TELKOMNIKA, Vol.12, No.1, March 2014, pp. 97 ~ 106
ISSN: 1693-6930, accredited A by DIKTI, Decree No: 58/DIKTI/Kep/2013
DOI: 10.12928/TELKOMNIKA.v12i1.1693

Water Pump Mechanical Faults Display at Various Frequency Resolutions

Linggo Sumarno*[1], Tjendro[1], Wiwien Widyastuti[1], R.B. Dwiseno Wihadi[2]
[1] Electrical Engineering, Sanata Dharma University, Yogyakarta, Indonesia
[2] Mechanical Engineering, Sanata Dharma University, Yogyakarta, Indonesia,
Kampus III, Paingan, Maguwoharjo, Yogyakarta, Indonesia
*Corresponding author, email: lingsum@usd.ac.id

Abstract

When an electrical machine suffered a mechanical fault, it generally emits certain sounds. These sounds came from the vibration. Therefore, based on the vibration, it could be detected if there was a mechanical fault in an electrical machine. This paper discussed the graphical display of the vibration of electrical machines in the form of household water pumps which were in good condition, faulty bearing, faulty impeller, or faulty foot valve. Vibration could be displayed in the time domain, or in the frequency domain, by using the three axes, i.e. X, Y, and Z. In the frequency domain, the vibration could be displayed at various frequency resolutions. Based on the observations, the higher frequency resolution, the lower detail in the graphical display of frequency domain would be shown. Although there was lower detail in the graphical display of frequency domain, at frequency resolution of 11.7 Hz in the X axis, showed that it could be visually distinguished among water pumps which were in good condition, faulty bearing, faulty impeller, or faulty foot valve.

Keywords: *faults, water pump, frequency resolution*

1. Introduction

Technological developments, especially computer technology has growing rapidly in the recent years. Computers that humans developed are increasingly sophisticated. With its sophistication, it is possible to make a computer that can mimic human abilities, such as the human ability to detect faulty mechanical components of an electrical machine.

For people who are experts, the detection of faulty mechanical components of an electrical machine is carried out by using the ear. If there are faulty mechanical components, it will be heard certain sounds. The principle is, the sounds came from the vibration. Therefore, it can be said that the detection of faulty mechanical components of an electrical machine can be carried out by means of vibration detection.

Generally, the researches on the detection of faulty mechanical components of a electrical machine was carried out by sensing the signals of electrical current [1] [2], temperature [3] [4], sound [5] [6], or vibration [7] [8]. The signals are then showed on a display. In a more detail, Janjarasjitt [7] showed vibrations in the time domain, while Ebrahimi [8] showed vibrations in the frequency domain, by using a single frequency resolution.

As a new alternative, in this paper it will be shown the vibration signals of an electrical machine in the frequency domain, at various frequency resolutions. The discussed vibration signals are the signals that come from the vibration of electrical machines which are in good condition, faulty bearing, faulty impeller, or faulty foot valve. Electrical machine that discussed in this paper is the household water pump.

The purpose of using various frequency resolution is related to the recognition of faulty mechanical components of electrical machines. At a certain frequency resolutions, graphically, it will not be able to be distinguished clearly, the difference among water pumps which are in good condition, faulty bearing, faulty impeller, or faulty foot valve, while at the other frequency resolutions, it will be able to be clearly distinguished the differences. In this paper it will be discussed graphically, until how high the frequency resolution is required, in order to be distinguished clearly among water pumps which are in good condition, faulty bearing, faulty impeller, or faulty foot valve.

Received September 11, 2013; Revised December 17, 2013; Accepted January 14, 2014

2. Research Method

In order to carry out this research, it has been developed a system, where its block diagram is shown in Figure 1 [9]. The input is the vibration from a water pump, whereas the output is a graphical display of the vibration on the computer.

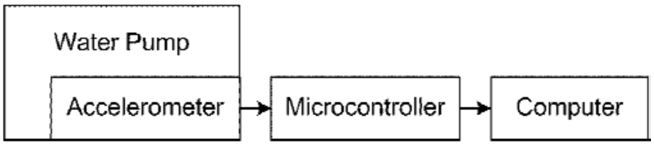


Figure 1. System block diagram [9]

The water pump in Figure 1 is a household water pump with output power rating of 125 watts. There are four water pumps used in this research which are in good condition, faulty bearing, faulty impeller, and faulty foot valve. The following will explain further about the faulty bearing, impeller and foot valve.

2.1 Mechanical Components of a Water Pump

Bearing

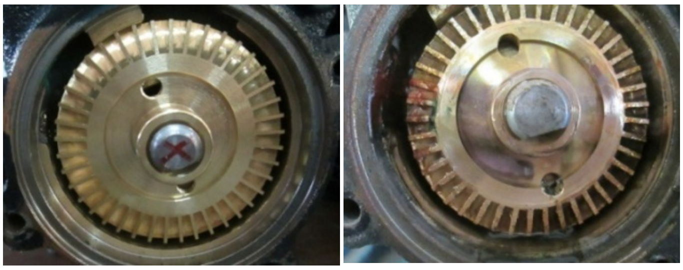
Bearing is a mechanical component that rotates in the electrical machine. Bearing serves to reduce friction at the shaft. When the bearings were damaged (in this case corrosion), can cause tight rotation on its shaft. Bearing faulty can be caused by excessive weight, excessive heat, corrosion, or misalignment. Figure 2 shows an example of a good bearing and a faulty one due to corrosion.

(a) (b)

Figure 2. Bearing examples; (a) A good bearing;
(b) A faulty bearing due to corrosion [9]

Impeller

Impeller is also a mechanical component that rotates in the electrical machine. This impeller is used to suck water from the ground and loaded up. When the impeller is faulty (in this case wear), it will lead to reduced water flow. Faulty impeller can be caused by friction between the impeller with the sand particles in the water. Figure 3 shows an example of a good impeller and faulty one due to wear.



(a) (b)

Figure 3. Impeller examples; (a) A good impeller;
(b) A faulty impeller due to wear

Foot Valve

Foot valve is not a rotating mechanical components. This valve serves to hold the water in the pump so that it will not to flow downward. When the valve is faulty (in this case leaking), it will cause water leak inside the pump, causing the water flow to be zero, because there is no water in the pump. Faulty valve can be caused by poor quality valves so that it easily leaking due to age. Figure 4 shows an example of a good foot valve and a faulty one due to leaking.

(a) (b)

Figure 4. Foot valve examples; (a) A good foot valve;
(b) A faulty foot valve due to leaking.

2.2 The Accelerometer, Microcontroller, and Computer

The accelerometer in Figure 1 is a three axis digital accelerometer ADXL 345 from Analog Devices. The accelerometer is attached to the water pump as shown in Figure 5 [9].

Figure 5. Attachment of the accelerometer on the water pump.
Axes X, Y, and Z are the direction of vibration [9]

The accelerometer in Figure 4 receives the vibration signals from the water pump. The vibration signals, which are analog signal, are first converted to an digital signal by using sampling frequency of 1500 Hz. That sampling frequency is the default sampling frequency of the accelerometer. Furthermore vibration signals from the accelerometer, which are digital signals, are sent to the microcontroller via I2C communication.

The microcontroller is assigned to carry out data formatting, so that the data can be sent to a computer via a USB port. In this case, microcontroller basically serves as an interface between the computer and the accelerometer. In the computer, the vibration signal which originally is a time domain signal is converted to frequency domain signal. In this research, the microcontroller uses AVR ATMEGA 328 that programmed using C language, whereas the computer uses processor Intel T7500 (2.26 GHz) and 4 GB RAM.

2.3 Frequency Domain and Frequency Resolution

Frequency domain is a domain that is typically used to display the frequency components of a signal. In order that a time domain signal can be displayed in the time frequency domain, a Fourier transform can be used for it. When the time domain signal is a discrete signal, a Fourier tansform is replaced by a DFT (Discrete Fourier Transform). Mathematically, the DFT of a discrete signal $x(n)$ is formulated as follow.

$$X(k) = \sum_{n=0}^{N-1} x(n) W_N^{nk} \qquad k = 0, \cdots, N-1 \tag{1}$$

where

$$W_N = e^{-j2\pi/N}. \tag{2}$$

Numerically, DFT computational load is quite heavy, as it requires a number of complex multiplication N^2. In order that the computational load becomes lighter, it can be used FFT (Fast Fourier Transform), that only requires a number of $N/2 \log_2 N$ complex multiplications, where N is the length of the FFT. As a note, the FFT with that computational load is a type of radix-2 FFT [10].

Frequency resolutions related with how much the detail of the signal will be shown in the frequency domain. If the resolution is bigger, then the details of the signals become less visible. Conversely, if the resolution is smaller, then the details of the signals become more visible. Mathematically, this resolution is shown in the following formula

$$\Delta f = \frac{f_s}{N_{FFT}} \tag{3}$$

where f_s is the sampling frequency and N_{FFT} is the FFT length used.

Conversion Steps

Figure 6 shows the conversion steps of time domain signal to frequency domain signal. The conversion steps, are started with the frame blocking step [11]. At this step a number of data (which is also called a data frame) are taken from a sequence of incoming data. The number of data which are taken in the frame blocking step are depends on the FFT points that used in the FFT step. The FFT points that evaluated were 16, 32, 64, 128, 256, and 512.

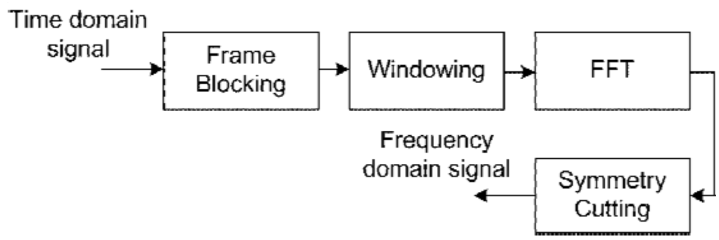


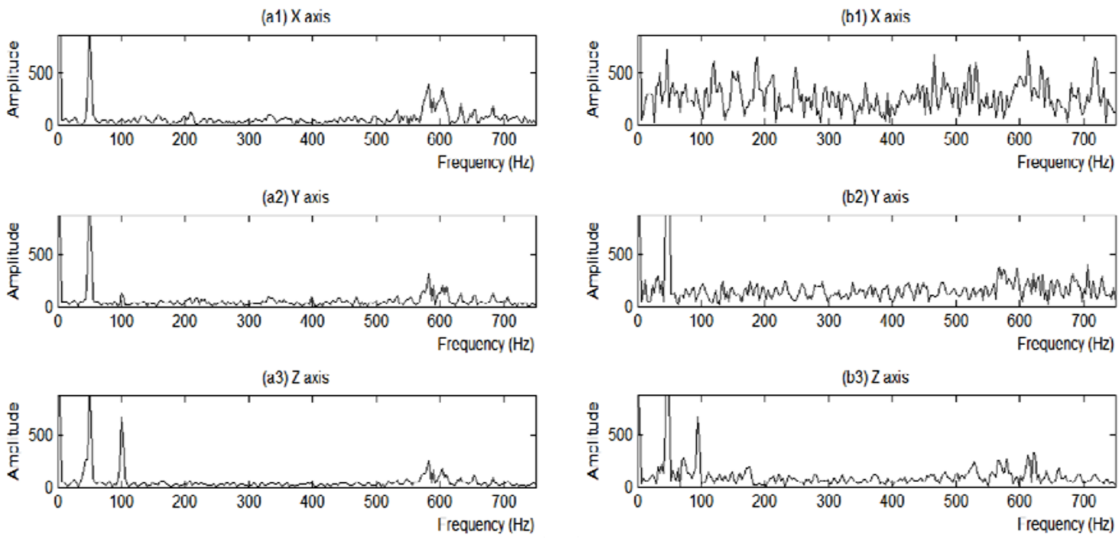
Figure 6. Block diagram of the conversion steps [9]

The windowing step in Figure 6, is carried out in order to reduce the discontinuity at the edges of the signal. This reduction is necessary in order to to reduce the appearance of harmonic signals in the FFT step [11]. The windowing step used a Hamming window [12], which is a kind of simple bell shape window. The FFT step used a radix-2 FFT. This kind of FFT is a common one that has been used in many purposes. Symmetry cutting is a cutting for the half of the FFT results at the right side. This cutting is necessary because basically FFT will give symmetry result, so that when only the half of the result used, it is sufficient. In this research, all steps in the conversion steps above were carried out using MATLAB software.

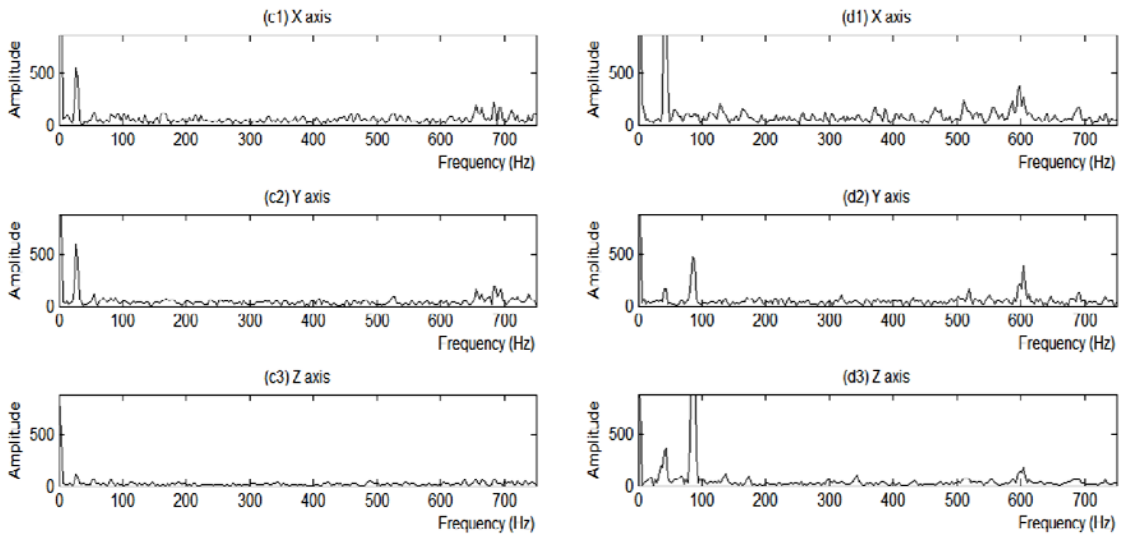
3. Results and Analysis

3.1 Results

The vibration test results in the frequency domain for water pumps which are in good condition, faulty bearing, faulty impeller, or faulty foot valve, are shown in Figure 7. The figure shows vibration in the time domain at X, Y, and Z axes. Figure 5 shows a picture of the real direction of the X, Y, and Z axes.



(a) Good (b) Faulty bearing



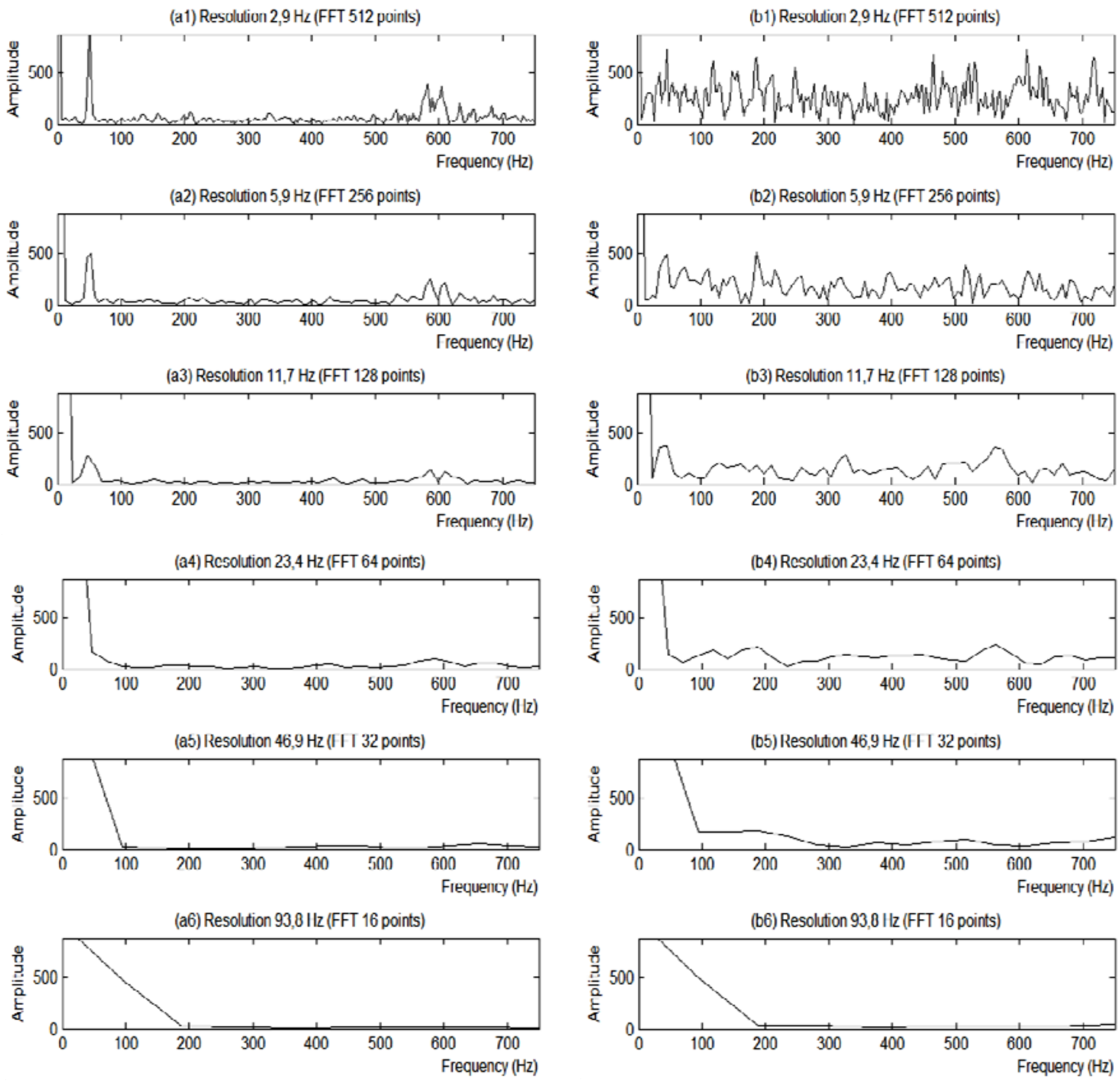
(c) Faulty impeller (d) Faulty foot valve

Figure 7. Graphical displays of water pump vibrations in the frequency domain, for X, Y, and Z axes. As a note, the frequency domain graphical displays are obtained from the use of 512 points FFT

The graphical displays of the frequency domain, for a various frequency resolution, are shown in Figure 8 and 9. The graphical displays are taken from the data on the X axis vibration. As a note, the data on the X axis vibration was chosen because its average amplitude is relatively greater than Y and Z axes.

3.2. Analysis

Figure 7 shows the water pump vibrations in the frequency domain. As seen in Figure 7 (a) the signal peaks are around 50 Hz, 100 Hz, and 600 Hz. The signal peak at around 50 Hz is caused by the power line electricity which have frequency 50 Hz. The signal peaks at around 100 Hz are caused by the multiplication of the vibration (on the water pump shaft) that caused by the frequency of power line electricity in the Z axis direction (this is the effect of the mechanical design of the water pump). The signal peaks around 600 Hz are caused by the friction between the bearing and the shaft (this is also the effect of the mechanical design of the water pump).



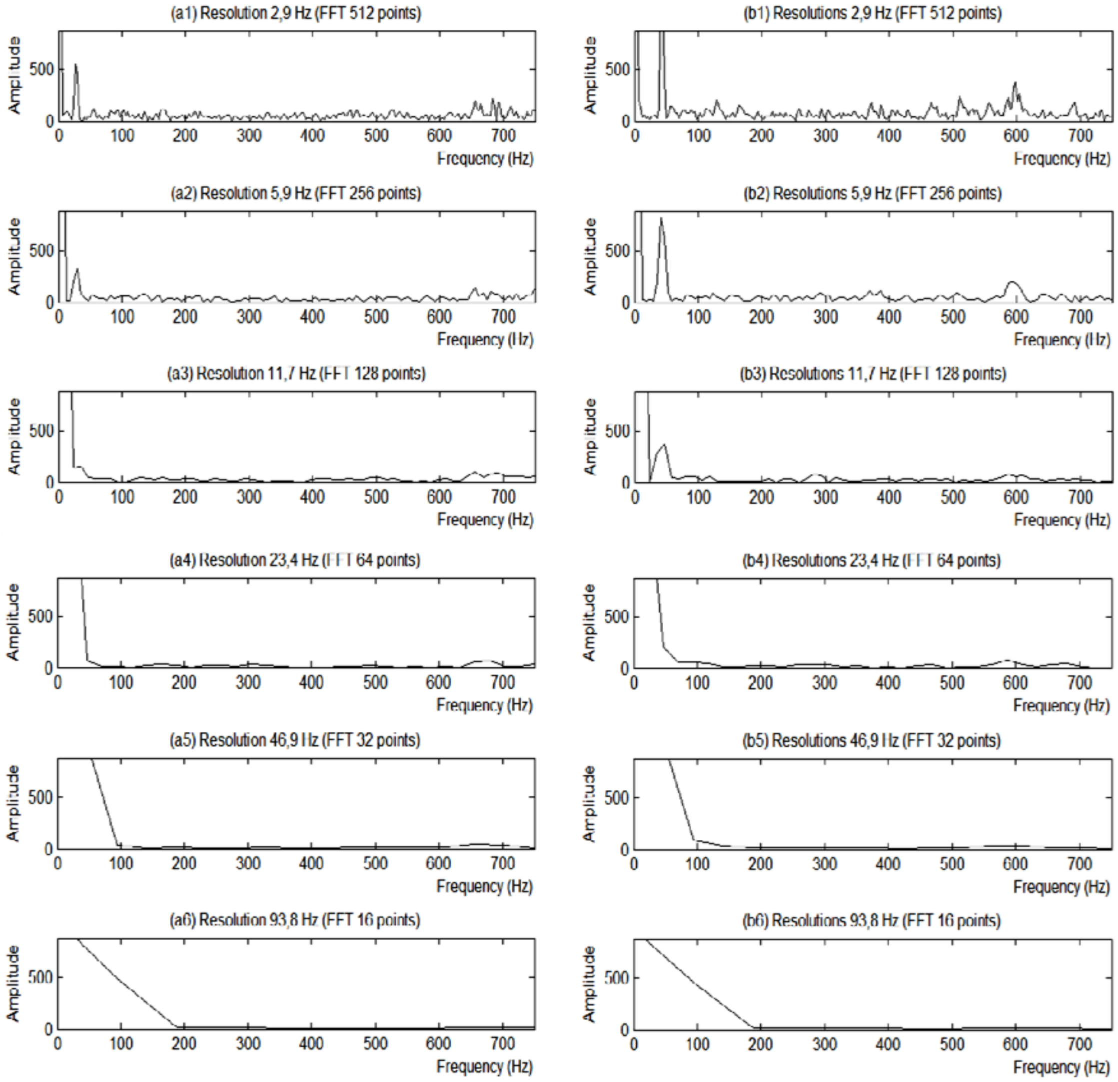
(a) Good (b) Faulty bearing

Figure 8. Graphical displays of water pump vibrations in the frequency domain on X axis direction, for a good and a faulty bearing water pumps

Compared with Figure 7 (a), the signal peaks in Figure 7 (b) are not clear anymore, because they are buried by the peaks of the other signals. This is caused by the wear of bearing that cause the bearing rotation become wobbly. As seen in Figure 7 (b1) in X axis direction, there are no longer visible the signal peak areas which are exist in Figure 7 (a1) in X axis direction. However, in Figure 7 (b3) in Z axis direction, there is a bit visible the signal peak areas which are exist in Figure 7 (a3) in Z axis direction.

In Figure 7 (c) there is a shift in the signal peaks if it is compared with the signal peaks in Figure 7 (a) due to reduced water flow in the pump. Visible peak around the 50 Hz signal in Figure 7 (a1) and (a2) shifted around the 30 Hz in Figure 7 (c1) and (c2). Besides, there are also peaks around the 600 Hz signal in Figure 7 (a) are no longer exist in Figure 7 (c). Additionally, the peaks around the 50 Hz signal in Figure 7 (a3) are also no longer exist in Figure 7 (c3).

In Figure 7 (d) there are changes in amplitude peaks of the signal compared with amplitude peaks in Figure 7 (a), due to no water in the pump. Visible peaks around 50 Hz signals in Figure 7 (a2) and (a3) are differ quite significantly with Figure 7 (d2) and (d3). In addition, there are also two dominant peaks around 600 Hz signals in Figure 7 (a), which are reduced only to one dominant peak in Figure 7 (d).



(a) Faulty impeller (b) Faulty foot valve

Figure 9. Graphical displays of water pump vibrations in the frequency domain on X axis direction, for a faulty empeller and a faulty foot valve bearing water pumps

Basically, Figure 7 shows the signals that represent water pumps which are in good or faulty condition. By observing signal peaks in Figure 7, it can be distinguished clearly among water pumps which are in good condition, faulty bearing, faulty impeller, or faulty foot valve.

Figures 8 and 9 show the vibration of the water pumps on the X axis direction, at various frequency resolutions. Generally it can be seen the trend, the higher frequency resolution, the lower details of the graphical display will be shown. If the frequency resolution is too high, it will show a graphical display that is similar between the good and the faulty bearing water pumps, as shown in Figure 8 (a6) and (b6) and Figure 9 (a6) and (b6). However, if the frequency resolution is too low, it will show a highly detailed graphical display, as shown in Figure 8 (b1). The highly detailed graphical display looks like a random graphical display.

For a frequency resolution which is not too big nor too small, it is shown in Figure 10. That figure is derived from Figure 8 (a3) and (b3) and Figure 9 (a3) and (b3). It can be seen in

Figure 10, by using frequency resolution 11.7 Hz, it has lower detail graphical display. However, it is clear that there are differences (see the hills and the valleys) among water pumps which are in good condition, faulty bearing, faulty impeller, or faulty foot valve. Therefore it can be said that, by using a frequency resolution which is not too big nor too small (i.e. 11.7 Hz), it can be visually distinguished among water pumps which are in good condition, faulty bearing, faulty impeller, or faulty foot valve.

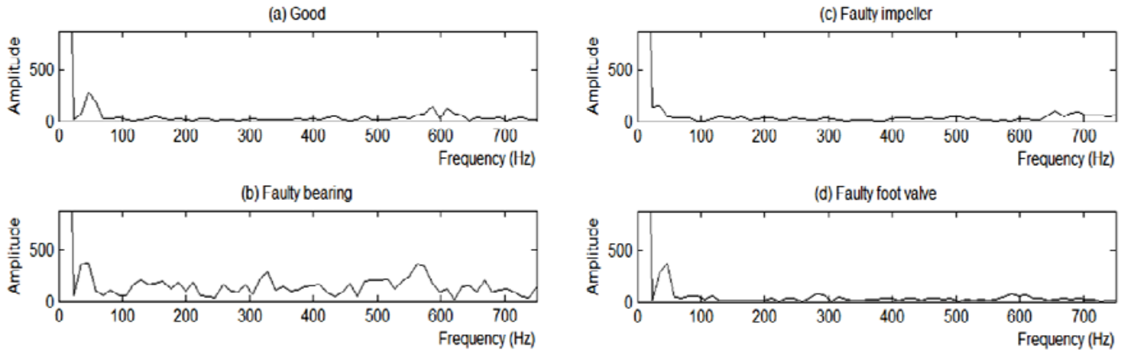


Figure 10. Graphical displays of water pump vibrations in the frequency domain on X axis direction, for various conditions of water pumps. As a note, they are displayed at the frequency resolution of 11.7 Hz which is obtained by the 128-points FFT

4. Conclusions and Further Research
4.1 Conclusions

Based on the above discussions it can be concluded the following.

a) Graphical display of vibration signals in the frequency domain shows the differences between the good and the faulty water pumps. By observing the signal peaks in the frequency domain, it can be distinguished clearly among water pumps which are in good condition, faulty bearing, faulty impeller, or faulty foot valve.
b) The higher frequency resolution, the lower detail in the graphical display of frequency domain will be shown, and vice versa. Although there is lower detail in the graphical display of frequency domain, at frequency resolution of 11.7 Hz in the X axis, showed that it could be visually distinguished among water pumps which are in good condition, faulty bearing, faulty impeller, or faulty foot valve.

4.2 Further Research

Here are a few suggestions, to continue research on mechanical faults of a water pump.

a) In this research, only the graphical display of vibrations from the X axis that explored further. This research can be continued to explore further not only from the X axis, but also from the Y and Z axes.
b) This research merely shows the graphical display of vibrations for a variety of mechanical faults. This research can be continued to be able to automatically recognize different levels of mechanical faults of a water pump in a real time manner.

Acknowledgement

This work has been supported by Coordinator of Private Colleges Region V, Ministry of Education and Culture Republic of Indonesia. Project number 1142.23/K5/KL/2013.

References

[1] Stack JR, Habetler TG, Harley RG. Fault Classification and Fault Signature Production for Rolling Element Bearings in Electric Machines. *IEEE Transactions on Industry Applications*. 2004; 40(3): 735-739.

[2] Omuaamar MEK, Razik H, Rezzoug A, Khezzar A. *Line current analysis for bearing fault detection in induction motors using Hilbert transform phase*. Proceeding of International Aegean Conference on Electrical Machines and Power Electronics (ACEMP). Istanbul. 2011: 28-293.

[3] Bagavathiappan S, Lahiri BB, Saravanan T, Philip J, Jayakumar T. Infrared Thermography for Condition Monitoring – A Review. *Journal of Infrared Physics and Technology*. 2013; 60: 35-55.

[4] Seo J, Yoon H, Ha H, Hong D, Kim W. Infrared Thermographic Diagnosis Mechanism for Fault Detection of Ball Bearing under Dynamic Loading Conditions. *Advanced Materials Research*. 2011; 295-297: 1544-1547.

[5] Yadav M, Wadhwani S. Vibration Analysis for Bearing Fault Detection using Time Domain Features and Neural Network. *International Journal of Applied Research in Mechanical Engineering*; 2011;1(1): 69-74.

[6] Arifianto D. *Source Separation using Independent Component Analysis Technioques for Machine Fault Detection in the Presence of Background Noise*. Proceeding of 2nd International Conference on Instrumentation Control and Automation (ICA). Bandung. 2011: 274-278.

[7] Janjarasjitt VS, Ocak H, Loparo KA. Bearing Condition Diagnosis and Prognosis using Applied Nonlinear Dynamical Analysis of Machine Vibration Signal. *Journal of Sound and Vibration*. 2008; 317: 112–126.

[8] Ebrahimi E. Vibration Analysis for Fault Diagnosis of Rolling Element Bearing. *Journal of American Science*. 2012; 8(2): 331-336.

[9] Sumarno L, Tjendro, Widyastuti W, Wihadi D. *Analysis of Bearing Faults at Various Frequency Resolutions* (In Indonesian). Proceeding of National Seminar FORTEI 2013. Andalas University. Padang. 2013: 14-18.

[10] Proakis JG, Manolakis DG. Digital Signal Processing: Principles, Algorithm, and Applications. Fourth Edition. New Jersey: Prentice Hall Inc. 2007: 511-562.

[11] Meseguer NA. Speech Analysis for Automatic Speech Recognition. *MSc Thesis*. Trondheim: NTNU; 2009.

[12] Harris FJ. *On the Use of Windows for Harmonic Analysis with the Discrete Fourier Transform*. Proceedings of the IEEE. 1978; 66(1): 51-83.