Identification of Vibration Signature and Operating Frequency Range of Ball Mill Using Wireless Accelerometer Sensor

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Abstract— This paper identifies the operating frequency of the ball mill using tri-axial wireless accelerometer sensor. The output from mechanical equipments mostly is a mixture of required pattern of signal with noise. If the frequency and strength of the signals are not perfectly considered, then it is mislead by the noise as the dominant signal. To analyze the vibration of the mill various experiments are conducted to determine the dominant frequency from a set of frequencies. The experiments are conducted with rotating as well as stationary ball mill. Here we have discussed the direction of propagation of the vibration and signal loss due to the wall of the ball mill once the impact is applied on to the mill under fixed and rotating conditions.

Keywords- Impact, Vibration, Wireless accelerometer Sensor

I. INTRODUCTION

The ball mill is a mechanical device used to grind different types of crushed ores. While grinding, the mechanism generates different patterns of impact and the right pattern of impact or the 'vibration signature' is the one being discussed here when the required output of grinding is achieved. This has significant effect on the material grinding as the impact helps in analyzing the level of grinding of the ores. A wireless accelerometer is used here to measure the vibration and transmit the signature to the base station connected to a computer. The response of the accelerometer under static and dynamic mill conditions are considered and analyzed in this paper. This paper discusses on the significant effects of the strength of the impact in selecting the frequency of the operating mill. The impact due to balls on the material bed produces vibration of certain frequency and strength at different levels of grinding.

The motion of the charge inside the ball mill [1] is an important factor to calculate the strength of the signal. The strength of the output signal depends on the type of grinding (dry and wet). Different approaches were tried to estimate the grinding condition of the mill i.e. using acoustic signals [2] from the mill and vibration signals [3]. Since the acoustic signal estimation is quite difficult in a noisy industrial environment and also the acoustic signal losses compound inside the mill before reception the estimation of the signals is carried out using accelerometer sensor. The vibration signal is acquired using a tri-axial wireless accelerometer sensor of 10g range. The signal from the sensor is further analyzed to get the vibration signature under rotating and stationary conditions of the ball mill. When the balls are falling due to the centrifugal force, the frequency response is more along X and Z directions and is least along Y-direction. The above phenomena can be analyzed by resolving the force acting on the mill at a particular instant. Independent experiments with sampling rate of 4000 samples/sec/channel are performed in order to predict the highest frequency of the vibration, so as to select a sensor of a particular sampling rate for a rotating condition. Figure 1 shows the position as well as the direction of the sensor along X, Y and Z channels. Whenever the impact is applied on to the mill, the frequency of vibration the mill produces depends on the type of the mill and the materials it is made up of. The strength of the signal depends on the total mass of the balls at that instant and the velocity with which the balls are falling. The experiments are conducted increasing the number of balls progressively at different instances, so as to use the static mill frequency as a reference for the dynamic mill.

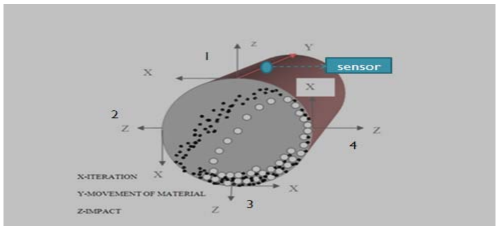

Figure 1. Accelerometer setup on the mill

II. METHODOLOGY

The phenomena of vibration in ball mill are used to analyze the grinding level of materials in industrial ball mill. As mentioned earlier, the experiments conducted using different count of balls (keeping vibration of the mill static) give an idea about the vibration signal.

The position identification of the sensors and the impact along the mill is discussed in [4]. The ball mill periphery is divided in to four sections (1, 2, 3 and 4) and the direction of the channels at each section is as shown in the Figure 1. The response of the accelerometer sensor for both the channels X and Z are as shown in the Figure 2. The position numbered 3 in the Figure is considered as the point of higher impact, so the maximum signal strength will be at position number 3 and it will be along the Z – channel (Impact is normal to the Z channel). Initial experiments are conducted on the static ball mill with accelerometer mounted on to the top of the mill.

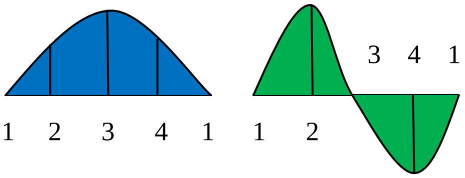

Figure 2. Z and X channel response of rotating accelerometer sensor

Under static condition the frequency is observed and is accounted in analyzing the response of the signal at that frequency in dynamic condition (the rotational speed of the mill is 70% of the critical speed as given in Equation "(1)"). This is to confirm whether the vibration is due to type of the mill or the types of balls (the materials it is made up of). The vibration experiments on static ball mill are done with different types of balls.

$$N_c = 42.3/\sqrt{D} \qquad (1)$$

where 'D' is diameter of the mill

We observed that the force exerted on the accelerometer can be written mainly as a function of the parameters as provided by the equation given below;

$$F\ (\text{sensor}) = f\ (LG, T, QI) \qquad (2)$$

Where LG =Level of grinding, T =Types of ore, QI (wt %) = Quantity (wt %) of balls at an instant of impact and

F= the force exerted as the function of different parameters.

III. RESULTS AND ANALYSIS

The time and frequency domain signals are obtained for both the stationary condition (4000samples/sec/channel) and rotating condition (2000samples/sec/channel) of the ball mill. The behaviour of the signal at different instances is characterized in relevance to both the rotating and stationary conditions. The results obtained in time domain are transformed in to the respective frequency equivalent using FFT. Both the time domain and its frequency domain are as shown in the Figures below. The frequency domain plot along X-axis represents the frequency of vibration and Y-represents the strength of the vibration signal.

A. Results at stationary condition (sampling rate 4000)

The Figures 3, 4 and 5 show both the time and frequency domain components of the vibration signals. These Figures are obtained when the outer wall of the mill is struck with an iron ball (the most significant parameter here is frequency rather than amplitude). The frequency response is not significant along the Y-channel as it is more around 400-450 HZ. The experiments on stationary conditions are performed manually. The maximum sampling rate is 4000 samples /second/channel.

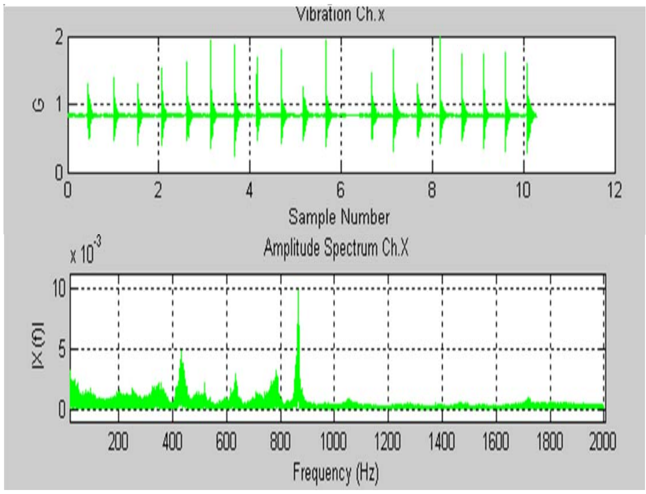

Figure 3. Time and Frequency domain along X-channel (outside top)

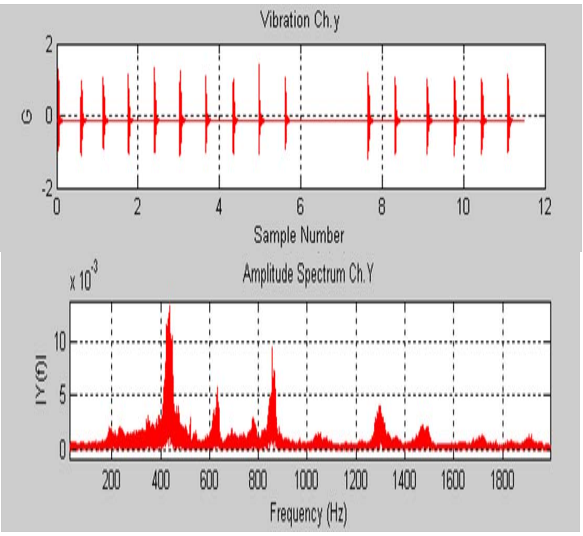

Figure 4. Time and Frequency domain plot along Y-channel (outside top)

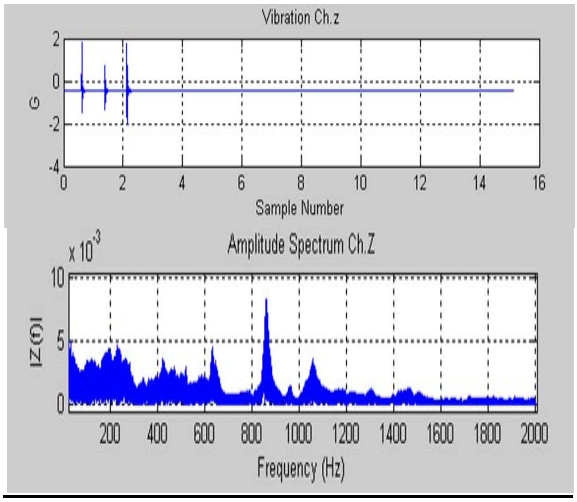

Figure 5. Time and Frequency domain along Z-channel (outside top)

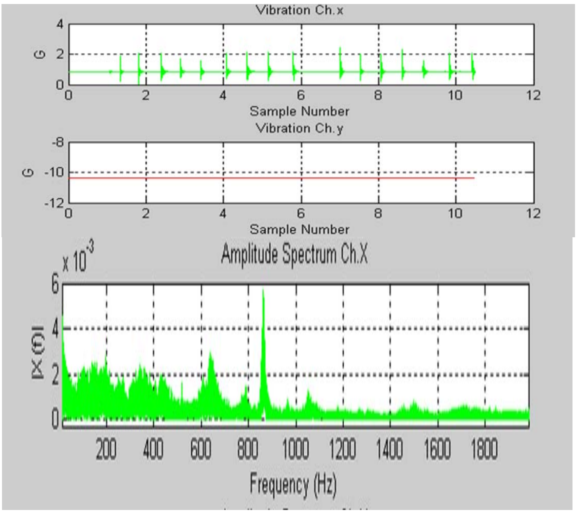

Figure 6. Time and Frequency domain along X-channel (inside top)

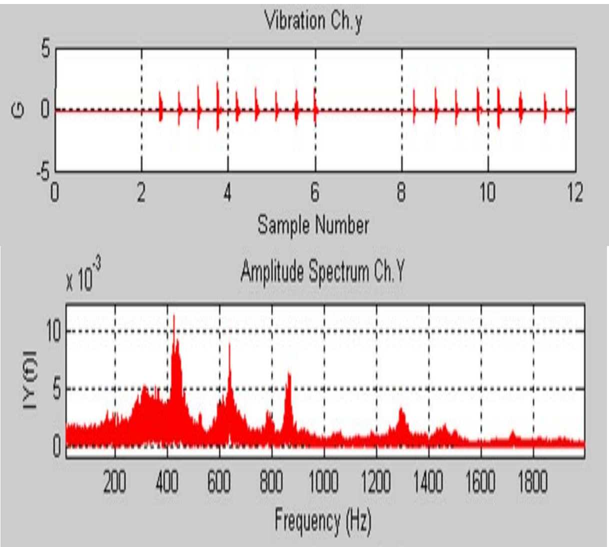

Figure 7. Time and Frequency domain along Y-channel (inside top)

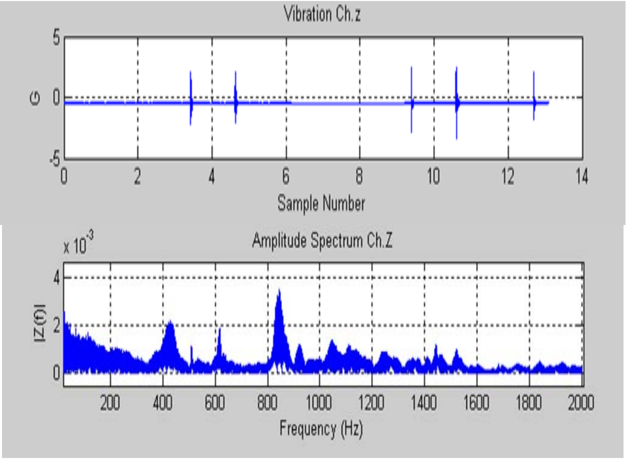

Figure 8. Time and Frequency domain along Z-channel (inside top)

B. *Analysis at stationary condition (sampling rate 4000)*

The Figures 3, 4 and 5 shows that the signal strength is more around 800-900 Hz and the frequency of vibration is more for channel X and channel Z. When the mill is subjected to force by means of ball on the top of the wall then the signal strength is higher compared to the signal strength collected, when it is subjected to force inside the mill (Figures 6, 7 and 8). There is a loss of vibration strength but the frequency remains constant. The loss of the signal strength is due to the thickness of the mill and the type of material it is made up of. To distinguish between vibration frequency and its strength, the above experiments are conducted using other materials. It is found that the strength of the signal depends upon the velocity of the projectile and its mass, but frequency of vibration is independent of these parameters. The dominant frequency is found to be around 800-900 Hz. The above analysis helps in keeping track of the vibration signature in the frequency band between 800-900 Hz. The sampling rate is fixed around 2000 samples/sec/channel to analyze the radial and tangential component of the vibration signals along Z and X – channels of the sensor (for rotating condition of the mill).

C. *Results at rotating condition (sampling rate 2000)*

It is very easy to monitor the frequency response of a system in static mode. Static condition frequency is kept as reference to conduct the experiments in dynamic mode. The significant changes in the received signals depend on the speed of rotation of the platform on which the sensor is mounted and the time delay between the transmitter and base satiation. The signal from the sensor mounted on the ball mill is weak because the diameter of the industrial ball mill is quite large. When a sensor is mounted on such huge structures the signal strength is weak due to the line of sight problem and multipath gain between the transmitter and receiver. The behaviour of the signals discussed in [5, 6] cannot be completely applied to the ball mill, but it can be taken as method to evaluate the system response during rotating condition.

The experiments are conducted with increasing order of the number of balls, to achieve significant frequency band obtained in the static condition. The Figures 9 and 10 show both the time domain and frequency domain response of the ball mill, when the count on the number of balls is increased. The signals obtained from the accelerometer sensor are directly transmitted to the base station connected to PC. The vibration signal obtained is transformed to the corresponding frequency domain using FFT. The frequency obtained is analyzed in reference to the signals obtained from the experiments performed in static condition. These types of experiments help in classifying the behaviour of the vibration of the material inside the mill.

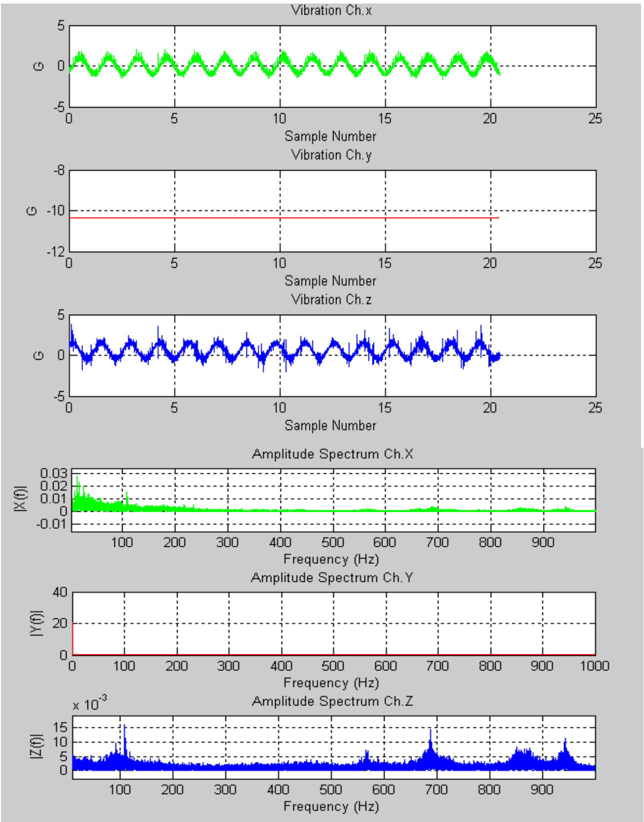

Figure 9. Time and Frequency domain with 4- balls rotating

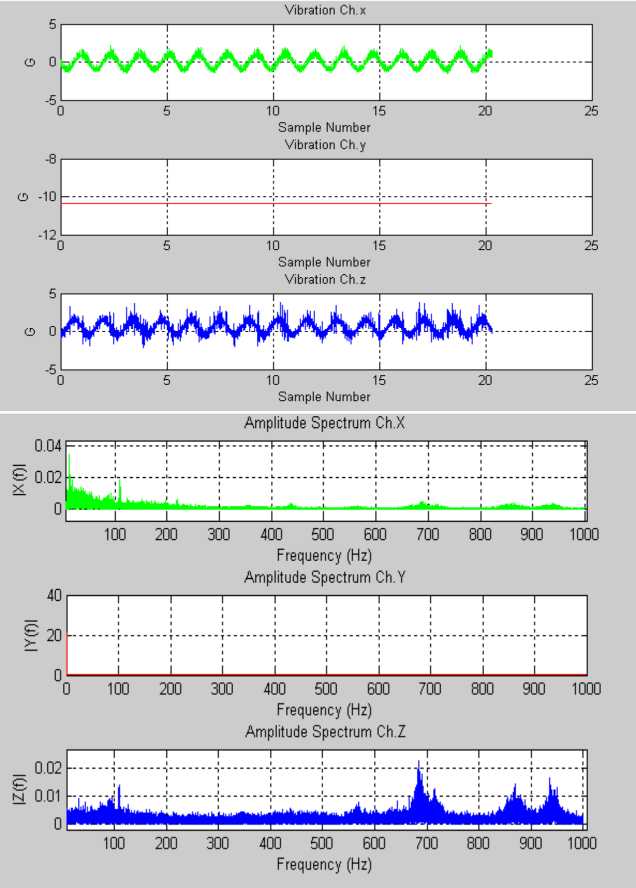

Figure 10. Time and Frequency domain with 12- balls rotating

D. Analysis at rotating condition

When the noise level dominates over the signal level the noise is generally mistaken as the signal. The signal is to be restricted in the region of the natural frequency in order to get the value of signal strength at that place. The time domain Figures 3, 4, 5 in static condition are more like impulses, whereas in the dynamic case they are sinusoidal. This happens due to the behaviour of the accelerometer during rotation as shown in the Figure 2. The Figure 9 shows that the noise is quite high at 100-150 Hz compared to the signal level around 650-750 Hz frequency. If proper frequency selection is not done prior to the rotating experiments, it may happen that we may always go around the 100-150 Hz as our original signal. The same experiments are conducted with increasing the ball count. The Figure 10 shows a significant improvement of the signal strength over the noise level. It is also observed that as the number balls is increased the frequency dominance approaches towards the natural frequency. The frequency observed in static condition of the mill is 800-900 Hz. The frequency at these conditions is quite low and is significant at 650-750 Hz. The loss in the frequencies may be due to the multipath gain and Doppler shift effects existing in the rotating wireless transmission.

In general, the loss of frequency is a significant issue when the mill starts rotating. In the practical case the diameter of the mill is more, i.e. the signal transmission and reception become poor. The analysis of the signal quality is to be carried out for different position of the sensor in static condition and for various rpm.

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