E.T.S. de Ingeniería Industrial,
Informática y de Telecomunicación

Vibration Analysis Techniques included in the Predictive Maintenance Plan of a Paper Machine

Grado en Ingeniería
en Tecnologías Industriales

Trabajo Fin de Grado

Realizado por: Paula Ibarrola Gutiérrez

Director: Francisco Javier García

Pamplona, a 12 de Junio de 2019

upna
Universidad
Pública de Navarra
Nafarroako
Unibertsitate Publikoa

ACKNOWLEDGEMENTS

I would like to thank my family for their continued support during these 4 years.

Also, I would like to thank my coordinator, Francisco Javier García, for his guidance during the realization of this project.

Finally, I would like to thank the personnel of the maintenance department of Smurfit Kappa Navarra, in which this project has been carried out.

ABSTRACT

The present project is practical study of the vibration analysis techniques included in the predictive maintenance plan of one of the paper machines located in Smurfit Kappa Navarra.

In the present project different topics are studied. First of all, there is an introductory part related to the fundamentals of vibration theory and measurement. Then, the productive process in the machine is explained, as well as the technology used to measure the vibrations in the different elements of the mentioned machinery. Finally, there are some real examples, where there is a description of the location and function of certain equipments, ending with the frequency analysis corresponding to a certain date in the machine history.

Keywords: vibration analysis, frequency, spectrum, amplitude, paper machine.

INDEX

LIST OF FIGURES

LIST OF TABLES

LIST OF ANNEXES

REPORT

1. INTRODUCTORY PART

1.1. Aim of the project

The aim of this project is to explain the functioning and the efficiency of the techniques of vibration analysis used in the predictive plan of one of the paper machines in Smurfit Kappa (using portable devices and a monitoring system), as well as providing real examples of different vibration spectrums, along with an explanation of the failure associated with the spectrum.

Also, the objective of this project is to study this topic from a practical point of view. The examples shown in the final part of this project are analysed from a completely practical point of view, which means the analysis shown are carried out each day in companies with a predictive maintenance plan.

1.2. Scope of the project

The present project contains the following information.

- The theoretical and historical frames of vibration analysis.
- The basics of vibration
- The characteristics of the paper machine in which the predictive plan is applied.
- The software used in the monitoring system.
- The portable vibration measurement devices.
- Real examples of the system application.

1.3. Justification

The topic of the present project has been chosen due to different reasons. First of all, vibration technology is a quite interesting topic from my point of view, as vibration analysis allows to predict whether a specific element of an equipment will fail, still being a non-destructive technique. Apart from that, the studied vibration techniques and the software used are rather new, as the monitoring system was implanted in 2016, which means the system installed is modern.

1.4. Location

This project has been developed in the company Smurfit Kappa Navarra (SKN). Smurfit Kappa Navarra belongs to Smurfit Kappa Group (SKG), an international company with 350 locations worldwide, which produces a wide variety of packaging solutions and different kinds of paper and cardboard, as well as providing other companies with packaging machinery.

Smurfit Kappa Navarra produces Kraft MG Paper, well known for its outstanding characteristics, for example, its humidity resistance. In this company, there are three paper machines, Paper Machine 2 (PM2), Paper Machine 3 (PM3) and Paper Machine 4 (PM4). The PM4 was the result of the modification of the PM1 in 2016.

The vibration monitoring system developed in the present project is installed in different elements located in the PM4, while the portable devices are used for the whole factory equipment (but only the application to elements corresponding to the PM4 will be studied).

2. HISTORICAL FRAME

Maintenance techniques were born during the industrial revolution, with the mechanization of the different industries. Machinery failures began to be taken into account, as they were provoking stops in the production process, which meant great profit losses. These first analysed failures were mainly due to incorrect use of the machinery.

Therefore, the maintenance history [1] has always been linked to technological and industrial development. At that time, maintenance had a bit part, which means machines were only repaired when continuing with its functioning was impossible. In other words, maintenance was considered a last resort.

With the beginning of First World War and the implementation of the chain production, the need of maintenance equipment that would enable industries to perform fast repairs appeared. Thus, **corrective maintenance** was born. This implied that machinery availability was never assured, and the industry worked at mercy of its equipment. This situation led to time and profit wastes.

During the 1950s, a Japanese group introduced a new point of view, which basically consisted in following the supplier recommendations about the attention that should be payed to the use and maintenance of the equipment. Periodic repairs started to be programmed and industries started to keep record of regular equipment failures. This new concept was called **preventive maintenance**.

However, the degree of uncertainty was very high, as it was complicated to determine when the machinery should be checked. To get rid of this drawback, **predictive maintenance**, which consisted in analysing the operative state of the equipment, was introduced. This technique is based on the fact that the majority of machine elements will show failure symptoms.

To properly carry out a predictive maintenance, the most used technique is the **vibrations analysis**, as it has been proved that vibrations give the greatest amount of information about the machine state. This technique has become a sophisticated tool as time passed. The first vibrations analysers were hearing and touch senses. Nowadays, these are still used due to the fact that, when trained, failure patterns and specific vibrations signatures can be easily recognized.

However, the necessity of keeping record of the measurements and working with numerical values began to grow as time passed. To fulfil these requirements, mechanical and electronic devices began to be developed [2]. The first measurement systems were introduced in the 50s and were able to measure the overall vibration level of the machinery. Later on, analogical filters were developed, so that something similar to vibration spectrums could be studied. In the 70s, the introduction of the FFT (Fast Fourier Transform) analysers enable a fast obtaining of vibration spectrums. However, these new devices were only suitable for laboratory purposes, as they could weigh up to 35 Kg.

In the 80s, thanks to the introduction of microprocessors on one silicon chip, the first portable signal analysers appeared. These devices, together with a software that keeps record of data, enabled the application of vibration analysis in machinery maintenance as it is nowadays.

3. THEORETICAL FRAME

3.1. Maintenance Methods

There are three main types of maintenance: corrective maintenance, preventive maintenance and predictive maintenance. In the present section, the three of them will be explained, as well as their advantages and disadvantages.

3.1.1. Corrective Maintenance

This method is also known as “crisis maintenance”. Corrective maintenance is the most traditional type of maintenance, and the first applied in industries. It consists in repairing or replacing a broken item or equipment when it breaks down, so that it can return to full working condition as soon as possible.

In Table 1 the most remarkable advantages and disadvantages [3] are appointed, and explained in the following paragraphs.

ADVANTAGES	DISADVANTAGES
Low short-term costs	High long-term costs
Minimal planning	Unpredictability
Simplicity	Unexpected stops
Most suitable solution (in some cases)	Not efficient machine preservation

Table 1: Advantages and disadvantages of corrective maintenance

- Advantages

First of all, there is few planning involved, which results in no time losses. As a consequence of the minimal planning, costs related to administrative or financial issues are low or non-existent. Also, just a few technicias are needed.

Apart from that, the process is quite simple as repairs are only carried out when failures appear.

Due to the mentioned advantages, corrective maintenance may sometimes be a better alternative than preventive maintenance, which could involve higher investment of assets.

- Disadvantages

As the machinery state is not checked, the failures are unpredictable. This situation can lead to undesirable periods of inactivity in the manufacturing process, whose duration can increase depending in the materials availability. Also, as the machinery is not being care taken of, its lifetime can be remarkably reduced. These facts results in higher long-term costs.

As it has been said in the advantages paragraph, corrective maintenance is a more suitable option than preventive maintenance, as the costs it involves is less. However, serious unpredictable failure can appear, in which case the necessary actions to be taken in order to fix it can be a very tedious process. As a consequence, the periods of inactivity can dramatically increase, leading to a decrease in benefits and reputation.

3.1.2. Preventive Maintenance

Preventive maintenance is a more advanced method than corrective maintenance, and it is also known as "periodic maintenance" or "historic maintenance". This technical activity consists in fostering a regular inspection and fine-tuning of the equipment, in order to increase the equipment useful lifetime. These regular repairs are programmed taking into account the machinery failure record.

Also, it is taken into account that the lifetime of a numerous elements evolves according to "the bathtub curve" [4], that shows a relation between the number of failures and the functioning time.

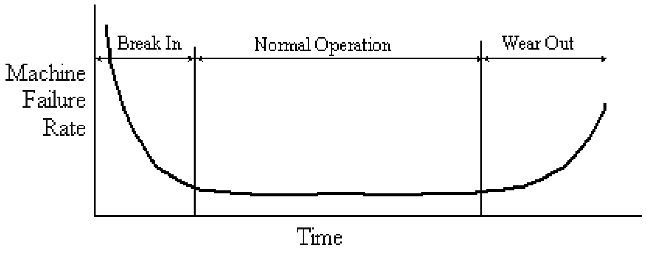


Fig. 1: Bathtub curve

The most important advantages and disadvantages [5] are listed in Table 2 and later explained.

ADVANTAGES	DISADVANTAGES
Low long-term costs	High short-term costs
Increased equipment life	Over maintenance
Less energy consumption	More complex planning
Less periods of inactivity	Catastrophic failure is still a risk

Table 2: Advantages and disadvantages of preventive maintenance

- Advantages

Unlike in the previous method, a regular inspection of the machinery is carried out, which leads to lower long-term costs as failures related to factors like corrosion and wear, among others, are in most cases avoided. As a result of this programmed maintenance, the equipment life is also increased, therefore decreasing last minute breakouts.

Apart from that, as the assets are kept in the best condition possible, these will drain less energy, a very important factor to take into account.

- Disadvantages

The necessary increase in the people in charge of the planning and regular repairs, the short-term costs are higher. Also, using this method can lead to a non-efficient use of the assets, as sometimes a revision of the equipment may not be needed.

Apart from that and according to the bathtub curve, the regular repair may provoke a reduction of the machines reliability, as the failure probability is higher at the beginning of the functioning time. Moreover, a programmed maintenance does not eliminate the risk of catastrophic failure.

3.1.3. Predictive Maintenance

This philosophy is the most advanced and modern one among the three mentioned in this project, and it is also known as “condition-based maintenance”. A predictive maintenance approach aims to diagnose the equipment condition in order to detect any failure or any failure symptom. Thereby, maintenance activities are scheduled only when necessary rather than periodically.

Thanks to this method, the equipment condition is well known at any time, so that the company has control over the machinery and the maintenance programmes, and not the other way around. As a consequence, unexpected inactivity periods are rare. In Fig. 2 [6], the lost time of the three methods is compared. It can be clearly seen that using predictive maintenance techniques, the waste of time is remarkably reduced.

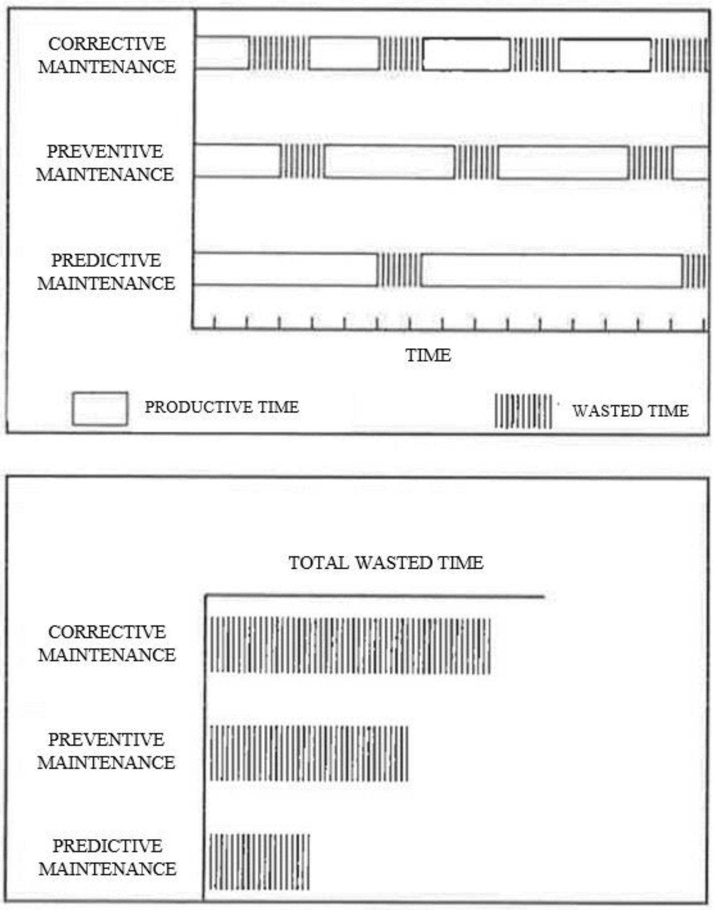


Fig. 2. Waste time in maintenance methods

The techniques studied in the present project, are part of the several predictive maintenance techniques that exists nowadays. In Table 3 the most remarkable advantages and disadvantages [7] are shown.

ADVANTAGES	**DISADVANTAGES**
Low long-term costs	High investment in diagnostic equipment
Higher equipment reliability	High investment in staff training
Higher energy and cost savings	Saving potential may not be seen in the short term
Reduction of catastrophic failure risk	

Table 3: Advantages and disadvantages of predictive maintenance

- <u>Advantages</u>

As it happens with the preventive maintenance, the long-term costs are lower as the assets useful lifetime is increased. Also, the replacement of parts of the equipment do not need to be ordered until a failure symptom is detected, which results in a minimization of the inventory. Moreover, as the equipment condition is continuously checked, so the plant operation is optimized.

The most remarkable advantage in applying predictive maintenance techniques, is the reduction of catastrophic failure, thereby increasing workers safety. In cases when the consequences due to downtime are considerable, predictive maintenance is essential.

- <u>Disadvantages</u>

The up-front investment needed to apply this philosophy can be rather high expensive, as diagnostic equipment and staff training is needed. Due to this fact, there could be difficulties in applying these techniques, due to the fact that the management department may be reluctant.

3.2. Predictive Maintenance Techniques

Nowadays, there is a vast maintenance techniques spectrum to choose from. This decision should be made taking into account the type of industry, the equipment used in the manufacturing process, the competent personnel available, and the formation the staff needs to carry out these techniques.

Among all these techniques, the most common ones [8] are listed and briefly explained below:

- <u>Acoustic emission</u>: this technique can be useful to locate cracks in structures and pipelines.

- <u>Lubrication oil and wear particles analysis</u>: the equipment condition is controlled thanks to a study in the oil composition.

- <u>Infrared thermography</u>: very efficient at detecting failure in electric and insulating elements, as it measures the temperature of the studied element.

- <u>Ultrasound scanning</u>: this technique is employed to detect leakages and to check corrosive wear levels.

- <u>Vibration analysis</u>: it has been demonstrated that, among all other non-destructive techniques, this one provides the greatest amount of information among all others.

In the present document, the application of vibration analysis to a paper machine is analysed. However, in a proper maintenance plan at least two techniques are applied, as the use of only one sometimes does not provide a clear equipment diagnosis.

3.3. Vibration Analysis

As it has been said in section 2, the most complete analysis of the studied element condition, is obtained through a vibration analysis. This technique is proved to be the most effective way to detect rotating elements failure. As a consequence of the wear of the machine's elements, vibrations begin to propagate all along the equipment, which leads to additional forces application. This vibration is measured in those points that put up with them.

One of the most remarkable advantages of this method is the ability of identifying failure symptoms before this failure appears. This technique can be employed to detect deterioration in bearings and gears, as well as misalignment and unbalance symptoms, before these result in a breakdown [9].

A complete vibration analysis system consists of four differentiated parts [9], listed below.

1. Signal receptors
2. Signal analyser
3. Analysis software
4. A computer to analyse and keep record of the measurements.

The vibration analysis is carried out using two systems. First of all, in the case of the elements that are part of the PM4 in a direct way, such as rolls, the measurements are taken automatically using a monitoring system. In the elements that are not part of the PM4, but are necessary in its functioning, such as feeding pumps or refrigerating fans, the measurements are taken manually using portable devices.

4. VIBRATION MEASUREMENT FUNDAMENTALS

4.1. Sensors and Measurement Points Placement

The **sensors assembly** is crucial, due to the fact that what is between the sensor and measured element could act as a filter. Fig. 3 [10] shows the sensitivity of the sensor as a function of its assembly.

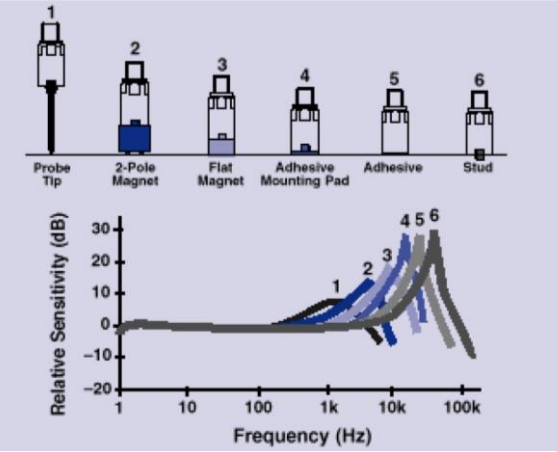


Fig. 3: Sensitivity as a function of the assembly

As it can be seen, the relative sensitivity of a sensor assembled with a stud, has a value approximate to 0 dB up to higher frequencies than the other assemblies, which means that the most suitable way to assembly a sensor is using a stud, so that the sensor is attached to the machine surface or to an intermediate metallic element. In the case of the system studied in the present project, this is the selected assembly of every permanent sensor. In Fig. 4 one of the assembly of one of the sensors can be seen.

Fig. 4: Sensor assembly in one of the rolls

The sensors used in the present project are accelerometers, which measure the acceleration experienced by an element due to inertial forces.

Also, the **measurement point's placement** is important. According to ISO 10816:1995 [11], "*measurements should be taken on the bearings, bearing support housing or other structural parts which significantly respond to the dynamic forces and characterize the overall vibration of the machine*". The most important factors to be taken into account are the following [12]:

- Easy access
- As isolated as possible from external conditions
- Maximum sensitivity to rare conditions
- Low signal loss

For example, in Fig. 5 [13], the suitable and unsuitable placement of an accelerometer is shown. As it can be seen, placement in the bearing covers and in places far from the bearing should be avoided.

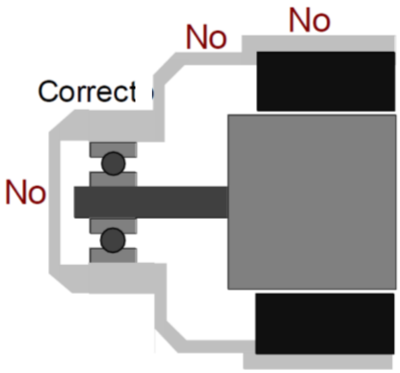


Fig. 5: Sensor placement in a bearing

4.2. Accelerometer Orientation

When measuring vibrations, it must be taken into account that vibration is **triaxial**, which means it propagates in the radial, axial and tangential directions. Depending on the failure an equipment presents, a vibration spectrum will have certain characteristics in one or more of the three directions.

In the monitoring system, the accelerometers are uniaxial, which means measurements can only be made in one direction at a time. The majority of the elements that are automatically checked by the monitoring system are rolls. In this case, uniaxial sensors are enough, since the failure that is being analysed is defect in bearings. In order to identify that kind of defects, it is enough to have data of the vibrations in one direction.

However, in the elements whose measurements have to be made with the portable devices, having information in one single direction is not enough in most cases. Therefore, triaxial sensors are used. In Fig. 6 [11], the points that need to be measured in a rotating machine are shown.

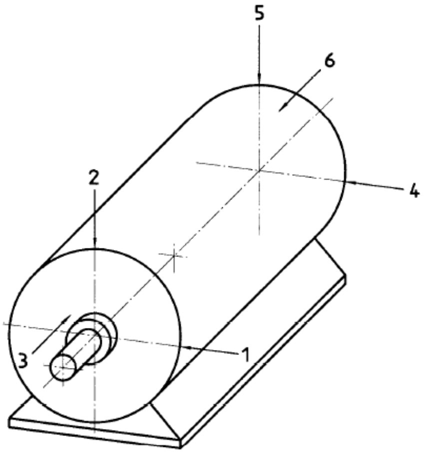


Fig. 6: Measuring points in rotating machinery

4.3. Measurement Conditions

When measuring a vibration, there are some factors that must be taken into account [14], as the vibrations it presents depend on different parameters. In the present section, these factors are briefly explained.

- Working conditions

The conditions in which the equipment when the vibration is measured should be normal. If work conditions such as velocity and load remarkably change, the vibration signature will not be the same as the one obtained in previous measurement. Thereby, the analyser will not be able to set a tendency and perform a proper analyse of the equipment status.

- Background vibration

Background vibration produced by adjacent machinery should be the same in every measurement. Hence, nearby machinery should not be shut down if previous measurements were made when those were working.

- Temperature

The machinery should present similar values of temperature when collecting vibration data, as temperature could slightly change the equipment characteristics due to thermic expansion. Also, these temperature values should be common working values; it is useless to measure vibration when the machine has just been turned on (and as a consequence, with a low temperature).

5. VIBRATION ANALYSIS FUNDAMENTALS

5.1. Vibration Characteristics

When using vibration analysis techniques, the state of the machinery is determined by studying the characteristics of its vibration, being the most important ones the frequency and the amplitude.

5.1.1. Frequency

The most basic characteristic of vibration is its frequency [15]. Frequency is defined as the inverse of the period, which is the time taken to complete one vibration cycle. Hence, frequency is the number of cycles that take place in a certain period of time. If the period of time is a second, the frequency unit will be Hertzio (Hz); if it is a minute, the unit will be cycles per minute (cpm).

Another unit of frequency is the orders, defined as the vibration frequency (cpm) referred to the turning velocity (rpm). For example, in a machine whose velocity is 1500 rpm, 3000 cpm corresponds to order 2. It is usually represented with an X, so order 2 would be 2X. This is important when analysing vibrations, as sometimes spectra are expressed in orders.

5.1.2. Amplitude

The amplitude of a vibration is an indicative of its magnitude and it can be measured as a function of the displacement, the velocity or the acceleration [12].

Displacement units are usually used when having frequencies lower than 600 cpm, which means it is recommended to use the amplitude displacement when measuring vibration in equipment working at low rpm.

If the vibration that wants to be measured is between 600 and 60,000 cpm, it is recommended to use **velocity units**. In vibration analysis, velocity units are more used than displacement units, since common failures such as unbalance or misalignment take place in the mentioned frequency range.

Finally, **acceleration units** are suitable when the frequency values overcome 60,000 cpm. Amplitude in acceleration units is used when the studied failure are seen at high frequencies (as bearing or gears defects).

In Fig. 7 [12] there is a summary of what has been said previously: it shows the ranges in which the amplitude units have to be used, and the ranges where different failures appear.

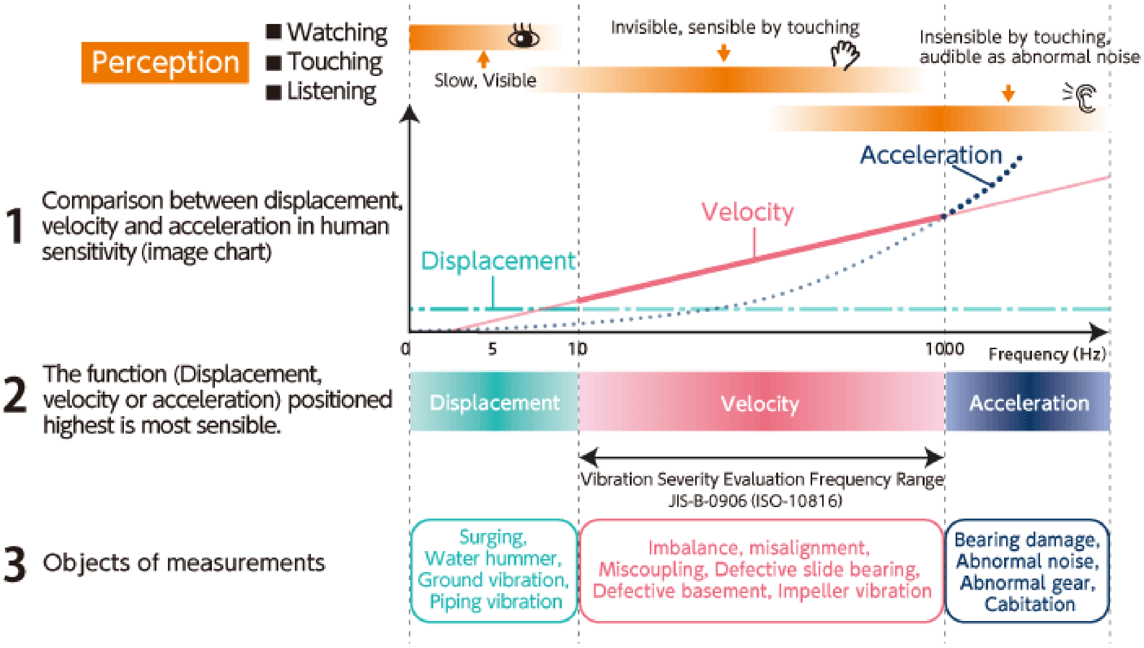


Fig. 7: Amplitude units' ranges

In the case of rotatory machines, usually medium sized machines, the most uniform spectrum are obtained using velocity units, so these will be used in the vibration analysis.

Apart from what has been said, another parameter used to measure the magnitude of the vibration is **global values**. A vibration global value is a scalar number that represents its amplitude. This scalar number can be represented as peak-to-peak value, peak value, or the effective value [16].

The **peak-to-peak** value is the difference between the highest peak and the lowest peak. Thus, it will always be a positive value. The **peak** value is the magnitude of the peak with the highest absolute value, which means that, in this case, the value can be positive or negative. The **effective** value or RMS value is the root mean square of the vibration wave, which can be expressed with the following expression:

$$RMS = \sqrt{\frac{1}{T}\int_{0}^{T} x^{2}(t)dt}$$

The vibration values are usually expressed in mm/s RMS, as it can be seen in the following table.

PARAMETER	UNITS
Displacement	µm peak to peak
Velocity	mm/s RMS
Acceleration	mm/s^2 RMS

Table 4: Amplitude units

5.2. Spectrum Analysis

In order to study the status of an equipment using vibration analysis, frequency analysis is always used. Vibration can be seen in the time domain and in the frequency domain, but in the case of machine vibration, data seen in time domain can be very complex and difficult to analyse. Because of that, the vibration analysis is usually carried out using the **frequency domain**. In the frequency domain the analyser can study the global values analysis or the spectra.

Global values analysis only gives information about the magnitude of the amplitude; in other words, the severity of the problem. Therefore, is it useful to create and analyse tendencies. However, it does not give enough information to recognize the failure in the studied equipment; for example, low amplitude vibrations practically does not affect the global values, and to recognize some failure symptoms these need to be taken into account.

Spectrum analysis is much more complex, because it can show the failure the analysed machine presents. For example, if the failure is due to a bearing defect, it is possible to know not only that the defect is in the bearing, but in which part of the bearing. In order to obtain a frequency spectrum, the time waveform measured is converted into the frequency domain. This will be explained in 5.3.

Frequency analysis is based on the fact that the different elements in the studied machine will produce forces which, at the same time, will produce vibrations at certain frequencies, called **forced frequencies** [17]. For example, the most important forced frequencies come from rotor misalignment, which produces a radial centrifugal force that causes vibrations at the fundamental frequency or 1X. Each forced frequency will appear as a peak in the frequency spectrum.

5.3. The FFT Spectrum Analysis

The Fast Fourier Transform (FFT) is an algorithm whose function is calculating the Discrete Fourier Transform (DFT) [18]. The DFT converts a discrete signal in the time domain to a discrete spectrum in the frequency domain. In other words, Fourier analysis is used to deconstruct vibration waveforms (difficult to analyse) and convert them into individual sine waves. As a result, amplitude is represented as a function of frequency. Fig. 8 [12] shows the conversion the vibration waveform to the frequency spectrum.

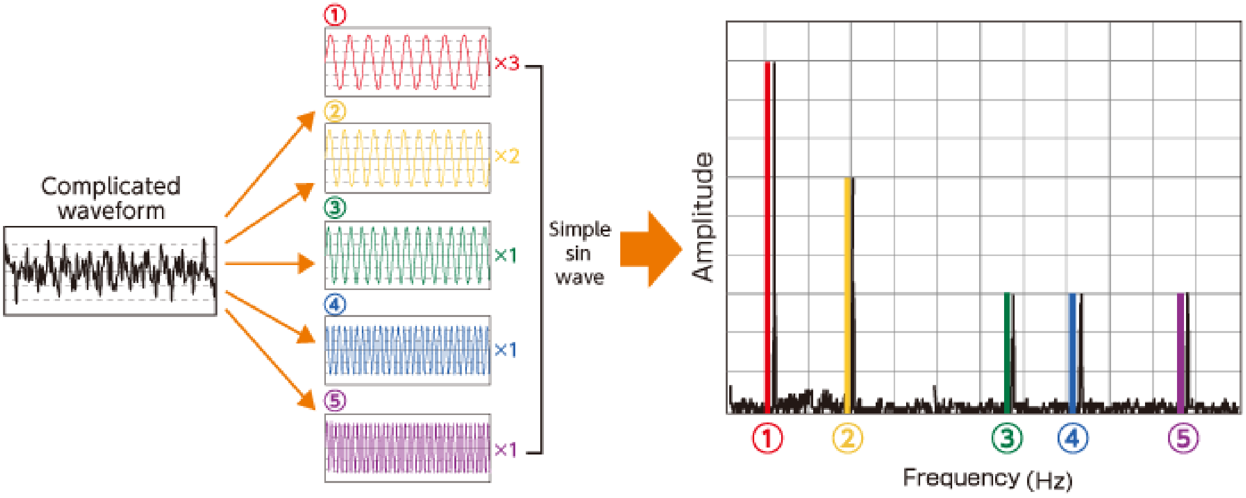


Fig. 8: Conversion of a waveform to frequency domain using FFT

Fig. 9 [12] is an example of the change that can be seen in the frequency spectrum when a defect appears. In both cases, the composite waveform is converted to the frequency spectrum. As a consequence, the abnormality can be easily seen.

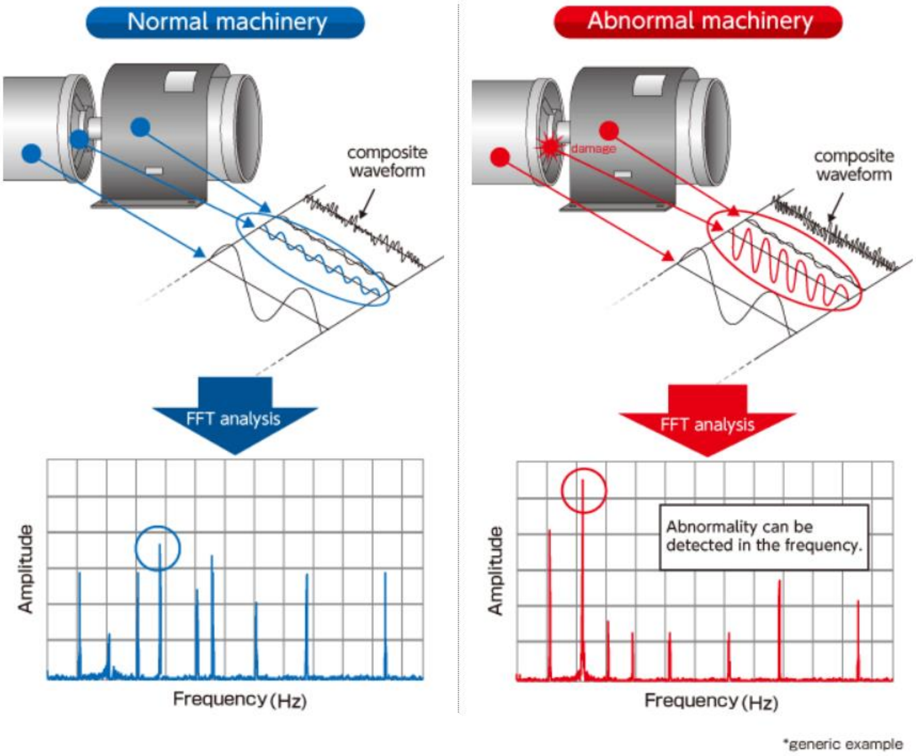


Fig. 9: Change in the frequency spectrum of a normal and abnormal machinery

5.4.Admissible Vibration Values

Depending on the power of the studied machine, admissible vibration values are set, as it can be seen in Table 5, an extract from ISO 10816:1995 [11].

Vibration Velocity (mm/s RMS)	**TYPE I**	**TYPE II**	**TYPE III**	**TYPE IV**
0.28	A	A	A	A
0.45				
0.71				
1.12	B			
1.80		B		
2.80	C		B	
4.50		C		B
7.10	D		C	
11.20		D		C
18			D	
28				D
45				

Table 5: Admissible vibration values according to ISO 10816:1995

Where:

- A: good condition.
- B: satisfactory condition, machinery will be able to continue working for a long period of time.
- C: unsatisfactory condition, machinery will not be able to continue working for a long period of time, its condition has to be checked periodically.
- D: dangerous condition, machinery is surely being damaged.

This table is set according to different machinery types, which are explained in Table 6.

Type I	Independent elements from motors or small machinery. Typical examples of this type could be generator motors up to 15 kW.
Type II	Medium sized machinery (usually motors from 15 kW to 75 kW) without especial support elements. Machinery up to 300 kW rigidly mounted.
Type III	Motors or other big sized machinery with rotatory masses supported by rigid elements. Relatively stiff machines in the measuring vibrations direction.
Type IV	Motors or other big sized machinery with rotatory masses supported by relatively flexible elements in the measuring vibrations direction (for example, power units).

Table 6: Machinery classification according to ISO 10816:1995

5.5. Common Failures Analysis

In the present section, the most common failures and the diagnosis for each one of them using spectrum analysis are briefly described. In previous sections, this information will be specified for the case of the paper machine. Among the most common failures, the following will be described in the present document:

- Unbalance
- Misalignment
- Bent shaft
- Eccentricity
- Mechanical looseness
- Bearing defects
- Failure frequencies

5.5.1. Unbalance

Unbalance is one of the most common failures in machinery. It takes place when the masses distribution is not uniform (due to a non-uniform wear of the rotor), which happens when the geometric centreline (GCL) and the rotating centreline, also known as principle inertia axis (PIA), do not coincide. In a rotor, the gravity centre will be in the GCL. When these centrelines do not coincide, there is unbalance [19]. It can be a consequence of inadequate assembly, material accumulation, machine wear or broken elements [20]. There are different types of unbalance, among which the most common are static and dynamic.

Static unbalance takes place when the GCL and the PIA are parallel, and it has the same effects as if a heavier load was located in one point of the rotor. As a consequence, a centrifugal force F is applied to the bearings in the radial direction with a frequency value of 1X.

$$F = m * r * \omega^2$$

Where m is the unbalanced mass, r is the distance to this mass and ω the angular velocity of the shaft.

The appearance of this force is due to the fact that, when measuring, each time the sensor measures the unbalanced point, it receives a higher amplitude value, which will be proportional to the square of the velocity of the shaft [20]. If the rotor has a velocity of 1500 rpm, the mentioned peak will appear at 1500 cpm.

The second type of unbalance studied in the present project is **dynamic unbalance**. This type of unbalance takes place when GCL and PIA are not coincident [19]. In this case, both a static unbalance and disequilibrium of a pair of forces take place. Dynamic unbalance can only be distinguish from static unbalance studying the relationship between the phases of the forces applied in the bearings, so in the frequency spectrum both types of unbalance will present a peak at 1X in the radial direction, as it can be seen in Fig. 10 [21]. Generally, peaks at harmonics of 1X are also present.

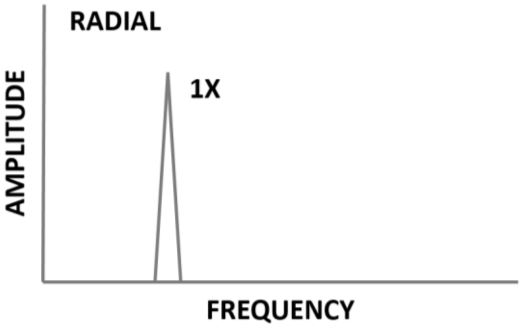


Fig. 10: Frequency spectrum due to static or dynamic unbalance

Unbalance could also be identified thanks to peaks at 1X in the tangential direction.

5.5.2. Misalignment

Misalignment is also a common defect in machinery. These defect can be a consequence of an imprecise assembly, an alteration of the different elements position, an expansion of the different components due to high temperature, distortion in the machinery support elements or an incorrect assembly of the coupling [22]. There are two types of misalignment, angular and parallel.

Angular misalignment appears when the driven and the driver shaft form an angle, as it can be seen in Fig. 11 [23].

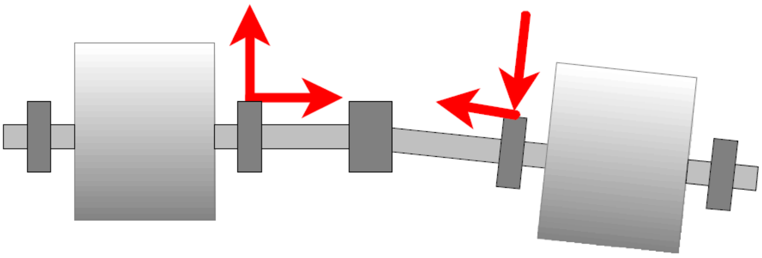


Fig. 11: Angular misalignment

Due to this angle between shafts, bending moments appear. These generate radial and axial vibrations in 1X and 2X, being peaks at 1X usually higher. Vibrations in the axial direction tend to be higher than those in the radial direction. There could also be peaks at 3X, as it can be seen in Fig. 12 [24]. Also, high amplitude levels could be seen in the tangential directions.

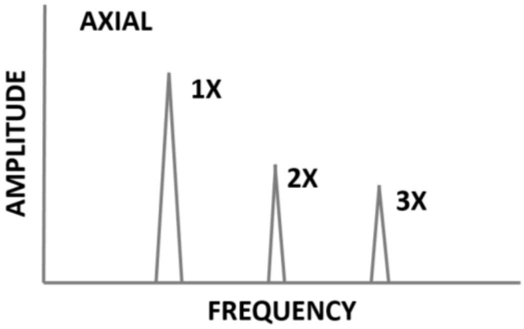


Fig. 12: Frequency spectrum due to angular misalignment

Parallel misalignment appears when the driven and driver shaft are not collinear, as it can be seen in Fig. 13 [23].

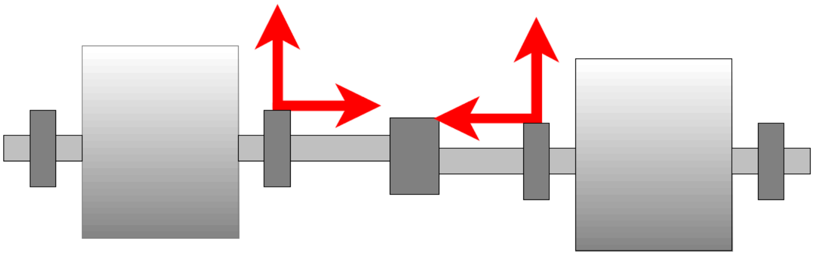


Fig. 13: Parallel misalignment

In this case, normal stress are applied, as well as bending moments. As a consequence, there are high vibration amplitude levels at 1X and 2X in the radial direction. The highest peaks are found at 2X, because there are two hits per cycle, as it is explained in Fig. 14 [24].

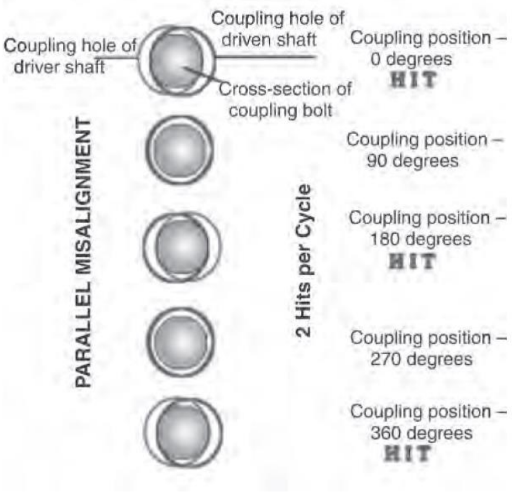


Fig. 14: Full cycle in parallel misalignment

Again, there could be peaks at 3X. As in the case of having an angular misalignment, vibrations in the tangential directions can also reach high values.

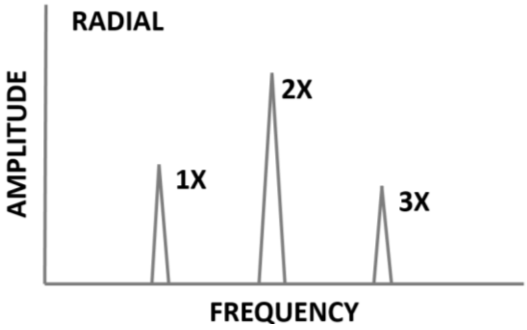


Fig. 15: Frequency spectrum due to parallel misalignment

Usually, there is a general misalignment, a combination of both types of misalignment.

5.5.3. Bent shaft

Another possible defect is a bent shaft, which is easily confused with misalignment. A shaft is considered to be bent when it is not symmetric with respect to the axis of rotation. As a consequence, there are high peaks at 1X and harmonics at 2X in the axial directions, usually higher than the vibrations in the radial and tangential directions.

Fig. 16: Bent shaft

5.5.4. Eccentricity

Eccentricity takes place when the centre of rotation does not coincide with the geometric centre of a pulley, bearing or gear, as it can be seen in Fig. 17 [21]. This type of failure is similar to unbalance, and is sometimes diagnosed as such.

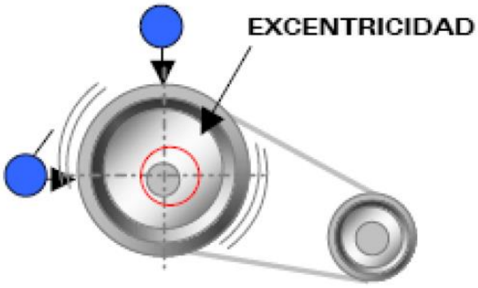


Fig. 17: Eccentricity in a pulley

When this defect appears, the highest vibration amplitude levels appear at 1X, in the direction of the line that passes through both centres (radial direction), as it is shown in Fig. 18 [21].

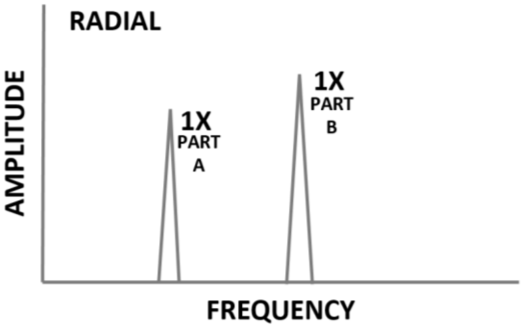


Fig. 18: Frequency spectrum due to eccentricity

5.5.5. Mechanical looseness

There are two types of mechanical looseness in a rotating machine, structure looseness and internal assembly looseness.

Structure looseness appears due to an excess of movement in the static parts that support machine or to a looseness of the bolts. As a consequence, high vibrations at 1X appear. This type of defect can be identified as unbalance. If the peak at 1X in the tangential direction presents a similar or smaller amplitude value than the peak at 1X in the radial direction, the defect should be consider as unbalance. However, if the peak at 1X in the tangential direction presents a much higher amplitude value, the defect should be considered as structure looseness [25].

In Fig. 19 [25] it can be seen that in a complete cycle, there are 4 hits. This means that, apart from peaks at 1X, there could be a multiple to 4 number of harmonics of the rotation speed.

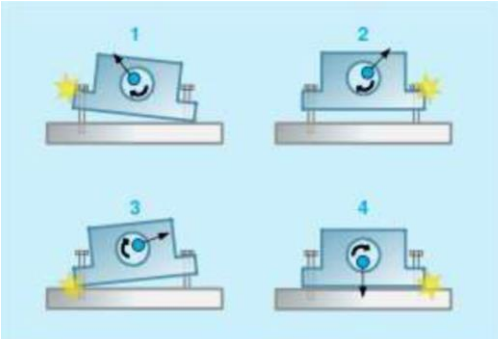


Fig. 19: Complete cycle due to structure looseness

Internal assembly looseness takes place between a hole and a shaft. This type of defect can be a consequence of an unsuitable fit between two elements of the machine, as it can be seen in Fig. 20 [21].

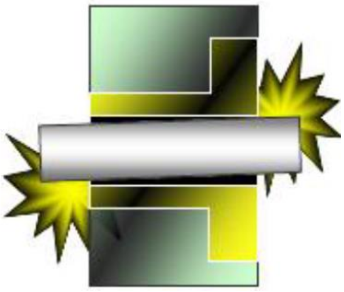


Fig. 20: Example of internal assembly looseness

This failure is easy to recognise, as it produces harmonics and sub-hamornic multiples in the radial direction (

Fig. 21 [21]) because of the inconsistent behaviour of the components towards the stresses coming from the rotor. The peak at 2X is usually dominant because, as in the case of parallel misalignment, there are 2 hits per circle. Apart from that, subharmonics (0.5X) and half-harmonics (1.5X, 2.5X…) can appear due to the nature of the defect. Generally, the amplitudes are higher in the radial direction.

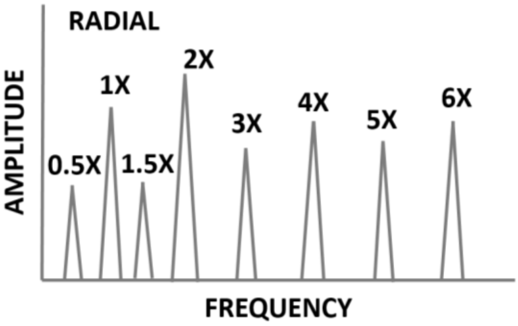


Fig. 21: Frequency spectrum due to internal assembly looseness

The severity of the looseness is determined depending on the frequency spectrum. There are four different groups:

- Mild looseness: harmonics up to 5X are easily identified, being higher harmonics very subtle.
- Potentially serious looseness: there is an increase of the amplitude at 1X and low amplitude values could be identified at half-harmonics.
- Serious looseness: increase of the amplitude values at the harmonics.
- Severe looseness: subharmonics, half-harmonics and harmonics are easily identified.

5.5.6. Bearing defects

Bearings are composed by four different elements: the inner ring, the outer ring, the balls and the cage, as it can be seen in Fig. 22 [26].

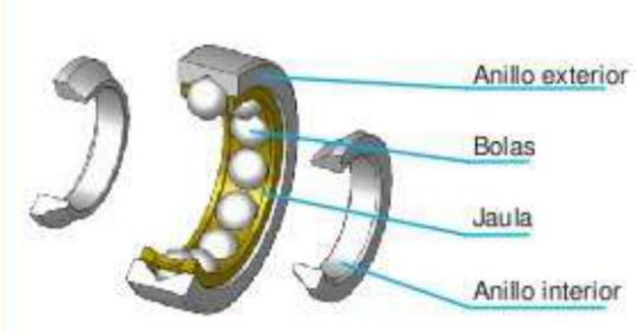


Fig. 22: Bearing parts

The defects in each of those elements produces vibration in a certain frequency.

- **BPFO** (ball pass frequency outer): failure frequency of the outer ring.
- **BPFI** (ball pass frequency inner): failure frequency of the inner ring.
- **BSF** (ball spin frequency): failure frequency of the balls.
- **FTF** (fundamental train frequency): failure frequency of the cage.

These frequencies can be calculated using the following expressions:

$$BPFO = \frac{N_b}{2} * RPM * (1 - \frac{B_d}{P_d} * cos\alpha)$$

$$BPFI = \frac{N_b}{2} * RPM * (1 + \frac{B_d}{P_d} * cos\alpha)$$

$$BSF = \frac{P_b}{2B_D} * RPM * (1 - \left(\frac{B_d}{P_d}\right)^2 * (cos\alpha)^2)$$

$$FTF = \frac{1}{2} * RPM * (1 - \frac{B_d}{P_d} * cos\alpha)$$

Where N_b corresponds to the number of balls or rolls in the bearing, P_d to the pitch diameter, B_d to the diameter of the balls or rolls and α to the contact angle. In Fig. 23 [27], the contact angle of a bearing is shown.

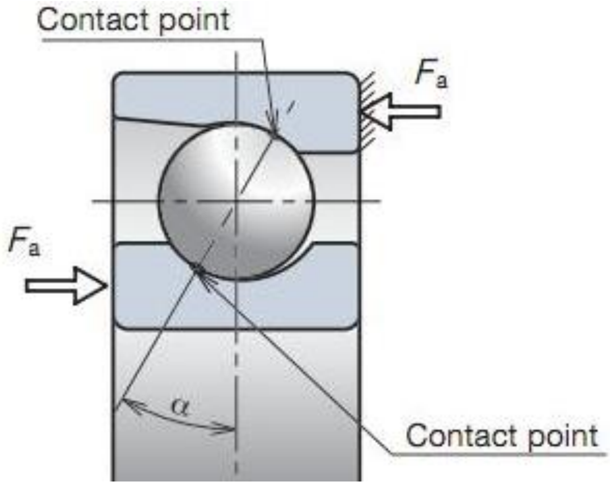


Fig. 23: Contact angle of a bearing

Different frequency spectra correspond to the defect corresponding to each part of the bearing [28].

Defects corresponding to the **outer ring** produce between 8 and 10 harmonics at the BPFO. An example of a frequency spectrum where this defect can be identified is shown in Fig. 24.

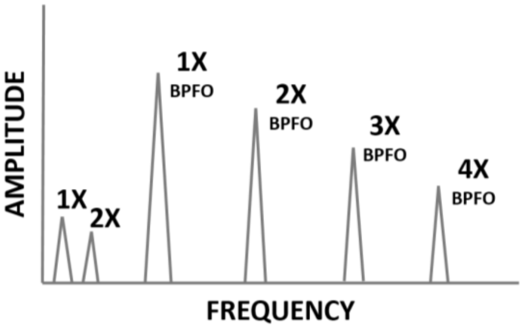


Fig. 24: Spectrum corresponding to a defect in the outer ring

In the case of defects corresponding to the **inner ring**, there are also between 8 and 10 harmonics, in this case modulated by side bands. This is shown in the spectrum in Fig. 25.

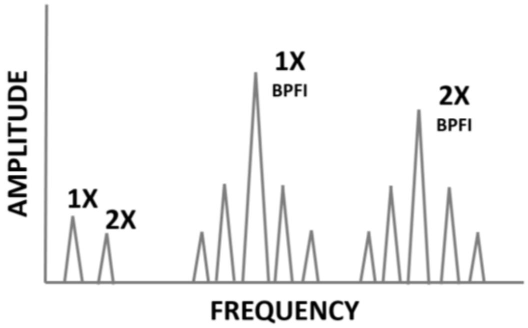


Fig. 25: Spectrum corresponding to a defect in the inner ring

If the defect is in the **balls or rolls** of the bearing, there are peaks at the harmonics of the BSF. The peak with the highest amplitude value could indicate the number of balls or rolls in the bearing.

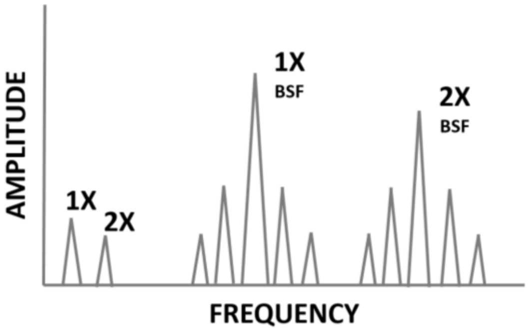


Fig. 26: Spectrum corresponding to a defect in the balls or rolls

Finally, if the defect is in the **cage**, there are peaks at the harmonics of the FTF.

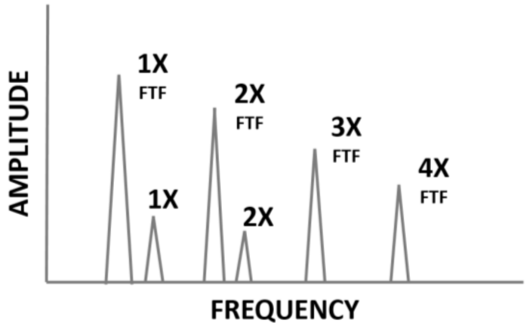


Fig. 27: Spectrum corresponding to a defect in the cage

5.5.7. Failure frequencies

Apart from the specific defects than have been mentioned, the failure frequency of an element has to be taken into account. The different elements in a specific machine will produce certain forces, which will lead to vibrations at what is called, failure frequency [29].

One of the most important failure frequencies is the velocity of the shaft, which has already been studied in the previous cases. Other examples are bearing tones, gear frequencies, blade pass frequencies, etc. These frequencies are usually obtained using the following expression, which is not valid in the case of bearings.

$$F_f = \omega * N$$

Where ω is the velocity of the shaft and N the number of elements (for example, the number of blades).

Since the response of the machine is not linear due to the presence of looseness and other defects, the vibration signal suffers a distortion, which lead to peaks at the harmonics ot the failure frequencies. When the non-linearity increases, **side bands** appear. In other words, the presence of harmonics and side bands indicates problems in the machinery.

6. THE PAPER MACHINE

6.1. Productive Process

In order to understand the different forces that the elements of the PM4 could suffer, the part of the productive process that corresponds to the paper machines need to be briefly explained [30]. A simplified flux diagram of the productive process is shown below.

Fig. 28: Flux diagram of a paper machine

In Fig. 29 [31] the sections of a paper machine involved in the production process can be easily identified. Each of these sections will be explained below.

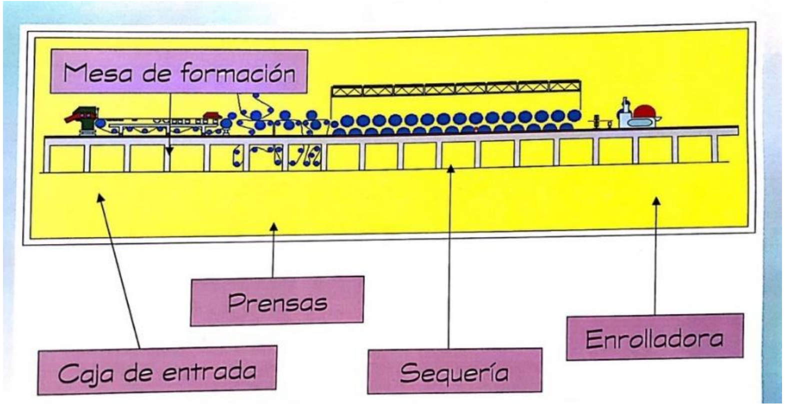


Fig. 29: Parts of a Paper Machine

6.1.1. Forming section

The first section in the paper machine is the forming section, also called the wet end. In Fig. 30 [32], the elements that are usually present in this section are shown.

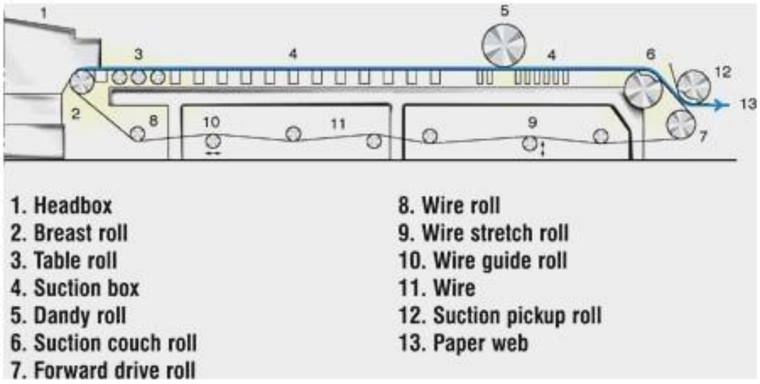


Fig. 30: Forming section of a typical paper machine

The slurry enters this section being 99% water [33]. The first part of this section is the headbox. Its function consists in regulating the pressure and the density of the slurry that reaches the table roll. Turbulence is created in order to uniformly distribute the slurry along the table.

As the slurry passes through the table, there are two systems whose function is to absorb water from the slurry: drip system due to gravity, and vacuum application thanks to the suction boxes. In this process the slurry turns into a wet paper web.

Finally, the paper web reaches the press section thanks to the suction pickup roll, a hollow shell with thousands of holes and applied vacuum.

In Fig. 31 taken during a stop period, the forming section of PM4 can be seen.

Fig. 31: forming section in the PM4

6.1.2. Press section

The water content of the paper web entering this section is approximately 80% [33]. The press section consists of a set of rolls pressed against each other and loaded with high pressure values. In this section there are also felts, in order to lead the paper web through the press nip, which is the contact point between two rolls. In Fig. 32 [34] the nip between two rolls, and the paper with the felt can be seen.

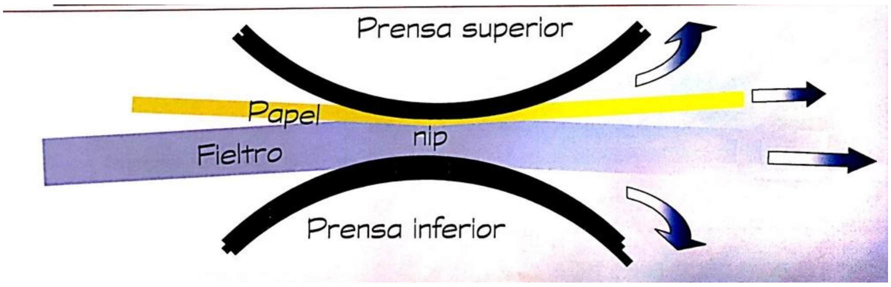


Fig. 32: Nip between two rolls

The main objective of this process is to squeeze out the higher amount of water possible from the paper web and transfer it to the felt, so that the water content in the paper sheet is reduced. The felts also smooth the surface and remove marks formed during the previous section. Fig. 33 shows the initial part of the press section in studied paper machine.

Fig. 33: Part of the press section of the PM4

6.1.3. Drying section

After the press section, the water content has been reduced up to 50% [33]. This third section consists of a set of internally steam-heated cylinders (with a vapour at approximately 100 ºC [30]) that evaporates the remaining water in the paper web.

In Fig. 34 [35] a basic scheme of the dryers can be seen. There is an entrance for the vapour coming from the boilers, that transfers heat to the paper web. As a consequence of this transfer, the vapour condensates and forms a ring around the drier. This comes out from the dryer through the syphon, so that the condensate vapour does not accumulated.

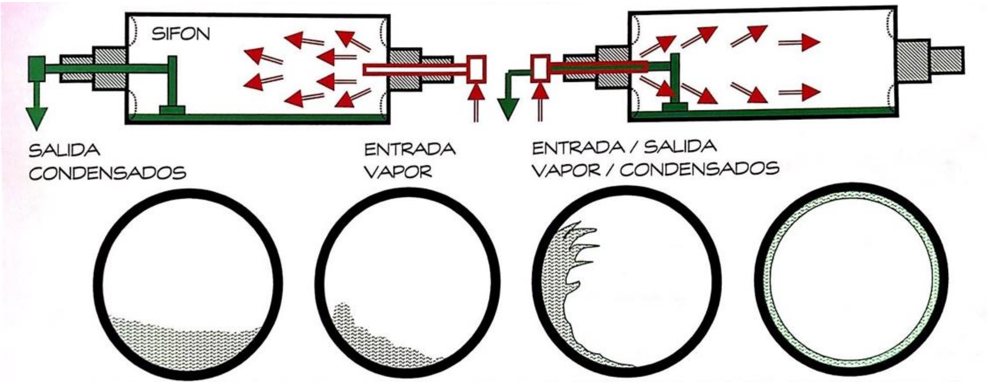


Fig. 34: Scheme of the functioning of a dryer

This section is enclosed in order to preserve heat. In the case of the PM4, there is a Pre-Drying section before the Drying section, and a Post-drying section after the Yankee section. The purpose in both cases is to keep reducing the water content.

6.1.4. Yankee section

In this section, the water content of the paper sheet is around 5% [33]. In the Yankee section, high pressure loads are applied to the passing paper in order to smoothen the sheet and obtain a uniform thickness.

This section is known for the Yankee dryer, a roll of large dimensions, approximately 6 m in diameter. As it is said in [36], the Yankee dryer can be considered as “the heart of a tissue machine”, due to the role it has. The Yankee dryer transports and support the paper sheet during the process.

Fig. 35: The Yankee drier in the PM4

The paper sheet will then reach 2 rolls, as it can be seen in Fig. 36 [30]. One of them contributes to the sheen of the paper, and the other one generates some lineal marks in the surface of the paper.

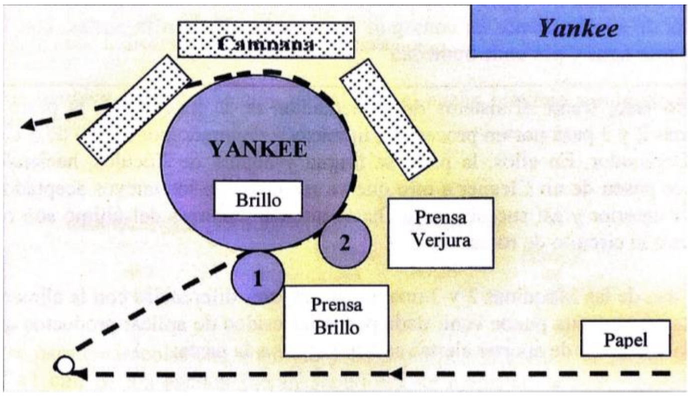


Fig. 36: Sketch of the Yankee section

In the case of the sheen roll, this sheen comes from the contact of the paper with the Yankee, thanks to the pressure applied by the sheen roll, the humidity in the surface of the Yankee and the high temperature of the Yankee.

6.1.5. Reel section

The different parts of this section are shown in Fig. 37 [32].

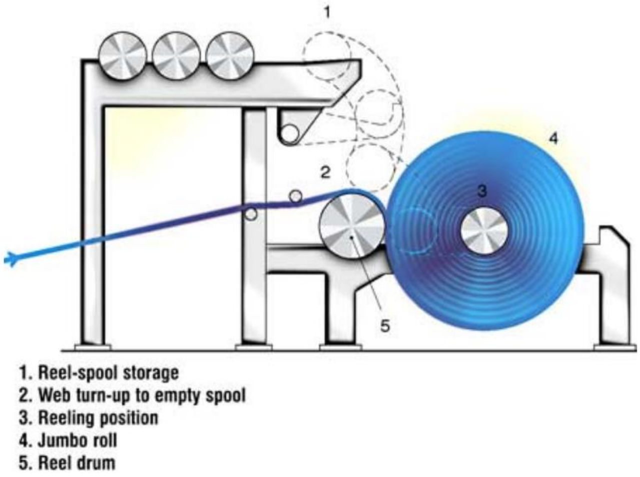


Fig. 37: Reeler section of a typical paper machine

The paper sheet coming from the Yankee is wound onto a master roll for further processing in the winder section, which is not part of the paper machine. The reel has to be able to wound the paper sheet onto a new cane when the jumbo roll is full. The jumbo roll will then be divided in smaller paper rolls according to the customer requirements.

In Fig. 38, the reel section of the PM4 can be seen.

Fig. 38: The reel section in the PM4

6.2. Machine Elements

A paper machine is composed by a vast number of elements: reduction gearboxes, motors, rolls or pumps, among others. In this section the elements where a permanent accelerometer is located will be listed, in other words, just the elements whose vibrations are measured using the vibration monitoring system. Other components studied in the present project will be described further on this document.

The reason why the only elements where vibration collectors are located are rolls and gearboxes, is that access to them may be rather complicated or even impossible. For example, due to the thermal conditions in the drying sections, measurement points of the dryers' vibrations are inaccessible, unless the machine is not working.

In the following table, the mentioned elements are listed.

SECTION	MACHINE ROLL	QUANTITY
Wire Section	Turning Rolls	1
	Wire Guide Rolls	9
	Couch Rolls	1
	Gearboxes	3
Press Section	Felt Rolls	14
	Pick-Up Roll	1
	Shoe Press Central Press Roll	1
	Gearboxes	2
Pre-Dryer Section	Fabric Rolls	35
	Vac Rolls	1
	Dryers	12
	Gearboxes	4
Yankee Section	Felt Rolls	5
	Paper Guide Rolls	3
	Yankee Dryer Counter Press Roll	2
	SYD	1
	Gearboxes	3
Post-Dryer Section	Fabric Rolls	17
	Dryers	4
Reeler Section	Paper Guide Rolls	2
	Reeler Drum	1
	Gearboxes	1

Table 7: Elements included in the vibration monitoring system of the PM4

Apart from the mentioned elements, different machinery can be found. For example, there are equipments formed by a pump and its motor all around the PM4, in order to pump different fluids (paste or water, among others) to certain parts of the PM4. There are also equipments formed by a fan and its motor, in order to refrigerate or apply vacuum.

7. MEASURING DEVICES

7.1. Ascent Software

In order to be able to keep record of different data obtained in the vibration measurement process, the use of a software is needed. In the case of Smurfit Kappa Navarra, Ascent was the selected software.

Ascent provides the features needed to analyse and keep records of the vibration data taken. With the collected data, spectra, waveforms and trends can be seen and studied. Although this program presents a huge potential due to its advanced features, it is still simple and easy to use, which makes it ideal for implementing a vibration monitoring system for the first time.

This software is available in three levels depending on the features needed. This project has been developed using Ascent Level 3, the most complete level. Ascent software works coupled with some complementary devices. These devices, as well as Ascent, are supplied by Commtest, which is a company dedicated exclusively to providing vibration analysers and data collecting products.

7.2. Portable Devices

There are portable data collectors and analysers, with their corresponding sensors, for those areas in which there are no sensors permanently installed, which is the majority of the elements in the factory.

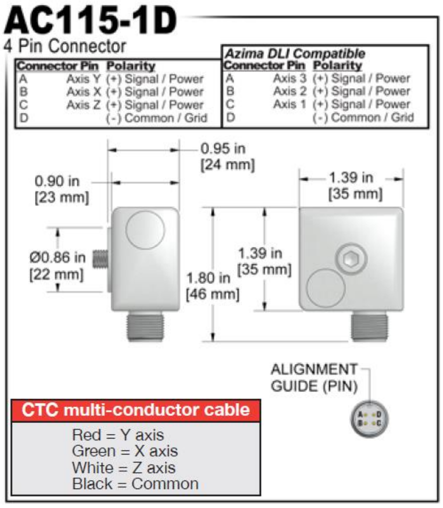
7.2.1. Data collectors

Portable data collectors are used in the task of measuring vibrations in different points. These devices, as it has been said, are provided by Commtest, and belong to the so called vbSeries. This series of collectors present an ergonomic design, as well as a 1 GB memory, which allows to store a vast amount of data, since the storage of spectra does not need much space. The collector used to make the measurements needed in the present project was the vb5, which presents a 6400 lines FFT resolution.

Fig. 39: Data collector vb5

7.2.2. Sensors

Each portable device obviously needs a sensor. In this case, triaxial sensors are used. This means that the sensor can obtain data of the vibrations in the three directions. In other words, in a single measurement point, just one measurement needs to be made. The sensor used is the AC115-1D.



AC115-1D
4 Pin Connector

Connector Pin		Polarity
A	Axis Y	(+) Signal / Power
B	Axis X	(+) Signal / Power
C	Axis Z	(+) Signal / Power
D		(-) Common / Grid

Azima DLI Compatible

Connector Pin		Polarity
A	Axis 3	(+) Signal / Power
B	Axis 2	(+) Signal / Power
C	Axis 1	(+) Signal / Power
D		(-) Common / Grid

CTC multi-conductor cable
Red = Y axis
Green = X axis
White = Z axis
Black = Common

Fig. 40: Sensor used in the portable system

7.3. Monitoring Devices

7.3.1. Network devices

The fundamental complementary device is the vbOnline system, a network device. It is a modular system that evaluates machinery condition automatically, resorting to the permanently installed sensors in PM4.

Fig. 41: vbOnline system installed

7.3.2. Sensors

In the monitoring system, there are two types of sensors, the AC102-1A and the AC104-3C. The most remarkable difference between them is the location of the exit of the cable, and the fact that AC104-3C is used in machinery in which is not enough to place the sensor on the surface of the machine. Because of that, it has a mounting bolt.

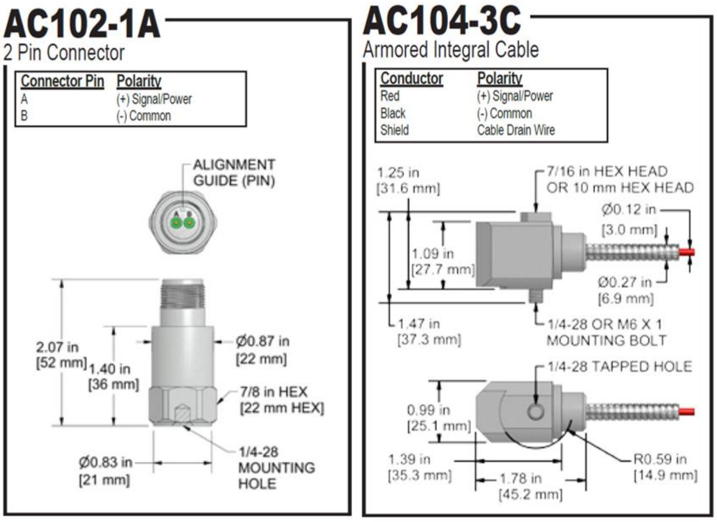


Fig. 42: Sensors used in the monitoring system

8. REAL EXAMPLES

In the present section, the application of the technology described along the project will be shown. From each case, the following information will be given:

- Equipment function
- Equipment location
- Equipment description
- RMS tendencies analysis
- Frequency spectrum analysis
- Conclusion of the failure
- If possible, solution given to the failure

8.1. Vacuum Fan

8.1.1. Equipment function

As it has been said in section 6.1.1, the main function of the forming section is extracting water from the paste. This objective is carried out applying vacuum to the slurry as it passes through the table. The vacuum is applied thanks to the fan which is going to be studied in the present section.

8.1.2. Equipment location

The analysed fan is located at the beginning of the forming section, in a level 5 meters above. The complete equipment of the fan and the motor can be seen in Fig. 43.

Fig. 43: Fan and motor studied

The fan applies vacuum to the slurry passing through the table thanks to a set of pipes distributed all along the table. This can be seen in Fig. 44, where one of the pipes is marked.

Fig. 44: Set of pipes thanks to which vacuum is applied

8.1.3. Equipment description

First, in Fig. 45, a sketch of the fan and the motor (which are joined by a coupling) can be seen. The coupling consists in two pulleys and a belt, located in the same plane. The points where vibrations were measured were the motor free side, the motor coupling side, the fan coupling side, and the fan free side, taking into account that the free side is the contrary side to the coupling. The points were measured placing the sensor as it can be seen in Fig. 5 [37].

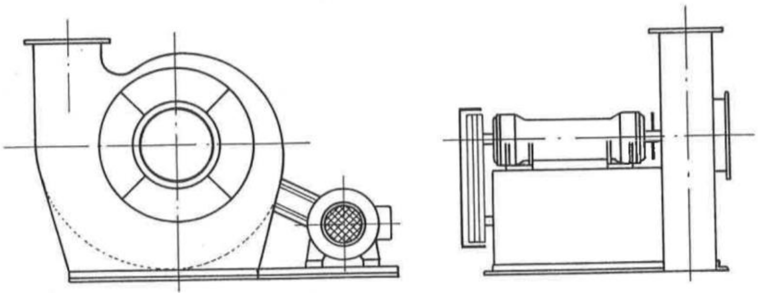


Fig. 45: Sketch of the fan, the motor and the coupling

There are four points to be measured, corresponding to the location of the bearings, and in each of them vibrations are measured in the three directions. This means, there will be 12 different vibration spectra, three for each of the four points. In Fig. 46 a simple sketch of the four mentioned points where the vibrations were measured can be seen.

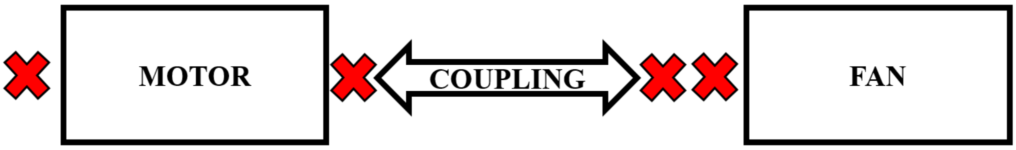


Fig. 46: Sketch of the points measured in the vacuum fan

The fan of the studied equipment is cantilevered. This means, the two bearings are located as it is shown in Fig. 47.

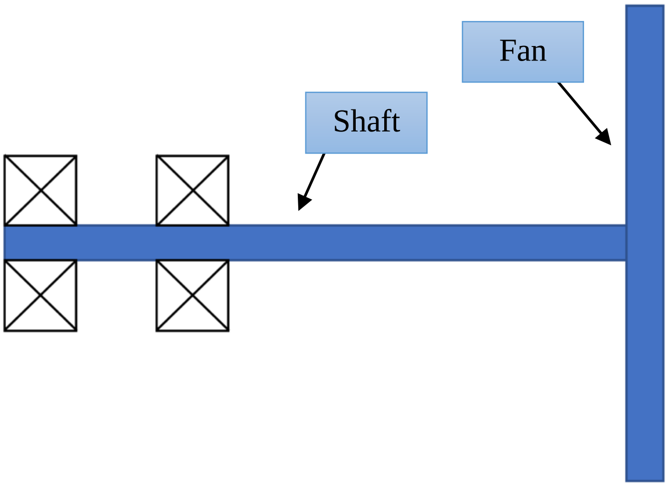


Fig. 47: Sketch of a cantilevered fan

The velocity of the fan is 3300 rpm, while the velocity of the motor is 1500 rpm. The transmission between the two machines is carried out using belts and pulleys. The power of the motor is 75 CV, which is 56 kW.

Taking into account all those data, the next step is to determine the machinery type according to ISO 10816:1995 (Table 6) in order to know the admissible vibration values. The motor can be considered as type II, since it is a motor with a power of 56 kW (between 15 kW and 75 kW). In the case of the fan, it can also be considered as type II, as it is medium sized machinery. In conclusion, according to Table 5 from 1.80 mm/s RMS it is in satisfactory condition, from 4.50 mm/s RMS it is in unsatisfactory condition, and from 11.20 mm/s RMS it is in dangerous condition.

The vibrations in this equipment are manually measured once a month, so it does not belong to the set of equipments that are checked with the vibration monitoring system.

8.1.4. RMS tendencies analysis

The first step in the process of performing a vibration analysis is the study of tendencies. Tendencies show the increase or decrease of the RMS value measured on different dates.

First of all, in Fig. 48 the tendencies in every point and direction measured from the 13/05/2016 to the 25/02/1019 can be seen.

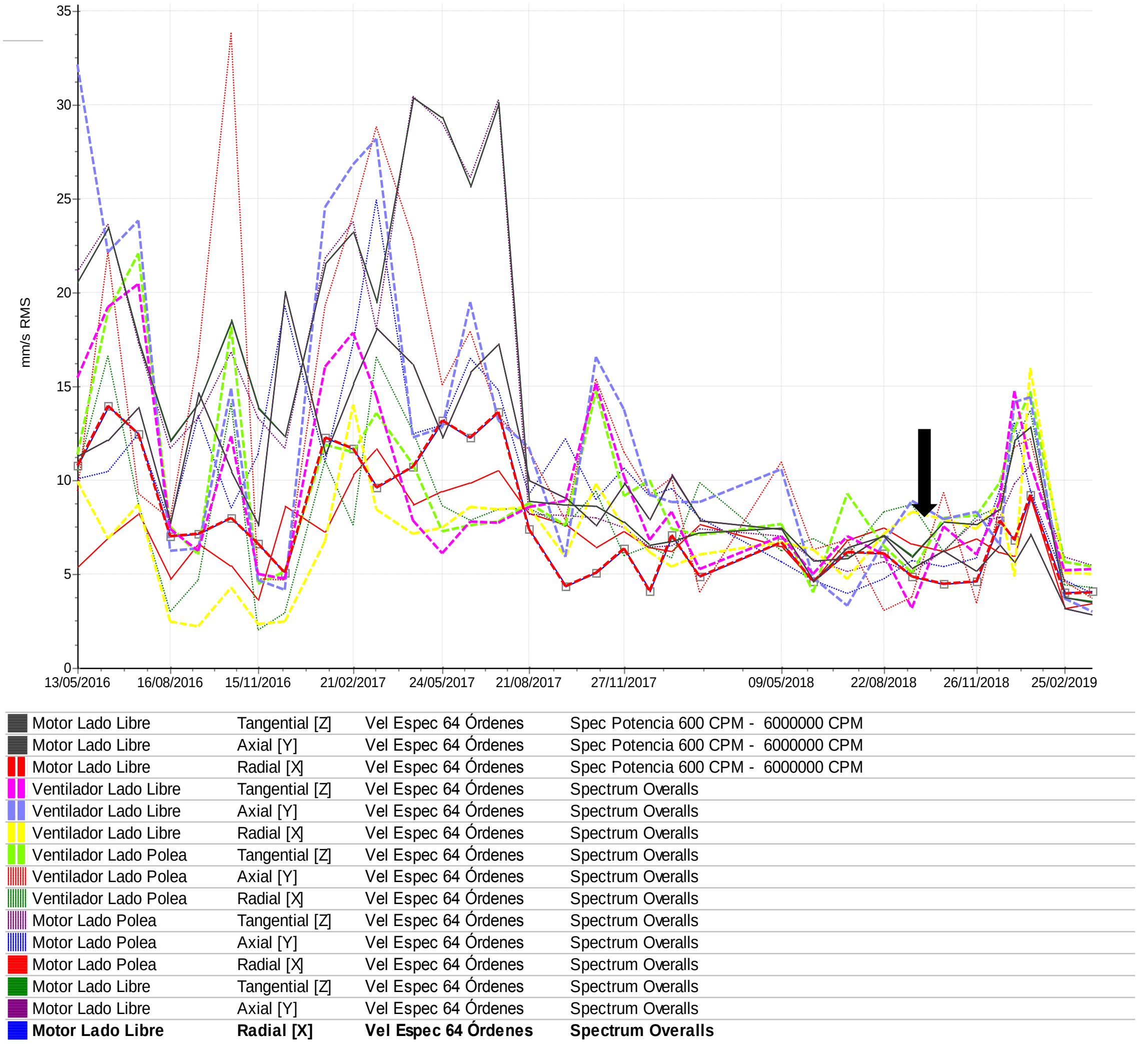


Fig. 48: RMS Tendencies in the vacuum fan

In this tendency it can be easily seen that this fan is a problematic equipment. There are several amplitude values going from 10 mm/s RMS to 34 mm/s RMS. As it has been said in the previous section, these values indicate that the equipment is in dangerous condition, since they are above 11.20 mm/s RMS.

Apart from that, the presence of several peaks indicates that this equipment has been repaired several times. For example, between the 26/11/2018 and the 25/02/2019, the amplitude goes up to 15 mm/s RMS, and then decreases to values around 5 mm/s RMS. This means a defect in the machinery was fixed in order to return to appropriate working conditions.

In the following section, there is an analysis of the spectra in one of the points in the tendency. It can be seen that, between the 22/08/2018 and the 21/11/2018 (marked in Fig. 48), the tendencies are not very clear, as some points indicate increasing values of the amplitude, and other points indicate decreasing values of the amplitude. On this dates, there are values between 3 and 9 mm/s RMS, which means the machine could be in unsatisfactory. This is the point that is going to be studied.

8.1.5. Frequency spectrum analysis

In the present section, the spectra in the three directions are studied for the different points that were measured on the 21/09/2018.

8.1.5.1. Radial direction

In the spectra corresponding to the four points measured, there is a peak at 1500 cpm and a peak at 3300 cpm, as well as peaks at harmonics of those frequencies, in the radial direction. This reveals that there could be an **unbalance** in both the motor (rotating at 1500 rpm) and the fan (rotating at 3300 rpm). The peaks mentioned could also indicate **eccentricity** in the pulleys. The spectra in the radial direction can be seen below.

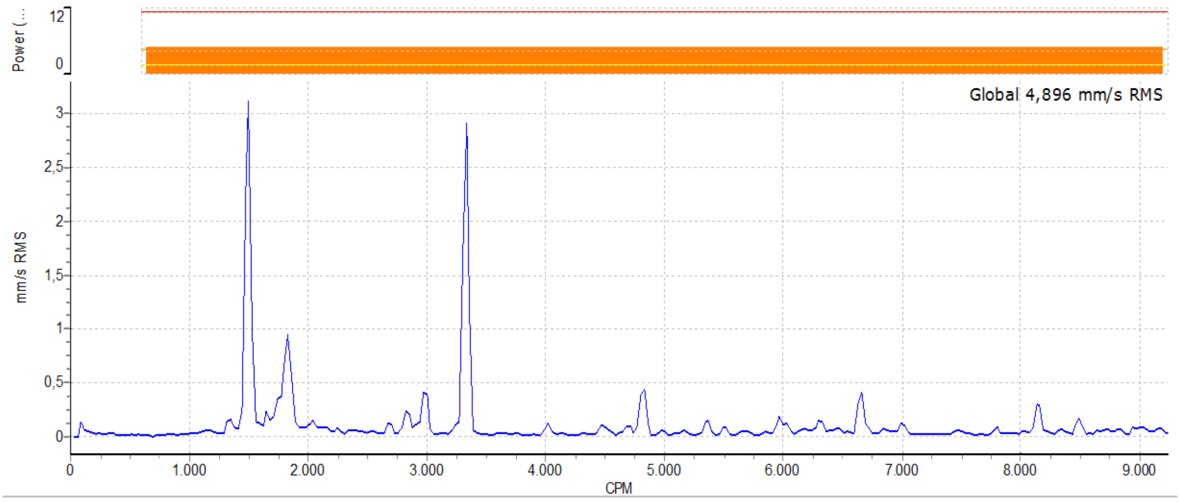


Fig. 49: Spectrum in the radial direction, free side of the motor (vacuum fan)

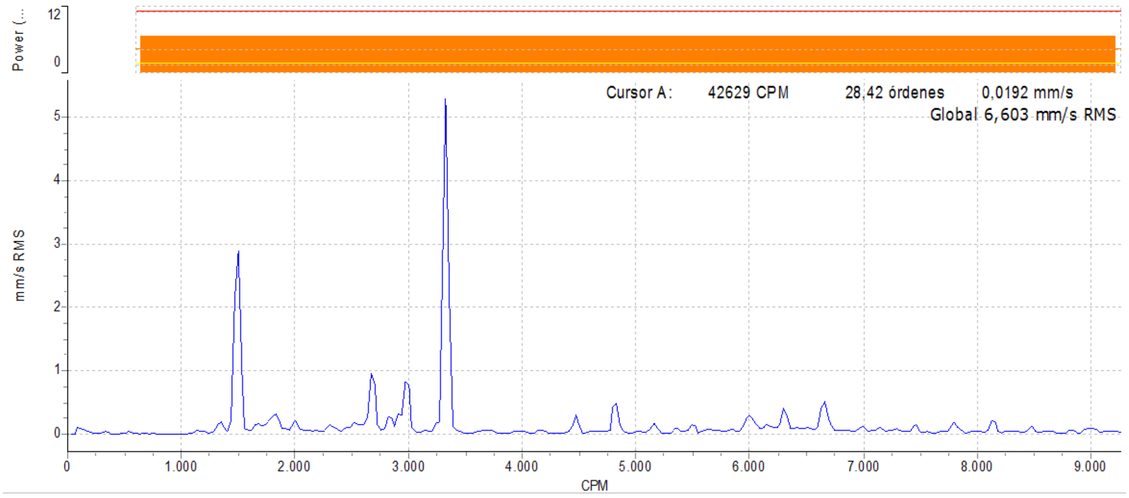


Fig. 50: Spectrum in the radial direction, coupling side of the motor (vacuum fan)

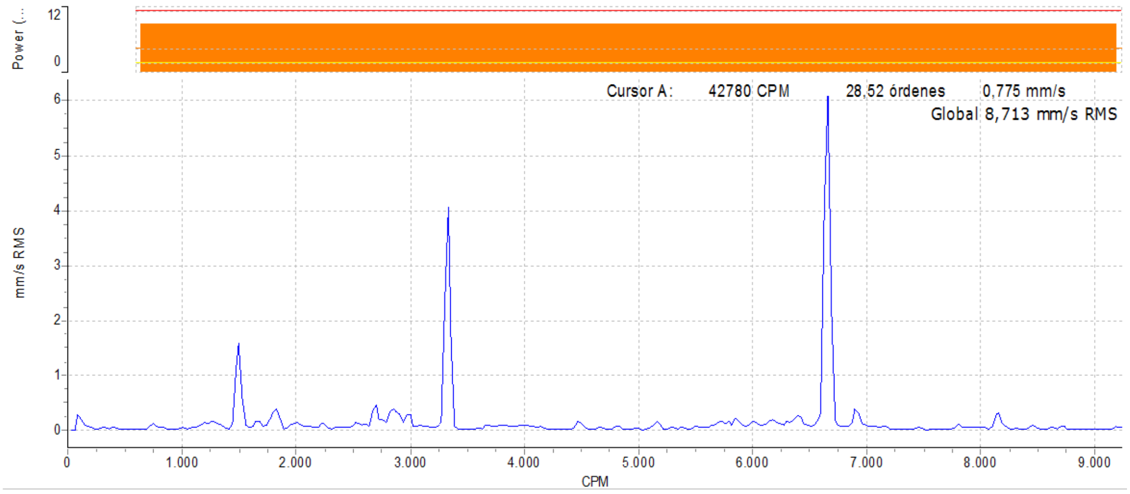


Fig. 51: Spectrum in the radial direction, coupling side of the fan (vacuum fan)

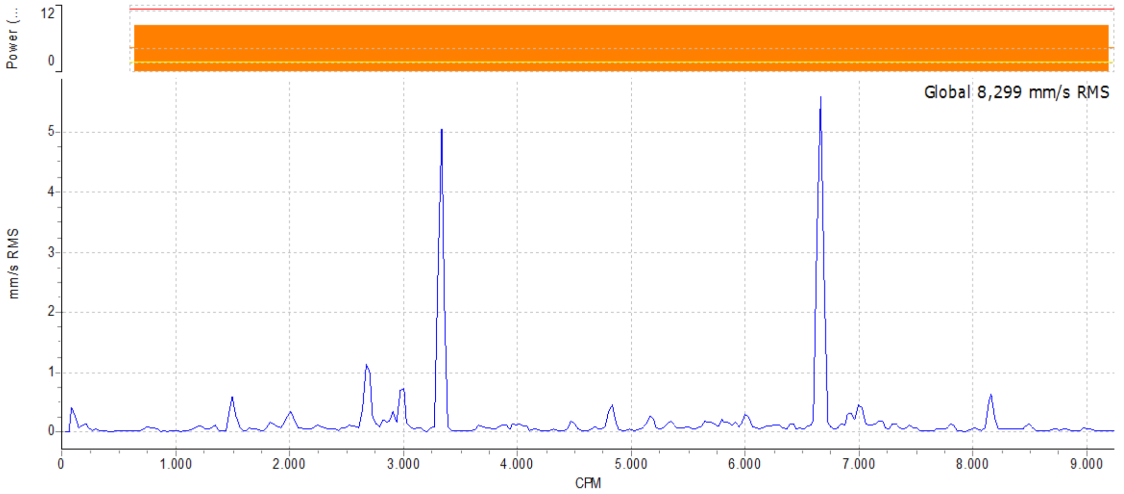


Fig. 52: Spectrum in the radial direction, free side of the fan (vacuum fan)

In the case of a fan, unbalance is more probable than eccentricity, due to the fact that an accumulation of some type of particles in one of the blades, which may easily happen, is enough to produce an unbalance in the whole fan. Therefore, one of the possible defects that this equipment presents is unbalance.

The peaks mentioned correspond to the following values of amplitude.

MEASURED POINT	DIRECTION	VELOCITY	AMPLITUDE (mm/s)
Free side of the motor	Radial	1500	3.106
		3300	2.909
Coupling side of the motor		1500	2.908
		3300	5.301
Coupling side of the fan		1500	1.587
		3300	4.057
Free side of the fan		1500	0.589
		3300	5.053

Table 8: Amplitude values in the radial direction (vacuum fan)

8.1.5.2. Axial direction

The second step is to study the axial direction. If the defect is unbalance, the amplitude at 1X should be lower in the axial direction than in the radial direction, since unbalance is a consequence of a centrifugal force (as explained in section 5.5.1). The spectra of the four points corresponding to the axial direction are shown below.

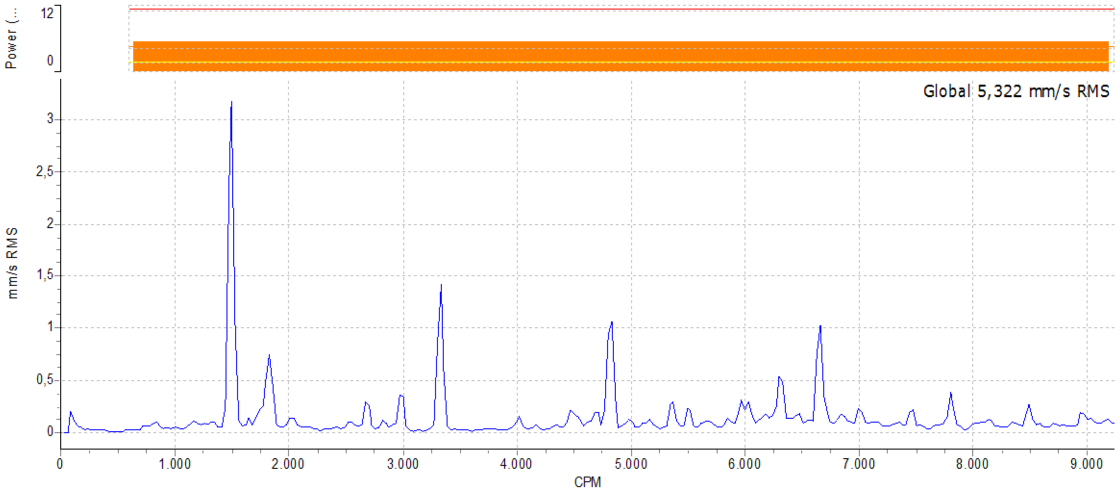


Fig. 53: Spectrum in the axial direction, free side of the motor (vacuum fan)

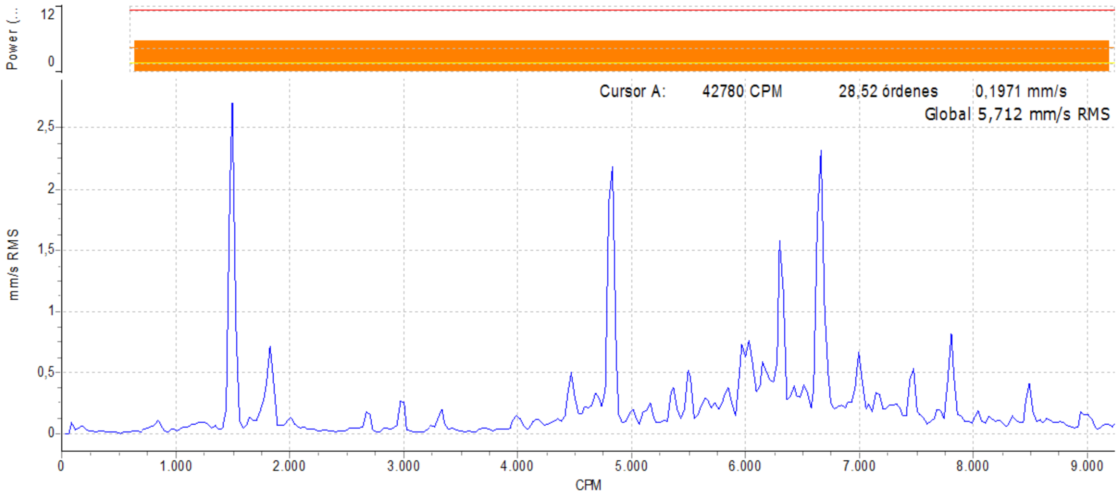


Fig. 54: Spectrum in the axial direction, coupling side of the motor (vacuum fan)

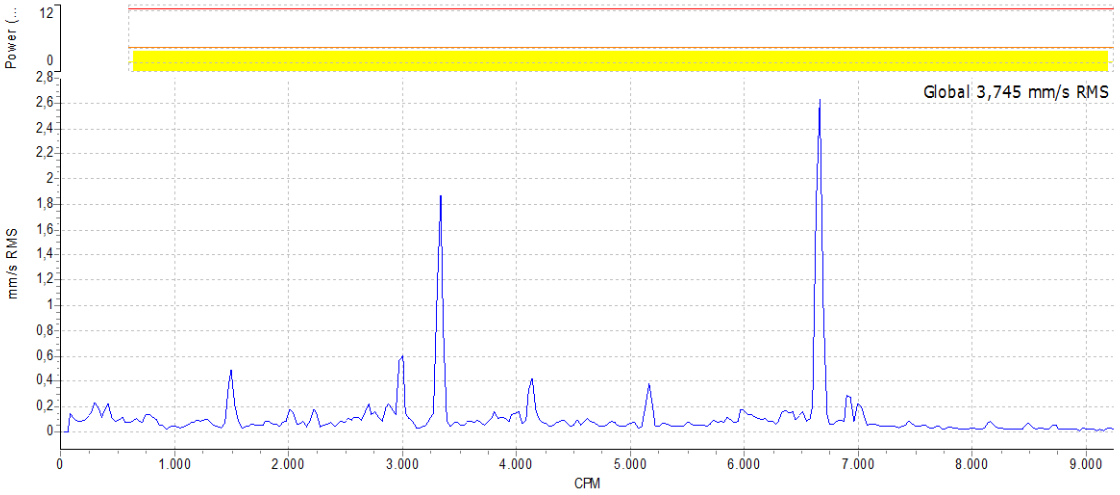


Fig. 55: Spectrum in the axial direction, coupling side of the fan (vacuum fan)

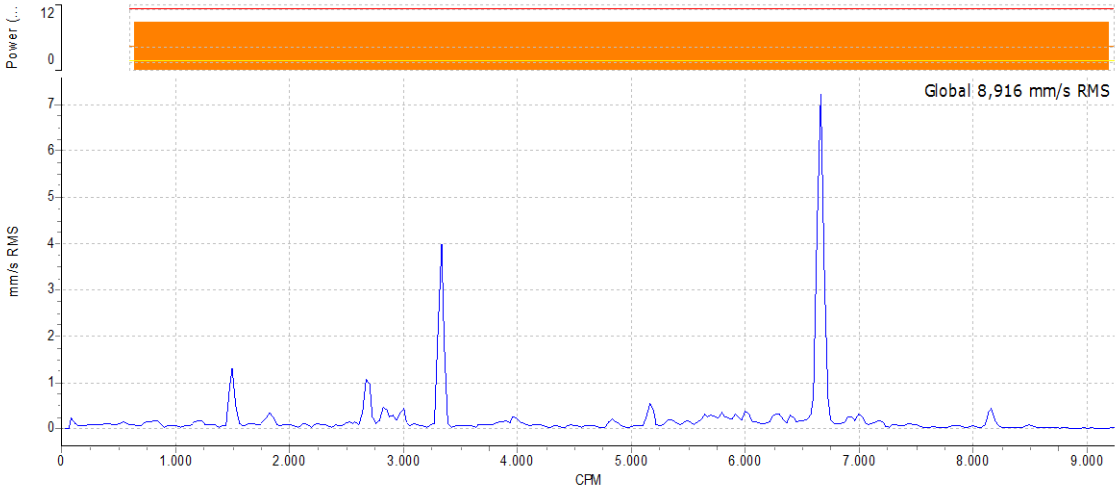


Fig. 56: Spectrum in the axial direction, free side of the fan (vacuum fan)

In Table 9 the values of the amplitude in the axial direction can be seen.

MEASURED POINT	DIRECTION	VELOCITY	AMPLITUDE (mm/s)
Free side of the motor	Axial	1500	3.185
		3300	1.41
Coupling side of the motor		1500	2.706
		3300	0.2032
Coupling side of the fan		1500	0.489
		3300	1.869
Free side of the fan		1500	1.318
		3300	3.992

Table 9: Amplitude values in the axial direction (vacuum fan)

In the case of the fan, the values of the amplitude at 1X are higher in the radial direction than in the axial direction. This means that, as it has been supposed previously, the fan presents an unbalance.

In the case of the motor, the values of the amplitudes at 1X presents similar values in the radial and axial directions. This means that the peaks at 1500 cpm in the radial direction are a consequence of the unbalance of the fan, and they do not indicate unbalance in the motor. The peaks at 1500 cpm in the axial direction, however, appear due to the fact that the fan is cantilevered. As a consequence, vibrations are transmitted from the fan to the whole equipment in the axial direction.

There is a possibility that the motor is also unbalanced, supposing that the peaks at 1X in the axial direction are amplified due to the unbalance in the fan. The only way to confirm this theory would be studying the vibrations of the motor working separated from the fan. However, it the motor is indeed unbalanced, it is a minor problem as the amplitudes of the vibrations are not very high.

8.1.5.3. Tangential direction

Finally, the results obtained in the tangential direction are studied. Since the unbalance of the equipment is not due to the motor, there should not be peaks at 1500 cpm, as the unbalance of the fan should not result in vibrations in the tangential directions. However, there could be peaks at 3300 cpm. As it has been mentioned, the unbalance in a fan is usually a consequence of the accumulation of particles in one of the blades. If this accumulation takes place in the blade end, it results in vibrations in the tangential direction.

The spectra corresponding to the tangential direction of the four points that are being studied are shown below.

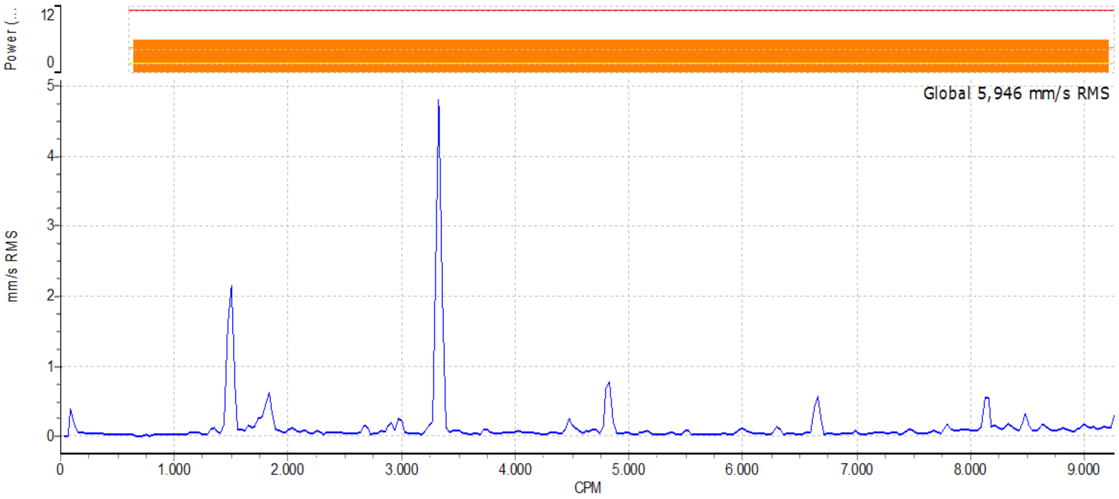


Fig. 57: Spectrum in the tang. direction, free side of the motor (vacuum fan)

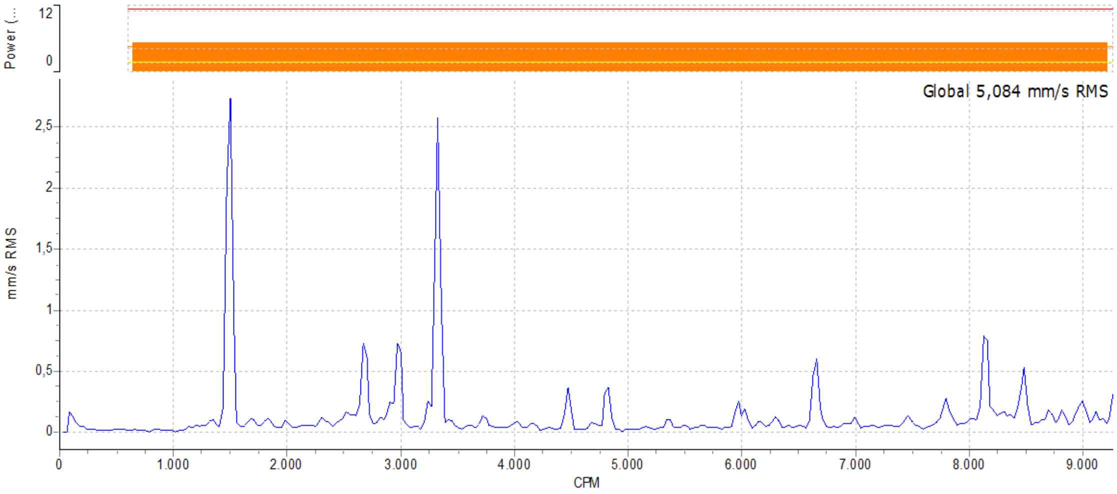


Fig. 58: Spectrum in the tang. direction, coupling side of the motor (vacuum fan)

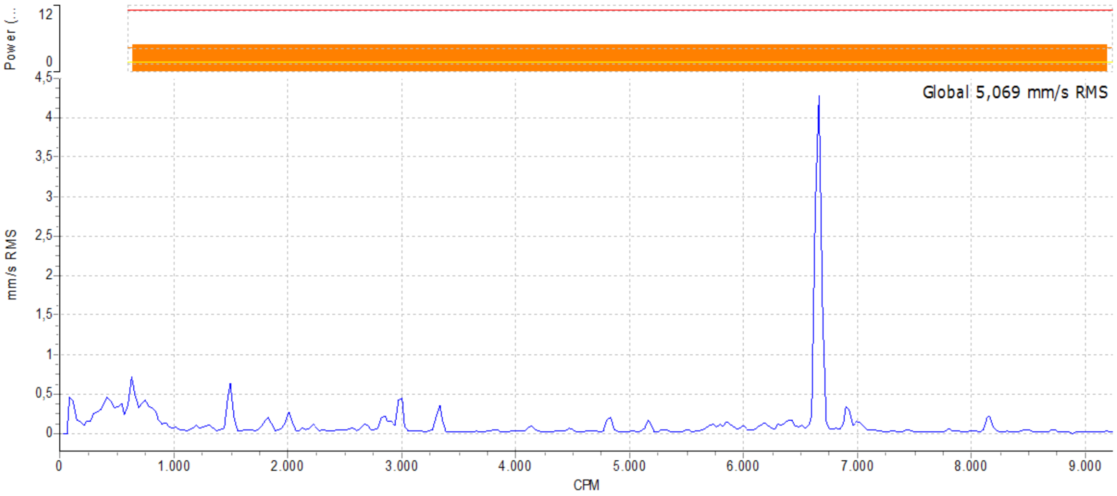


Fig. 59: Spectrum in the tang. direction, coupling side of the fan (vacuum fan)

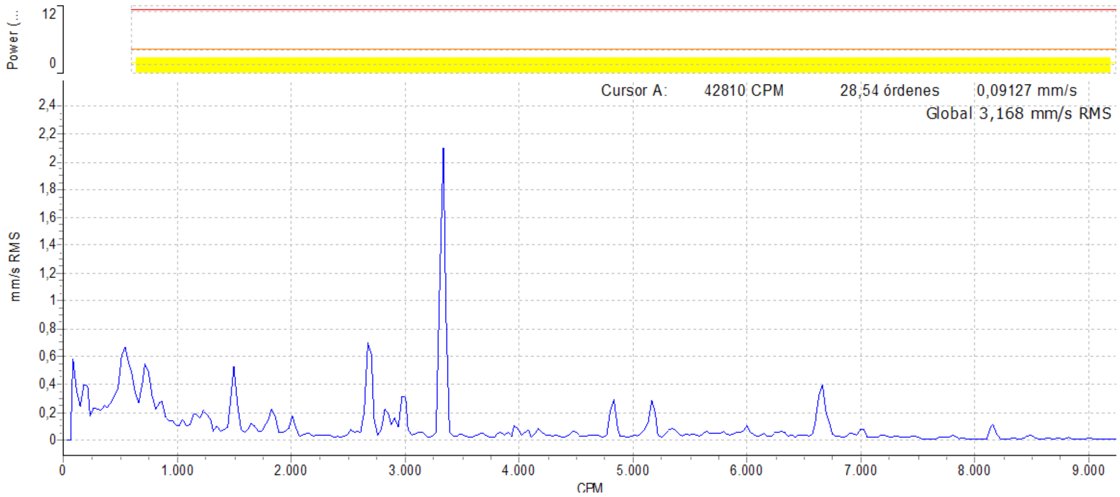


Fig. 60: Spectrum in the tang. direction, free side of the fan (vacuum fan)

In Table 10 values of the amplitude in the tangential direction are shown.

MEASURED POINT	DIRECTION	VELOCITY	AMPLITUDE (mm/s)
Free side of the motor	Tangential	1500	2.155
		3300	4.809
Coupling side of the motor		1500	2.738
		3300	2.569
Coupling side of the fan		1500	0.628
		3300	0.346
Free side of the fan		1500	0.529
		3300	2.098

Table 10: Amplitude values in the tang. direction (vacuum fan)

As it has been supposed, peaks at 1500 cpm are not very high.

8.1.5.4. Failure frequencies

Apart from what has been said, there is another important aspect in the spectra to mention: the **failure frequencies**. The fan has 13 blades and a cooling fan in the motor has 12 blades. As a consequence, the failures frequencies can be calculated with the expression in section 5.5.7. In this case they are call blade pass frequencies (BPF).

$$BPF_{fan} = 3300\ rpm * 13\ blades = \mathbf{42900\ cpm}$$

$$\mathrm{BPF}_{cooling\ fan} = 1500\ rpm * 12\ blades = \mathbf{18000\ cpm}$$

In the analysed spectra there are two differentiated: one at 18000 cpm and the other at 42900 cpm, as it can be seen in Fig. 61 and Fig. 62.

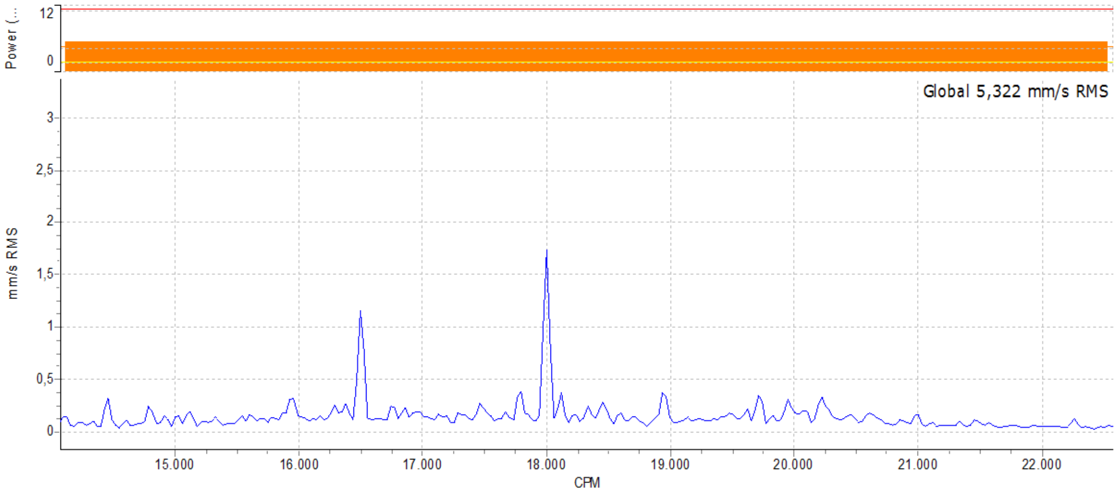


Fig. 61: Peak at 18000 cpm

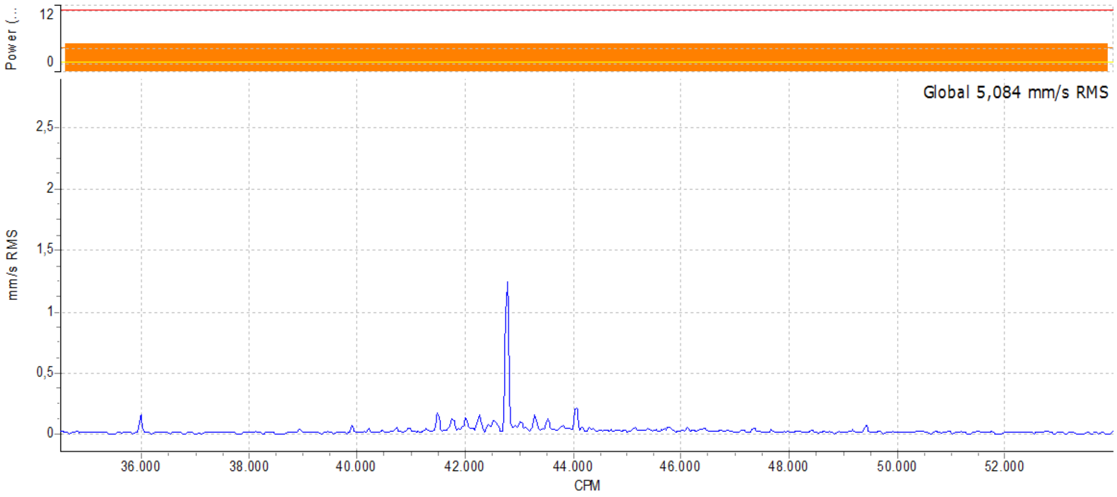


Fig. 62: Peak at 42900 cpm

These peaks may indicate a wear in one of the blades of both fans. However, the severity of a possible defect is determined studying the value of the amplitudes of the peaks. The value of the peaks at 18000 cpm varies from 0.5526 mm/s to 0.6955 mm/s, while the value of the peaks at 42900 varies from 0.0912 mm/s to 1.2512 mm/s. These are not problematic values, which means the two fans do not have to be repaired.

8.1.6. Conclusions

After the study of the spectra at the four points where the measurements have been taken, it can be confirmed that the main defect is the unbalance of the fan. The vibrations due to this defect are transmitted to the motor.

To determine the severity of the problem, the vibrations have to be compared to the admissible values. In Table 11 the global values of each of the spectra are shown.

DIRECTION	MEASURED POINT	GLOBAL VALUE (mm/s RMS)
Radial	Free side of the motor	4.896
	Coupling side of the motor	6.603
	Coupling side of the fan	8.713
	Free side of the fan	8.299
Axial	Free side of the motor	5.322
	Coupling side of the motor	5.712
	Coupling side of the fan	3.745
	Free side of the fan	8.916
Tangential	Free side of the motor	5.946
	Coupling side of the motor	5.084
	Coupling side of the fan	6.069
	Free side of the fan	3.168

Table 11: Global values (vacuum fan)

The **mean global value** of the vibrations in the fan is 6.039 mm/s RMS. As it has been said in 8.1.3, from 4.50 mm/s RMS the equipment is in unsatisfactory condition, and from 11.20 mm/s RMS it is in dangerous condition.

The equipment was on the 21/09/2018 in **unsatisfactory condition**, but it was nearer to a satisfactory condition (below 4.50 mm/s RMS) than to a dangerous condition (11.20 mm/s RMS). In the global tendency in Fig. 48, it can be seen that from the 24/12/2017 to the 26/11/2018, the amplitude values go from 5 mm/s RMS to 10 mm/s RMS, but stay in the same range. As a consequence, the equipment was not considered to be in an alarming condition, as it seems that the tendency is rather **stable**.

Checking the work orders of the company from the 21/09/2018, it can be seen that the order to repair the fan was not created until the 18/02/2019. This is an example of the necessity to check the vibration spectra taking into account also the tendency. In this case, according to the vibration spectra and the global values, the equipment was on an unsatisfactory condition. However, checking the tendency, it could be seen that the equipment vibration values remain stable in the range from 5 mm/s RMS to 10 mm/s RMS. As a consequence, the equipment did not have to be repaired until the 18/02/2019.

8.2. Refine Pump

8.2.1. Equipment function

Before entering the forming section, the paste needs to be properly refined so that there are no lumps, and its fibres need to be elongated as much as possible. This is carried out thanks to the refiners. In the PM4 there are two refiners, one of them shown in Fig. 63.

Fig. 63: Refinement machine of the PM4

This machine consists of two disks spinning and crashing each other, with the paste in between. Due to the protuberances of the disks, the paste is refined. Once the paste is refined, it goes through a cleaning process and then to the forming section.

The function of the analysed equipment is to pump the paste so that it reaches the refinement machine.

8.2.2. Equipment location

This equipment is located in the floor below the refiners area, which is located next to the PM4. The equipment can be seen in Fig. 64.

Fig. 64: Refine pump and its motor

8.2.3. Equipment description

The equipment studied in the present section is composed by a centrifugal pump and a motor, which are joined by a direct coupling. This means, in this example the velocity of the motor and the velocity of the pump are the same.

As in the previous case, there are 4 points to measure: the free and coupling sides of the motor, and the free and coupling sides of the pump. Vibrations are measured in three directions, so there are 12 spectra. Obviously, neither the pump nor the equipment are cantilevered, so the measured points are located as it is shown in Fig. 65.

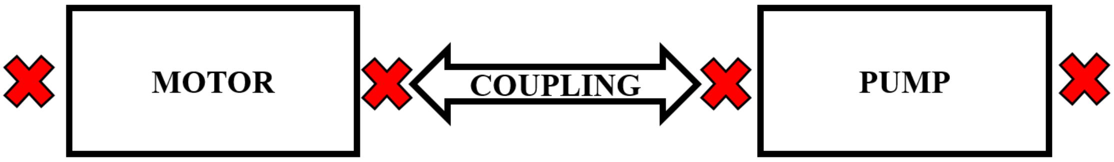


Fig. 65: Sketch of the measured points in the refine pump

An important aspect to mention, is the bad condition of the bench of the pump, as it can be seen in Fig. 66. The bench is an essential element of a machine, since its function is to transmit the vibrations directly to the ground.

Fig. 66: Bench of the refine pump

The motor has a power of 40 CV, equal to approximately 30 kW. As it a medium size motor with power between 15 and 75 kW, it is considered a type II machine according to ISO 10816:1995 (Table 6). The pump has a power of 37.4 kW. As it is a machinery with power up to 300 kW, the pump is also a type II machine. This means both machines are type II.

According to ISO 10816:1995 (Table 5), from 1.80 mm/s RMS the machine is in satisfactory condition, from 4.50 mm/s RMS it is in unsatisfactory condition, and from 11.20 mm/s RMS it is in dangerous condition.

Finally, this equipment is manually measured once a month, unless the vibrations increase and more measurements must be taken.

8.2.4. RMS tendencies analysis

As in the example of the vacuum fan, the first step is to study the tendencies. In Fig. 67 the amplitude values evolution from the 23/12/2015 to the 10/04/2019 are shown. It can be seen that the analysed pump is not a problematic equipment. The tendencies are rather stable and usually there are no values above 5 mm/s RMS. However, two peaks can be easily identified, one on the 10/08/2017, and the other on the 13/06/2018. In both peaks it can be seen that the amplitudes of the vibrations of the pump are much higher than those of the motor.

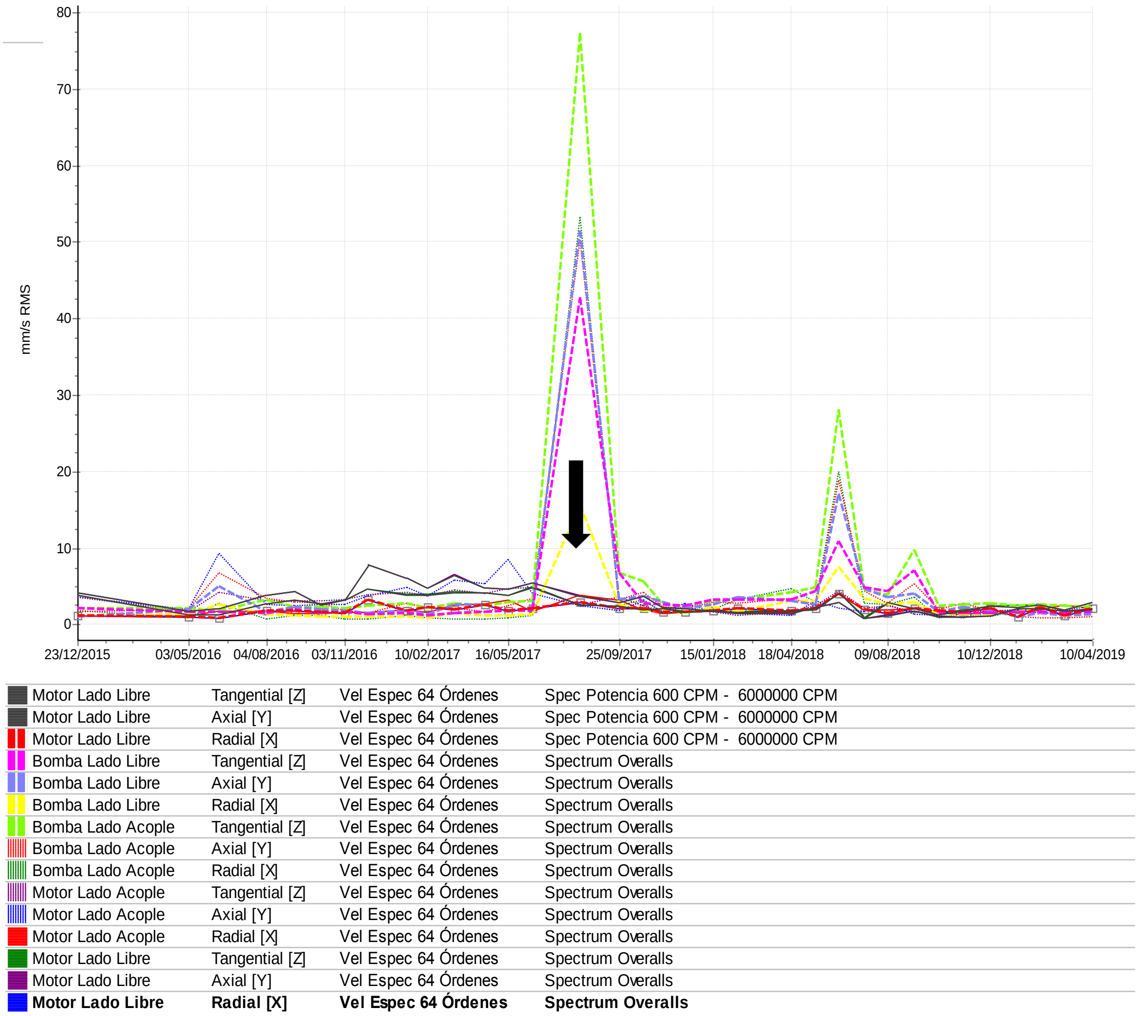


Fig. 67: RMS Tendencies in the refine pump

In this section, the vibrations on the 10/08/2017 are studied. As it can be seen in Fig. 68, in the coupling side of the pump the amplitude of the vibrations reaches a value of 78 mm/s RMS, which is rather alarming, but then remarkably decreases. This could mean that the increase of the vibrations is due to a punctual problem that was immediately fixed.

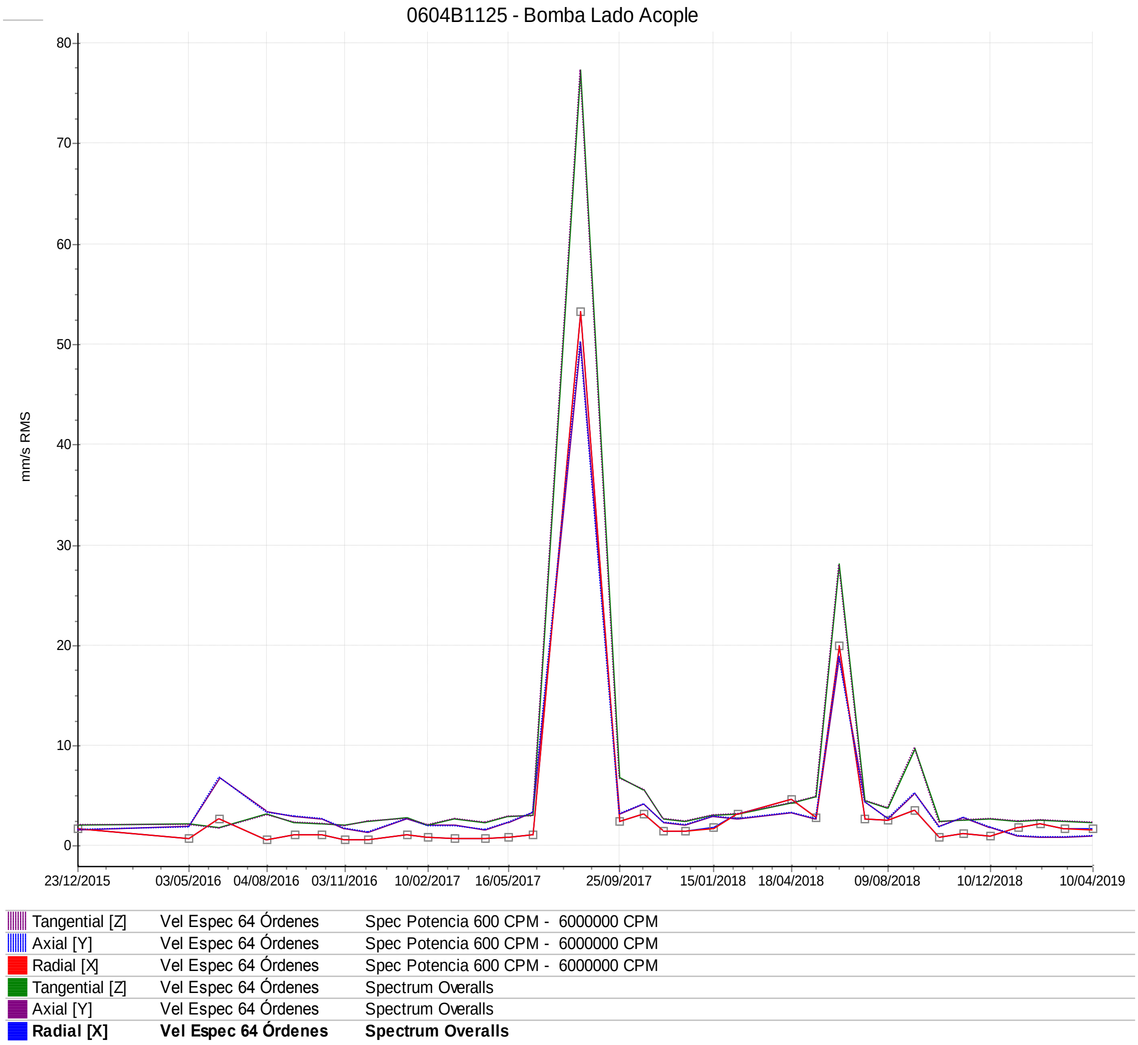


Fig. 68: RMS Tendencies in the coupling side of the refine pump

8.2.5. Frequency spectrum analysis

As the amplitude of the vibrations presents very different values in the pump and the motor, the two machines are studied separately.

8.2.5.1. Spectrum analysis of the pump

There are two points measured in the pump, the coupling and the free side of the pump. The frequency spectrum in the three directions of the **coupling side of the pump** are shown below.

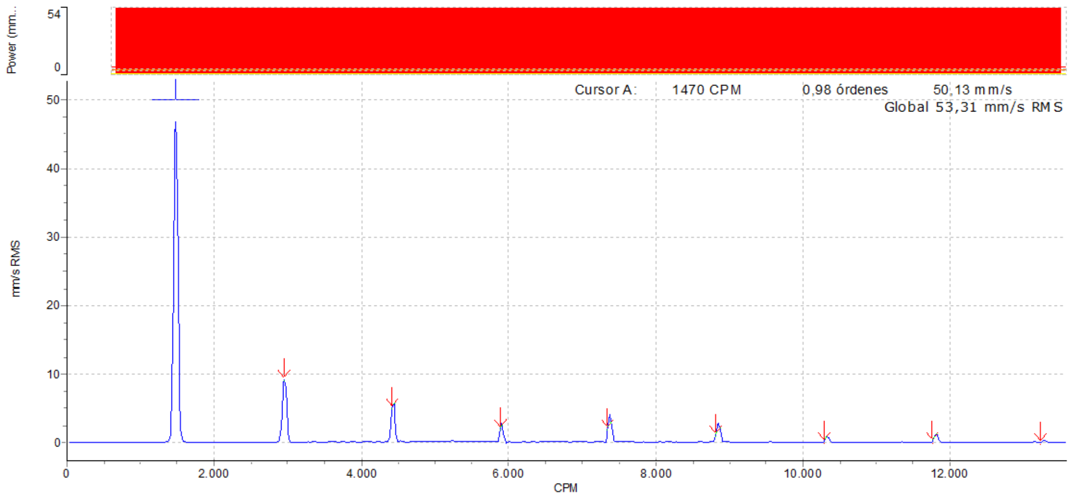


Fig. 69: Spectrum in the radial direction, coupling side of the pump (refine pump)

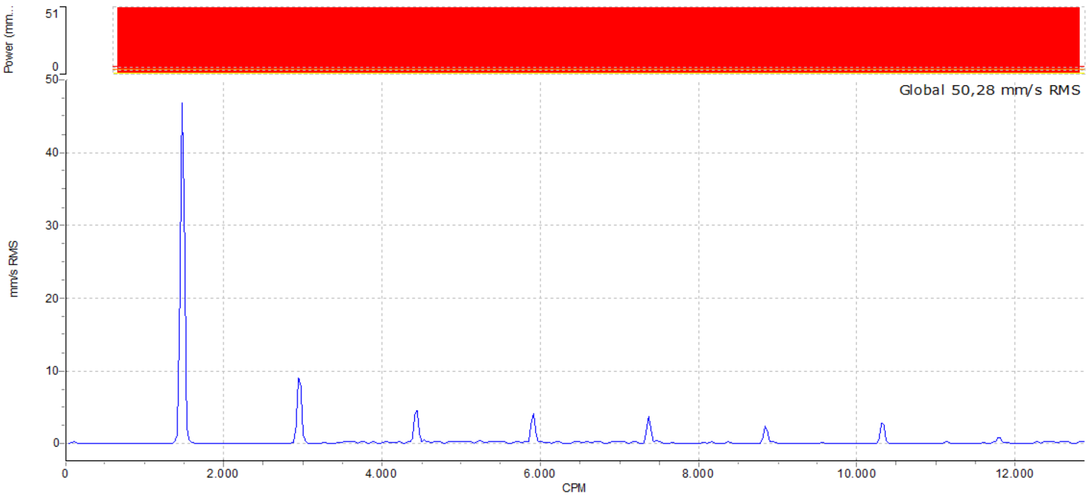


Fig. 70: Spectrum in the axial direction, coupling side of the pump (refine pump)

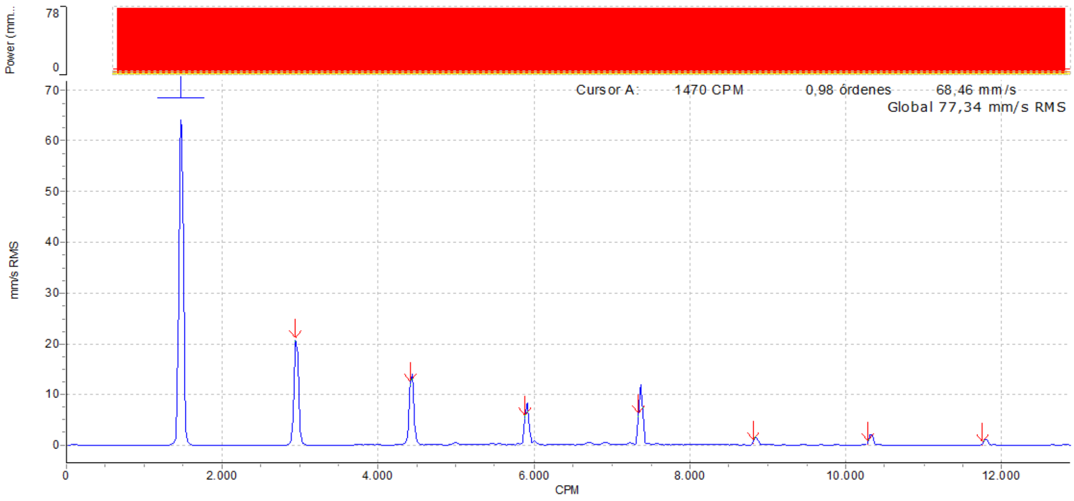


Fig. 71: Spectrum in the tang. direction, coupling side of the pump (refine pump)

The spectra are very similar in the three directions. The peak at 1X is higher than any other peaks, but there are also peaks at harmonics up to 8X. These are indicators of mechanical looseness, which could be structural looseness or internal assembly looseness. As it has been said in 5.5.5, there are 4 hits per cycle in the case of structural looseness. In this case there is a number of harmonics multiple to 4, which could mean the defect is due to structural looseness.

The spectra in the radial and axial direction are quite similar, as it can be seen in Table 12, where the amplitude values at 1X are shown.

MEASURED POINT	DIRECTION	PEAK	VELOCITY (mm/s)
Coupling side of the pump	Radial	1X	50.130
	Axial		46.840
	Tangential		68.460

Table 12: Amplitude values at 1X in the coupling side of the pump (refine pump)

It has to be taken into account that the measurements were made in the pump and not in points where the bolts that hold the pump to the bench are located. This means the directions in which vibrations are transmitted are not very clear. If the measurements were taken in the points where the bolts are located, the vibrations should be mostly transmitted in the radial and tangential direction. However, the tangential direction in the bolts location is not the same as the tangential direction in the pump. Therefore, the defect due to structural looseness in this case, is identified due to the harmonics, and not due to the directions in which the values of the amplitude are higher.

Below, the three spectra corresponding to the **free side of the pump** are shown.

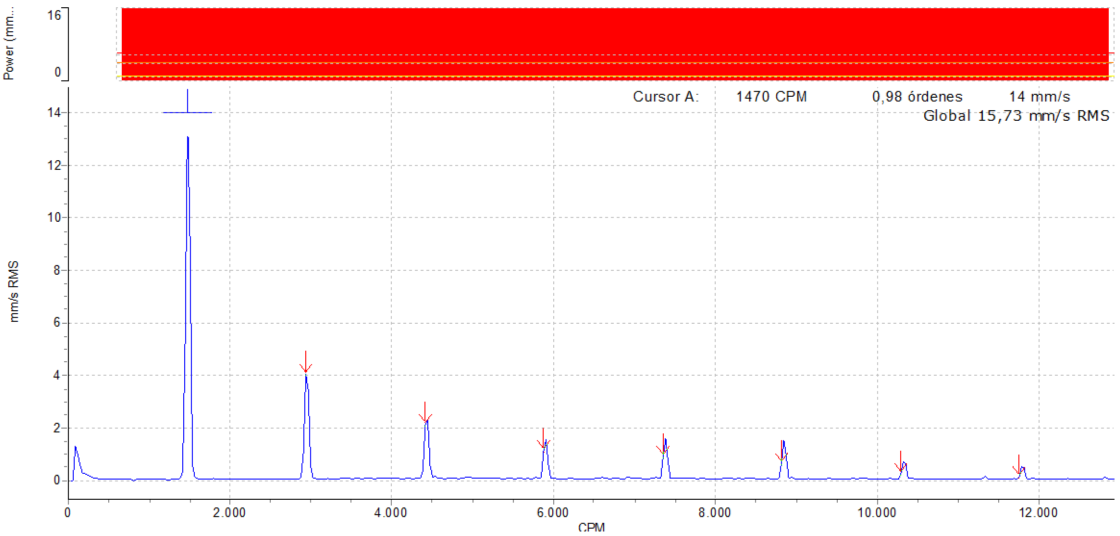


Fig. 72: Spectrum in the radial direction, free side of the pump (refine pump)

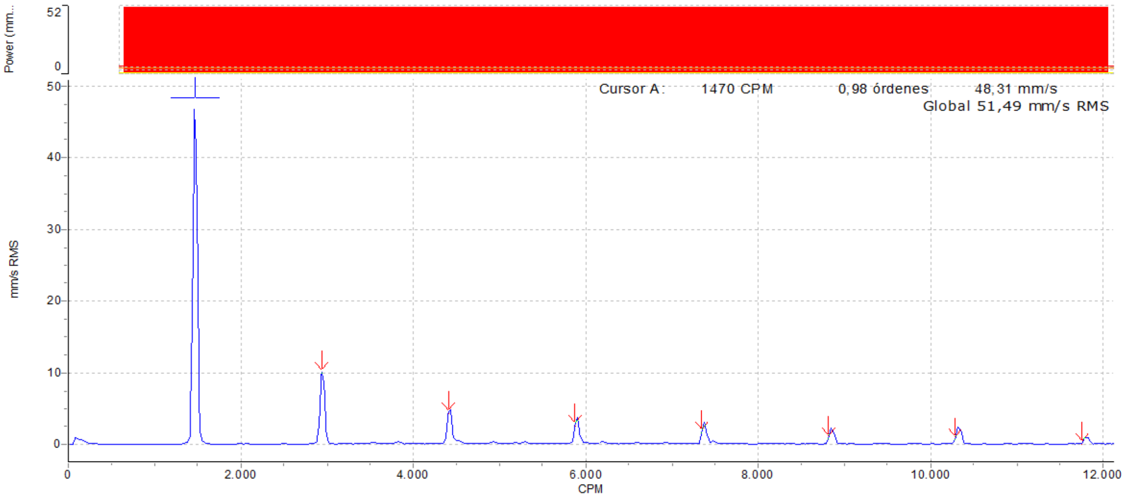


Fig. 73: Spectrum in the axial direction, free side of the pump (refine pump)

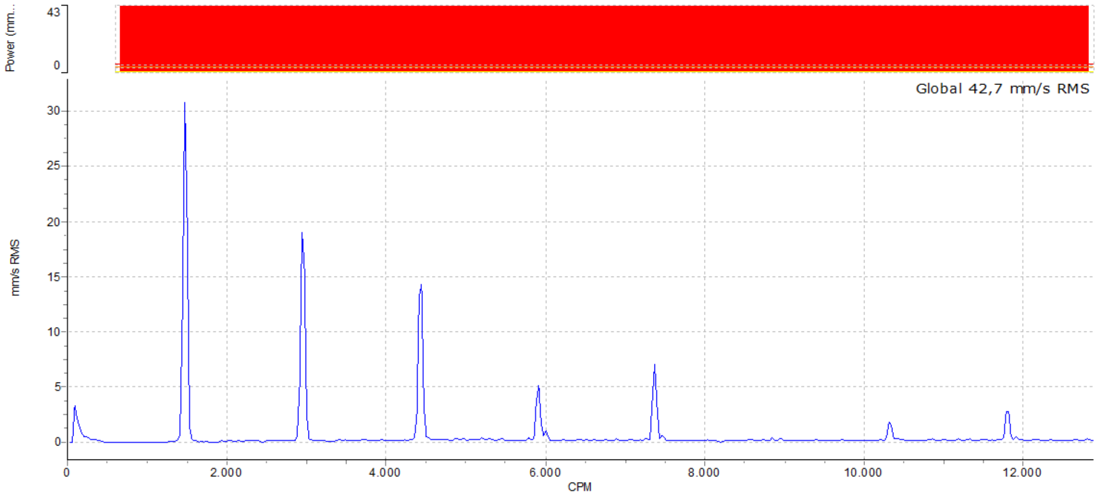


Fig. 74: Spectrum in the tang. direction, free side of the pump (refine pump)

In the free side of the pump, the spectra are very similar to those of the coupling side of the pump. There is a peak at 1X, and different harmonics up to approximately 8X. As it has been explained previously, this indicates structural looseness. In Table 13, the values at 1X are shown.

MEASURED POINT	DIRECTION	PEAK	VELOCITY (mm/s)
Free side of the pump	Radial	1X	14.000
	Axial		48.310
	Tangential		30.750

Table 13: Amplitude values at 1X in the free side of the pump (refine pump)

In the study of the spectra corresponding to the coupling side of the motor, it has been said that the directions (from the point of view of the pump) in which vibrations should be transmitted are not very clear. In that case, the amplitude of the vibrations was higher in the tangential direction. However, in the free side of the coupling, the higher amplitude values are not found in the tangential direction, but in the axial. This confirms what has been said in previous paragraphs: in this case the defect is identified due to the harmonics and not due to the direction in which the values of the amplitude are higher.

If in the spectra corresponding to both points, the higher vibrations were in the radial direction, the defect would not be structural looseness, but internal assembly looseness in the pump.

In conclusion, there is structural looseness between the pump and its bench.

8.2.5.2. Spectrum analysis of the motor

After analysing the spectra corresponding to the pump, the following step is to analyse the spectra of the motor, even though it is obvious that the main defect is at the pump, as it has been said in the tendency analysis (8.2.4). Those spectra corresponding to the **free side of the motor** are studied first.

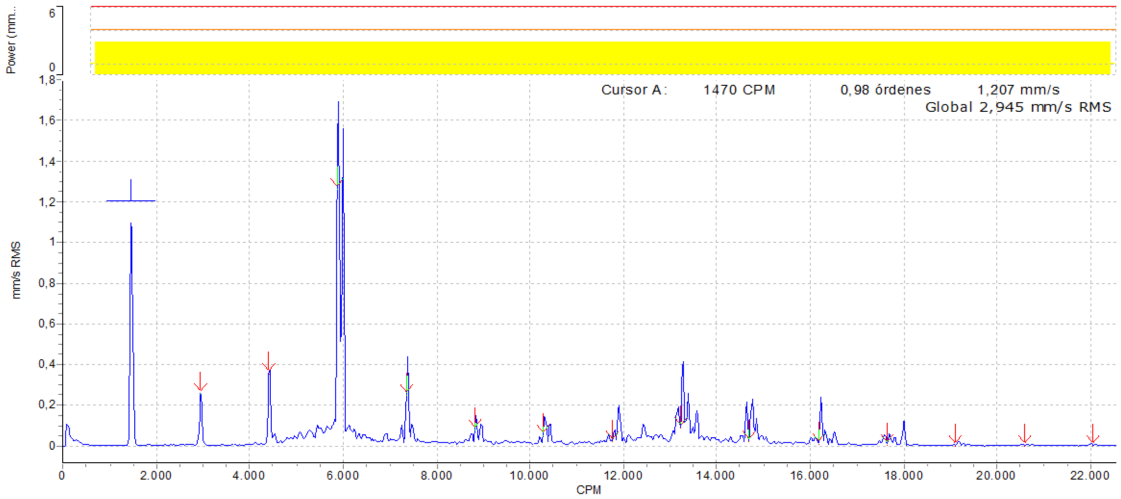


Fig. 75: Spectrum in the radial direction, free side of the motor (refine pump)

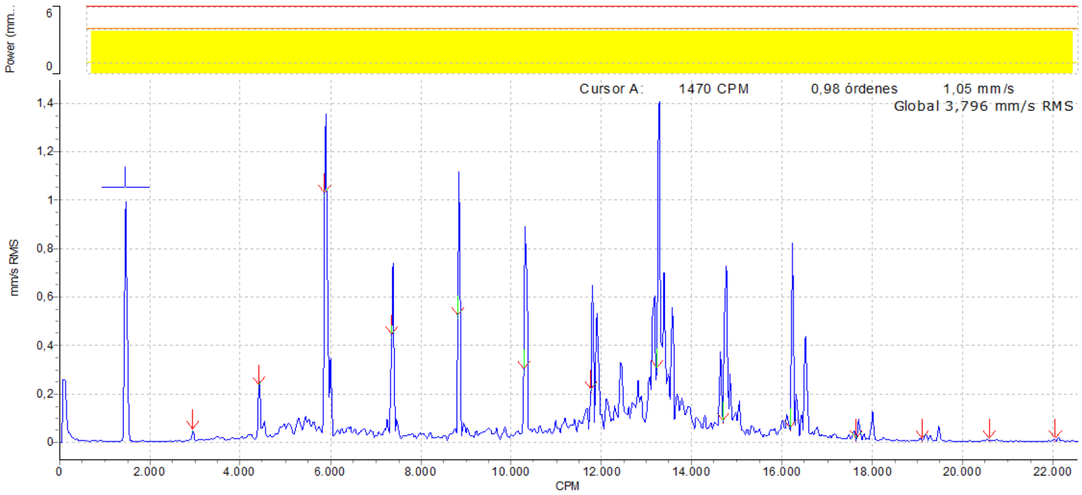


Fig. 76: Spectrum in the axial direction, free side of the motor (refine pump)

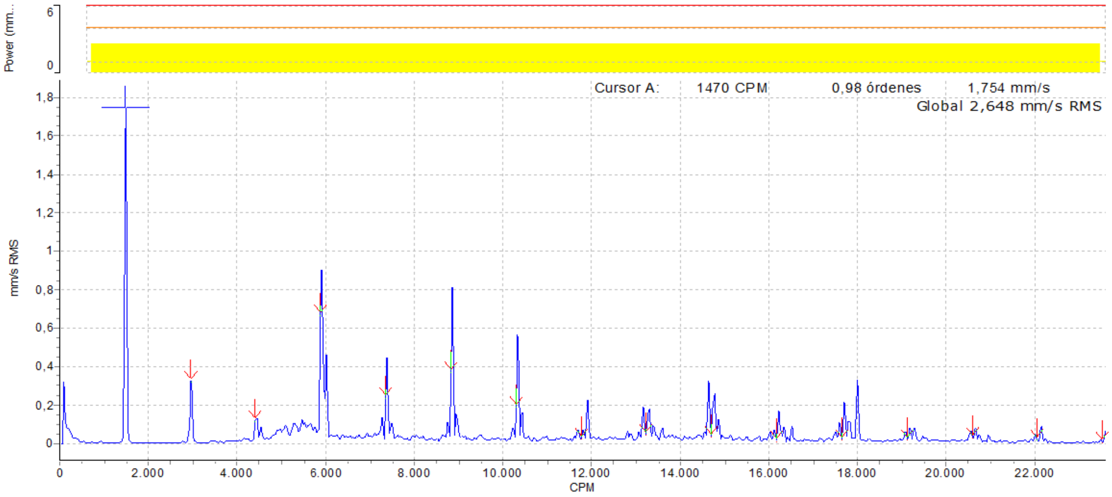


Fig. 77: Spectrum in the tang. direction, free side of the motor (refine pump)

The three spectra are quite similar, as there are harmonics of the fundamental frequency (1470 cpm). There are three possible causes for these harmonics:

- There is internal assembly looseness.
- As in the previous case, there are structural looseness.
- The vibrations are transmitted to the motor from the pump.

To identify the cause of the harmonics in the spectra, it is important to know the amplitude in the three directions, in order to compare them.

MEASURED POINT	DIRECTION	PEAK	VELOCITY (mm/s)
Free side of the motor	Radial	1X	1.207
	Axial		1.050
	Tangential		1.754

Table 14: Amplitude values at 1X in the free side of the motor (refine pump)

If the cause of the vibrations were internal assembly looseness, the amplitudes would be much higher in the radial direction. Vibrations in the tangential direction could also reach high amplitudes, but vibrations in the axial direction should present much lower values. In the three directions corresponding to the free side of the motor it can be seen that the amplitudes are nearly the same, which confirms the different peaks are not caused by internal assembly looseness.

The second option is that the defect is structural looseness. As it has been said in the analysis of the spectra corresponding to the pump, taking into account which points are measured, structural looseness are identified due to the harmonics and not due to the direction in which the vibrations are higher. Therefore, checking the spectra it could be supposed that the defect is structural looseness.

However, it there were structural looseness in the motor, the amplitude of the vibrations should be higher, due to the transmission of vibrations from the pump.

In the spectra corresponding to the **coupling side of the motor**, it can be seen that the amplitude values are much lower than in the case of the pump, as it was shown in the spectra corresponding to the free side of the motor.

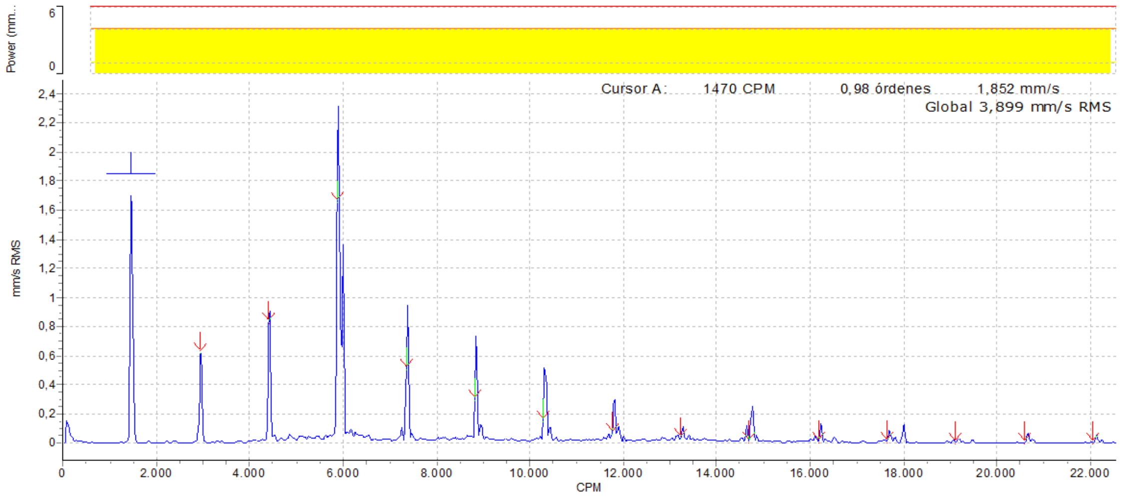


Fig. 78: Spectrum in the radial direction, coupling side of the motor (refine pump)

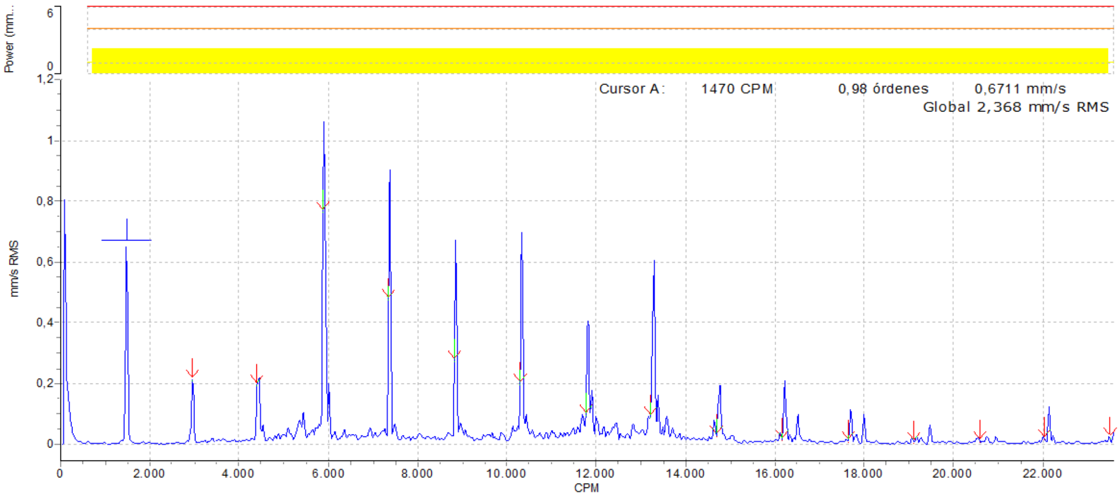


Fig. 79: Spectrum in the axial direction, coupling side of the motor (refine pump)

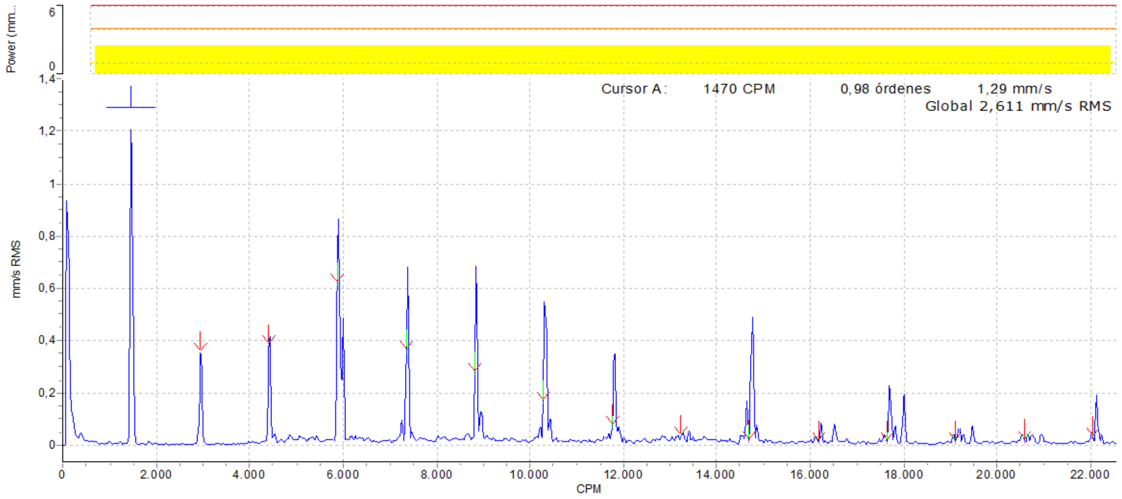


Fig. 80: Spectrum in the tang. direction, coupling side of the motor (refine pump)

The exact values at 1X can be seen in Table 15.

MEASURED POINT	DIRECTION	PEAK	VELOCITY (mm/s)
Coupling side of the motor	Radial	1X	1.852
	Axial		0.671
	Tangential		1.290

Table 15. Amplitude values at 1X in the coupling side of the motor (refine pump)

In conclusion, the vibrations of the motor are a consequence of the transmission of vibrations from the pump.

8.2.5.3. Bearing defect

Ascent software allows the user to see the different failure frequencies of the bearing in the frequency spectrum, so that possible defects can be identified as easy as possible. Below, the frequency spectra corresponding to the free side of the motor can be seen.

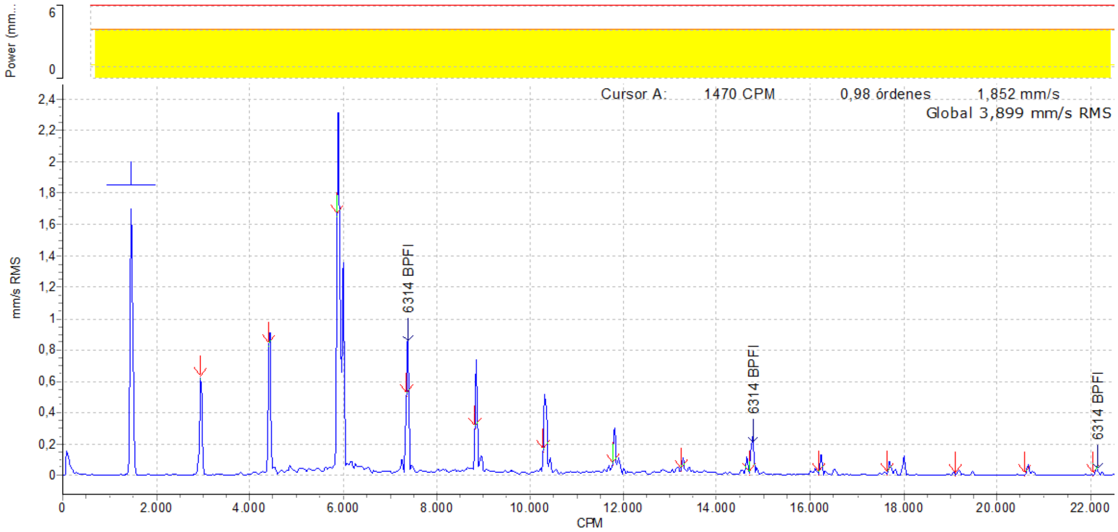


Fig. 81: BPFI in the radial direction, coupling side of the motor (refine pump)

Calculating the BPFI of the bearing located at the coupling side of the motor, it can be seen that it coincides to what appears in the spectrum.

BEARING 6314	
N_b: number of balls	8
B_d: diameter of the ball	1 cm
P_d: pitch diameter	4.33 cm
α: contact angle	0º

Table 16: Data corresponding to bearing 6314

$$BPFI = \frac{N_b}{2} * RPM * \left(1 + \frac{B_d}{P_d} * cos\alpha\right) = \frac{8}{2} * 1470 * \left(1 + \frac{1}{4.33} * \cos 0\right) = \boldsymbol{7238\ cpm}$$
$$\approx \boldsymbol{7350\ cpm}\ (\boldsymbol{5X})$$

In Fig. 81 it can be seen that BPFI almost coincides to the 5X, which is confirmed by calculating the BPFI. As a consequence, there is a peak at those frequencies. Since the amplitudes are very small, side bands can not be seen.

The fact that there is a peak at BPFI means that an upcoming defect in the inner ring may appear as time passes. As the BPFI almost coincides with 5X, the defect may be amplified, and the inner ring could be damage in less time.

However, taking into account that the amplitudes present small values and that there are no sidebands yet, this defect is not alarming at all.

8.2.6. Conclusions

After analysing the spectra in the four points measured, it can be concluded that the structural looseness between the pump and the bench bring out very high amplitude values in the spectra corresponding to the pump. These vibrations are transmitted to the pump, as it has been explained in the previous section.

The final step is to determine the severity of the problem, for which it is necessary to compare the global values of the vibrations that the equipment presents and the admissible global values according to ISO 10816:1995 (Table 5). In the following table, the global values in each spectrum are shown.

MEASURED POINT	DIRECTION	GLOBAL VALUE (mm/s)
Coupling side of the pump	Radial	2.945
	Axial	3.796
	Tangential	2.648
Free side of the pump	Radial	3.899
	Axial	2.368
	Tangential	2.611
Free side of the motor	Radial	53.310
	Axial	50.280
	Tangential	77.340
Coupling side of the pump	Radial	15.730
	Axial	51.490
	Tangential	42.700

Table 17: Global values (refine pump)

The mean global value of the vibrations of the equipment is 25.760 mm/s RMS. This is higher than 11.20 mm/s RMS, which means the equipment was by far in a dangerous condition on the 10/08/2017 and should be repaired as soon as possible.

Checking the work orders from the 10/08/2017, it can be seen that on the 10/08/2017 there was an order that said the pump must be hold onto the bench because the bolts were broken. This confirms what has been said in the previous section: there is structural looseness between the pump and the bench. As the bolts are broken, the amplitude of the vibrations presents such great values.

8.3. Cleaners Pump

8.3.1. Equipment function

Before entering to the forming section, there is a process of refinement and filtration of the paste. In the previous section, the condition of an equipment responsible for the refinement process has been studied. In this case, an equipment whose function is to depurate the paste is analysed.

In the PM4, the depuration process is carried out thanks the cleaners. These cleaners consists of conical filters through which the paste passes. There are 6 cleaners stages. The paste enters the first cleaners stage. The paste that is depurated enough enters the forming section, while the paste that is not goes to the second cleaners stage. The paste that depurate enough in this second stage, goes to the first stage, while the paste that is not goes to the third stage. The process continues until the sixth stage.

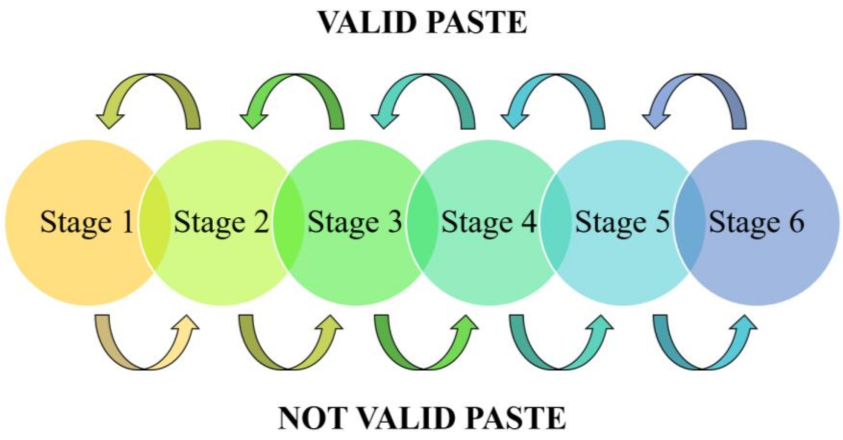


Fig. 82: Cleaners process

The equipment where the filters are located is called radiclone, and can be seen in Fig. 83.

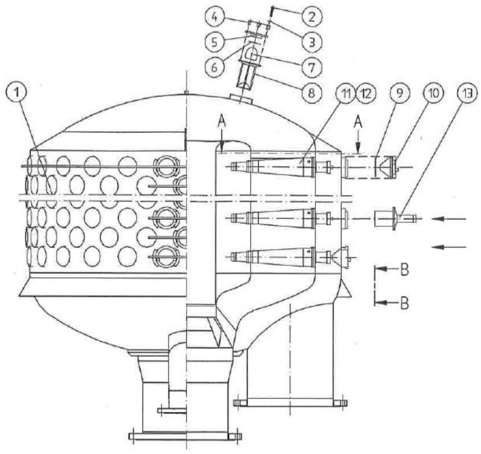


Fig. 83: Sketch of the radiclone

The equipment studied is the feeding pump of the third cleaners stage. This pump takes the rejected paste of the fourth cleaners stage to the third stage.

8.3.2. Equipment location

The radiclone systems are located at the beginning of the PM4, in front of the beginning of the forming section. These systems can be seen in Fig. 84.

Fig. 84: Radiclone systems of the PM4

The studied pump and its motor are located on the floor below the radiclone systems. All the feeding pumps of the six stages are located in the same area.

8.3.3. Equipment description

This equipment consists of a centrifugal pump and a motor, which are joined by a direct coupling. As in the previous examples, there are 4 points in which measurements are made: the free and coupling sides of the motor, and the free and coupling sides of the pump. Since vibrations are measured in radial, axial and tangential directions, there are 12 spectra.

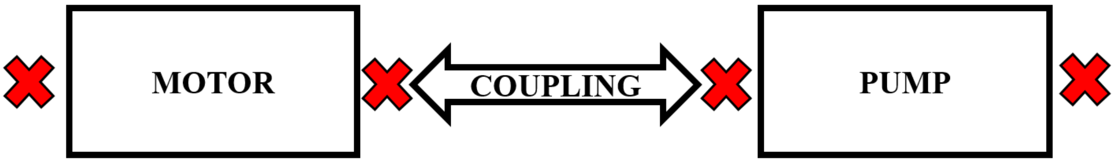


Fig. 85: Sketch of the measured points in the cleaners pump

The motor has a power of 75 kW. A type II motor has a power between 15 and 75 kW according to ISO 10816:1995. As the admissible values of a type II machine are lower than those of a type III machine, the motor is considered a type II machine, in order to use a more restrictive point of view. The pump has a power of 63 kW. As it is a machine with power up to 300 kW, the pump is also a type II machine.

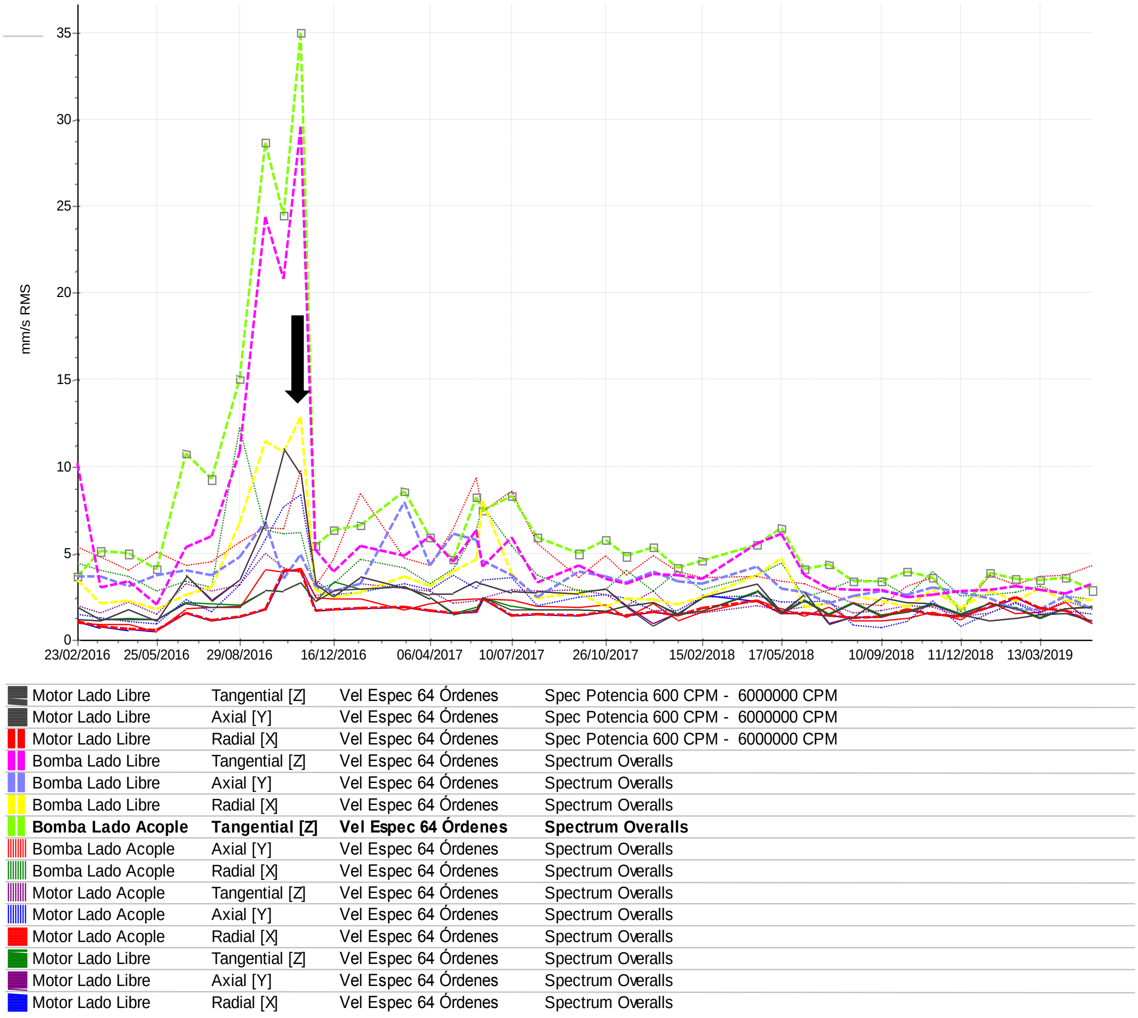
According to ISO 10816:1995 (Table 5), from 1.80 mm/s RMS the machine is in satisfactory condition, from 4.50 mm/s RMS it is in unsatisfactory condition and from 11.20 mm/s RMS it is in dangerous condition.

Finally, as in the two previous examples, this equipment is checked once a month.

Fig. 86: Feeding pump of the third cleaners stage and its motor

8.3.4. RMS tendencies analysis

As in the previous examples, the first step is to study the tendencies.



⬛ Motor Lado Libre	Tangential [Z]	Vel Espec 64 Órdenes	Spec Potencia 600 CPM - 6000000 CPM
⬛ Motor Lado Libre	Axial [Y]	Vel Espec 64 Órdenes	Spec Potencia 600 CPM - 6000000 CPM
🟥 Motor Lado Libre	Radial [X]	Vel Espec 64 Órdenes	Spec Potencia 600 CPM - 6000000 CPM
🟪 Bomba Lado Libre	Tangential [Z]	Vel Espec 64 Órdenes	Spectrum Overalls
🟦 Bomba Lado Libre	Axial [Y]	Vel Espec 64 Órdenes	Spectrum Overalls
🟨 Bomba Lado Libre	Radial [X]	Vel Espec 64 Órdenes	Spectrum Overalls
🟩 **Bomba Lado Acople**	**Tangential [Z]**	**Vel Espec 64 Órdenes**	**Spectrum Overalls**
▥ Bomba Lado Acople	Axial [Y]	Vel Espec 64 Órdenes	Spectrum Overalls
▥ Bomba Lado Acople	Radial [X]	Vel Espec 64 Órdenes	Spectrum Overalls
▥ Motor Lado Acople	Tangential [Z]	Vel Espec 64 Órdenes	Spectrum Overalls
▥ Motor Lado Acople	Axial [Y]	Vel Espec 64 Órdenes	Spectrum Overalls
🟥 Motor Lado Acople	Radial [X]	Vel Espec 64 Órdenes	Spectrum Overalls
🟩 Motor Lado Libre	Tangential [Z]	Vel Espec 64 Órdenes	Spectrum Overalls
🟪 Motor Lado Libre	Axial [Y]	Vel Espec 64 Órdenes	Spectrum Overalls
🟦 Motor Lado Libre	Radial [X]	Vel Espec 64 Órdenes	Spectrum Overalls

Fig. 87: RMS Tendencies in the cleaners pump

As it can be seen in Fig. 87, in this equipment the values of the amplitude are not greater than 10 mm/s RMS in any point but in the points corresponding to dates from September 2016 to November 2016. The highest peaks were measured on the 08/11/2016, and correspond to both points of the pump in the tangential directions. This is the point that is studied in the present section.

8.3.5. Frequency spectrum analysis

As in the previous case, since the vibrations measured in the pump and the motor present very difference values the two machines are studied separately.

8.3.5.1. Spectrum analysis of the motor

Below, the spectra corresponding to the coupling side of the motor are shown.

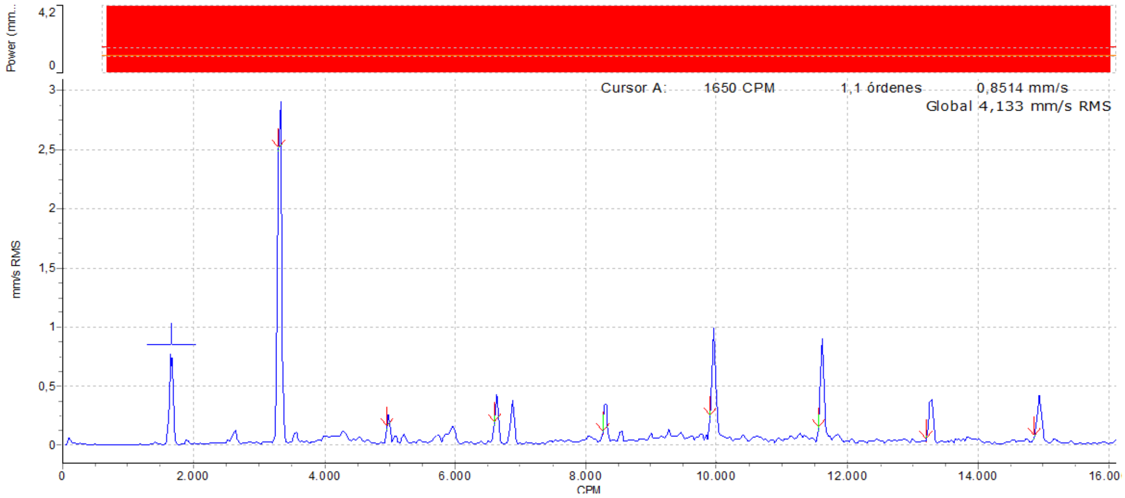


Fig. 88: Spectrum in the radial direction, coupling side of the motor (cleaners pump)

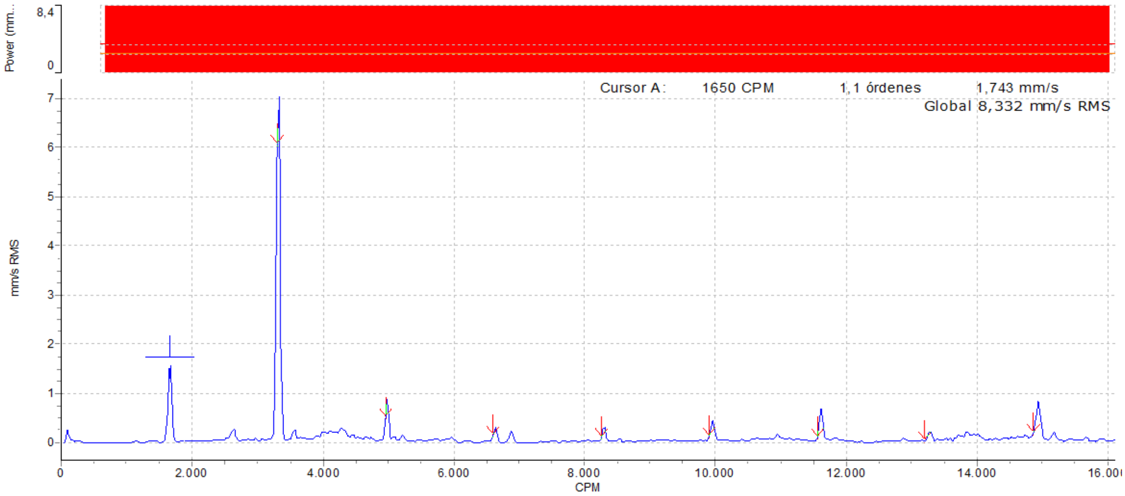


Fig. 89: Spectrum in the axial direction, coupling side of the motor (cleaners pump)

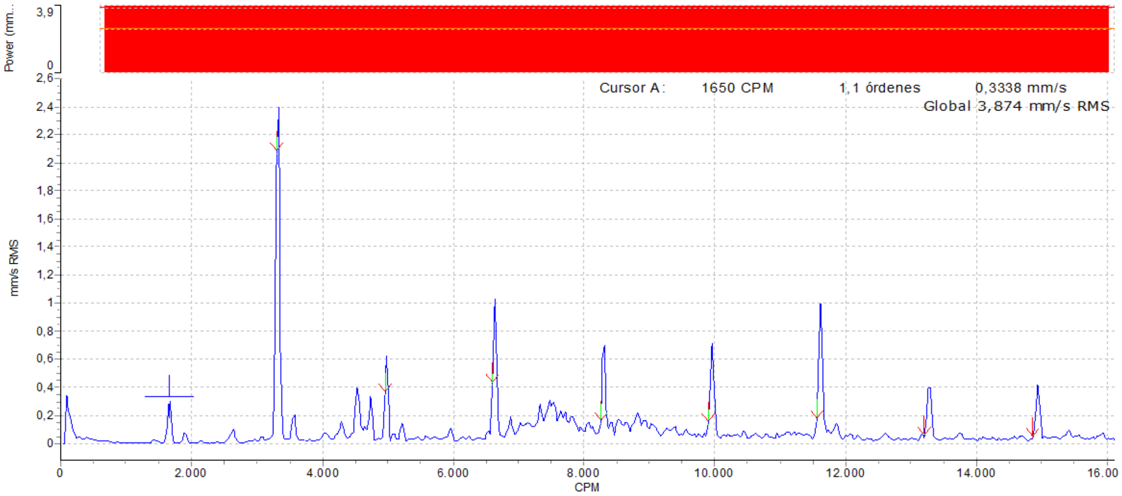


Fig. 90: Spectrum in the tang. direction, coupling side of the motor (cleaners pump)

It can be seen that in the three spectra the peak at 2X is dominant. This is an indicative of misalignment, which can be angular or parallel. Since the spectra corresponding to the free side of the motor are nearly the same, they are not shown in this document.

MEASURED POINT	DIRECTION	PEAK	VELOCITY (mm/s)
Coupling side of the motor	Radial	2X	2.904
	Axial		7.029
	Tangential		2.399
Free side of the motor	Radial	2X	3.147
	Axial		7.839
	Tangential		1.296

Table 18: Amplitude values at 2X in the motor (cleaners pump)

Vibrations are higher in the axial direction, which could be an indicative of angular misalignment or a bent shaft.

8.3.5.2. Spectrum analysis of the pump

In both the coupling and free sides of the pump, the spectra present the same structure as in the case of the coupling side of the motor. There are dominant peaks at 2X, and the only thing that varies is the value of the amplitude at the mentioned peak, which can be seen in Table 19.

MEASURED POINT	DIRECTION	PEAK	VELOCITY (mm/s)
Coupling side of the pump	Radial	2X	3.663
	Axial		8.329
	Tangential		31.770
Free side of the pump	Radial	2X	10.720
	Axial		2.877
	Tangential		25.090

Table 19: Amplitude values at 2X in the pump (cleaners pump)

In the coupling side of the pump, the amplitude at 2X is higher in the axial direction, but in the free side of the pump, the vibrations are higher in the radial direction. In both points, vibrations in the tangential direction are much higher.

This results can be rather confusing due to the fact that higher vibrations in the radial direction are an indicative of parallel misalignment, but greater amplitudes in the axial vibration indicate angular misalignment. Both types of misalignment can be the cause of the high vibrations values in the tangential directions.

8.3.6. Conclusions

After analysing the different spectra, there are two possible diagnosis:

- <u>The shaft of the motor is bent and there is parallel misalignment between the pump and the motor.</u>

The bent shaft could be the reason why the amplitudes in the motor are higher in the axial directions. This high amplitudes are transmitted to the coupling side of the motor, which also presents greater amplitudes in the axial direction. However, due to the parallel misalignment, in the free side of the motor the amplitudes are higher in the radial direction.

- <u>There is a general misalignment in the equipment, combination of both parallel and angular misalignments.</u>

Due to the fact that the misalignment is a combination of both parallel and angular misalignments, there are peaks at 2X in every spectrum, but they can be greater in the radial or axial directions. The great values the pump suffers in the tangential direction could be an indicative that this misalignment may come from the pump, which was working misaligned.

The second option seems to be more probable. If the shaft of the motor were bent, the difference between the peaks at 1X and 2X should not be so great. It is still possible, but the most probable defect is general misalignment.

Finally, in order to determine the severity of the problem, the global RMS value is calculated.

MEASURED POINT	DIRECTION	GLOBAL VALUE (mm/s)
Free side of the motor	Radial	3.988
	Axial	9.585
	Tangential	3.305
Coupling side of the motor	Radial	4.133
	Axial	8.332
	Tangential	3.874
Coupling side of the pump	Radial	6.180
	Axial	9.760
	Tangential	34.99
Free side of the pump	Radial	12.850
	Axial	4.909
	Tangential	29.540

Table 20: Global values (cleaners pump)

The mean global value is 8.038 mm/s RMS. This value is between 4.50 and 11.20 mm/s RMS, which means the equipment was in an unsatisfactory condition on the 08/11/2016.

Checking the work orders from the 08/11/2016, it can be seen that on the 21/11/2016 there was a work order that said the pump must be aligned with the motor. As a consequence, in the next measurement (made on the 24/11/2016). This confirms what has been said in the previous sections: the motor and the pump were misaligned.

8.4. Guide Roll

8.4.1. Equipment function

In the PM4 there are several rolls, which are the guide for the felt or the paper sheet. The analysed roll is the guidance of the paper sheet at the entrance to the Yankee. There are two rolls at the entrance to the Yankee and one roll at the exit.

8.4.2. Equipment location

As it has been said, the studied roll is located at the entrance of the Yankee, as it can be seen in Fig. 91.

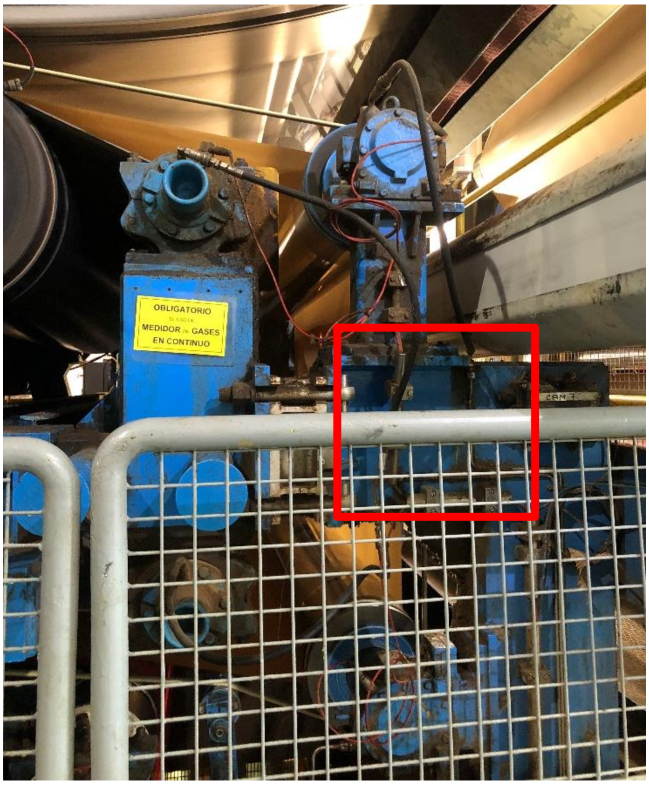


Fig. 91: Guide roll in the Yankee section of the PM4

8.4.3. Equipment description

All the guide rolls for the paper sheet present the same structure. There are fastening elements in both ends of the roll. This structure is shown in Fig. 92, which shows a general guide roll for the paper sheet.

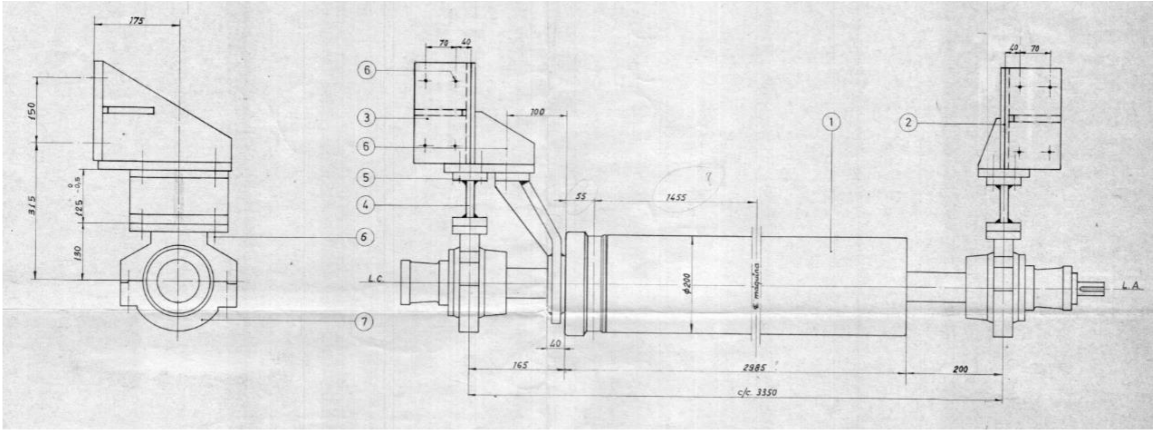


Fig. 92: Sketch of a guide roll for the paper sheet

In the case of the rolls, the measurements are made in the two ends of the roll. The end corresponding to the side where the control room is located, is called conductor side, and the end corresponding to the other end, where usually the engines and gearboxes are located, is called transmission side.

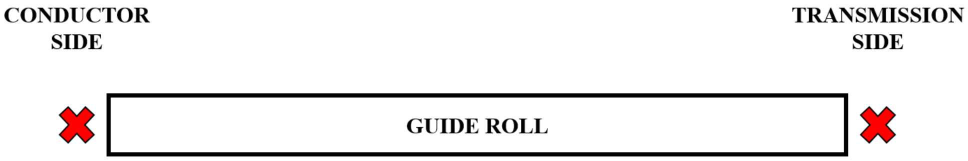


Fig. 93: Sketch of the measured points in the guide roll

Apart from that, the bearing located in both sides is the 6321.

BEARING 6321	
N_b: number of balls	8
B_d: diameter of the ball	1.5 cm
P_d: pitch diameter	6.496 cm
α: contact angle	0º

Table 21: Data corresponding to bearing 6321

Taking into account that the roll rotates at 600 rpm, the different failure frequencies, can be calculated as it follows:

$$BPFO = \frac{N_b}{2} * RPM * \left(1 - \frac{B_d}{P_d} * cos\alpha\right) = \frac{8}{2} * 600 * \left(1 - \frac{1.5}{6.496} * \cos 0\right)$$
$$= \mathbf{1845.81\ cpm}$$

$$BPFI = \frac{N_b}{2} * RPM * \left(1 + \frac{B_d}{P_d} * cos\alpha\right) = \frac{8}{2} * 600 * \left(1 + \frac{1.5}{6.496} * \cos 0\right)$$
$$= \mathbf{2954.19\ cpm}$$

$$BSF = \frac{P_b}{2B_D} * RPM * \left(1 - \left(\frac{B_d}{P_d}\right)^2 * (cos\alpha)^2\right)$$
$$= \frac{6.496}{2 * 1.5} * 600 * \left(1 - \left(\frac{1.5}{6.496}\right)^2 * (\cos 0)^2\right) = \mathbf{1229.93\ cpm}$$

$$FTF = \frac{1}{2} * RPM * \left(1 - \frac{B_d}{P_d} * cos\alpha\right) = \frac{1}{2} * 600 * \left(1 - \frac{1.5}{6.496} * \cos 0\right) = \mathbf{230.73\ cpm}$$

This roll can be considered a type I machine according to ISO 10816:1995, as it is an “independent element from motors or small machinery”. According to ISO 10816:1995 (Table 5), from 1.12 mm/s RMS the machine is in satisfactory condition, from 2.80 mm/s RMS it is in unsatisfactory condition and from 11.20 mm/s RMS it is in dangerous condition.

Finally, the vibrations of the guide roll are measure using the monitoring system, which means they are automatically measured once a month

8.4.4. RMS Tendencies analysis

This roll was recently added to the monitoring system. The system is programmed to collect data once a month.

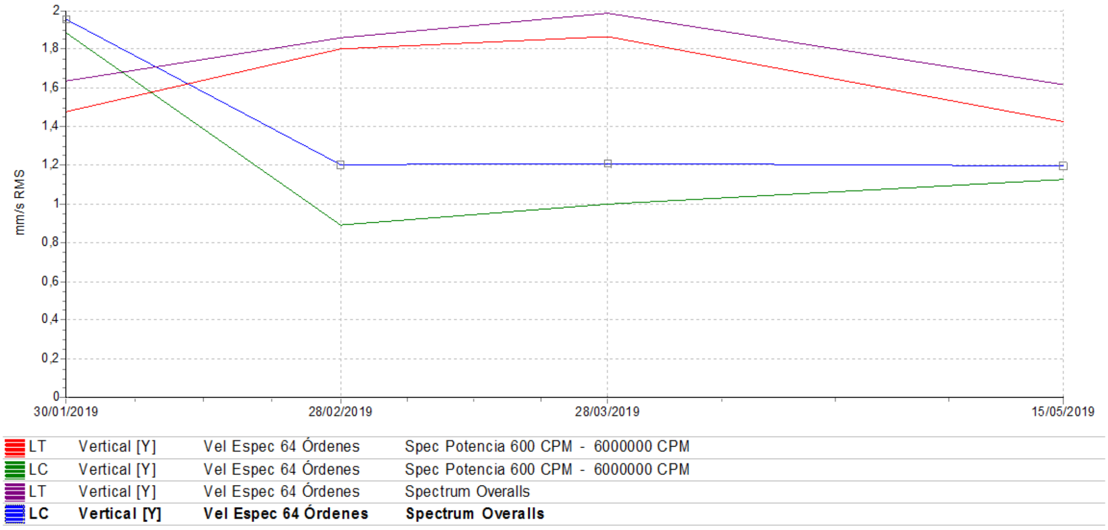


Fig. 94: RMS Tendencies in the guide roll

As it is shown in Fig. 94, there are no data on April. This is due to a failure in the sensor.

The point studied in this section, is the one corresponding to the 30/01/2019.

8.4.5. Frequency spectrum analysis

To study this equipment, the two points are analysed separately. In this section, it will be determine whether there is an error or not in the bearing. The possible existence of other defect will not be studied, as it has already been analysed in the previous sections.

8.4.5.1. Spectrum analysis of the conductor side

The spectrum corresponding to this point, is shown in Fig. 95.

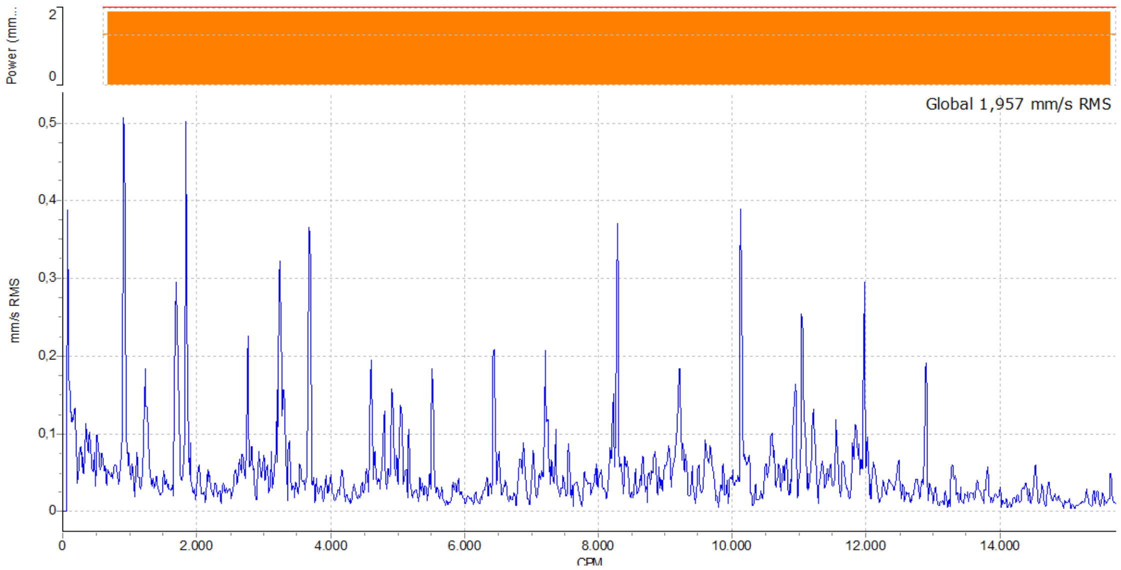


Fig. 95: Spectrum corresponding to the conductor side (guide roll)

As the objective of the monitoring system is to detect defects in the bearings, below the different frequencies of the located bearing in the spectrum can be seen.

First of all, the existence of a defect in the BPFI is studied.

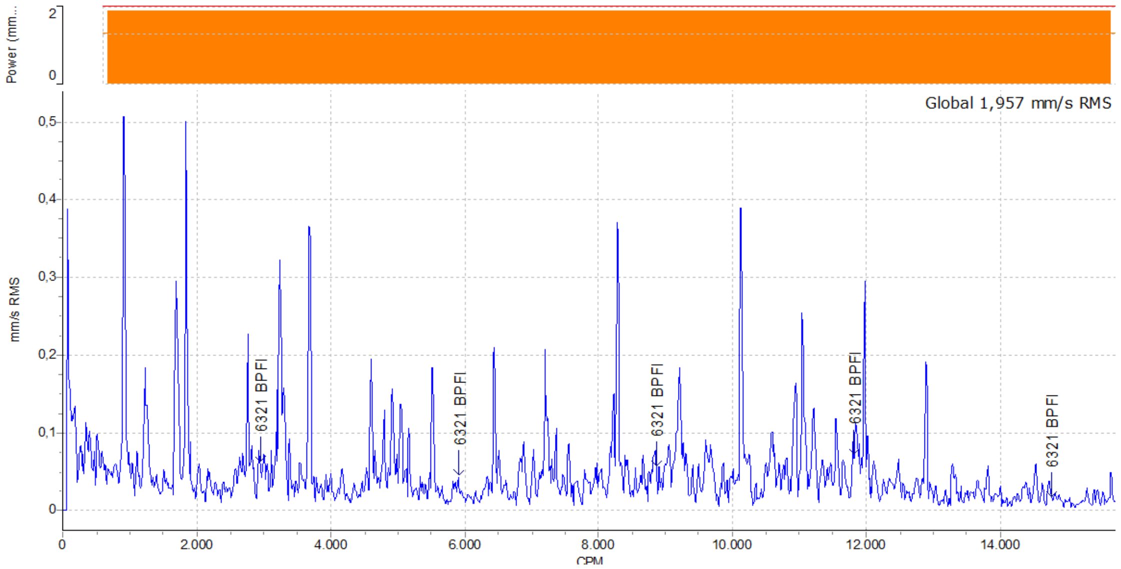


Fig. 96: BPFI in the spectrum corresponding to the conductor side (guide roll)

In this case, there are no significant peaks at the BPFI. As a consequence, there is no defect in this part of the bearing.

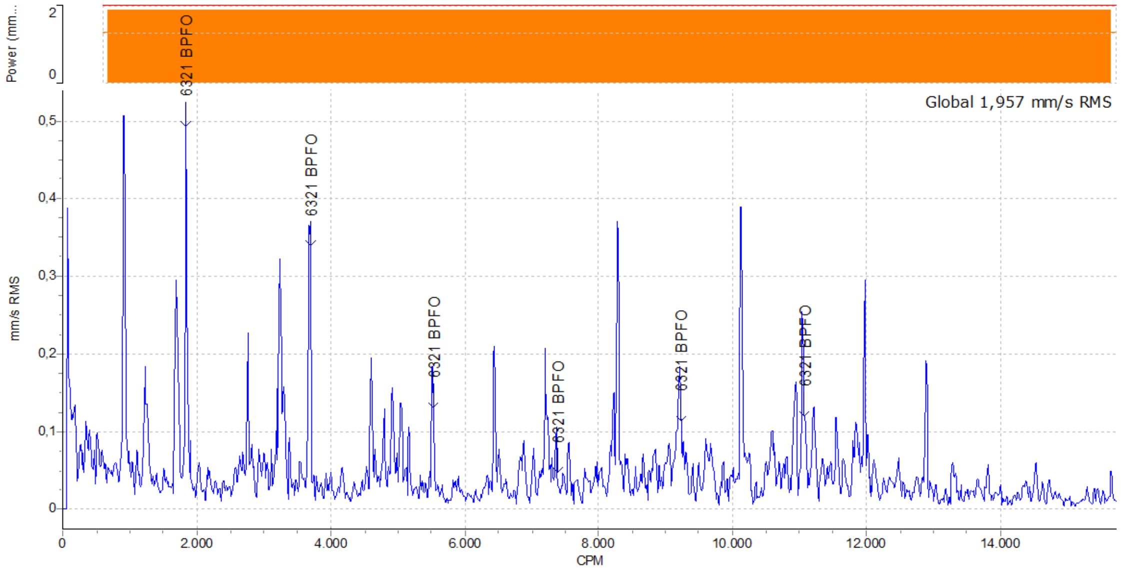


Fig. 97: BPFO in the spectrum corresponding to the conductor side (guide roll)

However, when studying the possible defect in the outer ring, it can be seen in Fig. 97 that there are peaks at the BPFO. The highest one is at BPFO, and then the amplitude of the peaks decrease in the following harmonics. The highest amplitude value is 0.502.

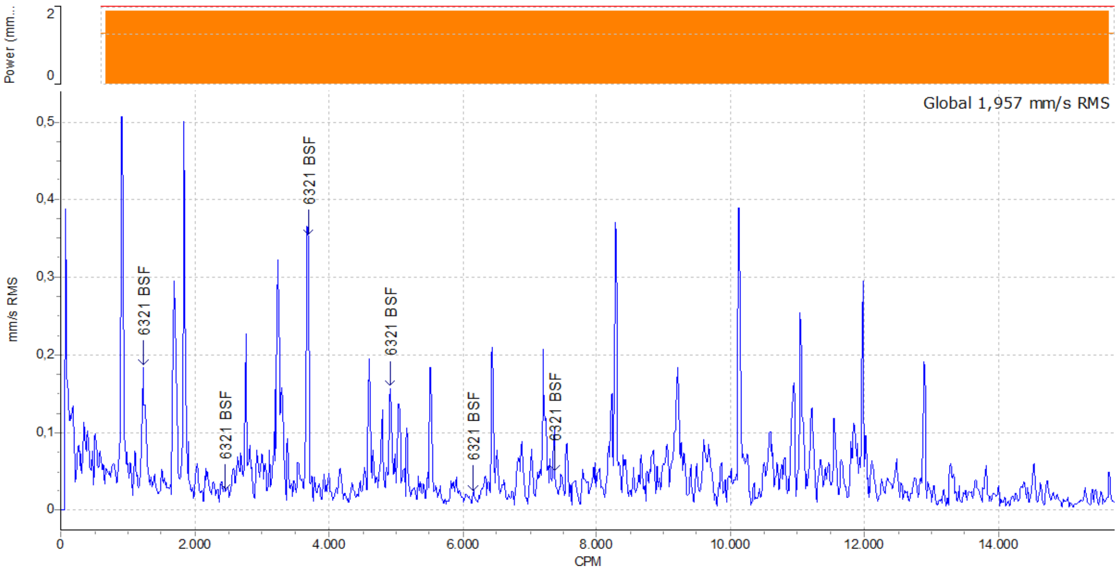


Fig. 98: BSF in the spectrum corresponding to the conductor side (guide roll)

In Fig. 98, it is shown that there are some peaks at the BSF. The mentioned peaks are not as high as those at the BPFO, but they could be an indicator of a defect in the balls of the bearing. Side bands can be clearly identified in fourth harmonic.

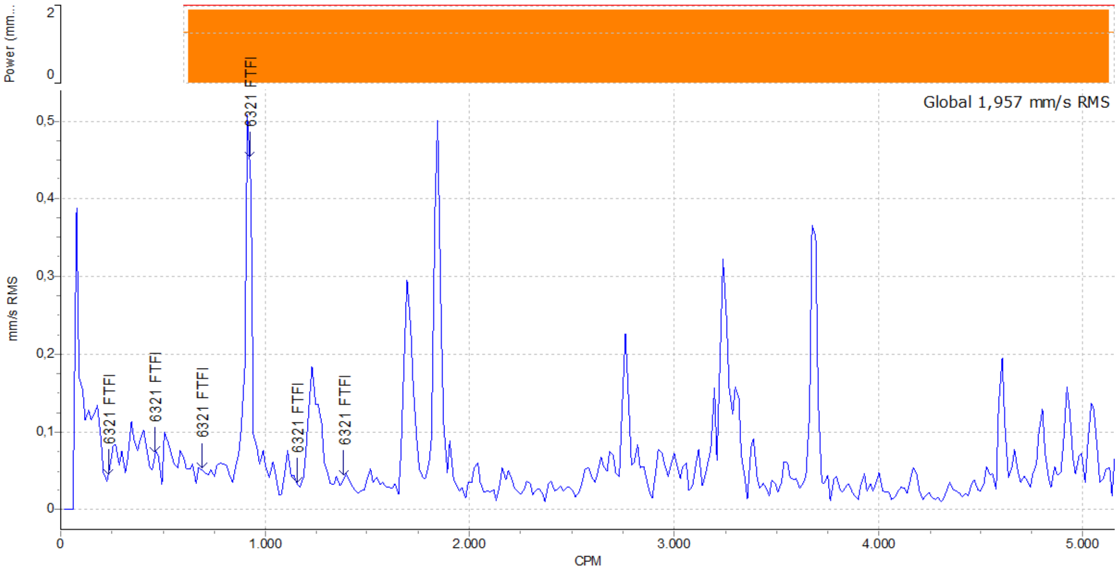


Fig. 99: FTF in the spectrum corresponding to the conductor side (guide roll)

Finally, in Fig. 99, it can be seen that there is just one peak at the fourth harmonic of the FTF.

8.4.5.2. Spectrum analysis of the transmission side

In this section, the spectra corresponding to the transmission side are shown.

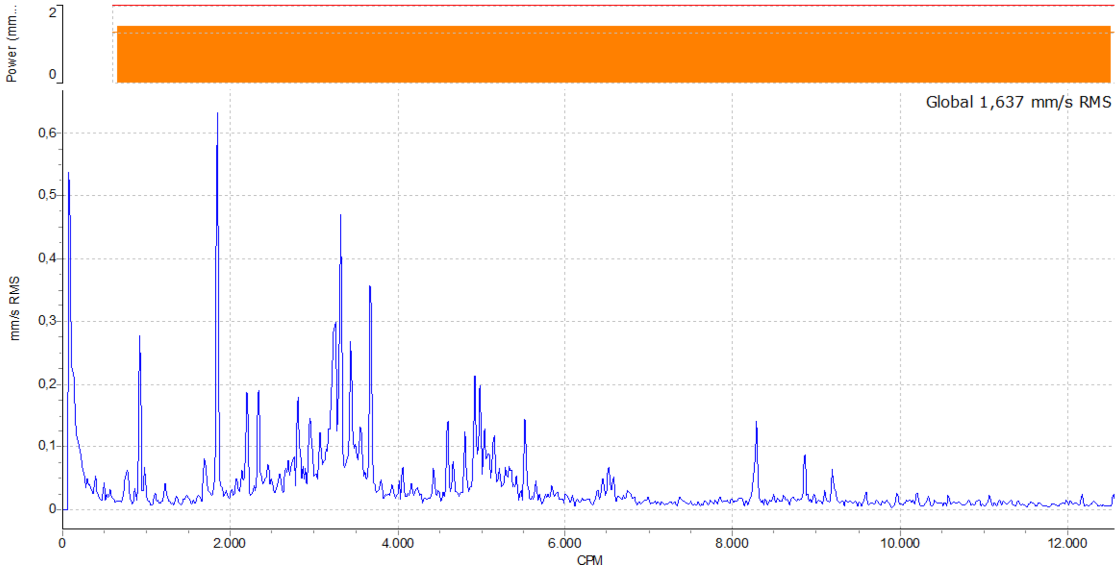


Fig. 100: Spectrum corresponding to the transmission side (guide roll)

As in the previous case, the spectrum with the failure frequencies of the bearing are shown.

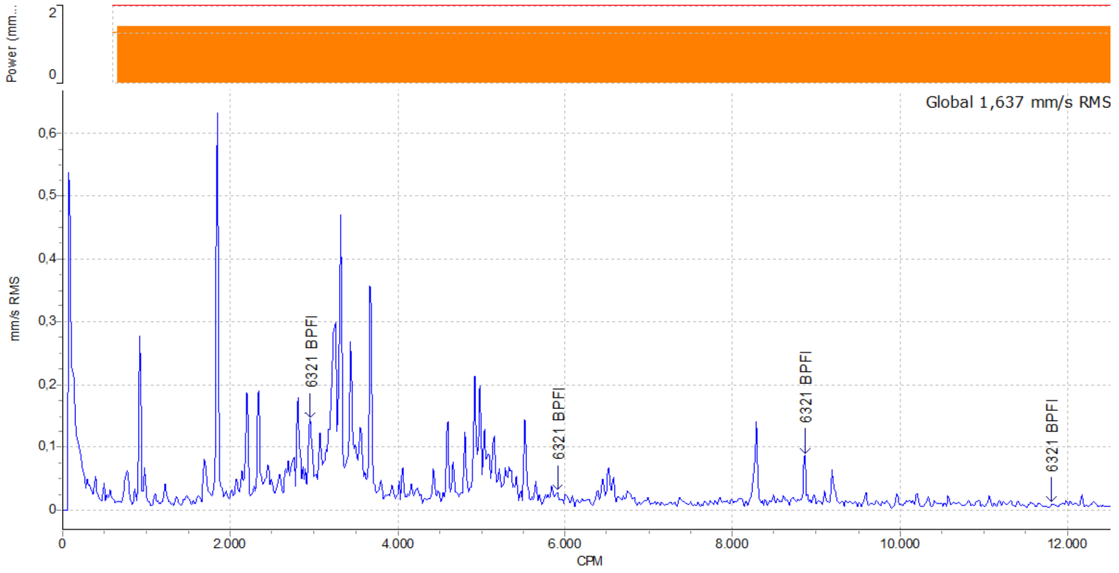


Fig. 101: BPFI in the spectrum corresponding to the transmission side (guide roll)

It can be seen that, as it happens in the case of the conductor side, there are no peaks at the BPFI, which means there is no defect in the inner ring.

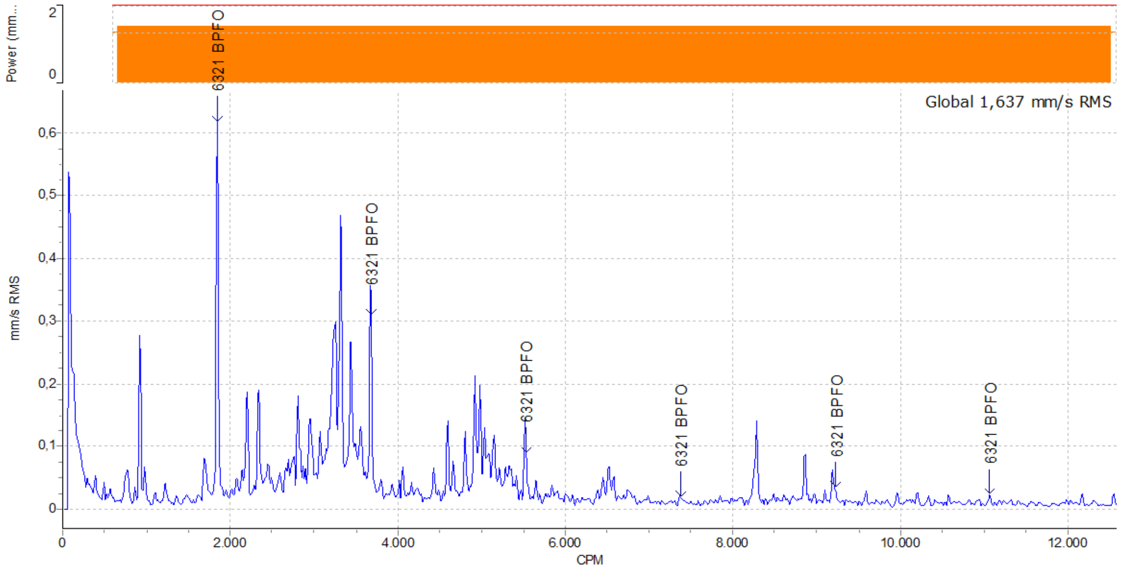


Fig. 102: BPFO in the spectrum corresponding to the transmission side (guide roll)

In this second spectrum, peaks at the BPFO are easily identified. The first peak is the highest one and then it decreases until there are no peaks. It can be seen that there are peaks only in the first 4 harmonics. The highest amplitude value reached is 0.632 mm/s.

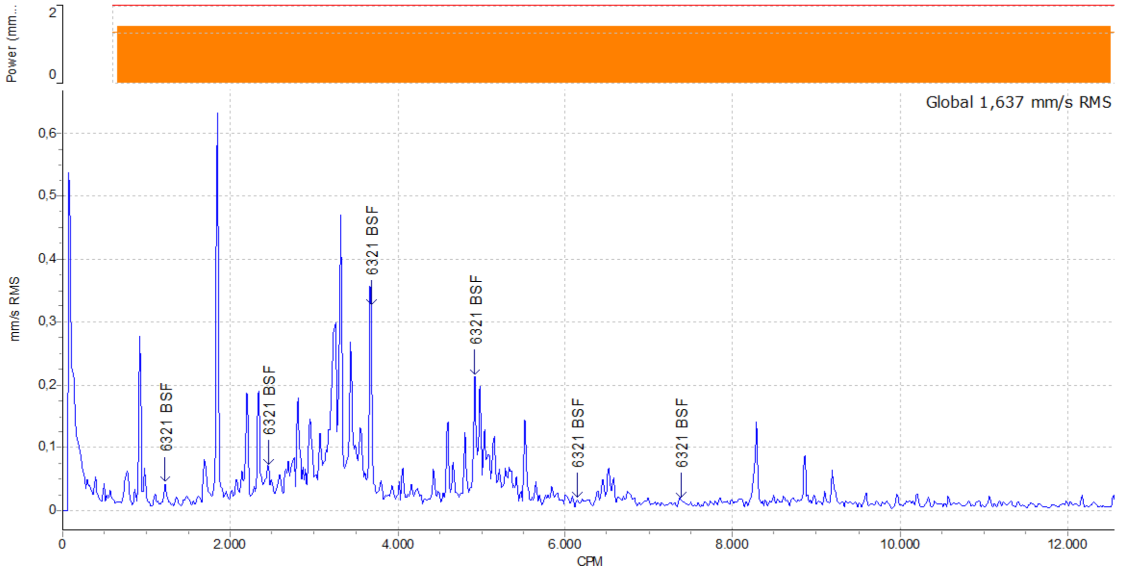


Fig. 103: BSF in the spectrum corresponding to the transmission side (guide roll)

In the case of the BSF, there are two significant peaks at this frequency, corresponding to the third and the second. Side bands are only clearly identified in the fourth peak. The highest amplitude is reached at the third harmonic of the BSF, with a value of 0.361 mm/s.

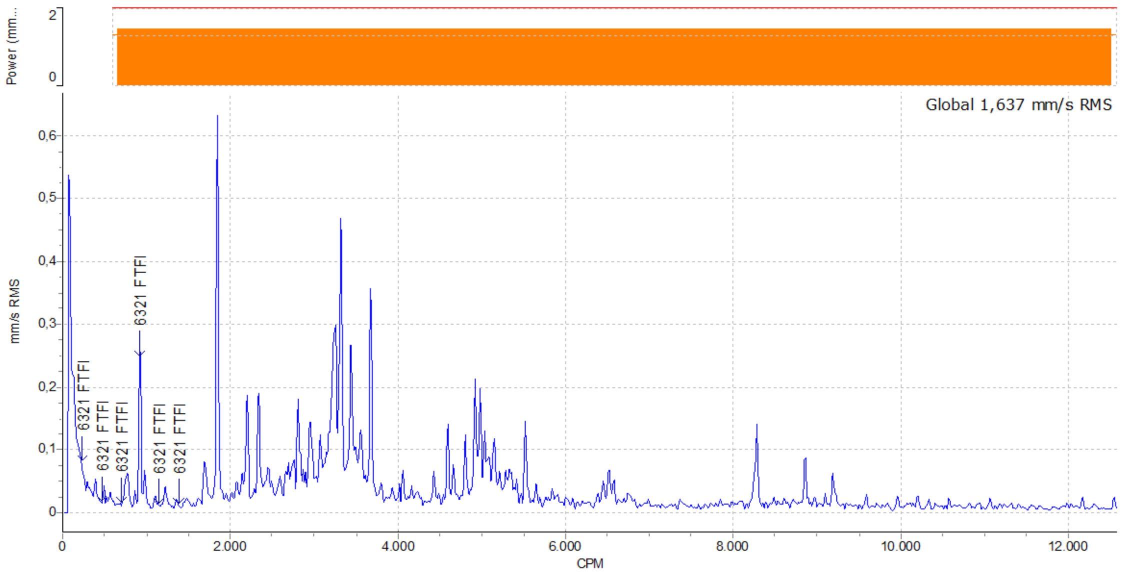


Fig. 104: FTF in the spectrum corresponding to the transmission side (guide roll)

Finally, in the case of the FTF, there is only one significant peak at the fourth harmonic.

8.4.6. Conclusions

After studying the spectrum corresponding to both sides, certain conclusions can be reached. There is no defect in the inner ring in none of the sides, because there are no peaks at the **BPFI**.

Then, when studying the peaks at the **BPFO**, it can be seen that in none of the points there are more than 6 harmonics. However, in section 5.5.6, it has been said that a defect in the outer ring produces between 8 and 10 harmonics. Apart from that, the highest amplitude reached is 0.502 mm/s in the conductor side and 0.632 mm/s in the transmission side. As a consequence, there could be an upcoming defect in the outer ring, but on the 30/01/2019 there was no defect.

In the case of the peaks corresponding to the **BSF**, there is just one significant peak in the case of the conductor side and two in the case of the transmission side. However, none of these peaks present a higher value than 0.400 mm/s. Therefore, there was no defect in the balls of the bearing on the 30/01/2019. Sidebands may be diffused because of the fact that there are peaks also at the BPFO and the FTF.

Finally, in the case of the **FTF**, the peaks present lower values than those in the previous cases. Again, there is no defect on the 30/01/2019.

9. GENERAL CONCLUSIONS

In the present project, 4 different examples have been analysed after showing general theoretical information.

In the first example corresponding to a vacuum fan, **unbalance** can be clearly identified due to the peaks at 1X of the motor and the 1X of the fan. After analysing the spectra corresponding to the three directions, it is confirmed that the unbalanced element is the fan, due to higher peaks at the radial direction than in the axial. As a consequence of this unbalance, the motor also present peaks at 1X.

Looseness can be clearly identified thanks to peaks at the harmonics of 1X, as it is studied in the second example, corresponding to the refine pump. The spectra corresponding to this equipment present clear peaks at the different harmonics, being much higher the amplitude values corresponding to the pump. That means the defect is in the pump and not in the motor. Finally, due to the fact that the amplitude values are not dominant in a certain direction, the defect is structural looseness and not internal assembly looseness.

The third example corresponding to the cleaners pump presents **misalignment**, which can be identified thanks to dominant peaks at 2X in all the spectra. As in some points the vibrations are greater at the radial direction and in other points at the axial, the final diagnosis is that the equipment presents general misalignment, a combination of parallel and angular misalignment. Finally, as the pump presents high values at the tangential direction, it is possible that the pump works misaligned, and therefore is the cause of the defect.

In the fourth example, the **defect in bearings** in a roll of the PM4 is studied. The peaks coincide with the BPFO, the BSF and FTF of the bearing in the both ends of the roll, but as the amplitude values are low, the final diagnosis is that there could be a future failure in those elements, but in the moment when those spectra were registered the defect was not alarming at all. Sidebands are not clearly identified in the case of the BSF. This may be because there are several peaks at different failure frequencies, and as a consequence the sidebands are diffused.

Comparing what has been explained in section 5.5, in which the different theoretical spectra corresponding to common defects are shown, and what is shown in section 8, in which the examples are studied, it can be clearly seen that there is a **good correlation** between theoretical spectra and real spectra. This does not happen in all cases, as it can be seen in the case of the guide roll, where sidebands can not be clearly identified.

After the study of different real examples, it can be confirmed that the vibration analysis is a **reliable technique** to predict early machine failure. In the case of the examples studied, the maintenance work orders of the factory confirm the diagnosis included in this project. This fact is a clear demonstration of the reliability of vibration analysis.

Apart from that, it can be seen in the analysis of the four examples that not only can a severe defect be identified (as in the case of the refine pump), but also an **incoming failure** (as in the vacuum fan and the guide roll), which makes vibration analysis an essential part of predictive maintenance.

In Pamplona, on the 31st of June, 2019.

Paula Ibarrola Gutiérrez.

REFERENCES

[1] S. Nieto, “Mantenimiento Industrial,” [Online]. Available: http://mantenimientosindustriales2009.blogspot.com/2009/05/historia-del-mantenimiento.html.

[2] G. White, “Historia del análisis de vibración y su uso en el mantenimiento de maquinaria,” in *Introducción al Análisis de Vibraciones*, 2010, pp. 70-71.

[3] Infraspeak, “What Are the Advantages and Disadvantages of Corrective Maintenance?,” [Online]. Available: http://blog.infraspeak.com/advantages-and-disadvantages-corrective-maintenance/.

[4] G. White, “Mantenimiento Periódico Preventivo,” in *Introducción al Análisis de Vibraciones*, 2010, pp. 10-11.

[5] ProTech, “Advantages and Disadvantages of Preventive Maintenance,” [Online]. Available: http://www.protechpropertysolutions.co.uk/advantages-and-disadvantages-of-preventative-maintenance/.

[6] IRD Mechanalysis Inc., “Comparación de los métodos de mantenimiento,” in *Tecnología de Vibración - 1*, 1988, pp. 1-4.

[7] RFD Reliability and PdM Technology, “Predictive Maintenance Implementation: Advantages and Disadvantages,” [Online]. Available: http://preventive-predictive-maintenance.blogspot.com/2010/01/predictive-maintenance-implementation.html.

[8] C. Sheffer and P. Girdhar, “Predictive maintenance techniques,” in *Practical Machinery Vibration Analysis and Predictive Maintenance*, 2008, pp. 7-8.

[9] C. Sheffer and P. Girdhar, “Vibration analysis (detection mode),” in *Practical machinery vibration analysis and predictive maintenance*, 2008, pp. 8-9.

[10] Predycsa, “Colocación de sensores,” in *Curso Básico de Mantenimiento Predictivo por Análisis de Vibraciones*, 2010, pp. 30-32.

[11] ISO 10816-1:1995, *Mechanical vibration - Evaluation of machine vibration by measurements on non-rotating parts - Part 1: General guidelines.*

[12] IMV Corporation, “Vibration technical guide,” [Online]. Available: https://www.imv.co.jp/e/pr/vibration_measuring/chapter03/.

[13] G. White, “Aspectos Prácticos en la Medición de Vibración,” in *Introducción al Análisis de Vibraciones*, 2010, pp. 70-75.

[14] Predycsa, “Condiciones de medida de vibración,” in *Curso Básico de Mantenimiento Predictivo por Análisis de Vibraciones*, 2010, pp. 36-37.

[15] IRD Mechanalysis Inc., “Las características de la vibración,” in *Tecnología de Vibración - 1*, 1988, pp. 2.2 - 2.6.

[16] Predycsa, “Valores globales de vibración,” in *Curso Básico de Mantenimiento Predictivo por Análisis de Vibraciones*, 2010, pp. 12-13.

[17] G. White, “Frecuencias Forzadas,” in *Introducción al Análisis de Vibraciones*, 2010, pp. 79-81.

[18] S. Hanly, “Vibration Analaysis: FFT, PSD and Spectrogram Basics,” 16 June 2016. [Online]. Available: https://blog.mide.com/vibration-analysis-fft-psd-and-spectrogram.

[19] C. Sheffer and P. Girdhar, “Unbalance,” in *Practical Machinery Vibration Analysis and Predictive Maintenance*, 2008, pp. 90-92.

[20] Predycsa, “Desequilibrio,” in *Curso Básico de Mantenimiento Predictivo por Análisis de Vibraciones*, 2010, pp. 47-48.

[21] B. Berrade, “Análisis de Vibraciones en Máquinas,” Smurfit Kappa Navarra, 2013.

[22] Predycsa, “Desalineación,” in *Curso Básico de Mantenimiento Predictivo por Análisis de Vibraciones*, 2010, pp. 49-50.

[23] G. White, “Desalineación,” in *Introducción al Análisis de Vibraciones*, 2010, pp. 109-111.

[24] C. Sheffer and P. Girdhar, “Misalignment,” in *Practical Machinery Vibration Analysis and Predictive Maintenance,* 2008, pp. 93-98.

[25] C. Sheffer and P. Girdhar, “Mechanical looseness,” in *Practical Machinery Vibration Analysis and Predictive Maintenance*, 2008, pp. 98-101.

[26] Predycsa, “Rodamientos,” in *Curso Básico de Mantenimiento Predictivo por Análisis de Vibraciones*, 2010, pp. 51-53.

[27] BCM, “High Precision Angular Contact Bearings,” [Online]. Available: http://drzbearings.sell.everychina.com/p-108072084-high-precision-angular-contact-ball-bearings.html.

[28] A. Fernandez, “Typical bearing defects and spectral identification,” 8 June 2017. [Online]. Available: https://power-mi.com/content/typical-bearing-defects-and-spectral-identification.

[29] Predycsa, “Frecuencias de fallo,” in *Curso Básico de Mantenimiento Predictivo por Análisis de Vibraciones*, 2010, pp. 40-43.

[30] J. R. Robinson, “Máquinas,” in *Proceso de Producción del Papel en Smurfit Kappa Navarra*, Sangüesa, 2008.

[31] M. Ojeda, "Máquina de Papel - Parte Húmeda," in *Fabricación de Papel*, 2001.

[32] R. Hink, “Best Practice Lubrication for Paper Machines,” [Online]. Available: https://www.machinerylubrication.com/Read/588/paper-machine-lubrication.

[33] D. M. D. Drummond, M. T. M. Rodrigues, I. E. Grossman and R. Guirardello, “Optimization of water removal in the press section of a paper machine,” *Brazilian journal of Chemical Engineering*, vol. 27, no. 2, June 2010.

[34] M. Ojeda, "Prensado," in *Fabricación de Papel*, 2001.

[35] M. Ojeda, "Secado del papel," in *Fabricación de Papel*, 2001.

[36] TissueStory, "Steel Yankee dryer: Advantages, development and rapid acceptance," [Online]. Available: https://www.tissuestory.com/2017/09/11/steel-yankee-dryer-advantages-development-and-rapid-acceptance/.

[37] Baltogar, “Manual de usuario B3 Fantech”.

BIBLIOGRAPHY

[1] G. White, *Introducción al Análisis de Vibraciones*, 2010.

[2] IRD Mechanalysis Inc., *Tecnología de Vibración - 1*, 1988.

[3] C. Sheffer and P. Girdhar, *Practical Machinery Vibration Analysis and Predictive Maintenance*, 2008.

[4] Predycsa, *Curso Básico de Mantenimiento Predictivo por Análisis de Vibraciones*, 2010.

[5] ISO 10816-1:1995, *Mechanical vibration - Evaluation of machine vibration by measurements on non-rotating parts - Part 1: General guidelines*.

[6] B. Berrade, “Análisis de Vibraciones en Máquinas,” Smurfit Kappa Navarra, 2013.

[7] J. R. Robinson, “Máquinas,” in *Proceso de Producción del Papel en Smurfit Kappa Navarra*, Sangüesa, 2008.

[8] M. Ojeda, *Fabricación de Papel*, 2001.

ANNEXES

ascent®

Award-winning vibration analysis software

Ascent® is award-winning vibration analysis software. It provides comprehensive data analysis and archiving capabilities that are integral to the Commtest® vbSeries® instruments, vbOnline® monitors, and the Ranger® wireless system.

Although powerful and highly developed with an impressive list of advanced features, the simplicity of Ascent® makes it an invaluable tool, ideal for implementing a vibration analysis program for the first time.

Ascent® is available in three levels, each providing greater benefits and more advanced capabilities.

Key features

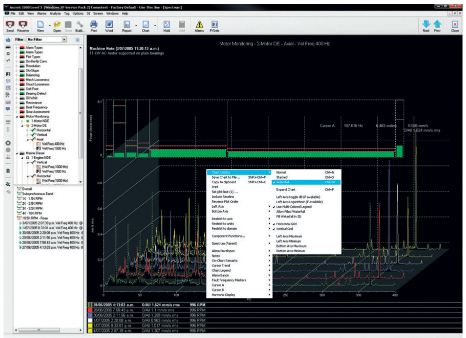
- Baseline record and display - Make instant comparisons against known good data
- Easily convert waveforms to spectra
- Export your favourite charts and reports to Microsoft Word® with one click
- Process parameter trending
- Intuitive database backup and restore facility
- Flexible and interactive charting - Zoom and pan charts to see close-up detail, rescale and overlay charts to compare peaks and identify machine component problems
- Customizable interface, charts, and reports enabling you to display information in a way that is meaningful to you
- All levels of Ascent® include a Commtest Bearing Database with over 30 000 bearings
- Frequently re-used components can be created once then stored in the Ascent® component storage library
- Create machine and alarm templates quickly and easily
- Keep only the most useful data accessible on a daily basis with selectable database optimization
- Multiple language support for international companies

commtest

Contact us on +64 3 943 0700, sales@commtest.com or visit www.commtest.com

Level 1

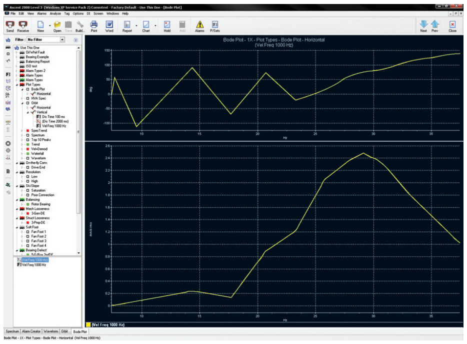
Ascent® Level 1 covers the essential requirements of both new and veteran analysts. It provides the ability to carry out in-depth fault analysis, but will not overwhelm entry-level vibration analysts with confusing features. Powerful simplicity is the hallmark of Ascent® Level 1.



Level 2

Ascent® Level 2 streamlines the vibration analysis process, optimizing time efficiency and simplifying the task of maintenance engineers and vibration analysts, regardless of experience.

Ascent® Level 2 provides greater benefit for both novice and advanced analysts. Novice analysts will appreciate the automated machine, measurement, and alarm setups provided by The Proven Method. Experienced analysts can also use this method to objectively evaluate and fine-tune their alarm settings and measurement criteria. Both groups can obtain the greatest value by using the statistically-generated alarm thresholds to create the most accurate warning system possible for individual machines.



Level 3

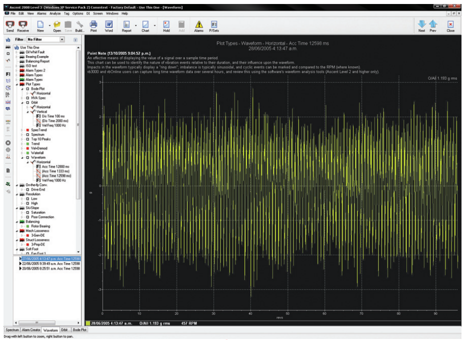
Ascent® Level 3 is a comprehensive software suite provided as an integral part of the vbOnline® solution. While Ascent® Level 3 is a must-have component of the complete vbOnline® surveillance system, there are also several valuable benefits for those relying solely on portable data collection.

Ascent® Level 3 includes the following applications:

- Ascent (Network License)
- AscentWatcher
- AscentOPC
- OnlineManager

Ascent® Level 3 provides you with enhanced access to information. You can install Ascent® on your company network, then either limit access to specific users, or allow open access to anyone within the network - The choice is yours.

You can also have text or email messages alert you to alarm states, or use a web browser to view your data in real time from anywhere in the world. You can even connect Ascent® to your existing Distributed Control System (DCS) and configure it to take automatic scheduled recordings while your machines are operating, by day or night.



PREDYCSA
PREDICTIVO Y CONTROL, S.A.

Avda. Ribera de Axpe, 11 B – Local 101
48950 ERANDIO (Bizkaia)
☎ +34 94 431 90 15
Fax +34 94 430 00 91
E-mail: info@predycsa.com
http://www.predycsa.com

commtest

Contact us on +64 3 943 0700, sales@commtest.com or visit www.commtest.com

vb5®

Economical data collection for proactive maintenance professionals

The vb5® data collector is a single channel, route-enabled instrument that provides everything you need for cost-effective data collection and analysis. This instrument enables maintenance professionals to easily take recordings with up to 6 400 lines of resolution and over 95 dB dynamic range - at exceptional value for money. Purchase of a vb5® instrument includes the powerful, award-winning Ascent® software.

Ascent® Level 1 enables you to program your instrument with thousands of separate machine definitions, covering a number of route choices. A library of over 300 customizable parameter sets is also available, enabling a vast array of measurement options.

Key features

Ascent® Level 1 software:

- Route enabled - Build routes in Ascent® and send these to your instrument
- CBDb - Commtest Bearing Database with over 30 000 bearings

Enhanced instrument functionality:

- 1 channel recordings
- 6 400 lines FFT resolution
- 40 kHz Fmax
- 1 GB memory – Virtually unlimited spectra storage
- Unique Commtest 6Pack™ recording system
- ≥ 95 dB dynamic range
- Spectrum and Waveform recordings
- Large, high resolution (HVGA) backlit LCD
- Cable Test mode
- 5 year instrument hardware warranty
- Option to add Flex features

commtest

Contact us on +64 3 943 0700, sales@commtest.com or visit www.commtest.com

SPECIFICATIONS	vb5® DATA COLLECTOR	REMARKS
Sensors		
Sensor input	1 channel	
Sensor	Accelerometer	
AC coupled range	16 V peak-peak	Allows for ± 8 V sensor output swing (± 80 g)
Connectors	1 x BNC (CH1)	Safety feature: Break-free inline connector
Analog to digital conversion	24-bit ADC	
Sensor excitation current	0 mA or 2.2 mA (configurable), 24 V maximum	2.2 mA required for IEPE/ICP®-type accelerometer
Sensor detection	Warns if short circuit or not connected	
Tachometer		
Sensor	Laser sensor optional	Sensor triggers on beam reflection
Laser sensor range	10 cm to 2 m nominal	Dependent on size of reflective tape
Other sensor types supported	Contact, TTL pulse	Instrument has optically isolated input
Power supply to sensor	5 V, 50 mA	
TTL pulse rating	3.5 V (4 mA) min 28 V (5 mA) max Off-state 0.8 V	Pulse width at least 0.1 ms
Speed range	10 RPM to 300 000 RPM (0.2 Hz to 5 kHz)	
Parameter Indication		
Maximum levels	›1000 g (10 000 m/s2), ›1000 in/sec (25 000 mm/s), ›100 in (2500 mm)	Effective limit is sensor sensitivity and output voltage
Dynamic signal range	> 95 dB (typical at 400 line resolution)	
Harmonic distortion	Less than -70 dB typical	Other distortions and noise are lower
Units	g or m/s2 in/s or mm/s mil or mm or µm adB, vdB, Amps	0-peak, peak-peak or RMS Auto-scale by 1000x when required US & SI options for both adB & vdB
Magnitude & cursors	Overall RMS value, dual cursors, harmonics	Digital readouts on chart
Accuracy	± 1% (0.1 dB)	For DC level (%F.S.) & AC measured at 100 Hz
Frequency response	± 0.1 dB from 10 Hz (AC) or 0 Hz (DC) to 10 kHz ± 3 dB from 1 Hz (AC) or 0 Hz (DC) to 40 kHz	Acceleration and velocity. From value measured at 100 Hz
Integration attenuation (single)	(Standard) < 1.5 dB 1 to 10 Hz, ≤ 0.1 dB 10 to 100 Hz	
Spectrum Display		
Fmax ranges	25, 50, 100, 125, 150, 200, 300, 400, 500, 600, 800, 1000, 1200, 1600, 2000, 2500, 3000, 4000, 5000, 6000, 8000, 10 000, 15 000, 20 000, 30 000, 40 000 Hz	Or equivalent CPM values Or orders-based from 1X to 999X
Fmin possible range	0 to Fmax	Instrument zeroes all spectral lines below Fmin
Resolution	400, 800, 1600, 3200, 6400 lines	3200 lines max. for dual channel measurements
Frequency scale	Hz, CPM, Orders	Linear scale with zooming
Amplitude scale	Acceleration, velocity, displacement	Linear or log scales Auto or manual scaling
Window shapes	Hanning, rectangular	
Overlap	(0, 12.5, 25, 37.5, 50, 62.5, 75, 87.5) %	Dependent on Fmax and number of lines
Number of averages	1, 2, 4, 8, 16, 32, 64, 128	Increases sampling time proportionally
Averaging types	Linear, exponential, peak hold	
Demodulation bandwidths	23 bandwidth options	From 125 Hz to 1250 Hz up to 16 kHz to 20 kHz
Waveform Display		
Number of samples	1024, 2048, 4096, 8192, 16 384	
Time scale	10 ms to 256 seconds	Or orders based from 1 to 999 revs

SPECIFICATIONS	vb5® DATA COLLECTOR	REMARKS
Logging & Analysis		
Output formats	Instrument screen, transfer to Ascent®, XML	
Data storage	Dual 1 GB non-volatile flash memories	Database mirror copy on second flash memory
Data storage structure	Folders / machines / points / locations /routes	No limits are applied, 50 character names
Max folder size	10 000 measurement locations	
Display & Communication		
Display	Graphic Grayscale LCD	
Resolution & size	480 x 320 (HVGA), 5.7"	
Backlight	White LED, 4V, 100 Cd/m2	
Communication with PC	USB and Ethernet	PROFLASH to upgrade instrument firmware
USB host port	2.0 to external USB memory device	Save folders to USB flash drive
Battery & Charger		
Battery type	Custom Lithium Ion pack, 7.4 V, 4500 mAh	
Operating time	10 hours	Backlight on (60 second time-out)
Charger type	Internal charging, automatic control	External Power pack 12 V DC, 3 A output, included in kit
Charge rate	3 A nominal	3 hours for complete charge
Mechanical		
Size	9.9" W x 5.8" L x 2.4" H (252 x 148x 60) mm	
Weight	2.7 lb (1.2 kg)	Including battery and strap
Environment		
Operating temperature	14 °F to 122 °F (-10 to 50) °C	
Storage temp. & humidity	-4 °F to 140 °F (-20 to 60) °C, 95% RH	If storage exceeds 1 month: Up to 95 F (35 C), 85% RH

AC115 Series

Low Cost Triaxial Accelerometer, Connector/Cable, 100 mV/g

Must Use J4A, J4C, J4N, or J4P Connectors
Must Use CB105, CB117, CB119
or CB218 Cables

Actual
Product
Size Shown

CE

Product Features

Low Cost Triaxial Sensor

Speeds Data Collection

- *±15% Sensitivity*
- *Monitor 3 Channels of Data Simultaneously*
- *Affordably Priced*

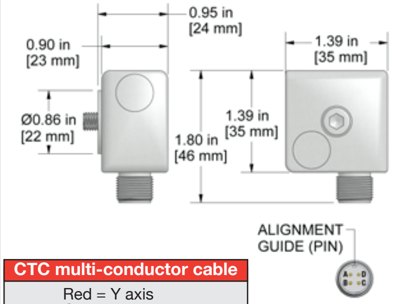
AC115-1D

4 Pin Connector

Connector Pin		Polarity
A	Axis Y	(+) Signal / Power
B	Axis X	(+) Signal / Power
C	Axis Z	(+) Signal / Power
D		(-) Common / Grid

Azima DLI Compatible

Connector Pin		Polarity
A	Axis 3	(+) Signal / Power
B	Axis 2	(+) Signal / Power
C	Axis 1	(+) Signal / Power
D		(-) Common / Grid



CTC multi-conductor cable

Red = Y axis
Green = X axis
White = Z axis
Black = Common

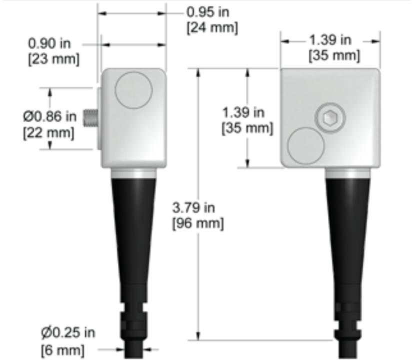
AC115-2D

Integral Cable

Conductor		Polarity
Red	Axis Y	(+) Signal / Power
Green	Axis X	(+) Signal / Power
White	Axis Z	(+) Signal / Power
Black		(-) Common / Grid

Azima DLI Compatible

Conductor		Polarity
Red	Axis 3	(+) Signal / Power
Green	Axis 2	(+) Signal / Power
White	Axis 1	(+) Signal / Power
Black		(-) Common / Grid



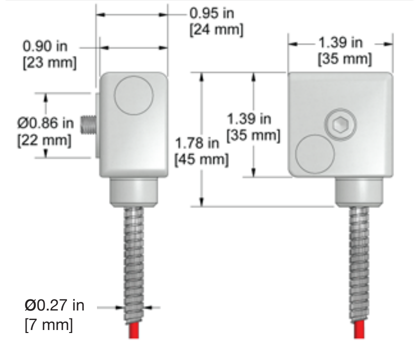
AC115-3D

Armored Integral Cable

Conductor		Polarity
Red	Axis Y	(+) Signal / Power
Green	Axis X	(+) Signal / Power
White	Axis Z	(+) Signal / Power
Black		(-) Common / Grid

Azima DLI Compatible

Conductor		Polarity
Red	Axis 3	(+) Signal / Power
Green	Axis 2	(+) Signal / Power
White	Axis 1	(+) Signal / Power
Black		(-) Common / Grid



Specifications	Standard	Metric
Part Number	AC115	M/AC115
Sensitivity (±15%)	100 mV/g	
Frequency Response (±3dB)	60-390,000 CPM	1,0-6500 Hz
Dynamic Range	± 50 g, peak	
Electrical		
Settling Time	<2.5 seconds	
Voltage Source (IEPE)	18-30 VDC	
Constant Current Excitation	2-10 mA	
Spectral Noise @ 10 Hz	27 µg/√Hz	
Spectral Noise @ 100 Hz	6.5 µg/√Hz	
Spectral Noise @ 1000 Hz	2.5 µg/√Hz	
Output Impedance	<100 ohm	
Bias Output Voltage	10-14 VDC	
Case Isolation	>10^8 ohm	

Specifications	Standard	Metric
Environmental		
Temperature Range	-58 to 250°F	-50 to 121°C
Electromagnetic Sensitivity	CE	
Sealing	IP68	
Submersible Depth (AC115-2D/3D)	200 ft.	60 m
Physical		
Sensing Element	PZT Ceramic	
Sensing Structure	Shear Mode	
Weight	7.1 oz	200 grams
Case Material	316L Stainless Steel	
Mounting	1/4-28	
Connector (non-integral)	4 Pin, J Connector	
Mounting Torque	1 to 2 ft. lbs.	1,4 to 2,7 Nm
Mounting Hardware	1/4-28 Captive Bolt	M6x1 Captive Bolt
Calibration Certificate	CA10	

Ordering Information

Standard	**AC115-1D** (1/4-28 Captive Bolt) Stock Product	**AC115-2D - /** ☐☐☐ - ☐ (1/4-28 Captive Bolt) Build To Order (length in feet) (termination)	**AC115-3D - /** ☐☐☐ / ☐☐☐ - ☐ (1/4-28 Captive Bolt) Build To Order (maximum armor length 100 ft.) (cable length in feet) (termination)
Metric	**M/AC115-1D** (M6x1 Captive Bolt) Stock Product	**M/AC115-2D - /** ☐☐☐ - ☐ (M6x1 Captive Bolt) (length in feet) (termination) ☐☐☐ M - ☐ (length in meters) (termination) Build To Order	**M/AC115-3D - /** ☐☐☐ / ☐☐☐ - ☐ (M6x1 Captive Bolt) (maximum armor length 100 ft.) (cable length in feet) (termination) ☐☐☐ M / ☐☐☐ M / ☐ (maximum armor length 30 m) (cable length in meters) (termination) Build To Order

Cable Termination Options: E3C

F3C

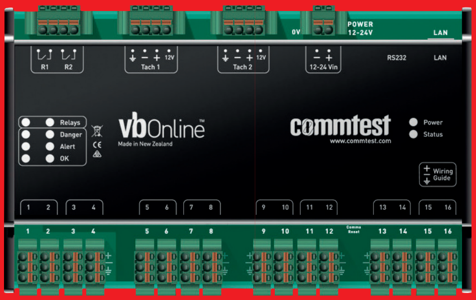
L

Z

Backed by our Unconditional Lifetime Warranty

vbOnline®

The standard for online machine surveillance



The vbOnline® machinery health information system provides automated, user-scheduled monitoring of the health of your critical assets. It is a flexible, modular system that automatically evaluates machinery condition using permanently installed sensors and the award-winning Ascent® analysis software.

Ongoing monitoring by the vbOnline® system assists in the early detection of mechanical problems, helping you avoid costly downtime.

The vbOnline® system performs frequent data collection more cost effectively. Accuracy and safety is improved when compared to traditional portable monitoring programs or when monitoring machines in dangerous or inaccessible environments.

Key features

- Modular design to support system expansion
- Compact and easy to install
- 4 to 16 channel options, expandable in the field
- Award-winning Ascent® Level 3 vibration analysis software - Common software platform supporting vbOnline® and vbSeries® portable systems
- Compatible with Ranger® wireless sensors
- Simultaneous dual-channel data sampling
- Support for use on single PC or network
- Wired or wireless Ethernet connection
- 24-bit analog-to-digital conversion
- Able to accept machine data from the following sensor types:
  - Accelerometers
  - Velocity probes
  - Proximity probes
  - 0 ... 10 V signals
  - 4-20 mA signals
  - Process parameters via OPC import
- 0 ... 10V, 4-20mA & OPC readings can be scaled into virtually any engineering units
- Support for variable-speed, bi-directional and intermittent-operation machines
- Parameter-triggered data collection based on speed or process state
- Support for order-tracking, Modbus communication, automatic alarm detection and reporting
- Email or text message alerts for plant personnel

commtest

Contact us on +64 3 943 0700, sales@commtest.com or visit www.commtest.com

SPECIFICATIONS	vbOnline®	REMARKS
Analog Inputs		
Number of channels	4 to 16	Configuration in blocks of 4
Simultaneous recordings	Dual channel	Any odd #channel with any even #channel
Channel scan rate	≤ 8s per channel	Accel. 1000 Hz 400 lines
Compatible sensors	Accel, Vel, Displ, Voltage Output, 4-20 mA	
DC-coupled ranges	0 V to 20 V -10 V to 10 V -20 V to 0 V	Selectable to suit sensor type
AC-coupled ranges	16 V peak-peak	Allows for ± 8 V sensor output swing
Sensor drive current	4 mA @ 24 V	Enable for IEPE/ICP® Type sensors
A to D conversion	24-bit	
Input impedance	>100 kΩ	
Analog Measurements		
Measurement types	Single Value, Time Waveform, Spectrum	
Quantities	Accel, Vel, Displ, Demod, User-scaled	User scaling for voltage and 4-20 mA sensors
Max levels	> 1000 g (10 000 m/s²) > 1000 in/s (25 000 mm/s) > 100 in (2500 mm) > 10 000 Amps	
Spectrum Fmax values	25 Hz to 40 kHz (1500 CPM to 2400 kCPM)	In 26 steps
Sampling rates	64 Hz to 102.4 kHz	In 26 steps
Dynamic range	≥95 dB	
Harmonic distortion	Less than -70 dB typical	Other distortions and noise are lower
Accuracy	± 1% (0.1 dB)	For DC level (%F.S.) and AC measured at 100 Hz
AC Frequency response	± 0.1 dB from 10Hz (AC) or 0 Hz (DC) to 15 kHz ± 3 dB from 1 Hz (AC) or 0 Hz (DC) to 40 kHz	From value measured at 100 Hz
Signal Processing		
Number of spectral lines	400, 800, 1600, 3200, 6400	Applies to single or dual channel recordings
Time waveform samples	1024, 2048, 4096, 8192, 16 384	
Window types	Hanning, Rectangular	
Averaging types	Linear, Exponential, Peak Hold, Synchronous	
Number of averages	1, 2, 4, 8, 16, 32, 64, 128	
Overlap	0, 12.5, 25, 37.5, 50, 62.5, 75, 87.5%	
Demodulation bandwidths	24 bandwidth options	From 125 to 1250 Hz up to 16 to 20 kHz
Order tracking	Up to 6 kHz Fmax, Orders-based	Tachometer required, mounted on high-speed shaft
Order tracking distortion	Less than -65 dB	Within 50% to 200% speed variation during recording
Quickscan Mode		
Scan rate	2 seconds per channel pair 5 seconds per channel pair	For DC-coupled sensors, no integration (e.g. prox probes) For other sensor types
Measurement type	Average DC value or 10 Hz to 1 kHz overall	Accelerometer readings are converted to velocity
Offline Mode		
Storage capacity and duration	8 MB, typically 40 days	At 8 channels, 3 recordings per channel, 4 recordings per day 1600 lines
Recording retrieval to database	Automatic	Upon re-establishment of communication

SPECIFICATIONS	vbOnline®	REMARKS
Tachometer Input		
Number	2	Multiplexed
Speedrange	10 RPM to 300 000 RPM (0.2 Hz to 5 kHz)	
Recommended sensor	Hall Effect	Also optical, laser and Keyphasor® tach sensors
Power supply to sensor	10 V	Current limited to 50 mA
Input type	Optically isolated, accepts TTL	
TTL inputs pulses	2.5 V (2 mA) min, 28 V (5 mA) max, off-state <0.8 V	
Keyphasor® threshold	13 V ± 1 V	
Serial Data Input		
Input type and connector	RS232, RJ12	
Protocol supported	MODBUS RTU	Supports Registers (16 and 32-bit), Input, Coils
Scaling of values	via Gain and Offset (both floating point)	Supports all engineering units
Relay Output		
Number and type	2, SPST normally open	
Voltage and current rating	250 V AC or 30 V DC, 5 A	
Controlled by	OnlineManager software on server	User-configurable, based on alarms
Status Indicators		
System status	2 x LEDs	One for power, one for DSP status
Vibration status	2 sets LEDs: red, yellow, green	Indicates alarm state, user-configurable
Relay status	2 x LEDs	Indicate when relays are energized
Communication and Power		
Network communication	Ethernet v2.0, TCP/IP, 10/100baseT	Auto senses 10/100 Mbps and half/full duplex
Network connection, link speed	RJ45 socket, ≥ 256 kbps (optimum), 2400 bps (min)	Via any commercially available link
Diagnostic communication	RS232 @ 115 kbaud, RJ12 socket	
Power supply	250 mA @ 9 V to 36 V	
Mechanical		
Mounting	Standard 35 mm DIN rail	For installation in enclosed control cabinet
Size	199 mm x 130 mm x 45 mm	(60 mm including DIN rail)
Optional sealed housing	IP 65 / NEMA 4	
Environmental		
Temperature range	-30 °C to +65 °C (-22 °F to +149 °F)	De-rates to -25 °C to +60 °C (-13 °F to +140 °F) when using relays
Humidity	95% RH non-condensing	
EMC	EN61326	Emissions and immunity
Analysis Software		
Name	Ascent® Level 3	
Compatible portables	vbSeries®	

PREDYCSA
PREDICTIVO Y CONTROL, S.A.

Avda. Ribera de Axpe, 11 B – Local 101
48950 ERANDIO (Bizkaia)
☎ +34 94 431 90 15
Fax +34 94 430 00 91
E-mail: info@predycsa.com
http://www.predycsa.com

commtest

Contact us on +64 3 943 0700, sales@commtest.com or visit www.commtest.com

AC102 Series

Multi-Purpose Accelerometer, Top Exit Connector/Cable, 100 mV/g

Actual
Product
Size Shown

Product Features

CTC's Most Popular Sensor!

High Performance in a Low Cost Sensor

- *Standard 2 Pin MIL Connection*
- *Perfect for Thousands of Applications*
- *Affordably Priced, Hermetically Sealed Sensors*

AC102-1A

2 Pin Connector

Connector Pin	Polarity
A	(+) Signal/Power
B	(-) Common

AC102-2C

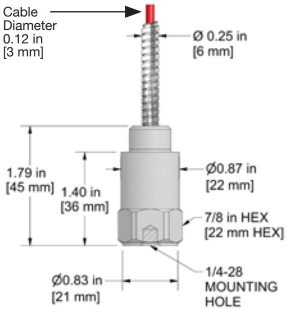
Integral Cable

Conductor	Polarity
Red	(+) Signal/Power
Black	(-) Common
Shield	Cable Drain Wire

AC102-3C

Armored Integral Cable

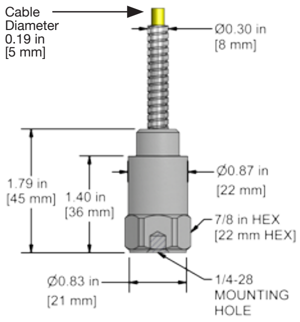
Conductor	Polarity
Red	(+) Signal/Power
Black	(-) Common
Shield	Cable Drain Wire



AC102-6C

Heavy Duty Armored Integral Cable

Conductor	Polarity
Red	(+) Signal/Power
Black	(-) Common
Shield	Cable Drain Wire



Specifications	Standard	Metric
Part Number	AC102	M/AC102
Sensitivity (±10%)	100 mV/g	
Frequency Response (±3dB)	30-900,000 CPM	0,5-15000 Hz
Frequency Response (±10%)	120-600,000 CPM	2,0-10000 Hz
Dynamic Range	± 50 g, peak	
Electrical		
Settling Time	<2.5 seconds	
Voltage Source (IEPE)	18-30 VDC	
Constant Current Excitation	2-10 mA	
Spectral Noise @ 10 Hz	14 µg/√Hz	
Spectral Noise @ 100 Hz	2.3 µg/√Hz	
Spectral Noise @ 1000 Hz	2 µg/√Hz	
Output Impedance	<100 ohm	
Bias Output Voltage	10-14 VDC	
Case Isolation	$>10^8$ ohm	

Specifications	Standard	Metric
Environmental		
Temperature Range	-58 to 250°F	-50 to 121°C
Maximum Shock Protection	5,000 g, peak	
Electromagnetic Sensitivity	CE	
Sealing	IP68	
Submersible Depth (AC102-2C/3C)	200 ft.	60 m
Physical		
Sensing Element	PZT Ceramic	
Sensing Structure	Shear Mode	
Weight	3.2 oz	90 grams
Case Material	316L Stainless Steel	
Mounting	1/4-28	
Connector (non-integral)	2 Pin MIL-C-5015	
Resonant Frequency	1,380,000 CPM	23000 Hz
Mounting Torque	2 to 5 ft. lbs.	2,7 to 6,8 Nm
Mounting Hardware	1/4-28 Stud	M6x1 Adapter Stud
Calibration Certificate	CA10	

Ordering Information

Standard	**AC102-1A** (1/4-28 Stud) Stock Product	**AC102-2C - /** ☐☐☐-☐ (1/4-28 Stud) (length in feet) (termination) Build To Order	**AC102-3C - /** ☐☐☐ / ☐☐☐ - ☐ (1/4-28 Stud) (maximum armor length 100 ft.) (cable length in feet) (termination) Build To Order	**AC102-6C - /** ☐☐☐ - ☐☐☐ - ☐ (1/4-28 Stud) (maximum armor length 20 ft.) (cable length in feet) (termination) Build To Order
Metric	**M/AC102-1A** (M6x1 Adapter Stud) Stock Product	**M/AC102-2C - /** ☐☐☐-☐ (M6x1 Adapter Stud) (length in feet) (termination) ☐☐☐M-☐ (length in meters) (termination) Build To Order	**M/AC102-3C - /** ☐☐☐ / ☐☐☐ - ☐ (M6x1 Adapter Stud) (maximum armor length 100 ft.) (cable length in feet) (termination) ☐☐☐M / ☐☐☐M / ☐ (maximum armor length 30 m) (cable length in meters) (termination) Build To Order	**M/AC102-6C - /** ☐☐☐ - ☐☐☐ - ☐ (M6x1 Adapter Stud) (maximum armor length 20 ft.) (cable length in feet) (termination) ☐☐☐M / ☐☐☐M - ☐ (maximum armor length 6 m) (cable length in meters) (termination) Build To Order

Cable Termination Options: E  F  L  Z 

AC104 Series

Multi-Purpose Accelerometer, Side Exit Connector/Cable, 100 mV/g

Actual
Product
Size Shown

CE

Product Features

**CTC's Most Popular
Side Exit Sensor!**

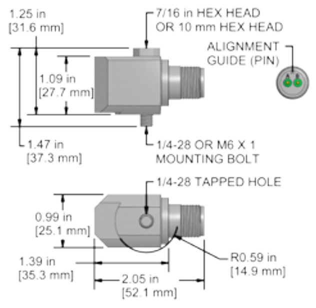
High Performance in a Low Cost Sensor

- *Standard 2 Pin MIL Connection*
- *Perfect for Thousands of Applications*
- *Affordably Priced, Hermetically Sealed Sensors*

AC104-1A

2 Pin Connector

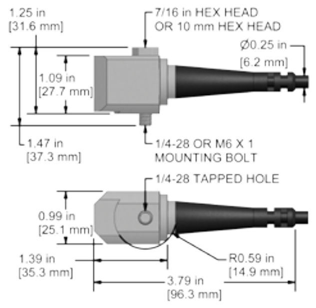
Connector Pin	Polarity
A	(+) Signal/Power
B	(-) Common



AC104-2C

Integral Cable

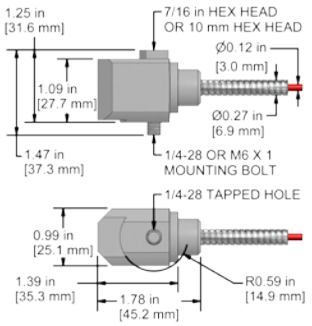
Conductor	Polarity
Red	(+) Signal/Power
Black	(-) Common
Shield	Cable Drain Wire



AC104-3C

Armored Integral Cable

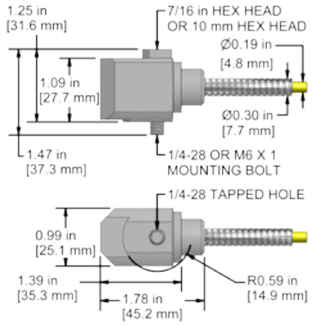
Conductor	Polarity
Red	(+) Signal/Power
Black	(-) Common
Shield	Cable Drain Wire



AC104-6C

Heavy Duty Armored Integral Cable

Conductor	Polarity
Red	(+) Signal/Power
Black	(-) Common
Shield	Cable Drain Wire



Specifications	Standard	Metric
Part Number	AC104	M/AC104
Sensitivity (±10%)	100 mV/g	
Frequency Response (±3dB)	30-600,000 CPM	0,5-10000 Hz
Frequency Response (±10%)	120-420,000 CPM	2,0-7000 Hz
Dynamic Range	± 50 g, peak	
Electrical		
Settling Time	<2.5 seconds	
Voltage Source (IEPE)	18-30 VDC	
Constant Current Excitation	2-10 mA	
Spectral Noise @ 10 Hz	14 μg/√Hz	
Spectral Noise @ 100 Hz	2.3 μg/√Hz	
Spectral Noise @ 1000 Hz	2 μg/√Hz	
Output Impedance	<100 ohm	
Bias Output Voltage	10-14 VDC	
Case Isolation	>10^8 ohm	

Specifications	Standard	Metric
Environmental		
Temperature Range	-58 to 250°F	-50 to 121°C
Maximum Shock Protection	5,000 g, peak	
Electromagnetic Sensitivity	CE	
Sealing	IP68	
Submersible Depth (AC104-2C/3C)	200 ft.	60 m
Physical		
Sensing Element	PZT Ceramic	
Sensing Structure	Shear Mode	
Weight	5.1 oz	145 grams
Case Material	316L Stainless Steel	
Mounting	1/4-28	
Connector (non-integral)	2 Pin MIL-C-5015	
Resonant Frequency	1,320,000 CPM	22000 Hz
Mounting Torque	2 to 5 ft. lbs.	2,7 to 6,8 Nm
Mounting Hardware	1/4-28 Captive Bolt	M6x1 Captive Bolt
Calibration Certificate	CA10	

Ordering Information

Standard	**AC104-1A** (1/4-28 Captive Bolt) Stock Product	**AC104-2C - /** ☐☐☐-☐ (length in feet) (termination) (1/4-28 Captive Bolt) Build To Order	**AC104-3C - /** ☐☐☐ / ☐☐☐ - ☐ (maximum armor length 100 ft.) (cable length in feet) (termination) (1/4-28 Captive Bolt) Build To Order	**AC104-6C - /** ☐☐☐ - ☐☐☐ - ☐ (maximum armor length 20 ft.) (cable length in feet) (termination) (1/4-28 Captive Bolt) Build To Order
Metric	**M/AC104-1A** (M6x1 Captive Bolt) Stock Product	**M/AC104-2C - /** ☐☐☐-☐ (length in feet) (termination) (M6x1 Captive Bolt) ☐☐☐M-☐ (length in meters) (termination) Build To Order	**M/AC104-3C - /** ☐☐☐ / ☐☐☐ - ☐ (maximum armor length 100 ft.) (cable length in feet) (termination) (M6x1 Captive Bolt) ☐☐☐M / ☐☐☐M / ☐ (maximum armor length 30 m) (cable length in meters) (termination) Build To Order	**M/AC104-6C - /** ☐☐☐ - ☐☐☐ - ☐ (maximum armor length 20 ft.) (cable length in feet) (termination) (M6x1 Captive Bolt) ☐☐☐M / ☐☐☐M - ☐ (maximum armor length 6 m) (cable length in meters) (termination) Build To Order

Cable Termination Options: E  F  L  Z 

NTN BOWER SNR BCA

An NTN brand manufactured in the USA An NTN brand manufactured in the USA

Bearing Frequencies

Formulas to Calculate Bearing Frequencies

(inner race rotating and our race stationary)

$$FTF = \frac{S}{2}\left(1-\frac{Bd}{Pd}\cos\varnothing\right)$$

$$BPFI = \frac{Nb}{2}\,S\left(1+\frac{Bd}{Pd}\cos\varnothing\right)$$

$$BPFO = \frac{Nb}{2}\,S\left(1-\frac{Bd}{Pd}\cos\varnothing\right)$$

$$BSF = \frac{Pd}{2Bd}\,S\left\{1-\left(\frac{Bd}{Pd}\right)^2(\cos\varnothing)^2\right\}$$

RPM - Revolutions Per Minute
S - Revolutions per secord or relative speed difference between inner and outer race (1)
FTF - Fundamental Train Frequency
BPFI - Ball Pass Frequency of Inner ring
BPFO - Ball Pass Frequency of Outer ring
BSF - Ball Spin Frequency
Bd - Ball or roller diameter
Nb - Number of balls or rollers
Pd - Pitch diameter
Ø - Contact angle

Bearing Number	NB	BD	PD	PHI	BPFO	BPFI	FTF	BSF
6309	8	0.687	2.913	0	3.06	4.94	0.38	2
6310	8	0.749	3.228	0	3.07	4.93	0.38	2.04
6311	8	0.812	3.503	0	3.07	4.93	0.38	2.04
6312	8	0.874	3.779	0	3.07	4.93	0.38	2.05
6313	8	0.937	4.035	0	3.07	4.93	0.38	2.04
6314	8	1	4.33	0	3.08	4.92	0.38	2.05
6315	8	1.062	4.625	0	3.08	4.92	0.39	2.06
6316	8	1.125	4.921	0	3.09	4.91	0.39	2.07
6317	8	1.187	5.216	0	3.09	4.91	0.39	2.08
6318	8	1.25	5.511	0	3.09	4.91	0.39	2.09
6319	8	1.312	5.807	0	3.1	4.9	0.39	2.1
6320	8	1.437	6.2	0	3.07	4.93	0.38	2.04
6321	8	1.5	6.496	0	3.08	4.92	0.38	2.05
6322	8	1.625	6.948	0	3.06	4.94	0.38	2.02
6324	8	1.625	7.48	0	3.13	4.87	0.39	2.19
6326	8	1.75	8.07	0	3.13	4.87	0.39	2.2
6328	8	1.875	8.661	0	3.13	4.87	0.39	2.2
6330	9	1.875	9.251	0	3.59	5.41	0.4	2.37
6332	8	2	9.842	0	3.19	4.81	0.40	2.36
6334	8	2.25	10.433	0	3.14	4.86	0.39	2.21
6336	9	2.25	11.023	0	3.58	5.42	0.40	2.35
6338	9	2.25	11.614	0	3.63	5.37	0.4	2.48
6340	9	2.5	12.204	0	3.58	5.42	0.40	2.34
6344	9	2.5	13.385	0	3.66	5.34	0.41	2.58
63300	6	0.281	0.913	0	2.08	3.92	0.35	1.47
63301	6	0.312	0.964	0	2.03	3.97	0.34	1.38
63302	7	0.312	1.161	0	2.56	4.44	0.37	1.73
63303	7	0.343	1.259	0	2.55	4.45	0.36	1.7
63304	7	0.375	1.417	0	2.57	4.43	0.37	1.76
633/22	7	0.406	1.535	0	2.57	4.43	0.37	1.76
63305	7	0.437	1.712	0	2.61	4.39	0.37	1.83
633/28	7	0.5	1.889	0	2.57	4.43	0.37	1.76
63306	8	0.468	2.047	0	3.09	4.91	0.39	2.07
633/32	8	0.5	2.125	0	3.06	4.94	0.38	2.01
63307	8	0.531	2.263	0	3.06	4.94	0.38	2.01
63308	8	0.593	2.559	0	3.07	4.93	0.38	2.04
63309	8	0.687	2.913	0	3.06	4.94	0.38	2
63310	8	0.749	3.228	0	3.07	4.93	0.38	2.04
63311	8	0.812	3.503	0	3.07	4.93	0.38	2.04
63312	8	0.874	3.779	0	3.07	4.93	0.38	2.05
63313	8	0.937	4.035	0	3.07	4.93	0.38	2.04
63314	8	1	4.33	0	3.08	4.92	0.38	2.05