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DIAGNOSIS OF DEFECTS IN ROTARY MACHINES THROUGH VIBRATION ANALYSIS

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Abstratct. *The monitoring of the operating conditions of a machine from the analysis of vibrations is a technique that has been little used in industry, however, there is already evidence that from medium to long term, predictive maintenance has a very high efficiency. The present work will consist of a study about vibration applied in the predictive maintenance of a rotary machine. Companies today can not see the benefits of well-developed predictive maintenance. Therefore, this work shows what a predictive analysis is capable of diagnosing through a vibrational analysis of a rotating component. This analysis was done using an accelerometer together with a data collector and computational software, which generates frequency spectra. The spectra will allow the observation of the operating conditions of the machine, allowing to verify if it is in proper conditions of operation, according to ISO 2372. In the present work were analyzed some mechanical components of a factory, which had some kind of defect, with the aid of the vibration analysis equipment it was possible to check the state of the current equipment of its components.*

Keywords: *Vibration Analysis, Predictive Maintenance , Machines Rotary, Spectrum Frequency, Time Domain*

1. INTRODUCTION

The objective of this paper is to show the spectra of defects in rotating machines, as well as the theoretical basis for the diagnosis of these spectra, which is an essential data for the elaboration of a predictive maintenance plan. This type of maintenance is fundamental to solve problems of vibration of the machines, fact that have worried the engineers and technicians of everywhere. As vibration reduction techniques became an integral part of the machine design itself, the need to measure and analyze the mechanical vibration became more and more widespread (Salomão Filho, 2013).

Vibration can be described as the oscillatory movement of a body in relation to a reference system (RAO, 2008). That is, the movement of a body around its equilibrium position.

In practice, it is very difficult to avoid mechanical vibration. It usually occurs because of the dynamic effects of manufacturing tolerances, clearances, contacts, friction between the parts of a machine and also due to unbalanced forces of rotating components and alternating motions (MARÇAL, 2005). It is common for insignificant vibrations to excite the natural frequencies of other parts of the structure, causing amplitudes of vibration to be amplified, transforming into highly destructive vibrations and noises for the health of man and machine (SEBASTIÃO, 2007, 2005).

When we analyze vibrations from a rotating machine, for example, we find a significant number of components at different frequencies, which are directly related to the fundamental movements of various machine parts. Therefore, through the frequency analysis, we can discover the cause of the vibrations and, through monitoring the evolution of the various components of the vibrations, detect defects and predict faults in the machine components (TAYLOR, 1994; BURBANO, 2005).

In order to obtain the objective of this work, a bibliographical review was carried out on general notions of vibration frequency analysis, acquisition of vibration data through transducers and diagnostics of rotating machine failures, such as: unbalance, misalignment, and defects in rolling bearings. The literature review followed the line of thinking of several authors, such as: Taylor (1994); Kardec, Nascif, & Baroni (2002); Burbano (2005); Marçal (2005); Abreu (2007); Sebastião (2007); Rao (2008); Dias (2009); Barilli (2013); Salomão Filho (2013); Soares (2015).

2. DEVELOPMENT

In a rotating machine, the various components can be revealed and quantified by recording the vibration amplitude as a function of its frequency. The graph showing the level of vibration as a function of frequency is called the spectrum. The subdivision of vibration into individual frequency elements, called frequency analysis, is a fundamental technique for the diagnosis of vibrations (ABREU, 2007).

When we analyze vibrations of a machine, we usually find a significant number of components at different frequencies, which are directly related to the fundamental movements of various machine parts. Therefore, through the frequency analysis, we can discover the cause of the vibrations and, by monitoring the evolution of the various components of the vibrations, detect defects and predict faults in the machine components.

There are important parameters that must be understood in a vibratory movement. The frequency is the number of oscillations that the movement performs in a certain time.

All matter has a frequency, where it is called natural frequency, which is termed as the free vibration frequency of a body and depends basically on body mass and rigidity (RAO, 2008). The natural frequency is calculated as shown in Eq. (1):

$$f_n = \frac{1}{2\pi} * \sqrt{\frac{k}{m}} \quad (1)$$

Where f_n is the natural frequency, k is the rigidity of the system and m is the mass.

Another important parameter is the time the oscillating body takes to cycle. This time is called the period and it is the inverse of the frequency (RAO, 2008). Shown in Eq. (2):

$$T = \frac{1}{f} \quad (2)$$

Amplitude is the magnitude or size of the vibrating motion. The unit of measure of this parameter depends on what quantity is being used: displacement, velocity or acceleration. The amplitude is related to the amount of energy contained in the vibratory signal showing the criticality of the present events (RAO, 2008).

There are two ways of observing the vibratory movement, through the time domain and the frequency domain. The two domains observe the same dynamic signal from two different angles.

The time domain is a two-dimensional amplitude display on the vertical axis along time along the horizontal axis, while the frequency domain sees the amplitude on the vertical axis with frequency displayed on the horizontal axis. Think of these two domains as two windows placed 90 ° apart. The following Fig. (1) illustrates this difference very well.

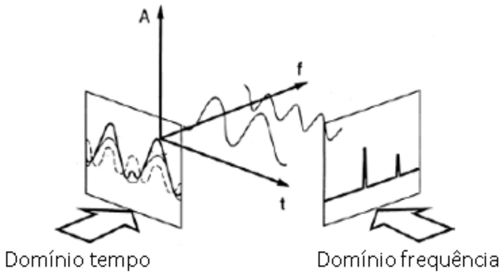


Figure 1. Vibration analysis in time domain and frequency domain

The most commonly used domain for vibration analysis is frequency domain. This is one of the most powerful techniques for monitoring machine conditions. Diagnostic-capable predictive maintenance instruments should display frequency domain vibration. The description of this form is called the spectral form or simply the Vibration spectrum.

To simplify this process, modern vibration analyzers use the Fast Fourier Transform (FFT). An FFT is a transformation of time domain data (amplitude X time) into frequency domain data (amplitude X frequency), made by a computer. We can, in this domain, verify which frequency spectrum is most relevant in the global spectrum of vibration (SOARES, 2015).

Measuring vibrations simply consists of transforming the mechanical signal from the vibrations into a measurable signal. Transducers, instruments that translate one type of energy form into another, or translate a physical, chemical quantity into another, are the devices used to verify these signals. A loudspeaker, for example, converts electrical energy into sound energy, whereas the microphone does the opposite conversion (KARDEC, NASCIF, & BARONI, 2002).

Based on the physical phenomenon used for conversion, it is possible to have transducers sensitive to the displacement, the speed of the moving parts and the acceleration.

The displacement transducers are sensitive to relative motion, for example, the distance between the fixed sensor in a bearing and a vibrating shaft. The principle of operation can be based on electrodynamics or capacitance variation, and consists of a coil immersed in a magnetic field and anchored through low resilient supports.

The speed transducers basically consist of coil wound on a mass suspended by a spring and surrounded by a permanent magnet fixed to the housing. This is an absolute sensor that measures the vibration velocity of the point at which it is fixed, relative to a fixed point in space.

Accelerometers are a class of transducers whose response is proportional to acceleration, and represent the development present in the field of vibration measurement and analysis.

When a frequency spectrum is analyzed, it will give us a north to be followed so that some kind of fault can be discovered. Some of the possible defects that can be found through vibration analysis are: unbalance, misalignment, clearances, and defects in rolling bearings.

Defects can be detected and assessed by monitoring vibration levels, while diagnosing their origins is done by identifying characteristic symptoms present in the spectrum and waveform of vibrations. In certain cases the phase relations between the vibrations of several points must be considered, to confirm the diagnoses (TAYLOR, 1994).

By gaining a basic knowledge of the vibrational patterns generated by the various defects and by learning to apply some basic rules of observation, the vibration analyst will be able to generate a great saving on the company, detecting potential failures in the equipment and revealing its origins without interrupting the process productive.

Detect defects in advance, it is possible to carry out an early planning of corrective interventions, defining the most opportune moment for their realization, in order to minimize their impact on production, and reducing the time and costs of interventions by the anticipated knowledge of the components to be replaced and the elimination of the exchange of components with a still remaining remaining useful life. Some types of defects in rotary machines are discussed below.

Unbalance of a rotor is caused by the mismatch between its center of mass and its rotational center due to assembly errors, fouling, wear, rupture or loss of components such as turbine vanes (TAYLOR, 1994; SOLOMÃO FILHO , 2013).

The symptoms of this type of failure are the high vibrations in the radial direction, with predominance of the 1N component, which is the first harmonic peak of the spectrum. Amplitude of the 1N component increases with increasing rotation, amplitude of the 1N manifolds are not high and the vibrations in the axial direction are not high. Fig. (2) shows the frequency spectrum for an imbalance fault.

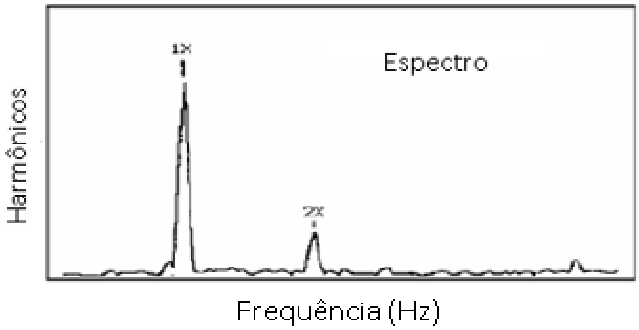


Figure 2. Frequency spectrum in an unbalance defect

Misalignment occurs when the axes of two coupled machines have angular or parallel displacement when the center of one of the bearings is not aligned with the other, or when one of the bearings is tilted relative to the others ("jambrado"). The misalignment can be caused by assembly errors, foundation rebounding, thermal expansion, structural deformation or coupling locking (TAYLOR, 1994; SOLOMÃO FILHO, 2013).

What shows that some element is misaligned are the high vibrations in the radial and axial directions, with predominance of components 1N, 2N or in certain cases 3N, as can be seen in Fig. (3).

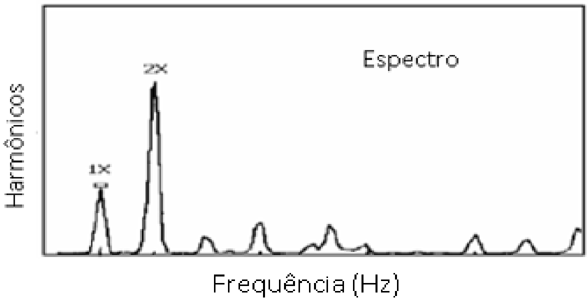


Figure 3. Frequency spectrum in a misalignment defect

The clearances are present in two categories: structural or rotating elements. Clearances may be caused by assembly errors, excessive wear, foundation or base damage, cracking or breakage of fastening components (TAYLOR, 1994; SOLOMÃO FILHO, 2013).

What shows the gaps in the frequency spectrum are the high vibrations in the radial directions, with high amplitudes in almost all the components, as shown in Fig. (4).

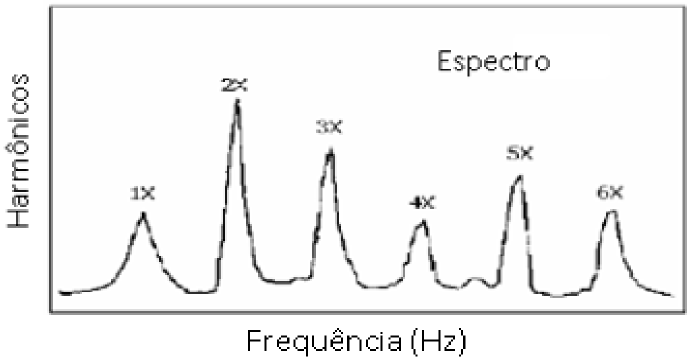


Figure 4. Frequency spectrum in a gap defect

Incorrect selection, overload, manufacturing defect, misalignment, "jambing", improper storage, improper lubrication, incorrect assembly and failure to seal are possible causes for bearing defects. (TAYLOR, 1994)

In order to detect defects in bearings, the frequency spectrum of axial and radial vibrations must be carefully examined in order to identify harmonically related peaks of frequencies not synchronous with rotation. The basic frequencies generated by rolling bearing defects are the cage passing frequency (FTF), ball rotation (BSF), external runway fault (BPFO) and internal runway (BPFI). One or more of these frequencies, with their harmonics can appear in the spectrum (TAYLOR, 1994; DIAS, 2009; BARILLI, 2013). The failure frequencies of bearings are shown in equations 3, 4, 5 and 6.

$$FTF = \frac{S}{2} * (1 \pm \frac{d}{D}\cos\theta) \quad (3)$$

$$BSP = \frac{Sd}{2D} * [1 \pm \left(\frac{d}{D}\cos\theta\right)^2] \quad (4)$$

$$BPFO = \frac{SN}{2} * (1 - \frac{d}{D}\cos\theta) \quad (5)$$

$$BPFI = \frac{SN}{2} * (1 + \frac{d}{D}\cos\theta) \quad (6)$$

Where, θ is the contact angle, S rotational speed, N is the number of rotating elements, D is the primitive diameter, and the diameter of the rotating elements.

Generally harmonics of order 4N to 6N are the highest in the velocity spectrum, when the defect is in the intermediate stage. When the defect progresses, the harmonic amplitudes of smaller order increase. Generally, if the fundamental frequencies are predominant the defect is severe and the remaining life is quite short (Dias, 2009).

Defects in bearings develop slowly and emit signals well in advance of the final failure, which can occur by locking or rupturing components. Typical defects that evolve in this way are: scratches on tracks, rollers or balls, pitting, cracking, corrosion, erosion and contamination. The most conventional techniques for the prediction and location of these defects are: Fast Fourier Transform (FFT) spectral analysis, cepstrum and envelope analysis (SOARES, 2015). The following Fig. (5) exemplifies a defect in the inner race of a bearing, shown by an envelope analysis.

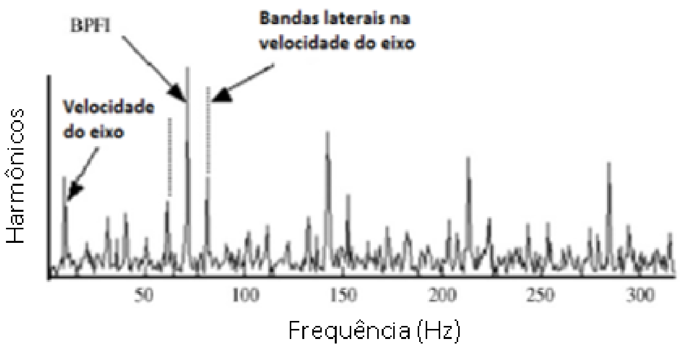


Figure 1. Envelope analysis, show a defect in the inner race of a bearing

3. MATERIALS AND METHODS

In this topic will be shown the equipment used and the equipment that were collected the spectra of vibrations to diagnose their behavior. The equipment analyzed is used in the cement production industry.

3.1 Description of the equipment

Figure 6 shows the collector with the rozh sensor that will be used to perform data collection to follow the diagnosis.

Figure 6. Collector and Vibration Analysis Sensor: Rozh

3.2 Details of Machines

The machines that will collect the vibration data for diagnosis are shown in Table 1 below:

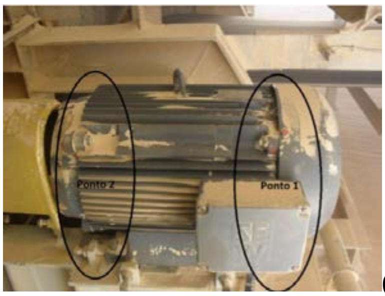
Identificação	Descrição	Rotação (RPM)	Potência (Hp)
Componente1	Motor Elétrico de uma transportadora de correias	1780	18
Componente2	Motor Elétrico do Separador	1760	50
Componente3	Mancal do eixo de um Ventilador	1790	10

Table 1. Description of the components

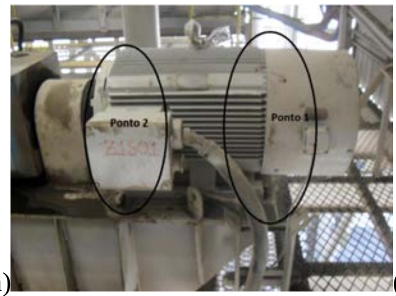
3.2.1. Analyzed Components

Component 1 refers to an Electric Belt Conveyor Motor used to transport limestone after it undergoes a grinding process on the Crusher. Component 2 refers to an Electric Separator Motor, where it is used in the process of separating cement grains with larger grades, in which they return to the grinding process, of smaller grains, already in the size specified by standard for this type of product. Component 3 refers to a Bearing that is mounted with an axis in the inlet of a Fan of an Air Slide.

Figure 7 shows the measurement points of the components, such as this type of motor, usually has two internal bearings, so they will be the points to be analyzed. The analysis was performed at the same points for each electric motor, however they are equipments that have completely different functions and requests. For the fan it was analyzed only at one point as shown in Fig. (7) (c). The measurements on each piece of equipment and its respective points will be obtained in the vertical, horizontal and axial positions.



(a)



(b)

(c)

Figure 7 - Points at which the vibrations will be collected - (a) Electric motor belt conveyor; (b) Separator electric motor; (c) Air Slide fan motor.

4. EXPERIMENTAL PROCEDURE

The vibration spectrum is obtained at different points in the equipment. The sensor is positioned on the bearing because this location has a better vibration pickup point as it transmits vibration to the machine frame. Figure 8 shows the numbering of the sensor positions.

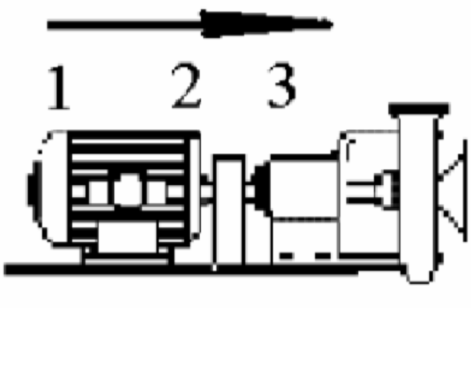


Figure 8 - Numbering convention for bearings and measurement points

The summary of the correct procedure is shown in Fig. (9), in case the spectrum has a diagnosis that this machine is good, it will serve only to make a history and be able to follow some possible defect that may arise over time, if Otherwise, planning should be done so that you can optimize the time the equipment will be stationary and thus lower the costs with a corrective maintenance that is the main objective of the vibration analysis in the predictive.

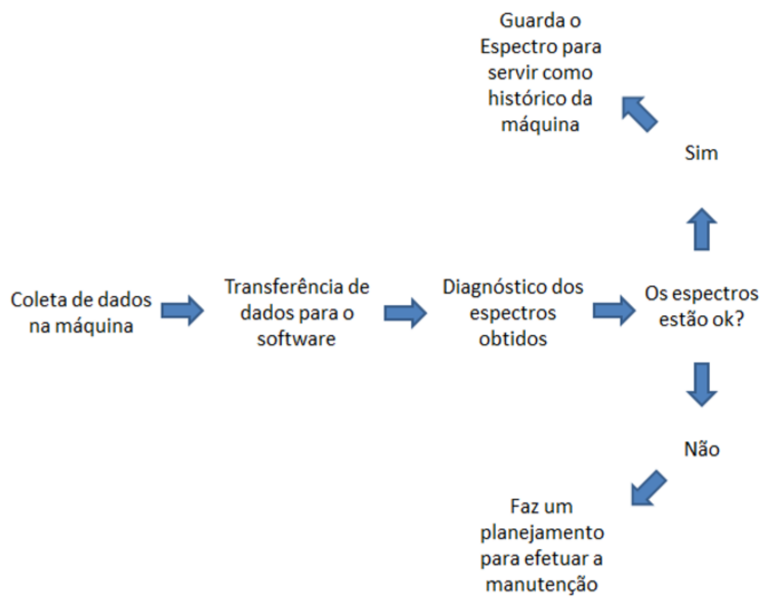


Figure 9 - Flow chart for vibration analysis procedure

5. RESULTS AND DISCUSSION

5.1. Component Spectrum Analysis 1

The frequency spectrum of Component 1 is shown in Fig. (10), containing a type of vibration that resembles a misalignment fault, because the second harmonic (2N) exists and has an amplitude that does not differ much from the fundamental harmonic (1N).

However, according to ISO 2372, equipment with this amplitude, considering the power of 18 Hp and a maximum peak value of approximately 0.52 mm / s, we can see that the equipment operates under permissible conditions (B).

What is needed is a more rigorous monitoring, if the vibration collection of this equipment before was monthly, to follow better, it is necessary that now is every two weeks, to follow the effects of this misalignment closely and only intervene when this equipment is in a slightly more critical state causing it to use full capacity.

Over time, all equipment has a tendency to worsen the state in which it is, for this reason, as Component 1 is in a class B situation, it is possible to follow this one without immediate intervention, thereby creating a growth pattern and predicting when this machine will be in a critical state for this misalignment to be corrected by conventional methods, such as a laser alignment, for example.

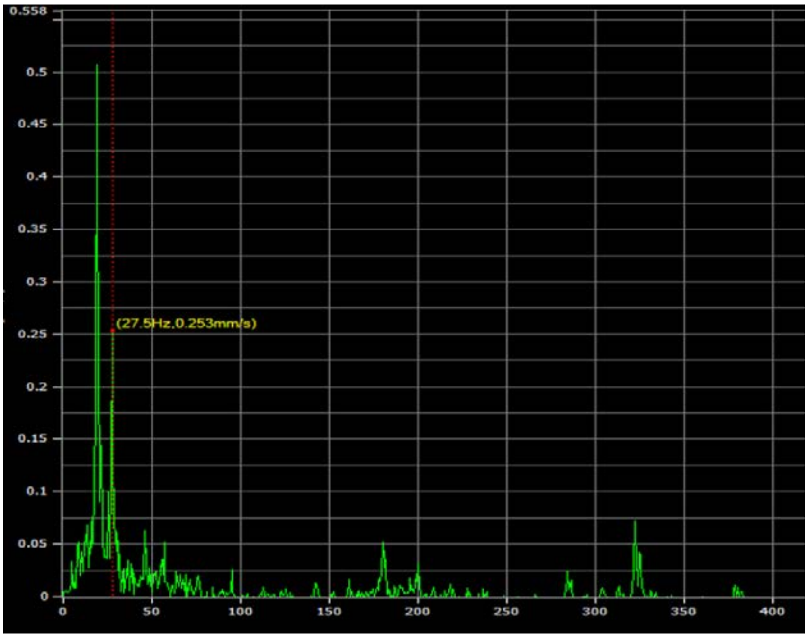


Figure 10. Vibration Spectrum Component 1

5.2. Component Spectrum Analysis 2

The frequency spectrum of Component 2 is shown in Fig. (11), containing a type of vibration that resembles an imbalance fault because the fundamental harmonic (1N) has a frequency with a high amplitude and there are no frequency peaks in its harmonics .

According to ISO 2372, the equipment having 50 Hp and having a maximum peak value of 2.7 mm / s, is already starting to exceed the limit of "acceptable" and reaching the limit of "tolerable" (C) .

This fact leads us to require maintenance planning to intervene in the equipment in order to adjust the balance of the equipment. In order for this maximum working peak of the equipment to decrease and thus the motor to operate in less severe conditions.

The balance of this equipment should be done more immediately, since this is already in Class C, which leads us to a more immediate intervention of this component balancing it to remedy the problem.

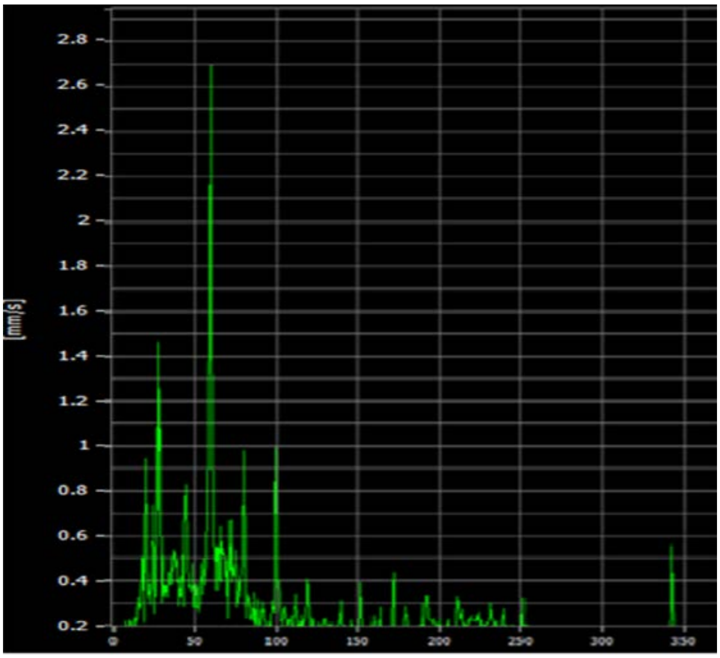


Figure 11. Vibration Spectrum Component 2

5.3. Spectrum Analysis of Component 3

The frequency spectrum of Component 3 is shown in Fig. (12), containing a type of vibration that resembles a gap fault, because the fundamental harmonic (1N) has a high amplitude frequency and its harmonics have a characteristic peak.

According to ISO 2372, the equipment that has 10 Hp and has a maximum peak value of 1.4 mm / s, is in class (C), for this type of machine, which approximates the equipment of the fault, soon it is necessary to make a plan for this bearing so that this problem is solved.

Problems like slack are simpler to solve, it will be necessary to list all the equipment that is involved in the place and to verify screws and fixations of each one to repair if there is some of these with slack or with problems in the fixation, so that, in this way, it can solve the problem.

Vital equipment for a company has to work at the limit of its useful life, so the role of predictive maintenance is to monitor the equipment and as the values move away from what is permissible or tolerable, organize an intervention with the planning and thus decrease any cost it would have compared to an unplanned stop.

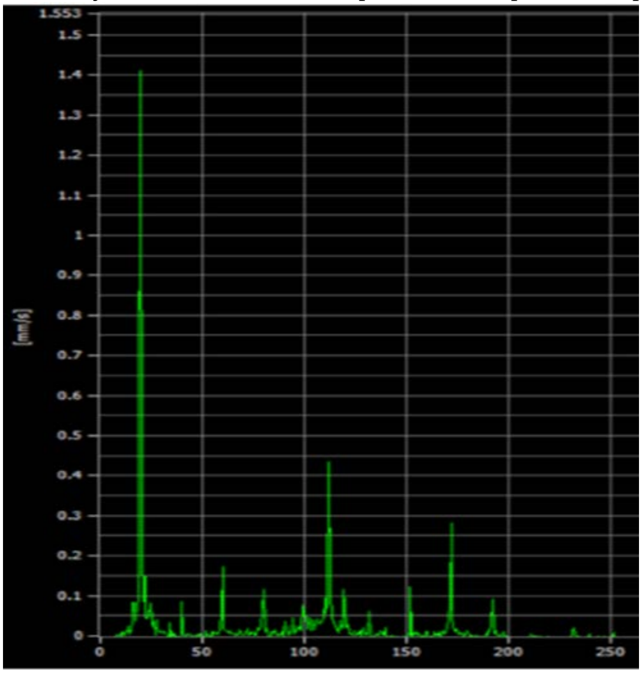


Figure 12 Vibration Spectrum Component 3

6. CONCLUSION

In this work, it was made the identification of different types of failures that occur in bearings, through techniques of vibration analysis applied in artificial signals.

The characterization of the faults that the component can present was demonstrated by the identification of harmonics corresponding to the faults in a frequency spectrum, obtained by the use of an accelerometer and a computational tool. These characteristics make it possible to extract important information about the state of the mechanical components and the possible faults that these components may present.

The results obtained in this work demonstrate how the frequencies of the components behave through different types of faults. With the information acquired through the analysis of vibration it is possible to plan a repair, avoiding an unexpected stop of the machine. From this study, it is a suggestion for future work, the accomplishment of laboratory tests to confirm the method and to improve the algorithms used.

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