Data Synchronization for Dynamic Contact Measurement

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Abstract

This paper explains the method to synchronize speed and distance for contact size measurement. The contact size was measured using ultrasound that strikes continuously onto the surface. Part of the ultrasound energy was transmitted and another part was reflected. As this happen, there is a reduction in pulse amplitude due to the fraction between the reflected energy and the transmitted one. A series of reflection pulses were obtained as the ultrasound pulses strikes. These amplitude pulses reduce when enters contact and eventually return to normal. If the speed and distance of a track were measured, then it is possible to measure the contact size as the contact passing. However, the speed and ultrasound pulsing rate must be synchronized so that the distance is proportionate to speed changes. In this work, a 6410 deep groove ball bearing were used to measure contact size in circular motion. The method, calculation steps and validation are shown. It was found that the distance remained constant as the speed and pulsing rate changed proportionally.

1. Introduction

When striking using ultrasound pulses on moving surface, varying pulsing rate plays role to locate and measure the contact. It is can also specify what level of detail of observation. Since rolling bearing measurements are dynamic, there is a need to synchronize the speed and sampling rate. This is to ensure the data captured corresponds to the change of speed and distance. Fig.1 shows an example of the synchronization of water drop at a period $T$ and the glasses while the conveyor is running with a speed $V$. Notation $x$ is the distance between the data points. This represents the rotating speed and the ultrasonic pulser. The requirement is that the droplet should fill every glass in a sequential order.
A simple mathematical solution is shown below in order to identify which pulsing rate \((1/T)\) in Hz to select;

\[
f_{P RR} = \frac{x}{V}
\]  \hspace{1cm} (1)

Eq. 1 is only valid if the speed is steady, and is not applicable in the case of oscillation motion where the speed is sinusoidal.

2. Ultrasound Background

Sound is a mechanical energy that is transmitted through a medium by vibration of molecules. If the sound wave is generated continuously above human hearing limit \((20\text{ KHz})\), it is called an ultrasound [1]. It has a shorter wavelength, which means it can be bounced off on small object such as cracks, defect, and bearing contacts. An ultrasonic transducer converts an electrical energy to a mechanical energy in the form of sound. The principle of the ultrasonic transducer is driven by a pulser. The transducer generates a high frequency ultrasonic energy. The sound energy is introduced on the surface and propagates through the materials in the form of waves. When there is a discontinuity (such as an oil film) in the wave path, a part of the energy will be reflected back from the flaw surface. The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen.

2.1. Reflection Pulses

It was observed that as the ball passed the transducer, the contact pulse waveform shifted to the left and the curve of the waveform became almost flat. However, it would return to its original position as the ball left the contact. This is because the reflected sound energy was weakened and much of it was transmitted throughout the contact (next medium). If these amplitudes were recorded for every pulse as the ball passed the transducer, a series of segment of the waveform was formed. By recording the ball location whilst the amplitude fell and then rose again, the size of the minor axis contact, \(b\) could be determined.

3. Experimental Approach

3.1. Ultrasound measurement system

The ultrasound measurement system is consisting of ultrasonic transducer, ultrasonic pulser-receiver (UPR), digitizer, oscilloscope, function generator, sensor and a desktop computer (PC) as shown in Fig. 2. In the past similar work also using this system [2][3][4]. A 6410 deep groove ball bearing was mounted on the test rig. The immersion transducer is located on top of the bearing in special water bath that was pre-filled with distilled water. The transducer was mounted on the retractable holder to vertically adjust its position. This was to ensure that the sound wave was focused at the correct location. During the experiment, the UPR is continuously pulsing and
receiving ultrasound signals. The pulses are sent to excite the piezoelectric element inside the focusing immersed transducer to produce ultrasonic wave. The wave strikes the oil film results partially reflected and partially transmitted. The reflected pulse is recorded by the UPR. The receiver part of the UPR was used to amplify and filter the signal to filter unwanted interference. The digitiser functions to convert the analogue signals to digital from the UPR. The signal goes to oscilloscope first for signal conditioning before digitiser. The digitiser card was plug-in a desktop PC and interface with Labview™ software. A trigger was used to ensure signals were captured as the balls pass over the transducer location.

3.2. Methods

Since it involved a relative motion, it requires measuring the shaft speed, ball speed and cage speed. Fig. 3 shows a sketch of bearing 6410 without cage which indicates the relationship between shaft speed, ball speed and cage speed. If there was no slip in outer raceway that was fixed to the housing wall, therefore the speed of outer raceway is zero. Hence only ball speed and cage speed are calculated. The sampling balance was occurred at an intersection between the contact and at the focal point. The three required parameters are pulsing rate, relative ball-cage rotational speed and the ball pitch (51.43 mm). Pulsing rate was displayed at the PC monitor was controlled by the user. The ball rotational speed was calculated relative to the shaft rotational speed through radial ratio. However, because of the direction of the cage motion is opposite than the ball rotational motion, therefore relative speed ball-cage was measured. The shaft speed and cage speed were measured using the optical tachometer that counts revolution per unit time. A dot of silver paint was painted on the cage that functions as the reflector for optical tachometer representing one rotation per cycle. Table 1 list of the bearing geometrical and operational parameters.

Fig.2 Bearing test rig and instrumentation [5].

Fig.3 Schematic diagram of ball motion in bearing 6410.
Table 1. Geometry and physical properties of deep groove roller bearing 6410

| Parameter                                      | Value          |
|------------------------------------------------|----------------|
| Outer race diameter, \( d_o \)                | 114.61 mm      |
| Ball diameter, \( d \)                        | 24.6 mm        |
| Number of ball in complete bearing, \( n \)   | 7              |
| Outer groove radius, \( r_o \)                | 12.35 mm       |
| Inner groove radius                            | 12.35 mm       |
| Ball center to shaft centre, \( r_b \)        | 32.695 mm      |
| Radial load on contact, \( w_z \)             | 6.4 to 49.3 kN |
| Shaft speed, \( N \)                          | 60 to 600 rpm  |

3.3. Calculation Steps

The calculation steps using parameters in Table 1 and calculate using approach in Fig. 4a. The relative speed between shaft speed and cage speed \((V_{shaft} - V_{cage})\) divided the ball pitch to obtain the elapse time from ball-to-ball. The elapse time was then divided by the pulsing rate to obtain number of data point per ball pitch. The ball pitch was divided by the number of data point to obtain the distance between data points. The function of cage is to retain the position of ball uniformly. Since the cage has a physical contact ball, there is possible friction between ball and cage that reduce the speed of the ball. Therefore, cage speed also needs to be measured. The shaft speeds were measured by using the digital rotating contact tachometer. Unlike, the shaft speed, the cage rotated around the shaft; therefore the cage speed was measured using the non-contact optical tachometer. Shaft speed and cage speed shown in Fig. 4b were obtained through the experiment. Fig. 5 plots of average of ten times of shaft speed and cage speed.
4. Results and Discussion

4.1. The effect of varying the pulsing rate at constant speed

Fig. 5 shows the effect of varying the pulsing rate at a constant speed. The sudden reduction in amplitude indicates that the ultrasonic beam was passing the contact. Each spike represents the passage of a ball in a sequential order. It is clear that the distances between the spikes are uniform. Therefore, validation is performed by counting the number of data point between the spikes, and multiplying by the calculated distance between points. This is shown in Table 2 where the number of data point between balls are listed.

![Fig. 5 The effect of different pulsing rate with constant shaft speed.](image)

Table 2. Number of data points between balls at varying frequency (spikes in Fig.5)

| Ball   | Frequency (kHz) |
|--------|-----------------|
|        | 1   | 2   | 3   | 4   | 5   |
| Ball 1-2 | 58  | 115 | 167 | 224 | 274 |
| Ball 2-3 | 57  | 115 | 167 | 222 | 271 |
| Ball 3-4 | 58  | 115 | 165 | 223 |
| Ball 4-5 | 58  | 115 | 165 |
| Ball 5-6 | 57  | 115 |
| Ball 6-7 | 58  | 115 |
| Ball 7-1 | 57  |

4.2. Sampling Balance

Table 3 is the complete distribution of distance for a maximum speed of 600 rpm and maximum pulsing rate at 10 kHz. It is shown that the sampling is balance with constant number of data point along the diagonal. The distribution can be used to select the shaft speed and the pulsing rate whilst the distance remain the same. It displays distance in mm of ball pitch.
4.3. Validation

In order to validate the distance between data points, an actual physical distance is needed. In this study, the distance between bearing or ball pitch may become the comparison. Those counts are reduced when the pulse repetition rate is increased. This is because high frequency generates finer data point resolution, which means the number of data point is increases. Table 4 below shows the validation of calculations that were made. It was found that the experimental ball pitch fell between 50.15 to 52.62 mm which was close to the geometrical ball pitch of 51.45 mm. The errors might be caused by the triggering device vibration that affected the starting point of capturing data. Delay in triggering may cause minimum point is not positioned at the center of the ball. Therefore, the minimum point might be located before the ball passing or after ball passing.

Table 4. The comparison between experimental ball pitch and calculated ball pitch

| Frequency, kHz | For 120 rpm | Total of Data Point between Balls, N | Calculated Distance between Data Point, L (mm) | Ball pitch, L (N x l) (mm) | Error % |
|----------------|------------|-------------------------------------|-----------------------------------------------|---------------------------|---------|
| 1              | 1          | 57                                  | 0.915                                         | 52.16                     | 1.38    |
| 2              | 115        |                                     | 0.458                                         | 52.62                     | 2.27    |
| 3              | 167        |                                     | 0.305                                         | 50.94                     | 0.99    |
| 4              | 224        |                                     | 0.229                                         | 51.25                     | 0.39    |
| 5              | 274        |                                     | 0.183                                         | 50.15                     | 2.53    |

Calculated ball pitch = 51.45 mm
5. Conclusion

It was found that the distance remained constant as the speed and pulsing rate changed proportionally. This was shown where the ball pitch was used to validate the sampling balance with some errors. Sampling balance is recommended to be implemented prior to the test to select the suitable shaft speed and pulser rate.

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