Vibration Analysis on Rotating Shaft using MATLAB

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Abstract

This study deals with analysing the signal behaviour between time domain and frequency domain when the shaft rotating at whirl speed and also indicating the filter specifications of the signal. These relations are obtained through whirling of shaft apparatus at various speeds. At critical speed the vibration of the shaft is enormously high and it becomes unstable. It is important to address the vibration parameters which could affect motion of the shaft are Velocity Root Mean Square. In signal, noises are always be present and it makes the observation of these vibration parameters might get inaccurate. It is necessary to remove the noises from the source. It is to be found that the inverse behaviour between time domain and frequency domain using accelerometer and MATLAB relations. The filter specifications have also been applied for the signal to get optimum results.
Keywords: Accelerometer, Critical Speed, Frequency Domain, Time Domain, Velocity Root Mean Square

I. INTRODUCTION

A. Shaft VRMS Scheme

Whirling is defined as the rotation of the plane made by the line of centres of the bearings and the shaft. A critical speed of shaft is existing when the frequency of the rotation of a shaft equals one of the natural frequencies of the shaft. The natural frequency of the system are expressed in

$$\omega_n = \sqrt{k/m} \qquad (1)$$

Where,
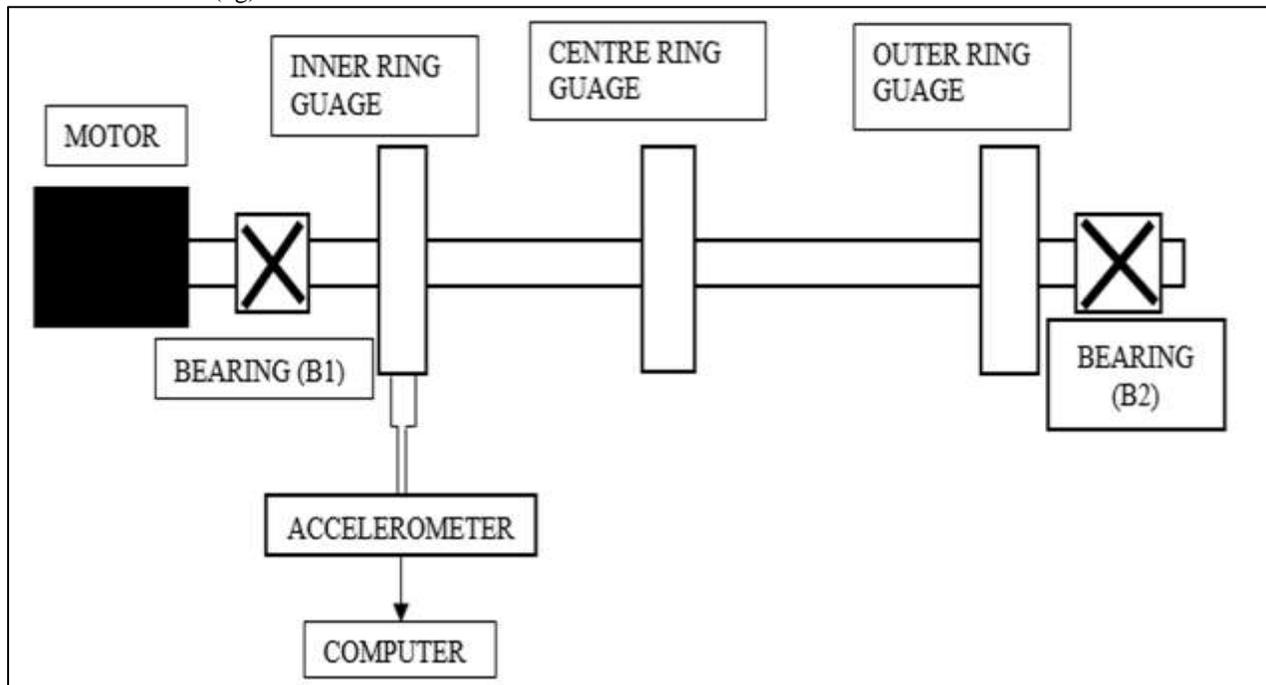k = stiffness of the shaft (N/m),
m = mass of the shaft (kg).

Fig. 1: Whirling of Shaft VRMS scheme

When the rotational speed is equal to this critical speed, the rotor undergoes large deflections and the force transmitted to the bearings can cause failures. A rapid transition of the rotating shaft through a critical speed is expected to limit the whirl amplitudes, whereas a slow transition through the critical speed aids the development of large amplitudes.

B. Time Domain

The most commonly used device for vibration measurement is the piezoelectric accelerometer, which gives an electrical signal proportional to the vibration acceleration. This signal can readily be amplified and analysed. The graphical displays of vibratory motion are useful tools for analysing the nature of vibration. But accelerometer displays only the vibration analyses in the waveform. The amount of information a waveform contains depends on the duration and resolution of the waveform. The duration of a waveform is the total period over which information may be obtained from the waveform. In most cases, a few seconds are sufficient. The resolution of a waveform is a measure of the level of detail in the waveform and is determined by the number of points or samples characterizing the shape of the waveform. The more samples there are, the more detailed the waveform is. In the negative side, a waveform does not clearly display the individual frequencies at which vibration occurs. A waveform instead displays only the overall effect. It is thus not as easy to diagnose machine problems using waveforms. With the exception of a few specialised cases, spectra are usually the primary tool for analysing machine vibration [5].

C. Frequency Domain

The frequency domain signal or frequency spectrum is a plot of the amplitude of vibration response versus the frequency and can be derived by using the digital Fast Fourier analysis of the time waveform. The frequency spectrum gives valuable information about the machine. In general, vibrating spectrum considered as the vibration signature of that machine. The important characteristic of a spectrum is that each rotating element in a machine generates identifiable frequency. The fault frequencies and noises can able to identify in the peaks of the spectrum related to the various rotating machine components [5].

D. Signal

In general, signal is a common term which has combination of both wanted and unwanted behaviour. It may suffer due to capture, storage, transmission, processing and conversion. It needs to be attenuated to a certain range which could not affect the original nature and the filtration done through designing the filter properly.

E. Abbreviations and Acronyms

- VRMS – Velocity Root Mean Square
- FFT – Fast Fourier Transform
- DFT – Discrete Fourier Transform
- MATLAB – Matrix Laboratory
- ms – Milli Seconds

II. NUMERICAL CALCULATION

Rayleigh's method can be applied to find the fundamental frequency of continuous systems. This method is much simpler than exact analysis for systems with varying distribution of mass and stiffness. But this method is not applicable for the system which is having own inertial weight [2]. In the case of Dunkerley's method, underestimates the natural frequency and its good practice suggest that the maximum operation speed should not exceed 75% of the critical speed [6]. The critical speed equation is expressed as

$$f_n = K\sqrt{(EgI/wl4)} \quad (2)$$

and

$$N = f_n \times 60 \quad (3)$$

Where,

f_n – Natural frequency of vibration in Hz
g – Acceleration due to gravity, (9.81m/s^2)
E – Modulus of elasticity of the shaft
I – Moment of inertia of shaft in m^4
W – Weight /unit length in N/m
L – Effective length of the shaft between supports in m
N – Speed of the shaft in RPM
K – Constant (3.75)

The Discrete Fourier Transform is a basic tool for digital signal processing. From a mathematical point of view the DFT transforms a digital signal from the original time domain into another discrete series, in the transformed frequency domain. This enables the analysis of the discrete-time signal in both the original and the transformed domains. The frequency analyses of a digital filter and of a discrete-time signal are very similar problems.

The DFT of finite time 1D digital signals, denoted by DFT_{1D}, is defined by:

$$X[k] = DFT_{1D}\{x[n]\} = \sum_{n=0}^{N-1} x[n] w_N^{kn} \qquad (4)$$

$$X[n] = DFT_{1D}^{-1}\{X[k]\} = \frac{1}{N} \sum_{k=0}^{N-1} X[k] W_N^{-kn} \qquad (5)$$

Where: $W_N = e e^{-j2\pi/N}$ and n, k=0…N-1

In the equation 4 and 5, the index of the vectors $x[n]$ and $X[k]$ should begin with 1 instead of 0, according to MATLAB notations, so that $n \rightarrow (n+1)$ and $k \rightarrow (k+1)$.

III. EXPERIMENTAL SOLUTION

The Root mean square velocity amplitude of a vibrating machine describes about the vibration energy in the machine [3]. Higher the vibration energy, higher will be root mean square velocity amplitude. The graphical displays of vibratory motion are useful tools for analysing the nature of vibration. A waveform is a graphical representation of how the vibration level changes with time.
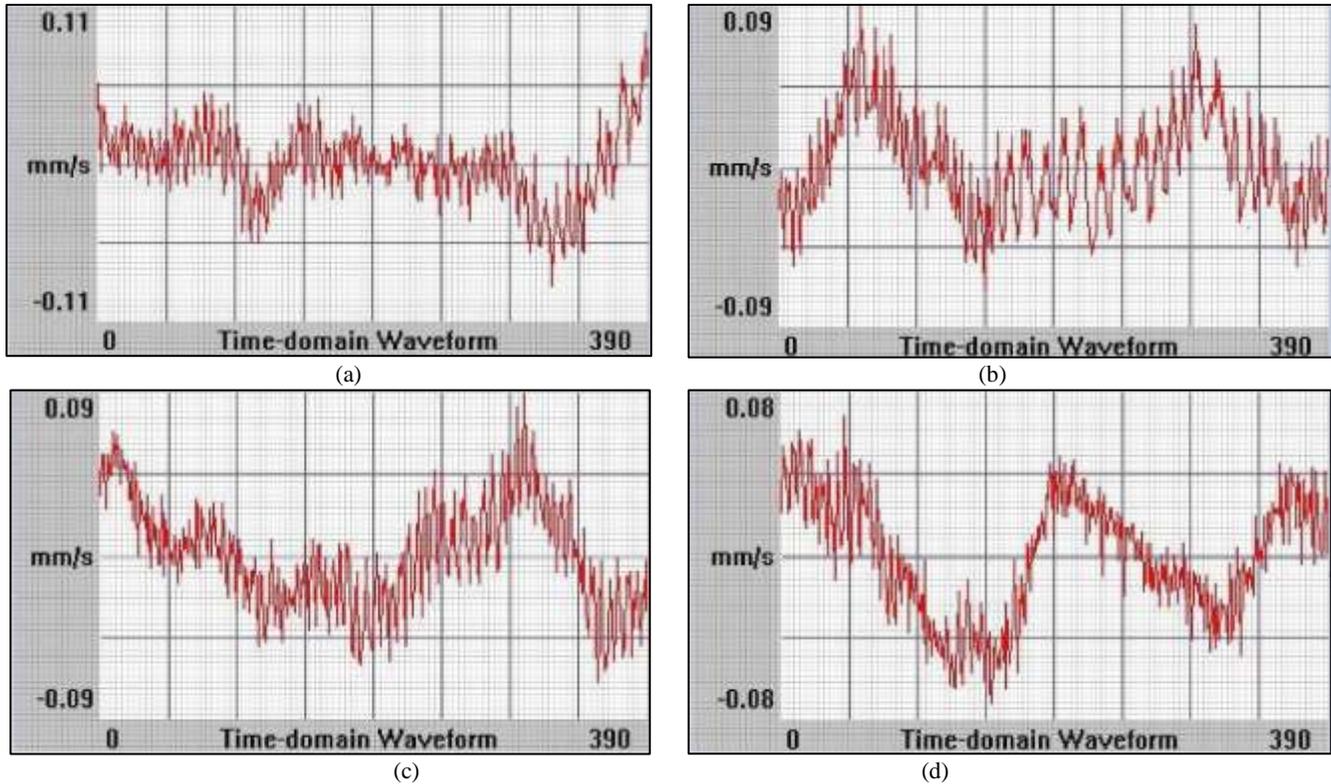

(a)

(b)

(c)

(d)

Fig. 2: Response of Shaft with respect to time

The velocity waveform [1] of a vibrating component shows how fast the component is moving at a given time. The responses of shaft with respect to time at various speeds are shown in figure 2. The waveform (a) shows the energy intensity of vibration whereas rotating. It varies randomly with respect to time. It is observed that the variation of V_{rms} considerably higher at 98 ms and 340 ms. The waveform (b) continuously varies with respect to time, it is considered as random nature. It is observed that the variation of V_{rms} considerably higher at 48 ms and 293 ms. The variation was received as early as the 850 RPM. The waveform (c) started to make its nature to be sinusoidal when it closes to mode 1, due to severity of oscillations. It is observed that the variation of V_{rms} considerably higher at 294 ms. The waveform (d) follows the sinusoidal motion and it attains the maximum severity, due to it reaches the mode 1. It is observed that the variation of V_{rms} considerably higher at 146.25, 195 and 318 ms. the consolidated waveform responses are shown in I.

Table – 1
Peak response of time waveform vs. speed

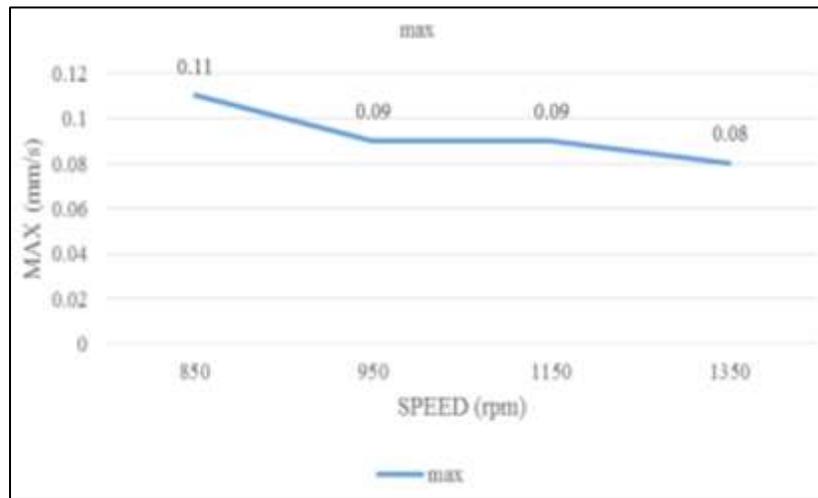| Speed (rpm)	max(mm/s)
850	0.11
950	0.09
1150	0.09
1350	0.08

Fig. 3: Consolidated time domain waveform

A spectrum is a graphical display of the frequencies at which a machine component is vibrating, together with the amplitudes of the component at these frequencies.
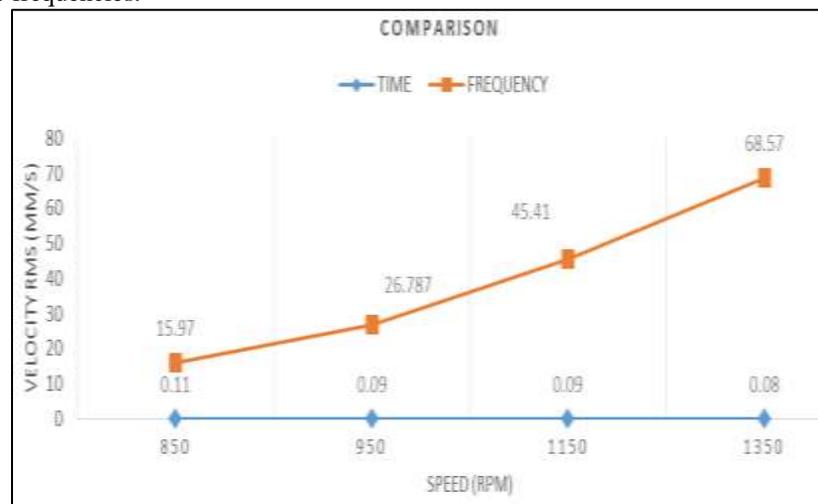

Fig. 4: Comparison of time domain and frequency domain

In general, source signal has combination of both useful and unwanted behaviour. The unwanted signals should attenuate with proper condition. This table shows that the proper filter specifications for attenuating that signal. These specifications got through trial and error method.

Table – 2
Filter specifications

Speed(RPM)	Fpass (Hz)	Fstop (Hz)	Apass (dB)	Astop (dB)
850	25	35	9.6208	100
950	25	35	9.6761090	100
1150	25	35	14.93775	100
1350	25	35	9.3904645	100

IV. CONCLUSION

The time domain and frequency domain of various signals were analysed using MATLAB. The sptool is used to analyse and compare the two domains of signals through FFT and it shown the inverse behaviour between these domains. A filter for vibration signals, with magnitude of pass band and stop band was developed successfully. The filter was implemented on a benchmark problem. The developed filter could be useful for analysing the nature of whirl without the noises. These analysis were done through the chosen vibration parameters. These analysing methods could be used to prevent the damage of shafts and also an increase the lifetime period of commonly used applications of turbines, gearboxes etc., by knowing the nature of vibration as an early phase it could be useful to prevent the damage through taking preventive maintenance.

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