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INSTRUMENTATION OF A DIDACTIC ROTATING MACHINE BENCH FOR FAULT DETECTION BASED ON FREQUENCY DOMAIN ANALYSIS

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Abstract. *Rotating machines are widely used in various industrial applications. Condition monitoring and fault detection of rotating machinery play a very important role to maintain these equipment in operant condition and predict potential failures, preventing undesirable accidents and increasing the devices' reliability. An approach for fault detection is vibration analysis, which is better represented in the frequency domain, and consider that rotating machinery presents a specific vibration signature for their standard condition that changes with the development of a fault. Moreover, it is demanding for mechanical engineers have knowledge of instrumentation to make use of predictive maintenance techniques. Therefore, it's essential to adopt methods to improve the learning retention making use of comprehensive experiments integrating the knowledge of these different areas during the students' academic lives. In this paper, a didactic rotating machine bench was instrumented using accelerometers to measure the vibration response and an unbalancing failure was imposed. The vibration was measured in the time domain and then transformed in the frequency domain applying the Fourier Fast Transform (FFT). The results have shown an amplitude change at the first harmonic as expected from the classical vibration theory. This procedure proved to be a simple but useful methodology, which can be reproduced in many teaching institutions lining up the theory and practice.*

Keywords: *Instrumentation, vibration analysis, rotating machines, fault detection, didactic bench*

1. INTRODUCTION

Rotating machines are extensively used in industrial applications, being some of these machines of critical operation (VISHWAKARMA, 2017). A machinery breakdown would result in costly downtime. Therefore, condition monitoring and fault diagnosis play a very important role to maintain these equipment in operant condition and predict potential failures, preventing undesirable accidents and increasing the devices' reliability.

One of the most used approach for fault detection is vibration analysis, which is better represented in the frequency domain. It's considered that a machine, even in standard conditions would present a specific vibrational response what is named vibration signature. However, if the machine undergoes any failure, the vibration feature will be modified. Based on that fact, it's possible to detect faults on machine analyzing the changes in its vibration signature.

Nonetheless, it's necessary to design and implement an efficient instrumentation system capable to detect these changes, and properly condition the data obtained for an appropriate analysis. Hence, mechanical engineers should have not only a vast knowledge of predictive maintenance, but a broad understanding of instrumentation, data acquisition, signal processing, etc.

Accordingly, it's essential to adopt methods to improve the learning retention making use of comprehensive experiments integrating the knowledge of these different areas during the students' academic lives, preparing the undergraduates more conveniently for the labor market.

This article aims to lining up the theory and practice, making use of an experimental methodology to illustrate the use of vibration analysis to fault detection in a didactic bench. An imposed unbalancing failure will cause changes in the vibration response characteristic format, and the effects obtained will be analyzed. It is possible to correlate the fault and its source. This method could be used in industries to predict failures and identify its root cause, so that, corrective action can be proceeded more efficiently.

Since for vibration systems its easier to notice frequency domain responses than in time domain, the Fast Fourier Transform (FFT) is used by the ADS2002 equipment with the conditioner AI2161 from the company Lynx and analyzed through AqDados software.

2. VIBRATIONS

2.1 Unbalanced Machines

One of the main causes of vibration in rotating systems is the presence of unbalancing in the shaft, which can be represented by a mass distanced by an eccentricity of the rotor, as shown in Fig. 1 (RAO, 2012).

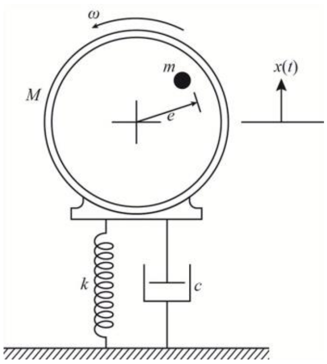

Figure 1. Schematic representation of rotating unbalancing.

A way to represent this type of system mathematically is through the equation (RAO, 2012):

$$m\ddot{x} + c\dot{x} + kx = m_0 e\omega_r^2 \sin \omega_r t \tag{1}$$

The equation above represents the mass m being excited by the mass m_0. Since the homogeneous part of the response of the equation is not the main interest of the study we can use only the particular solution, which is:

$$x_p(t) = X \sin(\omega_r t - \theta) \tag{2}$$

Where X:

$$X = \frac{m_0 e}{m} \frac{r^2}{\sqrt{(1-r^2)^2 + (2\zeta r)^2}} \tag{3}$$

And θ:

$$\theta = \tan^{-1} \frac{2\zeta r}{1-r^2} \tag{4}$$

And r:

$$r = \frac{\omega_r}{\omega_n} \tag{5}$$

In the equations above, X represents the magnitude of vibration, θ the phase angle, ω_r is the angular velocity and r the frequency ratio.

2.2 Measurement Devices - Accelerometers

Some devices used to measure vibration behave as the base-excitation vibration (INMAN, 2013). The base is fixed in the structure that is going to be measured as Fig. 2, so the motion will be transmitted to the mass, thus, the accelerometer measures the vibration by changing the mechanical motion to voltage. This type of device is called transducer.

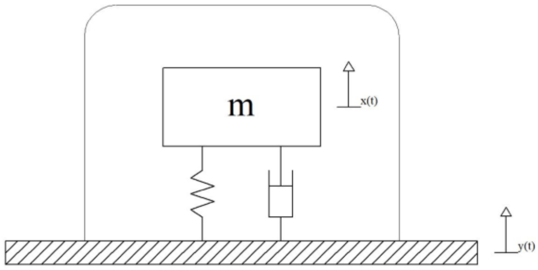

Figure 2. Schematic representation of accelerometer.

To measure vibration, the accelerometer used in this paper (AS-2GA) is built with a strain gauge as sensing element, it's immerse in a chamber with oil to act as damping and it only measures vibrations in one direction. The motion in the structure propagates to the strain gauge, causing its deformation, which can be measured using a Wheatstone bridge and related to the deformity by the gauge factor.

3. FAST FOURIER TRANSFORM

In order to measure vibration, the equipment used applies the fast Fourier transform (FFT), which is an algorithm used to calculate the discrete Fourier transform (DFT) and its inverse. The FFT algorithm takes finite points in the time domain and shows a discrete representation of the signal in the frequency domain, making it easier to notice the response.

There are several types of implementation for an FFT, but the most widely used and efficient method is FFT by frequency decimation that adopts all dimensions of the same size (PEREIRA, 2017).

4. EXPERIMENTAL PROCEDURE

An Automatus Vibrations Analysis Bench was used to simulate the failures that can happen in a real machinery. The bench itself is already unbalanced, so this configuration is used as standard condition of operation.

Before starting the tests it is important to perform the calibration of the accelerometers, in this case two one-dimensional accelerometers were used to measure the vibration in two different directions. The calibration of the accelerometers was performed by fixing them to a goniometer and varying the angulation in a predetermined range of values, so the acceleration measured by each accelerometer was a component of the gravity's acceleration (NEZ, 2016). Calibrated accelerometers were attached to the bearing closest to the rotor that was unbalanced.

To unbalance the rotor, masses were added at the edges of the disk. Two tests were executed at different speeds, the vibration signal was measured in both and acquired by the data acquisition equipment, which makes it possible to obtain the frequency response of this signal. In the frequency response, the influence of the unbalancing on the rotor was analyzed.

5. ACCELEROMETERS CALIBRATION

To proceed with the calibration of the accelerometers, the data acquisition system was used with a goniometer fixed in a surface plate as shown in the Fig. 3. The local value of the gravity used was 9,807 m/s^2.

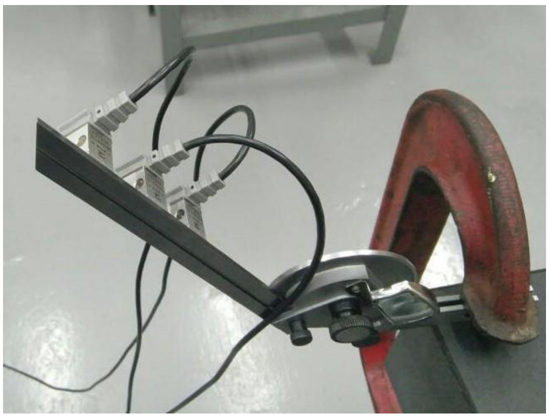

Figure 3. Accelerometers calibration.

A calibration method was used by positioning the accelerometers at 0° according to the goniometer, and recording the voltage shown in the data acquisition system by setting the corresponding gravity value. To calculate the angle increment, the gravity value was divided into fifty components and the increment was calculated to be added to the goniometer in order to obtain the gravity to be recorded. This procedure was done until reaching 90° in the goniometer. In Fig. 4, it's noticed the representation of the measured component g sin (θ).

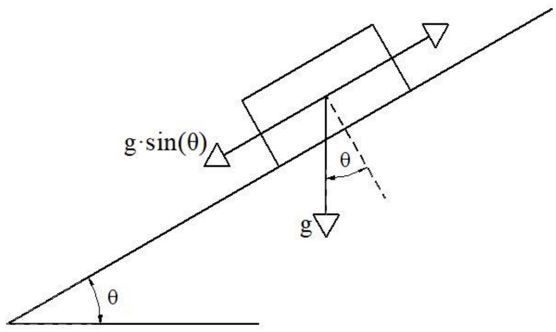

Figure 4. Schematic representation of component g sin (θ).

By having these data registered in the acquisition system, the accelerometers were calibrated and prepared for using in the didactic rotating machine bench. Above, the graph demonstrates the calibration curve of the accelerometers, the data was obtained from the acquisition system.

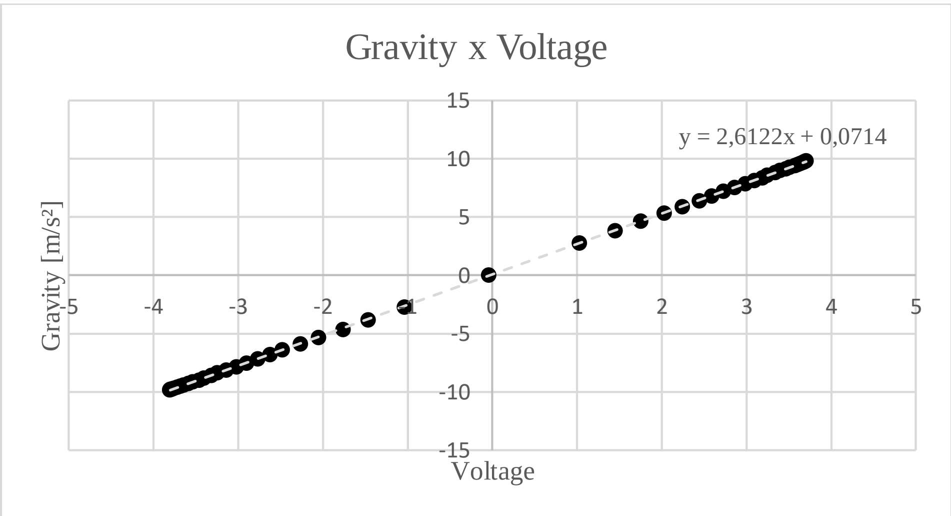

Figure 5. Calibration curve.

6. INTRUMENTATION OF THE BENCH

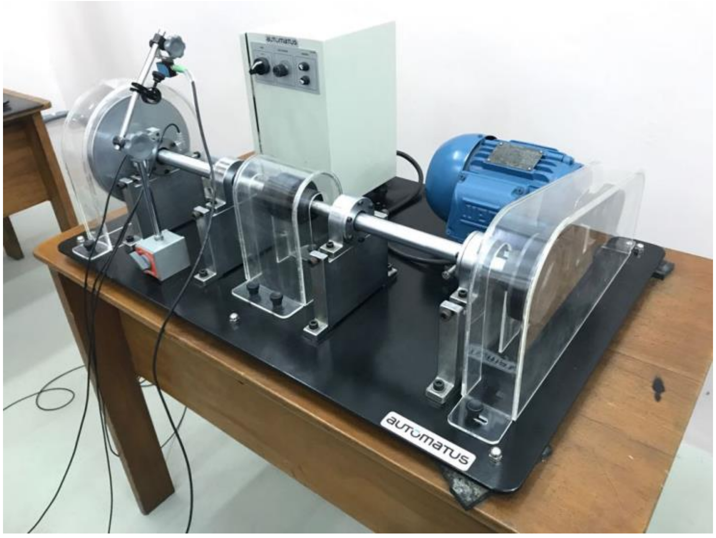

Figure 6. Automatus Vibrations Analysis Bench.

The accelerometers were installed using the proper cyanoacrylate glue recommended by the manual, in the closest bearing to the plane of unbalancing, as shown in Fig. 7.

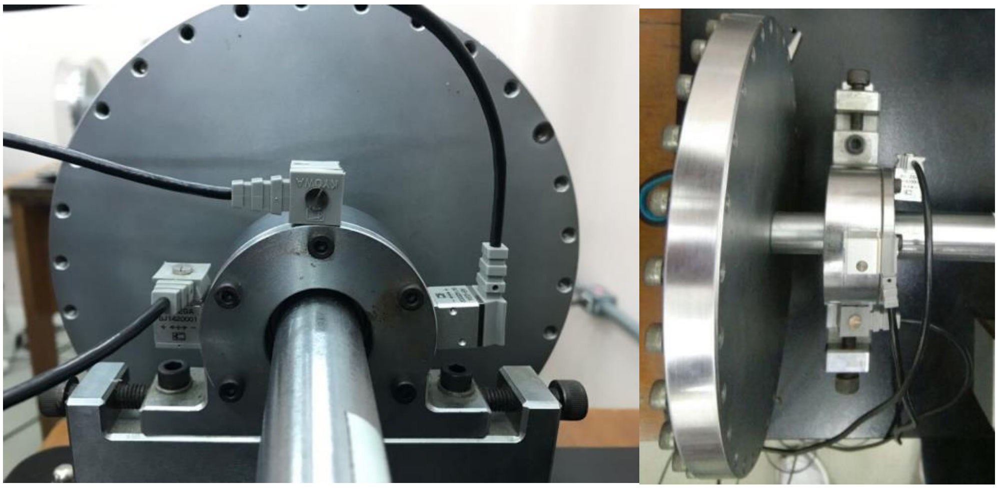

Figure 7. Accelerometers fixed in the bearing.

To proceed with the measurements, the pulleys of the bench were aligned (Fig. 8), all its standard weights were removed, to assemble a specific weight arrangement simulating the unbalancing as shown in the Fig. 9.

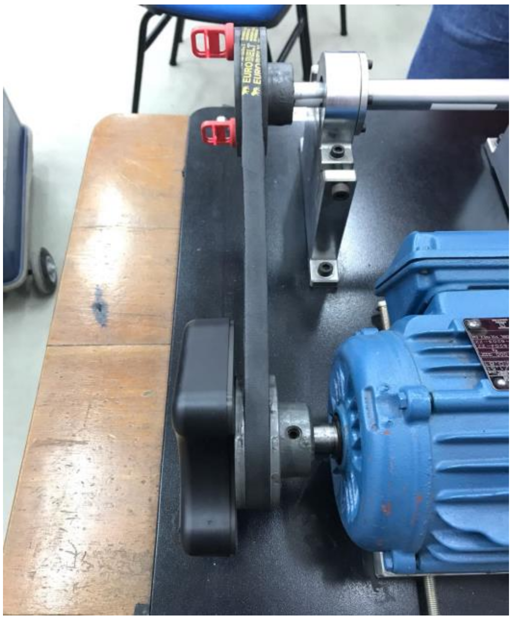

Figure 8. Alignment of the pulleys.

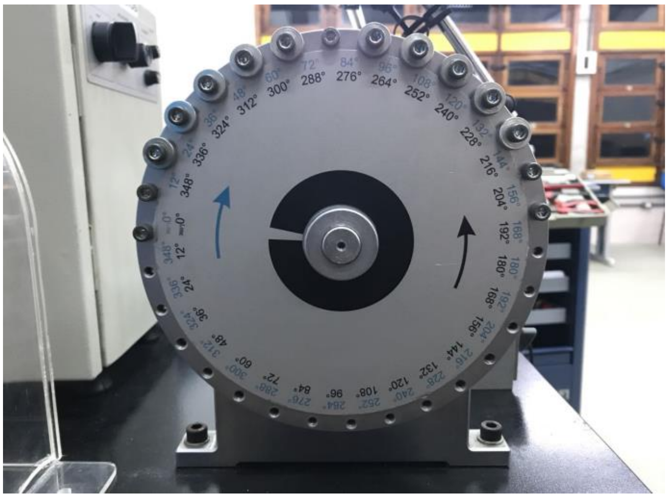

Figure 9. Arrangement of the masses to simulate the unbalancing.

7. RESULTS AND DISCUSSION

With the machine set at 520 rpm, it can be observed in the frequency response for vibration signal in the horizontal direction that the inclusion of masses for the unbalance causes an amplitude increment in the first harmonic (8.67 Hz) and there were no significant variations on the other frequencies. This is also noted in the vertical direction.

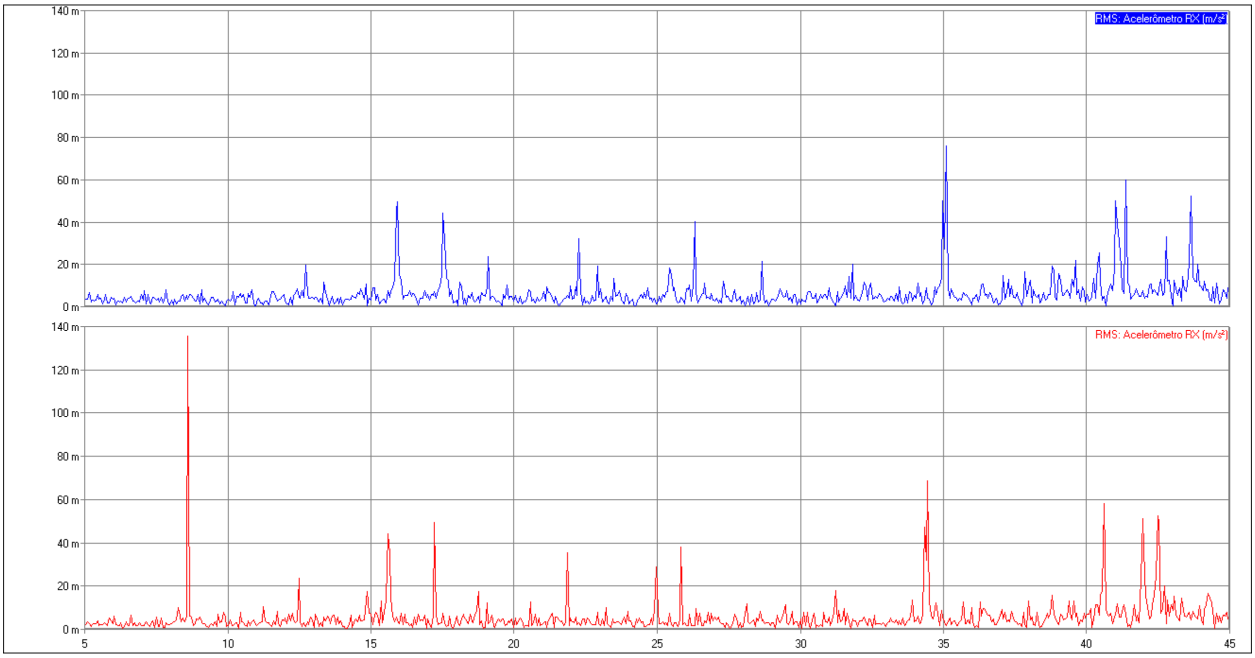

Figure 10. Frequency response for vibration on horizontal direction, operational condition set at 520 rpm. (a) Standard condition; (b) unbalanced condition.

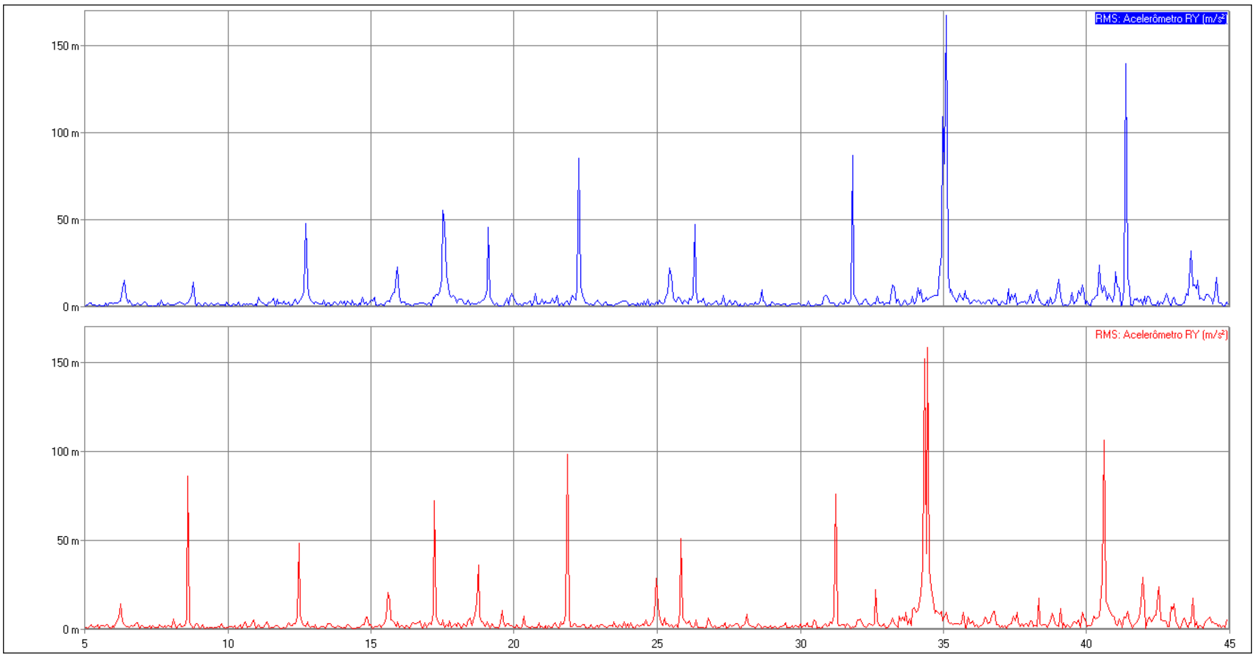

Figure 11. Frequency response for vibration on vertical direction, operational condition set at 520 rpm. (a) Standard condition; (b) unbalanced condition.

Then, with the machine set at a higher rotation at 700 rpm, it can be seen that the frequency response of the vibration signal in the horizontal and vertical directions keep the characteristic observed in the first test, which is the amplitude increment in the first harmonic, in this case up to 11.67 Hz. However, in the horizontal direction, a significant amplitude increase was also observed in the second harmonic and in the vertical direction a variation in the third harmonic.

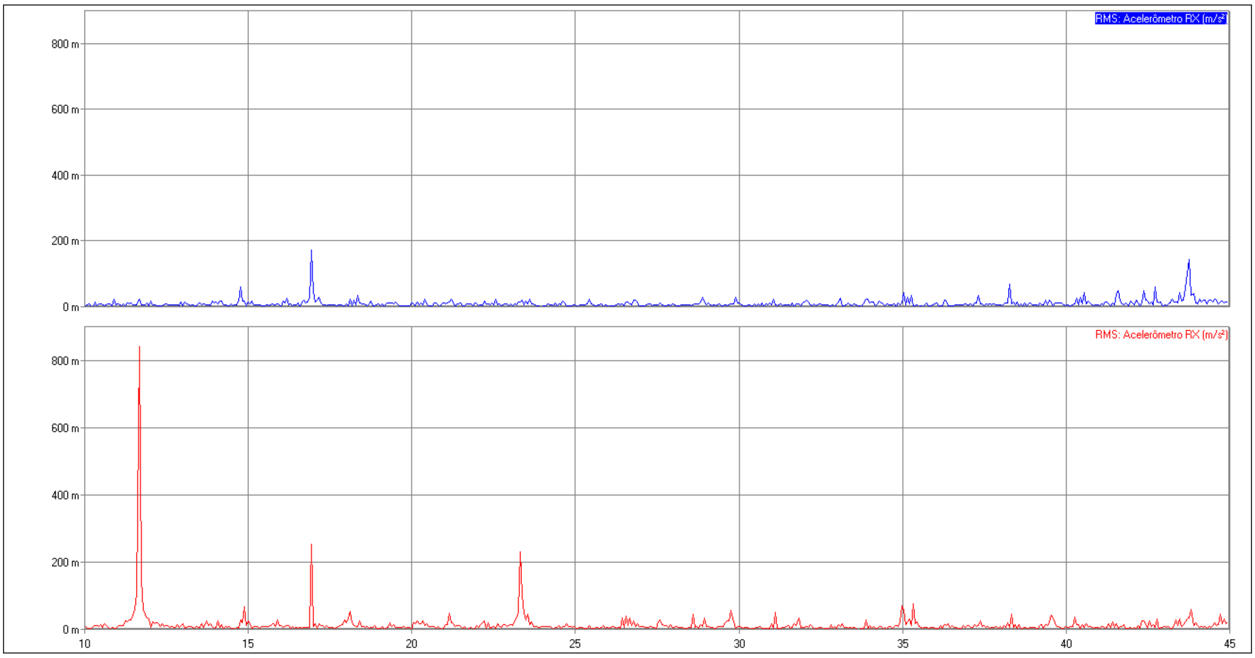

Figure 12. Frequency response for vibration on horizontal direction, operational condition set at 700 rpm. (a) Standard condition; (b) unbalanced condition.

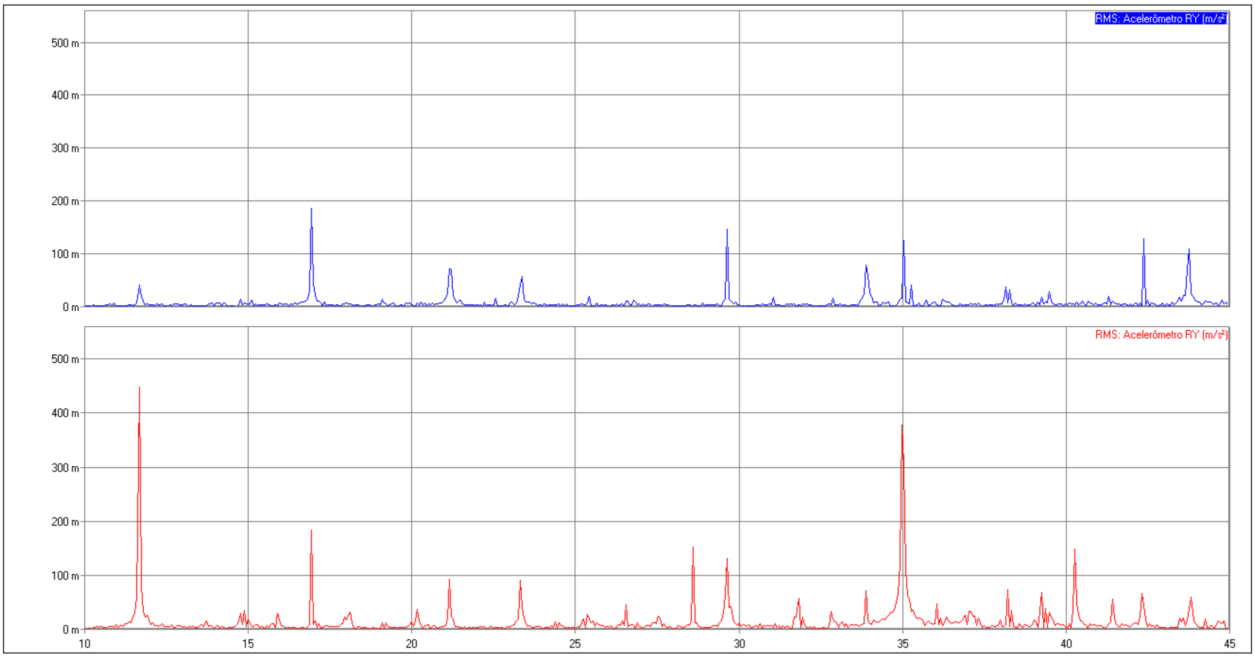

Figure 13. Frequency response for vibration on vertical direction, operational condition set at 700 rpm. (a) Standard condition; (b) unbalanced condition.

It is known from the theory of unbalanced machines that the unbalancing causes vibration to the axis in the radial direction and that the amplitude of the vibration increases according to the angular velocity. Both characteristics were observed in the results of the tests: the first one with the same vibration pattern for the horizontal and vertical directions and the second one with higher amplitude peaks. Therefore, for teaching purposes the test corroborates the theory of unbalanced machines and for a better visualization of the unbalancing influence on the vibration signal a higher angular velocity is indicated.

8. CONCLUSIONS

In this work an experimental procedure was performed, in which a didactic bench with a rotating machine was instrumented, then two tests with unbalanced rotor for different speeds of rotation were executed. It has been noticed in the frequency response of the tests that the unbalancing produces a first harmonic amplitude increment. Thus, an amplitude increase in the first harmonic may indicate this type of failure.

The calibration method of the accelerometers using the goniometer is a simple and practical application that gives good results for the experimental procedure described in this paper.

Also, the procedure showed the ability to demonstrate the practice of unbalanced machines theory. Furthermore, a higher speed rotation is recommended for a better perception of the unbalancing influence on the frequency response. For future works, a similar technique should be used for fault diagnosis and prognosis in other mechanical components such as gears and bearings.

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10. RESPONSIBILITY NOTICE

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