

Frequency Spectrum Filtering For Machinery Fault Diagnostics

Galal A. Hassaan

Abstract: This paper is a research effort to provide a stone in the building of machinery fault detection and diagnostics. It relies on using the spectrum analysis of the vibration signal using FFT. Depending on the expected faults of a specific machine, the technique of bandpass filtering is applied on the frequency spectrum of the vibration signal generating bandpass spectra helping in easier fault diagnostics. Central frequencies and proper bandwidth are assigned to generate the new spectra of the defected machine. A case study of an industrial fan is used as an application for the proposed technique.

Index Terms: Vibration waveform – FFT spectrum – Bandpass filtering – Machinery fault diagnosis.

1 INTRODUCTION

Machinery condition, life, reliability and accuracy are key factors in any industrial process supporting successful economical plans and outcome. Because of this the area of machinery faults diagnostics is very attractive to researchers around the world for decades. Every day we hear about a new idea or technique contributing to the objective of successful machine operation with minimum production losses. Lebold et. al. (2000) presented an attempt to define the terms and features used in vibration analysis methods to make the documented terms and features consistent among the users [1]. Ypma (2001) proposed a framework for health monitoring with learning methods. He found features extraction methods based on temporal correlations in vibration signal suitable for information extraction about machine health [2]. Yang, Mathew and Ma (2003) presented an updated review of a variety of vibration feature extraction techniques which demonstrated success when applied to rotating machinery [3]. Bachschmid, Pennacchi and Vania (2004) analyzed the vibration of a large turbine-generator unit excited by rotor-to-stator rubs. They used the results of the analysis to update the rotor-system model to identify the location and severity of the fault. They used the shape and directivity index of journal filtered objects to improve the accuracy of fault identification [4].

Rehorn, Sejdic and Jiang (2006) investigated the detection and diagnostic of brush seizing faults in the spindle positioning servo drive of a high-precision machining centre using time-frequency pattern classification technique. They compared their technique with other three time-frequency transformation techniques [5]. Haloui, Chikouche and Benidir (2007) proposed a method for fault diagnosis of a gear reducer based on Prony method. They showed that the fault diagnosis of the considered system can be performed by observing the evolution of the power spectrum of the vibration signal [6]. Iorgulescu and Beloiu (2008) analyzed the vibration and current of an induction motor to obtain information for bearing faults detection. They observed significant vibration and current spectrum differences between healthy motor and motor with faulty bearings [7]. Rafiee et. al. (2009) presented an optimized gear fault identification system using genetic algorithm to investigate gear failures in complex gearboxes using artificial neural networks. They considered slight-worn, medium-worn and broken-tooth faults [8]. Do and Chong (2011) proposed an approach for vibration signal-based fault detection and diagnosis system applied for induction motors. They compared with two other techniques showing high fault classification accuracy and better performance over other approaches [9]. Aherwar and Khalid (2012) made a review of some vibration analysis techniques used for condition monitoring of gear faults [10]. Bhowmik, Pradhan and Prakash (2013) studied conventional and innovative techniques for induction motor faults with an identification of future research areas [11]. He, Wang and Zhou (2014) introduced the time-frequency manifold concept into sensor data denoising proposing a denoising method for reliable machinery fault diagnosis. They presented a clustering-based statistical parameter to evaluate the proposed method [12].

2 VIBRATION SIGNALS

The mechanical vibration signals of structures and machines are captured in the time domain providing what is called waveforms [13]. If the excitation of the mechanical vibrations is multiple due to the existence of different machinery faults, then the wave form will be tedious and impossible to get any useful information out of it about the machine faults. For example, Fig.1 shows a simulated waveform for an industrial fan of 600 rev/min speed and 8 vanes. It has a parallel misalignment, ball defect, inner race defect and vane pass excitation.

-
- Galal A. Hassaan
 - Emeritus Professor, Department of Mechanical Design & production, Faculty of Engineering, Cairo University, Giza, EGYPT
 - galalhassaan@gmail.com

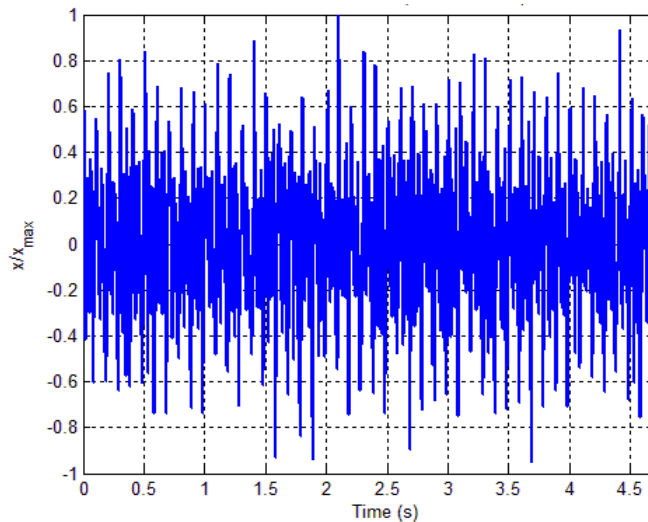


Fig.1 Fan waveform excited by 4 vibration sources.

To assess the complexity of the waveform of Fig.1, we show the waveform produced only by the parallel misalignment and the bearing defects separately in Fig.2.

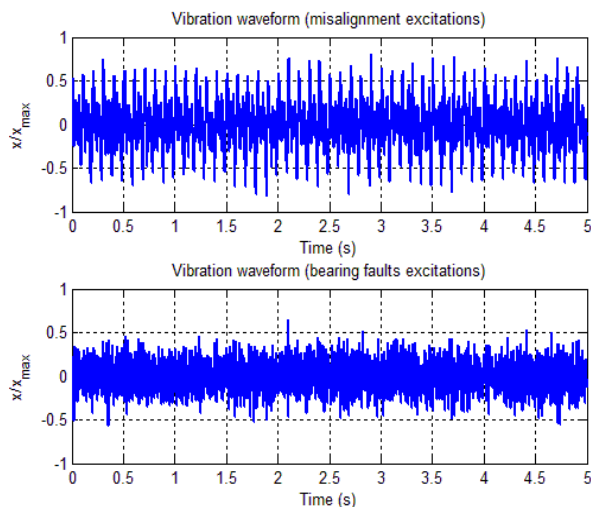


Fig.2 Fan waveform excited by misalignment and bearing faults.

The next step is to transfer to the FFT of the machine vibration waveform [14-18]. This reduces the very complex shape to easier to follow and use form of vibration amplitude against vibration frequency in Hz. Fig.3 shows the FFT of the vibration waveform signal of Fig.1 in a normalized form.

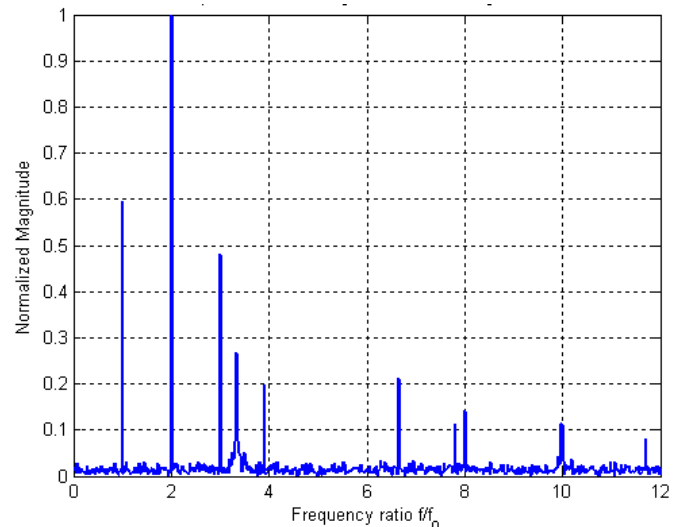


Fig.3 The FFT spectrum of the industrial fan vibrations.

The normalized amplitude is obtained by dividing the vibration amplitude by the maximum amplitude in the spectrum (X/X_{max}). The frequency ratio is obtained by dividing the vibration frequency by the frequency corresponding to the fan speed (f/f_0). The complex shape of Fig.1 is reduced to more simpler shape of only about 10 frequency components related to the fan mechanical faults.

3 FILTERING THE VIBRATION SPECTRUM

The vibration FFT spectrum of Fig.3 includes components related to well known machine defects:

Parallel misalignment: with 1X, 2X and 3X components. The 1X component is at 10 Hz (unit normalized frequency). The vibration components due to the parallel misalignment are at 1, 2 and 3 (normalized frequencies).

- Bearing ball defect: with 33.3 Hz frequency (3.33 normalized frequency) + 2 harmonics at 6.66 and 10 (normalized frequencies).
- Bearing inner race defect: with 39 Hz frequency (3.9 normalized frequency) + 2 harmonics at 7.8 and 11.7 (normalized frequencies).
- Vane pass excitation: with 80 Hz frequency (8 normalized frequency) .

The component frequencies can be further traced through filtering the spectrum around a centre value. This is based on the band-pass filtering technique [19-23]. This allows looking in a narrow band instead of looking at the whole spectrum.

4 THE NEW TECHNIQUE APPLICATION

The technique of filtering the frequency spectrum of the machine vibration signal is applied as follows:

- (i) Definition of desired centre frequencies. This is the centre frequency of the band-pass filter. It is set at the centre value of the expected components of a specific fault. For example it is set at the $f/f_0 = 2$ (for the misalignment fault), $f/f_0 = 6.66$ (for the bearing defected ball fault) and at $f/f_0 = 7.8$ (for the bearing defected inner race fault).
- (ii) A bandwidth of $\pm 55\%$ around each centre frequency is assigned.
- (iii) The FFT spectrum values inside each bandwidth is kept.

- (iv) Other values are set to zero.
- (v) New FFT spectra are generated for each centre frequency.
- (vi) The new FFT spectra will focus only on specific faults making it easy to trace the fault and its development in a trend analysis approach for a complete predictive maintenance program [24-28].

The application of this technique on the FFT spectrum of the industrial fan produced the 3 FFT spectra shown in Fig.4.

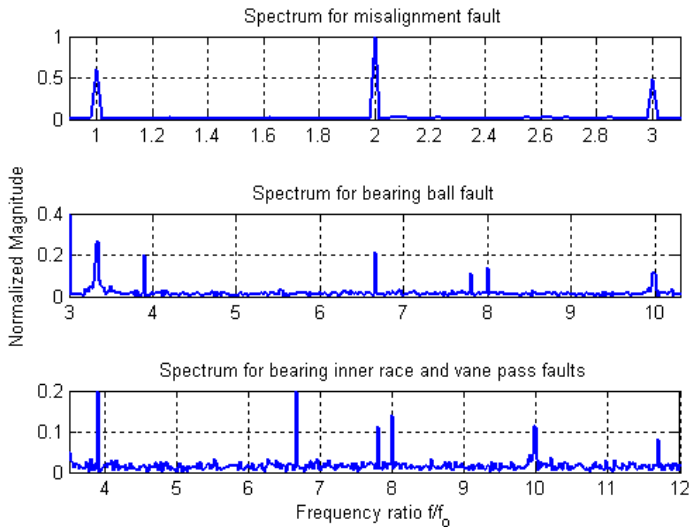


Fig.4 Filtered FFT spectrum for three fan faults.

The reading of the Fig.4 filtered spectra is as follows:

- The top filtered spectrum with a centre frequency ratio at 2 shows 3 clean components at 1X, 2X and 3X indicating clear dominant parallel misalignment.
- The middle filtered spectrum with a centre frequency ratio at 6.66 reveals components at 3.33X, 3.9X, 6.66X, 7.8X, 8X and 10X. The components at 3.33X, 6.66X and 10X belong to bearing ball defects. The 3.9X and 7.8X belong to the bearing inner race defects. The component 8X belongs to vane passing excitation.
- The bottom filtered spectrum with a centre frequency ratio at 7.8 reveals components at 3.9X, 6.66X, 7.8X, 8X, 10X and 11.7X. The first 5 components are interpreted as in the bottom spectrum. The last component at 11.7X belongs to the bearing inner race defect.

5 CONCLUSIONS

- The paper presented a new technique for fault diagnostics based on FFT spectrum filtering using band-pass filters.
- Central frequencies for the filters were carefully defined to help in capturing the machine defects.
- A band of $\pm 55\%$ was recommended around each central frequency.
- The new technique helped in efficient diagnosing of machinery faults.
- The technique can be simply integrated in predictive maintenance programs using vibration measurements or any other physical parameters such as voltage, current, temperature, pressure, etc.

REFERENCES

- [1] M. Lebold et. al., "Review of vibration analysis methods for gearbox diagnostics and prognostics", Proceedings of the 54th Meeting of the Society for Machinery Failure prevention Technology, Virginia Beach, VA, May 1-4, 2000, pp.623-634.
- [2] Ypma, "Learning methods machine vibration analysis and health monitoring", Ph.D. Thesis, ASCI Graduate School, Germany, November 2001.
- [3] H. Yang, J. Mathew and L. Ma, "Vibration feature extraction techniques for fault diagnosis of rotating machinery- A literature survey", Asia-Pacific Vibration Conference, 12-14 November 2003, Gold Coast, Australia.
- [4] N. Bachschmid, P. Pennacchi and A. Vania, "Diagnostic significance of orbit shape analysis and its application to improve machine fault detection", Journal of the Brazil Society of Mechanical Science and Engineering, Vol. XXVI, No.2, April-June 2004, pp.200-208.
- [5] A Rehorn, E. Sejdic and J. Jiang, "Fault diagnosis in machine tools using selective regional correlation", Mechanical Systems and Signal Processing, Vol.20, 2006, pp.1221-1238.
- [6] N. Haloui, D. Chikouche and M. Benidir, "Diagnostic of gear systems by spectral analysis of vibration signals", International Journal of Computer Science and Network Security, Vol.7. No.10, October 2007, pp.285-293.
- [7] M. Jorgulescu and R. Belouju, "Vibration and current monitoring for faults diagnosis of induction motors", Annals of the University of Craiova, Electrical Engineering Series, No.32, 2008, pp.102-107.
- [8] J. Rafiee, P. Tse, A. Harifi and M. Sadeghi, "A novel technique for selecting mother wavelet function using an intelligent fault diagnosis system", Expert Systems with Applications, Vol.36, 2009, pp.4862-4875.
- [9] V. Do and U. Chong, "Signal model-based fault detection and diagnosis for induction motors using features of vibration signal in two-dimensions domain", Journal of Mechanical Engineering, Vol.57, No.9, 2011, pp.655-666.
- [10] A. Atherwar and M. Khalid, "Vibration analysis techniques for gearbox diagnostics: a review", International Journals of Advanced Engineering Technology, Vol.3, No.2, April-June, 2012, pp.4-12.
- [11] P. Bhowmik, S. Pradhan and M. Prakash, "Fault diagnostic and monitoring methods of induction motor: a review", International Journal of Applied Control, Electrical and Electronics Engineering, Vol.1, No.1, May, 2013, pp.1-18.

- [12] Q. He, X. Wang and Q. Zhou, "Vibration sensor data denoising using a time-frequency manifold for machinery fault diagnosis", *Sensors*, Vol.14, 2014, pp.382-402.
- [13] R. Birajdar, R. Patil and K. Khanzode, "Vibration and noise in centrifugal pumps: sources and diagnosis methods", 3rd International Conference on Integrity, Reliability and Failure, Porto, Portugal, 20-24 July, 2009.
- [14] C. Hatch, A. Weiss and M. Kalb, "Cracked bearing race detection in wind turbine gearboxes", *Orbit*, Vol.30, No.1, 2010, pp.40-47.
- [15] S. Zhong, H. Shen and Y. Shen, "Real-time monitoring of structural vibrations using spectral-domain optical coherence tomography", *Optics and Lasers in Engineering*, Vol.49, 2011, pp.127-131.
- [16] Cozorici, F. Cozorici, R. Munteanu and H. Balan, "Vibration monitoring system of a wind turbine", *Buletinul AGIR*, Vol.3, June-August, 2012, pp.49-54.
- [17] T. Haniszewski and D. Gaska, "Overhead travelling crane vibration research using experimental wireless measuring system", *Transport Problems*, Vol.8, No.1, 2013, pp.57-66.
- [18] R. Mankar and M. Gupta, "Vibration-based condition monitoring by using FFT: a case on a turbine shaft", International Conference on Industrial Automation and Computing, 12-13th April, 2014, Jhulelal Institute of Technology, Lonam, Nagpur, pp.11-15.
- [19] L. Chen, F. Wei, W. Shi and C. Gao, "An ultra-wideband bandpass filter with a notch-band and wide stopband using dumbbell stubs", *Progress in Electromagnetics Research Letters*, Vol.17, 2010, pp.47-53.
- [20] S. Saha, U. Hankle, H. Sagberg, T. Fjeldly and T. Saether, "Tunable banpass filter using RF MEMS capacitance and transmission line", *ibid*, Vol.23, 2011, pp.233-247.
- [21] J. Rajendran, R. Peter and K. Soman, "Design and optimization of bandpass filter for software defined radio telescope", *International Journal of Information and Electronics Engineering*, Vol.2, No.4, July 2012, pp.649-651.
- [22] K. Yeo and A. Nwajana, "A novel microstrip dual-band bandpass filter using dual-mode square patch resonators", *Progress in Electromagnetics Research Letters*, Vol.36, 2013, pp.233-247.
- [23] K. Gowthami, S. Priya, S. Kiruba and S. Maheswari, "Design of micro-strip bandpass filter for L band frequency", *International Journal of Innovative Technology & Exploring Engineering*, Vol.3, No.11, April, 2014, pp.11-14.
- [24] S. Lacey, "The role of vibration monitoring in predictive maintenance", *Maintenance and Asset Management*, Vol.25, No.1, January 2010, pp.36-45.
- [25] S. Lacey, "The role of vibration monitoring in predictive maintenance", *Maintenance and Asset Management*, Vol.25, No.1, January 2010, pp.36-45.
- [26] S. Mahmood, 'Use of vibrations analysis technique in condition based maintenance', M. Sc. Thesis, Royal Institute of Technology, Sweden, 2011.
- [27] A Shrotri and S. Khandagale, "Design of predictive maintenance program", *International Journal of Engineering and Advanced Technology*, Vol.1, No.4, April 2012, pp.242-246.
- [28] G. Babu and V. Das, "Condition monitoring and vibration analysis of boiler feed pump", *International Journal of Scientific and Research Publications*, Vol.3, No.6, June 2013, pp.1-7.
- [29] R. Bajric, N. Zuber and R. Sostakov, "Relations between pulverizing process parameters and beater wheel mill vibration for predictive maintenance program setup", *Maintenance and Reliability*, Vol.16, No.1, 2014, pp.158-163.

BIOGRAPHIE



Synthesis

Prof. Galal Ali Hassaan, Emeritus professor of System Dynamic and Automatic Control, Department of Mechanical Design & Production, Faculty of Engineering, Cairo University. Research in Automatic Control, Mechanical Vibrations and Mechanism