Predictive Maintenance Approach, Vibration Analysis and Fault Detection in an Industrial Fan Motor

Mehmet Mandi

Istanbul Technical University

DOI: https://doi.org/10.51244/IJRSI.2025.12040029

Received: 21 March 2025; Accepted: 01 April 2025; Published: 02 May 2025

ABSTRACT

In industrial facilities, the expected production, quality and machine efficiency are directly related to the implementation of appropriate maintenance activities. In order to reduce the effects of failures on the production program and the product, maintenance approaches consisting only of breakdown maintenance have been abandoned over time and modern techniques such as predictive maintenance, which allows the detection of catastrophic failures before they occur, have begun to be implemented. This article examines the predictive maintenance approach and the vibration analysis technique, which is the most commonly used predictive maintenance method. The article also examines the detection of failures in an industrial fan using the vibration analysis technique as a sample study.

Keywords: Predictive maintenance, vibration analysis, fault detection, bearing fault, bearing frequency

INTRODUCTION

In industry, machine maintenance philosophies have evolved from breakdown maintenance to preventive maintenance over time. Today, proactive maintenance philosophies, especially predictive maintenance approaches, are the most popular types of maintenance.

Breakdown maintenance was used as a reactive type of maintenance in the early days of the industrial age. Equipment was operated until it could not perform its function and a failure occurred. Secondary damages and failures were often observed due to the primary failure.

This maintenance approach progressed towards time-based maintenance, or preventive maintenance. In this approach, equipment was taken into maintenance even if no failure was observed after completing a certain number of working hours. This type of maintenance style sometimes caused the replacement and maintenance of parts that had not completed their working life, which had a negative impact on maintenance costs.

The increase in maintenance costs based on preventive maintenance led to the need to switch to condition-based maintenance in equipment instead of calendar-based maintenance works. This led to the formation of the predictive maintenance philosophy. [1,2]

Predictive Maintenance

It is also called condition-based maintenance. It is a maintenance application that prevents failures, performed according to the physical properties and functions of materials or moving systems, and according to certain measurement and evaluation techniques. In predictive maintenance, machines in businesses are monitored from certain points. For this, a number of measurement devices are used. The measurement results taken at a certain time interval are evaluated. By examining the trend of the obtained measurement values, possible failures in the system are detected even when the machine is in good condition. Predictive Maintenance provides analysis of technical information in order to indicate whether a device is about to fail or at what stage its general condition is. Problems are corrected before they turn into more expensive and major failures. Since this method detects possible failures by monitoring the operating system, it prevents unnecessary system downtime and unnecessary

part replacements. A planned maintenance program is prepared by analyzing the trends of the measurement values and the system is taken into maintenance. One of the important issues in the predictive maintenance approach is deciding which machine or equipment, which points, which values (vibration, temperature, pressure, flow, current, thickness, etc.) are to be measured and how frequently.

Advantages:

It becomes possible to plan some part replacements when the machine is not needed to work. This reduces the total cost. The labor, tools and spare parts required for maintenance are ready for use at the planned downtime. Equipment is worked with real data that is an indicator of the real mechanical condition of the equipment. Maintenance plans are carried out and updated in the light of this real data. Predictive maintenance prevents unplanned failures to a great extent, as well as preventing the failures that will occur from wearing out other systems, and also provides real data about the situation after repair. Major failures for the machine can be minimized. Maintenance time, and therefore the downtime of the machine, can be minimized.

The predictive maintenance approach also has some advantages over the preventive maintenance approach. In preventive maintenance, just because the maintenance period has come, disadvantages such as replacing parts that have not failed in the system and can meet the need for a longer period and unnecessary stopping of the production flow can be observed. Fig.1 shows a typical graph showing the failure/operation time of a machine. The probability of failure is higher in the first few weeks when the machine or equipment is put into operation due to issues such as incorrect manufacturing, assembly or setup. After this first period, a long period occurs where the probability of failure is lower. With the preventive maintenance approach, it is possible to return to the first time period when the probability of failure is high. The predictive maintenance approach avoids this situation. Thus, machines that are in good condition and working without problem are not stopped unnecessarily. In this way, the time spent and the cost are kept to a minimum.

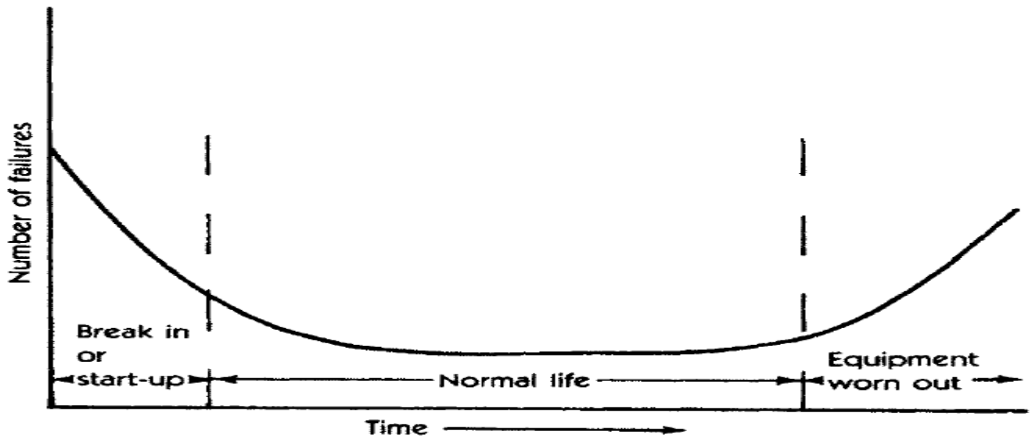


Fig.1 Bathtub curve (Mean time to failure) [3]

Disadvantages:

The initial investment costs of the condition monitoring devices required for predictive maintenance are high. The installation and use of these devices require qualified personnel. Determining which data should be collected from which machines, determining data collection points, interpreting the data received and determining faults require some special training. Although there are AI-supported diagnostic systems available today to interpret data, they are still far from providing fully reliable results. For this reason, the opinion of an expert personnel is still needed.

Computer-aided maintenance management systems should be established to store the values obtained and monitor their trends. Incorrect planning, measurement period and evaluation can cause unnecessary maintenance activities and increase labor and spare part costs. [1,2,3]

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

Vibration Analysys

In today's industry, the most reliable data regarding the health of rotating machines include vibrations occurring in machines. Every failure occurring on the machine manifests itself as vibrations at different frequencies according to its physical properties. Proper reading and analysis of these vibrations helps us predict which part of the machine is more likely to fail, what type of failure it has, or how long the machine can operate before a catastrophic failure occurs.

Vibration analysis is the most widely used predictive maintenance technique due to the detailed and reliable data it provides. This technique allows for maintenance planning by detecting failures in advance. Vibration analysis increases the reliability of the machine and prevents failures with negative consequences, and provides ease of maintenance. Depending on the criticality of the equipment, it can be performed by continuous monitoring or by taking measurements at certain periods.

Performing vibration analysis by analyzing and interpreting a value taken from the machine requires expertise and knowledge. The machine may have some minor defects that may cause vibration when it is first commissioned, or vibrations may be seen at certain frequencies due to surrounding factors (e.g., other operating machines). These vibrations, which often appear as faults, do not cause a major problem. For this reason, vibration analysis can be performed more accurately by comparing information obtained at regular intervals, rather than with a single measurement.

Vibration analysis requires understanding some basic vibration terms. These are vibration, frequency, period, amplitude, fundamental frequency, harmonics, displacement, speed, acceleration and phase.

Five components of vibration analysis are shown in Fig. 2. A sensor that converts the vibration into a signal, a device that can detect this signal and process the signal is required. The device must have a Fast Fourier Transform (FFT) feature for analysis. [4]

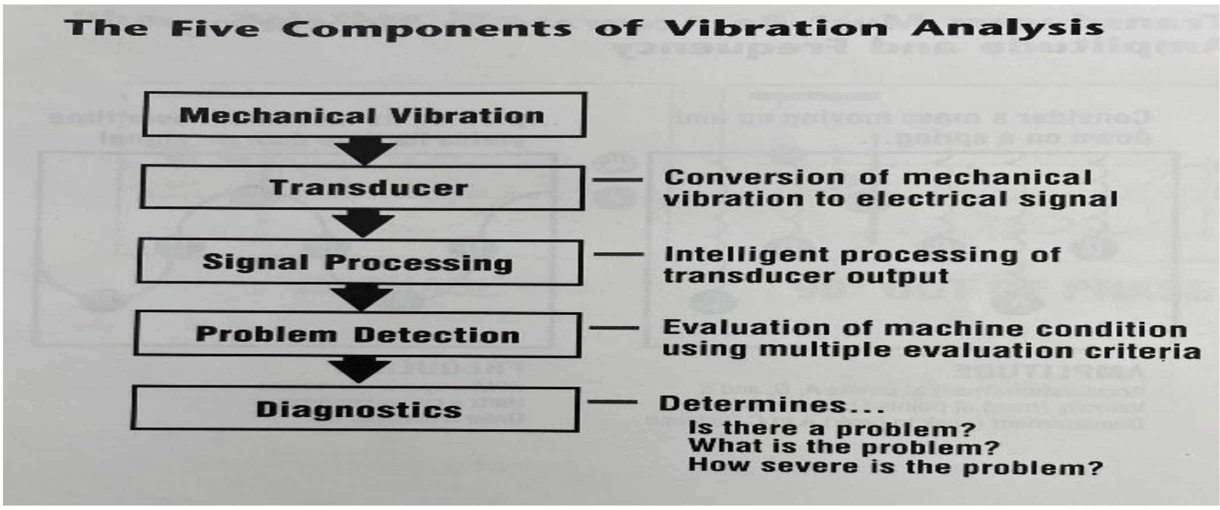


Fig.2 The five components of vibration analysis

Vibration

Vibration is the oscillation of a mass with respect to a reference point (For example, the relative vibration of a shaft with respect to the chassis of the machine or the relative vibration of a bearing with respect to its housing)

Vibration occurs when it responds to some internal and external excitations. The amplitude of the vibration depends on the magnitude of the excitation force, the mass, rigidity and damping of the system. Vibration may occur because we cannot manufacture a perfect machine part or because we cannot assemble it perfectly. If we could manufacture a perfect machine part, the center of mass of this rotating part would be exactly at the center of gravity. If the center of mass and the center of gravity do not meet at the same point, an eccentric center of gravity and imbalance will occur in the rotating bar. This imbalance will produce vibration in proportion to the

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

magnitude of the mentioned center of gravity. Other sources of vibration are; machine tolerances, machine structure, bearing design and loads, lubrication, foundations and machine assembly, rolling or friction contacts between parts. Vibration reduction and isolation techniques are a standard part of machine design, but in practice it is quite difficult to prevent vibration. With a few exceptions, it is very costly to build a vibration-free machine. For this reason, it is financially impossible to provide or install vibration-free machines in many industries. Therefore, the main thing is to find the source of the exciting force that causes vibration, to eliminate or at least minimize the force, and to reduce the damaging vibration.

Frequency

Frequency is the number of times a movement is repeated in a certain time interval. Hertz (Hz) is usually used as the unit of frequency, and CPM (cycles per minute) is the preferred number of movements per minute in the analysis of machine failures. Using CPM as the frequency unit provides faster access to the cause of the failure by knowing the machine speed. The problem causing the failure manifests itself in the harmonics of the machine speed frequency. This physical information forms the basis for determining failures through vibration analysis.

Period

The time required for one cycle of movement. The period (T) is obtained by dividing 1 by the frequency. For example, the period of a shaft rotating at 600 RPM (10 Hz) is T = 1/10 = 0.1 seconds. Fig. 3 shows the vibration cycle of a typical harmonic motion.

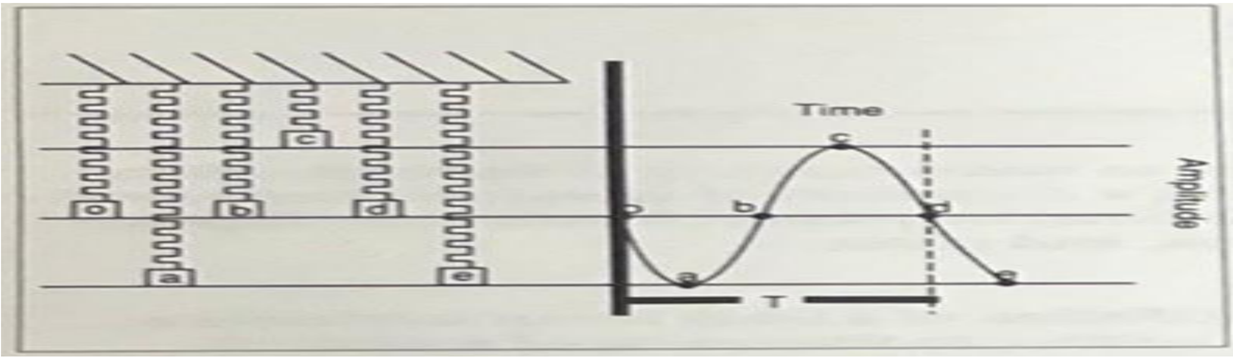


Fig. 3 Harmonic motion represented by a mass end spring

Amplitude

The vibration magnitude of an object that vibrates is defined as amplitude. Amplitude can be expressed as RMS (Root Mean Square), peak (Pk), peak-peak (Pk-Pk) as units. As seen in Fig. 4, the difference between the measured amplitude units is seen on the sinus curve created by the harmonic motion.

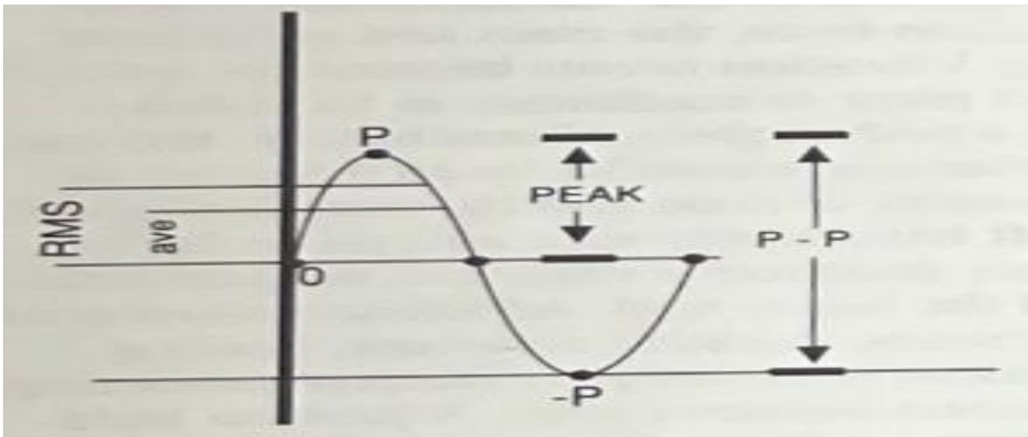


Fig4.Relationship of RMS, peak and Pk-Pk

INTERNATIONAL JOURNAL OF RESEARCH AND SCIENTIFIC INNOVATION (IJRSI)
ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

The relationship between the peak value and RMS in the sinus curve is Pk = 0.707 RMS

In vibration measurements, peak-peak is generally selected for displacement unit measurements, peak for velocity unit measurements, and RMS amplitude type is selected for acceleration unit measurements. The recommended amplitude unit for determining faults is "velocity". Velocity unit measurements optimally display signals occurring at both low frequencies and high frequencies as shown in Fig.5. [4]

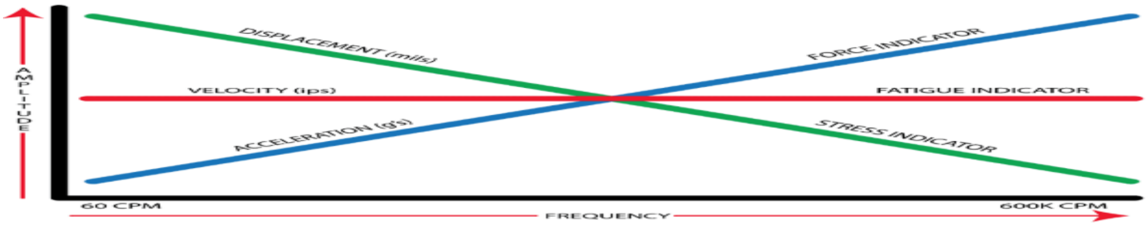


Fig .5 Vibration unit comparison

Vibration Units

Displacement:

Displacement is defined as the change in position of a rotating object from its final position to its initial position. Displacement is the actual physical movement of the vibrating surface. When measuring displacement, the amplitude is measured in peak-to-peak form.

Velocity:

It is the speed measured at the moment when the displacement occurs. In speed measurements, it is usually measured with amplitude in the form of a peak. It is mathematically expressed as the derivative of the displacement with respect to time (V= dD/dt).

Acceleration:

Acceleration is the rate of change in velocity over a given period of time. Acceleration gives the rate of change of velocity from zero to the peak. Mathematically, it is expressed as the derivative of velocity with respect to time (A=dV/dt)

Harmonics

Harmonics are vibration signals at multiples of frequency. In vibration analysis, multiples of the machine speed (harmonics) are usually examined for fault detection.

Phase

Phase measurements are expressed in degrees. One complete cycle of vibration (one complete sine curve) is equal to 360 degrees. It is the difference that occurs when vibration sources with different sine curves pass through a certain reference point. It can be understood more clearly when Fig.6 is examined.

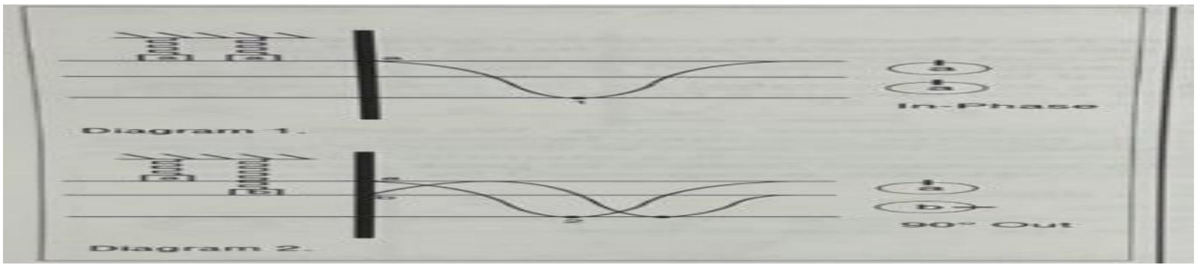


Fig. 6 Phase

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

Using a single channel vibration probe and laser tachometer, the phase angle of the vibration can be calculated by measuring the delay between the tachometer signal and the sine curve of the vibration (Fig. 7). [4]

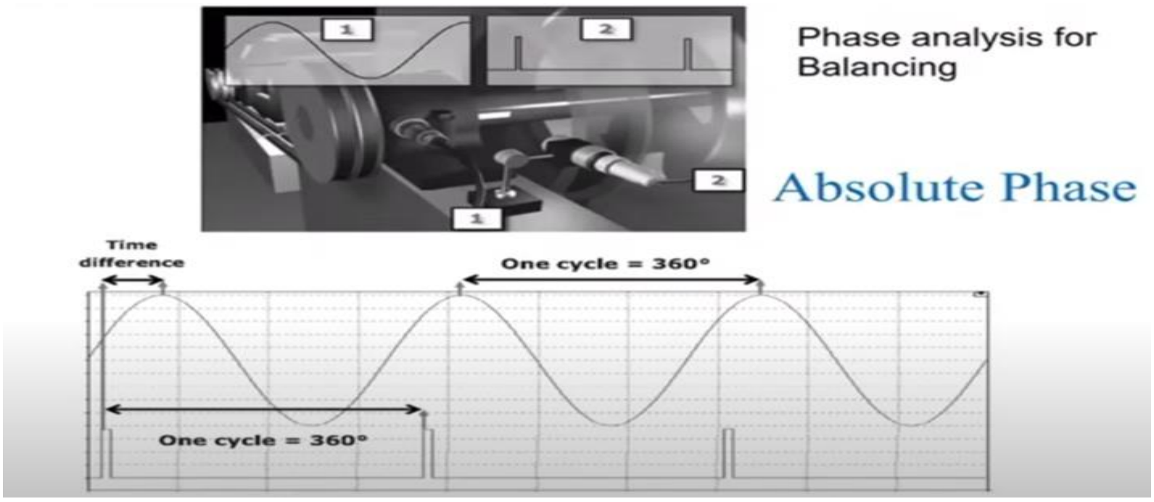


Fig. 7 Phase Analysis

With multi-channel vibration probes, the phase differences between the forces causing vibration can also be measured with measurements taken from three axes (horizontal, vertical, axial) or measurements made from multiple points. These phase differences can be analyzed to detect faults on the machine. Phase differences refer to specific faults. For example, in a vibration measurement taken vertically from two bearings of an engine with an imbalance in its shaft, the phase difference between the two bearings is measured as zero, while in a vibration measurement taken vertically from both bearings in a shaft with an axial misalignment problem, the phase difference is measured as 180 degrees(Fig. 8).[5]

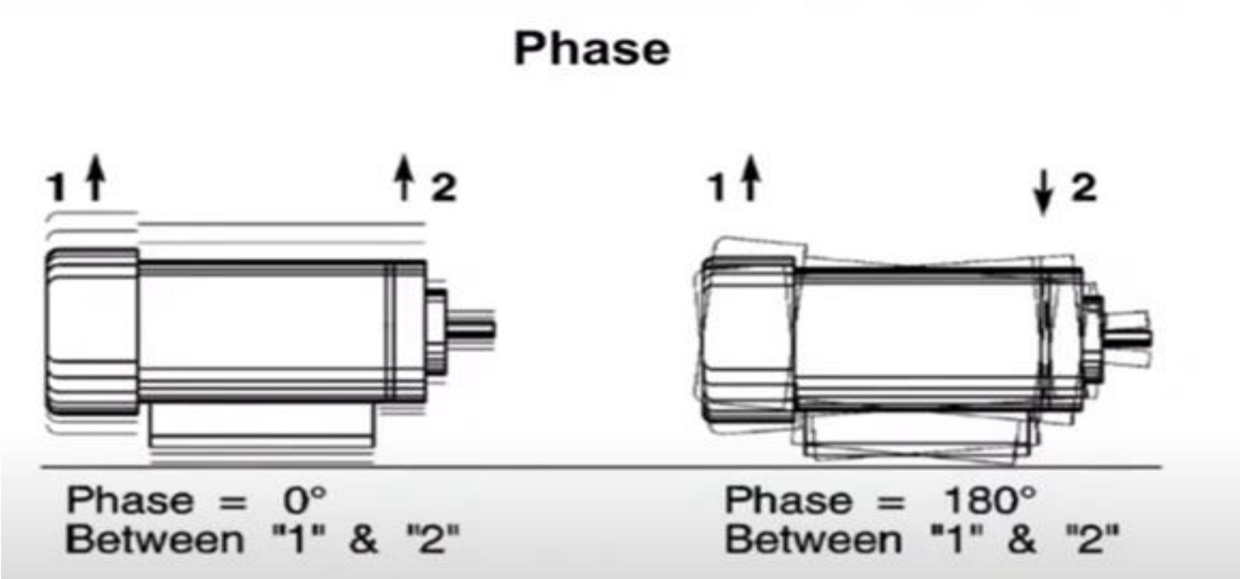


Fig. 8 Misalignment phase difference

Data Conversion and FFT

Vibration sensors produce a dynamic voltage proportional to the vibration at a certain moment. Vibration analyzers convert these signals into readable vibration values. Machine vibrations are the resultant of many sinusoidal vibrations of different amplitudes and frequencies. In a typical machine, we can talk about the simultaneous presence of more than one vibration source due to reasons such as imbalance, misalignment, looseness, other machines nearby, resonance. In this case, it can be quite difficult to diagnose a fault from the time waveform.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

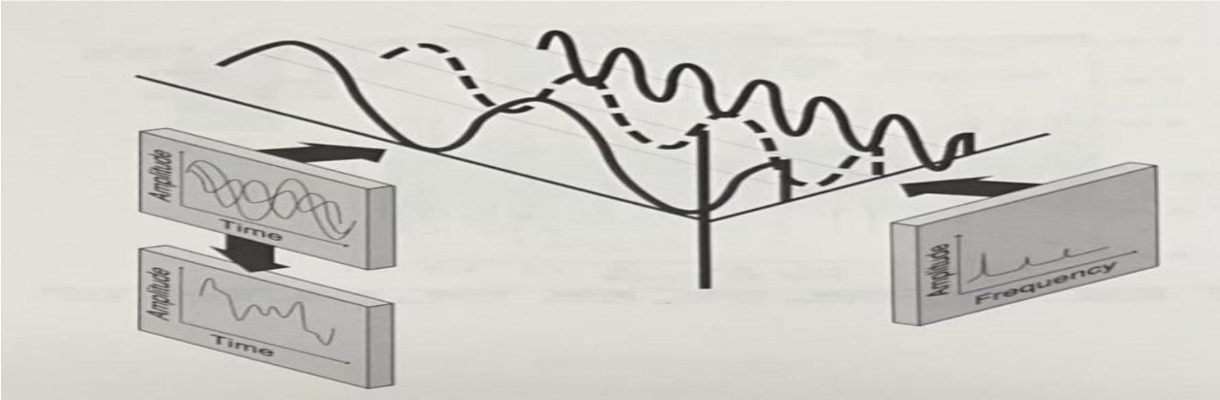


Fig. 9 Relationship of time and frequency

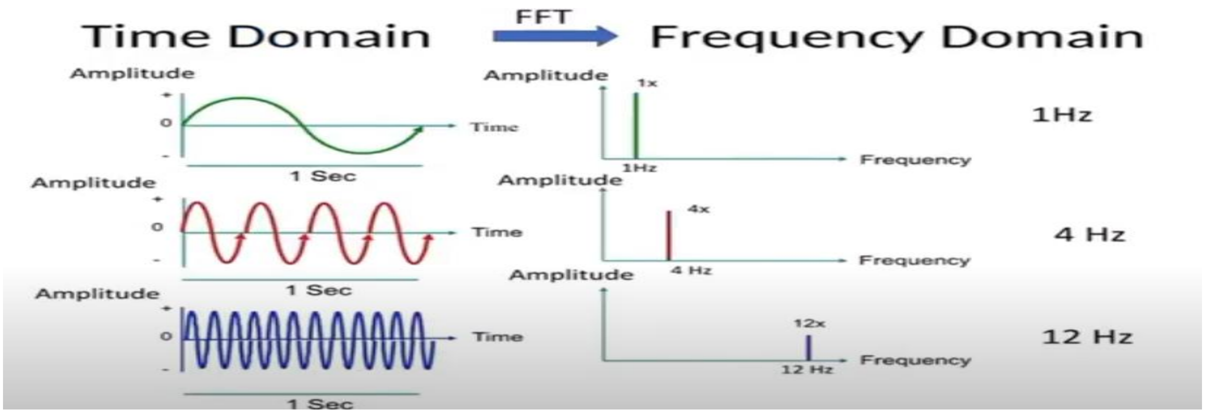


Fig. 10 Time domain and frequency relation by FFT transformation

By separating the time waveform into the frequencies of the vibrations that make up the waveform using the Fast Fourier Transform, a frequency spectrum graph is obtained (Fig.9, Fig.10) that is easier to read and interpret. This graph is much easier to read and interpret for fault diagnosis. As it is shown in Fig.11 frequency spectrum graphic is easier to read. [6]

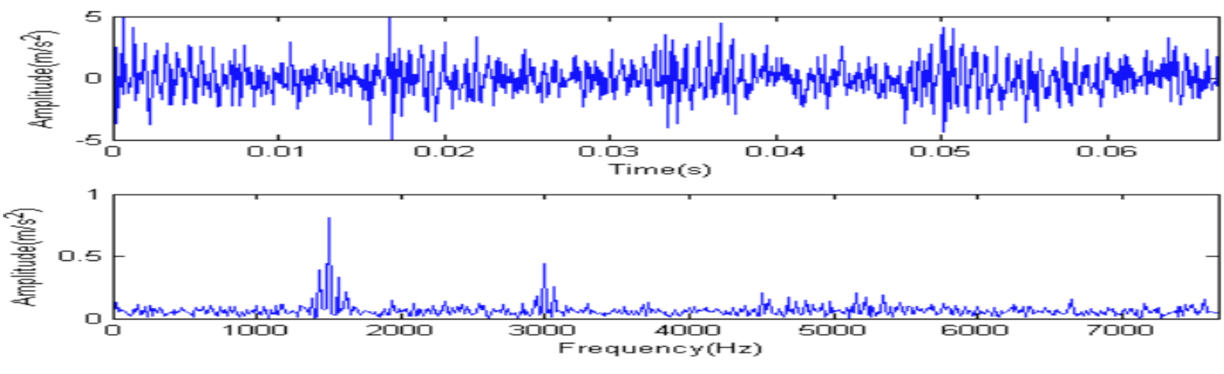


Fig. 11 Comparison of time wave form and frequency spectrum graphics

Fault Detection on An Industrial Fan Motor with Vibration Analaysys

Determining faults in rotating equipment with vibration analysis is one of the predictive maintenance applications frequently performed in industrial facilities. The presence of low frequency faults with high vibration amplitudes (axial misalignment, imbalance, mechanical looseness, etc.) can be easily detected due to the perceptible level of vibration.

With machine health monitoring software, the RMS values of the total vibration taken from the machines are usually monitored from the control rooms of the facility. However, this value indicates high amplitude faults in the low frequency region. Low amplitude faults in the high frequency region (bearing fault, gear fault, etc.)

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

only manifest themselves as high temperature or audible sound when the fault approaches the machine stop level. For this reason, the healthiest method is to detect such faults with frequency spectrum graph analysis before a serious fault or stop occur.

In the sample study, vibration measurements taken from an exhaust fan (Fig.12) of a Sinter Factory were evaluated. The motor bearing temperature and total RMS vibration speed (mm/s) values are continuously monitored from the control room of the factory. Bearing health is monitored by measuring the frequency spectrum of the bearings at certain periods.

Fig.12 Fan

Fig. 13 Fan motor

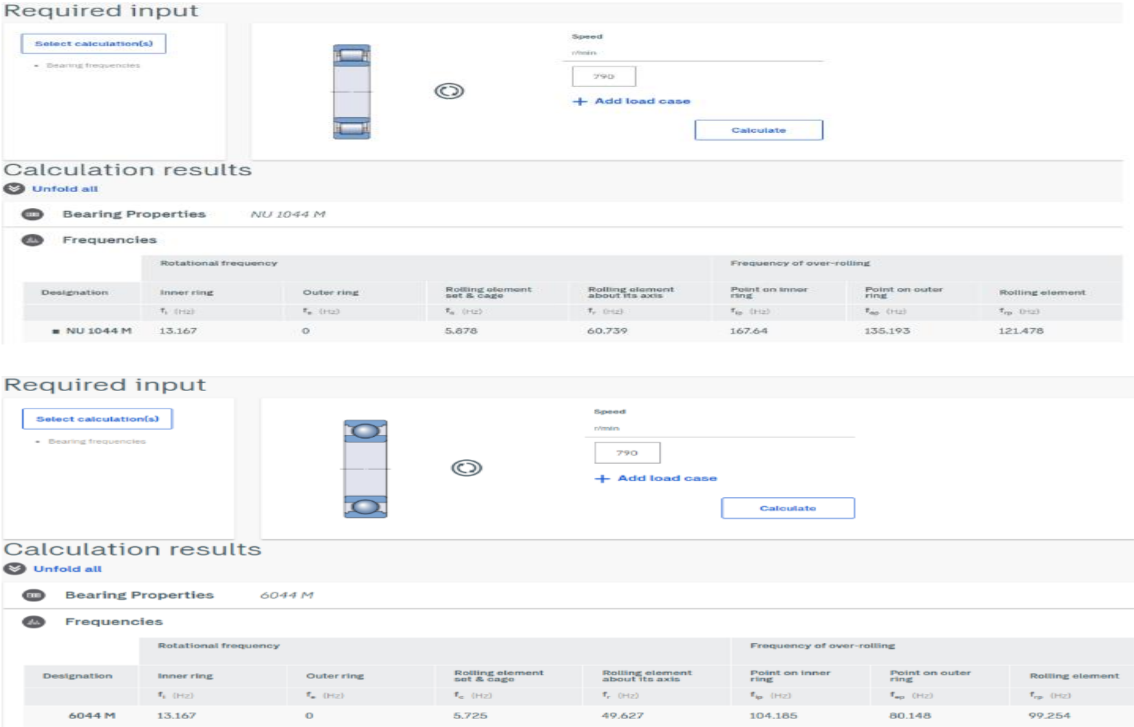
Roller bearings used in Fan motor (Fig.13):

Coupling Side 6044M + NU 1044M, free end NU 1044M

If the bearing used in the equipment being tested is known, bearing suppliers provides calculation tools that can determine bearing inner ring, outer ring and rolling element frequencies according to the fan speed (Fig.14). In addition, some analysis devices have similar calculation tools in their own libraries. Thus it is possible to mark fault frequencies on the spectrum by entering the bearing type. If the bearing used is not known, vibration peaks with harmonics and side bands in the frequency range of 10X-50X (between the tenth and fiftieth times of the speed) should be examined in the fans. Most of the vibration peaks in this range are due to bearings.

Fan bein tested has a variable speed fan. The flow rate required due to operating conditions is usually provided at 790 RPM. For this reason, the vibration test will be performed at 790 RPM. Accordingly, the failure frequencies of the bearings used are as in Fig.14.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025


Required input

Select calculation(s)

- Bearing frequencies

Speed

r/min

790

+ Add load case

Calculate

Calculation results

Unfold all

Bearing Properties NU 1044 M

Frequencies

	Rotational frequency				Frequency of over-rolling		
Designation	Inner ring	Outer ring	Rolling element set & cage	Rolling element about its axis	Point on inner ring	Point on outer ring	Rolling element
	f_i (Hz)	f_e (Hz)	f_c (Hz)	f_r (Hz)	f_{ip} (Hz)	f_{ep} (Hz)	f_{rp} (Hz)
NU 1044 M	13.167	0	5.878	60.739	167.64	135.193	121.478

Required input

Select calculation(s)

- Bearing frequencies

Speed

r/min

790

+ Add load case

Calculate

Calculation results

Unfold all

Bearing Properties 6044 M

Frequencies

	Rotational frequency				Frequency of over-rolling		
Designation	Inner ring	Outer ring	Rolling element set & cage	Rolling element about its axis	Point on inner ring	Point on outer ring	Rolling element
	f_i (Hz)	f_e (Hz)	f_c (Hz)	f_r (Hz)	f_{ip} (Hz)	f_{ep} (Hz)	f_{rp} (Hz)
6044 M	13.167	0	5.725	49.627	104.185	80.148	99.254

Fig.14 Bearing frequencies [7]

In order to test the bearing health, speed frequency spectrum measurements were taken from horizontal and vertical directions in the motor bearings. The measurements were taken using an accelerometer and a two-pole magnet connection.

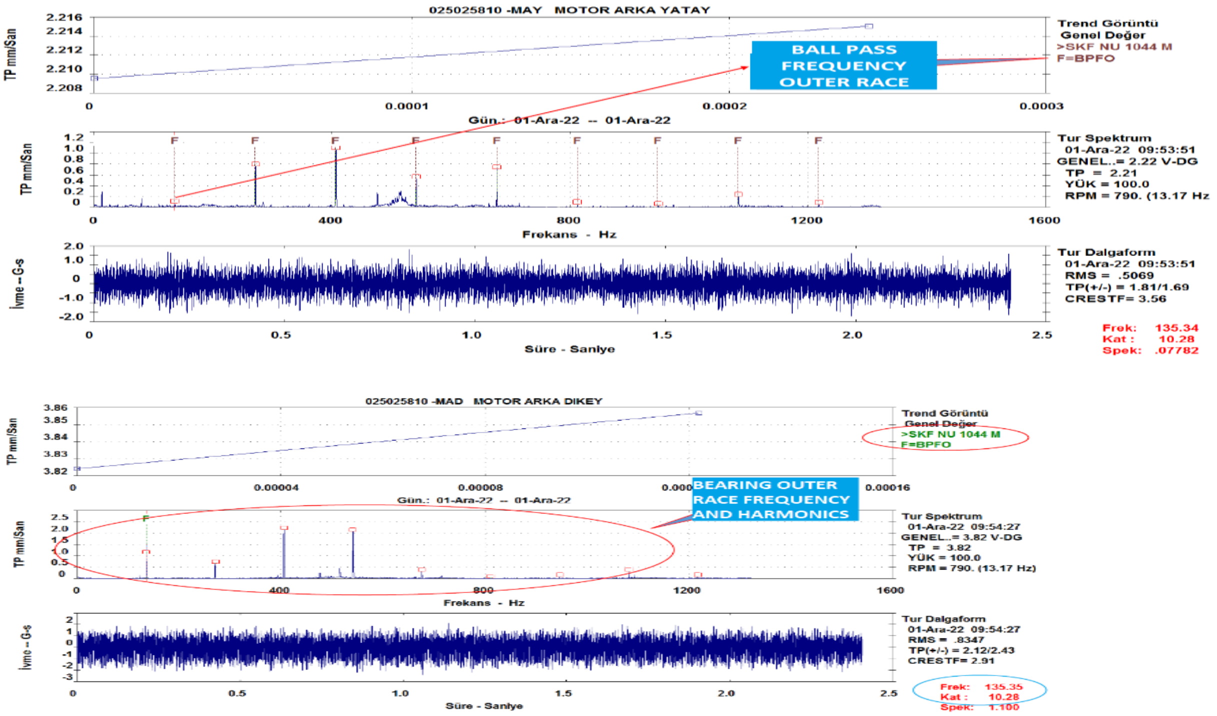


Fig.15 Motor Free end vertical and radial vibration readings

As seen in the measurements made in the high frequency region of the motor free end, vibration which have harmonics is observed at high frequency and the first peak is at the level of 10.28x of fan speed (Fig.15). The value of 10.28x (135.35 Hz) almost corresponds to the outer ring frequency (135.193 Hz) of the NU1044 M roller bearing, which is one of the fault frequencies we have detected. The fact that the vibration creates harmonics with high amplitudes, especially in the vertical direction, indicates that there is an outer ring fault in this bearing.

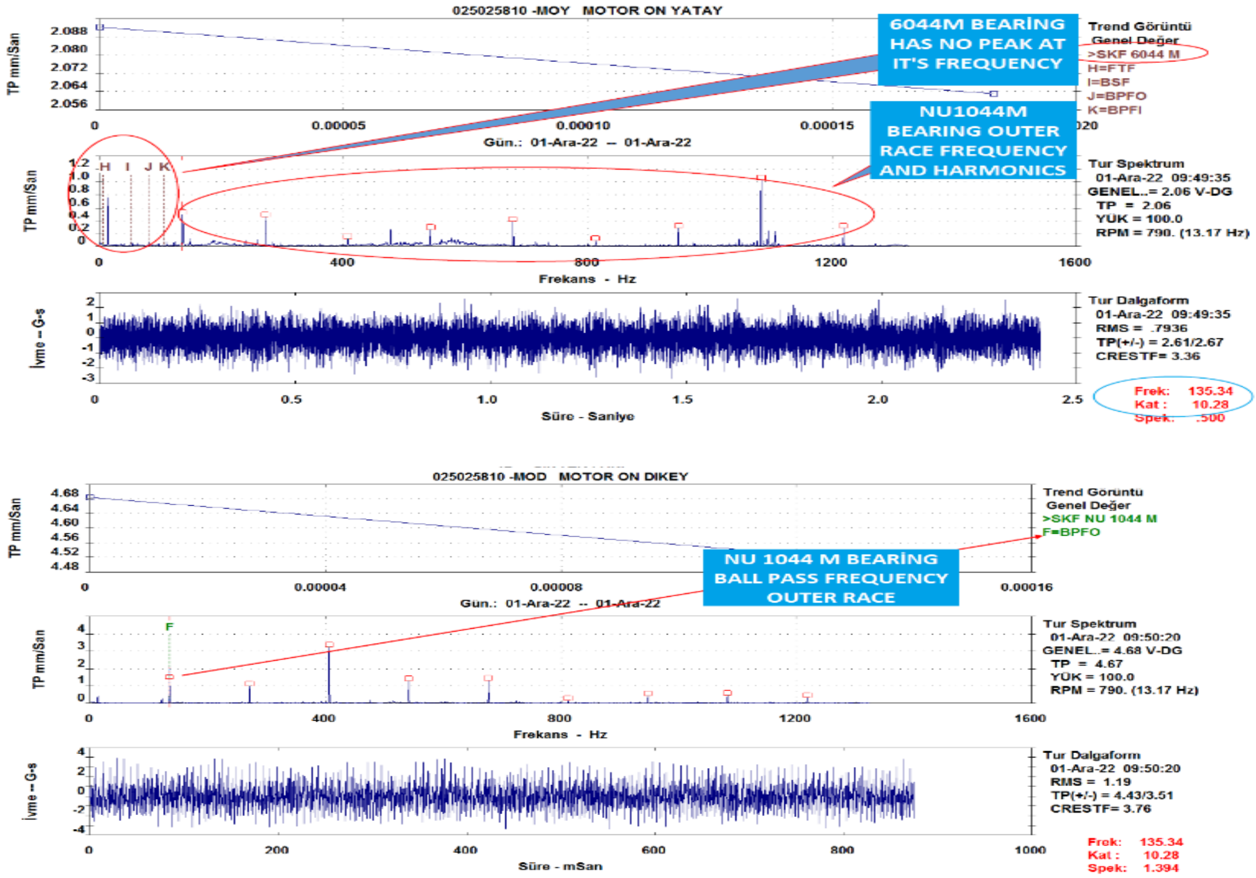


Fig. 16 Motor coupling side vertical and radial vibration readings

When the vertical and horizontal measurements taken from the motor coupling side bearing (Fig.16) are examined, vibration harmonics are seen similarly free end bearing. Lowest frequency of these harmonic vibration peaks is 135,24 Hz. Again, it almost corresponds to the outer ring frequency (135.193 Hz) of the NU 1044 M roller bearing. Especially the high amplitude in the vertical direction indicates that there is an outer ring fault in the NU 1044 M roller bearing here. Since no peak is seen in the frequency of the 6044 M roller bearing on the graph, it can be said that this bearing is in serviceable condition. As a result of this analysis, bearing faults were detected in both sides of the motor. It was seen that the fault was in early stage. In order not to cause more serious faults or uncontrolled plant or equipment stoppages in the future, the motor was disassembled and transported to the maintenance workshop (Fig.17) during the most appropriate planned maintenance stop and the bearing was replaced. The fault traces on the outer ring of the bearing are seen in Fig. 18.

Fig.17 Motor replacement for maintenance

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IV April 2025

Fig.18 Bearing fault traces

CONCLUSION

In today's competitive conditions, it is very important to ensure continuity of production, to produce the product with the requested quality at the planned time and to deliver it to the customer. It is very important to be able to manage failures in fulfilling these production criteria.

Monitoring the condition of the equipment with predictive maintenance activities and detecting failures before they reach the level of stopping the facility or machine makes it possible to manage failures and ensure production continuity. Also detecting possible failures enables the scheduling of planned maintenance stops in facilities and the highest use of maintenance resources.

One of the most effective techniques of the predictive maintenance approach is the vibration analysis method. As mentioned in the sample study in this article, it is possible to determine what the equipment failure is and at what stage it is with vibration analysis. Thus, a maintenance plan can be made, and in addition, the supply of spare materials and the production plan have been shaped according to the examinations performed. The facility has been protected from an unscheduled and long-lasting unexpected failure stop.

All these studies show that it is a necessity for modern industrial facilities to adopt and implement modern predictive maintenance techniques in order to maintain their profitability and existence.

REFERENCES

1. Paresh Girdhar, Scheffer C. “Practical Machinery Vibration Analysis and Predictive Maintenance”
2. Mobley R.Keith “An Introduction to Predictive Maintenance (2002)”
3. Mobley R.Keith “Maintenance Fundamentals (2004)”
4. CSI “Machinary Predictive Maintenance Utilizing Vibration Analysis” training book
5. “megatechnicalhub” youtube channel “Phase analysis , how to pin point the defects , vibration analysis ,phase difference in unbalance” , acces date 19.09.2023
6. “megatechnicalhub” youtube channel “Fast Fourier transform, FFT, time and frequency domain ,vibration analysis time wave form” , access date 19.11.2023 [7] www.skf.com , access date 15.12.2023