# MAINTAINING AVAILABILITY THROUGH PREDICTIVE MAINTENANCE ACTIONS THROUGH VIBRATION PROFILE ANALYSIS

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**ABSTRACT**: Reliability centered maintenance is a powerful tool in maintaining availability of technical systems. However, starting from it, to reduce production costs we must introduce predictive maintenance techniques (vibrations analysis, thermography, etc.) for a better estimation of technical systems evolving mode and of the moment when we have to intervene with maintenance actions. This paper presents a case study on item condition monitoring, following the implications of their predictive maintenance actions on item availability and on productions costs reduction.

**KEY WORDS**: condition monitoring, machine monitoring, maintainability, vibrations analysis.

## 1 INTRODUCTION

All mechanical systems in motion generate a vibration profile that reflects the operating conditions of the installation (Patalita 2014). Vibration profile variation indicates mechanical systems working conditions changes. If up to certain vibration amplitude limits is considered that the installation works normal, beyond these limits is necessary to intervene upon it by corrective maintenance actions. Vibration installation study showed that each failure has its own characteristic frequency.

In this paper is presented, on a case study, how installation availability is maintained at an optimum level by predictive maintenance actions based on vibration spectrum analysis, and production costs remain at low levels.

## 2 CONTENT

By installation availability is understood its ability to fulfill, during operation, the functions for which it was designed. The availability concept is basically the union of reliability and maintainability concepts. Mathematically, availability coefficient K is expressed by equation (1) (Ushakov 1995).

$$K = \lim_{t \to \infty} K(t) \tag{1}$$

Where $K(t)$ represents the probability that the device will work at moment $t$.

Availability calculation expression is given by relation (2) (Blebea 2015):

$$K(t) = R(t) + [1 - R(t) \cdot M(t)] \tag{2}$$

Where: $K(t)$ is availability, $R(t)$ is reliability and $M(t)$ is maintainability. Based on relation (2), is deducted that we can maintain the installation availability if we consider its reliability and maintainability.

If we take into consideration the installation reliability when we buy one, the installation maintainability must be taken into account the entire life of the installation.

There is a strategy to maintain availability using reliability-based maintenance concept. According to (Sopoian 2015), “Reliability-based maintenance is the set of actions and measures undertaken in order to establish the program and content of preventive maintenance works to be carried out in order to maintain and restore when necessary, the proper functioning of a technical system, in terms of maximum efficiency of use”.

Although it is an efficient strategy that reduces maintenance costs for maintaining installations availability, in some situations this concept has its limits, as will result from the case study presented below. As evidenced by numerous studies (Patalita 2014) is advisable to use predictive maintenance actions and techniques in case of installations for which failures generates significant time and financial resources loss to put back into operation. One of the most used methods in predictive maintenance is equipment condition monitoring (CBM – Condition-Based Maintenance) through periodic evaluation of vibration profile of installation.

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In operative time, all vibration sources transmit their energy, through bearings, to bed frame and groundwork. The only problem is vibration capturing with a suitable device and their decomposition in signal components, each signal with its frequency, depending on source that produced it. Thus, „vibration profile analysis is a useful tool for monitoring the condition of industrial installation and for the faults detection and diagnosis of mechanical components” (Patalita 2014).

The general condition of industrial installation can be simple evaluated by comparing the overall measured vibration level with the overall reference vibrations level (alert or alarm levels) (Randall 2011).

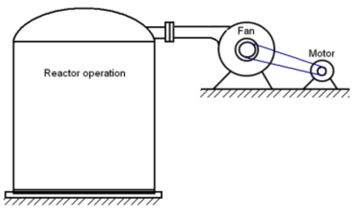
In principle, faults diagnosis is a mapping process of the information obtained in the space of vibrations measurements to possible defects from the space of monitoring faults (Vachtsevanos 2006).

## 3 VIBRATION ANALYSIS FOR A MOTOR OF 1,4 KW – CASE STUDY

In this case study is presented the monitoring method of a AC motor of 1,4 kW used to drive a cross-flow fan that evacuates the generated gases in a reactor during a chemical reaction. The AC motor works in difficult conditions (the ambient temperature ranges from 25-500 C; the environment contains dust and abrasive particles in suspension). It is important to maintain AC motor availability during all operative time taking place in the reactor. In reactor is prepared a substance for pharmaceutical industry and any undermining of the substance purity leads to the rejection of the entire batch of manufactured drugs. Any AC motor failure may lead to a compromised resulted substance and thus results in increased production costs.

Motor shaft bearing is realized with 2 bearings, 6005 type on free part and NU406 for shafts coupled part.

To avoid accidental failures, the AC motor behavior was periodically monitored and as predictive maintenance technique was used vibration spectrum analysis generated by AC motor bearings and cross-flow fan.

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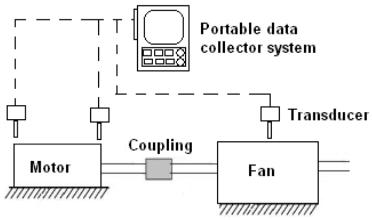



**b)**

**Figure 1. a) Sketch of the installation location, b)Experimental process of the fault diagnosis**

Data collection, vibration spectrum analysis and measuring were done with Vibroscanner Ex. The Vibroscanner Ex is used for monitoring and analysis of the machine condition.

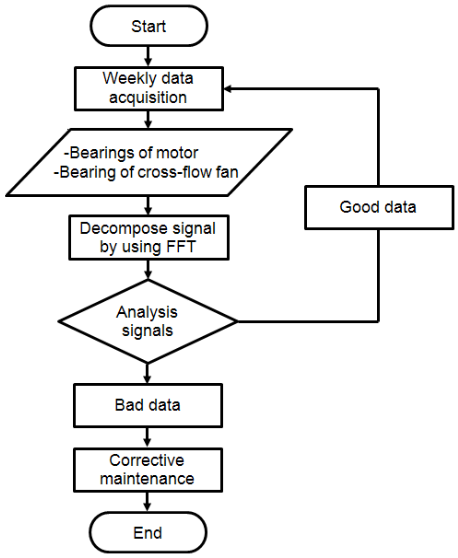



**Figure 2. Working methodology**

The working methodology is summerized in the diagram in Figure 2.

## 4 RESULTS INTERPRETATION

For each bearing type working frequency can be calculated within normal parameters using relations (3)-(6).

BPFI-Ball Pass Frequency Inner Ring

$$BPFI = \frac{N_b}{2}\left(1 + \frac{B_d}{P_d}\cdot\cos\beta\right)\cdot f \qquad (3)$$

BPFO-Ball Pass Frequency Outer Ring

$$BPFO = \frac{N_b}{2}\left(1 - \frac{B_d}{P_d}\cdot\cos\beta\right)\cdot f \qquad (4)$$

FTF-Fundamental Train Frequency

$$FTF = \frac{1}{2}\left(1 - \frac{B_d}{P_d}\cdot\cos\beta\right)\cdot f \qquad (5)$$

BSF-Ball Spin Frequency

$$BSF = \frac{P_d}{2B_d} \cdot \left[ 1 - \left( \frac{B_d}{P_d} \right)^2 \cdot \cos^2 \beta \right] \cdot f \qquad (6)$$

Where:

$f$ - shaft rotation frequency;

$N_b$ - number of rolling elements;

$B_d$ - ball diameter;

$P_d$ - pitch diameter;

$\beta$ - contact angle.

Overall, these data exist in databases that contain vibration spectrum in normal range for different range of revolutions, if the manufacturer delivers such data.

For each measurement point (bearing), after monitoring, characteristic frequencies of bearing failures are inserted in a table: BPFI – Ball Pass Frequency Inner ring; BPFO – Ball Pass Frequency Outer ring; BSF – Ball Spin Frequency si FTF – Fundamental Train Frequency.

In this case study is presented bearing 6005 evolutions that represented, between 07.2015-01.2016, a transition from the normal evolution to the abnormal evolution. In table 1 are presented failure characteristic frequencies of 6005 bearing, for different engine rotor speed. Knowing that AC motor operating speed is 720 rpm, characteristic frequencies were monitored in vibration spectrum for this engine speed.

**Table 1.**

| Shaft rotation | Frequency | Bearing | | | |
|---|---|---|---|---|---|
| | f | BPFO | BPFI | FTF | BSF |
| [rpm] | [Hz] | [Hz] | [Hz] | [Hz] | [Hz] |
| 60 | 1 | 3.59 | 5.41 | 0.40 | 2.37 |
| 360 | 6 | 21.5 | 32.5 | 2.39 | 14.2 |
| 720 | 12 | 43.1 | 64.9 | 4.78 | 28.4 |
| 1080 | 18 | 64.6 | 97.4 | 7.18 | 42.6 |
| 1440 | 24 | 86.1 | 129.9 | 9.57 | 56.8 |

After collecting and downloading data on a computer, spectrum analysis is started using Omnitrend, condition monitoring software. For each measurement point, in the failures table is inserted the speed at which the vibration signal was collected and failure frequencies, resulted in collected signal spectrum, are searched.

After analyzing collected vibrations spectrum at the free end of a AC motor (Fig.3.), it can be seen clear that for 6005 bearing failure frequency the vibration amplitude begins to grow since 11/04/2015 indicating a possible failure. Amplitude variation is also influenced by work load, but for monitored equipment from this case study, the work load variation is insignificant.

The graph in figure 4 presents vibration amplitude time variation for BPFO and BPFI. Amplitude growth indicates the appearance of an bearing clearance in 6005 bearing. Bearing clearance appearance is due to bearing raceway wear phenomena occurrence.

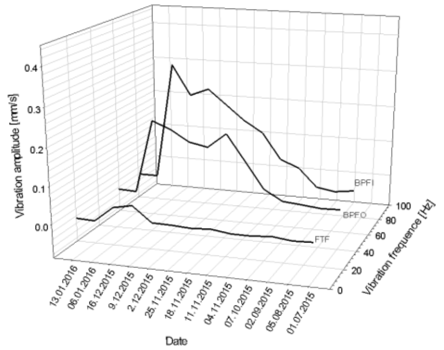
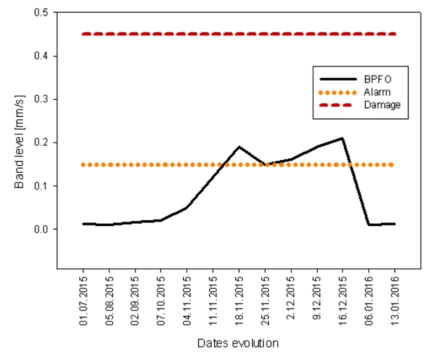



**Figure 3. Measurement general values graph**

It is noticed that the amplitude grows above alarm amplitude, in BPFO case approaching to failure level. Detecting this defect led to planning a corrective maintenance action for replacing 6005 bearing, on 01/05/2015. With the bearing replacement, it is observed that the vibration amplitude returned to normal values for a good functionality.

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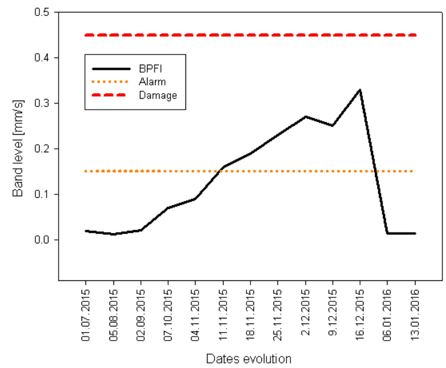


**b)**

**Figure 4. Vibration amplitude evolution for a) BPFO, b) BPFI**

After demounting, at bearing visual analysis it could be seen the failure to inner raceway, according to the failure resulted from vibration spectrum analysis. The failure appeared because of abrasive particles which penetrated by inside bearings sealing and increased the bearing clearance. At first, the fault was in the form of ridges, which in time were transformed in nicks and small craters as you can see in figure 5.

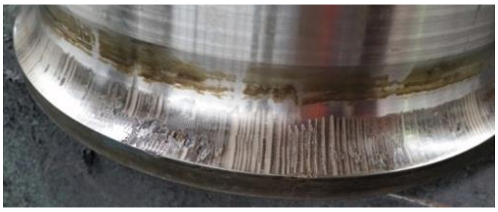

**Figure 5.Inner raceway fault on 6005 bearing**

## 5 CONCLUSION

Through predictive maintenance actions based on vibration spectrum analysis and through predictive maintenance actions based on reliability, a motor accidental failure and an unscheduled installation stop were avoided. A study was conducted on the impact that would have had such an accidental motor failure, estimating accidental failure costs compared to taken maintenance actions actual costs.

**Table 2.**

| | | |
|---|---|---|
| Bearing availability on MTBF | 12048 | [h] |
| Bearing availability after predictive maintenance | 8500 | [h] |
| Failure installation cost after MTBF | 200 | € |
| Failure installation cost before MTBF | 3500 | € |
| Associated costs generated by failure installation | 2600 | € |
| Installation monitoring cost during 2015-2016 | 500 | € |

It is noticed that the installation was stopped for corrective maintenance actions before bearing mean time before failure (MTBF) according with the above mentioned aspects. Predictive maintenance actions lead to costs reduction that can be possible for motor failure, that were estimated from 3500 € to just 700€, meaning a cost decrease of 2800 €.If we consider that in case of a company there are many installations of this kind, predictive maintenance actions are justified by costs reduction.

If installation maintenance would have been done based only on reliability centered maintenance, through preventive maintenance actions to replace bearing grease, at certain time intervals and through corrective maintenance actions to replace motor bearings at intervals determined only on reliability indicators of bearing (MTBF), then the total costs would have substantial increased in case of accidental failure and due to substance compromise in chemical reactor.

The two methods for analyzing monitored equipment status, vibration spectrum analysis (as predictive maintenance technique based on status monitoring) and reliability indicators analysis (as reliability centered maintenance), must be seen as complementary actions, that can be used in parallel to reduce costs. Therefore it is not rational to analyses vibration spectrum at relatively small time intervals because it involves additional costs. However, considering reliability indicators, we can increase or decrease indicators analysis interval based on the time elapsed since installation commissioning on which we carry out maintenance actions. Therefore, for an installation optimum availability we must take into account both the reliability indicators maintenance and spectral analysis predictive maintenance.

## 6 ACKNOWLEDGEMENTS

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