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The using of sound signal and simple microphone to detect damages in induction motor

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Abstract. In this work, the induction motor damage detection based on sound signal was developed by using simple microphone and sound card as sound data grabber to reduce the cost of instrument. For that purpose, the induction motor apparatus was constructed, and the artificial damages were applied to induction motor to make the conditions of unbalance, broken rotor, and bearing fault. The Fast Fourier Transform (FFT) and wavelet transform were then used to process sound signal, to show the signature of each type of damage. The results show that the unbalance exhibited very clear large wavelet coefficient in the frequency of 1x rotational speed. In the broken rotor bar damage, the strong red color of wavelet graph appeared in the sideband frequencies associated with the broken rotor bar (f_{BB}). Further more, the bearing fault case showed the different color contour of wavelet graph in the ball-pass outer raceway frequency (f_{BPOF}). It can be concluded that the using of sound signal and simple microphone were powerful tools to detect unbalance, broken rotor and bearing fault in induction motor.

1. Introduction

Induction motor is an electromechanical equipment used in various applications to convert electrical power into mechanical power [1]. In industrial world, induction motor becomes one of the most important components, which can be found as a drive in conveyor, pump, lathe, press machine, elevator and etc. Long time operation will let the induction motor undergoes aging that tends to have damages. The type of damages that often occur in induction motor are mechanical unbalance, bearing fault and broken rotor. Because of such crucial function of induction motor, damage detection of induction motor has became an important research area in mechanical engineering.

Several methods have been developed to detect damages in induction motor. The most popular method to detect damage in rotating machine is using vibration measurement as part of predictive maintenance [2]. In this method, accelerometers are usually used as sensor which have to be mounted in the area of measurement. This condition is inconvenient and may endanger the measurement operator in narrow, and restricted area.

In order to overcome the deficiency of measurement instrument, the non-contact measurement method need to be applied. One of the popular method of non-contact measurement is using the sound signal. The sound data can be grabbed by using microphone [3-5], however most of microphones used in Structural Health Monitoring are spending much budget, so the simple microphone with less expenses need to be investigated to find the solution of expensive instrument.

In this work, the simple microphone and sound card used as sensor to get the sound signal from induction motor with artificial damages (unbalance, broken rotor bar and bearing faults). The sound signals were then processed by using Fast Fourier Transform (FFT) and Wavelet transform. From this work, it is hoped that the potency of simple microphone and soundcard to detect damage in induction motor can be shown as the solution to get low budget instrument for induction motor damage detection.

2. Methodology

2.1. Experimental Set-Up

In this research, damages detection in induction motor was conducted by using simple microphone and sound card as sound signal grabber which connected to a PC. The *microphone* used in this setup was model of Zm-360 with frequency response 70-20KHz and the sensitivity of -20dB below 1 Khz, which usually used as a part of sound system. In induction motor, the artificial damages (unbalance, broken rotor bar and bearing fault) were applied. The experimental set-up can be seen in Figure 1.

The sound data of each type of damage were grabbed with microphone and PC sound card. The sound data were then processed in the PC. By using FFT and wavelet transform with Mexican heat mother wavelet [6], the sign of every damages could be displayed in the PC. The motor speed would be set in steady speed of 2850 rpm corresponds to 47.5 Hz.

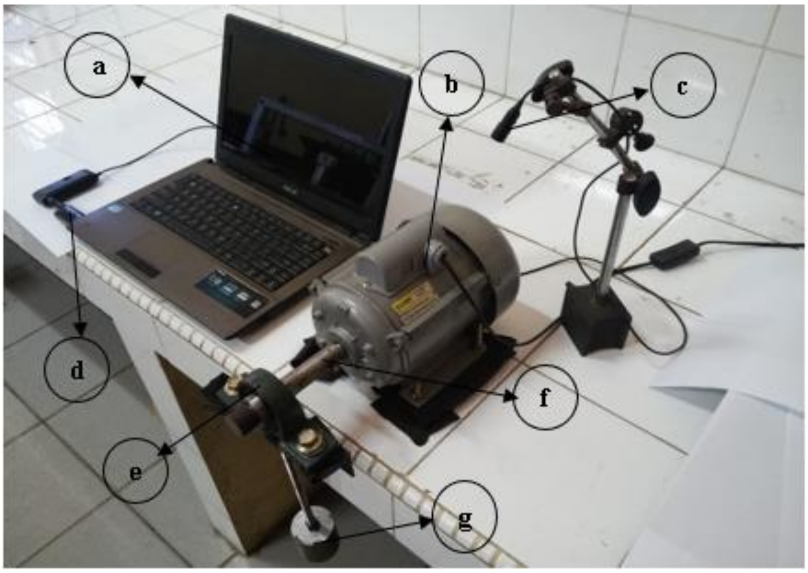
2.2. Experiment in Normal Condition

Induction motor testing in normal (without damage) conditions was conducted to show the sound signal of induction motor without any damages applied. Normal condition data will be used as a reference of the induction motor testing condition which will be compared with damage condition.

Before testing the induction motor in normal condition, the induction motor and rotor as shown in the experimental setup need to be balanced. The balancing process was applied the induction motor apparatus to make sure the rotor attached on motor well balanced. The balancing was conducted based on sound signal.

2.3. Experiment in damage condition

The experiment in damage condition were conducted by applying artificial damages to the induction motor. The damages were bearing defect, broken rotor bar, and unbalance. The given artificial damages can be seen in Figure 2. The bearing defect was applied by devastating the outer race of the motor bearing. The broken rotor bar was produced by making holes in the rotor bar using drilling machine. The unbalance condition was applied by installing unbalance disk to the motor setup.



a. PC
b. Induction motor
c. Microphone
d. Soundcard
e. Bearing of Load
f. Shaft
g. Load 0.8 kg

Figure 1. Experimental setup of induction motor damage detection

In early stage, the experiments were conducted for every single of damage, and continued with combination of two types of damages. Finally, the experiment was completed by combining all type of artificial damages. The sound signal data were then processed and analyzed by using FFT and wavelet transform-Mexican head mother wavelet, so that the signatures of damage in motor induction from sound signal could be determined.

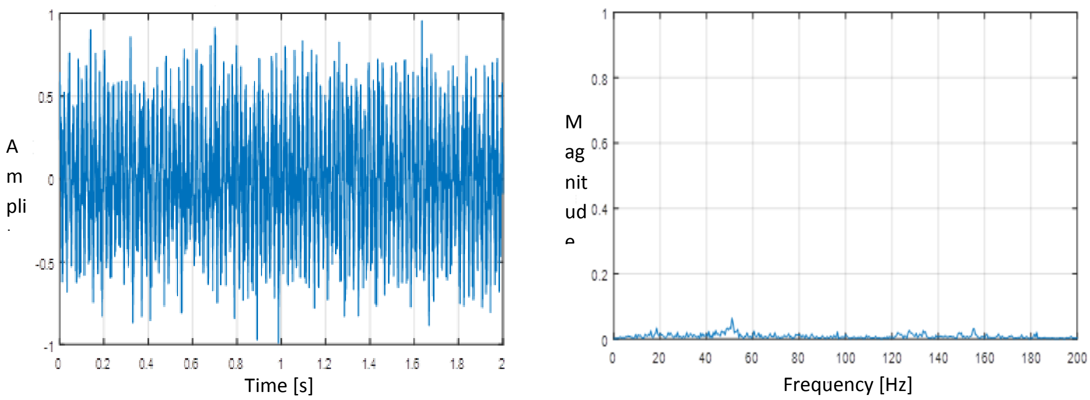
(a) (b) (c)

Figure 2. Artificial damages in Induction motor (a) unbalance, (b) Broken rotor (c) Bearing fault

3. Result and Discussion

3.1. Induction motor signal in normal condition

Figure 3 shows the sound signal of induction motor for normal condition in form of time domain and frequency domain. In the time and frequency domain signals, the high amplitude does not appear. It means that there are no any damages, even though there is a little bit high amplitude in around operational speed frequency, but it is still normal.



(a) (b)

Figure 3. The sound signal of induction motor in normal condition (a) Time domain (b) Frequency domain

3.2. Induction motor signal in unbalance condition

The signature of unbalance in a vibration signal normally has the form of increased amplitude along the rotor frequency, being located in this case at 49.5 Hz. The same tendency will appear in sound signal. To make sure that the rotor in unbalance condition, the rotor would be balanced by the process of balancing. After balancing, the unbalance mass was added to the rotor to give unbalance condition. 7 gram mass was attached to the rotor. Figure 4 shows the sound data signal for unbalance condition in form of frequency domain (Figure 4a), scalogram of wavelet transform (Figure 4b), 3-D wavelet coefficient (Figure 4c), and the view of time-frequency (Figure 4d).

Induction motor was operated in the speed of 2970 rpm corresponds to 49.5 Hz. The sound signal in frequency domain shows the high amplitude in the frequency of motor speed. In the scalogram, the yellow contour appears straight in the frequency of 49.5 Hz where the contour becomes wider as the scale raise up, and in time-frequency wavelet red-yellow and blue contours form row in the frequency 49.5. It could be analyzed that the unbalance problem is detected very well by using proposed method.

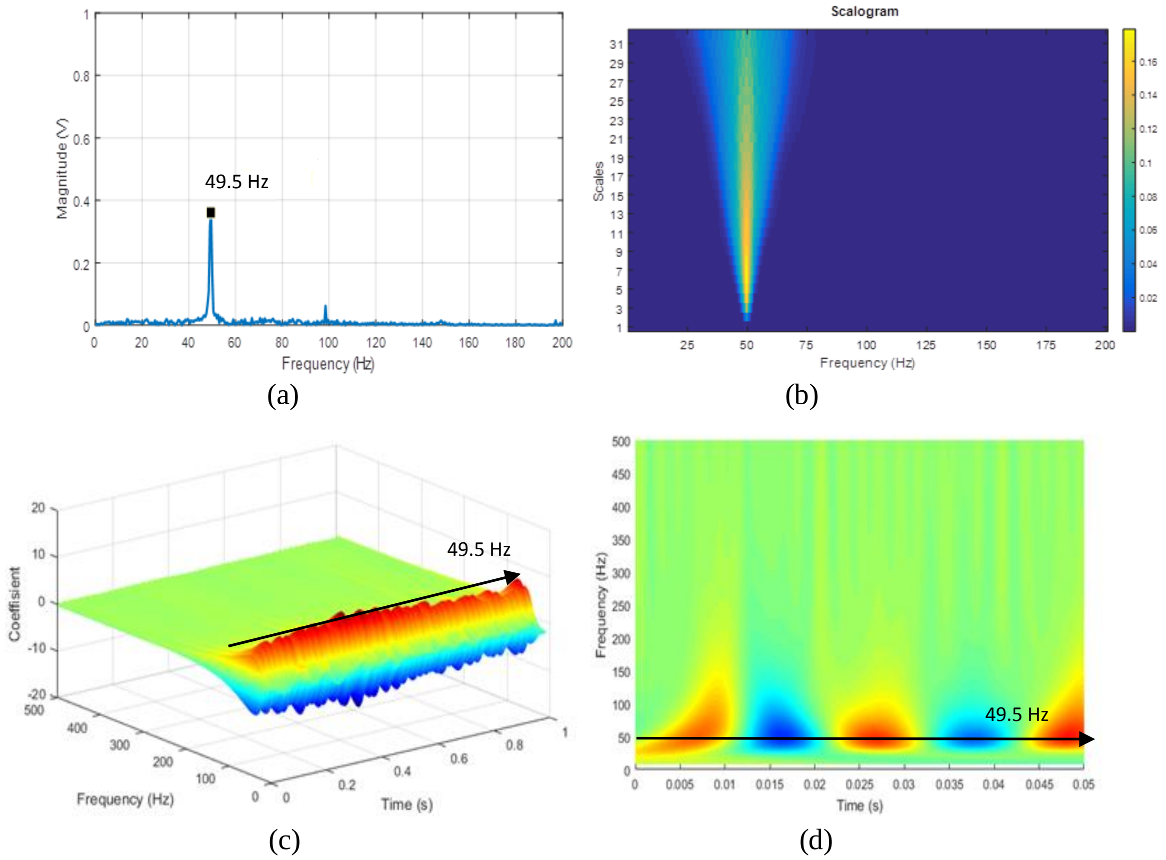


Figure 4. The sound data signal for unbalance condition (a) frequency domain (b) *scalogram* (c) 3-d *wavelet transform* (d) time-frequency *wavelet transform*.

3.3. Induction motor signal in broken rotor condition

In the case of rotor bars, the mechanism of the frequency modulation forming is mentioned by Arrendo et.al [4]; it is known that symmetrical currents in a symmetrical rotor of an induction motor induce a resultant forward rotating magnetic field at synchronous speed with healthy rotor bars. An induction motor operating with a broken rotor bar defect creates a negative sequence of rotor currents due to rotor asymmetry. It induces a principal component in the spectrum of stator current, which rises up to the frequency $(1 - 2s) f_s$ and it is close to the fundamental frequency. Due to reflection, the rotor asymmetry frequencies are $-2ksf_s$, where k = 1, 2, 3, … is any positive integer and s is the slip. Thus, in the case of broken rotor bars, there is a speed oscillation, which acts as a frequency modulation on rotation frequency and two side band frequencies appear around f_r in the vibration spectrum [7] that are given by:

$$f_{BB} = f_r \pm 2ksf_s \tag{1}$$

Where f_{BB} are the sideband frequencies associated with the broken rotor bar. The slip s is defined as the relative mechanical speed of the motor n_m with respect to the motor synchronous speed n_s as follows:

$$s = \frac{n_s - n_m}{n_s} \tag{2}$$

The motor speed was measured by *tachometer*, and it is found that the motor rotated in 2865 rpm corresponding to 47.75 Hz. The values of f_{BB} were calculated to be 39 HZ and 59 Hz.

The sound signal of the induction motor in the condition of broken rotor bar can be seen in the Figure 5. The frequency domain signal shows the high amplitude in the frequency of 78.5 Hz. This value is close to $2 \times f_{BB}$ (harmonic of f_{BB}), which reflect the signature of broken rotor bar. The difference of 0.5 Hz caused by fluctuation of motor speed.

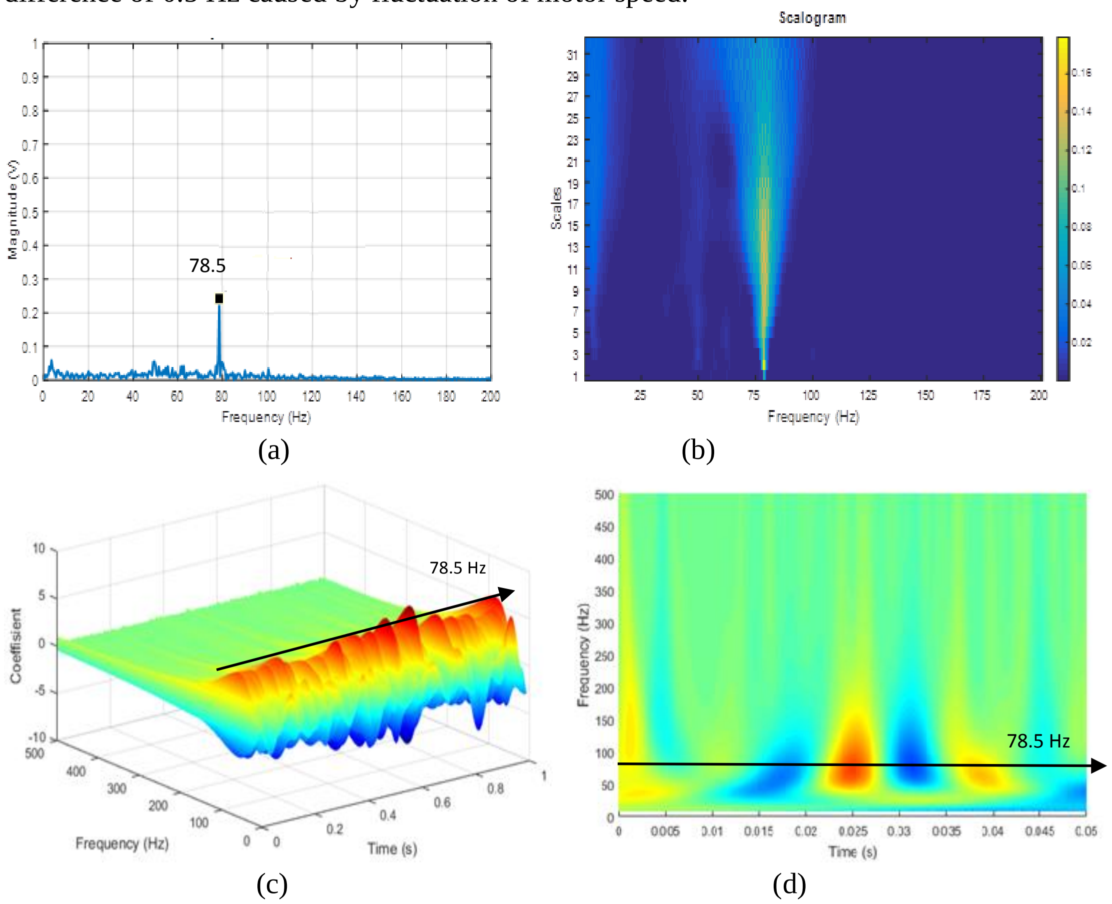


Figure 5. The sound data signal for broken rotor bar condition (a) frequency domain signal (b) *Scalogram* (c) 3-d *wavelet transform* (d) time-frequency *wavelet transform*.

In the scalogram, the yellow contour is shown clearly in line of 78.5 Hz. In the 3-D wavelet transform, very clear red contour appears in the same frequency line. In the time-frequency *wavelet transform*,

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the blue-yellow-red color form a line of 78.5 Hz. These results indicate that the simple microphone has a good ability to detect the induction motor sound.

3.4. Induction motor signal in bearing fault condition

The artificial damage which applied to induction motor's bearing was the outer race fault. As the bearing rotates, impacts occur at the ball-pass outer raceway frequency (f_{BPOF}) as given by [8]:

$$f_{BPOF} = \frac{N_B}{2} f_r \left(1 - \frac{D_B}{D_c} Cos\theta\right) \quad (3)$$

Where θ is the contact angle between the bearing surfaces, D_C is the cage diameter of the bearing and is measured from a ball center to the opposite ball center, D_B is the ball diameter, and N_B is the number of balls in the bearing. By calculating f_{BPOF} from the data of induction motor in the experimental setup, the ball pass outer race frequency defect was found to be 144.5 Hz.

Figure 6 shows the sound data signal for bearing fault condition in form of frequency domain (Figure 6a), scalogram of wavelet transform (Figure 6b), 3-D wavelet coefficient (Figure 6c), and the view of time-frequency (Figure 6d). It can be seen that the signature of damage caused by bearing fault f_{BPOF} in the frequency of 144.5 Hz. In the frequency domain, the high amplitude appears in that frequency. The wavelet transform were then used to show the other aspect of damage detection. By applying the wavelet transform, this signature is also visible clearly. In the scalogram, in line of 144.5 Hz, the yellow contours widen as the scale increases. The 3-D wavelet coefficient in Figure 6c shows the consistent high value of wavelet coefficient in the frequency of 144.5 Hz. In the view of Time-Frequency the red and blue contours have the centers in the line of $f_{BPOF.}$ This result show that by using sound signal and simple microphone, the bearing fault in induction motor can be detected well.

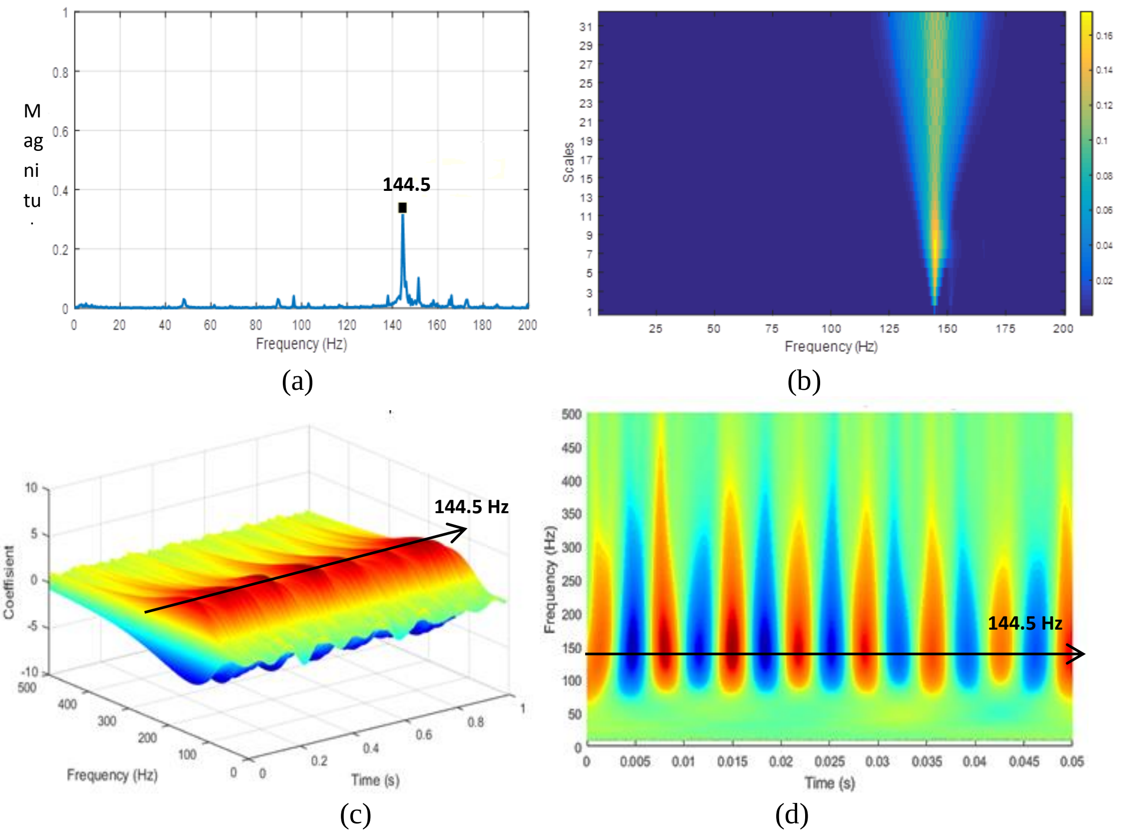

Figure 6. The sound data signal for bearing fault condition (a) frequency domain signal (b) *scalogram* (c) 3-D *Wavelet Transform* (d) time-frequency *wavelet Transform*.

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3.5. Induction motor signal in multiple damage condition

For multiple damage condition, the unbalance, broken rotor and bearing fault were applied to induction motor apparatus simultaneously. Figure 7 shows induction motor sound signal in multiple damage condition. In the frequency domain data, there are three dominant peaks which show the signature of unbalance, broken rotor and bearing fault respectively. The frequency value of damage signature in multiple damage are slightly different from the frequency value of single damage condition, which caused by the interplay between each type of damage. In the scalogram (Figure 7b) there are three contours in the signature of damage frequencies, but the contour in the frequency of 146.5 Hz as the signature of bearing defect is not clear. This condition is caused by the low amplitude at that frequency compared with other damage frequency signature, so it is overwhelmed. In the 3-D wavelet coefficient, so many peaks appear and it mixes all of the pattern. The same tendency is found in time-frequency *wavelet transform.*

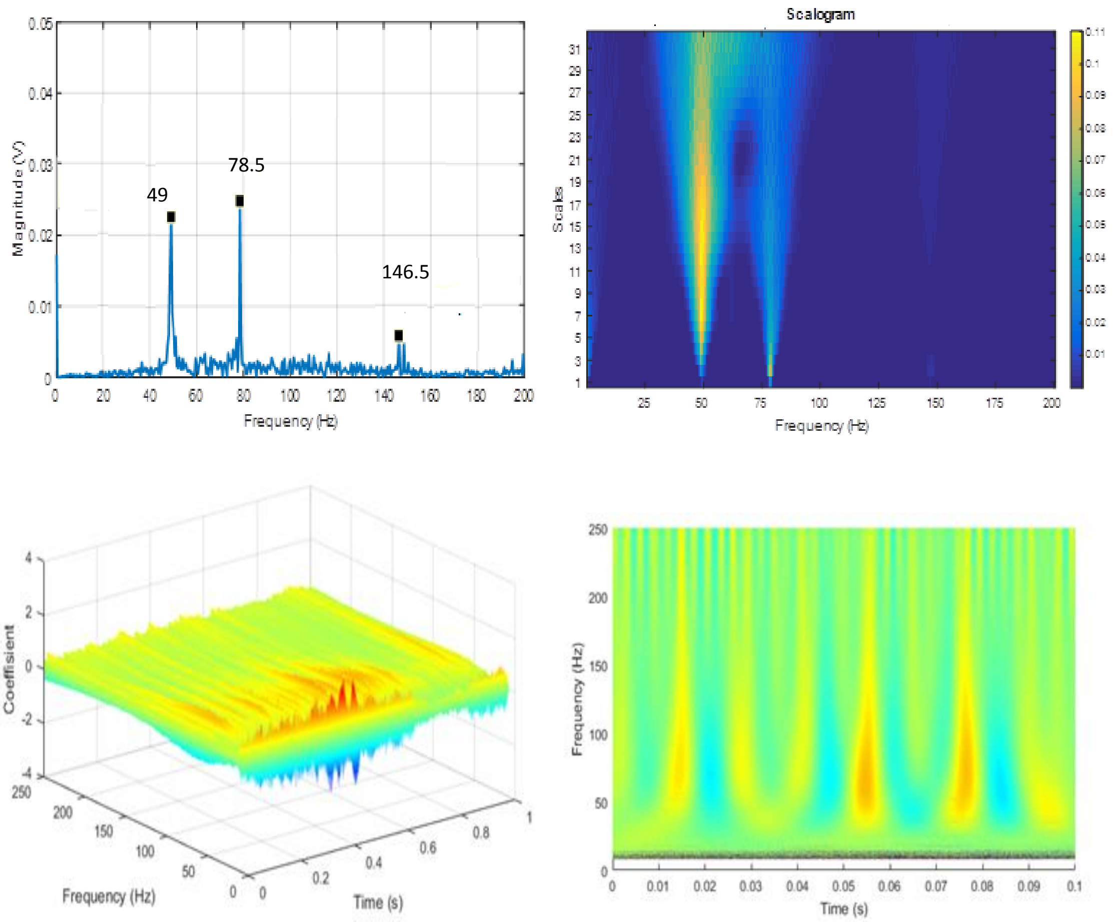

Figure 7. The sound data signal for multiple damage condition (a) frequency domain (b) *scalogram* (c) 3-d *wavelet transform* (d) time-frequency *wavelet transform*.

4. Conclusion

From the works that have been done, it is shown that the sound signal and simple microphone can be used to detect induction motor damage well, where the FFT and wavelet transform were applied as signal processor. By using this method, the unbalance condition, broken rotor bar and bearing fault could be detected well by recognizing their own signature in frequency domain sound signal and wavelet transformation for the single damage. For multiple damage, all of damage signature frequency appear clearly in frequency domain signal. In the scalogram, the high amplitude signature would close

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the lowest one, so the lowest amplitude signature was not so clear but it still could be detected. For future work it is really recommended to apply this method in industry, so the useful this method in the real application.

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