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MAINTENANCE SERVICE OF THE DYNAMIC MACHINERY USING VIBRATION ANALYSIS

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Abstract: *In this article we intend to provide information about the dynamic machinery maintenance activity, by using vibration analysis. This method involves the usage of vibration as a measure of the proper functioning of equipment, in order to increase efficiency of repairs, and operational safety. This article has as a main topic vibration analysis, and in this domain we intend to emphasize the importance of the creation of a database, data acquisition and fault diagnosis, especially. Finally we want to show the necessity of implementing such a program of maintenance in a factory by revealing the main advantages the predictive maintenance offers, vibration analysis more precisely.*
Key words: *predictive maintenance, vibration analysis, fault diagnosis.*

1. INTRODUCTION

Maintenance of dynamic equipment is the verification service measurement, diagnosis and repair to ensure their proper functioning. This service guarantees normal functioning of the equipment during working hours, ensuring product quality and minimizing production stops caused by accidents, providing a continuous flow of production and most importantly safety of personnel serving in their vicinity.

According to the European Standard 13306 [12], maintenance represents all technical administrative and management measures performed on a machine during its life cycle, in order to maintain or restore to a level that can perform the requested function. Health and worker's security are affected by maintenance in two ways, namely: firstly, to have reliable equipment you need to plan maintenance interventions, and this planning must be done regularly; Secondly, these maintenance interventions must be made in the safest conditions respecting labor protection rules.

Since the '80s, thanks to technological advances, machines being integrated in more complex processes, the term "preservation" was replaced with "maintenance". Currently, maintenance and production are working very closely together, in terms of importance being placed approximately at the same level.

Nowadays, besides quality of products, targets are aimed at preserving worker's safety. This can be seen-in Figure 1, where maintenance is in close connection with quality and safety.

Fig. 1. Maintenance engineering, Safety and Quality

Maintenance involves the performance of several operations that are grouped into four subcategories:

• configuration, training, assembly, installation, disassembly, removal;
• maintenance, repair, installation, adjustment;
• mechanical or manual cleaning of the premises and work equipment;
• monitoring, inspection of manufacturing processes, premises, vehicles, equipment - with or without monitoring equipment.[1]

Due to major changes, occurring both at national and global level, application of modern methods of maintenance of equipment has become, in factories, an objective necessity.
Maintenance service, one of the oldest services in a factory it has made its progress along with advances in technology. In Figure 2 it is represented the informational flow of maintenance and the four types of maintenance management systems:

- Run-to-Failure maintenance,
- Preventive maintenance
- Predictive maintenance
- Pro-active maintenance [2-7].

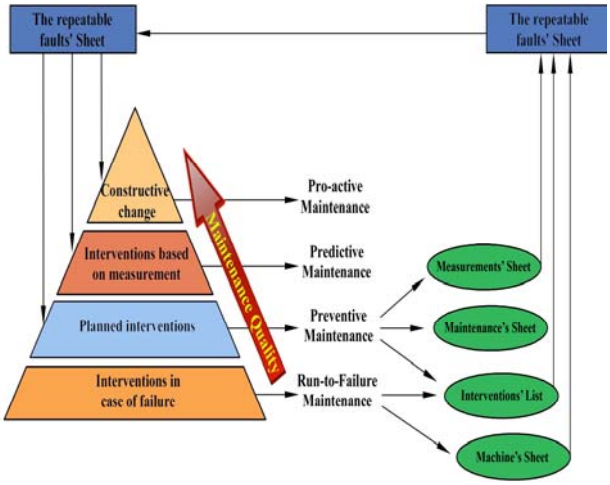


Fig. 2. The information flow of maintenance

Main objectives of the maintenance and refurbishment machinery activity are mainly the following:
a) Ensuring the equipment running a longer period of time;
b) Avoidance of excessive wear and equipment accidentally exit from function;
c) Increasing the uptime of the machinery either by increasing the period between two technical interventions, or by reducing the period for keeping it in repair;
d) Carrying out maintenance and repair costs as low as possible and a better quality by increasing the productivity of workers who perform these activities;
e) Modernization of obsolete machinery and equipment.[14]

2. VIBRATION ANALYSIS - A TOOL FOR MONITORING AND DIAGNOSIS

Each component of a moving machine causes a vibration with a certain frequency and the mechanical system where it belongs generates a vibration profile that reflects how it works. Through the interpretation of vibration and certain process data we can obtain some information on the proper functioning of components and consequently of the entire equipment.[8]

Vibrations are dynamic phenomena that are transmitted in elastic medium under the form of oscillations, after a local excitement.

Sizes that characterize the movement (vibration) of the system are: amplitude, speed, acceleration and frequency spectrum.

These relations are defined as:

$$d = D \cdot \sin \cdot \omega t \qquad -\ displacement \tag{1}$$

$$v = \frac{dd}{dt} = D\omega \cdot \cos \cdot \omega t \qquad -\ velocity \tag{2}$$

$$a = \frac{d^2 d}{dt^2} = D\omega^2 \cdot \sin \cdot \omega t \qquad -\ acceleration \tag{3}$$

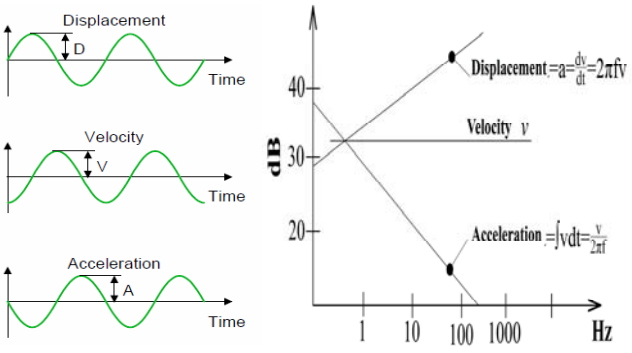


Fig. 3. Sizes that characterize the vibratory motion

These ratings give us information about the good function of the system, namely: speed vibration and vibration informs us about the energy of acoustic noise produced by the

medium that vibrates, vibration acceleration informs us about the intensity forces of application, which works because of vibration and amplitude of vibration give us information if there are movement between pieces of equipment.

It is considered that at the current technical status, the state of operation of a dynamic machine is best reflected by its vibration. The appearance is due to vibrations movement and contacts between components of a machine parts due to the dynamic effects of tolerance of the components, and parts of the effect of forces that are not in balance. Due to the large number of component parts of a machine some vibrations with small amplitude can excite the resonance frequencies of other parts, these frequencies being amplified in some cases to unacceptable levels.

Vibration is the dynamic phenomena which can have a positive role when they take advantage of the benefits it offers, namely: when the vibrations are required by the process, such as pneumatic hammers or baths for cleaning by ultrasound, but also in diagnostic equipment; undesirable in most cases, vibrations catastrophic cause crash in some situations, but certainly lead to shortened life of equipment. Following these statements the conclusion could be that a machine that does not vibrate will not fail soon, but this is an false conclusion. A correct conclusion would be that a machine that has significant vibration is to be short-lived.

3. MONITORING VIBRATIONS OF DYNAMIC MACHINERY

Monitoring vibration of a machine is a dynamic process of data collection, interpretation and evaluation of its trends, their evolution over time compared with a reference point in order to assess the operational state of the machine.

These data are collected periodically or permanently through specific devices, obtaining useful information in order to make a plan for the equipment maintenance. The monitoring can detect early defects, which if not resolved soon could lead to technological line-off at inappropriate times, there is the possibility of damaging other components which work properly. Specialists in this field can establish the source of fault occurrence, so it can be established the component / components to be repaired or replaced, to avoid replacement of all wearing parts. This way one will save money by reducing labor costs and by establishing the necessary spare parts, avoiding blocking of money in stock items. Through a proactive approach we can keep a database of previous monitoring results which lead to obtaining information that can lead us to avoid the appearance of damage in the future, thus making other major economies.

Currently, the state of operation of a machine is determined, one way or another, by using a variety of devices, depending on the monitored parameter. These devices vary in price depending on their complexity. The specialty papers say that devices that provide the clearest information about the state of operation of a machine are spectral vibration analyzers. These devices come at purchase with software that should allow a simple and accurate diagnosis, being able to keep, over time the evolution of each machine, individually.

4. THE DIAGNOSIS WITH VIBRATION ANALYSIS IN TECHNOLOGICAL SYSTEMS

By monitoring vibration of a machine we can see that each component corresponds to one or more specific frequencies. Detecting the problem of a machine component can be determined if we have knowledge about the spectral global vibration. Spectrum analyzer compared to the vibrometer, which measures only global vibration is used in a much wider range, it can highlight all the spectrum components of the vibration. Thus, by measuring vibration, one can detect many defects, specific to a variety of dynamic tools.

Depending on the parameters of a machine monitor (vibration, noise, temperature bearings, temperatures and pressure variations in the cooling circuit) one can appreciate its operating conditions. Most used parameters in

determining the operating condition of a machine are vibration level and noise level.

Vibration of the structure studied to be measured and analyzed is to be captured. Wave energy capture is achieved using a magnetic vibration transducer that is placed either directly on the track, or within walking distance.

Captured signal is converted into electrical signals, and this is processed to transform its characteristics and obtain the desired size. According to Figure 4, this is done with a device which performs signal processing integration, amplification, increase the square and square root, analog-digital conversion, etc. Further signal processing will be analyzed in time domain, frequency and amplitude.

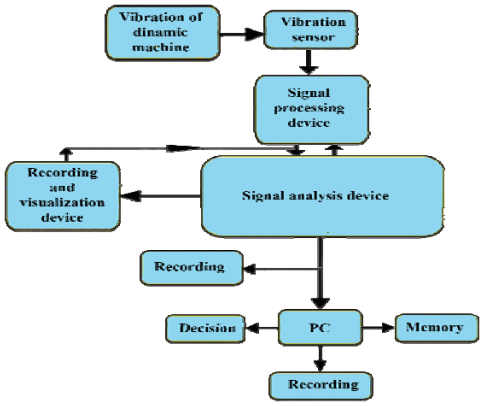


Fig. 4. The basic layout of a system for vibration measurements and analysis

Currently, the amplification is electric, to the detriment of the mechanical amplification, because it can amplify very low signals and inertial influences are eliminated. Next sinusoidal signal can be analyzed both in time and frequency domain. Key information is found in the frequency domain, by knowing the frequency, amplitude and phase of sinusoids components. In order to analyze the frequency of signals using band filters.

Finally, measurement results can be viewed and further processed using oscilloscopes and indicators devices, which are recorded on paper, film or tape, or can be viewed on a computer using the installed software.

Using this method stopping or dismantling the machinery is no longer necessary because it permits us to know the existing problems and any necessary corrective actions. One can also assess the degree of reliability of equipment by knowing the defects that influence good functioning of the machine.

Vibration diagnosing once included in a predictive or proactive maintenance system will have positive effects by reducing the monitored equipment, even avoiding an accidental interruption of the flow events and also by making technological maintenance activity.

Study of a prototype on a stand is another use of vibration analysis. This method allows observing the weaknesses and thus may interfere with the constructive characteristics prototype improvement.

In the diagnosis is necessary to analyze the vibration characteristics of the machine measured at different points, namely:

- the amplitude of one of the characteristics (displacement, velocity, acceleration) to assess the vibration severity; amplitude / frequency diagrams (spectrum); polar diagrams (amplitude / phase); vibration waveform (amplitude / time); evolution of the recorded vibrations; machinery manufacturer's stipulations of or applicable standards relating to the assessment of vibration severity.

All these data should be complemented with information related to the machine construction:

- rpm;
- nominal operating parameters;
- constructive characteristics of bearings;
- constructive characteristics of the transmission.

Measurement points will be set according to standards (eg. ISO 10816) or their application will be established according to manufacturer's specification. In a predictive maintenance system, minimal set of measurements is performed regularly, and if early detection of any damage will occur one will intervene with additional measures for the correct diagnosis.

5. CREATION AND CONFIGURATION OF A DATABASE

Appearance of defects is affecting several factors as follows: safety equipment in operation, there can be damaged equipment,

and catastrophic situations, nearby equipment, personnel injury that serves around it; productivity by sudden interruption of technological process flow, environmental security, and last but not least, the company's budget. A predictive and preventive maintenance program for detection defects since the early stages is necessary both in terms of safety and financial purposes. The success of such a program is seen by the number of preventable accidental falls and the number of monitored cars.

Before monitoring a machine one should create a database related to it. This database involves the following steps: (1) machine specific data entry and data collection process, and (2) database configuration.

5.1. Creating a database

Data collection should be done with maximum attention it is an important step to obtain analysis and diagnosis valuable and useful in the maintenance process. Interpretation and evaluation is impossible if data collection is not accurate and complete.

Nowadays, modern diagnostic systems work with databases that have entered accurate information related to: the monitored parameters, analysis parameters, routes traveled, and many other information-related to the equipment.

Equipment database must be properly maintained, completed and improved to always be current and useful.

Currently, there are specialized programs for equipment and technological process, which deals with data acquisition and data management, as well as processing and filtering in order to draw up reports extremely useful in the monitoring process.

To accelerate and simplify the creation of the database for each machine it is created: machine sheet and plug the process equipment.

- Equipment sheet

Equipment sheet will include all the specific equipment information, type of operation and data on train equipment, namely: type of operation; constant speed machines; variable speed machines; constant or variable load; machinery components; bearings; its natural frequencies; plates.

- Process equipment sheet

Process equipment sheet will include all process variables affecting at some point dynamics and vibration profiles of the monitored components.

5.2. Database configuration

Analysis systems differ among themselves depending on application performance, as well as from a manufacturer to another. That is why data entry and steps to follow in order to set up the database must be done according to the instructions of the supplier to ensure proper monitoring equipment in order to obtain maximum information.

Database configuration consists in setting the parameters of analysis, the attention and danger limits, filters, and determining routes for data collection.

- Setting the analysis parameters

Analysis parameters quantify the components of the machine, its dynamics, and the types of defects to be monitored at the equipment.

Analysis parameters are not set for particular situations but for classes of equipment, as some analysts may wish to establish one single set of parameters for each train analysis tools in hand, and the limit up to 256 parameters of analysis for a database that most microprocessor-based systems have can be an impediment.

Setting a set of parameters for analysis by class of equipment has some advantages as follows:

- database is greatly simplified, using a single set of parameters for all similar equipment, and the time for data entry is greatly reduced;
- possibility of direct comparison between the parameters of analysis tools introduced in the same class

- Alert / Alarm limit

A machine operating status is automatically assessed for maintenance systems with microprocessors. This machine's status is determined by tracking the change in amplitude of the vibration signal.

Because the system automatically notifies maintenance if the machine's condition is deteriorated, he must establish some limits of alert/alarm, namely: (a) limited attention, (b)

alarm gradient and (c) risk limit. Because the severity and magnitude of vibration depends on the machine speed and load limits of alert/alarm must be established taking into account variations in these two critical factors. These limits must be established in compliance with ISO 10816 standards.

a) Limit of attention

Limit of attention involves the appearance of anomalies in running the machine, not serious enough to recommend stopping it. Limit of attention once exceeded will require users to perform a more thorough diagnosis, to be detected in developing mechanical defects.

b) Alarm gradient

Second given warning, namely gradient alarm, is not known, because ISO 10816 standard does not provide implicit recommendations for this type of alarm. Gradient limit is established, depending on user's knowledge, considering that the amplitude of vibration increases with increasing wear. The alert automatically notifies the operator if the machine's condition deteriorated over the pre-selected, and this level varies from one equipment train to another depending on the degree of wear it has. Since this alarm is set by the users, at the new machines this limit must be set lower and later be adjusted.

c) Danger limit

Danger limit, called the critical limit is not adopted, as in cases of other limits, depending on speed and load. It is set according to class of equipment and based on international standards.

This limit is very dangerous, because once reached the probability of catastrophic damage likely exceeds 90%.[9]

6. IDENTIFICATION OF THE MAIN SOURCES OF VIBRATION IN DYNAMIC MACHINES

The vibration monitoring equipment means regular or permanent collection of data and comparing them with measured values prescribed by the manufacturer of equipment or valid standards in order to establish the proper functioning of equipment. If the vibration has reached the "still good," the maintenance team is warned for a planned intervention. This programming must be done so that production is not affected.

If the vibration level exceeded the maximum allowable amount it will immediately be required to stop the machine, its removal to determine the sources / causes of vibration and then repair the damages.

The vibration monitoring can reveal defects of electrical or mechanical nature such as: - Imbalance (mechanical or electrical); - Misalignment; - Eccentricities; - Wear of the bearings or rolling; - Wear of transmission parts (gears, belts); - Problems of lubrication; - Weakness; - Defects of the windings; - Operational issues.

All these defects cause additional forces supported by bearings and support structure of the machine and increases in vibration amplitude.

6.1. Diagnosing transmission through gears

Transmission gears, called gears are rotating equipment whose vibrations caused by a malfunction, determine the low frequency harmonics in the spectrum of vibration, but also in high frequency domain. Over the frequency any gear (GMF), the spectrum shows peaks at 1x any gear and 2xturatia tree.

GMF (frequency gear) is calculated as:

GMF = number of teeth x RPM shaft (4)

In the frequency spectrum of a gear on its own will be accompanied by sidebands GMF specific speed work, they increased with increasing load. These sidebands of their frequency with its harmonics are found in a frequency range around its frequency GMF. If the gear works normally peaks sidebands are low amplitude and frequency does not appear in its natural excitement.[13]

To study the side bands, the best tool is the Cepstrum analysis, along with mediation of the time domain and commonly analysis methods one can eliminate interference due to variations at low speed.

The most common problems of gears are:

- Wear on teeth;
- Overuse of teeth by excessive load;
- Eccentric gear;
- Gear misalignment;
- Gearing cracked or broken.

The defects that are represented by sidebands and harmonics, whose amplitude is

close to the natural frequency is due to gear eccentricity and gear misalignment. Defects manifested by sidebands distributed along the spectrum are due to defects such as impaired teeth.

6.2. Bearings diagnosis

Bearings are built car bodies of two horses running rings, one exterior and one interior, separated by rolling elements, which are held by a casing. The appearance of a defect can occur in any of these component parts, which is manifested by high frequency vibrations. Cause defects in the bearing components can be excited by specific frequencies. Defects occur a bearing housing is the hardest to detect, because defects are not fully harmonic bearings working speed.[10]

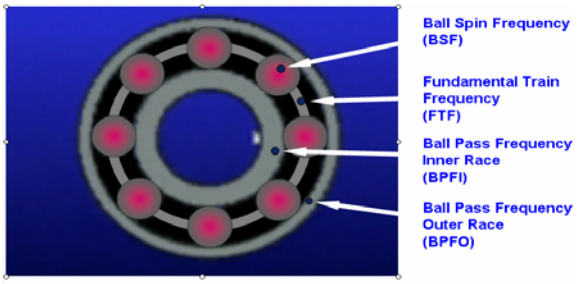


Fig. 5. Own frequencies components of a bearing[11]

Bearing's presents characteristic failure modes corresponding components, figure 5. To find out their frequencies of bearing components will use the following formula:

$$BPFI = \frac{N_b}{2}\left(1+\frac{B_d}{P_d}\cos\theta\right)\times RPM \quad (5)$$

$$BPFO = \frac{N_b}{2}\left(1-\frac{B_d}{P_d}\cos\theta\right)\times RPM \quad (6)$$

$$FTF = \frac{1}{2}\left(1-\frac{B_d}{P_d}\cos\theta\right)\times RPM \quad (7)$$

$$BSF = \frac{P_b}{2B_d}\left[1-\left(\frac{B_d}{P_d}\right)^2(\cos\theta)^2\right]\times RPM \quad (8)$$

Where:

N_b = Number of rolling elements;

B_d = Rolling element diameter (mm)

P_d = Diameter of the circle passing through the centers of the rolling elements;

θ = Contact between the rolling element and outer ring, in degrees.

Currently, own frequencies known components of the bearings are found in bearings databases available in electronic format.

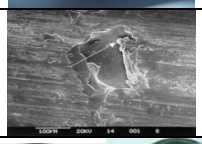
Between rolling elements and own frequencies of the outer ring and on the inner ring there is a strong connection that is: if we add these frequencies and divide the result by the machine speed, final outcome will result in the number of rolling elements.

Damage to bearings goes through four phases:

- in the initial phase, there is only a high frequency vibration;
- in this second phase one will see the resonance frequencies of the bearing;
- in the third stage it can be seen discrete frequencies;
- the final phase is a high-frequency noise, which increases in amplitude with increasing severity of the defect.[13]

The most common defects that occur in bearings can be seen in Table 1.[9]

Table 1

Inner ring	Fighting radial Ripple Single Defect (Pitting)	
Outer ring	Ripple Single Defect (Pitting)	
Body Rolling	Variation of diameter Ripple Single Defect (Pitting)	

7. CONCLUSION

This article aims to present predictive maintenance service using vibration analysis, implemented in order to bring and maintain a good operating state of a dynamic machinery.

Vibration analysis is considered the main leverage in the implementation and development of predictive maintenance programs. Predictive maintenance service by vibration analysis due to the benefits and

financial savings offers began to be borrowed in more and more industries.

By implementing a rigorous analysis of the vibration one can set some benchmarks that will be compared to later collected values.

The cost of implementing a program analysis consists of equipment, software and staff training. These costs can be quickly recovered by reducing parts, labor and in particular to reducing or avoiding the stationary production time.

Increased reliability and utilization of equipment, the possibility of crash prevention and reducing downtime of equipment are considered additional benefits of preventive maintenance service through vibration analysis.

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SERVICIUL DE MENTENANTA A MASINILOR DINAMICE UTILIZAND ANALIZA VIBRATIILOR

***Rezumat**: In acest articol se doreste sa se ofere informatii despre activitatile de mentenanta ale masinilor dinamice prin folosirea analizei vibratiilor. Aceasta metoda implica utilizarea vibratiilor ca unitate de masura referitor la buna functionare a echipamentelor, avand drept scop cresterea eficientei reparatiilor si a sigurantei operationale. Articolul are ca subiect principal analiza vibratiilor, iar in acest domeniu ne dorim sa subliniem importanta creerii unei baze de date si-n special achizitia si diagnoza datelor. In cele din urma vrem sa aratam necesitatea punerii in aplicare a unui astfel de program de intretinere intr-o fabrica prin punerea in evidenta a principalelor avantaje pe care le ofera intretinerea predictiva, mai precis, analiza vibratiilor.*

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