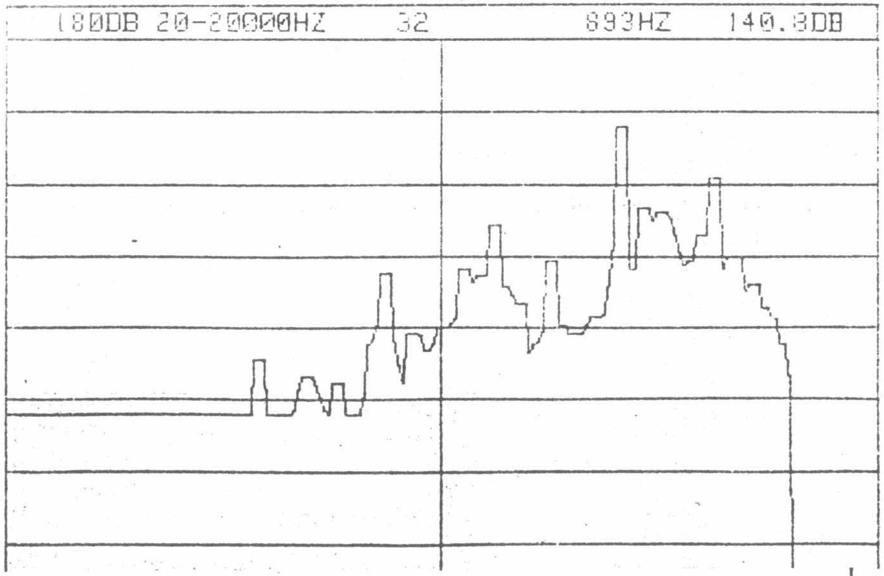

Fig.8.Reference Mast of a Turbojet Engine Vibration Signature.

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broadest bandwidth available in the used program. Fig.6 and Fig.7 show the same signal displayed in 30 channels/decade (1/9 Octave or 7,7%) and 60 channels/decade (1/18 Octave or 3,9%), respectively. It is worth noting that the use of small bandwidth as in Fig.7 results in a spectrum comprised of 180 values over 3 decades and gives a high degree of certainty that changes anywhere in the spectrum will be detected. However, the possibility of using a broader bandwidth, as shown in Fig.5, should be considered in the sake of economy, as only 30 values are required to cover the whole frequency range, thus reducing the data handling problem.

COMPUTERIZED FAULT DETECTION

Another important area in which the microcomputer is indispensable, is the formation and storage of a reference mask [5]. The reference spectrum of each turbojet engine can be reformed by broadening the width of the peaks of the frequency components to overcome the mentioned problems of the sensitivity of digital sampling to steeply sloping flanks of discrete frequency components. At the same time, the dynamic range of the reference spectrum is limited to avoid false alarms coming from changes in the base noise level. Thus, siginficant changes in the main frequency components will only be indicated. A typical example of a turbojet engine mask formed by broadening the peaks and limiting the dynamic range of a reference spectrum is shown in Fig. 8.

The fault detection program compares a new spectrum of a turbojet engine with a mask produced from a reference spectrum of the same engine previously stored on the floppy disc. Changes in the speed of the turbojet engine are automatically compensated by readjusting the reference speed to the same value chosen in the reference spectrum. A predetermined tolerance in dB gives the allowable increase in level in each frequency band. The tolerance can be either constant over the whole of the dynamic range of the spectrum (with a default value 6 dB) or a dynamic tolerance. In the latter case the default value is 10 dB at the lower spectrum dynamic range limit and 4 dB at the maximum level with linear change between these two limits. This results in de-sensitising of the lower signal levels which may vary more because of the noise.

The results of the comparison appear as a print out of the microcomputer. It includes the various frequencies with significant change in amplitude level together with the detected increase in dB and the amplitude levels. This automatic printing feature is extremely valuable in the case of the complicated vibration spectra of turbojet engine where visual comparison is not easy.

An example of the fault detection program output is illustrated in Fig.9. It is interesting to note that the three detected frequencies in this example are the blade passing frequency of the first stage rotor blades of the tested engine and its 1/3 and 1/8 subharmonics. (4.48 kHz= number of blades 24 x engine rotating speed 186,2 Hz). In fact, the inspection of the tested engine revealed that the blades of the first stage were damaged.

Obviously, the use of the computerized fault detection and the extension of the frequency range of the measured spectrum enable the detection and diagnosis of a greater number of faults. Hence, the present system is more advantageous than that of reference [6] where only unbalance and shaft bow are detected. Also, the utilization of the microcomputer to convert the spectrum to constant percentage bandwidth with broadened peaks, to overcome engine speed variations, eliminates the need of a tacho signal or a frequency counter to normalize the spectra to engine order components rather than the use of an absolute frequency scale as described in reference [7].

DATA STORAGE AND PRESENTATION

One of the major advantages of the used of microcomputers in vibration signature analysis of rotating machines is the efficient way in which large quantities of data can be handled [8] . A typical floppy disc ($5\frac{1}{4}$inch) can store up to 300 vibration spectra of turbojet engines with different forms of data thus eliminating the need for files filled with paper.

Fig. 10 is a three-dimensional plot of the vibration signatures of turbojet engine which depicts the variation of engine spectrum with time. Another important application of the 3-D plot is obtained when several spectra of the engine are drawn at equal intervals of the engine speed during run-up or run-down. This presentation of frequency spectra versus r.p.m; simplifies the separation between the engine order related harmonics (which

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010077STAB22/11/84FS2CH5MGT,V,LP

010077STAB10/11/84FS2CH3MGT,V,LPR
FREQ   INC   LEVEL

 564   11.6 151.7
1.47K  11.0 157.9
4.48K   9.9 171.6

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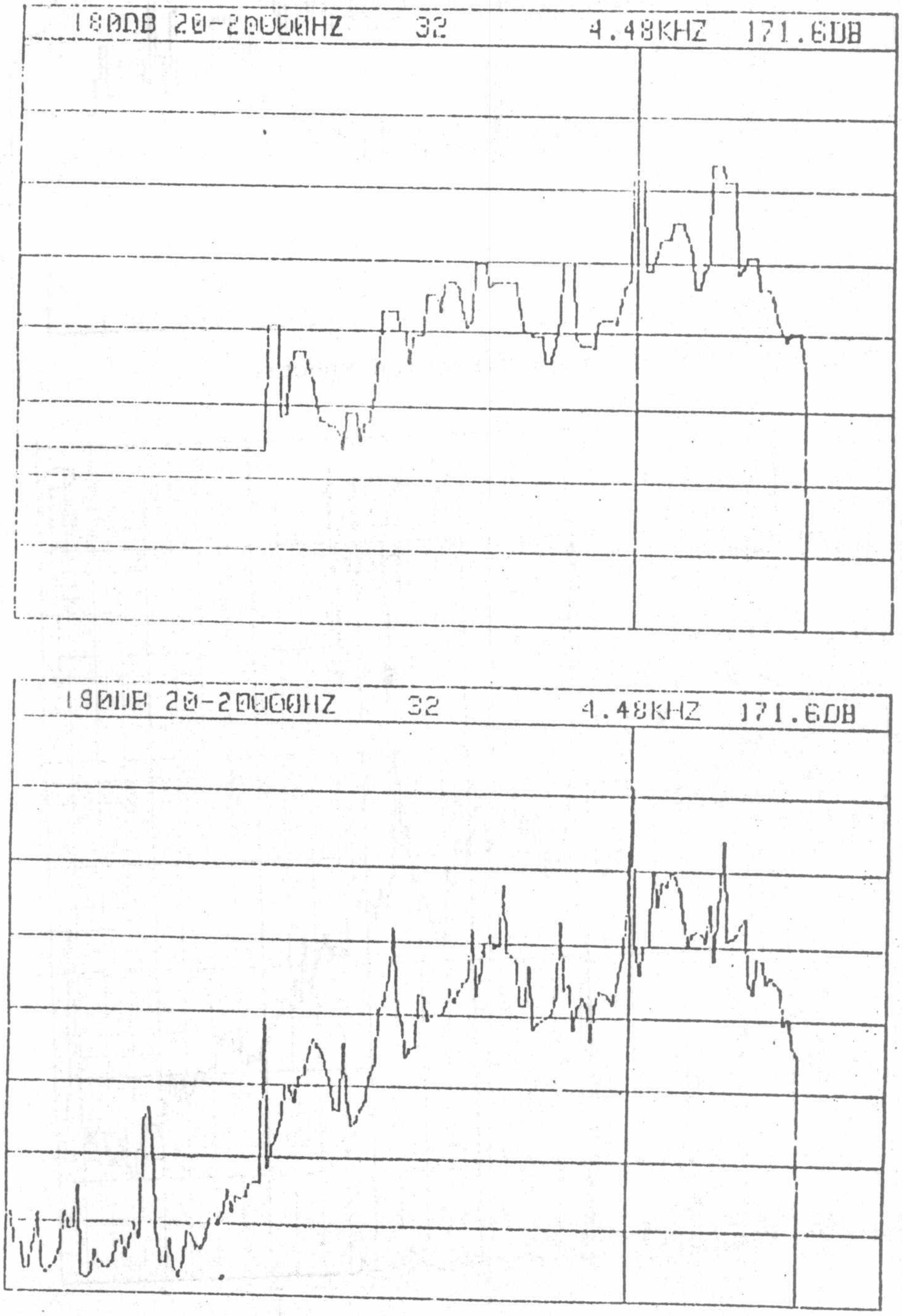

Fig.9. Output of a Fault Detection Program

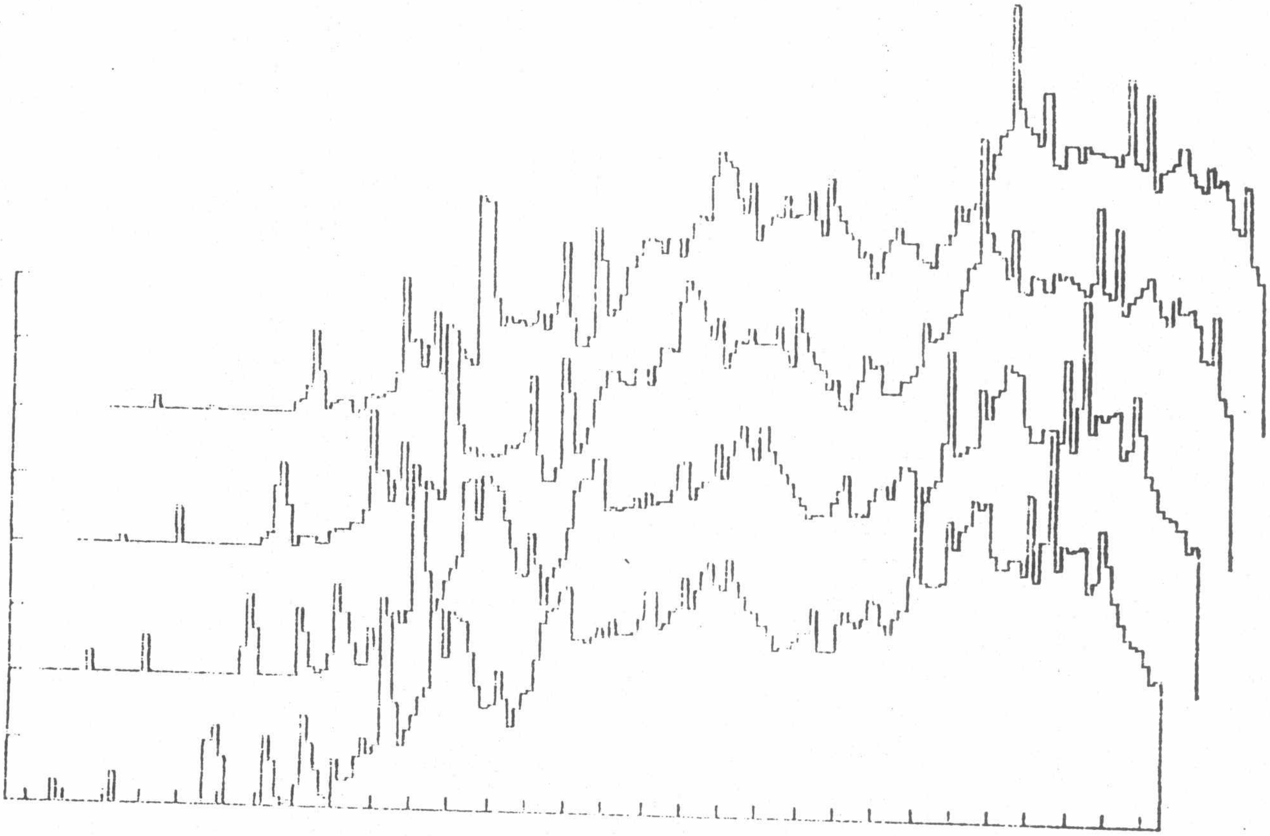

Fig. 10. 3-D Plott of Vibration Spectra

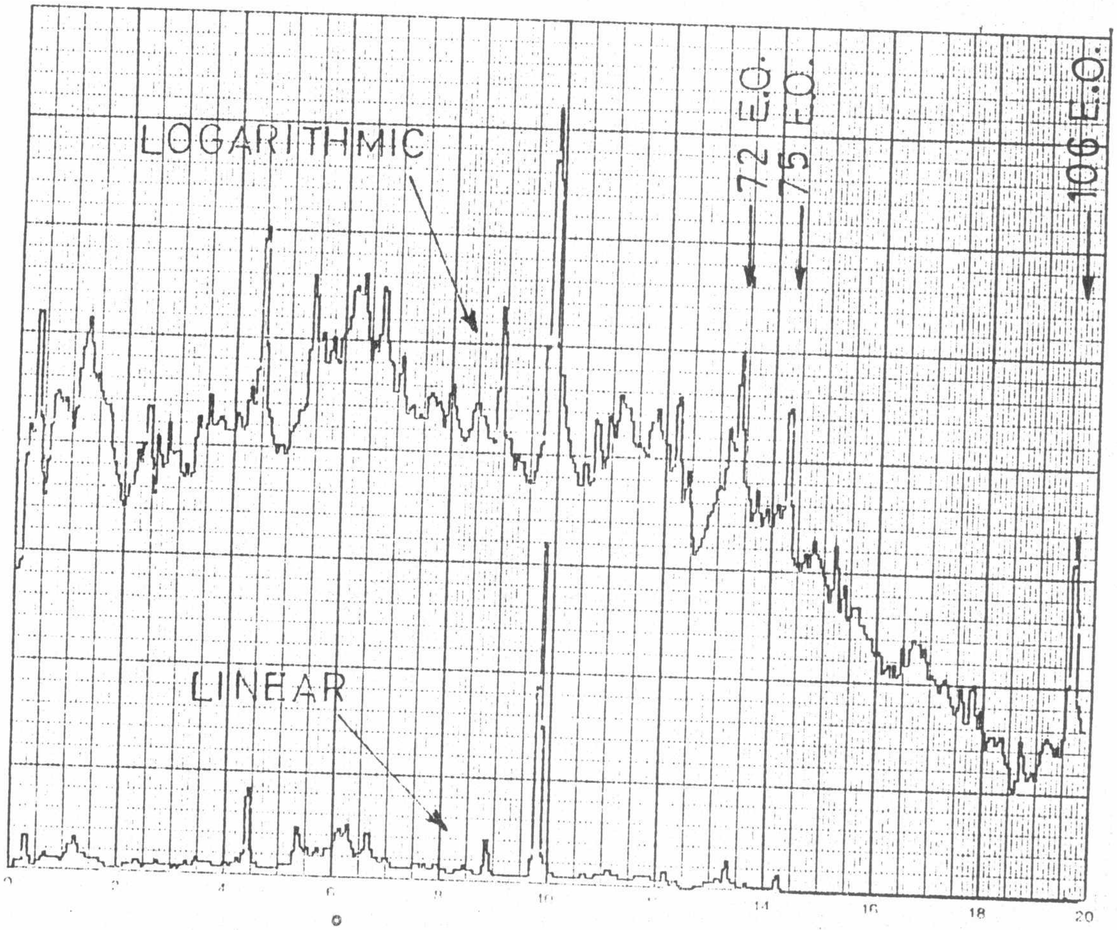

Fig.11. Comparison of linear and logarithmic Amplitude Scales.

appear as radial lines) and the structure resonances (which appear as vertical lines).

Another important advantage of using a microcomputer is that it enables the presentation of vibration spectra with logarithmic or linear scales for both the frequency and amplitude axes. For example, fig.11 depicts the same turbojet engine signature presented in a logarithmic and linear amplitude scales. It is clear that some of the significant engine order frequency components in the logarithmic scale (for example the 72, 75 and 106 E.O.) are nearly missed in the linear scale. However, the linear amplitude scale has the advantage of easy conversion to engineering units. Also, the linear frequency scale is more useful in fault diagnosis, while the logarithmic frequency scale is more helpful in fault detection [9].

However, in spite of the great success of microcomputer application in turbojet engine fault detection, it is still very difficult to fully automate fault diagnosis. It will normally be necessary for an engineer to make diagnosis. Providing reliable automated diagnostics is infact the central problem of rotor system monitoring by the way of vibration analysis [10].

CONCLUSION

The emphasis in this paper is placed on indicating the important role of microcomputers for automating fault detection in turbojet engines. In spite of the extremely complex nature of the vibration signature of turbojet engine, the used fault detection program gives the frequency components where significant changes occur in an efficient and clear way. The microcomputer is shown to facilitate considerably data treatment, storage and presentation. At the same time, the microcomputer allows easy conversion of vibration spectra from linear to logarithmic scales to gain the advantages of both types of presentation.

The microcomputer can be also very useful in making other calculations, which have not been discussed here, such as statistical calculations for deciding on the significance of a particular deviation from normal engine conditions. Another useful application is the trend analysis for predicting potential problem areas before the catastrophic failure stage is ever reached. Also, the microcomputer can be used for establishing a library of spectra, for each type of turbojet engines, measured at different conditions. This can be very useful in future for rapid diagnosis of turbojet engine conditions.

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