Inner and Outer Race Bearing Defects of Induction Motor Running at Low Speeds Signal Analysis with DWT

Belkacemi Bellal and Saad Salah

November 7, 2020

Inner and outer race bearing defects of induction motor running at low speeds signal analysis with DWT

Bellal Belkacemi*, Salah Saad*

* Laboratoire des Systèmes Electromécaniques (LSELM), Badji-Mokhtar University Annaba, BP 23000, Algeria

Email corresponding author: billel.belkasmi@gmail.com

ABSTRACT

The present work deals with bearing inner and outer races defects analysis using Discrete wavelet transform (DWT) decomposition finalized by MATLAB/ toolbox analysis. All previously studied methods and techniques used and applied for the detection of defects in induction motors bearing suffer from some drawbacks such as the difficulties of identifying bearing faults from the frequency spectrum because of non stationary vibration signals. In order to overcome this issue, the Discrete Wavelet Transform (DWT) decomposition is proposed for signal analysis as an efficient tool for various induction motor faults detection. In order to validate the proposed procedure, a setup is designed in LSELM laboratory for measuring vibratory signals of a bearing set driven by a 0.38 KW three phase induction motor operating at low speed (500tr/mn) for healthy and two bearing faults (inner race and outer race defects). The obtained results are discussed and analyzed

Keyword: Induction machine, fault diagnosis, inner and outer races defects, Fourier transform, induction motor, Discrete Wavelet transforms (DWT)

1. INTRODUCTION

In general, bearing consists of inner and outer races, the rest of bearing elements such as balls. Usually, the rolling elements in a bearing are arranged or guided in a cage, in order to guarantee uniform spacing between elements to prevent metal to metal contact. The majority of faults in induction machines are related to bearing which is considered as the most critical component. Thus, both the detection and diagnosis of mechanical faults in bearing elements are very important for the induction motor operation reliability.

Acoustic analysis, electrical current signature analysis and vibration analysis are the three most used techniques because they allow the detection and diagnosis of most faults. Also, intelligent techniques are very reliable and very effective for diagnosing faults on electrical machines. Their operation requires learning based on a large amount of data. In the literature many works were undertaken in order to find a suitable and effective tool for bearing elements defects detection.

K.A. Ibrahim Sheriff et al [1] have compared the acoustic emission technique and the vibration analysis technique, it was found that the acoustic emission technique is more sensitive than the vibration analysis. The authors of [2] introduced the analysis of variance using a comprehensive plan of experiments proved the capability to evaluate the factors effect on the vibration behavior and acoustics bearings at an early stage of degradation. They have concluded that the acoustic emission is ideal for cases of low speeds but vibration measurement is appropriate for monitoring the defect size evolution while the acoustic emission is more suited to the detection of frequencies characteristic of bearing defects at an early stage.

In [3], [4], [5] bearing failures detection in induction motors, suitable for the electrical current spectral analysis of the motors supplied by inverters they have concluded that for all signatures it is recommended to detect rotor faults at high motor load levels, while it is better to detect stator faults at low load levels. The work presented in [6] proposes a new approach based on stator current and efficiency of induction motors as indicators of rolling-bearing faults. The approach was applied on four different types of bearing defects: crack in the outer race, hole in the outer race, deformation of the seal, and corrosion. Yu Wei et al and Zhang, W [7], [8] presented a review on rotating machinery early fault diagnosis techniques and a comprehensive review summarizing the computational intelligence in machinery condition monitoring and fault diagnosis. The authors of [9] proposed an approach based on current space vector transformation analysis taking in account all the induction machine information then analyzed by the means of Power Spectral Density and the Wavelet Packet Decomposition techniques. It has been proved that the proposed technique is more effective compared to single-phase analysis. The advantages and limitations of each techniques in practical applications are also discussed.

The work carried out in [10] have studied the vibration analysis of rolling element bearings defects. A defect of any bearing element is transmitted to all other elements such as outer race, inner race, ball and, train cage of the bearing. Ashish Kumar Sinha, *et al* [11] proposed fault detection scheme with the standard deviation of level-five detailed coefficient [d5] from the pre-fed values for the detection of ball bearing damage. The work reported in [12] studied the suitability of vibration analysis technique to detect the distributed defects in bearing, the results show that comparison of vibration spectrum of healthy bearing and vibration spectrum of defected bearing can help to recognize faults in the bearing especially outer and inner races.

The work presented by V. Shanmukha Priya et al [13] uses Discrete Wavelet Transform to decompose the vibration signal into 9 levels. The mean ± standard deviation values of the approximate and detail coefficients were found for nine levels of wavelet decomposition of the signal. DWT is appropriate and effective tool in detecting defect features in bearings. Thus in the present work the Discrete Wavelet Transform (DWT) decomposition is extended to inner and outer races defects.

In this paper this procedure is applied to outer raceway and inner raceway defects and data representing healthy bearing state at a running speed of 500 tr/mn. The obtained results have proved that the DWT is appropriate and effective tool in detecting defect in induction motor bearing.

2. DWT AS VIBRATORY SIGNAL ANALYSIS TECHNIQUE

The theory and the detailed information of Discrete Wavelet Transform (DWT) are reported in the literature [14 -20]. The overall flow of wavelet decomposition process is conducted in many steps, firstly the raw vibration signal is decomposed into several levels of frequency bands, then the approximate and detail coefficients in each level with standard deviation values for approximate and detail coefficients are found, finally, a comparison of standard deviation values for normal and faulty bearings is carried out [7]. The approximation part is obtained by passing the signal through Low Pass Filter (LPF) and Detail part is obtained by passing the signal through High Pass Filter (HPF)

3. DATA ACQUISITION

The tests were carried out using the designed setup shown in Fig.1. The measured vibration signals are generated by the setup shaft driven by a three phase induction motor through a coupling, a bearing unit and a balanced flywheel (load). The designed test rig consists of a PC, three phase induction motor with of 0.78 Kw, USB measuring device, accelerometer, bearing unit and balanced flywheel (load). The vibration sensor used in the experiment measures the vibration generated by two bearing states, outer race and inner race defects as illustrated in Fig.2 a, b. The vibratory signals are measured and recorded for different tests with a low rotational speed of 500 turn/mn.

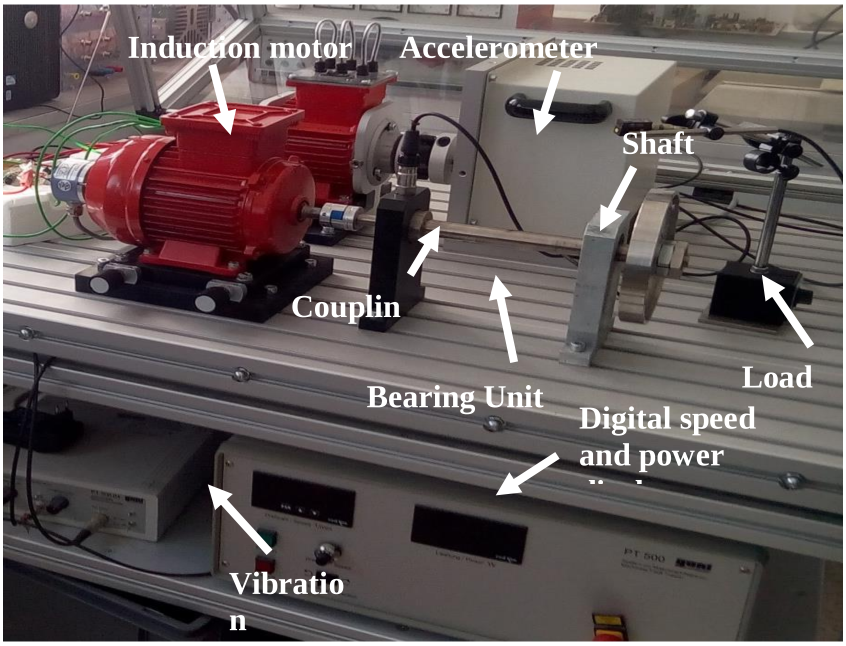


Fig.1. Experimental setup

In the first step the vibratory signal of a healthy bearing is measured for a rotational speed of 500tr/mn. Then, the vibratory signals of outer race and inner race bearing defects are measured. Finally, the obtained signals are analyzed by DWT decomposition technique.

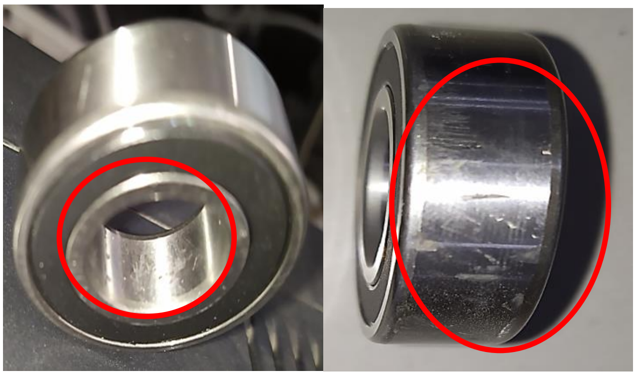
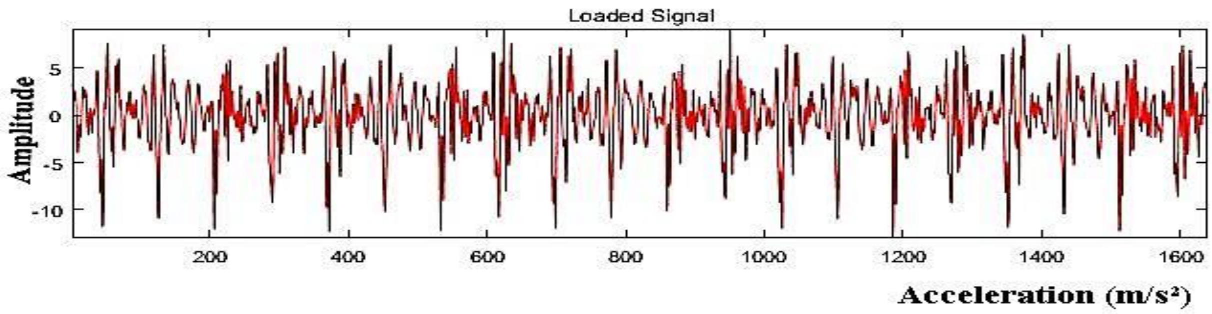
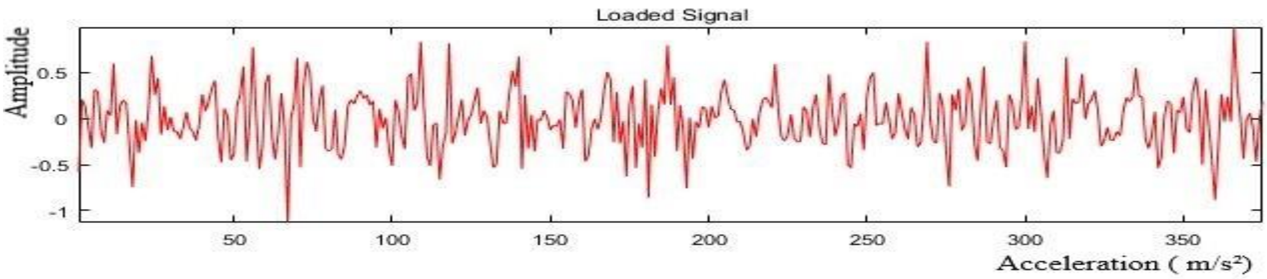


Fig.2. Bearing with inner race and outer race defects used in the experimental tests

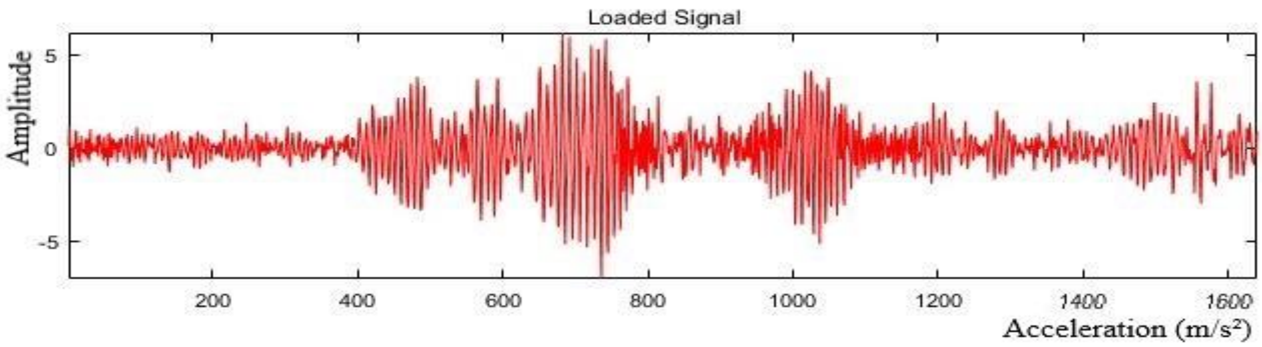
Discrete Wavelet Transform (DWT enhanced by MATLAB Toolbox signal analysis is proposed as a tool for different bearing inner race and outer race defects. The recorded data used for the validation of this method are the signals of healthy and faulty bearing.



a) Vibratory signal of bearing in healthy condition



b) Vibratory signal of bearing with outer race defect

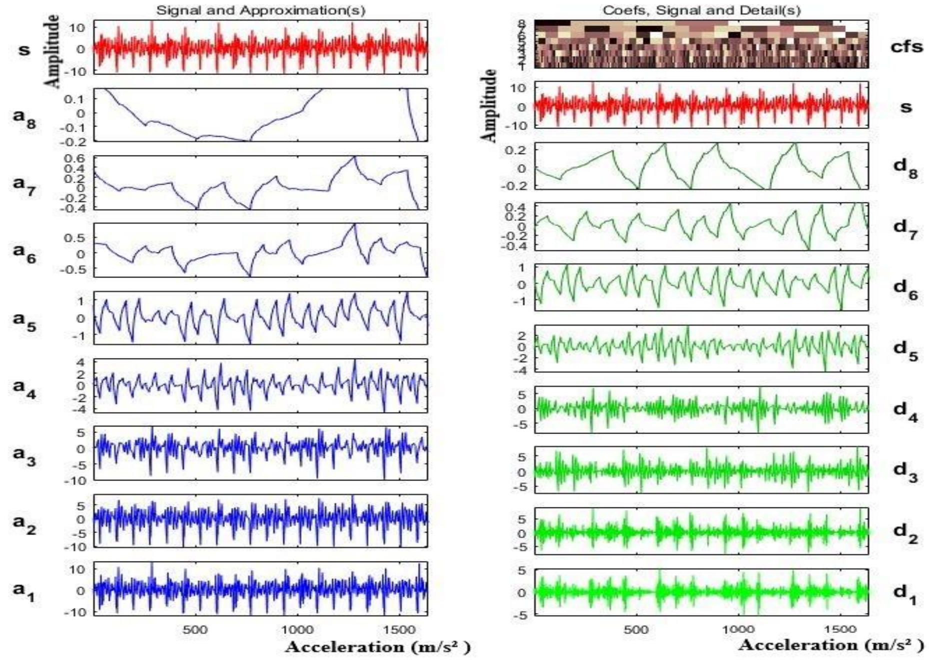


c) Vibratory signal of bearing with inner race defect

Fig.3. healthy, outer race and inner race bearing defects vibratory signals

The decomposition levels and De-Noising the original recoded signals using MATLAB Wavelets Toolbox [11], the exact range values of all detail and approximation coefficients at different levels are obtained. Approximate and detailed coefficients of wavelet transform at each level of decomposition for healthy and faulty bearings are illustrated in Fig.4, 5 and 6, respectively.

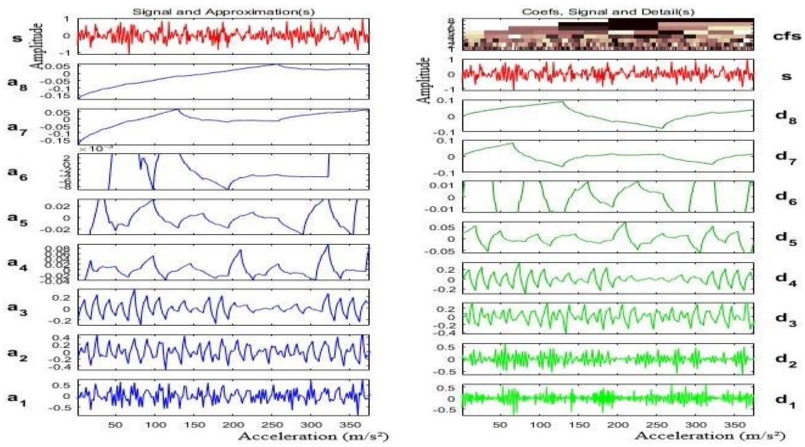
a) Wavelet decomposition of vibration signal with healthy bearing at a rotational speed of 500tr/mn



a) Approximation coefficients b) Detail coefficients

Fig.4. The eight-level wavelet decomposition of healthy bearing signal

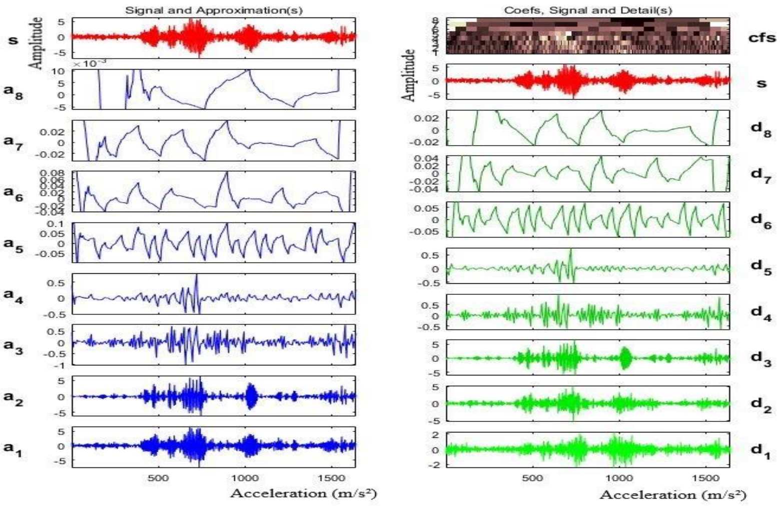
b) Wavelet decomposition of vibratory signal of a bearing with outer race defect at a rotational speed of 500tr/mn



a) Approximation coefficients b) Detail coefficients

Fig.5. The eight-level wavelet decomposition of bearing outer race defect

c) Wavelet decomposition of vibratory signal of a bearing with inner race defect at rotational speed of 500tr/mn



a) Approximation coefficients b) Detail coefficients

Fig.6. The eight-level wavelet decomposition of a bearing with inner race defect

The results of vibratory signals of healthy bearing, bearing with outer race and inner race defects, are summarized and presented in Table 1.

Table 1. Results of approximation and detail coefficients magnitudes

Decom level	Approximation level	Healthy bearing		Outer race defect		Inner race defect		Detail level	Healthy bearing		Outer race defect		Inner race defect	
		Amplitude variation	Range	Amplitude variation	Range	Amplitude variation	range		Amplitude variation	Range	Amplitude variation	Range	Amplitude variation	Range
Lev1	A_1	-3.323—2.716	6.039	-0.8997—0.7398	1.639	-6.103—6.429	5.21	D_1	-0.8332—0.808	1.641	-0.799—0.632	6.43	-2.438—2.253	4.691
Lev 2	A_2	-2.99—2.702	5.692	-0.5064—0.6004	1.107	-6.103—6.429	4.53	D_2	-1.228—2.056	3.283	-0.6432—0.6364	4.23	-5.282—5.153	10.44
Lev 3	A_3	-1.736—1.251	2.987	-0.2927—0.3327	0.6254	-1.024—0.8051	1.829	D_3	-3.042—2.514	5.556	-0.4381—0.5492	0.9873	-6.059—6.577	12.64
Lev 4	A_4	-0.6182—0.6309	1.249	-0.167—0.09425	0.2613	-0.5101—0.7752	1.285	D_4	-1.318—1.327	2.645	-0.2981—0.3336	0.6317	-0.6728—0.9643	1.637
Lev 5	A_5	-0.5766—0.5176	1.094	-0.1871—0.09599	0.2831	-0.1402—0.3924	0.5325	D_5	-0.5328—0.4322	0.9649	-0.09464—0.07174	0.1664	-0.55—0.7556	1.306
Lev 6	A_6	-0.2537—0.3646	0.6183	-0.1865—0.08005	0.2665	-0.1181—0.3849	0.503	D_6	-0.4773—0.2899	0.7672	-0.09367—0.08802	0.1817	-0.1926—0.1578	0.3504

Lev 7	A_7	-0.1656—0.3359	0.5015	-0.1852—0.07091	0.2561	-0.13—0.3807	0.5107	D_7	-0.1519—0.1983	0.3501	-0.06484—0.081	0.1458	-0.2475—0.14	0.3875
Lev 8	A_8	-0.1644—0.2156	0.38	-0.1792—0.06383	0.243	-0.1453—0.3749	0.5202	D_8	-0.2149—0.1865	0.4014	-0.07966—0.0886	0.1683	-0.1577—0.1187	0.2764

4- RESULTS AND DISCUSSIONS

From Fig.2, it can be observed that the recorded vibration signal of healthy bearing has lower magnitude peaks regarding the vibration signals of bearing with faults (outer race and inner race defects) Fig.3 b), c), d), and e) respectively.

According to table 1, The approximation coefficient of healthy bearing reaches its maximum range value at level 1 than decreases reaching its minimum range value at level 8, and the detail coefficient of faulty bearings (outer race, inner race defects) reach their maximum range values at level 1, than decrease reaching their minimum values at level 8. It can be concluded that the maximum value of healthy bearing is higher than the maximum values of faulty bearings (outer race, inner race defects) which means that the detail coefficient range values at level 1 are sensitive to bearing faults.

The detail coefficient of healthy bearing has reached its maximum range value at level 3 than decreases reaching its minimum range value at level 8, whereas the detail coefficient of faulty bearings (outer race, inner race defects) reach their maximum range values at level 1, level 3 respectively than decreases reaching their minimum values at level 8. It is observed from these results that the maximum value of healthy bearing is less than the maximum value of faulty bearings which means that the approximation coefficient at levels 1 and 3 are sensitive to bearing faults (outer race, inner race defects).

Thus it can be concluded that, for low speeds (500 tr/mn) DWT decomposition enhanced by MATLAB Wavelets Toolbox procedure is an efficient tool for fault detection. However, the wavelet approximation and detail coefficients can be easily used for the detection of different bearing defects. The obtained results are in agreements with the results of the previously reported literature [19-20].

5 - CONCLUSION

Bearing faults detection approach is proposed in this work for detecting outer race, inner race bearing defects. According to the results, it can be concluded that, for low speeds DWT with MATLAB Wavelets Toolbox procedure is efficient for fault detection. Therefore, the wavelet approximation and detail coefficients can be easily used for the detection of different bearing defects in induction motors. The DWT has shown its effectiveness and is appropriate for bearing faults detection.

6 - ACKNOWLEDGEMENT

The authors gratefully acknowledge the Algerian General Direction of Research (DGRSDT) for providing the facilities and the financial funding of this project.

7 - REFERENCES

[1] K.A. Ibrahim Sheriff, V.Hariharan, B.Mathan Kumar, Review On Condition Monitoring Of Rotating Machines, International journal of scientific & technology research, Volume 9, issue 02, February 2020.

[2] Salim Meziania , Djamal Zaroura , Marc Thomas, Experimental study for early detection of bearing defects by vibration and acoustic emission, 23 ème Congrès Français de Mécanique Lille, 28 Août au 1er Septembre 2017.

[3] O. Duque, M. Perez and D. Morinigo, "Detection of Bearing Faults in Cage Induction Motors Fed by Frequency Converter using Spectral Analysis of Line Current," *IEEE International Conference on Electric Machines and Drives, 2005.*, San Antonio, TX, 2005, pp. 17-22.

[4] Somaya A. M. Shehata, et al, Detection of Induction Motors Rotor/Stator Faults Using Electrical Signatures Analysis, International Conference on Renewable Energies and Power Quality (ICREPQ'13) Bilbao (Spain), 20th to 22th March, 2013.

[5] Srivani, Anbu., et al.: Fuzzy C-Means Based Clustering and Rule Formation Approach for Classification of Bearing Faults Using Discrete Wavelet Transform. Computation 2019 (2019). https://doi.org :10.3390/computation7040054.
[6] L. Frosini and E. Bassi, "Stator Current and Motor Efficiency as Indicators for Different Types of Bearing Faults in Induction Motors," in IEEE Transactions on Industrial Electronics, vol. 57, no. 1, pp. 244-251, Jan. 2010.
[7] Yu Wei, et al, A Review of Early Fault Diagnosis Approaches and Their Applications in Rotating Machinery, Entropy 2019, 21, 409; doi:10.3390/e21040409.
[8] Zhang, W., *et al.* Comprehensive Overview on Computational Intelligence Techniques for Machinery Condition Monitoring and Fault Diagnosis. *Chin. J. Mech. Eng.* 30, 782–795 (2017). https://doi.org/10.1007/s10033-017-0150-0.
[9] Lahouasnia, N., Rachedi, M.F., Drici, D. *et al.*: Load Unbalance Detection Improvement in Three-Phase Induction Machine Based on Current Space Vector Analysis. J. Electr. Eng. Technol (2020). https://doi.org/10.1007/s42835-020-00403-y.
[10] C. Harlişca, I. Bouchareb, L. Frosini and L. Szabó, "Induction machine bearing faults detection based on artificial neural network," *2013 IEEE 14th International Symposium on Computational Intelligence and Informatics (CINTI)*, Budapest, 2013, pp. 297-302.
[11] Ashish Kumar Sinha, et al, Wavelet transform based ball bearing fault detection scheme for heavy duty mining electrical motors under supply frequency regulation using MCSA, International Journal of Technology (2018) 1: 170-180
[12] H. Saruhan et al. Vibration Analysis of Rolling Element Bearings Defects, Journal of Applied Research and Technology , Vol.12, June 2014. 384-395
[13] V. Shanmukha Priya, P. Mahalakshmi and V. P. S. Naidu, Bearing Health Condition Monitoring: Wavelet Decomposition, Indian Journal of Science and Technology, Vol 8(26), IPL0569, October 2015.
[14] Phuong, H. Nguyen ., Jong-Myon, Kim, Multifault Diagnosis of Rolling Element Bearings Using a Wavelet Kurtogram and Vector Median-Based Feature Analysis. Shock and vibration (2015). https://doi.org/10.1155/2015/320508.
[15] Yusof, N.F.M., Ripin, Z. M, The effect of lubrication on the vibration of roller bearings. MATEC Web of Conferences (2017). https://doi.org:10.1051/matecconf/201821701004.

[16] Adrian, E., Villanueva, L., et al, De-Noising Audio Signals Using MATLAB Wavelets Toolbox. in IntechOpen, book chapter (pp.2-54) (2011). https://doi: 10.5772/19851.
[17] Ali, Ibrahim., et al, Electrical signals analysis of an asynchronous motor for bearing fault detection. IECON 2006 - 32nd Annual Conference on IEEE Industrial Electronics (2006). https://doi**:** 10.1109/IECON.2006.347805.
[18] Sakhara, S., Saad, S. & Nacib, L, Diagnosis and detection of short circuit in asynchronous motor using three-phase model. Int J Syst Assur Eng Manag (2017). https://doi.org/10.1007/s13198-016-0435-1.
[19] Neha, S., Kandale., et al.: Bearing Fault Detection Using Gaussian Filter Bank. International Conference on Computing, Communication, Control and Automation (ICCUBEA) (2017). https://doi**:** 10.1109/ICCUBEA.2017.8463979.