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A simulation of vibration analysis of crankshaft

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ABSTRACT
Crankshaft is used to transfer reciprocating motion/power from piston to gear/clutch in desired velocity/torque ratios with high efficiency. However any crankshaft defect (e.g. cracks, notch) occurring deteriorate the performance of the engine. In the present research work vibration analyses have been focused to detect crankshaft fault at the early stage, followed by the literature review of the shaft and the experimental methodologies. A simulation for the study of crankshaft is carried out by acquiring its fault signaland its fast Fourier transform is plotted to show the characteristics frequencies and its harmonics. A comparison of simulated data is also made to validate the experiment based condition monitoring.
Keywords: crankshaft defect, characteristics frequencies, fast Fourier transform, condition monitoring

I. Introduction

High-quality, minimum cost products and safe production has hiked the style of machine maintenance strategy from corrective over preventive to condition-based maintenance, for which real-time fault diagnosis and prognosis are needed. Crankshafts are basically used in rotating device like engines or generators. They transmit heavy loads of the flywheels and internal gaseous pressure of the engines at a very high rate. So, if any fault arises in the crankshaft, it must be alarmed & noticed by the operator or driver timely, to avoid the mass damage or catastrophe. Timely detection of fault/defect is very important in order to keep the entire system halt.

A far as, signal analysis is concerned, crankshaft fault diagnosis uses various time domain, frequency domain and both time-frequency domain techniques for the early detection of the gear failures [1] whereas, for the mathematical and dynamic modeling rotor dynamics is the fore front for the rotors like shaft fault diagnosis or crankshaft fault diagnosis . These methods have been widely used to detect the rotor failures. However they all have some limitations and cannot be applied to all conditions, i.e., some types of failures cannot be detected by these methods. Many articles have been published to compare these techniques [2].

Most vibration analysis instruments today utilize a Fast Fourier Transform (FFT) which is a special case of the generalized Discrete Fourier Transform and converts vibration signal from its time domain representation to its equivalent frequency domain representation. However, frequency analysis (sometimes called Spectral Analysis or Vibration Signature Analysis) is only one aspect of interpreting the information contained in a vibration signal. Frequency analysis tends to be most useful on machines that employ rolling element bearings and whose main failure modes tend to be the degradation of those bearings, which typically exhibit an increase in characteristic frequencies associated with the bearing geometries and constructions. In contrast, depending on the type of machine, its typical malfunctions, the bearing types employed, rotational speeds, and other factors, the skilled analyst will often need to utilize additional diagnostic tools, such as examining the time domain signal, the phase relationship between vibration components and a timing mark on the machine shaft. The portable and permanently-mounted vibration analyzers are used in this monitoring process. The vibration analyzers record machine vibrations using sensors such as accelerometers and tachometers.

Accelerometers used to record the vibration signals in time domain, are the ears of our instruments and are connected to rotating machinery such as electro-mechanical drives and gearboxes. The vibrations and movements of the equipment are then recorded. These recordings are later transferred to a computer and analyzed using the Lab View software, which provides a visual display of the vibration waveforms. We can compare these recordings over time and use the gradual development of new vibrations to detect wear at the earliest stages. This process is generically known as condition monitoring.The scheme of the machinery condition monitoring system is shown below

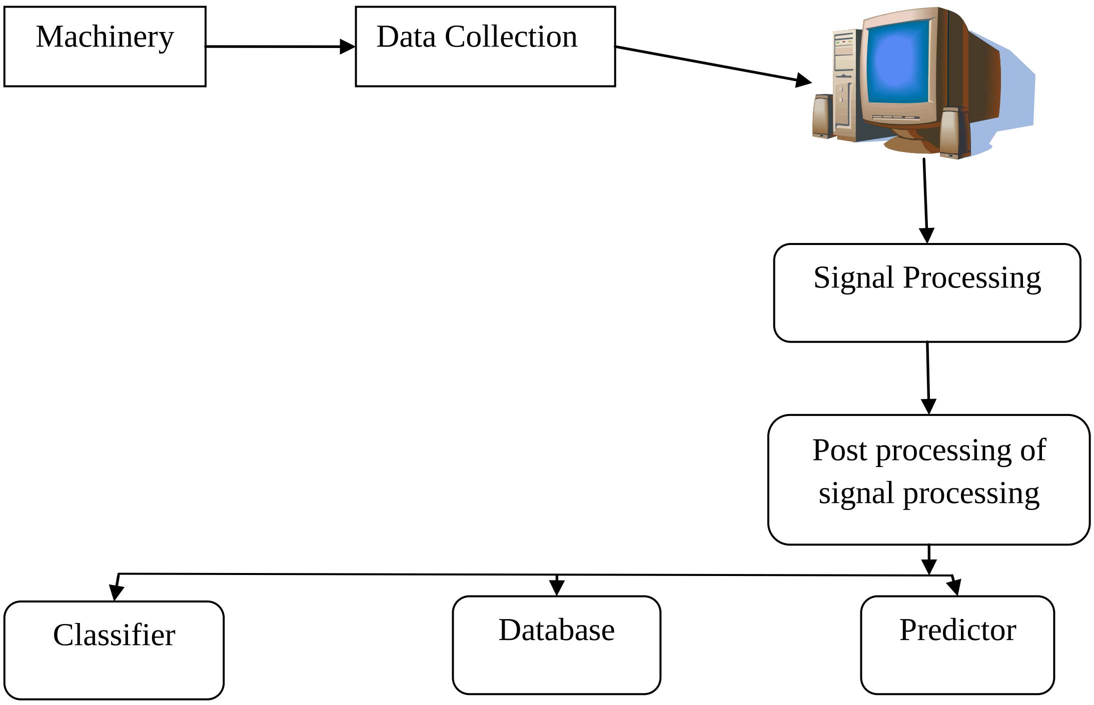

Figure 1, Mechanism of condition monitoring

The concern of this work is to understand the behavior of the signal acquired from the rotor bearing test rig for the healthy and the faulty bearing. The goal of this document is to utilize the wavelet transform to read the fault. When a fault in one surface of a bearing strikes another surface, a force impulse is generated which excites resonances in the bearing and the machine. The successive impacts produce a series of impulse responses which may be amplitude modulated as a result of the passage of the fault through the load zone or of the varying transmission path between the impact point and the vibration measurement point [3].

II. Equation Of Motion Of A Rotor System

Aschematicrepresentationofarotorbearingsystemconsideredinthisstudyispresentedin Figure2. Thisfigurealsorepresentstheexperimentalrotorwhosedataanddetailsaregivenin Section 3.

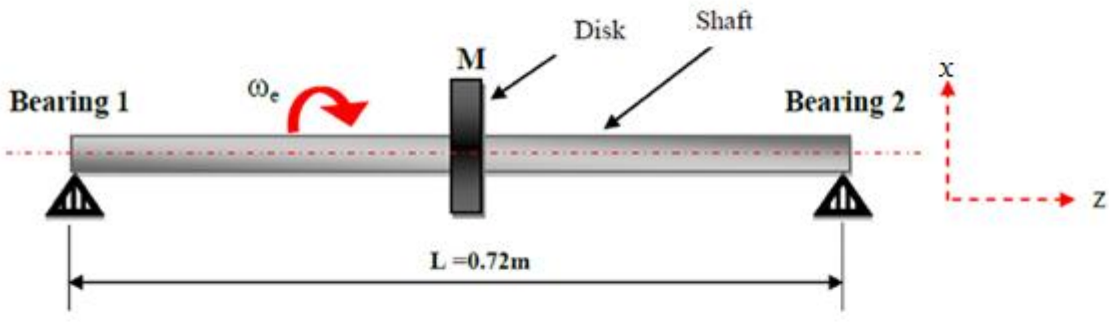

Figure 2, model of a rotor (crankshaft)

Theequationofmotionofarotorbearing system [4] for arun-upresponsewithuniformangularacceleration(‘α’ or sweeprate)isgivenasfollows:

$$M\ddot{x} + C\dot{x} + Kx = F(\omega)\cos\left(\frac{\alpha}{2}t^2 - \emptyset\right)$$

Where, excitation force ‘F’ with a phase shift ‘□’ is given by

$$F(\omega) = \sqrt{(-me\alpha)^2 + (me\omega^2)^2} = me\sqrt{\alpha^2 + \omega^4}$$

In most of the rotor dynamic applications the operating speed is only just above the first critical speed of the rotor. Thus, in this work analysis on rotor-bearing system excited above the first critical speed is only considered.

1. Simulation Study

In this section we utilize the noisy simulation signal to illustrate the effectiveness of the proposed method for FFT development, with the study of the FFT, various frequencies and their harmonics of the component can be studied. If the effect of the transport function to the gear vibration signal is omitted, the vibration signal of a crankshaft can be expressed by:

$$x(t) = \sum_{m=0}^{N} A_m[1 + a_m(t)]\cos[2\pi m f_n t + \varphi_m + b_m(t)]$$

WhereAmis the amplitude of the mth meshing harmonic;$\varphi_m$is the phase of the mth meshing harmonic; $a_m(t)$ and $b_m(t)$are the amplitude and phase modulation functions of themth meshing harmonic, respectively;fnis the meshing frequency; andNis the numberof tooth meshing harmonics. A gear with a local faultmeshes once when the shaft rotates through one cycle,so; $a_m(t)$ and $b_m(t)$are theperiodic functions whose frequencies are the rotating frequency and it's multiple.Therefore,$a_m(t)$ and $b_m(t)$included fault informationfor the gear vibration signal.

In the gear vibration signal collection process existsthe influence of the noise, so under normal conditions if only single frequency modulation is considered, the simulation vibration signal of a gear becomes

$$x(t) = [1 + 0.5\cos(2\pi 8t)]\cos[2\pi 100t + 1.5sin(2\pi 8t)] + n(t)$$

Where, $n(t)$ is the random noise signal; the amplitude and phase modulation frequency are 8Hz; and the meshing frequency is 100Hz.

III. Experimentation

Introducing the theoretical aspects of the frequencies and the signal processing techniques, now its turn for the experimentation, this records the observations as well. The test rig to be prepared consists of a 3HP motor for driving rotors controlled by a speed controller, a tachometer finally a magnetic brake at the end, as shown in figure 5.

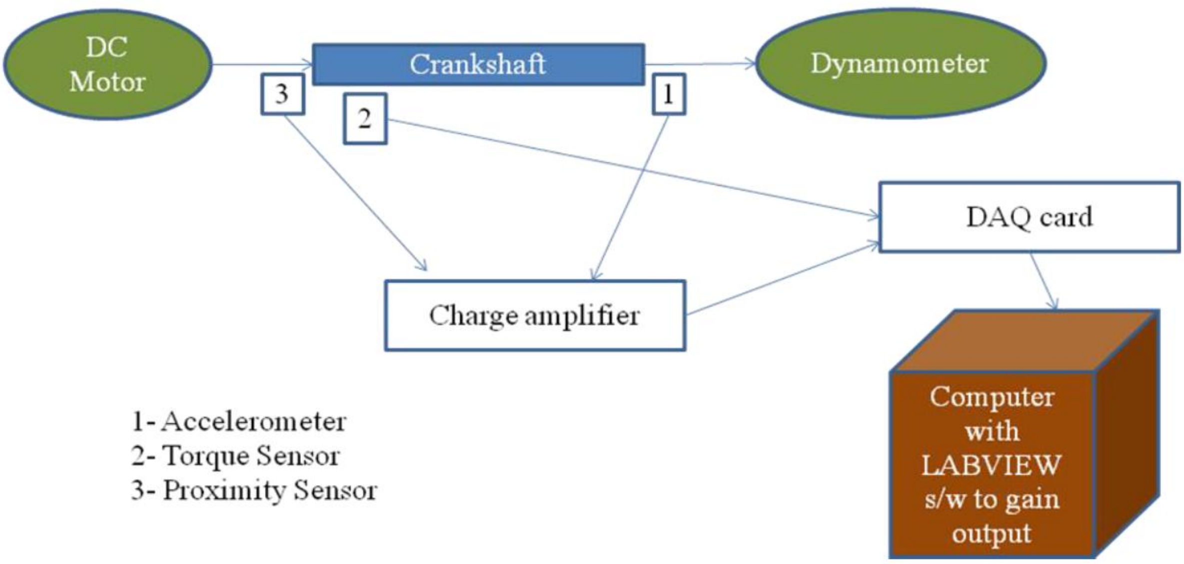

Figure 3, Crankshaft test rig

The dimensions of the crankshaft were noted down. The crankshaft was then monitored for its vibrational behavior and the data were recorded. Snaps of crankshaft is shown in figure 4.

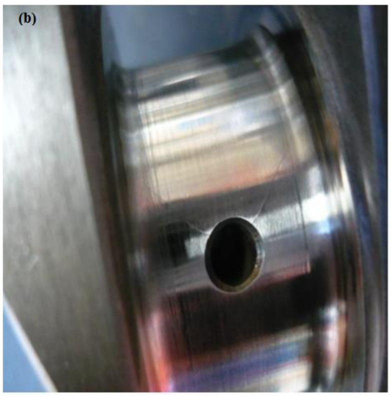

Figure 4 (a)crankshaft, (b) cracked portion

A vibration signal will be measured by the accelerometer with a sampling frequency of 65.4 kHz under the faulty condition of the faulty bearing test case. The input frequency provided to the whole transmission is 5 Hz. The brake load is kept at 0% means it's a no load test case

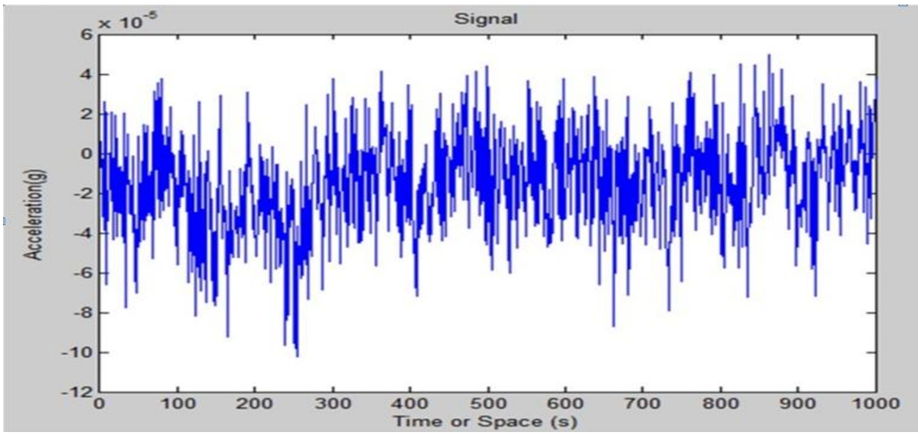

Figure 5, time domain signal

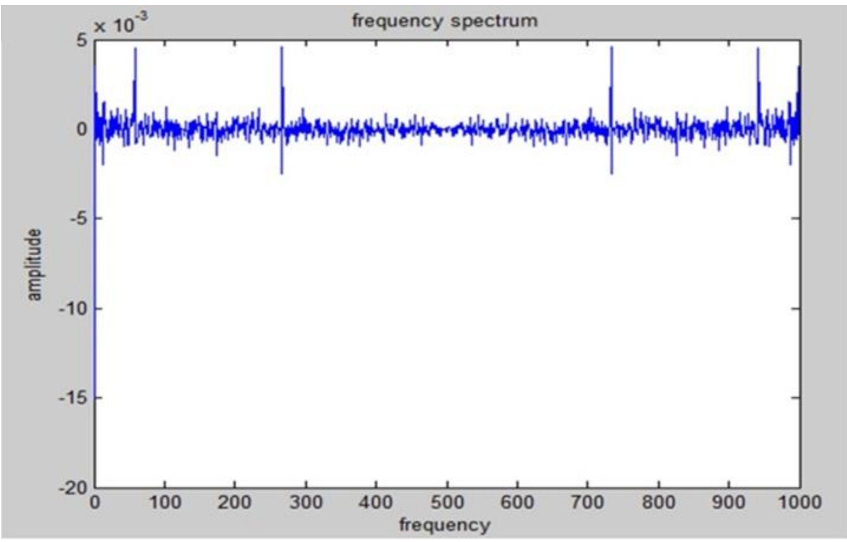

Figure 6, frequency spectrum of the simulated signal

IV. Conclusion

This work present here is for the signal of the faulty crankshaft only, the first characteristics frequency noticed in the FFT of the signal is 265 Hz, while if it is solved analytically, it would come 263-267 Hz, this variation may be because of the some systematic parameters of the crankshaft set up like placing of accelerometer, level of oil, etc. The load and the input frequency given are 0% and 25 Hz, which is quite low as for the actual test conditions. When raise these input factors, positively there could be variations in the characteristic frequency, their harmonics and the frequency spectrum; the energy distribution will also be changed for this case.

Moreover, this work can be supplemented by signal of defected inner web; the respective plots can be drawn then and compared for the fault diagnosis of the bearing. If we keep the inputs constant and just get a faulty signal probably there will be change in the critical frequency f_i. The energy plot, i.e., scalogram of the healthy signal will have some regular color format to show the absence of impulse signal in it.

V. Further Possibilities

Summing up the work, some light has been drawn to the respective proposed points in the context of the crankshaft fault.

1) A signal of defected bearing compared with healthy bearing need to be used to studythe wavelet transform effectively.
2) Initially the idea of defect can be observed by the FFT, but its actual behavior is understood by wavelet transform.
3) Techniques like second generation wavelet transform or wavelet packet transform could be used in this area.

VI. References

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