A Hardware and Software Integration Approach for Development of a Non-invasive Condition Monitoring Systems for Motor-Coupled Gears Faults Diagnosis

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Abstract. A non-invasive condition monitoring system for diagnosis of faults is vital for induction motors to operate safely and reliably. The currently used invasive techniques need direct access to the motor to collect and analyze data. Furthermore, the sensors used in invasive techniques are relatively expensive. This paper presents the development of hardware and software integrations for non-invasive diagnostic system to monitor specifically motor-coupled gear defects. The proposed system employs instantaneous power analysis, a unique technique for diagnostic condition monitoring which allows real-time non-stop tracking as well as assesses the severity of the defects. This technique can be adopted for decision-making that is not only fast but reliable. The severity of different gear defects have been studied experimentally, and the results were analyzed. The effectiveness of the proposed method has been verified through experimentation from the actual hardware implementation through the system-design platform and development environment software tool, LabVIEW.

Keywords: System-design platform and development environment · Condition monitoring · Instantaneous power analysis · Fault diagnosis · Gear faults

1 Introduction

In industry, induction motors are encompassing up to 95% of the prime movers [1, 2]. Several applications utilize these motors that include paper mills, power plants, mining plants and process industry. Even though induction motors need simple maintenance, faults may occur incidentally [2, 3]. These faults may in turn cause production loss. Therefore, it is necessary to detect these emerging failures to avoid unexpected breakdowns [2, 4]. By avoiding induction motor breakdowns, unpredicted downtime and plant maintenance cost can be decreased [5].

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For applications based on electro-mechanical power transmission, gears play a major role. In the case of wound rotor induction generators (WRIG) based wind turbine, downtime depends greatly on multistage gearbox which connects the rotor blades to the generator [6]. For railway traction systems, gearboxes link traction motors to the wheels. Thus, proper working of gears is important to ensure reliability and security [7]. Early fault detection in gear performance can avoid unpredicted breakdowns and in turn decreasing downtime and maintenance cost. Consequently, the development of an efficient fault diagnosis and condition monitoring system is necessary [8–10].

Notably, a non-invasive method for gear failure diagnosis will have the benefits of easy installation and lower cost. It is because of these advantages that several researchers have focused on non-invasive gear failure diagnosis methods [12–17].

Stator current monitoring was used for diagnosis of mechanical fault-related load torque oscillations in induction motors, [18]. However, the theoretical model presented in the work did not take into account the influence of gear stiffness on the stator current. According to a study of gearbox specific frequencies in stator current, three different shaft frequencies along with mesh frequencies emerge in the electromagnetic torque spectrum. These sideband frequencies around the electric supply frequency of stator current in the multi-stage gearbox are related to input, output and layer shafts. Some of these frequencies are related to the gear tooth fault [11, 19, 20]. The effects of motor coupled gear on stator current spectrum were studied in [21, 22]. This study has shown that for healthy gears, harmonics occur at the mesh and mesh-related frequencies. On the other hand, supplementary harmonics associated with fault-induced mechanical effects appear at the rotational frequency for faulty gears.

In order to investigate the effect of gear torsional vibrations on a motor current spectrum, a simplified dynamic model was used by taking into consideration the realistic behavior of a gear under the minimum number of mechanical parameters for the gear [23, 24]. The influence caused by the transmission error in the gear was found to have a relation to the wheel and pinion eccentricities as well as the tooth profile abnormalities. This had developed the sideband frequencies of the pinion and wheel rotation around the fundamental and mesh frequencies in the spectrum of the stator current. In [25], the same technique was used to investigate how the torsional vibrations of the planetary gear box influence the electrical signatures of a generator with a wound rotor induction. In [26], an attempt was made to join the experimental work with the numerical simulations so that the tooth pitting defect in a gear that is multi-staged could be detected. A model with a low-degree of freedom was used for the gear dynamic modeling which was comparable to the one employed in an earlier work [24]. The results in [27] verified that it is possible for the gear teeth faults to produce mechanical effects which are observable in the torque and thus, are noticeable in the electrical signatures of the machine. In a recent work, [28] has focused on extracting operating point independent fault signatures by using a kinematic error observer, spatial domain sampling methods, and spatial domain signal filtering methods for gear fault diagnostics of electromechanical actuators. The identification of mechanical vibrations due to backlash phenomena appearing between the pinion gear and the girth gear rim of the kiln using the motor current stator analysis (MCSA) was reported in [29]. The proposed diagnostic method was tested on under-scale laboratory test rig. It was shown that due to fault in pinion gear, the pinion rotation frequencies appear around fundamental supply frequency.

Although the MCSA technique has been proven to be non-invasive and economical for the motor gear fault detection, however, the amplitudes changes at characteristic defect frequencies are affected by highest amplitude peak at fundamental frequency especially when fault frequencies lie in a region near to the fundamental frequency. This factor could influence the reliability of the on-line fault diagnosis system and could lead to wrong decisions. As related to this, the instantaneous power analysis (IPA) carries three characteristic defect frequencies two side band components and one component directly at vibration frequency. The amplitude of this extra frequency component is not affected by the highest peak at the fundamental frequency and thus could be utilized to enhance the decision making capability of the on-line fault diagnosis system. The usage of the IPA method for analysis of gear defects in induction motors has not being investigated previously, and this paper addresses this new approach for the analysis of various gear defects for on-line condition monitoring of motors. This technique provides continuous real-time tracking of faults and estimates the severity through visual indication [33–38].

In this work, a real condition monitoring system are integrated with the system-design platform and development environment software tool, LabVIEW, for analysis and design of a non-invasive condition monitoring systems. This has involved in brief the work undertaken in developing the program routine in LabVIEW, engineering analyses, system data, and all other qualitative and quantitative engineering data related to conditioning and monitoring operation, focusing on motor-coupled gear defects fault detections.

This paper first highlights the issues in induction motor fault diagnosis and thus Sect. 1 gives an overview of motor-coupled gears fault analysis techniques. Section 2 discusses the software and hardware for the system. Section 3 highlights the experimental procedures of the proposed non-invasive fault diagnosis system and gives the mathematical formulation of gear defect frequencies. Section 4 presents the implementation of the proposed technique to analyze various gear defects. Finally, Sect. 5 presents the conclusions of this paper.

2 Software and Hardware for the On-Line Condition Monitoring System

This section provides an overview of the software and hardware module used in the development of experimental test rig for the non-invasive diagnostic condition monitoring system. The experimental test rig has been developed using the commonly used firm-wares in industry i.e. induction motor, current and voltage transducers, data acquisition module (DAQ) and LabVIEW software. The DAQ is interfaced with LabVIEW to acquire and process the data coming from the transducers. LabVIEW was interfaced with power switching circuit to turn-off the motor if a fault exceeds some threshold values.

The experimental test rig is developed that allows performing 3-phase currents and voltage measurements and can be used as the data to analyze and detect any faults as defined in the study. From these experimental data, the mathematical equation or the algorithm representing instantaneous power analysis (IPA) can be realized and evaluated. The IPA technique has been employed to recognize the characteristic frequencies related to gears defects. The amplitude at characteristic frequencies utilized as the indices to indicate faulty or healthy conditions of the motor. In this work, a code was created in LabVIEW so that the fault frequencies from the instantaneous power spectrum could be identified. The LabVIEW block diagram window was used to write the code for the acquisition of real time data from the current (SCT-013-005) and voltage transducers (LF-AV12-T4A25-0.5/400 V). The main purpose for this software is to collect real time data, perform analysis and display results on the screen. The data coming from the current and voltage transducers was read by the LabVIEW program and processed to record the instantaneous power spectrum. The hanning window was applied to avoid spectral leakages. The spectrum was normalized with respect to the highest peak (fundamental element). The noise and DC bias variations have been calculated based-on the design thresholds for reliable decision on the existence of fault signatures.

The data acquisition system consist of an electronic device designed to acquire data from sensors and transducers and to monitor parameters such as voltage and current, by conversion of physical analog quantities into digital data and rescaling them into physical quantities according to the transducers sensitivities. A DAQ has two parts: hardware and software. The hardware consists of the data acquisition card and a host PC computer with control software and data storage space. Complementary, the software controls the data collection process and has basic data analysis tools such as spectrum calculation for on-line data inspection. The data acquisition and processing system used in this work consists of National Instruments data acquisition card NI 6281, AC current and voltage transducers and LabVIEW.

Sampling is an essential process of data acquisition system in which the continuous analog signal is converted to a discrete signal. The output of any transducer is a continuously varying voltage. The ADC samples the analog signal as discrete values and stores it in the computer. LabVIEW has the configuration utility known as Measurement Automation Explorer (MAX) for the configuration and installation of all external data acquisition devices. MAX reads the information from device manager windows registry and assigns it specific device name from which the information is collected. The relation between the MAX and data acquisition device is shown in Fig. 1, [39].

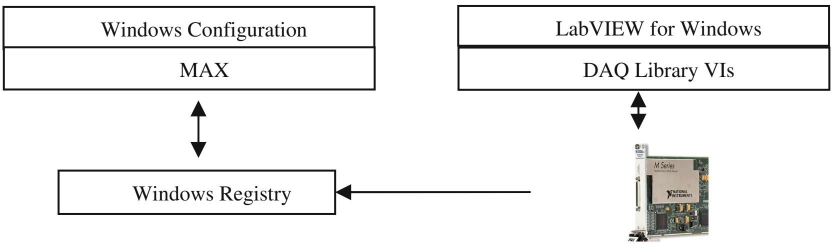
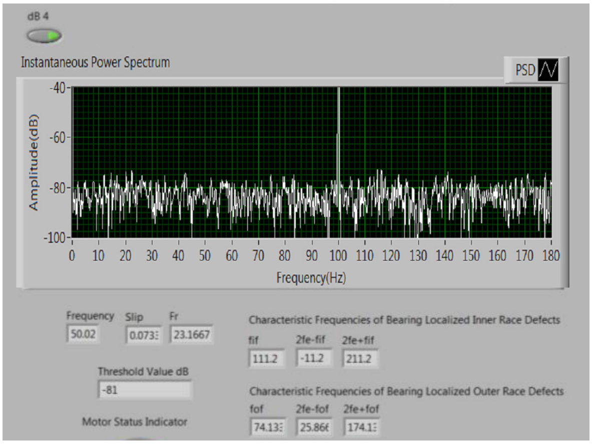
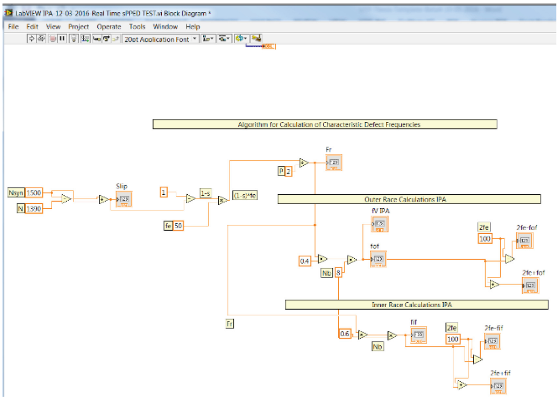


Fig. 1. Relation between DAQ and MAX.



(a)



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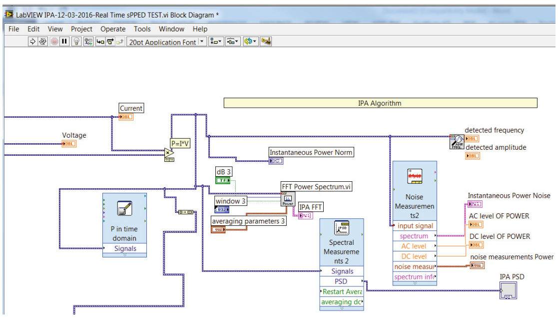
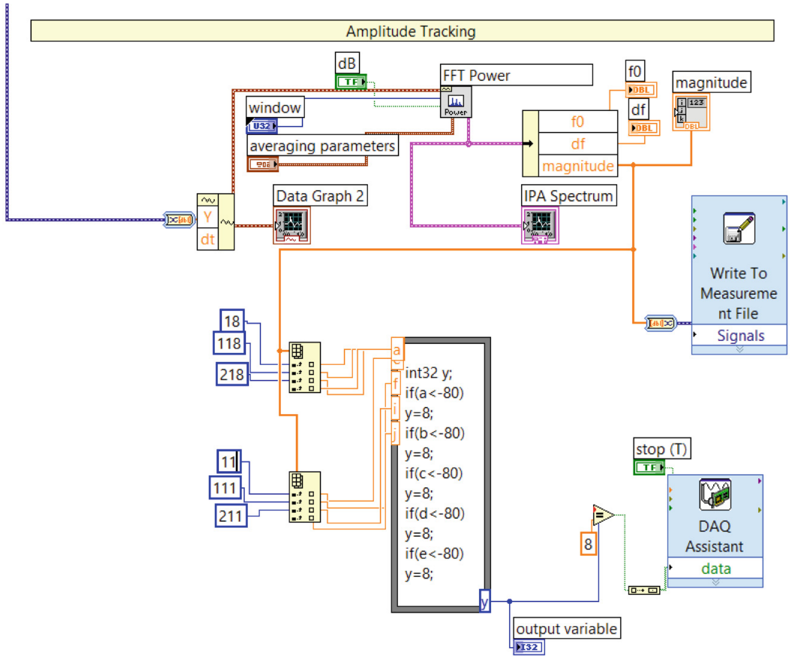
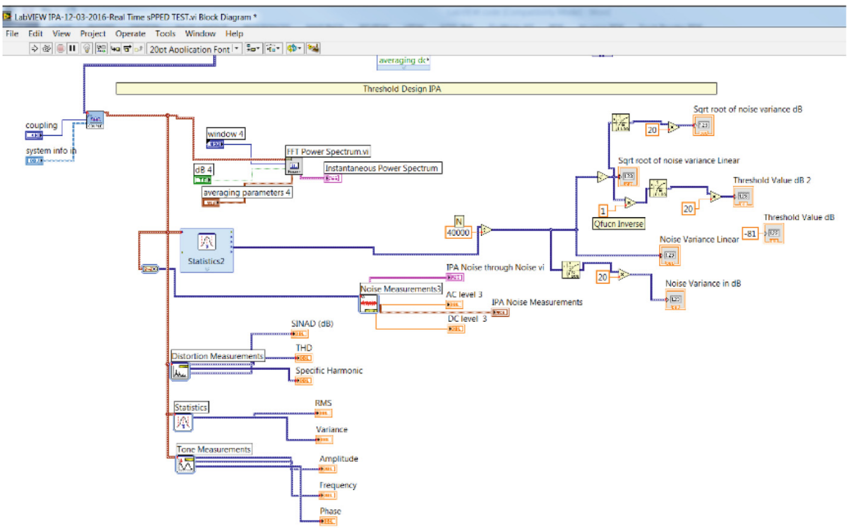


(c)

Fig. 2. The developed condition monitoring system (a) LabVIEW front panel display (b) Subroutine of characteristic defect frequency calculations (c) Subroutine of IPA algorithm (d) Subroutine for tracking amplitude values (e) Subroutine of threshold design algorithm.



(d)



(e)

Fig. 2. (continued)

Data acquisition (DAQ) assistant is used in continuous mode to configure the LabVIEW window with the MAX. The DAQ assistant is placed inside the loop to acquire data continuously from the data acquisition device.

2.1 Design of LabVIEW Program

This section discusses briefly the design of LabVIEW program for the diagnosis of mechanical fault at various operating conditions of the induction motor. The developed algorithm has five subroutines to perform various tasks related to condition monitoring and fault diagnosis of induction motor. The LabVIEW front panel window and program subroutines are shown in Fig. 2.

2.2 Subroutines of the Graphical Block in the LabVIEW Program

Data acquisition (DAQ) assistant was used in continuous mode to configure the LabVIEW window with the MAX. The DAQ assistant was placed inside the loop to acquire data continuously from the data acquisition device. A brief description of each subroutines are as follows:

Subroutine for the Calculation of Characteristic Defect Frequencies:
This program subroutine collects the stator current and voltage data from DAQ assistant and calculates the characteristic defect frequencies related to gear defects based on the mathematical formulation.

Subroutine for the Measurement of Instantaneous Power Spectrum:
This subroutines measure the instantaneous power of the motor using the stator current and voltage measurements. The built-in power spectrum density sub.vi inside LabVIEW was used to plot the instantaneous power spectrum.

Subroutine for the Threshold Design:
The statistical analysis sub.vi inside the LabVIEW was utilized to calculate the threshold through the analysis of the instantaneous power signal under various operating conditions.

Subroutine for the Tracking of Amplitude Values:
This subroutine track the amplitude values at specific characteristic defect frequencies and set an alarm if amplitude value increases the set threshold limits.

3 On-Line Condition Monitoring System

The test rig developed for the on-line condition monitoring system consists of an induction motor, data acquisition device, a current and a voltage transducer and LabVIEW®. The schematic diagram of the experimental set-up is shown in Fig. 3. A gear assembly has been used for the analysis of gear teeth faults.

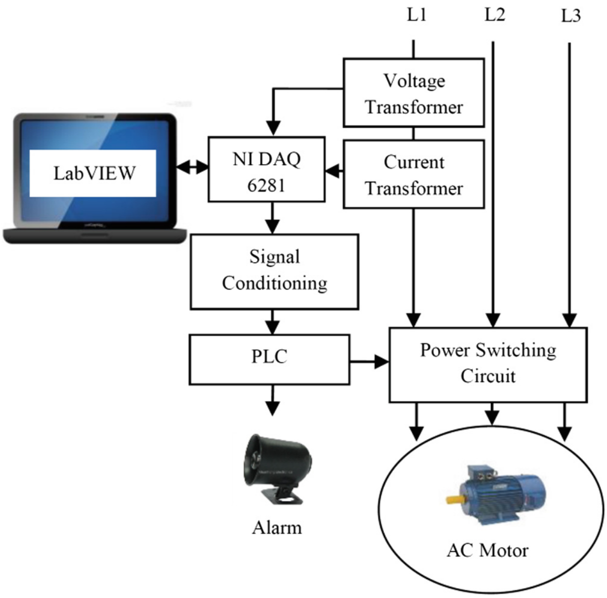


Fig. 3. The block diagram of the developed experimental test rig.

Table 1. Expected pinion gear defect frequencies under various loading conditions.

Load conditions	Motor speed (rpm)	Characteristic defect frequency (Hz)		
		f_{g1}	$\lvert 2f_e - f_{g1} \rvert$	$\lvert 2f_e + f_{g1} \rvert$
No load	1480	24.6	75.4	124.6
Full load	1390	23.2	76.8	123.2

In normal situations, both gears have a smooth surface so contact of pinion with wheel does not create any impact. However, fluctuations of air-gap are produced due to presence of gear defect. Due to these fluctuations, gear defect frequencies (f_g) are induced in motor electric supply and could be calculated using (1) and are shown in Table 1.

$$f_{es} = \lvert f_e \pm m f_g \rvert \tag{1}$$

where:

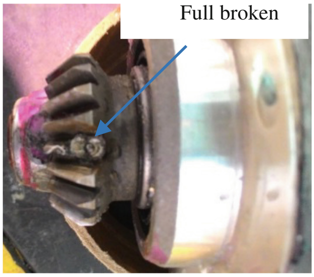
f_e, is the electric supply frequency
m, is the modulation index
f_g, is the gear characteristic defect frequency

4 Results and Analysis

A total of eight tests have been conducted on the healthy gear, 25% broken teeth (fault type 1), 50% broken teeth (fault type 2) and full broken teeth (fault type 3) of the pinion gear. The electric discharge machine (EDM) has been used to create faults in the gear teeth. The healthy and defected gears are shown in Fig. 4.

The IPA spectrums of the defected pinion gear and the healthy pinion gear for the conditions of both no-load and full-load are illustrated in Figs. 5 and 6, respectively. Each spectrum has been normalized with regards to the highest peak of the fundamental power element. In each spectrum, the highest peak is related to the fundamental element of 100 Hz. It has been noticed that under the condition of no-load, the change in amplitude value at the characteristic defect frequency is very small for fault type 1 as compared to fault type 3. However, under the condition of a full-load, the change in values of the amplitude shown to have much larger increased at the characteristic defect frequency.

(a)



(b)

Fig. 4. Example (a) healthy gear (b) full broken teeth in pinion.

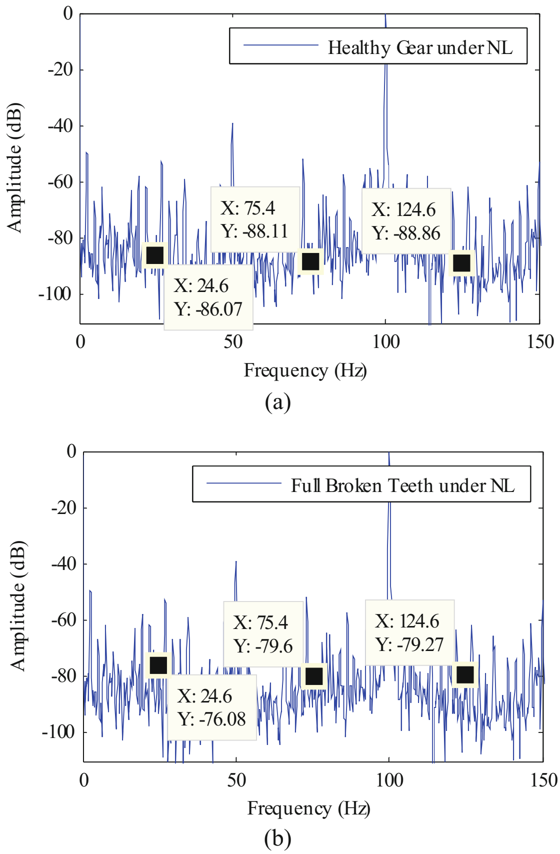


Fig. 5. The normalized instantaneous power spectrum of the motor for pinion gear defects under no-load condition (a) Healthy motor (b) 100% broken teeth.

The analysis of the spectrums of the frequencies for all three types of defects under a variety of loading conditions has been summarized in Table 2. The results show that at the characteristic fault frequencies, the values of the amplitude grow larger as the fault size of the gear teeth increased. Moreover, it has been observed that the increased in the values of the amplitude was even more prominent under the conditions of full-load.

It has been demonstrated that the IPA technique provides stronger fault frequencies components. This implies that the IPA is a better alternative for diagnosing motor coupled gear faults. This is due to the fact that the IPA has an additional element of the characteristic vibration frequency, f_{g1}, (other than just the two sideband elements). This gives a bit of additional data for enhanced fault detection in an on-line diagnostic system for defect determination.

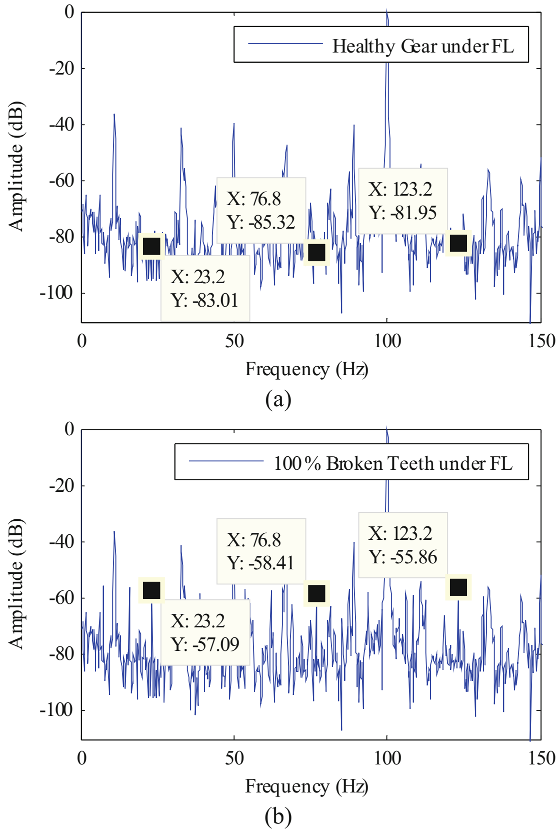


Fig. 6. The instantaneous power spectrum of the motor for pinion gear defects under full-load condition (a) Healthy motor (b) 100% broken teeth.

Table 2. Summary of change in amplitude values at various defects levels.

Defect type (broken tooth)	Characteristic defect frequency (Hz)		Change in amplitude (dB)	
	No load	Full load	No load	Full load
25%	24.6	23.2	3	10
50%	75.4	76.8	5	16
100%	124.6	123.2	9	26

5 Conclusions

This paper presents the development of a non-invasive condition monitoring system using system-design platform and development software tool for fault diagnostic of gears faults in induction motors. The fault analysis software created in LabVIEW is used for the identification of the fault frequencies of the induction motor. The test rig is designed to be flexible that facilitate the acquisition of experimental data in the form of the 3-phase currents and voltages measurements containing information about the fault types. The LabVIEW program has been designed and coded to represent the IPA algorithm. As a demonstration platform and 'proof-of-concept', the on-line non-invasive system for condition monitoring has been able to determine the various motor-coupled gears defects using the IPA technique. A significant level of amplitude (dB) value changes is observed at specific fault frequencies for both the no-load and full-load conditions, which verifies the viability of the proposed method. In the IPA spectrum, the additional information with regards to the characteristic vibration frequency element (f_{g1}) has given the relevant information on the detection of the gearing fault. This has resulted in enhancement of the accuracy and the reliability of the detection and diagnosis of the defects in motor-coupled gears.

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References

1. Irfan, M., Saad, N., Ibrahim, R., Asirvadam, V.S.: A non invasive method for condition monitoring of induction motors operating under arbitrary loading conditions. Arab. J. Sci. Eng. **41**(9), 3463–3471 (2016)
2. Irfan, M., Saad, N., Ibrahim, R., Asirvadam, V.S.: Condition monitoring of induction motors via instantaneous power analysis, J. Intell. Manuf. doi:10.1007/s10845-015-1048-2, February 2015
3. Irfan, M., Saad, N., Ibrahim, R., Asirvadam, V.S.: An intelligent diagnostic condition monitoring system for ac motors via instantaneous power analysis. Int. Rev. Electr. Eng. **8**(2), 664–672 (2013)
4. Irfan, M., Saad, N., Ibrahim, R., Asirvadam, V.S., Hung, N.T., Magzoub, M.: Analysis of bearing surface roughness defects in induction motors. J. Fail. Anal. Prev. **15**(5), 730–736 (2015)
5. Irfan, M., Saad, N., Ibrahim, R., Asirvadam, V.S.: An online condition monitoring system for induction motors via instantaneous power analysis. J. Mech. Sci. Technol. **29**(4), 1483–1492 (2015)
6. Irfan, M., Saad, N., Ibrahim, R., Asirvadam, V.S.: An intelligent fault diagnosis of induction motors in an arbitrary noisy environment, J. Nondestr. Eval. **35**(12) doi:10.1007/s10921-015-0327-3, March 2016
7. Kia, S.H., Henao, H., Capolino, G.-A.: Development of a test bench dedicated to condition monitoring of wind turbines, IEEE-IECON, Dallas (TX, USA), 28 October–1 November 2014
8. Dalpiaz, G., Rivola, A., Rubini, R.: Effectiveness and sensitivity of vibration processing techniques for local fault detection in gears. Mech. Syst. Signal Process. **14**(3), 387–412 (2000)

9. Baydar, N., Ball, A.: Case study-detection of gear failures via vibration and acoustic signals using wavelet transform. Mech. Syst. Signal Process. **17**, 787–804 (2003)
10. Loutas, T.H., Sotiriades, G., Kalaitzoglou, I., Kostopoulos, V.: Condition monitoring of a single-stage gearbox with artificially induced gear cracks utilizing on-line vibration and acoustic emission measurements. Appl. Acoust. **70**, 1148–1159 (2009)
11. Mohanty, A.R., Kar, C.: Monitoring gear vibrations through motor current signature analysis and wavelet transform. Mech. Syst. Signal Process. **20**(1), 158–187 (2006)
12. Feki, N., Clerc, G., Velex, P.: An integrated electro-mechanical model of motor-gear units - applications to tooth fault detection by electric measurements. Mech. Syst. Signal Process. **29**, 377–390 (2012)
13. Strangas, E.G.: Response of electrical drives to gear and bearing faults - diagnosis under transient and steady state conditions. In: Proceedings of Workshop on Electrical Machines Design Control and Diagnosis (WEMDCD), invited paper, Paris (France), pp. 289–297, 11–12 March 2013
14. Henao, H., Kia, S.H., Capolino, G.-A.: Torsional vibration assessment and gear fault diagnosis in railway traction system. IEEE Trans. Ind. Electron. **58**(5), 1707–1717 (2011)
15. Bogiatzidis, I., Safacas, A., Mitronikas, E.: Detection of backlash phenomena appearing in a single cement kiln drive using the current and the electromagnetic torque signature. IEEE Trans. Ind. Electron. **60**(8), 3441–3453 (2013)
16. Trajin, B., Regnier, J., Faucher, J.: Comparison between stator current and estimated mechanical speed for the detection of bearing wear in asynchronous drives. IEEE Trans. Ind. Electron. **56**(11), 4700–4709 (2009)
17. Ibrahim, A., El-Badaoui, M., Guillet, F., Bonnardot, F.: A new bearing fault detection method in induction machines based on instantaneous power factor. IEEE Trans. Ind. Electron. **55**(12), 4252–4259 (2008)
18. Blödt, M., Chabert, M., Regnier, J., Faucher, J.: Mechanical load fault detection in induction motors by stator current time-frequency analysis. IEEE Trans. Ind. Appl. **42**(6), 1454–1463 (2006)
19. Mohanty, A.R., Kar, C.: Fault detection in a multistage gearbox by demodulation of motor current waveform. IEEE Trans. Ind. Electron. **53**(4), 1285–1297 (2006)
20. Kar, C., Mohanty, A.R.: Vibration and current transient monitoring for gearbox fault detection using multiresolution Fourier transform. J. Sound Vib. **311**(1/2), 109–132 (2008)
21. Kia, S.H., Henao, H., Capolino, G.-A.: Analytical and experimental study of gearbox mechanical effect on the induction machine stator current signature. IEEE Trans. Ind. Electron. **45**(4), 1405–1415 (2009)
22. Kia, S.H., Henao, H., Capolino, G.A.: Gear tooth surface damage fault detection using induction machine stator current space vector analysis. IEEE Trans. Ind. Electron. **62**(3), 1866–2001 (2015)
23. Kia, S.H., Henao, H., Capolino, G.-A.: Torsional vibration effects on induction machine current and torque signatures in gearbox-based electromechanical system. IEEE Trans. Ind. Electron. **56**(11), 4689–4699 (2009)
24. Feki, N., Clerc, G., Velex, P.: Gear and motor fault modeling and detection based on motor current analysis. Electric Power Syst. Res. **95**, 28–37 (2013)
25. Daneshi-Far, Z., Henao, H., Capolino, G.-A.: Planetary gearbox effects on induction machine in wind turbine: modeling and analysis, In: Proceedings of International Conference on Electrical Machines (ICEM), Marseille (France), pp. 1790–1796, 2–5 September 2012
26. Ottewill, J.R., Orkisz, M.: Condition monitoring of gearboxes using synchronously averaged electric motor signals. Mech. Syst. Signal Process. **38**(2), 482–498 (2013)

27. Girsang, I.P., Dhupia, J.S., Muljadi, E., Singh, M., Pao, L.Y.: Gearbox and drive train models to study of dynamic effects of modern wind turbines. IEEE Trans. Ind. Appl. **50**, 3777–3786 (2014)
28. Huh, K.-K., Lorenz, R.D., Nagel, N.J.: Gear fault diagnostics integrated in the motion servo drive for electromechanical actuators. IEEE Trans. Ind. Appl. **48**(1), 142–150 (2012)
29. Bogiatzidis, I.X., Safacas, A.N., Mitronikas, E.D.: Detection of backlash phenomena appearing in a single cement kiln drive using the current and the electromagnetic torque signature. IEEE Trans. Ind. Electron. **60**(8), 3441–3453 (2013)
30. Kia, S.H., Henao, H., Capolino, G.-A.: A real-time platform dedicated to on-line gear tooth surface damage fault detection in induction machines. In: International Conference on Electrical Machines (ICEM), Berlin, 2–5 September 2014
31. Kia, S.H., Henao, H., Capolino, G.-A.: Gear tooth surface damage fault detection using induction machine stator current space vector analysis. IEEE Trans. Ind. Electron. **62**(3), 1866–1878 (2015)
32. Fournier, E., et al.: Current-based detection of mechanical unbalance in an induction machine using spectral kurtosis with reference. IEEE Trans. Ind. Electron. **62**(3), 1879–1887 (2015)
33. Irfan, M., Saad, N., Ibrahim, R., Asirvadam, V.S., Hung, N.T.: Analysis of bearing outer race defects in induction motor. In: The 5th IEEE International Conference on Intelligent and Systems (ICIAS), Kuala Lumpur, Malaysia, June 2014
34. Irfan, M., Saad, N., Ibrahim, R., Asirvadam, V.S.:An intelligent diagnostic system for condition monitoring of ac motors. In: The 8th IEEE Conference on Industrial Electronics and Applications, Melbourne, Australia, June 2013
35. Irfan, M., Saad, N., Ibrahim, R., Asirvadam, V.S., Hung, N.T.: A non-invasive fault diagnosis system for induction motors in noisy environment. In: IEEE International Conference on Power and Energy (PECon), Kuching, Malaysia, pp. 271–276, December 2014
36. Irfan, M., Saad, N., Ibrahim, R., Asirvadam, V.S.: An approach to diagnose inner race surface roughness faults in bearings of induction motors. In: IEEE International Conference on Signal and Image Analysis (ICSIPA), Kuala Lumpur, Malaysia, October 2015
37. Irfan, M., Saad, N., Ibrahim, R., Asirvadam, V.S.: An online fault diagnosis system for induction motors via instantaneous power analysis, Tribol. Trans. doi:10.1080/10402004.2016.1190043, May 2016
38. Irfan, M., Saad, N., Ibrahim, R., Asirvadam, V.S.: Development of an intelligent condition monitoring system for AC induction motors using PLC. In: 2013 IEEE Business Engineering and Industrial Applications Colloquium (BEIAC) (2013)
39. Bishop, R.H.: Learning with LabVIEW 8, Pearson/Prentice Hall (2007)