USE OF DIGITAL SIGNAL PROCESSING FOR NOISE ANALYSIS OF ROTATING ELECTRICAL MACHINES

Dr. M.N. Bandyopadhyay

Director, Haldia Institute of Technology, mail: mbandyopadhyay@yahoo.com

ABSTRACT : A software algorithm is being developed utilizing the most sophisticated DSP tools, i.e., FFT for vibration analysis of the rotating electrical machine. The most modernized transducers are utilized to obtain the vibration signal from the machine. The software has been tested on the signal generated in the motor and vibration signal from a vibration table using piezeo resistive accelerometer.

Keywords: DSP; DFT; FFT; Piezo-electrical; Cepstrum; Sampling-frequency; Transducer.

INTRODUCTION

The principal method of monitoring state of electrical machines is the spectrum analysis of vibration velocity signal recorded at the surface and bearing housing. Vibration data is collected at suitable points and it is coded to identify the measurement point, the load condition of the machine, collecting data and instrumentation settings. The vibration data recorded is analysed using spectrum analysis. One of the commonest methods of transient signal analysis is frequency analysis which is based on fourier series. The FFT is computationally efficient method for computing the Discrete Fourier Transformation (DFT) and it can compute the discrete fourier transform much more rapidly than other available algorithm. Utilizing the above tool of digital signal processing, an elaborate study has been made on the vibration analysis of the rotating electrical machine. Efforts are also made to record the real vibration data from the rotating electrical machine surface. Comparison is also being made on the mathematical analysis and the actual recorded vibration signal.

PRINCIPLE OF MATHEMATICAL ANALYSIS

The background of the frequency analysis is the Fourier transform which is based on the fact that any periodical function which satisfies certain mathematical conditions can be expanded in a fourier series, in the form of sinusoidal and non-sinusoidal signals with well defined frequencies. Owing to the fact that the transient signals are not periodic, their fourier transform exists only if the buffer form of the transform is applied. But when the signals are not continuous in time but are characterized by a series with points taken at equal time intervals, then the analysis of such signal is performed by the discrete fourier transform. The wave form F(t) is sampled at N time intervals. The DFT of F(n) is defined as

$$F(k) = \sum_{n=0}^{N=1} f(n)e^{j\pi\pi kjn/N}$$

where

$$k = 0,1,2 - - - - - N-1 \qquad (1)$$

If the sampling frequency is inadequate, higher frequency components of the true waveform F(n) will appear as lower frequency component in DFT. Hence the outcome is frequency aliasing. There is no way to correct the data after the sampling has been performed. The usual solution to this problem is to use a low pass analog filter that eliminates all frequency above F/2 before sampling, where F is the sampling rate. The sampling frequency F must be at least twice the highest frequency in the signal to recover completely the continuous signal from the sample counter part. The direct computation of DFT involves 2N evaluation of trigonometric function, 4N real multiplication, 4N(N-1) real additions and number of indexing and addressing operations. For speeding up discrete fourier transform computation, fast fourier transform is applied. It is an algorithm of calculation procedure for obtaining the discrete fourier transform with a greatly reduced number of arithmetic operations compared with the direct evaluation. The number of multiplication is being reduced by approximately a factor of 2. The number of addition is also reduced by about a factor of 2. Divide and conquere approach to computation of DFT has been applied. This approach is based on decomposition of an N-point DFT into successively smaller DFT. The basic approach leads to a family of computationally efficient algorithm known collectively an effective algorithm.

ANALYSIS OF VIBRATION SIGNAL

In vibration measurement, the quantity is to be measured in vibration acceleration from the surface of the electrical machine. From the measured quantity velocity and displacement of vibration are obtained by integration. The algorithm and flowchart developed are discussed as follows.

Integration of Vibration Signal

Integration of vibration signal is performed using numerical methods of integration. The acceleration is integrated in frequency domain instead of in time domain. In fourier analysis, any steady state complex vibration signal, however complex it may be, is separated as combination of pure sinusoidal motions with harmonically related frequencies.

$$F(T) = X_1 \sin(\; + {}_1) + X_2 \sin(2 \; + {}_2)$$

$$+ \text{-------} X_n \sin(n \; + {}_n) \qquad (2)$$

As more and more terms are added to above series the description of the non-harmonic periodical vibrations become more precise. By integrating equation (2).

$$+"F(t)dt = (X_1/ \; \sin\left(\; + {}_1 - (?/2)\right) + (X_2/ \; 2 \; \sin$$

$$\left(2 \; + {}_2 - (?/2)\right) + \text{- - - - - -} + (X_n/n \; \sin \left(n \; + {}_n - (?/n)\right) \qquad (3)$$

From equation (2), it is clear that after integration, acceleration vector is rotated backward 90° in complex plane, and its amplitude is modified by dividing it by its corresponding frequency.

Amplitude of displacement at any frequency is determined by dividing the amplitude of the velocity by its corresponding radial frequency. The phase of displacement at any frequency is determined by subtracting 90° from the velocity at its corresponding frequency.

Spectrum Analysis

Power spectrum of vibration data is determined by multiplying each vibration data by itself. If X(i) is vibration data sample, then power spectrum P(i) is determined as

$$P(i) = X(i) * X(i) \qquad (4)$$

The Fourier transform of power spectrum has been performed by FFT algorithm. If the Fourier transform of power spectrum is denoted by $P_{gg}(f)$ then

$$\mathrm{Log}_e\ P_{gg}(f) = \log_e\ |P_{gg}(f)\ | + j\,|P_{gg}(f)\ | \quad (5)$$

If

$$P_{gg}(f) = X + jY$$

then,

$$\log_e P_{gg}(f) = \log_e\left[\text{"}X^2 + Y^2\right] + j\tan^{-1}(Y/X)$$

Overall Level of Vibration Velocity

Overall level of vibration velocity shows rms value of vibration velocity in pre-selected frequency bands. By using hardware, the overall level of vibration velocity is calculated, first by generating the effective value of the individual harmonic vibration components as given by the following equation.

$$V_{ie} = \left[(1/T)\int_{O} V_i(t)dt\right]^{1/2} \quad (7)$$

where V_{ie} is effective value of ith harmonic vibration component $V_i(t)$ the instantaneous value of the ith harmonic vibration components. T is the duration of the effective value generation. The resultant rms value of harmonic components falling within the range 10 Hz to 1000 Hz is found by the following equation.

$$V_{rm\lambda} = \left[\sum_{1=1}^{n} V_{ie}^{\ 2}\right]^{1/2} \quad (8)$$

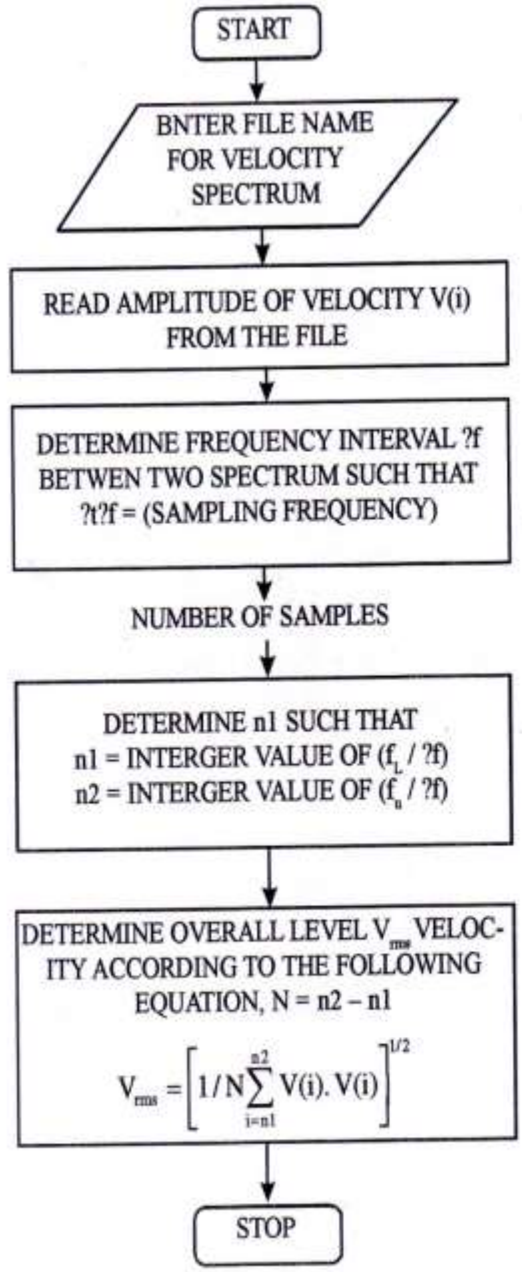

Fig 1 Flowchart for overall velocity computation

Where V_{rms} is the resultant rms vibration velocity. The rms is produced by means of band pass filters with cut off frequencies 10 Hz and 1000 Hz. The flowchart for the determination of the overall value is given in Fig. 1.

CASE STUDY ON VIBRATIONAL ANALYSIS

Fig. 2 shows a diagram of electrical machine and the points where the vibration recording is done.

Most suitable transducer are utilized for vibration sensing, since it is one of most important monitoring tool available to the operator of the electromechanical plant for measurement of displacement, velocity and acceleration. The proximity transducers are used to measure the displacement. It is effectively applied to measure rotational speed by sensing the pressure of key ways on shaft. The velocity transducers are

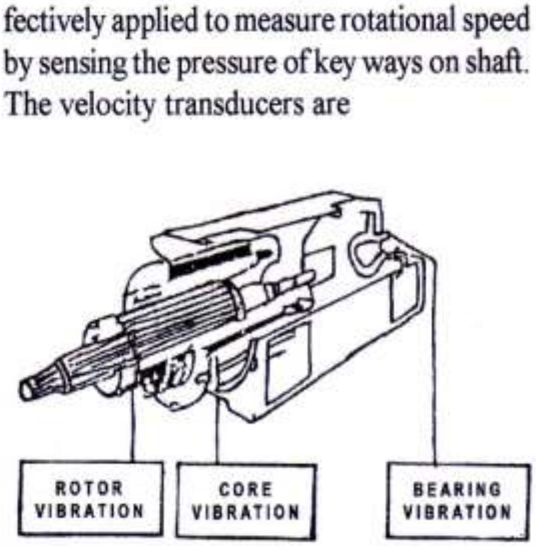

Fig.2 Points of vibration measurement for typical large Electrical machine

used in the frequency range from 10 Hz to 1kHz. These are designed using a spring mass system with a vibration frequency less than 10 Hz and letting the mass take the form of permanent magnet, the magnet is surrounded by a coil which is securely attached with the housing. Whenever the housing is placed in contact with vibration surface, the housing and coil move with respect to the magnet and cause an emf to be induced in the coil. The piezoelectrical device has been utilized for acceleramatric transducers. This produces an electrical output which is directly proportional to acceleration to which they are subjected. Two case studies are discussed below.

Case Study 1 – Out of Balance Vibration

The study refers to sea water injection power set comprising the pump drive by a 6.6 kV, 3.6 MW and 3560 rpm squirrel cage induction machine. After the analysis of the vibration signal of the machine, it was found that overall radial vibration level, measured at the motor bearing was too high and that principle component was at the fundamental rotational frequency. This was diagnosed as the case of rotor unbalance and the machine was subsequently rebalanced. Fig. 3(a) shows the record produced by the monitoring system before balancing and Fig. 3(b) shows the record produced by the monitoring system after balancing. The overall vibration level before rotor balancing was 10.5 mm/s and after rotor balancing 4.7 mm/s.

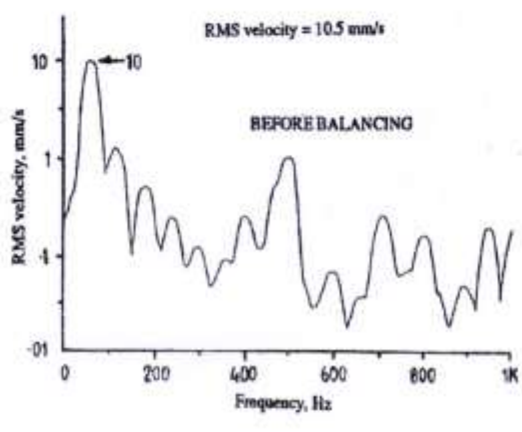

Fig. 3(a) Effect of balancing on bearing vibration (before balancing)

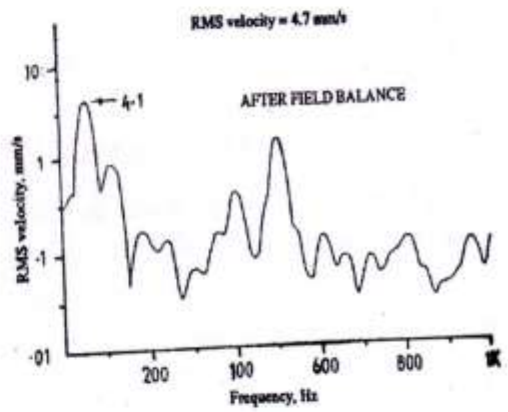

Fig. 3(b) Effect of balancing on bearing vibration (after balancing)

Case Study 2 – Identification of Cracked Rotor Bars

The study indicated the presence of loose bars in a rotor of a gas booster compressure drive. This machine is a two pole 6.6 kV, squirrel cage induction machine with a nominal speed of 370 rpm. The vibration spectrum of the machine indicated

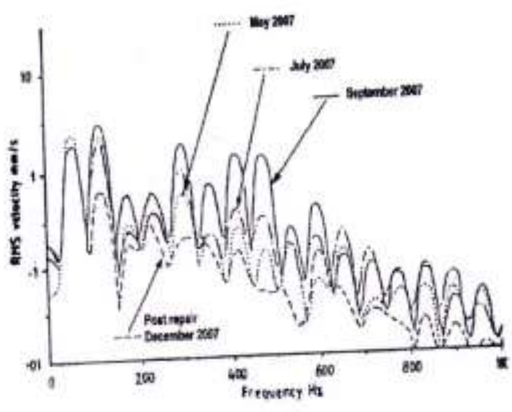

Fig.4 Progressive degradation due to rotor bar looseness

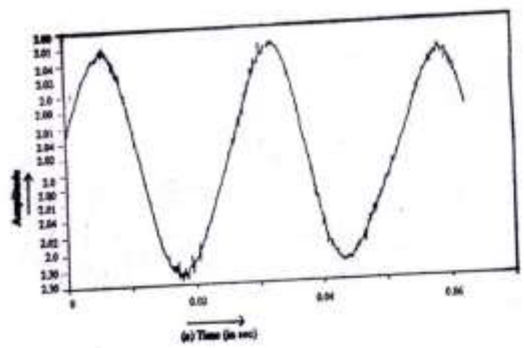

Fig.5(a) Vibration signal recorded : signal in time domain.

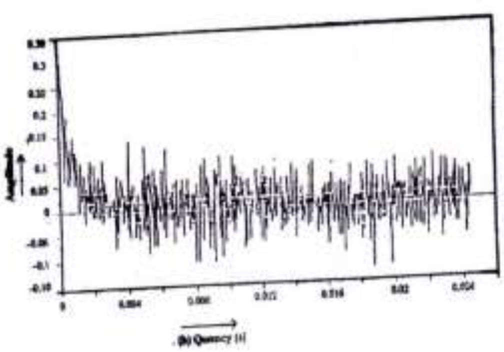

Fig.5(b) Vibration signal recorded : cepstrum

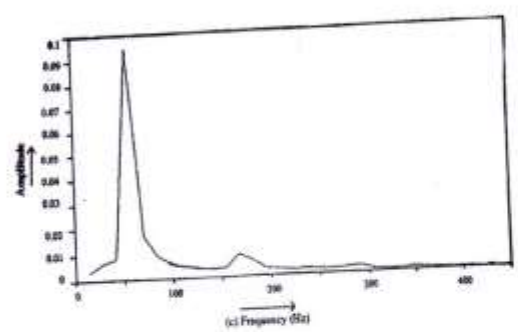

Fig.5(c) Vibration acceleration : amplitude

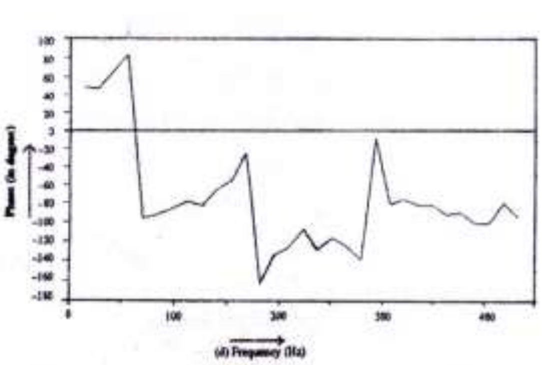

Fig.5(d) Vibration acceleration : phase

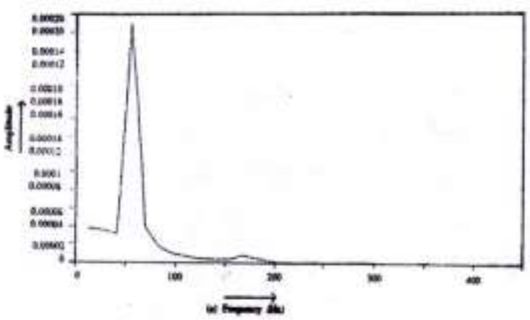

Fig.5(e) Vibration velocity : amplitude

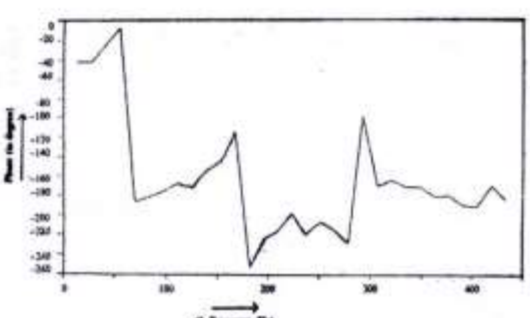

Fig.5(f) Vibration velocity : phase

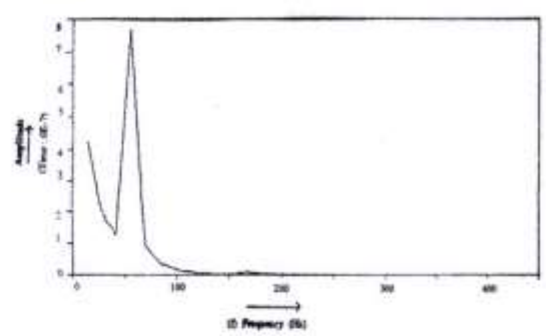

Fig.5(g) Vibration displacement : amplitude

a degree of electromagnetically induced components, principally the twice line frequency peak at 120 Hz and the higher frequency at 5,6,7 and 8 times the running speed. Although the overall level of vibration was still relatively low, the characteristics of the spectrum held the key to the diagnosis of broken bar. The spectrum changes at a two monthly intervals is shown in Fig. 4.

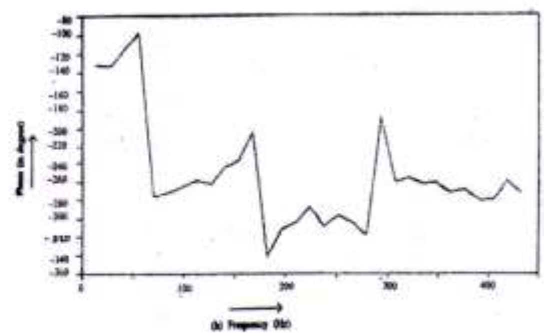

Fig.5(h) Vibration displacement : phase

For testing the developed FFT software, vibration signal was recorded from vibration tables for different settings of frequency and amplitude. A real time signal was also recorded from rotating machine for testing authenticity of the developed software. The results of the same is shown from Fig.5(a) to 5(h).

CONCLUSION

The work has been carried out for developing a software package for the measurement, monitoring analysis and feature extraction of vibration signal. The work was tested on rotating electrical machine. With the suitable transducer the software has been tested on the signal generated in the motor and vibration signal from a vibration table using piezo resistive accelerometer. The result of the analysis was consistent and established the authenticity of the method to be used for real time vibration signal analysis for rotating electrical machines. It is explained in the work that the spectrum analysis of the vibration signal recorded for the surface of the rotating electrical machine is one of the best methods of detecting the inner problems of the machine without dismantling it. The vibration monitoring can be used to find our various faults inside the machine, for examples, eg, unbalance of the rotor, unbalance magnetic pull, cracks in rotor bars, the looseness of the end windings, faults inside bearing, dynamic unbalance, coupling misalignment, etc.

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