People's democratic republic of Algeria
Echahid Cheikh Larbi Tebessi university of Tebessa
mining institute
mining and geotechnology department

Course handout

# Fault detection techniques

Level: Master II

Field: Science and Technology

Sectors: Electromechanics

Specialty: Industrial Maintenance



Prepared by: Dr. Taleb Mounia

MCA at the University of Tébessa

# PREFACE

This handout of fault detection techniques is intended for Master II students in Industrial Maintenance. It is structured into five chapters presenting a theoretical section, enriched by examples and practical applications of the various techniques most used in industry.

There are many techniques for detecting failures, including visual inspections, non-destructive testing (NDT), chemical and vibration analyses, dimensional measurements, and monitoring systems. These techniques help identify anomalies and defects in systems or processes in order to repair or prevent them.

Researchers have developed several techniques and methods for monitoring industrial installations, the aim of which is to ensure maximum availability of production equipment at optimal cost under good quality and safety conditions.

This course handout covers the most commonly used failure detection techniques in industry, namely vibration analysis, infrared thermography analysis, non-destructive testing, ultrasonic acoustic analysis and oil analysis.

**Dr. Mounia Taleb**

Department of Mining and Geotechnology

Institute of Mining

University of Tébessa

# Table of Contents


| | |
|---|---|
| Preface | |
| General introduction | 5 |
| Chapter I: Vibration Analysis, Areas of Application, Principle of Vibration Analysis, Main Faults. | |
| 1.1 Introduction | 6 |
| 1.2 Vibration analysis | 6 |
| 1.2.1 Definition of a vibration | 6 |
| 1.2.2. Description of a vibration signal | 7 |
| 1.2.3 Monitoring and detection | 8 |
| 1.2.4 The signals | 9 |
| 1.2.4.1Transient and random signals | 11 |
| 1.2.5 Vibrational signatures | 12 |
| 1.2.6 Vibration sensors | 13 |
| 1.2.6.1 The piezoelectric sensing accelerometer | 13 |
| 1.2.6.2 Sensor Location Selection | 14 |
| 1.3 Principle of vibration analysis | 14 |
| 1.3. 1 Vibration signatures | 14 |
| 1.3.1 .1 Harmonic Analysis | 14 |
| 1.3.1. 2. Spectrum analyzers | 15 |
| 1.3.1.3 Measurement of the overall level | 15 |
| 1.3.1.4 Spectral analysis | 15 |
| 1.4 Areas of application of vibration analysis | 16 |
| 1.5 The main flaws. | 17 |

| | |
|---|---|
| 5.1Gear defects | 17 |
| 5.2 Bearing defects | 18 |
| 5. 3. Tree defects | 19 |
| Chapter II: Infrared thermography analysis | |
| 2.1 Introduction | 26 |
| 2.2 Infrared thermography analysis | 26 |
| 2.3 Areas of application | 27 |
| 2.4 Principle of thermographic analysis | 28 |
| 2.5. Temperature and heat | 29 |
| 2.6 Infrared radiation | 30 |
| 2.6.1 Laws of infrared radiation | 30 |
| 2.6.1.1The electromagnetic spectrum | 31 |
| 2.6.1.2 Planck's Law | 31 |
| 2.6.1.3 principle of radiant heating | 33 |
| 2.6.1.4 Incident Radiation | 33 |
| 2.7 Means of measurement | 35 |
| 2.8 Structure of an imager | 36 |
| 2.8.1 Fixed thermal imager | 36 |
| 2.8.2 Thermal image analysis techniques | 36 |
| 2.8.2.1 Thermal framing | 36 |
| 2.8.2.2 Isothermal | 37 |
| 2.8.2.3 Color palettes | 37 |
| 2.9 Methodology, Approach, Creation of a signature | 38 |
| 2.9.1 Methodology | 38 |
| 2.9.1 Creation of a signature | 39 |

## Chapter III : Non-destructive testing


| | |
|---|---|
| 3.1 Introduction | 40 |
| 3.2 Non-destructive testing methods. | 40 |
| 3.2.1 Penetrant testing | 40 |
| 3.2. 2 Magnetic particle testing | 42 |
| 3.2.3 Radiography | 42 |
| 3.3 Foucault current | 44 |
| 3.4 Areas of Application | 45 |
| 3.4 .1Tube, bar and wire inspection | 45 |
| 3.4 .2 Surface control plan | 45 |


## Chapter IV : Ultrasonic acoustic analysis


| | |
|---|---|
| 4.1. Introduction | 47 |
| 4.2 Theory of sound and ultrasound. | 47 |
| 4.2.1 The sound | 48 |
| 4.3 Presentation to ultrasonic detection | 49 |
| 4.3.1 Ultrasound | 49 |
| 4.3.1 .1 Physical characteristics of ultrasound | 50 |
| 4.3.1 .2 Equipment used | 50 |
| 4.4 Ultrasonic inspection integrated into a conditional maintenance program. | 51 |
| 4.4.1 internal defects | 51 |
| 4.4.2 Tightening control | 51 |

| Chapter V : Oil analysis | |
|---|---|
| 5.1 Introduction | 52 |
| 5.2 Types of oil analysis. | 52 |
| 5.3 Main means of oil analysis | 53 |
| 5.3.1 By Centrifugation | 54 |
| 5.3.2 By Filtration | 54 |
| 5.3.3 By Ferrography | 54 |
| 5.3.4 By Spectrometry | 55 |
| 5.3.5 By Flash point measurement | 55 |
| 5.3.6 By Counting. | 56 |
| Bibliographic references | |


# General Introduction

*This manuscript is intended for second-year Master's students (LMD system) specializing in Industrial Maintenance, as well as anyone interested in the field of failure diagnostics and detection techniques. It conforms to the official program.*

*The main objective of this course material is to present fundamental concepts of diagnostics and facilitate students' learning of the various methods for detecting failures in industrial equipment and its component parts, after outlining the different types of defects related to mechanical systems.*

*This course covers the most commonly used failure detection techniques in industry, namely vibration analysis, infrared thermography analysis, non-destructive testing, ultrasonic acoustic analysis, and oil analysis.*

*All machines, especially rotating machines, vibrate, and the vibration pattern changes as soon as wear, fatigue, aging, misalignment, imbalance, etc., appear. Vibration analysis remains the most effective method for detecting most of these mechanical defects.*

*Thermography is one of the techniques used to monitor the condition of industrial systems. It measures the intensity of infrared radiation emissions using an infrared camera, in order to determine the operating conditions of the equipment.*

*The purpose of non-destructive testing is to detect material defects, manufacturing defects and defects due to fatigue, cracking in general, which are not visually detectable and which cause equipment breakage.*

*The oil analysis fault detection technique allows for the detection of any anomaly or characteristic change resulting from a problem. The study of degradation and contamination phenomena is carried out using laboratory analysis methods or rapid control methods applied directly at industrial sites.*

# Chapter I: Vibration Analysis, Areas of Application, Principle of Vibration Analysis, Main Faults.

## 1.1 Introduction

Understanding the failure mechanisms that are likely to appear on the constituent elements of a piece of equipment is a crucial step because it is useful to distinguish the most frequent failure mechanisms in our workshops (wear, fatigue, corrosion, aging, etc.) in order to be able to apply the most appropriate failure detection techniques.

## 1.2 Vibration analysis

One of the most important questions here is how and where do malfunctions, breakdowns, or failures in an installation originate? Vibration signature analysis is the most well-known diagnostic method that answers this question.

**1.2.1 Definition of a vibration:** A mechanical system is said to be vibrating when it undergoes a back-and-forth motion around an average position, called the equilibrium position.

If we observe the motion of a mass suspended from a spring, we see that it is characterized by:

- Displacement: the position of the mass varies on either side of the equilibrium point;
- Velocity: the change in displacement with respect to time;

- Acceleration: the change in velocity with respect to time.

The vibration of a machine subjected to a periodic force can be described in terms of displacement, velocity, or acceleration. The velocity of the vibratory motion corresponds to the change in its displacement per unit of time. Acceleration represents the change in velocity per unit of time. A vibration is primarily characterized by its frequency, amplitude, and nature. **[1]**

**a. Frequency**

Frequency is the number of times a phenomenon repeats itself in a given time. When the unit of time chosen is the second, frequency is expressed in hertz (Hz).

1 hertz = 1 cycle/second. A vibration that occurs 20 times per second will therefore have a frequency f of 20 hertz.

**b. Amplitude**

**c. Nature of a vibration**: any rotating machine in operation generates vibrations that will be described in the following section.

**1.2.2**. **Description of a vibration signal**: Generally, a vibration is characterized mainly by its frequency, its amplitude, and its nature, figure 1

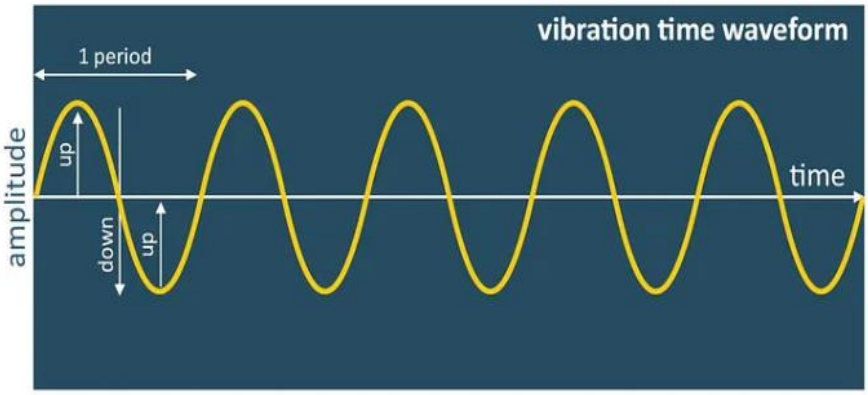
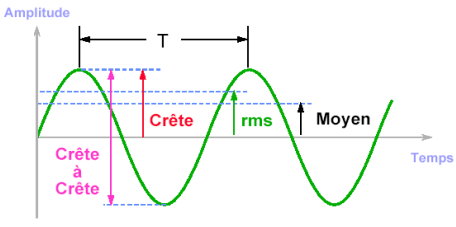
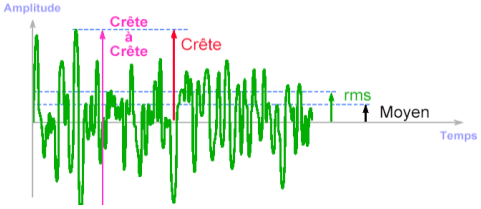



Figure1. Vibration time waveform **[2]**



a-periodic signal b- temporal signal

Figure 2: Description of the vibration signal **[3]**

The maximum value Xc (peak): this is the highest value reached, which does not take into account the evolution of the vibration over time. It is rarely used;

- The peak-to-peak value Xcc (peak-to-peak): this is the difference between the highest and lowest values of the signal;

- The absolute average value Xmoy: this is the average of the rectified signal over one period; it is rarely used because it is not directly related to a physical quantity.

$$X \text{ moyenne} = 1/T \int x(t)dt \qquad (1\text{-}1)$$

- The RMS (Root Mean Square) value: this represents the energy contained in a signal. It is expressed in physical units (m/s², m/s, m, or g for vibrations, for example). It is very well suited for deterministic components of the spectrum (pure lines). The RMS value is determined by the following formula:

$$(\mathrm{RMS}) = \sqrt{1/T \int_0^T x^2 \, dt} \qquad (1\text{-}2)$$

The crest factor: this factor is defined by the following relationship:

$$F_c = X_c / \mathrm{RMS} \qquad (1\text{-}3)$$

It is a dimensionless indicator. It should be noted that the amplitude tells us about the importance of the monitored fault, while the frequency tells us about its origin.

The following figure shows the different amplitudes.

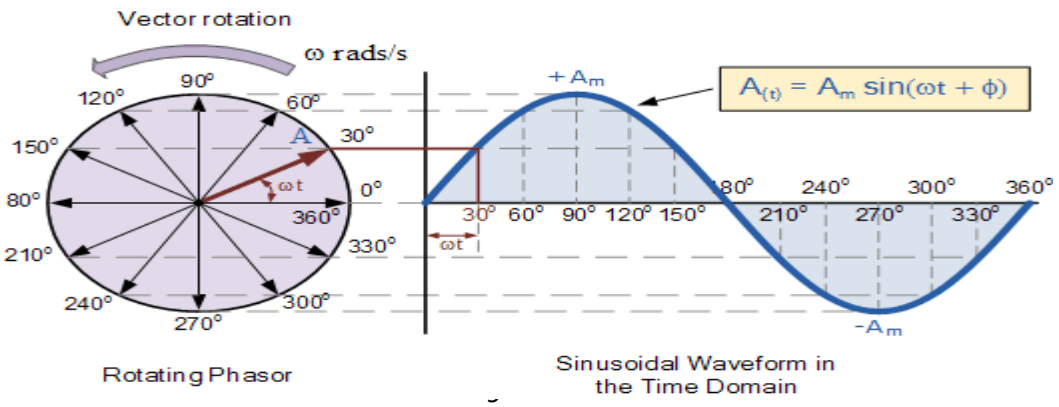


Figure 3. Different amplitudes (sinusoidal vibration) **[4]**

### 1.2.3 Monitoring and detection

Turbines, pumps, motors, compressors, alternators, centrifuges, fans… all these machines, which we call rotating machines, have one thing in common: they contain rotating parts. Depending on the case, these can be relatively simple structures, consisting of a single shaft rotating through one or more bearings, or more complex machines composed of several shafts rotating at different speeds. But what characterizes these machines above all is that they are composed of fragile components (bearings and gears, in particular) subjected to significant mechanical stresses and harsh industrial environments. The sources of failure are therefore numerous: chipping of a bearing, breakage of a gear tooth, misalignment of one of the shafts, etc. When a machine plays a vital role in production (for example, a printing press, a cement plant crusher, or a centrifuge in a chemical reactor), these defects can have serious consequences. To avoid unexpected production stoppages and losses Given the resulting economic consequences, these facilities must be constantly monitored and all early warning signs of defects tracked before it is too late **[5].**

**Table 1: Preferred usage of vibration transducer.**

| Vibration transducer | Preferred usage |
|---|---|
| Velocity pickup | General purpose monitoring |
| Accelerometer | Machines with rolling element bearings or gear sets that generate high vibration frequencies when defective |
| Displacement probe | Rotating machinery with journal bearing, high speed turbomachinery |
| | |

### 1.2.4 The signals

This very general term refers to any quantity that can affect a structure, modifying its equilibrium or behavior: force, tension, acceleration, velocity, acoustic pressure, etc. Mechanical vibrations are movements oscillating around an average equilibrium position. These oscillatory movements, characteristic of the force that generates them, can be either periodic or aperiodic (transient or random), depending on whether they repeat themselves identically after a determined duration.

Motion can be divided in to harmonic motion and nonharmonic motion. Harmonic motions repeat themselves every complete cycle. On the other hand, nonharmonic motions represent superposition of motions from numerous sources with different frequencies. Given X1 and X2 are two vibration displacements with different frequencies:

$$X1 = a\sin(\omega 1t) \qquad (1\text{-}4)$$

$$X2 = b\sin(\omega 2t) \qquad (1\text{-}5)$$

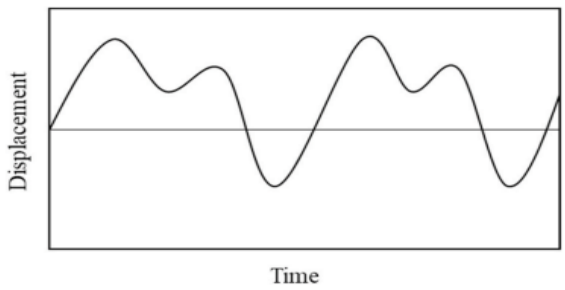
where a and b are maximum displacements or amplitudes, ω1 and ω2 are circular frequencies and it is time. The total vibration, which is the sum of the two vibrations above is as follows:

$$X = X1 + X2 = a\sin(\omega 1t) + b\sin(\omega 2t) \qquad (1\text{-}6)$$

Any vibration can be shown as a series of sine functions with the circular frequencies (i.e., ω1, ω2) are referred to as the harmonics of the primary frequency ω. The equation is also known as a Fourier Series. A1, A2, etc. are the amplitudes if the various discrete vibrations and Φ1, Φ2, etc. are their corresponding phase angles. The terms 2ω, 3ω etc. reflect the harmonics of the primary frequency ω.

$$f(t) = A0 + A1\sin(\omega t + \Phi 1) + A2\sin(2\omega t + \Phi 2) + A3\sin(3\omega t + \Phi 3) + \ldots \qquad (1\text{-}7)$$

A vibration profile can be displayed in time domain and frequency domain. A time domain profile (or waveform) shows amplitude versus time (Fig. 3). The sum of vibration signal is used to represent total displacement at any given time. Hence it is hard to identify a particular source of vibration. However, time domain data are still useful in overall analysis. A frequency domain profile (or spectrum), on the other hand, shows amplitude versus frequency (Fig. 4). It is obtained by converting a time-domain profile using Fast Fourier Transform (FFT) algorithm. FFT allows vibration signals to be shown as discrete frequency peaks. Identifying these frequency peaks is very crucial in VA. FFT is the most common processing technique. Some steps in processing signals using FFT algorithm are analog signal input, antialias filter, analog to digital converter, windows, FFT and averaging. Sampling is generated based on recorded vibration signature at given instants. The rule is to sample at a frequency rate of at least twice the highest frequency component of interest to avoid losing any information in a sampled signal **[6].**




1

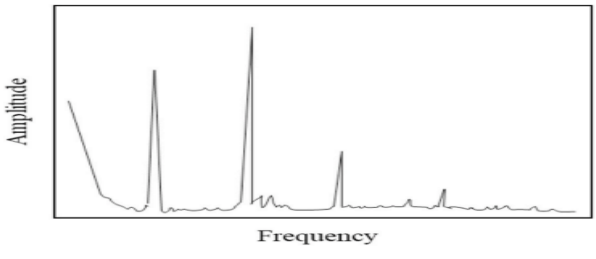


Figure. 4. An example of time domain

Figure 5. An example of frequency domain

Machine's dynamic tends to generate unbalanced forces in one or more directions causing vibrations (whether normal or abnormal behaviors). Hence, vibrations should be measured in radial and axial orientations for accurate determining causes of vibration in a machine **[6].**

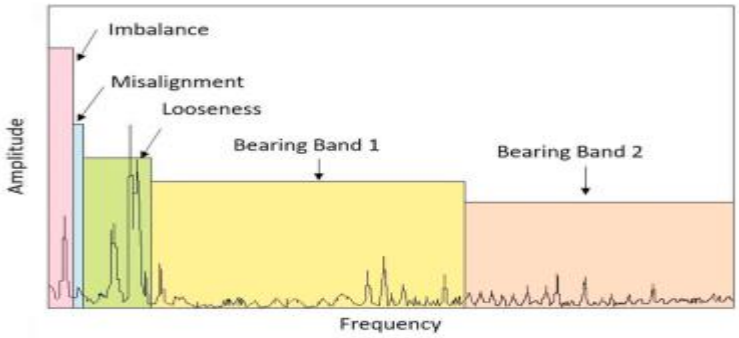
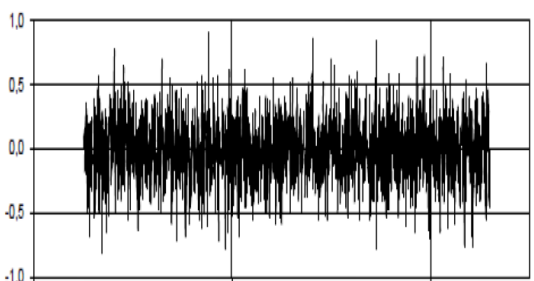



Figure. 6. An example of frequency bands in spectrum **[6].**

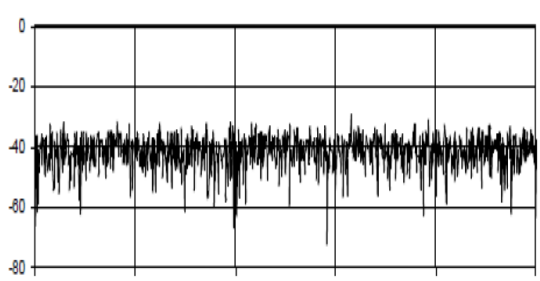
### 1.2.4.1Transient and random signals

An aperiodic vibration is a vibration whose temporal behavior is arbitrary. In such a situation, reproducibility over time is never observed Figure 07.

This is the case with shocks recorded, for example, on a crusher. A transient signal occurs during a limited time interval. Random signals have amplitude and frequency characteristics that change randomly over time. These characteristic vibrations are therefore all identifiable and measurable. The tendency for their intensity to increase is representative of the evolution of the force that generates them and reveals the developing defect. Among all stochastic processes, the Gaussian random process is particularly used in the study of vibrational behavior **[7].**





7

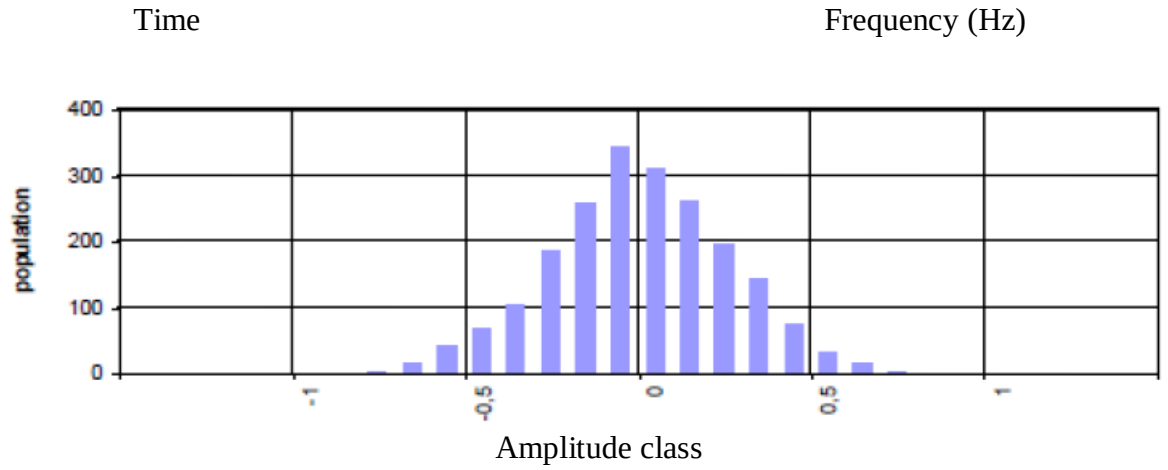



Figure 8. Chronogram, spectrum, and histogram of a random signal from a Gaussian process **[8].**

### 1.2.5 Vibrational signatures

Vibration signatures are suitable for detecting anomalies affecting mechanical assemblies whose structural elements are subjected to dynamic mechanical stresses resulting in mechanical vibrations. Vibration analysis detects repetitive movements of a surface belonging to dynamic mechanical equipment (rotating machines, reciprocating machines, etc.) or static equipment (structures, piping, etc.)

Essentially, movements characterized by vibrations are appreciated by amplitudes and frequencies, which is why the interpretation of vibrational signals relies on time analysis and frequency analysis, most often using the Fourier transform.

Industrial signal processing always results in spectra represented by continuous curves containing numerous peaks. The presence of peaks indicates that the signal contains periodic components.

$$f(x) = a_0 + \sum_{K=1}^{\infty} \left( a_k \cos \frac{2\pi kt}{T} + b_k \sin \frac{2\pi kt}{T} \right) \quad (1\text{-}8)$$

The set of values for the coefficients ak and bk forms the frequency spectrum of the function f(t). A simpler formalism is possible using imaginary exponential functions, namely:

$$f(t) = \sum_{k=-\infty}^{+\infty} c_k \exp\left(2i\frac{\pi kt}{T}\right) \quad (1\text{-}9)$$

$$c_k = 1/\mathrm{T}\int_0^{\mathrm{T}} \mathrm{f(t)}\exp\left(-2i\frac{\pi kt}{T}\right)\mathrm{dt} \quad (1\text{-}10)$$

## 1.2.6 Vibration sensors

The first element in the measurement chain is the vibration sensor. In industry, the most commonly used type is the accelerometer, or piezoelectric sensor. Generally, the operating principle of accelerometers is to produce an electrical signal related to the level of vibration **[9].** The choice of how to use the accelerometer plays a crucial role in measurement.

### 1.2.6.1 The piezoelectric sensing accelerometer

A body exhibiting a potential across its terminals when subjected to a force is called a piezoelectric body. The materials used are often zinc (ZnO) or piezoelectric lead zirconate titanate (PZT). To generate negative feedback on the structure, the inverse property of piezoelectricity is used.

For this type of accelerometer, a single piezoelectric element can be used (in this case, time is sampled and divided between actuation and measurement), or two piezoelectric elements (here, the two elements form a sandwich, one used for actuation and the other for measurement). The advantage of this detection method is zero-power transduction (since stress variations generate a potential) **[9].**

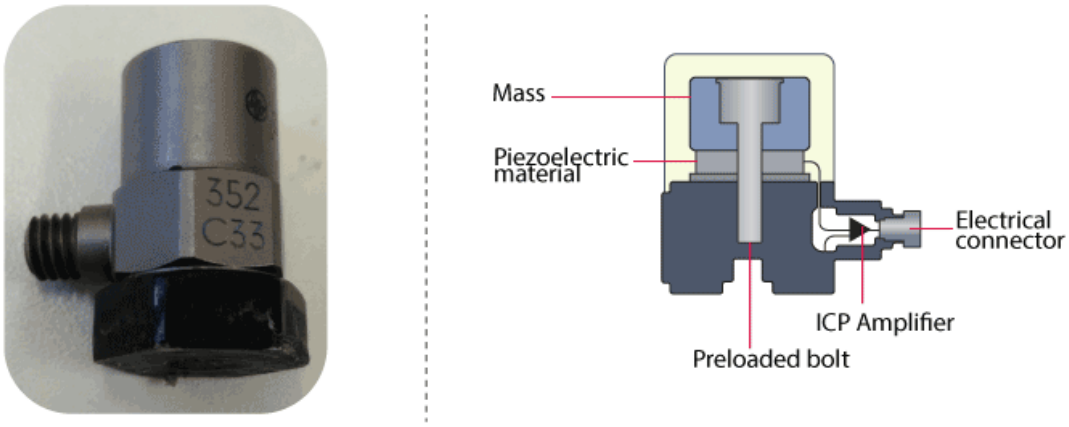



Figure 9: Example of a piezoelectric accelerometer

#### 1.2.6.2 Sensor Location Selection

**Sensor Mounting**

• Sensors must be directly connected to the bearings, minimizing the number of parts ensuring the interface between the moving element and the sensor.

• The measurement points must be clean (no traces of grease or paint), and the contact surfaces with the sensors must be smooth, flat, and vertical in the direction of measurement.

• Measurement is taken by a sensor at a judiciously chosen point stiffness function when the bearing is difficult to access directly.

Measurements are always taken at the same location on the machine. Measurement points are marked either by paint or by stud locations **[1].**

## 1.3 Principle of vibration analysis

### 1.3. 1 Vibration signatures

Vibration signatures are suitable for detecting anomalies affecting mechanical assemblies whose structural elements are subjected to dynamic mechanical stresses resulting in mechanical vibrations.

#### 1.3.1 .1 Harmonic Analysis

Harmonic analysis, Fourier Series: Physically, signals are recorded as the variation of a parameter (force, stress, amplitude, acceleration, tension, pressure, etc.) over time. However,

it is often easier to characterize a signal in the frequency domain. This representation is obtained using Fourier's theorem, which demonstrates that any periodic function f(t) with period T can be represented by the sum of a series of sinusoidal functions with periods T, T/2, ..., T/k… called a Fourier series, which can be written as an expansion:

$$f(x) = a_0 + \sum_{K=1}^{\infty} \left( a_k \cos \frac{2\pi kt}{T} + b_k \sin \frac{2\pi kt}{T} \right) \quad (1\text{-}11)$$

### 1.3.1. 2. Spectrum analyzers:

FFT analyzers employ a hardwired FFT algorithm that can only operate with a fixed number of words (sometimes variable in a few steps). This number of words is a power of 2 for Coley-Tukey algorithms and those derived from them, or a product of integer powers of prime numbers (Vinograd algorithms).

Vibration analysis allows us to understand the various stresses caused by any potential defect affecting the machine. It enables us to gather all the information necessary to make an accurate diagnosis of its mechanical condition. A vibrational wave can be studied using several methods that correspond to different levels of knowledge of the phenomenon and the use of more or less sophisticated analytical equipment, namely:

- Simple indicators: overall level, crest factor, defect factor, kurtosis, etc.;

- Qualitative analysis methods: temporal analysis, frequency analysis, envelope analysis, and cepstral analysis **[3].**

**1.3.1.3 Measurement of the overall level**: The amplitude of a vibration, which is the parameter describing the importance of the vibration, can be evaluated in different ways. Figure 2-a shows the relationships between the peak-to-peak value, the peak value, and the average and RMS values for a pure vibration.

The effective value is determined by the following formula:

$$Vrms = \sqrt{\frac{1}{T}} \int_0^T x^2 t dt \quad (1\text{-}12)$$

The average absolute value is determined by: (1-13)

$$Vm = \frac{1}{T}\int_0^T x\,dt$$

**1.3.1.4 Spectral analysis:** Any anomaly affecting a rotating machine result in vibrations whose frequencies correspond to the frequencies at which the forces inducing them appear and their harmonics. Therefore, for diagnostic purposes, it is useful to decompose the measured vibration signal into its elementary sinusoids, whose amplitudes and frequencies can be read.

Spectral analysis aims to identify the frequency and amplitude of these sinusoids and is performed by a Fourier transform of the time-domain signal. The result is a spectrum in the form of a graph showing the amplitude at each frequency, called a spectrogram.

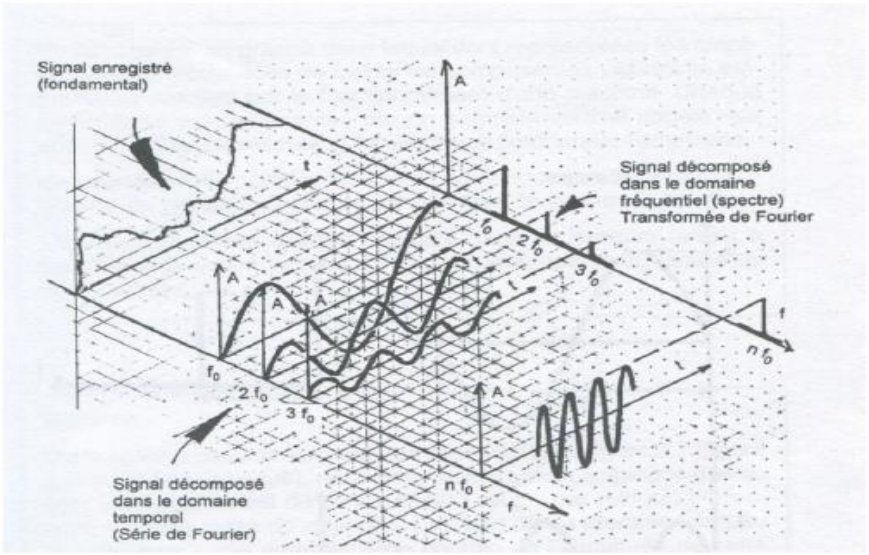



Figure 10: Obtaining the spectrum from the time-domain signal **[8].**

## 1.4 Areas of application of vibration analysis

A predictive maintenance uses data analysis tools and techniques to detect possible failures in advance. Among various predictive maintenance methods, vibration monitoring is the most powerful tool **[10].** Vibration data reflect conditions of mechanical equipment. Analyzing them helps detect abnormal operating conditions and early faults that can gradually become severe and affect performance of a machine. Maintenance plans could be made in advance to reduce downtime when the machine is shut down for maintenance or replacement. Vibration is a

movement relative to a reference position caused by a force. It can be random or periodic. Machines produce some oscillatory motion during their normal operation. These are benign vibrations (e.g., blade passing frequency, gear mesh frequencies, broadband turbulence from fluid-handling machines). The amplitudes of the vibrations vary from machine to machine and depend on load condition. If the amplitudes are above normal levels, these vibrations will cause accelerated wear or premature failure and should be taken care of. In addition, each mechanical fault generates a specific vibration pattern depending on the geometry of the machine and operating condition. Hence, VA plays an important role in monitoring machine health, identifying failing elements and predicting **[06].**

## 1.5 The main flaws.

### 5.1Gear defects

Two main categories of defects that can affect gear backlash are distinguished: generalized

**A Widespread defects**

**- Abrasive wear:** A phenomenon present on a large portion of the gear teeth, characterized by material removal due to the sliding of the two contacting surfaces. The development of this wear is linked to the mechanical load to be transmitted and the sliding speed, as well as the presence of abrasive elements in the lubricant **[11].**

**- Pitting refers** to holes of varying depths that affect all the teeth. It occurs primarily on gears made of relatively hard construction steel. This damage can appear as a result of slight shaft misalignments, for example, due to localized overpressure.



Figure 11. Abrasive wear **[12].**

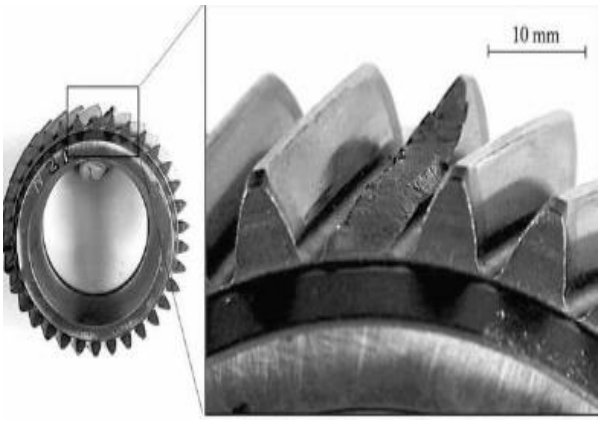



Figure 12. Effect of wear on a gear**[13]**

**-Localized defects**

**Spalling** manifests as fewer holes than pitting, but deeper and more extensive. The damage is caused by fatigue in the sub-layer, at the point of maximum shear. This phenomenon, most often encountered in case-hardened gears, progresses very rapidly towards failure, without going through a wear phase.

**Cracking:** Generally occurring at the root of the tooth, it progresses with each load application. Its appearance is due to exceeding the elastic limit under stress at the root of the tooth, on the side of the tooth under tension **[12].**

- **Seizing:** A direct consequence of a sudden breakdown of the oil film, or of friction under load causing temperature increases. Seizing is favored primarily by high speeds, large modules, and a low number of teeth in contact.

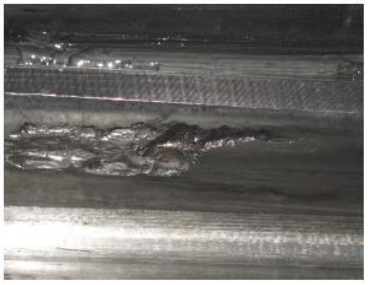


**Figure 13. Spalling**

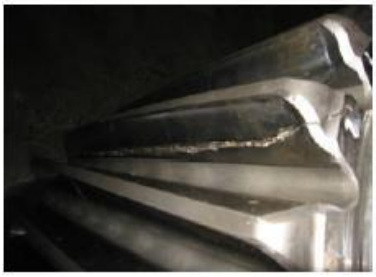


**Figure 14. Cracking**



**Figure15. Seizing**

In general, the vibration signal of a gear tooth misalignment can be represented as shown in Figure 16. Gear systems generate a vibration signal at the fundamental frequency of gear tooth meshing, which is generally different for each gear pair **[14].**

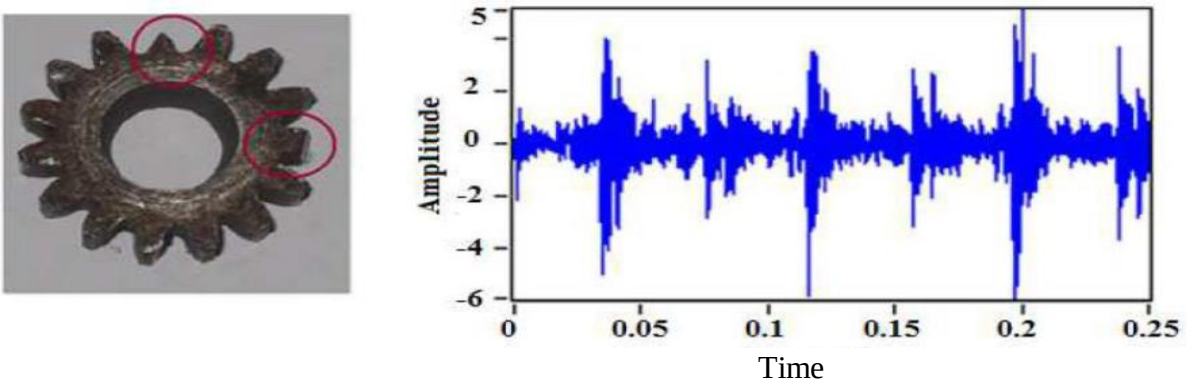



Figure 16: Gear tooth breakage and its vibration signal **[15].**

### 5.2 Bearing defects

A bearing consists of two concentric rings, an outer ring and an inner ring, one fixed and the other rotating with the rotor. These are separated by a set of rolling elements such as balls, rollers, or needles. The bearing's lifespan is limited by surface fatigue of the materials due to stresses created by the repetitive movement of the balls on the raceways, resulting in the appearance of micro-cracks.

Several failures can affect bearings. We describe below the most frequent types of deterioration:

**-Seizing:** In mechanics, seizing is a deterioration occurring between two surfaces rubbing against each other, when metal particles detach from one surface and scratch the other to varying degrees, causing heat buildup.

- **Spalling:** This is damage characterized by the detachment of material and the appearance of cracks.

- **Generalized wear:** Appearing on rolling elements, tracks, and cages (grayish tint), due to the intrusion of an abrasive particle.

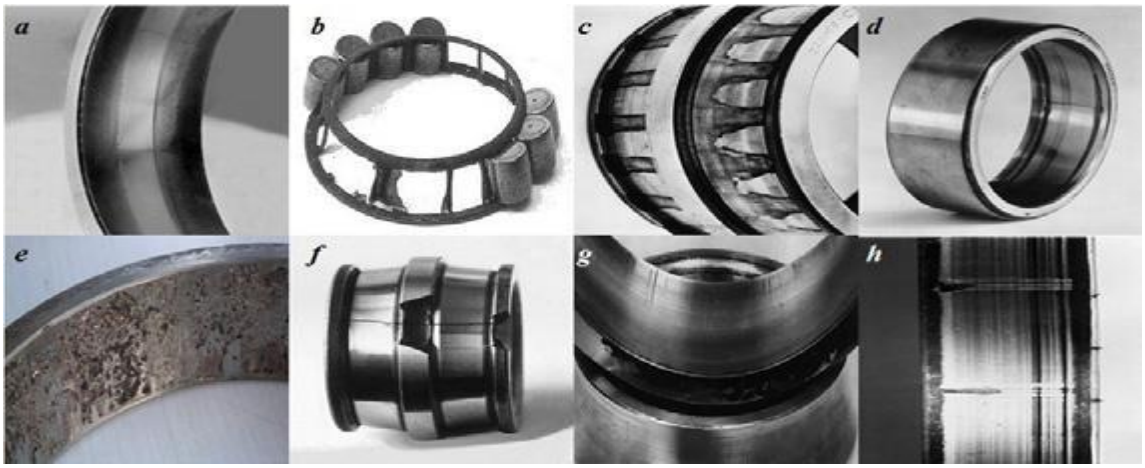



Figure 17 – Some failures affecting bearings: a- General wear b- Deteriorated cage c- Corrosion d- Presence of craters e- Spalling f- Cracks and breaks g- Seizures h- Footprints **[15]**

### 5. 3. Tree defects

**Unbalance Defect**: Unbalance is a defect that occurs when the shaft of a rotating machine is unbalanced. This phenomenon occurs at rotational speed and is caused by an improper spatial distribution of mass within the structure, resulting in a displacement of the center of gravity outside the geometric axis of the rotating machine's rotor **[16].**

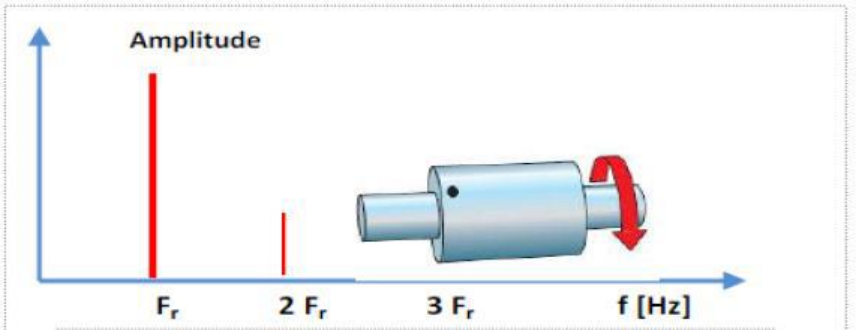



Figure 18: Unbalance defect **[17].**

Misalignment defect: A misalignment defect can be (Figure 19), a defect of concentricity: The shaft axes exhibit misalignment at the coupling.

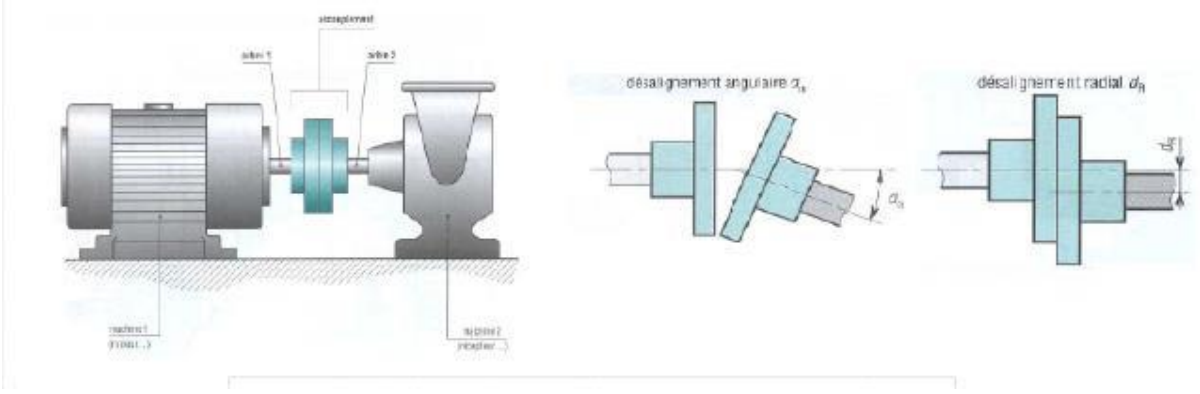



Figure 19: Misalignment defect **[17].**

## TD series

## Exercise1:

The guide bearing in Figure 1 is tested by the IQO/Water 4 inspection method to detect manufacturing defects. It is placed on a vibration test bench, and four sensors are positioned on the bearing to record the signals.

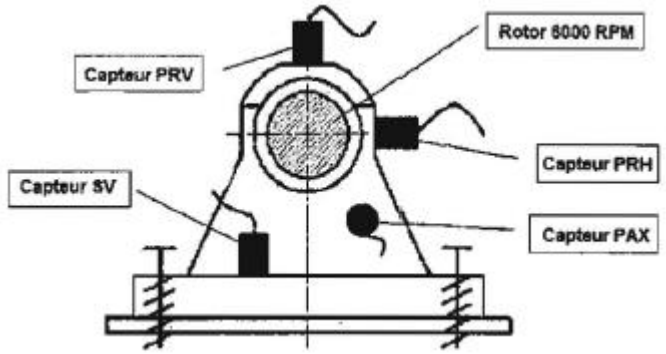
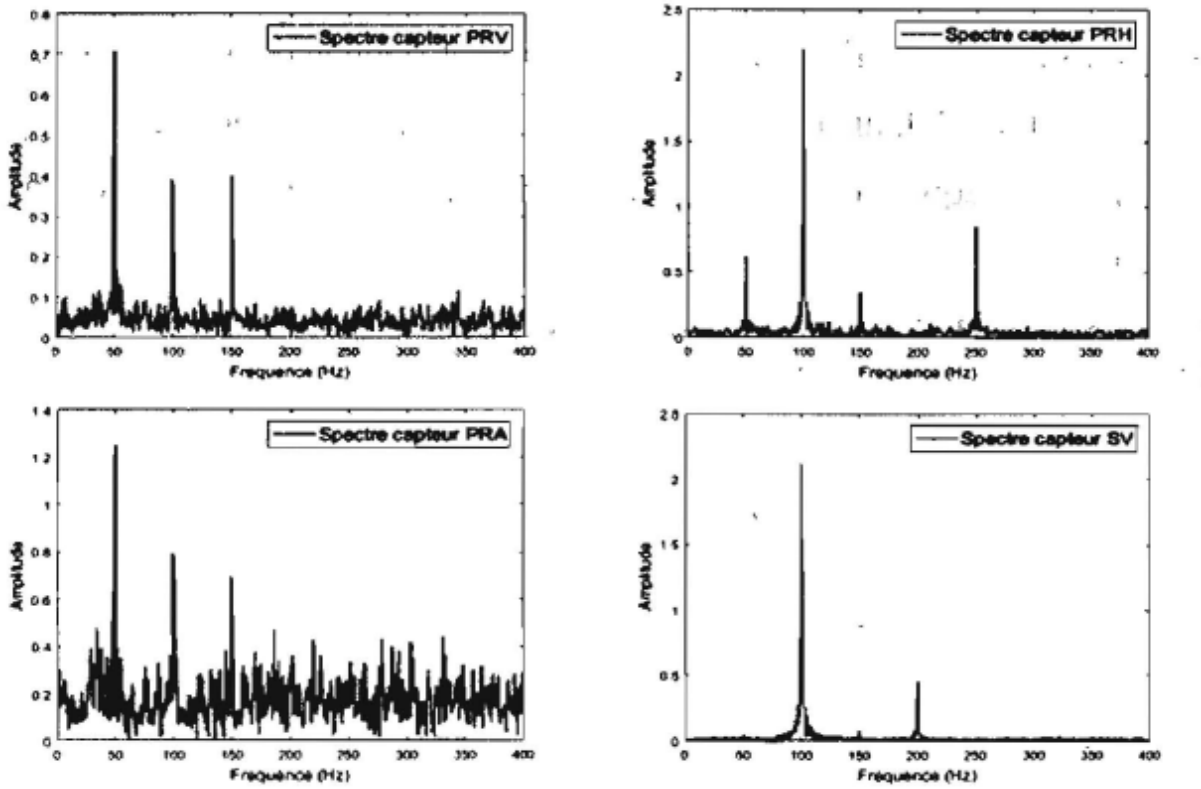



Figure 1. Guide bearing

1. What are the likely faults in this system?

2. Analyze and determine the type of faults based on the spectral signatures of the faults recorded by each sensor.



**Solution**

**1-**

• Unbalance: (Static unbalance, Torque unbalance, and Dynamic unbalance)

• Misalignment (Parallel, Angular, and Mixed)

• Bearings (Inner ring, Outer ring, Rolling element, and Cage)

• Hydrodynamic plain bearings, mounting defects, play, wear...

• Phenomena specific to turbomachinery

• Periodic shocks

2- According to Figure 1, we can see that the shaft rotates at a speed of 6000 rpm. Therefore, we can say that the fundamental frequency is equal to: f = N/60 = 100Rz.

PRV Sensor Spectrum:

This spectrum indicates an oil fault (oil leak). This fault is characterized by a frequency of approximately 50 Hz (0.50 x Fr).

PRH Sensor Spectrum:

This spectrum indicates an unbalance fault. This fault is characterized by a frequency of approximately 100 Hz (1 x Fr).

PRA Sensor Spectrum: This spectrum indicates an oil fault (oil leak). This fault is characterized by a frequency of approximately 50 Hz (0.50 x Fr).

SV Sensor Spectrum: This spectrum indicates an unbalance fault. This fault is characterized by a frequency of approximately 100 Hz (1 x Fr).

## Exercise 2:

An exhaust fan is belt-driven by a motor with a power rating of P = 37 kW and a rotational speed of N = 1420 RPM (Fig. 1). The pulley diameters are chosen so that the fan speed is N ~ 820 RPM.

This fan is inspected by vibration analysis; the overall measurement of the effective value of the speed in the frequency band [OHz-500~] is given in Fig. 2.

Part 1:

1. The sensor position is relevant for diagnosing a rotating machine. List the different sensor positions.

2. According to the criticality table according to ISO/DIS 10816-3, determine the alarm and danger thresholds, knowing that the fan and motor assembly is considered elastic.

3. How do you assess the effective vibration values on the motor side and the fan side (Figure 1)?

4. What are the possible causes of this vibration?

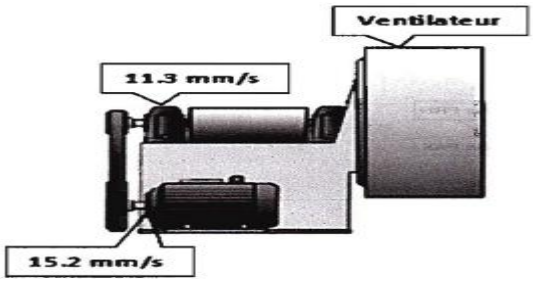
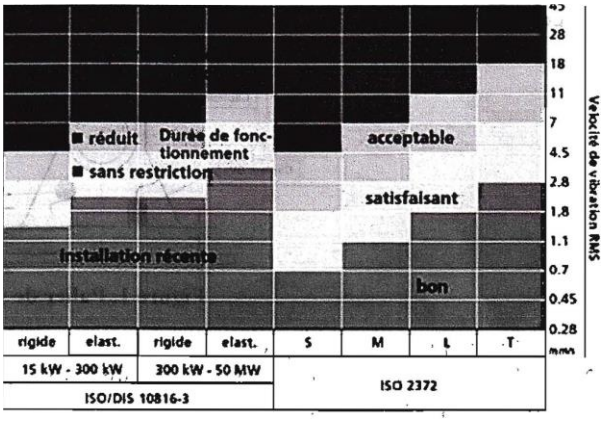



Figure 1.'Exhaust fan




Part 2:

The spectral analysis of the vibrations on the fan side is shown in Figure 2.

1) Briefly list the defects that can cause vibrations in this system.

2) What are the frequencies, angular frequency, and period associated with the fan's rotation?

3) What is the purpose of the reference spectrum?

4) What does the peak frequency of the spectrum (Figure 2) correspond to? Explain the phenomenon.

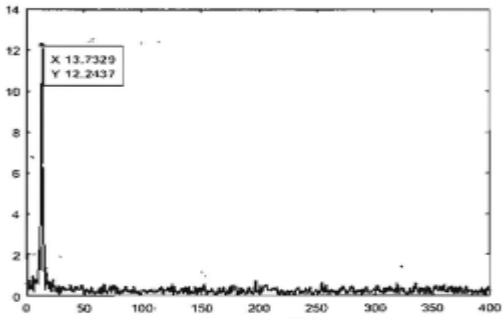



Figure 2. Vector-side spectrum

**Solution**

## Part I

- The sensor positions are:

1. Horizontal Radial

2. Vertical Radial

3. Oblique Radial

4. Axial

2- -

-The alarm threshold is: 4.5 mm/s

- The danger threshold is: 7 mm/s

3-Comparing the vibration values at the motor (15.2 mm/s) and at the fan (11.3 mm/s) with the ISO/DIS 10816-3 standard, we find that the values have exceeded the danger threshold (7 mm/s). Therefore, there is a malfunction.

- Misalignment (parallel, angular, and mixed)

-Courroie

- Bearing play

- Fastening defect

## Part II

1-

• Unbalance: (Static unbalance, Torque unbalance, and Dynamic unbalance)

• Misalignment (Parallel, Angular, and Mixed)

• Bearings (Inner ring, Outer ring, Rolling element, and Cage)

• Belts

• Periodic shocks

• Magnetic (electrical) phenomena

• Hydrodynamic plain bearings, mounting defects, play, wear...

• Phenomena specific to turbomachinery

2--Rotation frequency Fa = Fr = N/60; Fo = 820/60 = 13.6666 ~

-Pulsation (i) = 2.n.Fo; (i) = 2.3.14. 13.6666 = 85.87 rad/s' ~

-Period : T=l/Fo : T=1/313.6666 = 0.07

3-A reference spectrum can be established when the machine is new or after a new maintenance operation.

4-This spectrum exhibits an imbalance defect, characterized by a frequency of approximately 50 Hz, which is repeated in harmonics at 100 Hz, 200 Hz, ... (F=, IxFr, 2xFr).

The phenomenon of mechanical imbalance is linked to a non-homogeneous distribution of mass around the axis of rotation: the axis of inertia of the shaft is not aligned with the axis of rotation. Different types of imbalances can be identified: static imbalance, torque imbalance, and dynamic imbalance.

# Chapter II: Infrared thermography analysis

## 2.1 Introduction

Thermography is a technique used to monitor the condition of industrial structures and systems. It measures the intensity of infrared radiation (i.e., heat) emissions using an infrared camera to determine the operating conditions of the equipment. By detecting thermal anomalies—areas that are hotter or colder than they should be—an experienced inspector can locate and identify problems as soon as they arise. The applications of this technique are very broad and include:

• Detecting hot spots in electrical equipment (undersized conductors, loose connections, etc.) or mechanical equipment (bearing failure).

• Detecting thermal leaks in furnaces, pipes, etc.

**AFNOR definition:** "Thermography is the technique of obtaining, using appropriate equipment, a thermal image of a scene observed in the infrared spectral range."

Thermography means "writing with heat," just as photography means "writing with light." The resulting image is called a thermogram or thermal image.

## 2.2 Infrared thermography analysis

Depuis 1979, Analyse thermographique infrarouge (ITA) offre une vaste gamme de services de thermographie commerciale et industrielle aux petites, moyennes et grandes entreprises partout dans le monde. Cette technique utilise la technologie la plus avancée du secteur pour identifier rapidement et avec précision les problèmes d'entretien potentiels et existants.

This is one of the most widely used techniques for monitoring the condition of industrial structures and systems. It measures the intensity of infrared radiation (i.e., heat) emissions using an infrared camera to determine the operating conditions of the equipment. By detecting thermal anomalies—areas that are hotter or colder than they should be—an experienced inspector can locate and identify problems as soon as they arise. The applications of this technique are very broad and include:

• Detecting hot spots in electrical equipment (undersized conductors, loose terminals, etc.) or mechanical equipment (bearing failure).

• Detecting thermal leaks in furnaces, pipes, etc.

• Detecting faulty overhead and underground electrical connections.

• Detects moisture in flat roofs.

## 2.3 Areas of application

1- Using infrared thermography for predictive and preventive maintenance is essential in a wide range of mechanical systems and industrial applications. Below are some key thermography industrial applications:

**1-Electrical systems**

- Detects overheating circuits caused by excessive current flow.
- Identifies loose electrical connections in panels or wiring.
- Monitors overloaded circuits components.

**2-Mechanical equipment**

- Spots heat buildup in rotating equipment like bearings, motors, or belts.
- Helps in early detection of lubrication issues, as improper lubrication can cause excessive heat in mechanical parts.
- Identifies overheating of drive systems (such as gears or pulleys).

**3-Building inspections**

- Locates thermal leaks in walls, ceilings, and floors, highlighting areas where heat is escaping.
- Identifies HVAC inefficiencies, such as poorly performing heating or cooling systems.
- Detects moisture intrusion, which can be a sign of leaks or water damage.
- Monitors steam traps in heating systems or industrial processes, ensuring they are functioning properly and not wasting energy through steam leaks.

**4-Industrial process inspections**

- Monitors the wear of pipe coatings, identifying areas where protection may be compromised and at risk of corrosion or damage.
- Assesses tank levels by detecting temperature variations, which can indicate the level of contents.
- Identifies anomalies in industrial processes, such as heat patterns that could signal a need for maintenance or optimization.

Bien que ces applications de la thermographie infrarouge en maintenance prédictive soient parmi les plus courantes, cette technologie est adaptable à de nombreux autres domaines **[18].**

## 2.4 Principle of thermographic analysis

The process involves producing images from invisible thermal radiation. As a result, infrared thermography provides an instantaneous means of detecting problem areas, highlighting defects that more conventional methods cannot detect.

The infrared camera captures, through a transmitting medium, the radiation emitted by a thermal scene. The radiometric system converts the radiation power into digital or analog signals: these are translated into temperature by the computer and transformed into points of light on a screen. The resulting image is called a "thermogram".

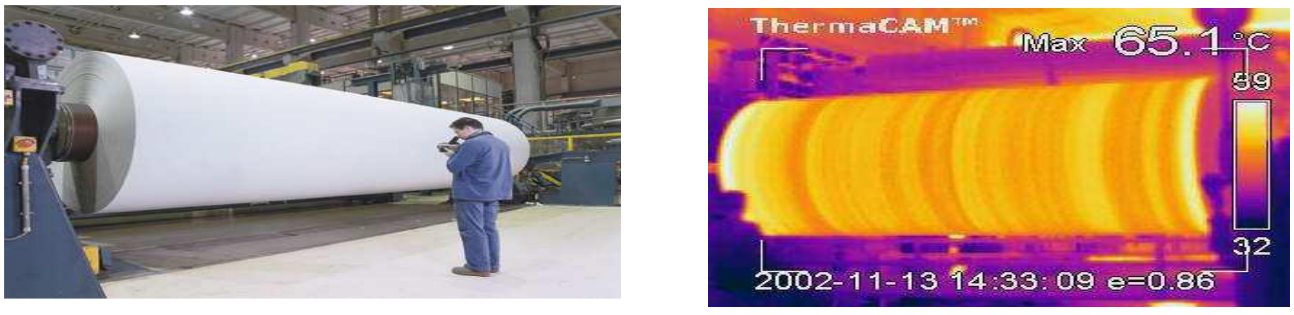



Figure 20. Visible image and corresponding thermogram of a roll **[19]**

Figure 21 shows a common example of a fault in an electrical cabinet. The infrared camera measures all emitted radiation and presents it as a thermogram.

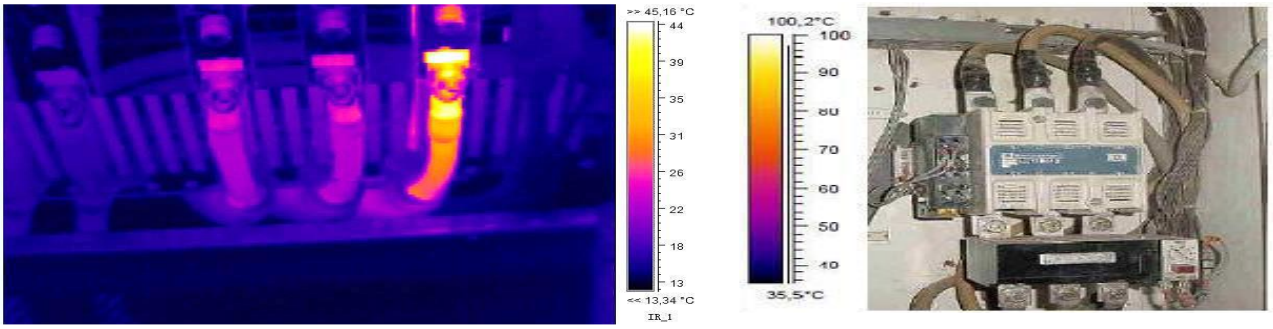



Figure 21: Example of electrical connection fault (poor tightening) **[19]**

This thermal image is composed of color levels, which are correlated with the measured temperature levels (temperature scale). In this case, by comparing the temperatures of the three connections, the thermogram indicates a loose connection on the right cable.

## 2.5. Temperature and heat

Real-world bodies exhibit highly diverse radiation properties. It has therefore proven useful to begin by examining the simplified laws of a model body with ideal radiation properties, in order to then apply them to real objects. This model body is known in radiation physics as a "black body." It is distinguished by the fact that, among all bodies of equal temperature, it emits the most radiation possible **[23]**

The spectral distribution of the radiation emitted by a black body is described by Planck's law of radiation, presented in the preceding paragraph.

The following figure shows that the spectral composition varies as a function of temperature of the object.

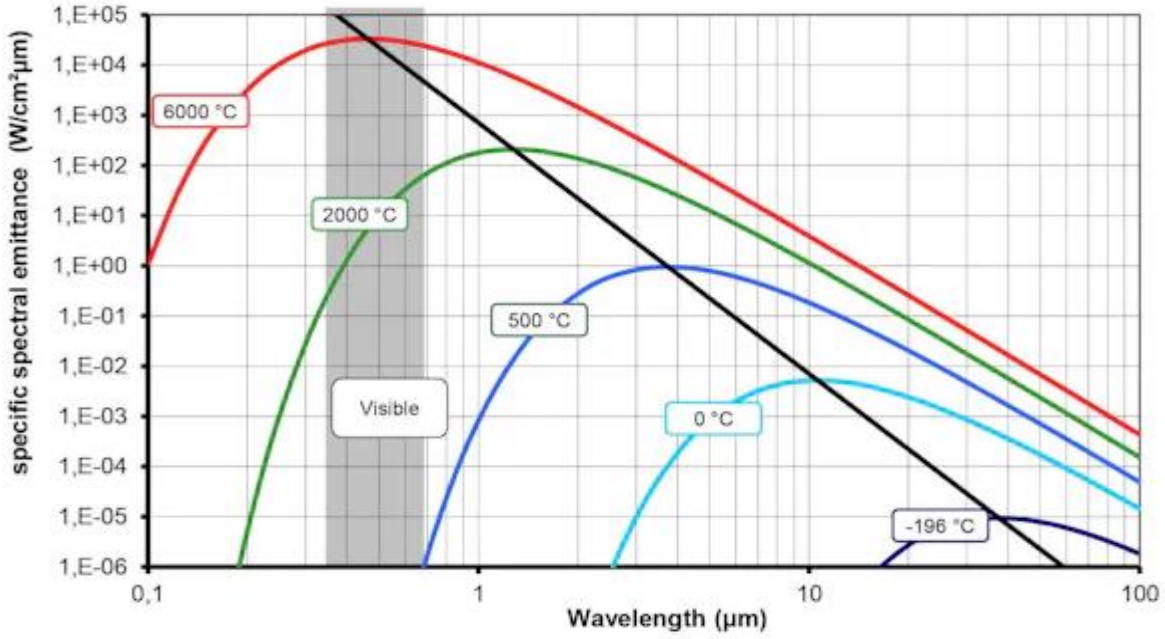



Figure 30. spectral composition varies depending on the temperature of the object **[23]**

This representation shows that the spectral composition varies depending on the object's temperature. Bodies with temperatures exceeding 500 °C, for example, also emit radiation in the visible range. Furthermore, it should be noted that at each wavelength, the intensity of the radiation increases with temperature.

## 2.6 Infrared radiation

### 2.6.1 Laws of infrared radiation

Infrared radiation was discovered around the year 1800, when the German-British astronomer and musician Herschel sought to measure the temperatures of different colored wavelengths of sunlight. He passed sunlight through a prism and held a thermometer to the various wavelengths. He observed that the highest temperature could be measured in an invisible range, beyond red light. This spectral range is now called the infrared range (infra = beyond), and we further divide it into near, mid, and far infrared.

### 2.6.1.1 The electromagnetic spectrum

Visible light, radio waves, TV, and X-rays are electromagnetic radiation. The visible spectrum extends from wavelengths of 0.4 to 0.8 μm.

The infrared band (Figures 22,23) extends from 0.8 to 1000 μm. In infrared thermography, we generally work in a spectral band extending from 2 to 15 μm, and more specifically in the 2–5 μm and 7–15 μm windows **[19]**

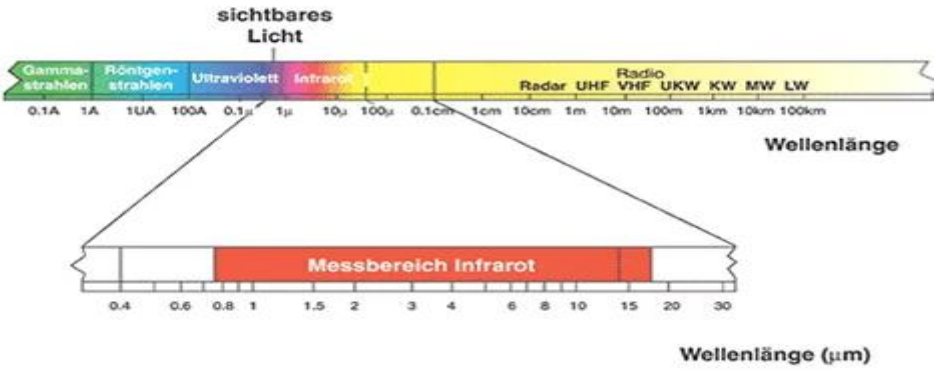



Figure 22. Electromagnetic spectrum **[20]**

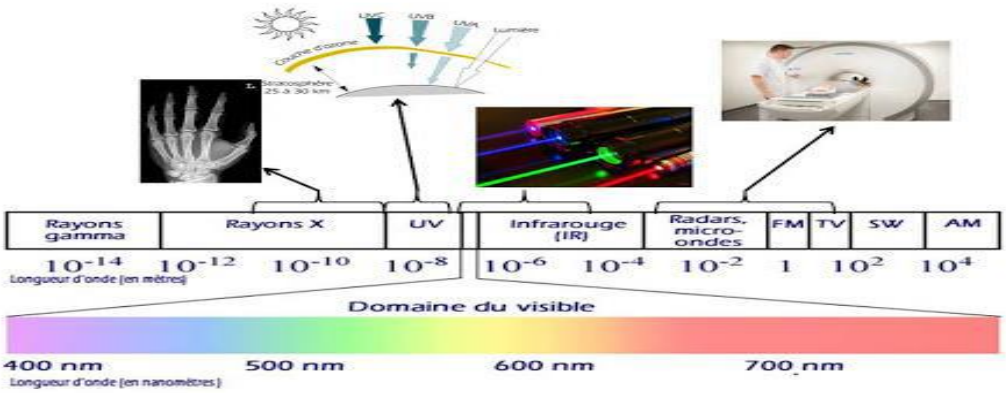



Figure 23: Electromagnetic radiation **[19]**

### 2.6.1.2 Planck's Law

Max Planck calculated the electromagnetic power fluxes emitted by a black body.

$$\omega_\lambda = \frac{2.\pi.\lambda.c^2}{\lambda^5\left(e^{h.c.\lambda.K.T}\right)-1}\ \left(\frac{watts}{cm^2\mu}\right)$$

With:

λ: Wavelength.

$\omega_{\lambda:}$ Power flux emitted by a black body at wavelength λ.

c: Speed of light = 3 x $10^{10}$ cm/s.

h: Planck constant = 6.6 x $10^{-34}$ W·$s^2$.

k: Boltzmann constant = 1.4 x $10^{-23}$ W·$s^2$/°K.

T: Absolute temperature of the black body in Kelvin.

These complex mathematical formulations are represented by curves (Figure 24).

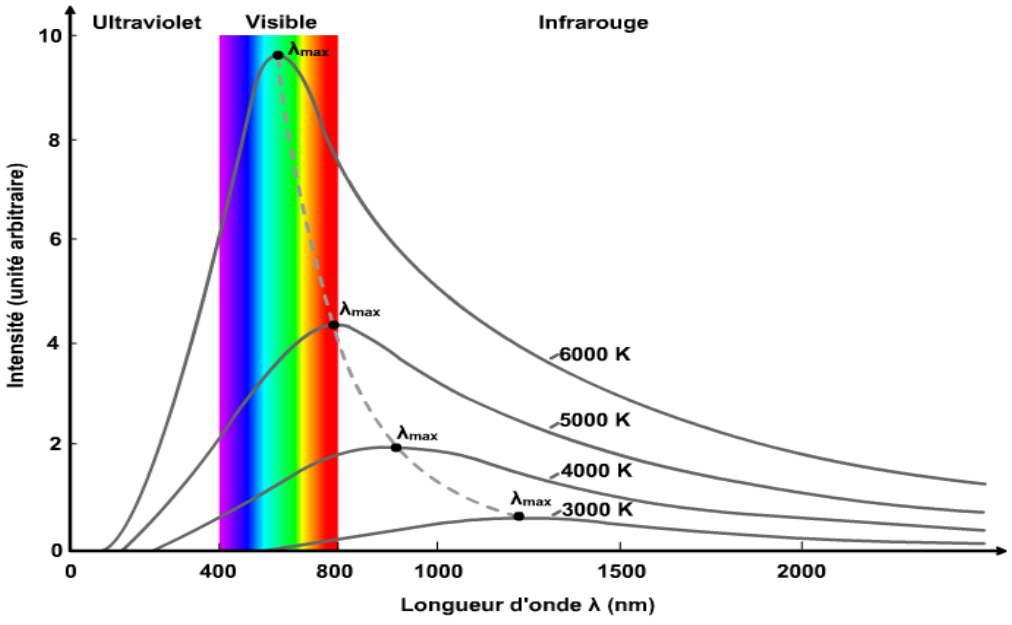



Figure 24. Blackbody radiation for different temperatures **[19]**

### 2.6.1.3 principle of radiant heating

When radiation strikes an object, it can be: transmitted, absorbed, or reflected.

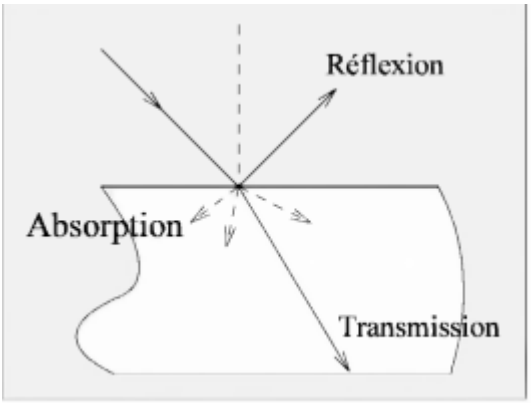



Figure 25. Reflection, transmission, and absorption of radiation **[21]**

### 2.6.1.4 Incident Radiation

Incident radiation refers to all external radiation striking an object. In Figure 3.15, incident radiation, denoted WINCID, is the radiation striking the target object from one or more sources. A portion of the radiation, denoted Wα, will always be absorbed, and the target object will retain that energy. A certain amount, denoted Wρ, will be reflected. This latter amount will not affect the target object. Finally, it is possible that a certain proportion of radiation, denoted Wϕ, will pass through the target object **[22]**

$$WINCID = W\alpha + W\rho + W\boldsymbol{\tau} = 100\% \qquad (2\text{-}1)$$

An object possesses a certain capacity or ability to:

- ✓ Absorb: this is called absorptivity,
- ✓ Reflect: this is called reflectivity,

✓ Transmit: this is called transmissive power.

The sum of the three parameters is equal to 1

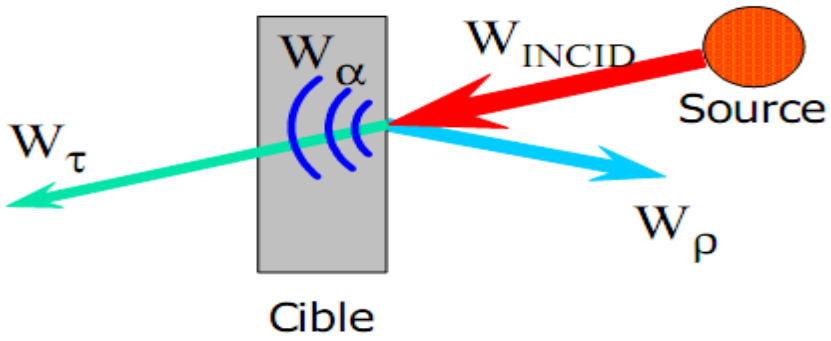



Figure. 26. Distribution of incident radiation into different components **[22]**

The radiation detected by an infrared camera consists of the total radiation emitted from the surface of an object, regardless of its original source. This radiation originates from three types of sources.

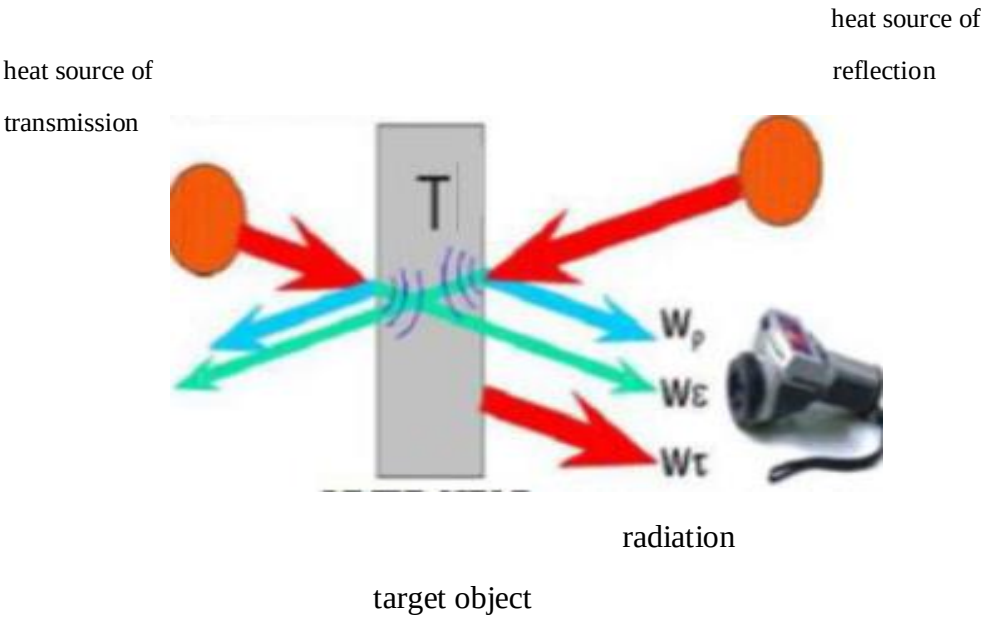



Figure 26. The three sources of reflected radiation emanating from the object.

## 2.7 Means of measurement

Infrared thermography is relatively expensive (approximately 45,000 DA to 699,000 DA for the camera and associated image processing software). The latest generation of conventional infrared equipment currently available is very compact, portable and autonomous (Figure 27) **[22].**



Figure 28. Means of measurement of infrared thermography **[22].**

Each thermography device is equipped with accessories and digital processing systems that expand its initial capabilities (figure 29).



Figure 29. Set of TIR measurement equipment **[22].**

## 2.8 Structure of an imager

### 2.8.1 Fixed thermal imager

In thermography, fixed infrared thermometers are used, which are generally employed in industrial processes where the thermometer can be installed in a fixed location.

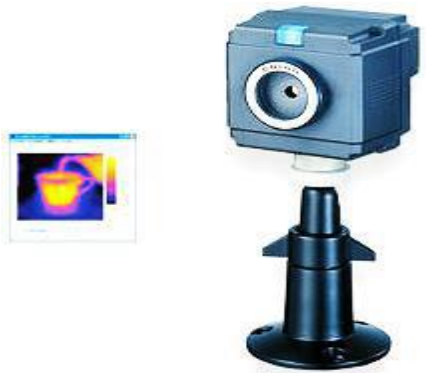


**Figure 30. Fixed thermal imager [19].**

### 2.8.2 Thermal image analysis techniques

The three most important functions for improving thermal images are thermal framing, isotherms, and palettes. Thermal image analysis often involves searching for singular areas whose behavior differs from the rest of the image.

#### 2.8.2.1 Thermal framing

What does thermal framing mean? It's the adjustment of the image scale to optimize contrast for analysis purposes. This framing requires the use of the camera's level and gain controls. Once the area of interest in the image is selected, these two parameters must be adjusted so that the colors in the palette cover that part of the image as accurately as possible. Less interesting areas of the image can be located outside the scale. They will then generally be represented in black or white (see Figure 31).

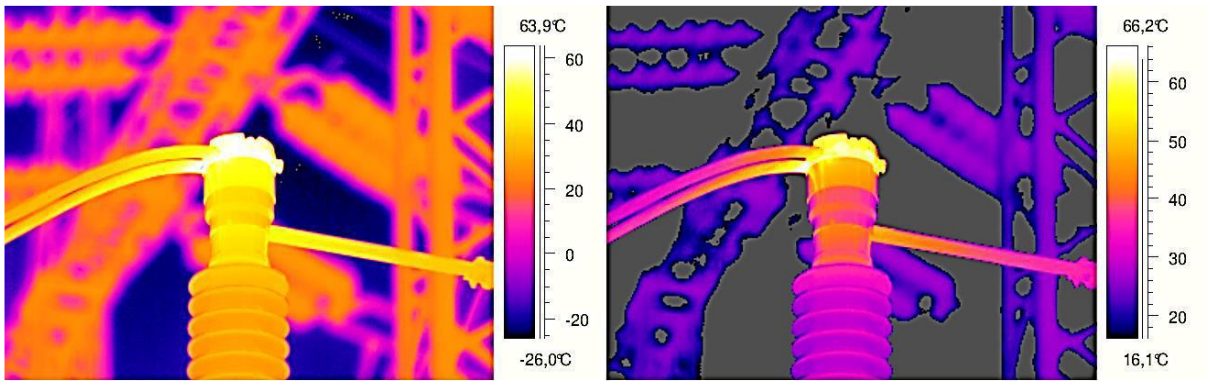



Figure 31. Same image, automatically adjusted (left) and thermally framed on the component (right) **[19].**

### 2.8.2.2 Isothermal

For the isothermal effect, it replaces a range of colors with another that contrasts more sharply with the colors used in the image. It can be moved up and down the scale and expanded or reduced as needed (see the example shown in Figure 32).

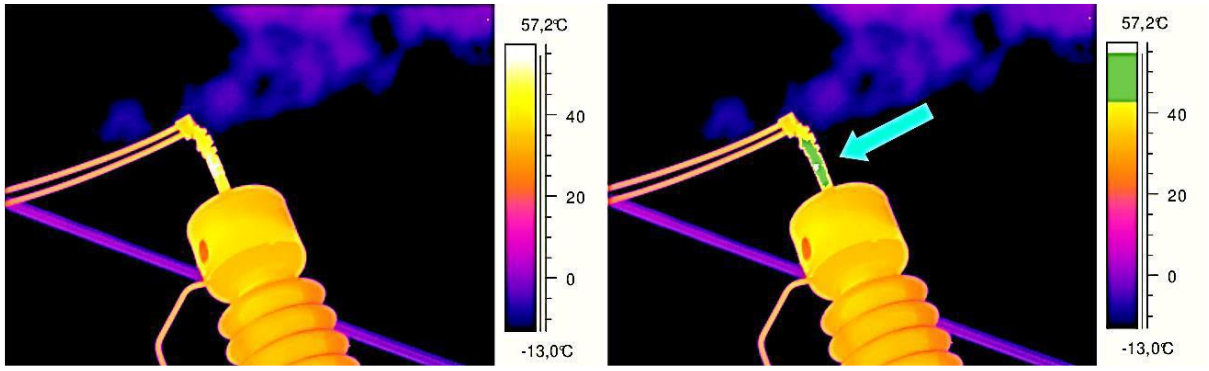



Figure 32.High voltage transformer head with an isotherm **[19].**

### 2.8.2.3 Color palettes

A color palette designates different colors to denote defined levels of apparent temperature. It can be more or less contrasting depending on the colors used (see the example of a thermogram of a storage tank taken with different pallets illustrated in Figure 33).

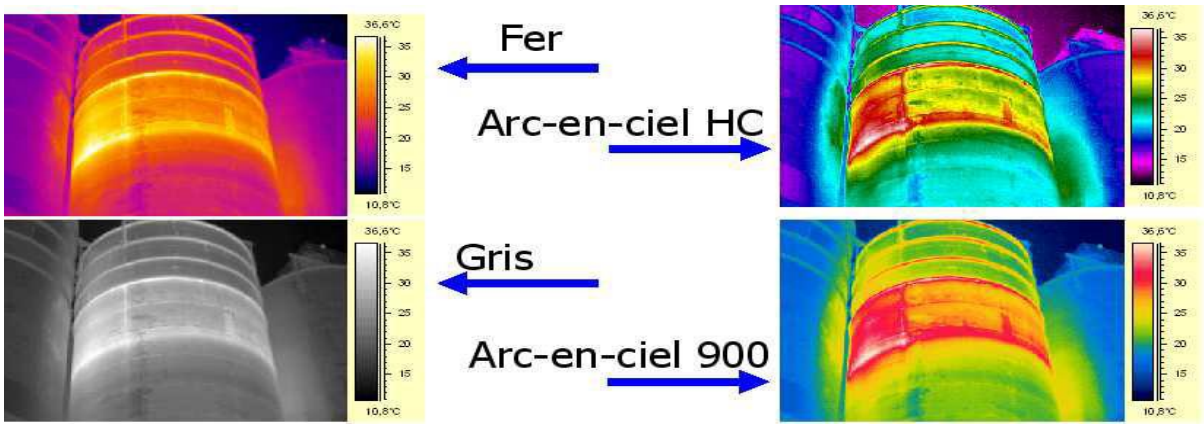



Figure 33. Examples of different palettes **[19].**

## 2.9 Methodology, Approach, Creation of a signature

### 2.9.1 Methodology

Several thermographic methods can be used, as presented in Table.1. These methods are specific to different applications and are used according to the measurement requirements:

• Contact measurement of the target.

• Non-contact measurement.

• Heat diffusion.

• Cost.

• Implementation difficulty.

**Table 1. Thermography methods.**

| Method | Contact | Contact | Contactless |
|---|---|---|---|
| | Battery of thermoelectric couples | Liquid crystals, heat-sensitive paints... | Infrared<br>Issued |
| Image or thermal measurement | Map and measurement | Image and measurement | Image and measurement |
| Presentation | Map | Colorful image | Display interface |
| Implementation | Report on map | Fast (0.1 s) | Real-time (up to 60 frames per second) |
| Temperature range | From -260°C to +2000°C | From -240°C to +1500°C | From -50°C to +2000°C |

### 2.9.1 Creation of a signature

The thermal signature is the temperature measured by an infrared radiation sensor (thermal camera). This allows access to the measurement of thermal fields. The processing of the images obtained makes it possible to analyze the thermal signature of moving objects or flowing fluids.

Various analysis tools can be used to detect defects in infrared images.

The process of creating a thermographic signature involves the following steps:

1-Selection of components or parts of the equipment to view

2-Definition of the equipment's reference state

3-Definition of shots

4-Filming

5-Report writing

# Chapter III : Non-destructive testing

## 3.1 Introduction

One technique that allows for the non-destructive assessment of the condition of parts and provides an opinion on their suitability for their intended function is non-destructive testing (NDT). Despite the difficulties faced by NDT specialists responsible for inspection, the problem lies in interpreting test results against criteria established in conjunction with the part's designer. In this context, NDT is essentially about qualifying, without necessarily quantifying, the condition of a product, without altering its characteristics. Therefore, it is a set of procedures for examining parts that ensures the absence of defects that could compromise their performance in service.

Non-destructive testing (NDT) makes it possible to identify discontinuities in a part without damaging it, in other words, to verify the quality of the material.

## 3.2 Non-destructive testing methods.

Several methods are used for non-destructive testing (NDT). We will mention the most important:

1. Dye penetrant testing.
2. Magnetic particle testing.
2. Radiographic control: X-rays (XR) and Gammagraphy (γ).
4. Foucault current testing.

### 3.2.1 Penetrant testing

It is a very simple technique in its application, allowing for examination of the entire surface of the part while highlighting discontinuities as small as a few tens of micrometers. Dye penetrant testing comprises three steps.

**First Step**

The first phase involves cleaning the surface of the part and applying a penetrating liquid, either by immersion or spraying, for a duration that varies depending on the type of penetrant, generally between 15 and 30 minutes. The penetrant can be a colored, pre-emulsified, or fluorescent product that seeps into the small crevices on the surface; a certain amount of time is needed to allow the penetrant to "set."

**Second step**

The second step involves rinsing the surface of the part to remove excess penetrant. This operation is delicate because excessive or insufficient rinsing can distort the final result.

**Third step**

During the third step, a developer, either liquid or powder, is applied to the rinsed and dried surface. The liquid (penetrating agent) that has seeped into the cracks then "emerges" on the surface within the developer and expands at the defect. It becomes clearly visible under appropriate lighting.

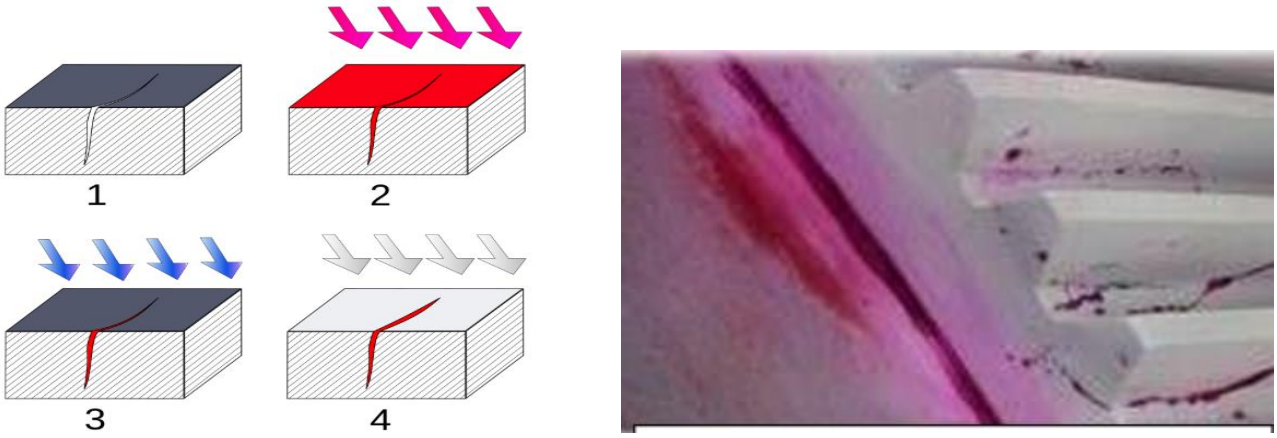



Figure 34. Crack detection on the gear

### 3.2. 2 Magnetic particle testing

This method is only applicable to magnetic materials for detecting defects. This technique is used when dye penetrant testing is insufficient, meaning that surface defects remain barely

visible. This method involves locally or fully magnetizing the part to a value close to magnetic saturation. Any discontinuity in the material will cause a decrease in the cross-sectional area and therefore an increase in the magnetic induction field (conservation of flux). This increase will cause magnetic leakage at the surface of the part. Ferromagnetic particles contained in a developer accumulate at the defect. The resulting spectrum is observed under appropriate lighting.

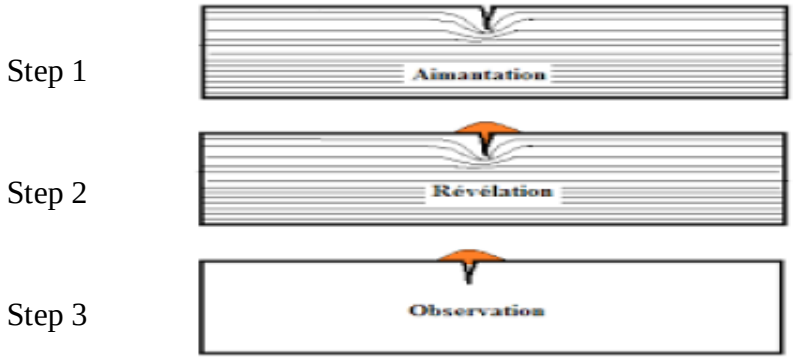



Figure 35. The steps of magnetic particle inspection.

### 3.2.3 Radiography

The technique of detecting defects by radiography consists of passing short-wavelength electromagnetic radiation (X-rays and gamma rays) through the object whose internal examination is to be carried out in order to detect defects; subsequently, the variations in intensity of the beam are recorded in the form of an image.

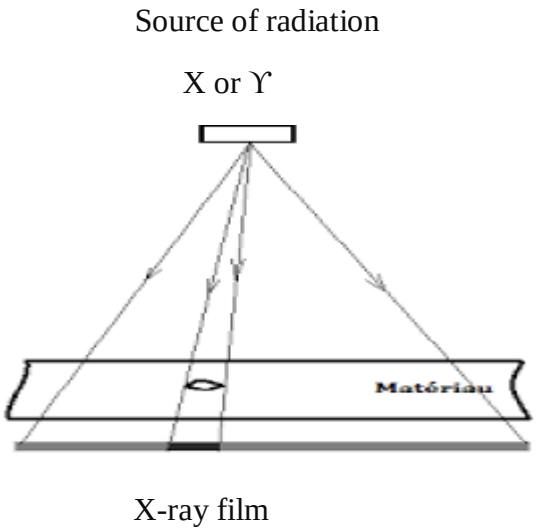



**Figure 36. Imprinting the image of the defect onto the radiographic film [19]**

**Example of a radiographic image**

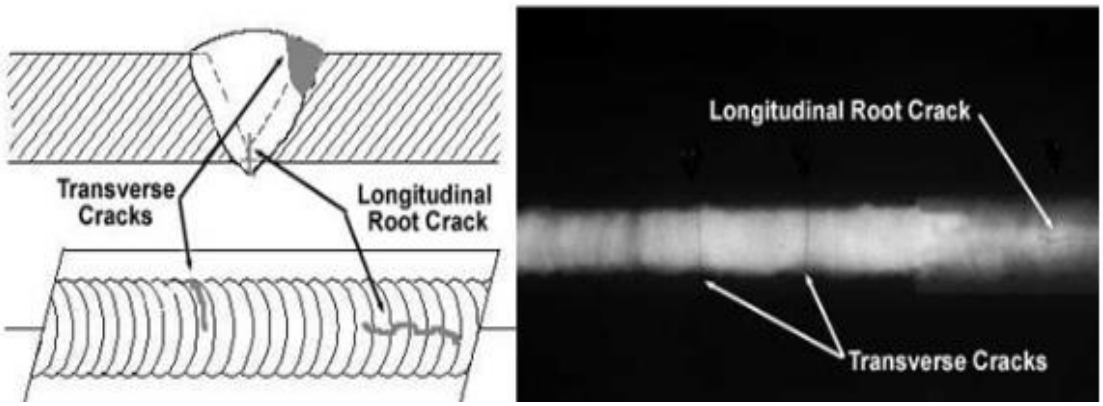



**Figure 37. Detection of cracks by radiography [24]**

For gamma radiography, no water or electricity supply is required. The source can be positioned in small-diameter tubes and radiates in all directions, allowing for panoramic radiography of a tank. The use of ionizing radiation requires special facilities and must be

transported in accordance with regulations for the transport of dangerous goods and radioactive materials.

### 3.3 Foucault current

By placing a conductive body in a changing magnetic field, induced currents develop within the material in a closed circuit.

A coil carrying an alternating current generates induced currents, which in turn create a magnetic flux. This flux, by opposing the generating flux, modifies the coil's impedance. The presence of a defect disrupts the flow and distribution of eddy currents. The impedance variation detectable at the excitation coil is used to detect surface defects. Generally, a comparative method is used, which consists of measuring the difference between the impedance Z of the coil on the part being studied and the impedance Z0 of a reference part without defects.

The intensity of the eddy currents I is maximum at the surface of the part and decreases according to an exponential law. In the case of a solid with a flat surface, it is written as:

$$I = I_0 exp - \delta\sqrt{\pi f \sigma \mu} \qquad (3\text{-}1)$$

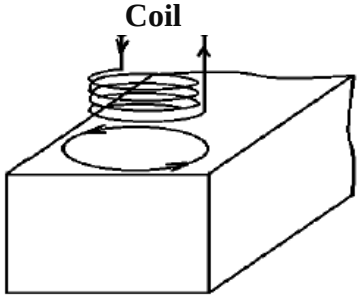
The standard penetration depth δc (m) for which the intensity is decreased by 0.37 (≈ 1/e), that is:

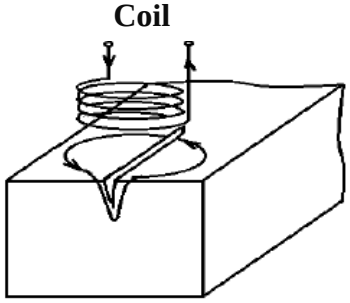
$$I = I_0 exp - 1 = 0{,}37 I_0$$

Thus, δc is equal to:

$$\delta_c = \frac{1}{\sqrt{\pi f \sigma \mu}} \qquad (3\text{-}3)$$

f: frequency in Hz; δc: depth in meters; σ: electrical conductivity in Ω.m-1 and μ: magnetic permeability H.m-1.



Piece without defect Piece with defect

Figure 38. Modification of the path of eddy currents.

In the case of non-magnetic materials such as light alloys, copper alloys, zinc, we have:

$\mu = 4\pi$ 10 H.m-1 and the standard depth is written:

$$\delta_c = \frac{1503}{\sqrt{f\sigma}} \qquad (3\text{-}4)$$

### 3.4 Areas of Application

#### 3.4 .1Tube, bar and wire inspection

This technique is widely used in the industrial sector and can reveal, on the equipment, not only superficial health defects such as cracks, pits and small straws, but also geometric defects such as abrupt variations in diameter or wall thickness, structural heterogeneities such as areas with large grains, etc.

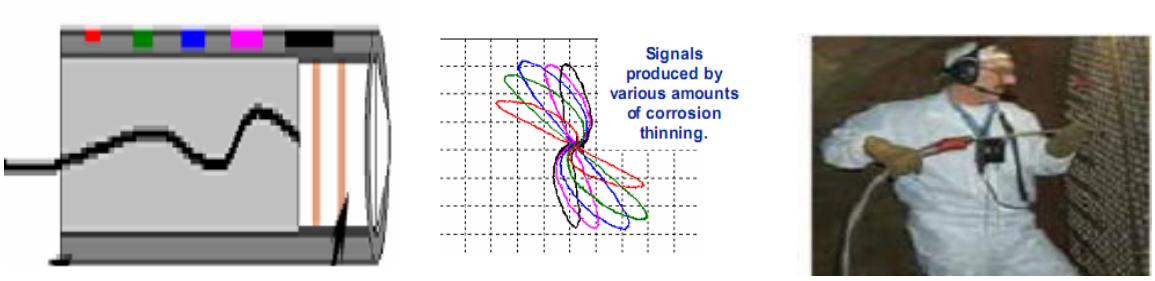



Figure 39. Evaluation of losses of equipment in service **[19]**

#### 3.4 .2 Surface control plan

Eddy current testing is commonly used to detect fatigue cracks during aircraft maintenance. The testing can be manual or automated, using a robotic arm to move the probe and an information processing system that maps and archives the results.



Figure 40. Applications in aeronautics.

# Chapter IV: Ultrasonic acoustic analysis

## 4.1. Introduction

Ultrasonic non-destructive testing is a method for detecting material defects. It allows for the localization and measurement of discontinuities (defects) using acoustic waves. Ultrasonic testing involves observing the echoes produced by a material defect during the propagation of a very high-frequency, very short-duration vibration within the material.

This fault analysis technique offers multiple applications in the control of hydraulic and pneumatic equipment (leak detection, sealing control) and also allows the detection of ultrasound emitted by faults of electrical origin (bad contacts, corona effects, arc effects, etc.).

## 4.2 Theory of sound and ultrasound.

The application of this control, that is to say, performing an ultrasonic examination of a mechanical part, requires the operator to provide a certain number of choices:

- ✓ Acceptance criteria.
- ✓ Materials used (device, translator, reference block, etc.).
- ✓ Scanning (translator scan).
- ✓ Control sensitivity.

The application of ultrasonic testing is very easy to implement on the production site using lightweight and portable equipment, in addition to other advantages of this technique, namely:

- ✓ It provides immediate results.
- ✓ It is fast.
- ✓ It can be applied to most materials.
- ✓ Access to both sides of the part is not required.

### 4.2.1 The sound

Sound is a mechanical wave produced by any solid, liquid, or gaseous body that vibrates and propagates through an elastic medium before reaching our ears.

Three elements are necessary for sound to exist:

- ✓ A source, producing a mechanical vibration.
- ✓ A medium that carries the vibration.
- ✓ A receiver, the ear, that receives this vibration.




Figure 41. Elements that enable the existence of sound **[19]**

A sound or acoustic wave is a longitudinal wave that propagates through the compression and decompression of molecules in a material medium. These waves have the same direction of vibration as their direction of propagation (Figure 42)

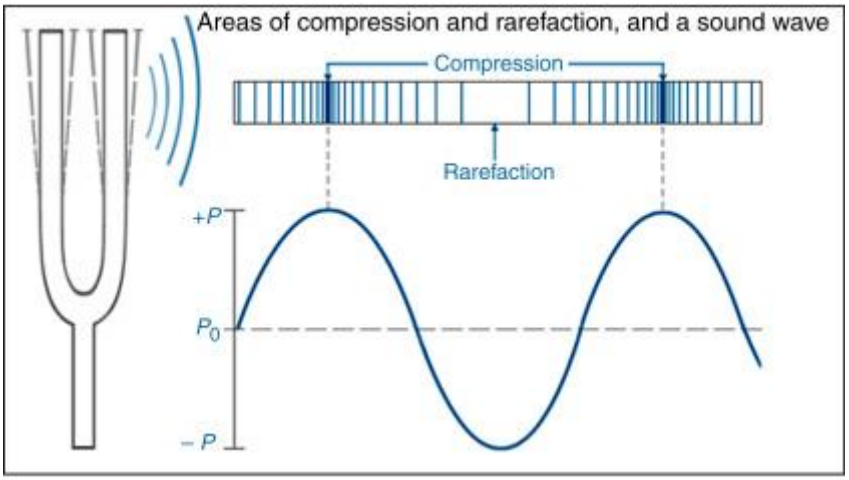



Figure 42. Audible signal **[25]**

The speed of propagation or speed of sound depends on the nature of the medium (solid, liquid or gaseous), the temperature and the pressure of the medium.

$$c = \sqrt{\frac{K}{\rho}} = \sqrt{\frac{1}{\rho \varkappa}} \qquad (4\text{-}1)$$

**c:** Speed of sound.

K: Compression modulus.

x: Compression coefficient's  x= 1/K.

Sound does not propagate in a vacuum because there is no matter to carry the waves.

## 4.3 Presentation to ultrasonic detection

### 4.3.1 Ultrasound

Ultrasound waves are mechanical vibrations of the same physical nature as sound; only their frequency distinguishes them. The frequency range of ultrasound is between 20 kHz and 100 MHz, too high to be perceived by the human ear.

In a homogeneous material medium, sound and ultrasound waves propagate at the same constant speed; that is, this speed depends on the nature of the medium and not on the frequency

of the sound wave **[19].**

### 4.3.1 .1 Physical characteristics of ultrasound:

- Frequency f (Hz): 20 kHz and 100 MHz.

- Period T (s): $T=1/f = \lambda/c$

-Wavelength λ(m): $\lambda= c / \lambda = cT$

- Speed c (m/s): $C=f / \lambda$

- Intensity I (Watt/cm²) = Energy Transported per unit area: $I= P_c{}^2/2pc$

The mechanical vibration generated by the piezoelectric element of the transducer propagates through the cross-section of the part, reflecting off its surfaces. A portion of the acoustic beam is intercepted by the defect and reflected back to the transducer, which converts the vibration into an electrical signal.

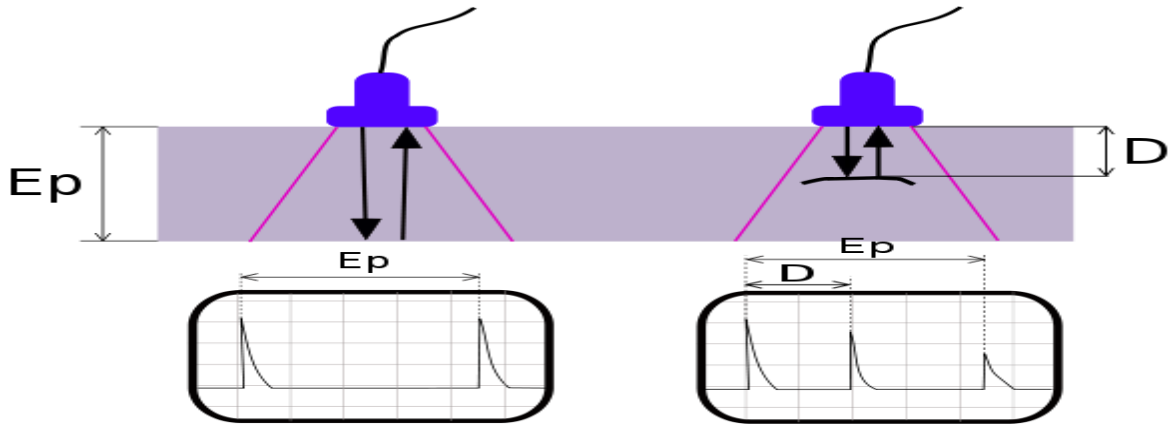



Figure 44. Principle of ultrasonic control **[19]**

### 4.3.1 .2 Equipment used

- ✓ Analog or digital U.S. radios;
- ✓ OL, OT, and variable-angle transducers;
- ✓ Thickness gauges;

- ✓ Software for entering and tracking thickness measurement




Figure 45. Equipment used in ultrasonic testing **[19]**

## 4.4 Ultrasonic inspection integrated into a conditional maintenance program.

The use of ultrasonic testing allows the following defects to be identified:

### 4.4.1 internal defects

- ✓ Crack detection on in-service installations
- ✓ Inspection of castings
- ✓ Welding defects: porosity, lack of fusion, penetration defects, slag inclusions, edge cracks, root cracks.
- ✓ Thickness measurements...

### 4.4.2 Tightening control

This type of inspection measures the elongation of screws or studs under the effect of tightening tension. The ultrasonic transducer, placed on the head of the screw or stud, acts as a transmitter of ultrasonic waves that propagate longitudinally through the material and as a receiver that collects the wave reflected off the base of the screw. This operation is repeated several hundred thousand times per second.

**Examples of applications:**

Cranes, heavy machinery (public works), bridges and civil engineering structures, cable cars, heavy industry (rolling mills), power plants, aeronautics, ships (bolt sections), railways…

# Chapter V: Oil analysis

## 5.1 Introduction

The technique of detecting failures through oil analysis is of crucial importance in industries, particularly in any industrial machinery maintenance program. Its use is simple and can be applied to the diagnosis of almost all lubricated mechanisms. Since the oil is in constant contact with moving parts, this technique provides a wealth of information about the machine's health.

This technique (oil analysis) allows for the monitoring of the lubricant's physicochemical characteristics over time. This enables the assessment of its degradation state and therefore its ability to perform its function. The analysis results can detect anomalies, including:

• Contamination by internal equipment particles

• Pollution by external agents

• Wear due to abrasion

Oil analysis is one of the tools used for preventive maintenance. Along with vibration analysis and thermography, it helps avoid unexpected breakdowns and costly repairs.

## 5.2 Areas of application of oil analysis

Examining the lubricants used helps improve maintenance costs (direct and indirect) through a better understanding of machine condition and lubricant development.

This method is implemented across the entire fleet of lubricated machines. This approach is Complementary to vibration and thermographic analyses, monitoring using these methods is also employed. Oil examination, performed within the context of condition-based preventive maintenance, will facilitate the detection and monitoring of potential problems such as:

**1- Hydraulic systems:**

- ✓ Residual lubricant characteristics.
- ✓ Component wear: pumps, motors, valves...
- ✓ Circuit contamination: solids, water...
- ✓ Filtration efficiency: contamination level...

**2- Compressors:**

- ✓ Lubricant evolution during operation: deposits, oxidation...
- ✓ Mechanical condition.
- ✓ External contamination: water, silica...

**3- Internal combustion engines:**

- ✓ Engine mechanical condition: wear.
- ✓ Air filtration leaks.
- ✓ Fuel injection system malfunction.
- ✓ Coolant leaks.
- ✓ Driving style or operating conditions (more or less severe).

4- **Poor condition of a bearing or bushing.**

- ✓ Defective transmission: damaged gears.
- ✓ Additive performance.
- ✓ Assessment of residual lubricant characteristics.
- ✓ External contamination: water, dust...

## 5.3 Main means of oil analysis

Various methods of oil analysis can be used; we present the main ones:

- ✓ By Centrifugation
- ✓ By Filtration

- ✓ By Ferrography
- ✓ By Spectrometry
- ✓ By Flash Point Measurement
- ✓ By Counting

### 5.3.1 By Centrifugation

Oil analysis by centrifugation allows for the separation of solid particles of different densities in a liquid solution. The particles move radially and horizontally rather than being in vertical suspension, and they then accumulate in an orderly fashion at the bottom of the centrifuge tubes.

### 5.3.2 By Filtration

Filtration is essential and should not be sacrificed for the sake of oil analysis. Identifying faults through oil analysis is a complex procedure. The particles captured by filtration represent only one segment of this process. It might be optimal to conduct oil analyses in conjunction with the examination of filter debris to obtain effective analytical results while preserving engine oil filtration.

### 5.3.3 By Ferrography

There are two types of ferrographic analysis:

**Quantitative ferrographic analysis** (also called direct reading analysis): this form allows the identification of the proportions of fine and coarse ferrous particles to signal any variation in the level and intensity of abrasion within rotating element bearings and gear reducers.

**Analytical ferrographic analysis:** A highly sophisticated diagnostic method for identifying large particles down to 100 μm. Microscopic analysis of abrasion particles, impurities, and oxidation residues present in a used oil specimen provides information on the progressive wear process. It is used to conduct a detailed analysis of contaminating particles when direct ferrography indicates significant or atypical wear. It is also employed for complex hydraulic systems.

### 5.3.4 By Spectrometry

There are two types of spectrometry analysis:

**Optical emission spectrometry analysis:** This method allows for the rapid determination (by analyzing the light produced by the very high-temperature "plasma" combustion of an oil sample) of the mass concentrations, expressed in ppm (parts per million), of the various elements present in oils as additives (calcium, magnesium, etc.), metallic wear particles (iron, nickel, chromium, tin, copper, aluminum, etc.), or various solid contaminants (atmospheric dust, silicone, etc.).

Examining these components helps to understand what is happening within the equipment (for example, the detection of an unusual level of tin or aluminum will indicate unusual bearing deterioration in an engine).

**Absorption spectrometry analysis:** This technique uses infrared radiation to determine the general chemical structure of a substance or mixture of substances, as well as the concentration of compounds within the mixture, by decomposing light outside the visible spectrum. Absorption spectrometry allows for the determination of the characteristics of hydrocarbons present in base oil, the identification of additives, and the monitoring of their condition through comparative analysis between new and used oil.

### 5.3.5 By Flash point measurement

The method involves heating 4 $cm^3$ of oil to 180°C for 2 minutes, then assessing its flammability by exposing it to a flame. If no "flash" occurs, the measurement is considered satisfactory and the level of contamination by light fractions acceptable. If a "flash" occurs, the measurement is repeated starting at 100°C, and then every 5°C until the "flash" is observed.

The appearance of the "flash" at a certain temperature, combined with the evaluation of viscosity in relation to standard values of new oil and based on predetermined tables, offers the possibility of evaluating the degree of dilution of a used engine lubricant by the fuel.

The decrease in flash point, as well as in viscosity, is generally linked to the presence of light fractions from the fuel following malfunctions of the injection system or to use involving prolonged slowdown phases.



Figure 46. Pensky Martens apparatus used for determining the flash point **[19]**

### 5.3.6 By Counting.

Control of the size and volume of solid contaminating particles in hydraulic oils. The degree of cleanliness or contamination is determined in accordance with ISO 4406.

We filter an oil sample through an extremely fine filter (e.g., 0.8 to 1.2 μm), then count the retained insoluble particles according to their size. Examining the filter allows us to count the particles according to standardized sizes. The number of particles is then scaled to a 100 $cm^3$ sample for each size. Subsequently, a pollution category is assigned to each size. All these categories together constitute the oil pollution code.

The highest value of this code represents the oil's contamination level (the higher the number corresponding to the class, the more contaminated the oil is considered). A check is then carried out to ensure the oil is suitable for its intended use. The increase in contamination over time can also be monitored to identify any problems (conditional preventative maintenance).

## Bibliographic references

**[1] LANDOLSI F,** part I, monitoring of machines by vibration analysis course of monitoring techniques.

**[2]** SPASESKI P, 2021, Vibration Analysis 101, A simple guide to understand vibration.

**[3] CHAIB R,** 2009, Contribution to the optimization of condition-based maintenance through vibration analysis, doctoral thesis in mechanical sciences, University of Constantine.

**[4] CHERIF B. D.E,** 2020, Course Material, Failure Detection Techniques, Mouhamed Boudiaf University M'Sila.

**[5] NABTI, MT**, 2011, Study of the evolution of spectral and cepstral indicators in the detection of mechanical defects, Master's thesis, Farhat Abbas University, Setif.

**[6] CHU T** and all ,2024, A review of vibration analysis and its applications, Department of Petroleum and Natural Gas Engineering, New Mexico Institute of Mining and Technology, Socorro, Helyon 10, journal.

**[7] TALEB.M,** 2018, Monitoring, detection and diagnosis of failures in a cement plant using functional analysis, Doctoral thesis, University of August 20, 1955 Skikda.

**[8] RAKOTO R GM**, 2010 Numerical methods for the vibrational characterization of complex structures, Other University of Paris-Est. French NNT 2010PEST1086.

**[9] CHAEHOI A,** 2005 « Design and modeling of monolithic CMOS MEMS in FSBM technology: application to accelerometers » Doctoral thesis, University of Montpellier II, 12, France.

**[10]** MOBLEY R.K.,2002, An Introduction to Predictive Maintenance, Elsevier Science & Technology.

**[11] FEKI N**, 2012, Electromechanical modeling of gear transmissions – Applications to fault detection and monitoring. Doctoral thesis, INSA Lyon, (Cited on pages 9, 26 and 27).

**[12] KHELF I,** 2014, Diagnostics of rotating machinery using artificial intelligence techniques Doctoral thesis, Badji Mokhtar University of Annaba.

**[13] THE BTS MS** Archives - Resources and Online Courses, The failures for the BTS Maintenance of Systems (hubertfaigner.fr).

**[14] FAKHFAKH, T, CHAARI, AND HADDAR M**, 2005, Numerical and experimental analysis of a gear system with teeth defects, International Journal of Advanced Manufacturing Technology, 25 (5), pp. 542-550.

**[15] AYAD, M,** 2015**,** Search for robust signatures of defects in a rotating machine through the analysis of vibration signals, doctoral thesis in Electromechanical Sciences, Farhat Abbes University Setif.

**[16] CHIKH N**, 2005, Spectral analysis of vibration Application to the maintenance of mechanical equipment, Master's thesis, M'hamed Bougara Boumardes University.

**[17] NABTI, MT**, 2011, Study of the evolution of spectral and cepstral indicators in the detection of mechanical defects, Master's thesis, Farhat Abbas University, Setif

**[18] TREMBLAY.R,** 2026. What is thermography? The ultimate guide.

**[19] CHERIF. B. D. E** ,2020, Failure detection techniques, Course material, Mohamed Boudiaf University - M'sila.
**[20]** https://www.orglmeister.de/fr/histoire-et-physique-du-rayonnement-infrarouge, **consulté le 22/04/2026 à 20h**

**[21] HATTAB. Y,** 2016, Radiation course, Physics, University of Science and Technology of Oran
**[22] BOURAS .A ,** Fault detection techniques, infrared thermography analysis, chapter.

**[23**] https://photinnov.com/thermographie-infrarouge-principes-physiques/

**[24]**https://www.ndeed.org/NDETechniques/Radiography/TechCalibrations/RadiographInterp_Castings.xhtml

**[25]** YOUNG .S Carl,2016 ,Information, Security Science ,book, science direct