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Wireless Motor Vibration Monitoring with MEMS Accelerometers

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Keywords

«DC Machine», «Nanotechnology», «Wireless Control», «Intelligent Drive», «Radio Frequency (RF)»

Abstract

This paper presents a novel wireless solution to detect radial micro-vibrations of DC Smart Machine. MEMS accelerometers are associated to the transmission channel with Arduino Uno and transmitter ESP8266 as wireless link. Known vibrations injected on DC machine shaft are characterized. Experimental results are presented using conceived Human Machine Interface (HMI).

Introduction

A flexible and intelligent advanced technology increases in electrical engineering applications and needs the using of several wireless solutions to offer great gain in term of cost, size and power consumption. According to ON WORD source [1], more than 25 million of wireless sensors and actuators are installed in the world in the end of 2016. The presence of cables increases the weight of gear, raises the consumption of copper and of course of power energy in classical vehicle realization. So, wireless technology takes place in modern electrical vehicle system, offering more flexibility, reliability and security. This technology becomes also popular in all smart systems with different “connected objects”. All these reasons, have improved by applying wireless sensors for their control and supervision. They are called or will be called in multiple societal domains such as: smart homes, smart grids, smart roads, railway, vehicular, aeronautic transports and industry automation, in our case “smart machine”
Micro-Electro-Mechanical System (MEMS) technology presents one of the most widely used sensors for wireless applications. There is an attractive solution for remote monitoring and data processing in complex environmental systems [2] as electrical rotating actuators.

Some solutions based on wireless control of rotating motors have been proposed [3], [4]. In this study new approach to remote vibration monitoring of electrical motor is developed applying wireless MEMS accelerometers. The vibration monitoring strategy consists on detection of correlation link between observed signals and typical dysfunctional mechanisms namely those related to mechanical problems as discussed previously and/or also those related to electrical ones. The monitoring task helps user to set alarm or danger thresholds from which decision can be taken to avoid motor aging or its damage and to ensure service continuity. In this paper, a simplified structure based on intelligent sensor is proposed to identify radial motor vibration. This solution is characterized by its simplicity of implementation and its low cost. To validate the proposed concept, an experimental LAPLACE Laboratory test bench has been developed and an HMI was conceived under LABVIEW software.

Wireless sensor node presentation

In order to perform in situ measurements of vibrations during the operation of the rotating electrical machine, we designed the wireless sensor node applying four basic components, i.e. the MEMS accelerometer (ADXL203), the ARDUINO UNO board (based on the Atmega328P microcontroller), the wireless transceiver (ESP8266-ESP-01) and the "Inverted-F-Antenna (IFA)" (Fig.1). In this paper, we describe briefly the global device integrated on the rotor shaft of the machine. In the current version, this device has a form of 6 mm thick ring, its outer and inner diameters are respectively of 30 mm and of 10 mm. It can be easily installed on the shaft of the tested motor.

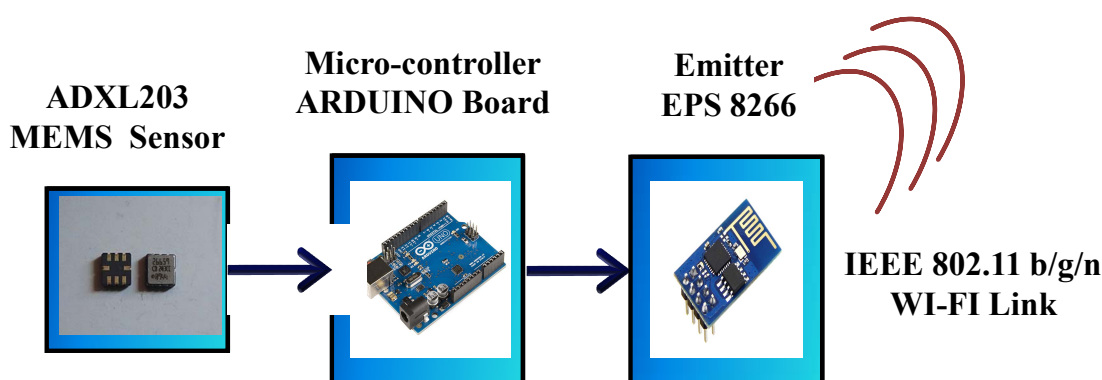


Fig. 1: MEMS sensor node

Accelerometer general information and choice of two ADXL203 MEMS architecture

Analog Device MEMS Accelerometers ADXL203 are frequently applied for vibration monitoring of electrical actuator [6,7]. This technology offers also new perspectives for the remote control of smart systems [8] due to its precision, low power, low cost and also small size. ADXL 203 constitutes a capacitive accelerometer from MEMS technology. This sensor has to allow obtaining the rotation speed and acceleration.

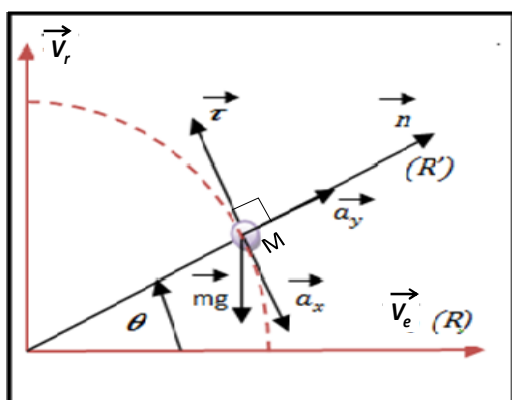


Fig. 2: Different forces acting on the MEMS sensor

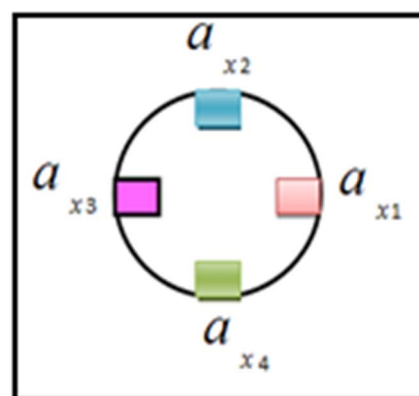


Fig. 3: Configuration of four MEMS on the motor shaft

We can note that the sensor outputs (Fig. 2) depend on the angle deviation θ , the disk velocity Ω , its radius r and also the gravity g . According to the MEMS configuration shown in the Fig. 3, four accelerations are expressed as follows:

$$\begin{aligned} a_{x1} &= g \cos \theta \\ a_{x2} &= g \cos \left(\theta + \frac{\pi}{2} \right) = g \sin \theta \\ a_{x3} &= g \cos (\theta + \pi) = -g \cos \theta \\ a_{x4} &= g \cos \left(\theta - \frac{\pi}{2} \right) = -g \sin \theta \end{aligned} \quad (1)$$

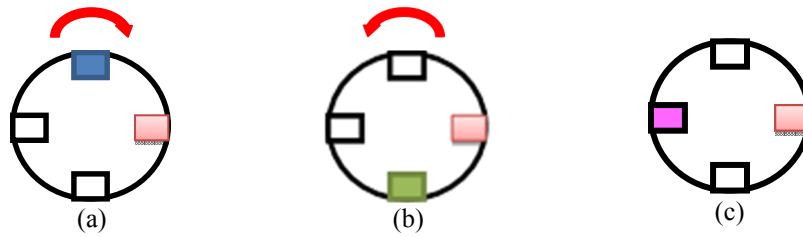


Fig. 4. Two MEMS configurations to obtain the rotation speed in steady state (a), (b)

As it was presented in our previous studies [10], the different MEMS configurations allow determining the motor acceleration, its rotation speed with direction of rotation. So, for two MEMS sensor applications (Fig. 4a, Fig. 4b), in steady state the rotation speed can be expressed as below:

$$\Omega = \frac{d\theta}{dt} \quad \text{with} \quad \frac{a_{x2}}{a_{x1}} = \tan \theta \quad (\text{Fig. 4a}) \quad \text{or} \quad \frac{a_{x3}}{a_{x4}} = \tan \theta \quad (\text{Fig. 4b}) \quad (2)$$

In transient state, the rotation speed is defined by another configuration of two MEMS sensors, as shown in the Fig. 4.c. In this case the value of rotation speed can be defined as follows:

$$\Omega = \int \frac{a_{\tau}}{r} dt \quad \text{with} \quad a_{\tau} = \frac{a_{x1} - a_{x4}}{2} = r \frac{d\Omega}{dt} \quad (3)$$

So, we exploit the difference of the values obtained from two accelerometers placed symmetrically and radially vs the motor axis to ensure the reliability and precision of measurements. We have developed data acquisition algorithms and signal processing adapted for two MEMS and also for other sensor monitoring of several motor operation parameters. This was realized locally on the node and also on the operator terminal. This study will be the subject of our next communications, once the patent procedure completed.

Reception and Pre-processing of MEMS Measurements

The Arduino / Genuino board based on ATmega328P [11], is pre-processing modulus for MEMS accelerometers' signals. Its program implementation is very simple and easily adapted to an open source development environment.

Wireless Communication

ESP8266, Wi-Fi autonomous module (802.11), works at 2,4GHz and supports the WPA/WPA2 wireless security modes. This module, characterized by its low cost and small size, integrates TCP/IP protocol

stack. It allows establishing an autonomous Wi-Fi connection with Arduino microcontroller. It uses a TX / RX serial pins to send and receive data. For the reason of its simplicity of implementation, this device is perfectly adapted to data storage in this application. It presents a powerful embedded processor having minimum response time [9].

Transmission Channel

An overview of a transmission channel is illustrated in Fig.5. This channel is composed essentially of Transmitter with Antenna (ESP8266), Router TP-Link (TL-WR740N) and a Receiver, constituted by a Personal Computer (PC) which stores all received data. In this study, the MEMS sensor acceleration signal is sent to transmitter which converts it to digital form and sends it to receiver. Note that in this work, the sample time used to transmit data to database is equal to 0,1ms.

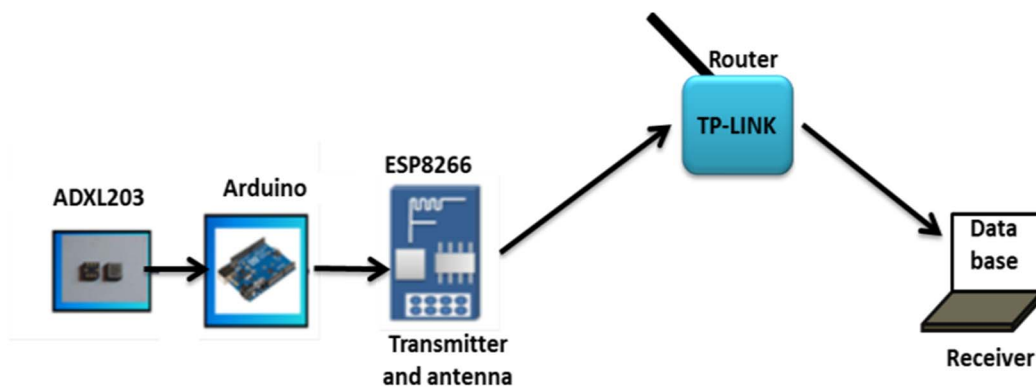


Fig.5. Transmission channel overview

Wireless sensor node presentation

The data delivered from MEMS sensors is collected in a Data Base which is developed using "PhpMyAdmin" and under MySQL. In the other hand, three programs are settled using Php language code to ensure communication to this database as well as the recovery of accelerations. An overview of reception part is illustrated in Fig.6.

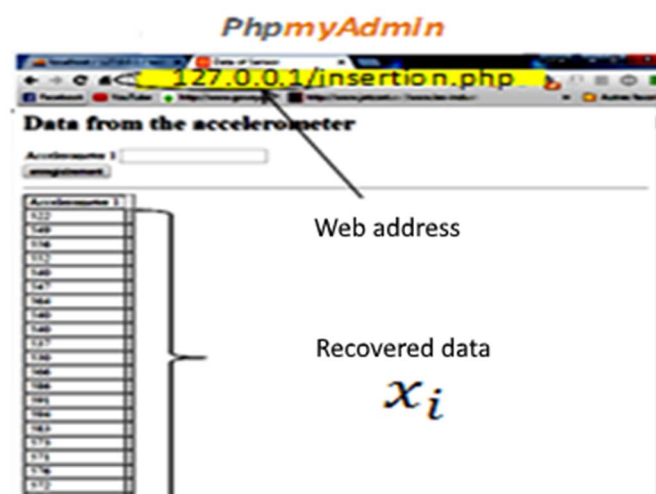


Fig.6. Complete description of reception part

It can be remarked that the recovery of data from wireless sensors was done on a web page in the first step to test the transmission success. This figure represents the web page on which a data recovery table is displayed. The displayed values are those related to accelerations due to the displacement of the assembly (emitter and sensor). It will be noted that the value of each sample of data is calculated in volt as follows.

$$a_{x_i} = \frac{x_i * 4096}{5} \quad (4)$$

The data transmission sequence with x_i index number has to be digital coding.

Human Machine Interface (HMI)

Data collected in the database developed under MySQL are also transmitted to HMI interface (Fig. 7) which is developed under LABVIEW software. This one ensures displaying and remotes signals coming from ESP8266 emitter and making it closer to the user. Furthermore, it allows followed the instantaneous values of sensor

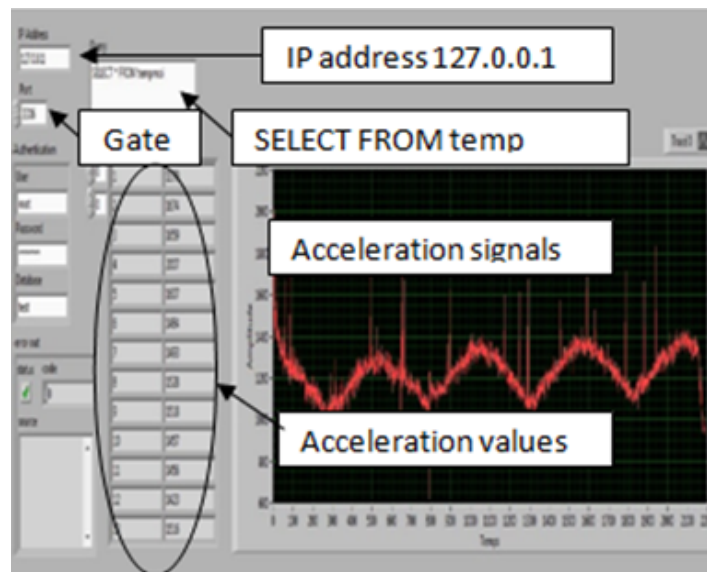


Fig.7 HMI overview.

Results and Discussions

Experimental test bench presentation

Different tests have been done using the LAPLACE laboratory test bench shown in Fig.8. The vibration injections are realized using LDS V408 Low Force Vibration Tester, fed from an Amplifier activated by a Low Frequency Generator (LFG) with amplitude and frequency variable. So, this vibration source has to generate different vibration values by changing the LGF amplitude and frequency. The visualization and data storage are achieved firstly using database and then are treated under HMI.

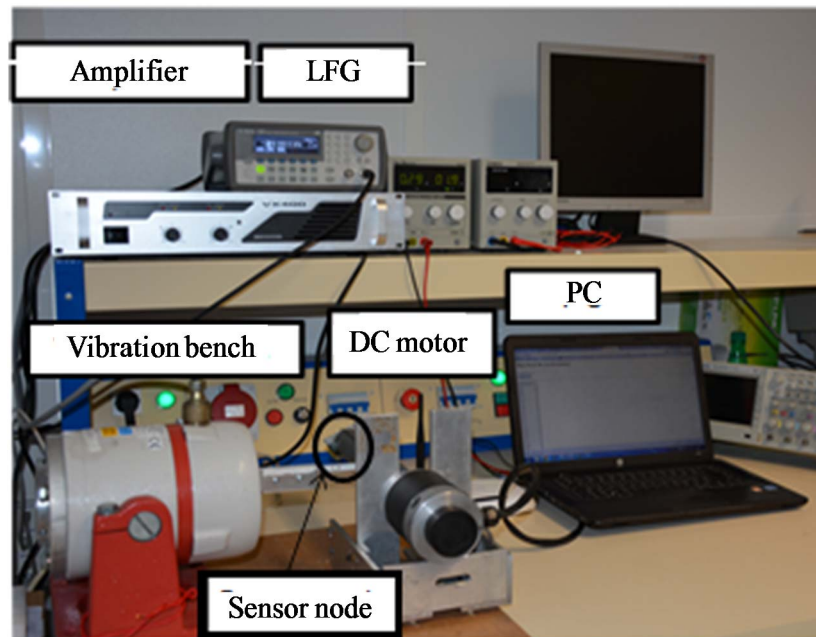


Fig.8 LAPLACE laboratory test bench

Observation of vibration results

As example, we realize the monitoring of a Permanent Magnet DC Motor, working with controlled rotation speed. Artificially, its failed operation was provoked. For this, we have fixed a PVC disk on the motor shaft. This disk allows injecting of different but known, vibrations generated by the "LDS V408 Low Force Vibration Tester". The injected signal form can be adjusted in amplitude, in frequency, and also in cyclic ratio (value regulated by a LFG signal connected to the amplifier). A comparison between different operation conditions is made. However, it is important to note that the original signal is already disrupted due to environmental perturbations and sensor localization in motor shaft.

In first part of this section, a comparison will be done between original and perturbed signals after injecting of external vibrations using specific vibration bench LDS V408 Low Force Vibration Tester. Different states have been studied and multiple values of vibrations have been tested. The system response over this perturbation is analyzed.

Injection of vibration 200mV/500Hz and 200mV/200Hz

The amplitude value and frequency attributed to the vibration signal are well-ordered set using the LFG which controls the vibration bench. First, the value of vibration amplitude is fixed to 200mV and the frequency is equal to 500Hz. Temporal and spectral evolution of the motor acceleration, before and after vibration injection are illustrated respectively in Fig. 9a and Fig. 9b. It can be noted that the vibration signal is injected when angular rotation speed of electrical motor is equal to 39rad/s.

Temporal development shows that the injection of vibration, radially according to the axis of the rotating motor shaft, has a compensation effect on the acceleration evolution. Indeed, during nominal rotation speed, the motor shaft has a certain misalignment related to the node weight and its placement in the rotation axes. Furthermore, the perturbation environment affects the signal quality.

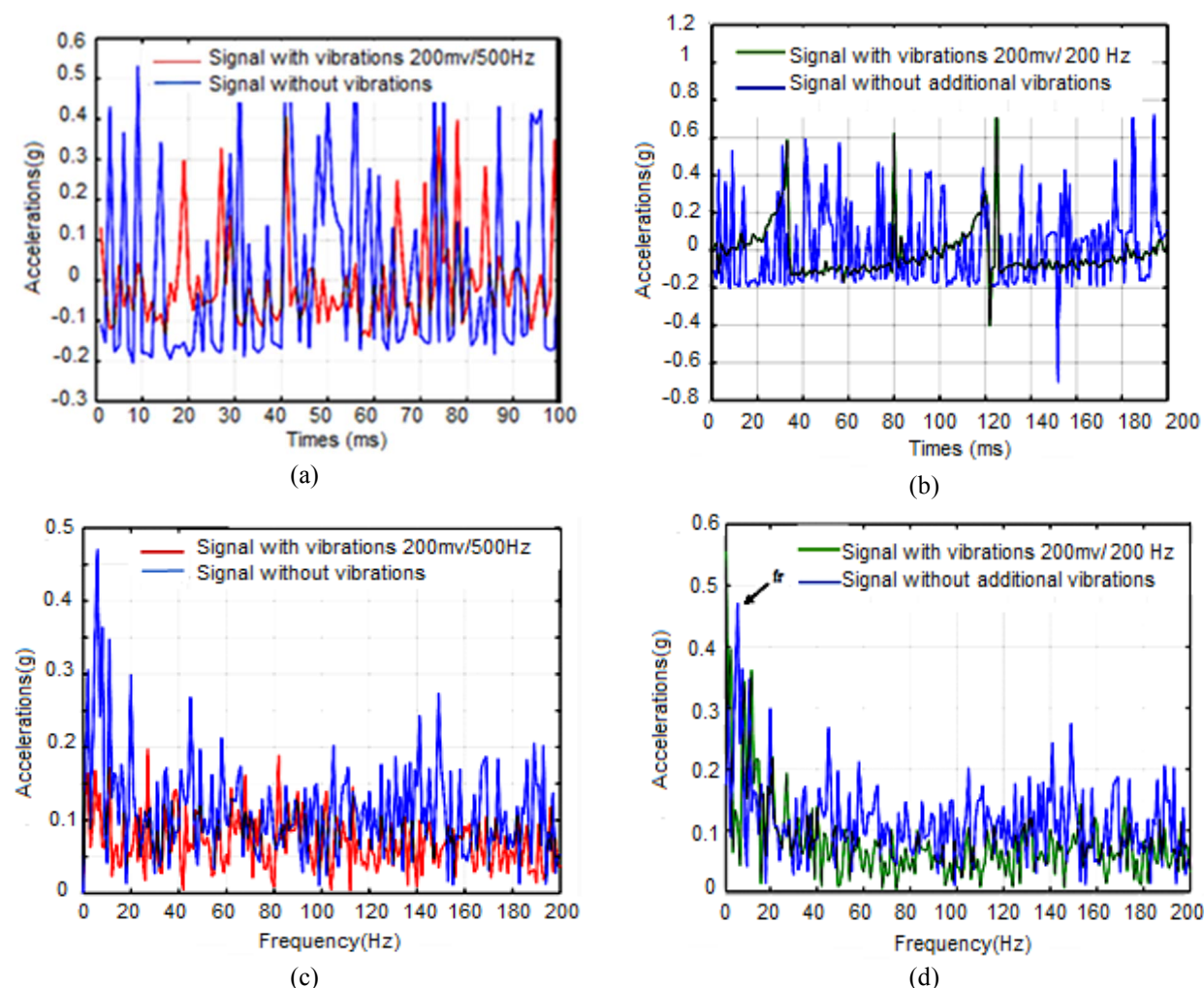


Fig.9. Temporal variation of acceleration, injection of vibration 200mV/500Hz (a), injection of vibration 200mV/200Hz (b), spectral variation of acceleration, injection of vibration 200mV/500Hz (c), injection of vibration 200mV/200Hz (d)

So, an introduction of repetitive radial vibrations decreases its effect, because in this case they are shaped in phase opposition relative to the original acceleration signal. In spectral analysis, by comparing the two situations (with and without vibrations), we observe a weakening of the fundamental term of all, while keeping the same frequency position (low offset <1Hz). In what follows, we use 1024 points FFT.

Next we keep fixed amplitude (200mV) and we change the frequency value to 200Hz in order to follow its effect on temporal acceleration evolution. The effect of vibrations injected is also identified in spectral domain (Fig. 9c and Fig. 9d). We can observe that injected value of vibration allows having a compensation effect on the original signal evolution as shown in Fig.9d. It can be remarked that the frequency modification has an important role in the temporal signal sharp evolution. A comparison has been done between the two situations. The presence of vibrations at 200 Hz generates a different mode of response in comparison to those generated on 500Hz.

Indeed, an illustration of spectral analysis relative to these two situations (200Hz and 500Hz) is given in Fig.10. It can be observed that the spectrum corresponding to the highest amplitude depends essentially on frequency interval. This ascertainment is well illustrated in Fig. 10, where a comparison between harmonic amplitude under frequency perturbations is shown. Before 200Hz, the spectral amplitude

relative to the vibration in 200Hz is the most dominated (have the highest amplitude). However, from 200Hz the spectral amplitude related to the vibration (200mV/500Hz) becomes the more important. The results presented in this study have well highlighted, the feasibility of vibration detection using temporal and spectral analysis of acceleration signal obtained from MEMS sensor.

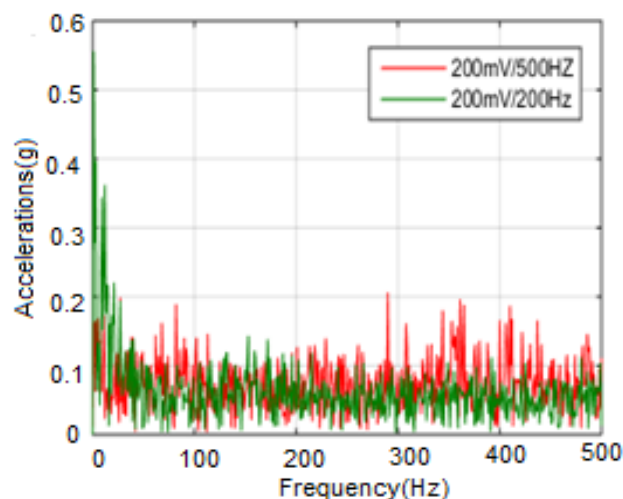


Fig.10. Effect of vibration with the frequency variation

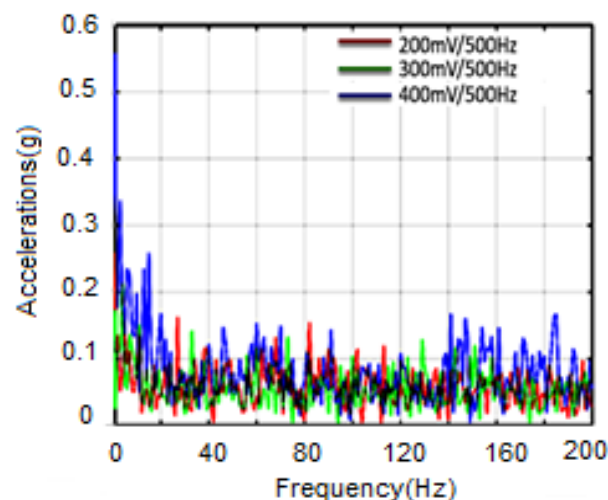


Fig 11. FFT under different amplitude variation

Modification of amplitude of injected vibrations

In this section we analyze the influence of amplitude vibration variation on signal spectral evolution. Thus, the acceleration signal evolution is examined for three amplitudes respectively 200mV, 300mV, and 400mV as shown in Fig. 11.

We can observe that the injection of different amplitudes of vibration perturbation (200mV, 300mV and 400mV) is received by modification of the motor rotation speed. In order to highlight if the proportionality link already found in the previous section (for one rotation speed value) can be retrained for others rotation speeds. Thus, we proceed in this case to increase the rotation speed of 27rad/s. Results corresponding to these modifications, defined as acceleration signals recovered with different amplitude variations are illustrated in Fig. 11.

Vibration signature control

In this paper the impact of fault in temporal and spectral evolutions is highlighted. Its severity is detected by the calculation of Average Squared Error (A.S.E) between the reference signals corresponding to the healthy state established using experimental data and faulty one. In this context many algorithm has been proposed and tested by the author we can cited those based on Allan Variance [2] or also Genetic Algorithm [3]) and then according to the value of ASE the severity of fault is deduced.

After exploiting the reliability to distinguish between the presence or not of vibration signature and also its severity by using wireless dispositive. In this section, we exploit the monitoring task which is based principally on the calculation of averages squared error between the real and the perturbed signal. A decision will be made related to the severity of error by taking a limit of 25%. An algorithm is developed in this context to have the information of motor behavior during its operation.

Conclusion

The presented study shows the feasibility of wireless vibration monitoring using a simple dispositive based essentially on MEMS accelerometers and ESP8266 WI-FI module. Apart, supervision task, the proposed system can be used to determine and consequently to control motor rotation speed. Of course, it presents very interesting redundancy solution to replace failed speed sensor (incremental, absolute, etc. ...).

An experimental test bench has been developed in LAPLACE Laboratory to validate the feasibility of proposed solution. Finally, a Human Machine Interface (HMI) has been proposed to facilitate results' analysis and also to allow any remote user action. It is also important to note that this work offers new perspectives for wireless supervising in the system health monitoring and control of electrical motors.

The authors have shown that “smart actuator” can be design in very simple and economic way. This wireless solution can be proposed for multi-machine installations especially in different intelligent embedded system (aeronautic, vehicular, naval and space). Evidently, an autonomous low power feeding in our solution, an improving of reliability, IEM environmental protections and also a cohabitation of energy and telecommunication wireless networks, focus the principal objectives of our study in the future.

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