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Abstract. The study of Noise, Vibration and Harshness (NVH) is becoming a key element when it comes to design and maintain a system that have rotatory elements. The understanding of the source of the vibrations can lead to a way of mitigating them, thus ensuring a better operation and expanding the life of the components. In this work, an analysis of the vibrations' frequency spectra of an electric drive is developed, extracting some conclusions from it and deducing a source. The possibility of operating this system remotely makes it a perfect experiment for a remote lab, operating through Internet, being a novelty for this kind of studies.

Keywords: harshness, noise, NVH, PMSM, remote, vibrations.

1 Introduction

Rotating machines have vibrations associated with its functioning, though it does not mean any abnormal operation. If we particularize for the case of an electric drive, the vibrations' sources may come from the mechanical part of the system (construction, misalignments, unbalance load, design flaws, etc) or the electric part (harmonics, unbalanced voltages, voltage gaps, etc). Noise, vibration and harshness (NVH) studies' aim is to identify those sources and propose solutions [1-4].

This work uses the advantages of a rapid prototyping platform and the ability to remotely control an electric motor in order to develop the bases for a remote controlled laboratory. This will allow users to monitor and experiment with the machine through the internet, for research and educational purposes [5-6]. The analysis of the vibration spectra plays a key role in the NVH studies, which are especially important for the design and control of electric vehicles. This work is proposed as a first step towards the implementation of active control techniques, like active damping, suitable for the cancellation of vibrations from different sources.

This paper is schematized as follows. For a first section, the NVH techniques available will be discussed and a suitable one for this project will be selected. Then, the control employed for the system, which will use the Field Oriented Control [7] and Pulse Modulating Techniques, will be described. The acquisition of the data and processing will follow, finishing with an analysis of the results obtained and drawing some conclusions.

2   Relationship to Smart Systems

In the days we live in, information can be accessed almost anywhere. From the pc, laptop, smartphone, tablet or even wearable devices; all you need is an internet connection. In this sense, this work aims the possibility of remotely supervising or even control a research laboratory.
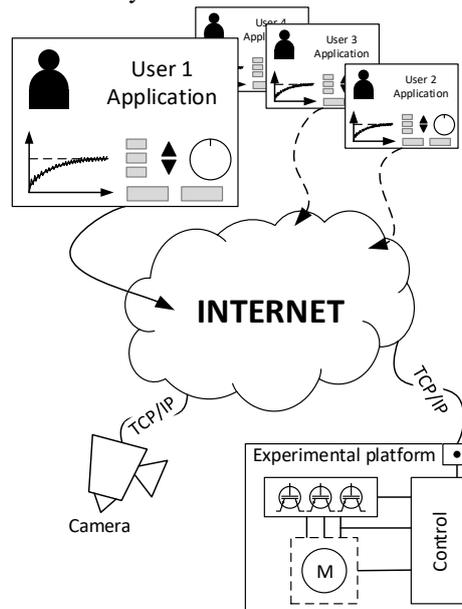
Fig. 1. Scheme of a remote laboratory, allowing researchers and students to access and remotely control the system via the internet using protocol TCP/IP.

In Fig. 1, a scheme for this kind of application is shown. The user has an application window from which he can monitor and control the system via the internet. The system connects to the internet using the TCP/IP protocol, and it consist of the control platform, an IGBT inverter and the electric drive. The control platform receives the orders from the user and generate the control signals for the inverter, as well as collects data from the inverter itself and the motor. A camera could be used for supervision of the hardware platform in anytime.

The remote laboratory represents a good implementation of a smart system, since it can be applied to industry besides research and education. This means that once it is fully developed, new UIs for controlling the system can be programmed using a web interface, for instance.

3   NVH and Control Algorithm

There are three groups in which NVH techniques can be classified into: numeric, experimental and analytic. Each of them have its advantages and disadvantages, and

one should decide which method suits better for the application. For instance, analytic methods are useful for a first understanding of the problem and modeling. However, due to the increase in microprocessors' speed, numeric methods are getting more powerful and widely used every day. In the particular case of NVH, there are several numeric methods used, like the Finite Elements Method (FEM) or the Boundary Elements Method (BEM) [8].

On the other hand, although it cannot give solutions in design phase because they can only be used with prototypes, experimental methods are useful when it comes to ease of realization, especially if you also use rapid prototyping. The data can be simply obtained using transductors, for later analysis using Fourier for studying the spectra.

This work aims the last type of the above, the experimental method. For conducting this kind of technique, the control platform used is dSPACE, from MATLAB, which allows remote controlling via Ethernet. The control algorithm is first elaborated and tested in simulations in Simulink, then is compiled and dumped in the dSPACE platform. The whole scheme of functioning can be observed in Fig. 2.
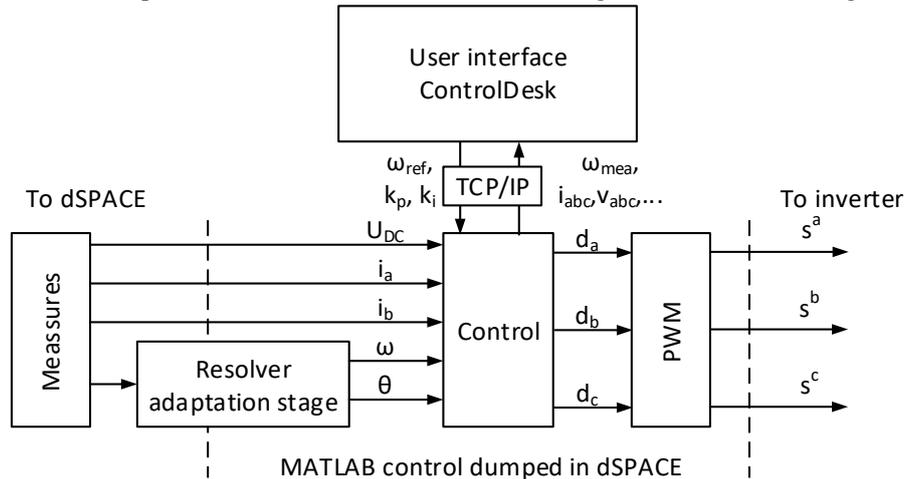
Fig. 2. Control block diagram. The block "Measures" takes the voltages, currents and speed values from sensors. "Resolver adaptation stage" block takes the information from the resolver and outputs speed and position. "Control" inputs all values from sensors and outputs the duty cycles for the PWM block. U_{DC}, i_a, i_b, ω and θ are the bus voltage, motor currents, speed and position, respectively. Ω_{ref}, k_p, and k_i are the speed reference, and controller gains selected by user. The variables d_{abc} are the duty cycles and s^{abc} the switching signals.

The control strategy, a FOC strategy, is depicted in Fig. 3. The measured currents in stationary reference frame are inputs to the system, as well as the motor speed and DC bus voltage. The controller uses these inputs for generating the duty cycles that ensures that the references are met.
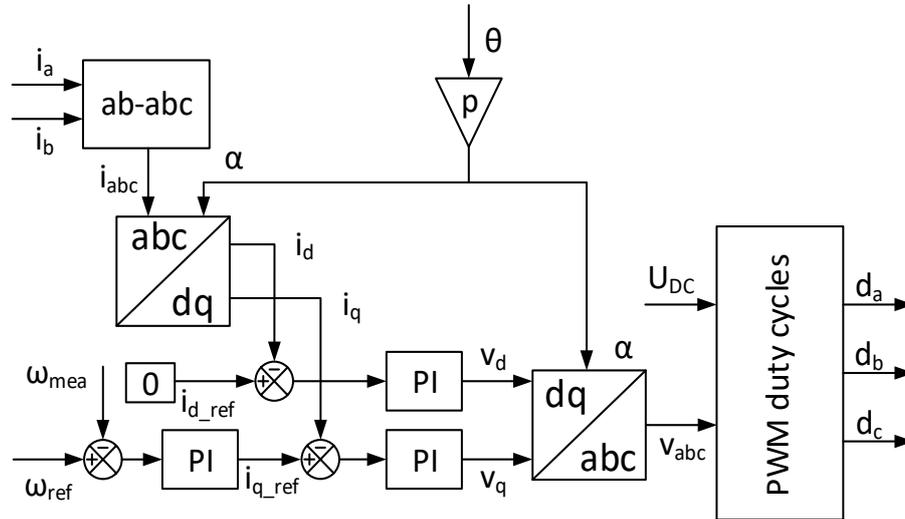
Fig. 3. Scheme of the FOC control used for the inverter-PMSM system. θ is the rotor position, p are the pole pairs and α the electrical angle.

4   Experimental NVH Analysis

In this section the physical system will be described, and the later on the process for filtering the data obtained will be explained. For the last part, the results will be presented and some conclusions drawn.

4.1   Test Bench

In order to carry out the NVH study, a test bench consisting of a PMSM, an IGBT inverter, the dSPACE platform and a PC running MATLAB Simulink is employed. The electric drive is equipped with a resolver for speed measuring, for the obtaining of the current and voltage values, transducers are used. For the acquisition of vibration data, a piezoelectric accelerometer is employed and it stored for later processing in the PC. The PMSM properties are displayed in Table 1.

Table 1. PMSM properties.

Variable	Value	Units
Pole pairs (p)	4	-
Stator windings resistance (R)	0.2	Ω
Rotor inertia (J)	3.6	$Kg \cdot m^2 \cdot 10^{-3}$
d-axis inductance (L_d)	$1.871 \cdot 10^{-3}$	H
q-axis inductance (L_q)	$1.616 \cdot 10^{-3}$	H
Magnet flux linkage	0.1323	$V \cdot s \cdot rad$

As was stated previously, a piezoelectric accelerometer has been used for the acquisition of the vibration data, its position is showed in Fig. 4.

Fig. 4. Transversal vibrations measuring using an accelerometer.

4.2 ControlDesk

The application interface presented to the user is elaborated using ControlDesk. This software allows the user to both monitor and control the dSPACE platform, been able to change control variables without the need of recompiling. One of the biggest advantages of this rapid prototyping tool is that it lets you change parameters of the control while executing it, thus making the tuning much faster.
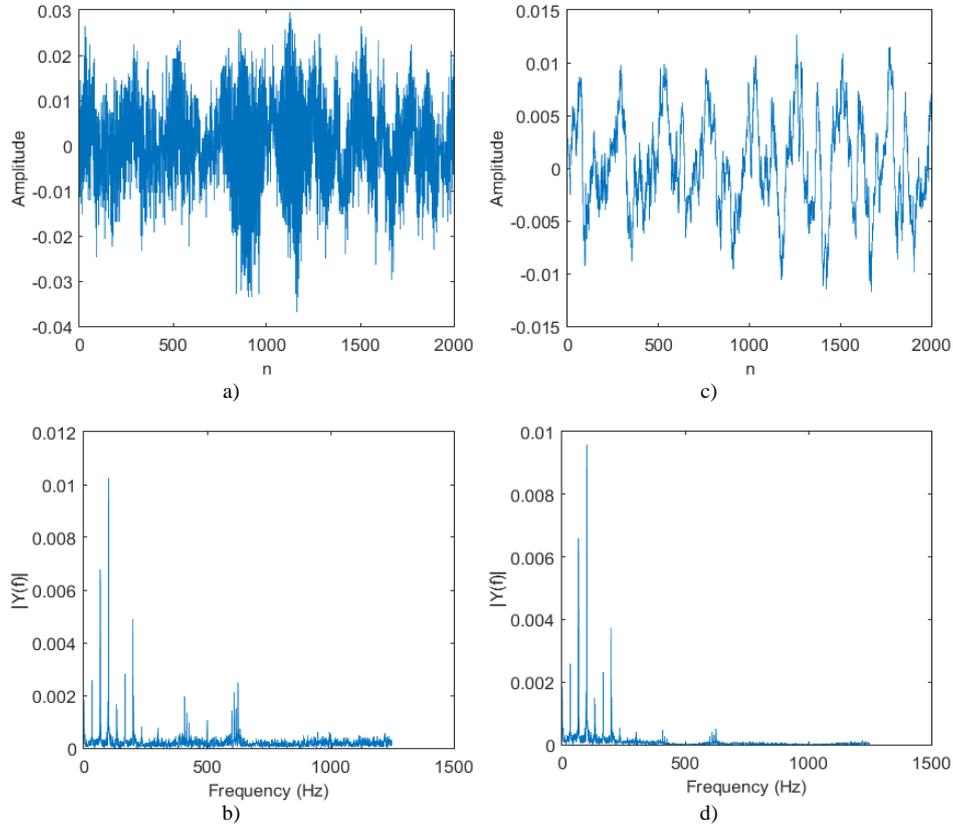
4.3 Analysis of the Results

Once the vibration data is obtained and processed, one is interested in studying the low frequency amplitudes, since these are the one associated to vibrations. The high frequency amplitudes may have different causes, like electromagnetic noise, switching-frequency noise, etc. Therefore, a filter has been employed for removing the latter.

The filter proposed is a moving average, which formula is presented in (1). Lowering the window size M of the average lowers the cut-off frequency, eliminating the high frequency content.

$$P_n = \frac{\sum_{n-M}^{n} p_i}{M} \tag{1}$$

Since the frequency content we are interested in is located below 250 Hz, different values of the window size have been tried out until the high frequency content is eliminated. The raw data is shown in Fig. 5 a), with its frequency spectra (b)), and then the filtered data and its frequency spectra (Fig. 5 c) and d)).

Fig. 5. Vibration data. a) Raw data. b) Fourier analysis of the raw data. c) Moving average with window size of 5 points. d) Fourier analysis of the filtered data.

The speed equation of the PMSM is shown in (2), where n_m the motor rpm, f is the frequency of the inverter's voltage and p are the pole pairs.

$$n_m = f\,\frac{60}{p}\,;\, f = n_m\,\frac{p}{60} \qquad (2)$$

The PMSM has 4 pole pairs (Table 1), so if the motor is running at 300 RPM, the main frequency would be 20 Hz, the second harmonic 40 Hz, and so on. The data obtained shows this behavior exactly (**Fig. 6**).

The results obtained show a relationship with the motor speed that is associated with misalignments in the rotor axis. This causes that the drive has to overcome an extra load at a determined angle, producing the vibration spectra observed.
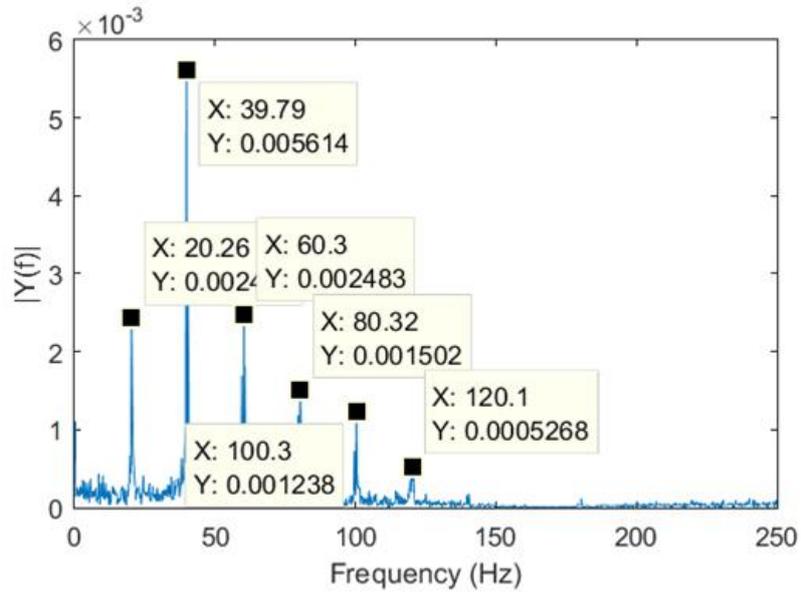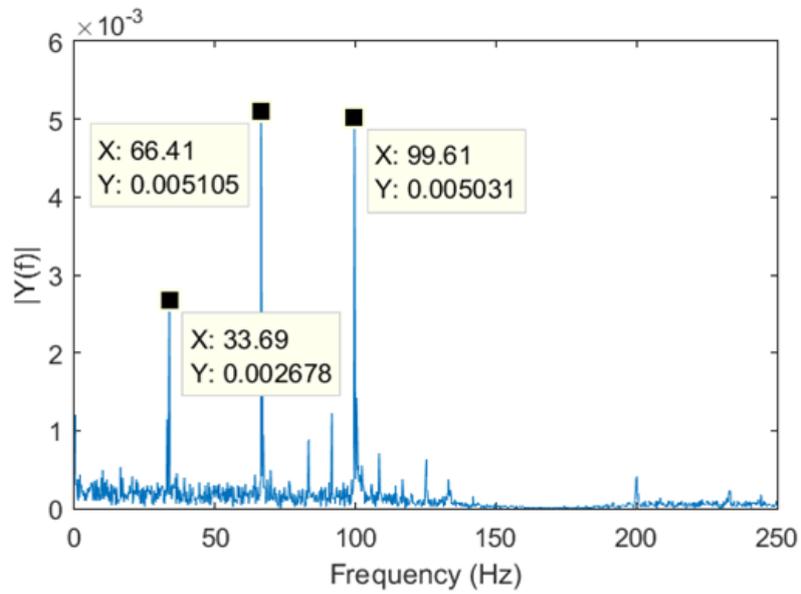
Fig. 6. Peaks separating according to motor speed. (a) Motor speed: 300 RPM. (b) Motor speed: 500 RPM.

5   Conclusions

Experimental analysis for a NVH study has been the method selected and the data obtained processed. The control employed for this work uses a the FOC technique and a PWM algorithm for controlling the inverter which feeds the PMSM. The platform used, dSPACE, allows the user to remotely control the system via TCP/IP protocol and the user interface, ControlDesk, to take advantage of the rapid prototyping. The processing of the data is necessary for the elimination of the high frequency noise.

Using Fourier analysis, a cause for the vibration spectra is deduced: rotor misalignment. For future works, the authors would like to go deeper into the frequency spectra trying to stablish more causes for the vibrations as well as associating the vibrations' amplitude values with the motor speed.

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