Fusion of Microphone and Accelerometer Sensing for the Identification and Measurement of Inner Race Defect

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Abstract. *Use of uni-axial accelerometer is simplest and cost effective way to monitor vibration in a single direction. Situation in which, fault is rotating/changing its direction extraction of defect frequency is difficult from it. However, some of the bursts can be properly analysed. The acoustic sensor is another cost effective device which is generally omnidirectional and can be used in identification of bearing defect. In this paper, data from both the acoustic sensor and accelerometer are utilised and fused to have complete information for identification of defect type and estimation of its width. The present work utilizes defect identification using envelope demodulation of acoustic signal. Subsequent measurement of defect width is carried out from accelerometer signal. Continuous wavelet transform (CWT) of vibration signal is carried out using adaptive wavelet to produce 2D scalogram. Finally, time marginal integration (TMI) of CWT coefficient is performed for the measurement of defect width.*

Keywords: Bearing, Inner Race Defect, Adaptive Wavelet, Time Marginal Integration.

Introduction

Components of rotating machine having relative motion are susceptible to failure due to dynamic stressing conditions. Rolling element bearing is one of such components. In recent past, development has been made in sensing technology as well as in digital signal processing [1-3]. Fusion of data to get the required information is also being attempted [4].

The uni-axial accelerometer is a cost effective vibration sensor but it captures burst with sufficient amplitude only in the direction of its sensitivity. This works well for stationary defect like outer race defect which generally remains fixed. However, in the more multifaceted case like inner race defect which rotates with the speed of the shaft, defect identification from frequency domain vibration signal using uni-axial accelerometer is difficult. On another hand acoustic sensor is generally omnidirectional and can overcome this problem but the data is contaminated by the noise from surrounding.

Utilising the advantage of both the acoustic and vibration sensing towards a low cost solution to complex problems, a signal processing scheme is proposed. The scheme is implemented for identification and measurement of inner race defect of a cylindrical roller bearing. The defect identification is carried out by envelope spectrum of Intrinsic Mode Function (IMF) generated by Ensemble Empirical Mode Decomposition (EEMD) of acoustic signal. After identification of defect, evaluation of its size is made by applying Continuous Wavelet Transform (CWT) using adaptive wavelet to the vibration signal to produce 2D map of CWT coefficient. CWT operation act as band pass filtering and produce high coefficient at scale analogous to frequency of burst. Finally Time Marginal Integration (TMI) of CWT coefficient is carried out for the measurement/evaluation of defect width.

Theory

Signals from both the microphone and accelerometer can be recorded simultaneously on different tracks using the same data acquisition system. For identification of type of defect and measurement of its size a processing scheme for microphone/acoustic signal and accelerometer/vibration signal respectively is proposed and given in Fig.1.

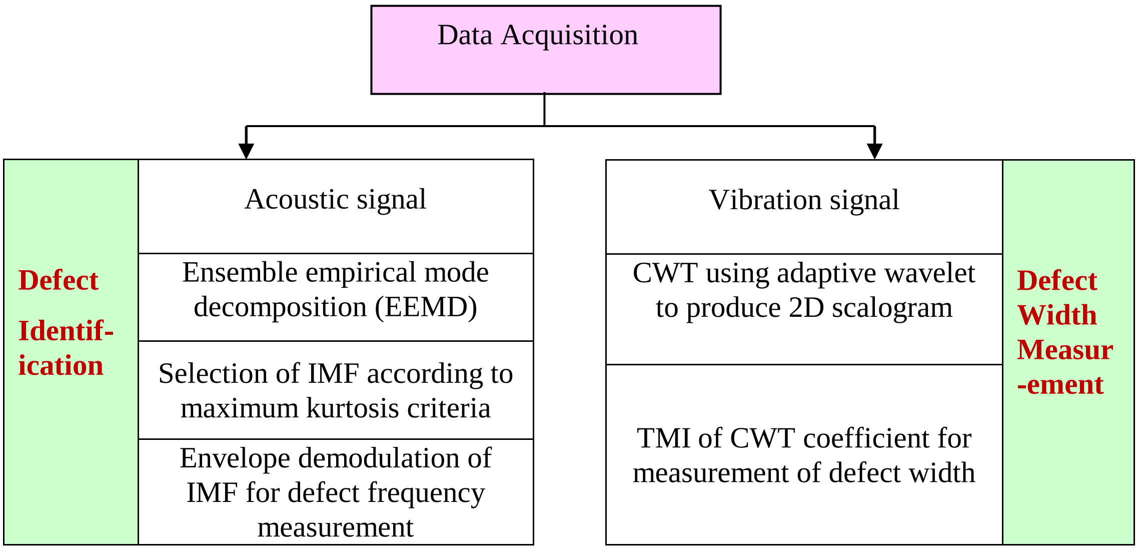

Fig. 1: Processing scheme for identification of bearing defect and measurement of its size

The EEMD is employed to decompose the nonlinear and non-stationary acoustic signal due to race defect into a number of intrinsic mode functions (IMFs) [5]. Out of which, IMF having maximum kurtosis is further processed by envelope demodulation for identification of defect frequency [6].

To enhance feature of defect in the vibration signal, CWT is carried out using adaptive wavelet [7]. TMI of CWT coefficient is carried out for evaluation of defect width. The TMI is analogous to the instantaneous power of the signal and reveals how the power of signal changes with time. TMI of CWT coefficient over scale a and time location b can be expressed as [8]:

$$TMI = \int_{-\infty}^{+\infty} CWT(a,b)da \tag{1}$$

Experiment analysis

Experiment is performed on a bearing test rig. Seeded groove of width 0.94 mm in axial direction is introduced by electric discharge machining (EDM) process on the inner race of the cylindrical roller bearing (NBC NU205). The bearing has 13 rollers of diameter (d) as 7.50 mm. The microphone and accelerometer are used for acquisition of acoustic and vibration data using NI-USB-4431 DAQ system. Both the data are acquired simultaneously using two different ports of the DAQ system.

A typical acoustic signal of 0.1 sec for defective bearing is shown in Fig. 2(a). For identification of defect, EEMD of the signal is carried out. Application of EEMD produces several IMFs. Out of this, IMF1 has maximum kurtosis and is presented in Fig. 2(b) and is selected for further processing by envelope demodulation. Envelope spectrum of IMF1 is shown in Fig. 2(c). The spectrum has peak at shaft speed (F_d) and it's multiples which indicates presence of misalignment. The obtained defect frequency (F_d) is 258.5 Hz which is close to theoretical inner defect frequency (265 Hz) of the specified bearing at the specific speed. This indicates presence of inner race defect. Presence of inherent misalignment due to defect is observed at frequency $2F_s$. The interaction of defect frequency with the speed of shaft is also present in frequency spectrum in Fig. 2(c).

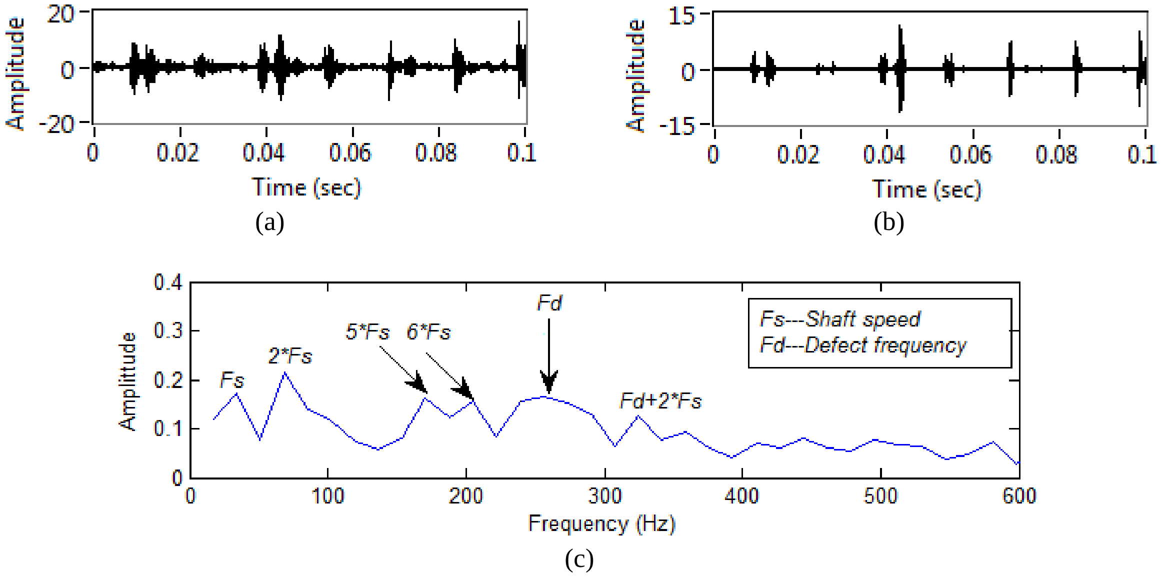

Fig. 2. A typical acoustic signal of bearing inner race defect (a) Raw signal (b) IMF1 using EEMD of signal in Fig. 2(a), and (c) Envelope spectrum of signal in Fig. 2(b)

A typical vibration signal for estimation of defect size is presented in Fig. 3(a). The magnified view of encircled burst in Fig. 3(a) is shown in Fig. 3(b). Although point of exit (GC2) of roller from the defect is easy to detect, spotting defect commencement point (GC1) from raw signal is difficult because of low energy of signal at that point of time. To minimize the ambiguity in spotting the GC1, a process stated in Fig.1 is implemented. Outcome of corresponding stages of processing is shown in Fig. 3(a), Fig. 3(b), Fig. 3(c) and Fig. 3(d). Defect commencement (GC1) and exit (GC2) can now be easily spotted from the TMI signal.

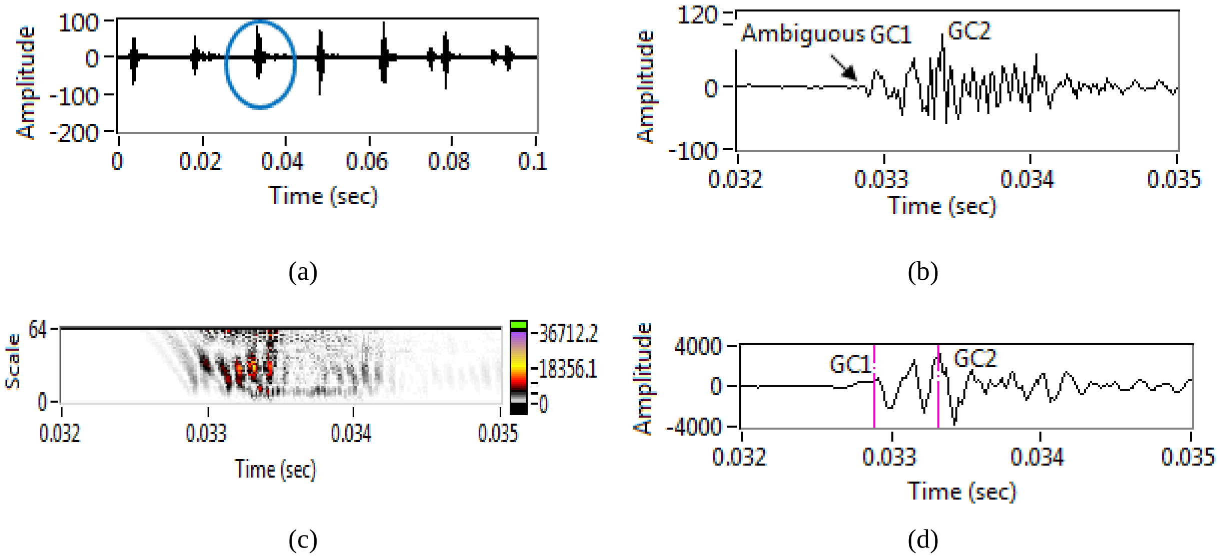

Fig. 3. A typical vibration signal for inner race defect (a) Raw signal (b) Magnified view of encircled burst in signal, (c) CWT scalogram of signal in Fig. 3(b) using adaptive wavelet, and (d) TMI of CWT coefficient

The inner race defect width (L_{IR}) can be calculated by making use of burst duration (Δt) determined from TMI graph, inner race diameter (D_I), shaft speed (F_S) and fundamental train frequency ($F.T.F$). The mathematical expression of inner race defect width is expressed as [9]:

$$L_{IR} = \pi \times \Delta t \times D_I \times (F_s - F.T.F) \quad (2)$$

The inner race diameter (D_I) of the specified bearing is 30.96 mm. The burst duration (Δt) is calculated by averaging taken from 10 bursts and is 0.0004432 sec. At shaft speed of 34.16 Hz and FTF of 13.75 Hz the defect width evaluated using the proposed scheme is 0.89 ± 0.07 mm.

Conclusions

A simple method to process the fused data of acoustic and vibration sensors has been proposed to resolve complicated issues such as identification of inner race defect as well as estimation of defect size. The processing scheme uses EEMD, envelope demodulation, CWT and TMI as applicable. Defect frequency has been identified with accuracy of 97.54% and the defect width has been evaluated with accuracy of 94.15%.

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