Global Journal of Enterprise Information System

DOI: 10.18311/gjeis/2017/15865

A Defect Diagnosis in Bearings of a Centrifugal Pump using Vibration Analysis

Mohamad Danish Anis*

School of Mechanical, Aerospace and Civil Engineering, The University of Manchester, United Kingdom; danishanis10@hotmail.com

Abstract

This paper presents an overview of defect diagnosis in bearings of a centrifugal pump. The data obtained using vibration-based condition monitoring (VCM) technique was recorded at regular intervals. The analysis provided using conventional methods would then be used for pump fault prognosis and trend pump conditions. Having studied the conventional method of analysing results off-line, the research uses a VCM system to predict bearing faults on-line. Several techniques for pattern recognition were considered, including Feed Forward type Neural Network (FF-NN) and Recurrent Neural Networks (RNN). The author decided to adopt the Artificial Neural Network (ANNs) to propose a solution and classify bearing faults. Since bearing faults don't begin to appear before prolonged pump operations, the faults on bearings were simulated using a test-rig pump where an electrical discharge machine (EDM) would generate pit marks on bearings and the vibration signals thus collected be fed into the neural networks. An easy method of designing neural network models is by using the MATLAB Neural Network Toolbox. To carry out the analysis, only MATLAB models that are specifically functional to vibration signals are chosen for pump bearing fault diagnosis.

Keywords: Bearing Fault Analysis, Centrifugal Pump, Fault Classification, Neural Networks, Rotating Equipment, Vibration-based Condition Monitoring

Manuscript Accepted: 11-Jan-2017; **Originality Check:** 23-Jan-2017; **Peer Reviewers Comment:** 09-Feb-2017; **Double Blind Reviewers Comment:** 12-Feb-2017; **Author Revert:** 15-Feb-2017; **Camera-Ready-Copy:** 26-Feb-2017)

1. Introduction

Artificial Neural Networks (ANNs) have previously been used to detect and analyze faults in blast furnace cooling water pumping systems in steel works (Ilott et al., 1997)[2.] Their combination with vibration analysis techniques for routine identification of machinery faults have been well documented over the years in several researches. While Ogunfunmi et al. (1993)3 and Gao et al. (1998)1 have used Boltzmann neural networks for the diagnosis in bearing faults, Wang et al. (1998)5 investigated rotating shaft faults using Feed Forward Neural Networks. However, the author through this paper, would like to add to the existing research works in the field of vibration analysis to monitor centrifugal pumps specifically in the waste water industry.

Inspired by Yang's (et al., 2002)8 in-depth diagnosis of motor bearing condition using ANNs, the author initiated a literature review of diagnosis tools in industry and the different approaches used to classify fault patterns in vibration responses of rotating machines. When looking at bearing conditions specifically, several approaches based on signal pre-processing techniques have been investigated by researchers. However, according to the research of Wang et al. (2003)6, power spectrum and bispectrum approaches have been most successful in categorizing almost all of the bearing condition patterns. Apart from using pit marks generated vibration signals as inputs to ANN, prior researches have also used alternative characteristics of vibration signals like Root Mean Square (RMS), Kurtosis and variance (Samanta et al., 2003)4. Such time-domain features can be successfully used to achieve the accurate classification of the faulty condition of an equipment.

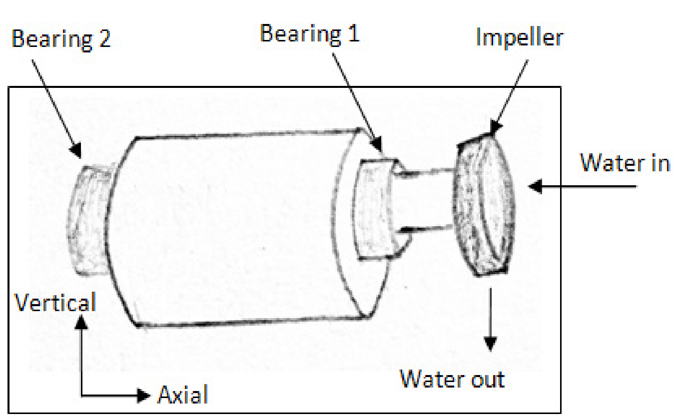

Figure 1. Schematic of Laboratory test-rig pump

*Author for correspondence

2. Simulation of Defect on a Test-Rig Pump

The author realized that achieving the necessary results of a VCM system for a centrifugal pump at a water pumping station would take a very long time and therefore, a laboratory test-rig was utilized in simulating common pump faults in a horizontal centrifugal water pump. In the process, the pump was run at 360 W and 3000 rev/min.

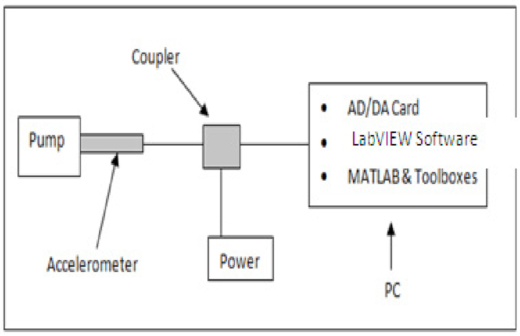

Figure 2. Vibration Sensing and data acquisition system.

As indicated in Figure 2, Kistler miniature accelerometer was used as a vibration sensor. For power supply and amplification, a Kistler single coupler was used. Proceeding with the analysis, three components on the test-rig were monitored, namely both the bearings and the impeller, as shown in Figure 1 and vibration signals were collected in vertical and axial directions.

3. Feature Extraction and Bearing Defect Classification

Feature extraction algorithm is an important presentation technique as it reduces training time and input dimension of the network, thereby improving generalisation capability of the network. The aim of employing feature extraction is to present efficiently the important features of the original data. For the investigation in this paper, time domain vibration signals obtained from the test-rig pump were pre-processed as per the classification criteria of the bearing faults before any of the vibration data was provided as input to the neutral network. This classification can be carried out using both traditional and artificial intelligence methods.

In spite of several literatures being available on ANNs, their haven't been many applications of ANN in defect diagnosis of bearings in waste water pumps. Non-availability of faulty bearings meant that six different artificial bearing faults were to be created on new bearings using EDM technique and vibration signals collected under similar conditions. The six defect setting types had the following features- hole diameter 0.5 mm and depth 0.3 mm. More detailed description is provided in Table 1 below, which includes the MLP target of six category ranges for six bearing fault types set to be compared against simulated outputs.

Table 1. Network Output Categories for Bearing Classification

Pump Bearing Condition Setting	Network Target Output	Category Output Range	Bearing Defects
Setting 1	0	-0.1 – 0.1	One Ball
Setting 2	0.2	0.1 – 0.3	Two Balls
Setting 3	0.4	0.3 – 0.5	Inner Race
Setting 4	0.6	0.5 – 0.7	Outer Race
Setting 5	0.8	0.7 – 0.9	Cage
Setting 6	1.0	0.9 – 1.1	One Ball, Inner & Outer race, cage

4. Targets for MLP Networks

As a result of the above set up, the ANN had 11 frequency domain vector inputs and 1 time domain vector input with one set of data being 24 elements in length (2×12). Thus, with six bearings having 10 samples in a 24 element vector each, the total input matrix size was $24 \times 10 \times 6 = 1440$ elements. Figure 3 below shows the ANN input pattern classification of bearing defects. As explained earlier, vibration data collected in both axial and vertical directions from the faulty bearings was to be pre-processed in RMS calculations (Time, Frequency and Band-Frequency Domains) and used as inputs to the networks. Along with time domain RMS values, the RMS values in frequency domain range from 0 to 5kHz and between 0 and 4kHz in ten frequency bands. The distribution of values is slightly irregular for the sake of faulty bearings presenting a significant change in characteristic fault frequencies in creating high resonance harmonics of defect frequencies and side-bands around them. The distribution is as follows- 0 to 100Hz, 100 to 200Hz, 200 to 300Hz, 400 to 1000Hz, 1000 to 1500Hz, 1500 to 2000Hz, 2000 to 2500Hz, 2500 to 3000Hz, 3000 to 3500Hz, 3500 to 4000Hz.

5. Network Training Results

The simulation result for two layer networks tabulated in Figure 4 below indicate that the network displayed results worth 96.7% accuracy at hidden layer having 10 neurons. Furthermore, the trend line on the graph helps us reassert the 3rd order polynomial function that training time increases with the number of neurons in hidden layer.

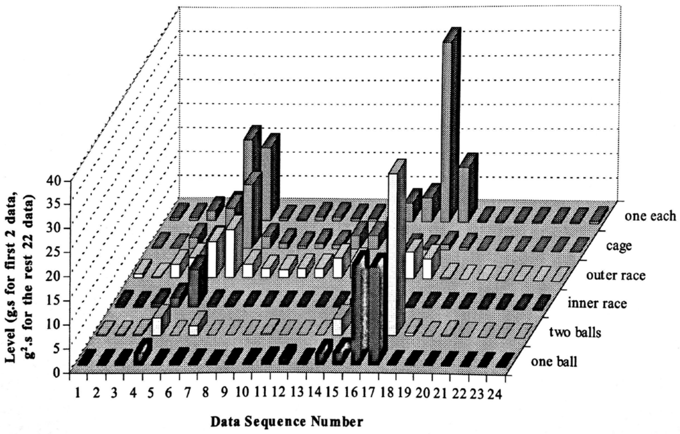

Figure 3. ANN input pattern for Bearing Fault Classification

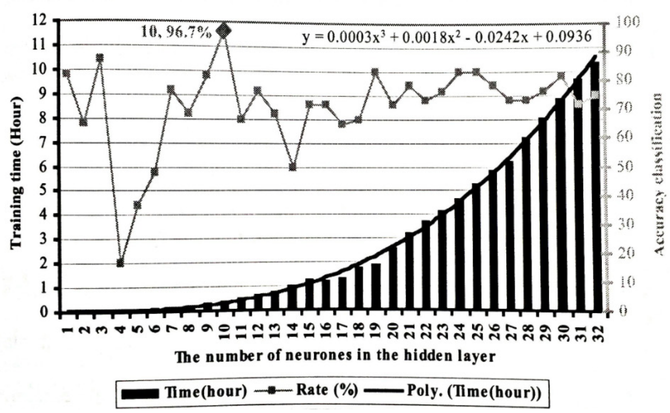

Figure 4. MLP Network Simulation results for Bearing Faults Classification.

It is appropriate to predict that if the neurons in the hidden layer reaches 40 with the existing trend, the training would take 20 hours. Wang et al. (2000)7 used similar investigation model to train neural networks on a similar 2-layer MLP network to achieve a 100% classification rate with the two networks having first and second hidden layer neurons of value 20 & 2 and 30 & 25 respectively.

6. Conclusions

Using ANN in MATLAB toolbox, failure patterns in bearings of a centrifugal pump were classified by investigating their parameters using feature extraction methods. Simulating 6 different bearing faults on a laboratory test rig, the trend line obtained in network training results classified the bearing faults at 96.7% accuracy classification rate. Further literature reviews indicated that a 100% accuracy was achievable if the classification was done using 'cascade-forward back propagation' neural networks at 2 hidden layers. The proposed model of an MLP network construction for pattern recognition is a systematic way of finding the performance networks in a large number of similar models using MATLAB program as per the transfer function.

7. References

1. Gao Y, Randall RB. Using CPB spectrum differences to train neural network to recognise faults in helicopter gearbox bearings. Proceedings of COMADEM, Australia. 1998; 1:295–304.
2. Ilott PW, Griffiths AJ. Fault Diagnosis of Pumping Machinery using Artificial Neural Networks. Proceedings of IMechE. 1997; 211(E):185–94.
3. Ogunfunmi T, Chen Z, Haddad S. Vibration Signal Analysis using Boltzmann Neural Networks. Intelligent Eng Systems Through Artifical Neural Networks. 1993; 3:763–8.
4. Samanta B, Al-Balushi KR. Artificial Neural Network based Fault Diagnostics of Rolling Element Bearing using Time-Domain Features. Mechanical Systems and Signal Processing. 2003; 17(2):317–28
5. Wang K, Lei B. Genetic Algorithms for Constructing Feed Forward Multiple Layered Neural Networks in a Centrifugal Pump Condition Monitoring. Proceedings of Artificial Neural Networks in Engineering Conference ANNIE, St. Louis, MO, USA. 1998. p. 303–10.
6. Wang L, Hope AD. A Systematic Procedure for the application of Artificial Neural Networks to Pump Fault Diagnosis. Proceedings of Condition Monitoring 2003, St. Catherine's College, Oxford, UK. 2003; 477–90.
7. Wang L, Hope AD, Sadek H. Vibration-based Condition Monitoring of Pumps in the Waste Water Industry. INSIGHT. 2000; 42(8):500–3.
8. Yang DM, Stronach AF, MacConnel P. Third-order Spectral Techniques for the diagnosis of Motor Bearing Condition using Artificial Neural Networks. Mechanical Systems and Signal Processing. 2003; 16(2-3):391–411

Citation:
Mohamad Danish Anis
"A Defect Diagnosis in Bearings of a Centrifugal Pump using Vibration Analysis",
Global Journal of Enterprise Information System. Volume-9, Issue-1, January-March, 2017. (http://informaticsjournals.com/index.php/gjeis)
Conflict of Interest:
Author of a Paper had no conflict neither financially nor academically.