Article **Journal of Technologies in Industrial Processes**
June, 2022 Vol.6 No.14 1-9

Ultrasonic detector for predictive maintenance

Detector ultrasónico para el mantenimiento predictivo

DUARTE-LOERA, Jorge†*, REYNOSO-JARDÓN, Elva Lilia, DÍAZ-RIVERA, Abelardo and ARÁMBULA-LEDEZMA, David Daniel

Universidad Tecnológica de Chihuahua, Av. Montes Americanos, Sector 35, 31216 Chihuahua, Chih. México

ID 1st Author: *Jorge, Duarte-Loera* / **ORC ID:** 0000-0002-6721-1406, **Researcher ID Thomson:** X-9796-2019, **CVU CONACYT ID:** 69449

ID 1st Co-author: *Elva Lilia, Reynoso-Jardón* / **ORC ID:** 0000-0002-0729-2822, **Researcher ID Thomson:** AFZ-2483-2022, **CVU CONACYT ID:** 264446

ID 2nd Co-author: *Abelardo, Díaz-Rivera* / **ORC ID:** 0000-0001-7511-2697, **Researcher ID Thomson:** X-9791-2019, **CVU CONACYT ID:** 990710

ID 3rd Co-author: *David Daniel, Arámbula-Ledezma* / **ORC ID:** 0000-0003-0267-8803, **Researcher ID Thomson:** AGO-9021-2022, **CVU CONACYT ID:** 1063890

DOI: 10.35429/JTIP.2022.14.6.1.9 Received March 16, 2022; Accepted June 30, 2022

Abstract

In the industry it is very common for failures to occur in machinery and equipment such as poorly lubricated elements; friction between mechanical elements; gas or vacuum leaks in pressurized systems; and electric arcs in motors, transformers and electrical installations. Each of these faults emits ultrasound and can be detected early using an ultrasonic detector. The objective of this work is to present a proposal for the development of a system capable of opportunely detecting the ultrasound emitted by faults, which is very useful for predictive maintenance. The methodology consists of the development of a system that detects the ultrasound decibels emitted by the fault using an ultrasonic sensor of the last generation, and the necessary interfaces. Ultrasound decibels will increase exponentially in the presence of these flaws, allowing their detection. This document offers an alternative for the development of an ultrasonic system useful in predictive maintenance, which is within the reach of any company.

Predictive maintenance, Ultrasonic sensor, Ultrasonic detector

Resumen

En la industria es muy común que se presenten fallas en las maquinarias y equipos como elementos mal lubricados; fricción entre elementos mecánicos; fugas de gases o de vacío en sistemas presurizados; y arcos eléctricos en motores, transformadores e instalaciones eléctricas. Cada una de estas fallas emite ultrasonido y pueden ser detectadas oportunamente utilizando un detector ultrasónico. El objetivo de este trabajo es presentar una propuesta para el desarrollo de un sistema capaz de detectar oportunamente el ultrasonido que emiten las fallas, el cual es de gran utilidad para el mantenimiento predictivo. La metodología consiste en el desarrollo de un sistema que detecte los decibeles de ultrasonido que emite la falla utilizando un sensor ultrasónico de última generación y las interfaces necesarias. Los decibeles de ultrasonido se incrementarán exponencialmente en presencia de estas fallas, lo cual permite su detección. Este documento ofrece una alternativa para el desarrollo de un sistema ultrasónico útil en el mantenimiento predictivo, que esté al alcance de cualquier empresa.

Mantenimiento predictivo, Sensor ultrasónico, Detector ultrasónico

Citation: DUARTE-LOERA, Jorge, REYNOSO-JARDÓN, Elva Lilia, DÍAZ-RIVERA, Abelardo and ARÁMBULA-LEDEZMA, David Daniel. Ultrasonic detector for predictive maintenance. Journal of Technologies in Industrial Processes. 2022. 6-14: 1-9

*Correspondence to Author (e-mail: agonzalez@utectulancingo.edu.mx)
† Researcher contributing as first author.

Introduction

Ultrasound is defined as sound waves with frequencies higher than 20 KHz which are outside the audible range for human beings, and that in order to be perceived, the inaudible sound must be transformed into frequencies that can be heard. It should be noted that the useful equipment to make this change is the ultrasonic detector for predictive maintenance (Ortega, 2004; Martinez, 2006). The basis of the operation of ultrasonic detectors is that when a fault occurs, very high frequency sound waves known as ultrasound are generated. By scanning the test area with an ultrasonic meter, the fault can be heard through the headphones as a flow sound which can also be observed on the display/decibel meter.

The closer the sensor is to the fault, the louder the flow sound and the higher the decibel reading. Ambient noise can be a problem, where a rubber focusing probe is normally used, in order to reduce the instruments receiving field and to protect against conflicting ultrasound. Also, frequency tuning drastically reduces background noise interference to facilitate more efficient ultrasonic detection (Realibity Web.Com, 2020). These detectors are part of the so-called non-destructive testing and allow the detection of faults in multiple systems and mechanisms in an early manner, relative to the detection done with vibration analysis.

It should be noted that the detection of incipient faults allows the programming of corrective actions without affecting production, without downtime and providing for the supply of spare parts in a timely manner. The faults that can be detected with this technology are poorly lubricated or defective bearings; detection of leaks in piping systems pressurised by any type of gas or vacuum; friction between mechanical elements; detection of electric arcs in motors, electrical installations and transformers.

The aforementioned breakdowns are common in industry and can be diagnosed in a timely manner if the company has this equipment, but due to its high cost it is not within the reach of companies with few resources. The aim of this work is to show an alternative for the development of an ultrasonic detector for predictive maintenance that is within the reach of any company.

Development

1. Industrial maintenance

It is a field of engineering of great interest and with a wide economic impact, as justified by the fact that in industrial societies, maintenance costs constitute an appreciable percentage of their gross domestic product. In some sectors, maintenance is essential for the development of the activity to which it is applied, while in others, the existence of effective maintenance is one of the most important elements for achieving competitiveness in the global economic framework (González, 2010). Industrial maintenance is defined as the set of activities aimed at guaranteeing the correct operation of the machines and installations that make up a production process, allowing it to reach its maximum performance.

The general objective of industrial maintenance is to plan, schedule and control all the activities aimed at guaranteeing the correct operation of the equipment used in production processes. Good maintenance scheduling provides companies with the following advantages: production of high quality products at low cost; customer satisfaction with regard to the delivery of the product in the agreed time; reduction of risks in work accidents caused by the poor condition of the machines or their components; reduction of costs caused by production process stoppages when unforeseen repairs occur; detection of faults caused by the wear and tear of parts allowing an adequate programming in the replacement or repair of the same; prevents irreparable damage to the machines; facilitates the preparation of the budget according to the needs of the company.

When companies do not have well-planned maintenance, losses can occur due to the following problems: Production process stoppages; unexpected equipment breakdowns, damage to raw materials; production of defective products; non-compliance with product delivery times; and accidents at work (Olarte, 2010). The main types of industrial maintenance that exist are corrective maintenance, preventive maintenance, predictive maintenance and reliability-based maintenance (González, 2010).

ISSN 2523-6822

2. Predictive maintenance

The increase in automation meant that every failure that occurred had a more serious impact on productivity and product quality standards, in addition to the serious consequences it had on safety and the environment, at a time when the demands in these areas were growing rapidly. The inspection techniques developed in the decade by vibration analysis methods, ultrasound analysis, infrared thermography and other intensive and systematic inspection techniques, which were based on the prediction of failure before it occurred, following the behaviour through the monitoring of the condition of the equipment, in previously established time intervals, came into action. Maintenance that uses tools and techniques for measuring physical parameters to inspect equipment at regular intervals, taking action to prevent failures before they occur, is called Predictive Maintenance (Moubray, J. 2001).

Predictive maintenance consists of a series of non-destructive tests aimed at monitoring the operation of equipment to detect warning signs that indicate that some of its parts are not working properly. Through this type of maintenance, once faults have been detected, the corresponding repairs can be programmed in a timely manner without affecting the production process and thus prolonging the useful life of the machines. The techniques most commonly used in industry for industrial maintenance are vibration analysis, infrared thermography, ultrasound analysis and oil analysis (Olarte, 2010).

3. Types of predictive maintenance

3.1. Vibration analysis

This is the study of the operation of rotating machines through the behaviour of their vibrations. All machines present certain vibration levels even when they are operating correctly; however, when an anomaly occurs, these normal vibration levels are altered, indicating the need for an overhaul of the equipment. For this method to be valid, it is essential to know certain data about the machine such as: its rotation speed, the type of bearings, belts, the number of blades, blades, etc.

It is also very important to determine the points on the machines where the measurements will be taken and the most suitable analysing equipment for carrying out the study. With vibration analysis it is possible to detect faults in machinery and equipment such as: detecting friction in rotating machines; detecting faults and/or leaks in valves; detecting leaks in fluids; detecting vacuum losses; detecting electric arcs; verifying the integrity of seals in sealed enclosures.

The Vibration Analyser, as can be seen in Figure 1, is a specialised equipment that displays on its screen the vibration spectrum and the measurement of some of its parameters (Olarte, 2010). This technique is used to identify and predict mechanical anomalies in industrial machinery by measuring the vibration and identifying the frequencies involved. These vibrations are recorded by one or several accelerometers and the data are processed by a spectrum analyser.

The application of this technique in predictive maintenance greatly improves the efficiency and reliability of industrial machinery. Vibration analysis does not require disassembling or stopping the machine and is therefore a non-invasive method. In fact, a sensor that transforms motion into an electrical signal is the principle of a vibration analyser. Secondly, the analyser calculates all predefined parameters and then stores this signal (ERBESSD INTRUMENT, 2022).

Figure 1 Vibration analyser
Source: (Motionics, 2022)

3.2. Infrared thermography

Infrared thermography is a modern technology that uses cameras to measure and image the infrared radiation emitted by bodies without the need for visible light. As this radiation is a function of the body's surface temperature, the camera allows the calculation and visualisation of the body's surface temperature.

In recent years it has become a key and affordable technology with multiple applications in numerous professional fields. It is being used from energy efficiency diagnostics in industrial and building installations, to medical diagnostics, research, art and security (Pérez, 2016). It is a technique that studies the temperature behaviour of machines in order to determine whether they are operating correctly. The energy that machines emit from their surface travels in the form of electromagnetic waves at the speed of light; this energy is directly proportional to their temperature, which implies that the greater the heat, the greater the amount of energy emitted.

Because these waves are longer than the human eye can see, it is necessary to use an instrument that transforms this energy into a visible spectrum in order to observe and analyse the distribution of this energy. Figure 2 shows the instrument used to generate an image of infrared radiation from the surface temperature of the machines, which is called a Thermographic Camera (Olarte, 2010).

Figure 2 Thermal imaging camera
Source: (Fluke, 2022)

Thermal imaging has developed into an indispensable aid in the maintenance of buildings and technical installations. Invisible infrared radiation not only makes it possible to monitor the function and condition of electrical and mechanical installations safely, but also to detect weak points and wear and tear in a timely and non-destructive manner, enabling timely solutions to be found. In addition, thermography provides services for quality control and fill level measurement of technical production facilities.

For example, system management enables perfect control of heating systems as well as simple and safe inspection of electrical systems (Testo, 2019).

3.3. Oil analysis

Oil analysis is one of the most important tools for preventive maintenance and allows quick and accurate laboratory evaluations of the lubricant used in equipment. With oil analysis, it is possible to detect both wear on moving parts of equipment and the presence of contaminants. An accurate diagnosis from oil analysis allows the people responsible for the maintenance of your company's machines and equipment to identify more quickly and even anticipate possible errors, avoiding compromising service performance or product quality. By betting on oil analysis, companies have only benefits. The useful life of components is extended, thus reducing expenses with replacement materials, unnecessary oil changes and labour for unscheduled maintenance (ALS, 2022).

This technique determines the operating condition of machines by studying the physical and chemical properties of their lubricating oil. Oil is very important in machines because it protects them from wear, controls their temperature and removes impurities. When the oil presents high degrees of contamination and/or degradation, it does not fulfil these functions and the machine starts to fail. The oil analysis technique makes it possible to quantify the degree of contamination and/or degradation of the oil by means of a series of tests carried out in specialised laboratories on a sample taken from the machine when it is operating or when it has just stopped.

The degree of contamination of the oil is related to the presence of wear particles and foreign substances and is therefore a good indicator of the condition of the machine. The degree of degradation of the oil serves to determine its condition because it represents the loss of lubricating capacity caused by a change in the properties of the oil and its additives. The contamination in an oil sample is determined by the quantification of: metallic wear particles, fuel, water, carbonaceous and insoluble matter. The information from the physical and chemical tests of the oil allows to decide on the lubrication and maintenance plan of the machine (Olarte, 2010).

ISSN 2523-6822

3.4 Ultrasonic detection

It is a very useful technique in Predictive Maintenance because it is used to detect the exact place where some type of breakdown or fault is occurring. For this reason, this detection technique is currently used throughout industry in Predictive Maintenance in the equipment of production plants, taking advantage of the properties of sound waves. That is why the use of ultrasound in Predictive Maintenance is an important tool for the development of the industry. Because it makes it possible to detect and locate problems in equipment long before they cause interruptions that lead to large economic losses (IMG, 2020).

Ultrasound is defined as "Sound waves with frequencies above the human audible limit, or in excess of 20,000 cycles per second (Hertz)". Because of this, this inaudible sound must be transformed into frequencies or signals that we can detect. Ultrasonic detectors measure the ultrasonic decibels and convert them into audible frequencies that can be heard with headphones. On the principle that faults emit ultrasound, it is possible to detect them by measuring the decibels of ultrasound they emit, as the decibels of ultrasound detected will increase exponentially in their presence. By means of ultrasound detection and analysis it is possible to detect faults in: poorly lubricated or defective bearings; leaks in piping systems pressurised by any type of gas; leaks in vacuum systems; presence of electric arcs in motors, transformers and electrical installations.

This technique used in predictive maintenance, which is part of the so-called non-destructive testing, allows the detection of faults in multiple systems and mechanisms even earlier than, for example, vibration analysis. The detection of incipient failures allows the programming of corrective actions without affecting production, without downtime and providing for the supply of spare parts in time (Olarte, 2011; Díaz, 2019). Ultrasonic fault detection is an easy, fast and effective method in noisy environments. Ultrasound accurately locates those areas where there are incipient problems. All this allows the proper scheduling of predictive maintenance of equipment without hindering the normal development of the company.

It is important to know that all mechanical and electrical problems, as well as vacuum or pressure leaks, generate ultrasonic waves. These are detected by means of meters in order to locate the problem and take corrective action to solve it. So to detect ultrasound, an instrument called an ultrasonic detector is used, designed to capture ultrasonic waves and convert them into signals with frequencies within the range of human hearing. This device has the technology so that once converted, the waves can be heard through headphones or displayed on a screen. Figure 3 shows an ultrasonic detector via headphones, and Figure 4 shows one via a display.

Figure 3 Ultrasonic detector with earphones
Source: (Zamtzu, 2022)

Figure 4 Ultrasonic detector with display
Source: (Zamtzu, 2022)

ISSN 2523-6822

Ultrasonic detectors are easy to use equipment where the sound is directional. Thus, the operator can check any area by locating the source of the problem which manifests itself as a much louder sound than at other points. These detectors have a frequency selector that allows the operator to filter out ambient noise and hear the ultrasonic wave clearly. The internal design of an ultrasonic detector is shown in Figure 5 (Olarte, 2011; IMG, 2020).

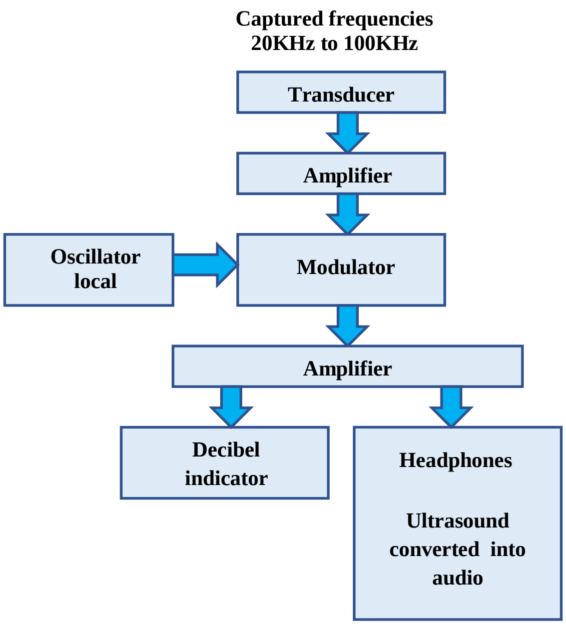

Figure 5 Internal design of an ultrasonic detector
Source: (Olarte & Botero, 2011; IMG, 2020)

4. Development of the Ultrasonic Detector

Figure 6 shows the block diagram of the ultrasonic detector.

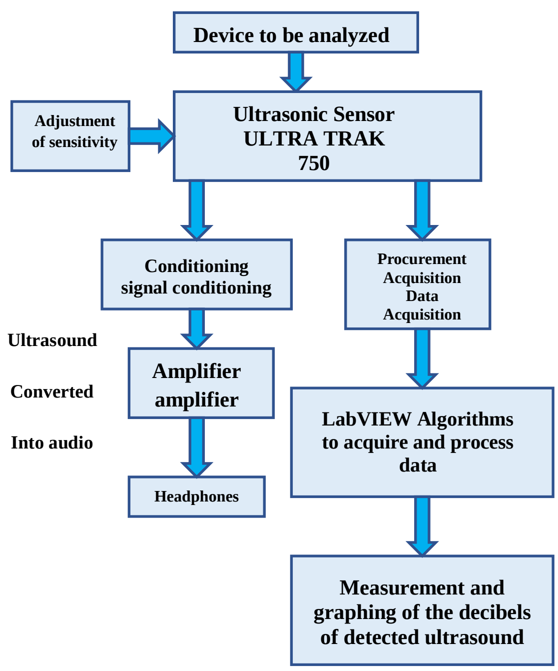

Figure 6 Block diagram of the ultrasonic detector
Source: (Diaz, 2019)

A ULTRA-TRAK 750 UE System sensor is attached to the mechanical system that is intended to sense the ultrasound it emits. This is a contact ultrasonic sensor and is shown in Figure 7.

Figure 7 Ultrasonic detector Ultra Trak 750
Source: (UESYSTEM, 2022)

The sensor has a current source proportional to the decibels of ultrasound detected, the operating range of this source fluctuates between 0 and 30 milli amperes (mA) and is proportional to the detected ultrasound peaks in decibels (dB). The output current is converted to voltage by passing it through a 249 Ω resistor. This voltage is proportional to the detected dB and is digitised by a National Instruments NI USB-6008 data acquisition board. The data is fed in real time to a laptop via a USB port. The laptop uses National Instrument's LabVIEW algorithms to acquire data; calculate the ultrasound dB; display and graph it all in real time. The transfer function of the sensor is shown in equation (1) and is used by the algorithms to calculate the ultrasound dB (UESYSTEM, 2022).

$$dB = 2.4403 I_s - 6.5144 \quad (1)$$

Where dB is the detected ultrasound decibels and I_s is the output current in milliamps. The output current is converted to an output voltage by passing it through a 249 Ω resistor according to Ohm's law and is described by equation (2) (UESYSTEM, 2022).

$$V_s = 249000 I_s \quad (2)$$

Where V_s is the output voltage proportional to the dB of detected ultrasound.

ISSN 2523-6822

The ULTRA-TRAK 750 sensor internally converts the detected ultrasound into an audible frequency by heterodyning. The audio is conditioned by a pre-amplifier and a low-pass filter, then amplified in power and channelled to headphones. There are therefore two indicators that ultrasound is detected, the decibel graphs on the laptop and the audio present in the headphones. The ULTRA-TRAK 750 sensor also has two internal lines for adjusting the sensitivity of the sensor, one line can be adjusted manually and the other line can be adjusted from the laptop using an algorithm. Figure 8 shows the prototype of the ultrasonic detector.

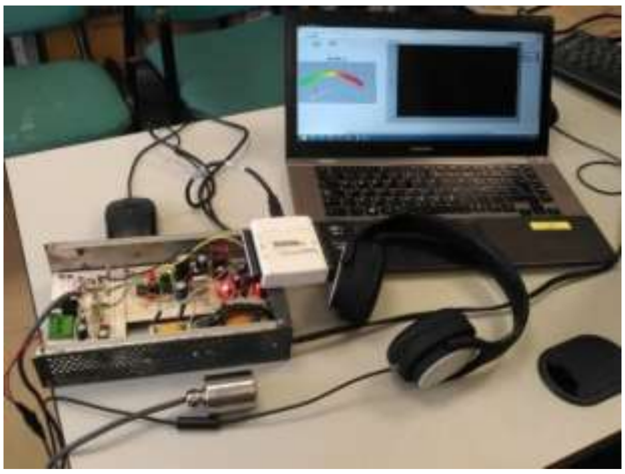

Figure 8 Prototype of the ultrasonic detector

Figure 9 shows the front panel of the LabView algorithms developed by measuring and plotting the ultrasound.

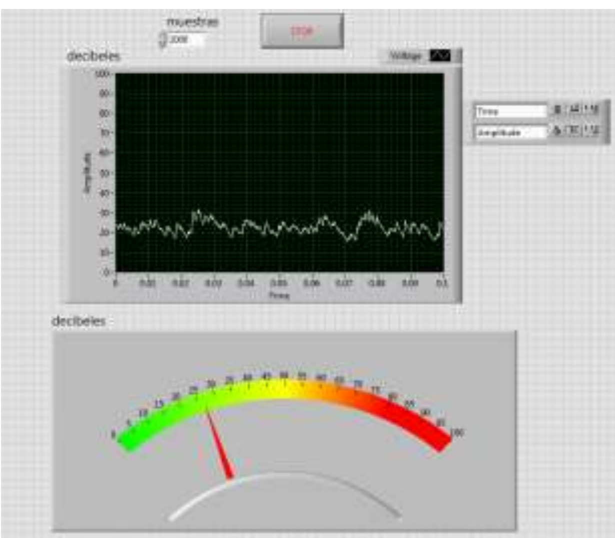

Figure 9 Front panel displaying and graphing dB of ultrasound

5. Results

A pipig system to which a vacuum pressure of 25 inches of mercury is applied was fabricated as a test platform to validate the effectiveness of the ultrasonic detector. The test platform is shown in Figure 10.

Figure 10 Vacuum leakage test platform
Source: (Diaz, 2019)

Several vacuum leakage points are intentionally placed in the initially hermetic system. Table 1 shows the behaviour of the measured ultrasound dB readings in the system with the developed ultrasonic detector in the presence of a leak.

Position	dB ultrasound
At the point of leakage	40
5 cm from the leak	15
10 cm from the leak	12
20 cm from the leak	10
30 cm from the leak	8
At 40 cm from the leak	5
At 50 cm of the leakage	5
At 60 cm of the leakage	5
At 100 cm from the leakage	5

Table 1 Ultrasonic decibels measured at different distances from a vacuum leak using the developed ultrasonic detector

The detector shows small ultrasonic dB readings in the leak-free pipe sections, and little flow noise in the headphones. These readings are due to ambient noise. In the presence of a leak, the measured dB increases exponentially with increasing flow noise in the headphones. Each leak is located by the ultrasonic detector.

Measurements are also carried out on bearings operating in a hydraulic pump. The bearings are known to be in good condition. The dB measurements are small (5 dB) due to the ambient noise as well as the flow noise in the headphones. The same operation is performed but now the bearings are known to be in bad condition. The dB measurements are high (35 dB), as well as the flow noise in the hearing aids. It is observed that the ultrasonic detector discerns between good bearings and those that are defective or poorly lubricated.

6. Conclusions

From the validation of the ultrasonic detector through the tests carried out, it is clear that it performs well, which makes it valuable for use in predictive maintenance. In addition, it can also be used by schools in laboratory practices related to non-destructive testing. The developed system is low cost which makes it accessible to companies with few resources but mainly to educational institutions.

Acknowledgement

Funding: The present work has been funded by the Universidad Tecnológica de Chihuahua for the academic body Sistemas de Mantenimiento Predictivo. The authors would like to thank PRODEP, the Technological University of Chihuahua and the Autonomous University of Ciudad Juarez for their support in different areas.

References

ALS, (2022). El análisis de aceite.URL en https://www.alsglobal.com/%2Fesco%2Fnews%2Farticulos%2F2018%2F07%2Fanlisis-de-aceite-todo-lo-que-usted-necesita-saber-sobre-el-tema

Díaz, A., Duarte, J. & Silva, D. (2019). Detección de fugas de vacío con ultrasonido en moldes para fabricación de asientos de avión en Planta Safran Seats Shells. Revista de Ingeniería Industrial. Marzo 2019 Vol.3 No.7 páginas 11-16

ERBESSD INTRUMENT, (2022). 10 Principios de análisis de vibraciones que debes conocer. URL en https://www.erbessd-instruments.com/es/articulos/analisis-de-vibraciones/

González, F.J. (2010). Teoría y práctica del mantenimiento industrial avanzado.

FUNDACIÓN COMFEMETAL. Madrid, España.

Grainger México, (2022). Catálogo de productos Fluke. URL en https://www.grainger.com.mx/producto/FLUKE

Martínez, J.A., Vitola, O.J. & Sandoval, S. (2006). Fundamentos teórico-prácticos del ultrasonido. Bogotá, Colombia: Tecnura.

Motionics, (2022). Motionics, LLC, Catálogo de productos. URL recuperada de https://www.directindustry.es/prod/motionics-llc/product-161298-1651445.html

Moubray, J. (2009). Introducción al RCM. Editorial Aladon, Ltd, 2001

Olarte, W. & Botero, A. (2011). La detección de ultrasonido: Una técnica empleada en el mantenimiento predictivo. Scientia Et Technica, vol. XVII, núm. 47, abril, 2011, pp. 230-233 Universidad Tecnológica de Pereira.

Olarte, W., Botero, M. & Cañón, B. (2010). Importancia del mantenimiento industrial dentro de los procesos de producción. Scientia et Technica Año XVI, No 44, Abril de 2010. Universidad Tecnológica de Pereira. ISSN 0122-1701

Ortega, D. & Seguel, S. (2004). Historia del Ultrasonido. Santiago de Chile: Providencia.

Olarte, W., Botero, M. & Cañón, B. (2010). Técnicas de mantenimiento predictivo utilizadas en la industria. Scientia et Technica Año XVI, No 45, Agosto de 2010. Universidad Tecnológica de Pereira. ISSN 0122 - 1701.

Pérez, F.I., (2016). La termografía infrarroja: un sorprendente recurso para la enseñanza de la física y la química. Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, vol. 13, núm. 3, pp. 605-615. Universidad de Cádiz. URL disponible en https://www.redalyc.org/journal/920/92046968008/html/

Realibity Web. Com. (2020). Recuperado de https://reliabilityweb.com/sp/articles/entry/ vibraciones-vs- ultrasonido-dos-tecnicas-a-tomar-en-cuenta-en-cbm/.

Testo, (2019). Termografía para el mantenimiento predictivo. Revista de ingeniería eléctrica. URL disponible en https://www.editoressrl.com.ar/revistas/ie/340/testo_mantenimiento_predictivo

UESYSTEM (2022), Manual de usuario Ultra Trak 750. URL disponible en https://www.uesystems.com/esmx/downloads/ manual-ultra-trak-750/

Zamtzu, (2022). Zamtzu Corporation, Catálogo de productos. URL recuperada de https://zamtsu.com/producto/detector-de-fallas-ultrasonico-tud310/

ISSN 2523-6822