International Journal of Applied Engineering Research ISSN 0973-4562 Volume 19, Number 4 (2024) pp. 268-274

Educational Module for Ultrasonic Bearing Inspection

Jorge Duarte Loera[1*], Elva L. Reynoso Jardón[2], Abelardo Díaz Rivera[1], Yahir Mariaca Beltrán[2], Oscar Tenango Pirin[2], Raúl Ñeco Caberta[2], Juan Carlos García Castrejón[3]

[1]Department of Industrial Maintenance, Technological University of Chihuahua. Av. Montes Americanos, Sector 35, C.P 31216,
[2]Department of Industrial Engineering and Manufacturing, Autonomous University of Ciudad Juárez. Avenida del Charro, C. Henry Dunant 450, C.P 32320, Cd. Juárez, Chih, México.
[3]Mechanical Engineering Department, Centro de Investigación en Ingeniería y Ciencias Aplicadas (CIICAp)-UAEM, Cuernavaca, Morelos, 1001, México.

Abstract

The document presents the development of an educational module for examining bearings by ultrasound. The development of the mechanical device is described, where an electric motor drives the bearing under inspection, which can be exchanged for other bearings that present a certain degree of damage such as lack of lubrication, oxidation, and dust contamination. The bearing failure types are identified from the ultrasonic decibel (dB) readings generated when operating. Also, the development of an ultrasonic detector that measures the dB of ultrasound that the bearings emit is described, which allows the type of failure to be identified. Likewise, experiments that validate the functionality of the module are shown. The educational module developed is economical and can be replicated in educational institutions, or by the training departments of companies that use bearings in their machinery. In addition, the ultrasonic detector is useful in the industry to find other types of faults that generate ultrasound in machinery and facilities.

Keywords: Ultrasonic detector, Ultrasonic analysis, Bearing failures.

Introduction

An educational module has been developed for the ultrasonic inspection of bearings, suitable for training maintenance personnel in companies that utilize bearings in their machinery and useful for educational institutions that include bearing failure identification in their curricula. The type of damage that a bearing presents is identified by measuring the increase of ultrasound dB levels, based on a reference dB level established when the bearing is new. A mechanical device was designed to drive the bearing under inspection at 1400 revolutions per minute (RPM) using an electric motor. This device allows for the exchange of bearings with various failures, such as lack of lubrication, oxidation, or contamination. An ultrasonic detector was also developed to measure the ultrasound dB generated by the bearing over two seconds, displaying the measured dB graph and averaged dB value as a result. Tests were conducted to validate the educational module's functionality by identifying various types of failures based on the increase of measured ultrasound dB levels generated by the bearings.

Ultrasound refers to any sound wave with a frequency greater than 20,000 Hertz (20 kHz), making it inaudible to the human ear. The characteristics of ultrasound that make it highly applicable in engineering include its ability to be directed as a beam, in compliance with the laws of reflection and refraction, and the capacity to be reflected by small objects [1]. Furthermore, ultrasound can propagate through solid, liquid, or gaseous media [2]. Sonar, an important application of ultrasound, enables the creation of seabed images, which is crucial for ship and submarine navigation [3]. Another significant use of ultrasound is in non-destructive testing (NDT). The NDTs are a valuable tool for industry, allowing to evaluate the material quality through non-invasive means by sending an ultrasonic burst and analyzing the reflected ultrasound to detect cracks [4]. One technique employed by NDTs is ultrasound analysis for predictive maintenance [5].

Predictive maintenance encompasses a series of techniques employed in industrial maintenance to provide early-stage information on equipment status. This enables scheduling corrective actions during periods that do not impact productivity. The techniques utilized in predictive maintenance include vibration analysis, infrared thermography, oil analysis, and ultrasound analysis. Ultrasound analysis is a technique that determines the status of a machine or its components by measuring the ultrasound dB emitted by defects [6]. By measuring ultrasound dB and applying the principle that faults generate ultrasound, it is possible to detect poorly lubricated or deficient bearings, excessive friction between mechanical parts, pressurized gas leaks, vacuum leaks, electric arcs in equipment and installations, and cavitation in hydraulic systems [7]. The equipment used to measure ultrasound dB is the ultrasonic detector, which identifies faults in areas with maximum dB readings [8]. Notably, ultrasonic detectors for predictive maintenance can detect faults at earlier stages than vibration analysis [9]. Figure 1 illustrates an ultrasonic detector for predictive maintenance, displaying the measured dB graph and average dB value for a specific time segment as a result of its measurements.

Figure 1. Ultrasonic detector [10]

One of the most significant applications of ultrasound is monitoring bearings in machinery and industrial equipment. Bearings are mechanical components that reduce friction between a shaft and connected parts through a support that facilitates movement. They are rolling elements widely used across various industries. Figure 2 shows an NSK bearing (Nippon Seiko K.K. Company), and Figure 3 illustrates the bearing mounted in its support (pillow housing) [11]. Every type of bearing, new or used, emits ultrasound waves generated by the friction between its parts. By analyzing changes in the ultrasound dB emitted by the bearing, its condition and potential problems can be determined. Ultrasonic bearing monitoring offers a reliable diagnostic capability. When changes in the measured dB begin to occur in the ultrasonic range, there is still time to plan maintenance and to avoid unnecessary downtime. Research from the National Aeronautics and Space Administration (NASA) indicates that when a bearing enters in its initial stages of failure, there is an increase in the dB compared to a baseline established when the bearing is in good condition. Continuous monitoring of the dB emitted by the bearing with an ultrasonic detector allows to identify signs such as lack of lubrication, early stages of failure, and catastrophic failure. Table 1 shows the corresponding failures in bearings based on the levels of change in the ultrasound dB that they emit [12]

Figure 2. Bearing [11]

Figure 3. Support Mounted Bearing [11]

Table 1. Failures according to dB of change [12]

Type of fault	Levels of change
Lubrication failure	8 dB
Beginning of failure stage	16 dB
Catastrophic failure	35 to 40 dB

Materials and Methods

Figure 4 shows the block diagram of the materials and the methods used in the educational module for the ultrasonic bearing inspection. Initially, four new and identical bearings from the same manufacturer and model are used, each of them in optimal condition. One bearing is kept in its original condition to establish the reference dB level. The other three bearings are intentionally damaged: one is contaminated with dust, another is degreased of lubricant, and the last one is immersed in water to cause oxidation. A mechanical device was developed to rotate the bearing under inspection, allowing for easy exchange of bearings to determine the type of fault they present. As shown in Figure 4, the bearing in good condition is installed in the mechanical device, and its emitted dB is measured for 2 seconds to establish the reference dB level with the average dB value. An ultrasonic detector was developed to measure the dB using a contact ultrasonic sensor, displaying a graph of the measured dB and the average dB value. The bearing in good condition is then replaced with another bearing known to have a fault, such as lack of lubrication, oxidation, or dust contamination. The ultrasonic detector measures the dB generated by the faulty bearing, and the average dB is subtracted from the reference average dB to determine the level of change. Based on the level of change, the bearing defect is identified using the information in Table 1. The developed educational module enables the identification of bearing faults based on the increase in measured dB levels. In industry, early detection of bearing faults allows for planned corrective actions during non-productive periods.

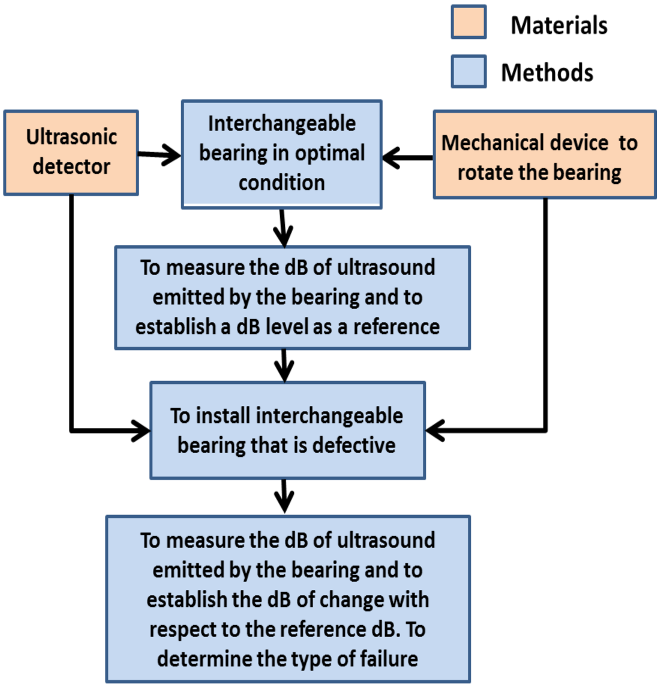

Figure 4. Materials and methods implemented

Figure 5 shows the mechanical device developed to rotate the bearing under inspection. A 120-volt alternating current (VAC) motor operates at 1400 revolutions per minute (RPM) and drives, via a belt, a pulley connected to a transmission shaft supported by two bearings. One end of the transmission shaft is attached to a support housing the interchangeable bearing under inspection, designed for easy replacement during testing. Safety guards are also shown to prevent accidents during device operation. Figure 6 shows the three interchangeable bearings and their corresponding defects.

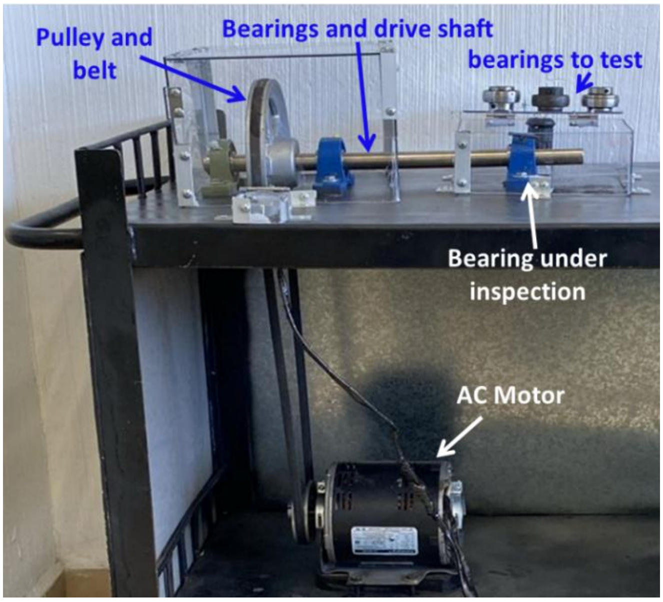

Figure 5. Mechanical device developed

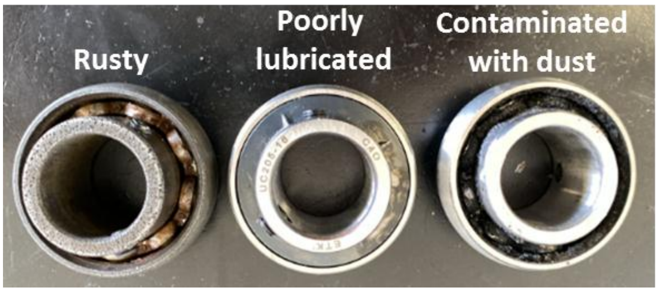

Figura 6. Bearings for inspection

To measure the ultrasound dB in bearings and to identify the type of failure, an ultrasonic detector was developed. Figure 7 shows the block diagram of the developed ultrasonic detector. The UESYSTEM UE Ultra-Trak 750 contact ultrasonic sensor [12] is used to capture the ultrasound generated by the bearing under inspection, requiring a 24-volt direct current (VDC) power supply. A regulated 24 VDC source is developed from the 120 VAC line voltage. The 120 VAC is stepped down to 24 VAC using a transformer capable of supplying at least 100 milliamperes (mA). The 24 VAC is then converted to VDC using a 1 ampere (A) rectifier diode bridge and a 2200 microfarad (µF) capacitor. The output voltage of the rectifier bridge is 33.8 VDC, calculated using equation 1 [13].

$$V_{dc}\ out = \sqrt{2}\ \ V_{ac}\ in \quad \textbf{(1)}$$

where:

$V_{dc}\ out$ = VDC at the output of the diode bridge

$V_{ac}\ in$ = VAC at the input of the diode bridge

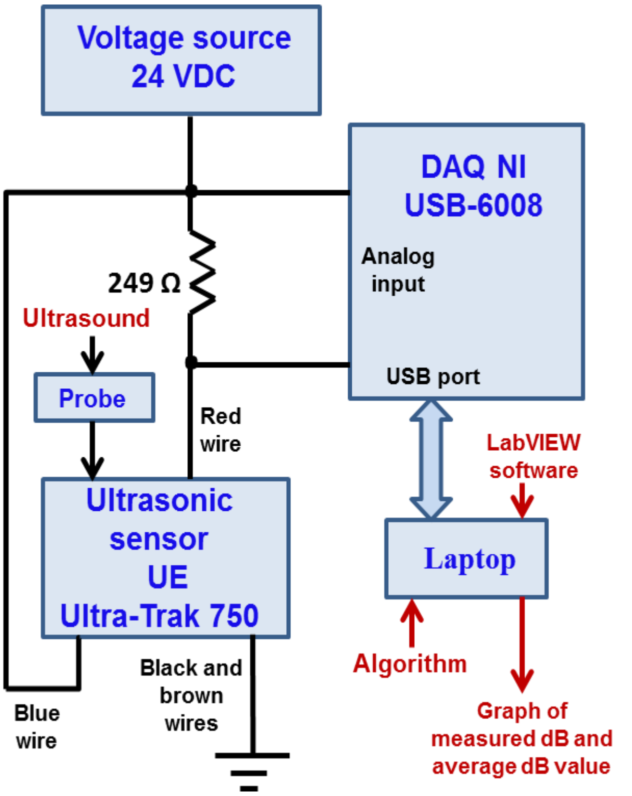

Figure 7. Ultrasonic detector

The 33.8 VDC is converted to a regulated 24 VDC using the LM7824 regulator [14]. The 24 VDC is then filtered with an LC filter [13]. As shown in Figure 7, the Ultra-Trak 750 ultrasonic sensor has a series of color-coded wires for control. The black and brown wires are connected to the ground, while the blue wire is connected to 24 VDC to enable maximum sensitivity mode. The red wire is connected to 24 VDC through a 249 Ω current-limiting resistor. The voltage drops across the 249 Ω resistor generate an analog signal proportional to the dB of ultrasound detected by the sensor probe [12]. This signal is digitized at 10,000 samples/second and 12-bit resolution by the National Instruments' DAQ NI USB-6008 card [15]. The digitized data is then sent from the DAQ NI USB-6008 to a laptop via a USB port for processing.

A graphical software, LabVIEW 2020, was utilized [16] to develop an algorithm responsible for data acquisition and processing, which displays a graph of the measured dB and average dB value as output. Figure 8 illustrates the flow chart of the developed algorithm, which configures the DAQ NI USB-6008 to acquire 20,000 samples at a sampling rate of 10,000 samples/second per measurement. The acquired 20,000 data points are stored in a data vector, as described in equation 2 [17].

$$R(n) = \{R(0), R(1), R(2), R(3), \ldots, R(19{,}999)\} \quad \textbf{(2)}$$

where:

R(n)= vector with the acquired data

n= vector index

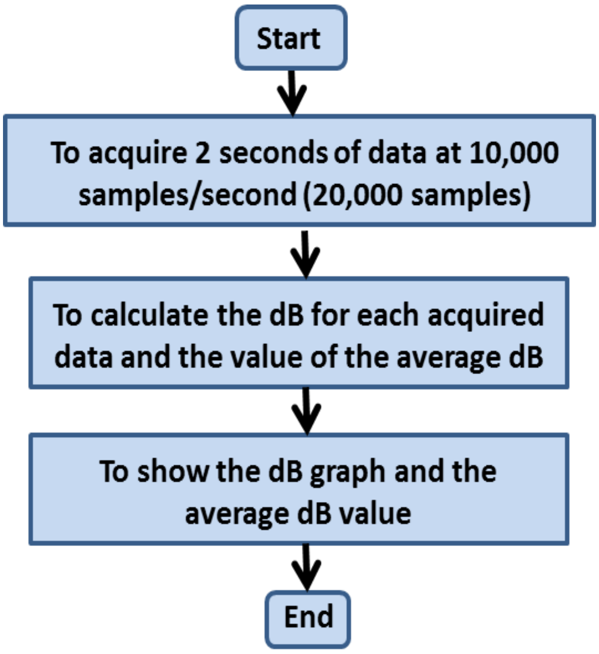

Figure 8. Ultrasonic detector algorithm

The transfer function of the UE Ultra-Trak 750 ultrasonic sensor is provided by the manufacturer and is represented by equation 3 [12].

$$decibels = 2.4403 I_s - 6.51 \quad \textbf{(3)}$$

where:

$decibels$ = dB measured

I_s = current in 249 Ω resistor in mA

The voltage drop across the 249 Ω resistor is indicated by the equation 4 [13].

$$V_s = 249 I_s \quad \textbf{(4)}$$

where:

V_s = voltage drop across 249 Ω resistor

I_s = current in the resistor in ampers

Equation 5 is deduced from equations 3 and 4, with which the *dB(n)* vector is calculated and contains the values in dB for each data in *R(n).*

$$dB(n) = \frac{(2.4403)(1000)}{249} R(n) - 6.5144 \quad \textbf{(5)}$$

The average value *prom* of *dB(n)* is calculated with the equation 6 [17].

$$prom = \frac{1}{20{,}000} \sum_{n=0}^{19{,}999} dB(n) \quad \textbf{(6)}$$

As shown in Figure 8, the algorithm displays the graph of the measured dB for the 20,000 acquired samples and the average dB value as output. Figure 9 illustrates the results presented by the ultrasonic detector for each measurement taken. Figure 10 depicts the educational module inspecting a bearing.

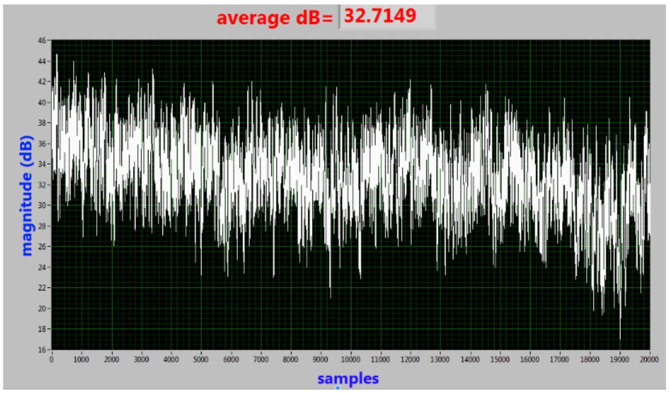

Figure 9. *Ultrasonic detector results*

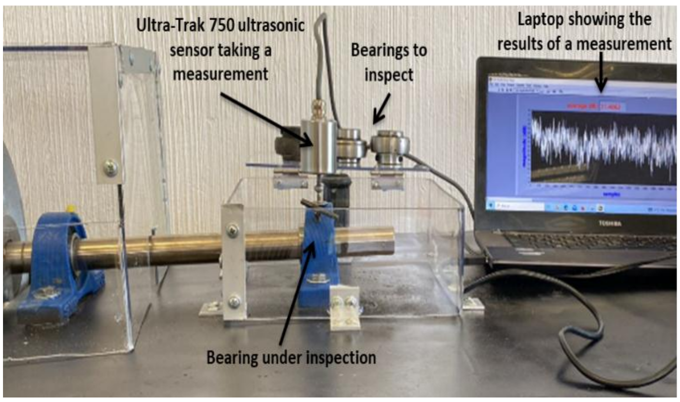

Figure 10. Educational module inspecting a bearing

Results

The functionality of the educational module is validated by establishing a reference dB level with a bearing in good condition and then measuring the dB change from this reference level to identify the type of defect in bearings that are failing. Figure 11 shows a measurement taken on a bearing under inspection, where the Ultra-Trak 750 ultrasonic sensor, along with its probe, is seen measuring the support containing the bearing. A bearing in good condition is installed in the educational module, and its emitted dB is measured for 2 seconds to establish the reference dB. Figure 12 displays the graph of the measured dB and the average dB value, which is used to establish the reference level at 17.1812 dB, based on the measured average dB value.

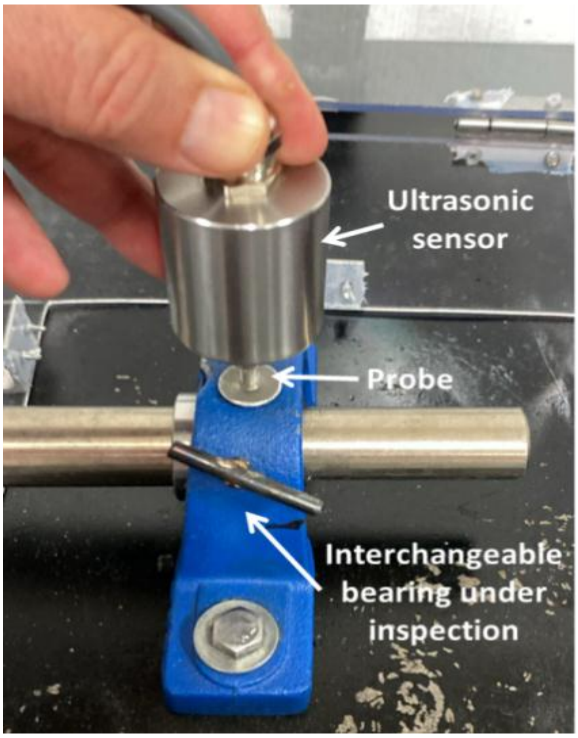

Figure 11. Measuring dB in bearing

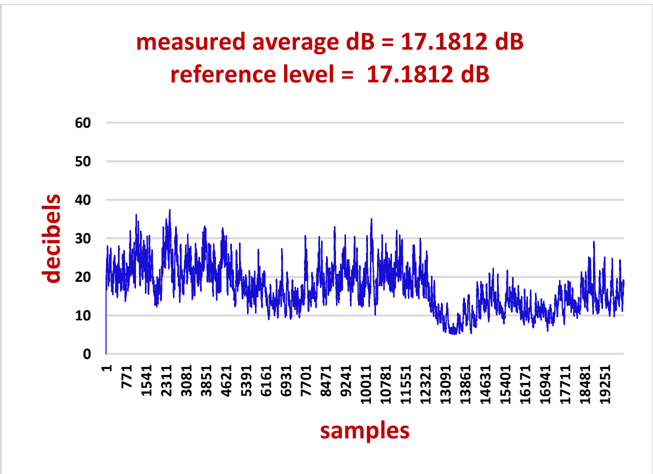

Figure 12. Decibels measured on the bearing in good condition

The bearing with the poor lubrication defect is installed in the educational module, and its emitted dB is measured for 2 seconds. Figure 13 displays the graph of the measured dB, the average dB value (22.9381 dB), and the level of change concerning the established reference level (8.7569 dB). According to Table 1, a measured level of change between 8 dB and 16 dB indicates poor lubrication, which confirms that the bearing lacks sufficient lubrication. In industrial settings, this type of defect is commonly addressed by applying the appropriate lubrication to the bearing, thereby restoring its optimal functioning.

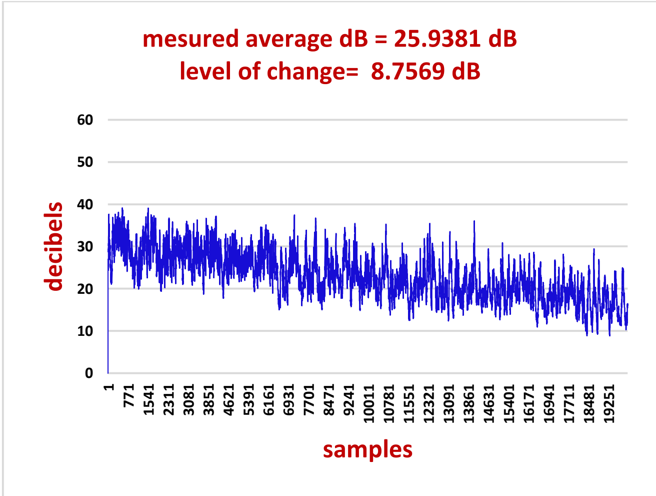

Figure 13. Decibels measured in poorly lubricated bearing

The bearing with the dust contamination defect is installed in the educational module, and its emitted dB is measured for 2 seconds. Figure 14 displays the graph of the measured dB, the average dB value (37.7273 dB), and the level of change concerning the established reference level (20.5461 dB). According to Table 1, this level of change indicates that the bearing is in the early stages of failure, as it falls within the range of 16 dB to 35 dB. In industrial settings, this information suggests that the bearing should be replaced with a new one, allowing for planned maintenance that minimizes downtime and optimizes productivity.

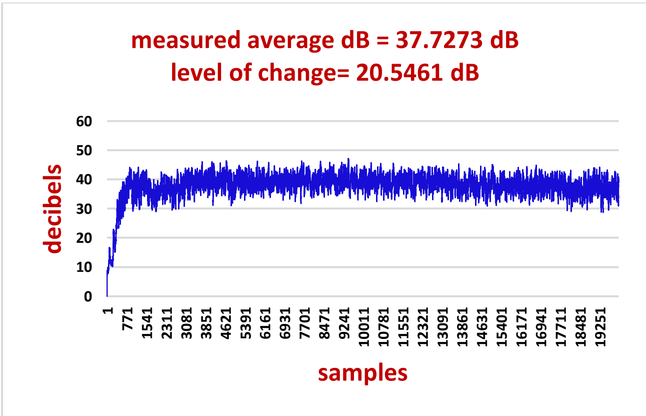

Figure 14. Decibels measured on the bearing contaminated with dust

The bearing with the oxidation defect is installed in the educational module, and its emitted dB is measured for 2 seconds. Figure 15 displays the graph of the measured dB, the average dB value (47.023 dB), and the level of change concerning the established reference level (29.8418 dB). According to Table 1, a measured level of change between 16 dB and 35 dB indicates the beginning of failure, while a change between 35 dB and 50 dB indicates catastrophic failure. With a measured change of 29.8418 dB, the bearing is nearing to a catastrophic failure. In industrial settings, this information still allows for planned bearing replacement, enabling maintenance scheduling that minimizes downtime and optimizes productivity.

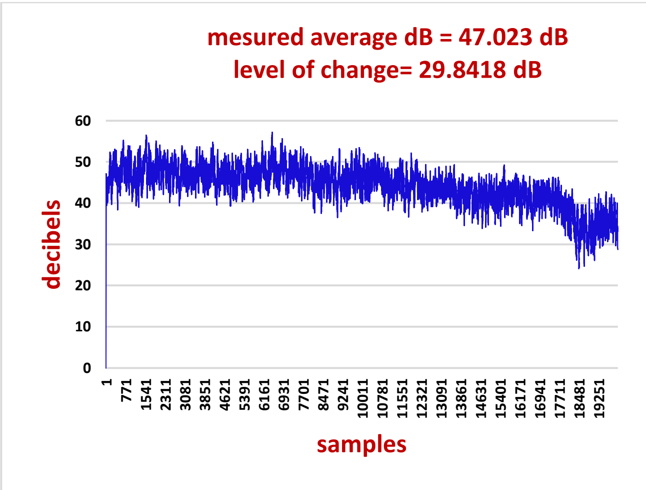

Figure 15. Decibels measured on rusty bearing

Table 2 presents a summary of the bearing fault types identified based on the measured dB change levels using the developed educational module. Additionally, it outlines the corresponding corrective actions commonly taken in industrial settings to address each type of fault.

Table 2. Faults found from measured dB changes

Type of bearing failure	Measured average dB	Established reference level	dB level of change	Corrective action in the industry
Lubrication	25.9381 dB	17.1812 dB	8.7569 dB	Lubricate
Pollution	37.7273 dB	17.1812 dB	20.5461 dB	Plan bearing change
Oxidation	47.023 dB	17.1812 dB	29.8418 dB	Plan bearing change

Conclusions

The reference dB level was established by measuring the average dB generated by the bearing in good condition, which is 17.1812 dB. This reference level was subtracted from the dB emitted by each bearing under inspection to determine the change in dB level, allowing for the identification of the type of failure based on the information shown in Table 1. For instance, the poorly lubricated bearing was identified with a change level of 8.7569 dB, as poor lubrication typically generates a change level between 8 dB and 16 dB. In industrial settings, this type of defect is corrected through proper lubrication. Furthermore, the dust-contaminated bearing presented a change level of 20.5461 dB, indicating the beginning of the failure stage, as this defect typically manifests with a change level between 16 dB and 35 dB. This early detection enables planned bearing replacement in a timeframe that does not impact the productivity. Finally, the oxidized bearing showed a change level of 29.8418 dB, nearing catastrophic failure, as this type of failure typically generates a change level between 35 dB and 50 dB. Early detection allows for timely planning of bearing replacement, minimizing downtime and optimizing productivity.

The results demonstrate that the developed educational module for bearing inspection successfully identifies the type of failure based on the measured dB change in the ultrasonic range, thereby validating the module's functionality and confirming that the objective of this work has been achieved. Furthermore, the information presented in this document enables the replication of the educational module, allowing it to be manufactured for the benefit of other educational institutions or companies that utilize bearings in their processes. Additionally, the developed ultrasonic detector can be applied to various practices, detecting other types of failures that generate ultrasound, such as pressurized gas leaks, vacuum leaks, cavitation in hydraulic systems, electric arcs, and excessive friction between mechanical elements. Its industrial applications also extend to predictive maintenance, enhancing reliability and efficiency.

References

[1] E. Santos, N. Cancino, J. Yenque, D. Rámirez and M. Palomino, "El ultrasonido y su aplicación," *Revista de la facultad de ingeniería industrial, Vol 8, No 1*, pp. 25-28, 2005.

[2] J. Martínez, J. Vitola and S. Sandoval, "Fundamentos teórico-práctico del ultrasonido," *Tecnura, Vol 10, No 20*, pp. 4-18, 2007.

[3] B. Rodríguez, F. Vallejo and D. Ramírez, "Desarrollo de un sistema de detección de distancia en agua mediante sonar activo," in *Desarrollo e innovación en ingeniería*, Medellin, Instituto Antioqueño de Investigación, 2017, pp. 552-563.

[4] E. Pulido, "Los ensayos no destructivos como respaldo a los programas de Mantenimiento," Predictiva 21, 15 Julio 2021. [Online]. Available: https://predictiva21.com/ensayos-destructivos-end-mantenimiento/. [Accessed 30 Mayo 2023].

[5] R. López, C. Trujillo and H. Parra, "Aplication and selection of non-destructive test for the evaluation of welded joints," *Scientia et Technica* , vol. XVI, no. 48, pp. 196-201, 2011.

[6] 6, J. Medrano, V. González and V. Díaz de León,

Mantenimiento. Técnicas y aplicaciones industriales, Ciudad de México: Grupo Editorial Patria, 2018.

[7] R. IMG, "Revista IMG," 30 Enero 2020. [Online]. Available: https://www.revistaimg.com/ultrasonido-una-tecnica-empleada-en-el-mantenimiento-predictivo/. [Accessed 20 Septiembre 2023].

[8] "Preditécnico," Aplicaciones de los ultrasonidos en el mantenimiento industrial , 4 Julio 2012. [Online]. Available: http://www.preditecnico.com/2012/07/aplicaciones-de-los-ultrasonidos-en-el.html. [Accessed 2 Junio 2023].

[9] W. Olarte and M. Botero, "La detección de ultrasonido: una técnica empleada en el mantenimiento predictivo," *Scientia Et Technica*, vol. XVII, no. 47, pp. 230-233, 2011.

[10] C. Zamtsu, "Zamtsu, Corporación," 2023 Sep 2023. [Online]. Available: https://zamtsu.com/detector-de-fallas-ultrasonico-tud310/. [Accessed 20 Agosto 2020].

[11] NSK, "NSK," 13 Mayo 2024. [Online]. Available: https://www.nsk.com/content/dam/nsk/common/catalogs/ctrgPdf/e1102m.pdf.

[12] USER_UT750, "UE SYSTEMS INC," 12 01 2023. [Online]. Available: https://www.uesystems.com/wp-content/uploads/manual-usa-UT750.pdf. [Accessed 10 Mayo 2023].

[13] A. Malvino, "Circuitos con diodos," in *Principios de electrónica*, México, McGRAW-HILL, 1984, pp. 70-121.

[14] LM7824_data, "Data sheet of LM7824," FAIRCHILD semiconductor, 15 March 2023. [Online]. Available: https://pdf1.alldatasheet.com/datasheet-pdf/view/131019/FAIRCHILD/LM7824.html. [Accessed 12 06 2023].

[15] User_USB-6008, "USER GUIDE NI USB-6008/6009," 12 March 2021. [Online]. Available: https://c7076-control.chem.sfu.ca/interlock_monitoring_system_resources/usb6008.pdf. [Accessed 14 June 2023].

[16] J. Lajara and J. Pelegrí, "Introducción a LabVIEW," in *LabVIEW, Entorno gráfico de programación*, México, Alfaomega, 2018, pp. 1-20.

[17] J. Proakys and D. Manolakys, Muestreo de señales analógicas, Madrid: PEARSON. Prentice-Hall, 2007, pp. 18-22.