Industrial approach in vibration analysis of mechanical elements

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Abstract

Predictive maintenance of machinery is becoming more and more important every day, and within maintenance, reliability analysis of equipment operation. During the performance of vibration analysis, noise, present in most of the industrial situations, in which predictive maintenance plays a fundamental role, is one of the main problems that have to be faced while analyzing the vibration levels of machinery. The main purpose of this study is to analyze and identify the different regions in which the main failures that can originate in the bearings, which are located in all industrial machinery. The objective of this work is to identify and isolate from noise, the harmonics coming from defects in bearings. These results enable more accurate vibration analysis to be carried out, optimizing predictive maintenance processes. To carry out this study, a vibration analysis test bench is used in which bearings with different failures are tested and with this it is possible to associate the problem of each bearing not with specific vibration levels but with the probability bands in which are the peaks obtained in their characteristic vibration spectra.

Keywords
Bearings, Machines, Vibration, Engineering and Mechanics.

1. Introduction
Predictive maintenance of machinery is becoming more important every day, and within maintenance, reliability analysis of equipment operation. During the performance of vibration analysis, noise, present in most of the industrial situations, in which predictive maintenance plays a fundamental role, is one of the main problems that have to be faced while analyzing the vibration levels of machinery **(Montes 2009)**.

In the case of failures in bearings, in the industrial context, a failure not detected in time entails a very high cost. Bearing failure can affect other mechanisms. Additionally, it can even cause personnel injury. In addition, when the failure occurs unexpectedly, it can occur at critical moments for the industrial process for which the machine is intended. With preventive maintenance, not only is the repair optimized at the cost of the replacement bearing, but the best time can also be scheduled with respect to the industrial process of the machine. There is currently a growing demand for vibration detection experts from the industry. Given the lack of personnel, it is necessary to train engineering students in these skills, to meet future demand with greater flexibility **(Perrenet 2000, Grocheva 2015, Alam 2014, Chowdhury 2019)**.

1.1 Objectives

The main purpose of this study is to develop an applied training for engineering students in this field. This will focus on analyze and identify the different regions in which the main failures that can originate in the bearings, which are located in all industrial machinery. The objective of this training is to identify and isolate from noise, the harmonics coming from defects in bearings. These results enable more accurate vibration analysis to be carried out, optimizing predictive maintenance processes. To carry out this study, a vibration analysis test bench is used in which bearings with different failures are tested and with this it is possible to associate the problem of each bearing not with specific vibration levels but with the probability bands in which are the peaks obtained. in their characteristic vibration spectra.

2. Literature Review

The failures of rotating machinery can be very critical because these lead to machinery damage, production losses and personnel injury. So, a very important duty of the maintenance department is to prevent these failures when they are in its initial stage. The predictive maintenance by vibration analysis is the best tool for this purpose.

The proposed preventive analysis, with vibration analysis techniques, consists of quantifying and analyzing the vibrations that occur in the machine. Through a sensor, the analog vibration signals, measured over time, are converted to frequency pulses that are subsequently processed. The measurements, carried out periodically, can be compared over time. Thus, the machines will always have vibrations, within their normal operation. It is about effectively detecting those that reflect failures in the bearings of the mechanism. In general, when the operation is correct, the vibrations should be constant and have a low rate. However, failures in the mechanisms cause certain changes in said spectrum of vibrations **(Zarei 2014, J. S. Liu 2012, Dolenc 2016, X. H. Liu 2019, Peeters 2018, Mishra 2016, Rai 2016)**.

3. Methods

Any machine with movements of rotation and/or translation (periodic) generates vibrations. The main causes are rotating and oscillating mass forces, shocks, and gas, flow, or electromagnetic forces.

Vibrations are movements of a part or element of the machine and can be transmitted as noise propagated by solid structures. While the applied forces are constant, these vibrations will also remain constant or vary within corresponding limits.

In the following engineering training a PT 500 test platform is used, with the flexibility to design a series of specific tests related to the diagnosis and control of machines. This platform is showed in Figure 1.

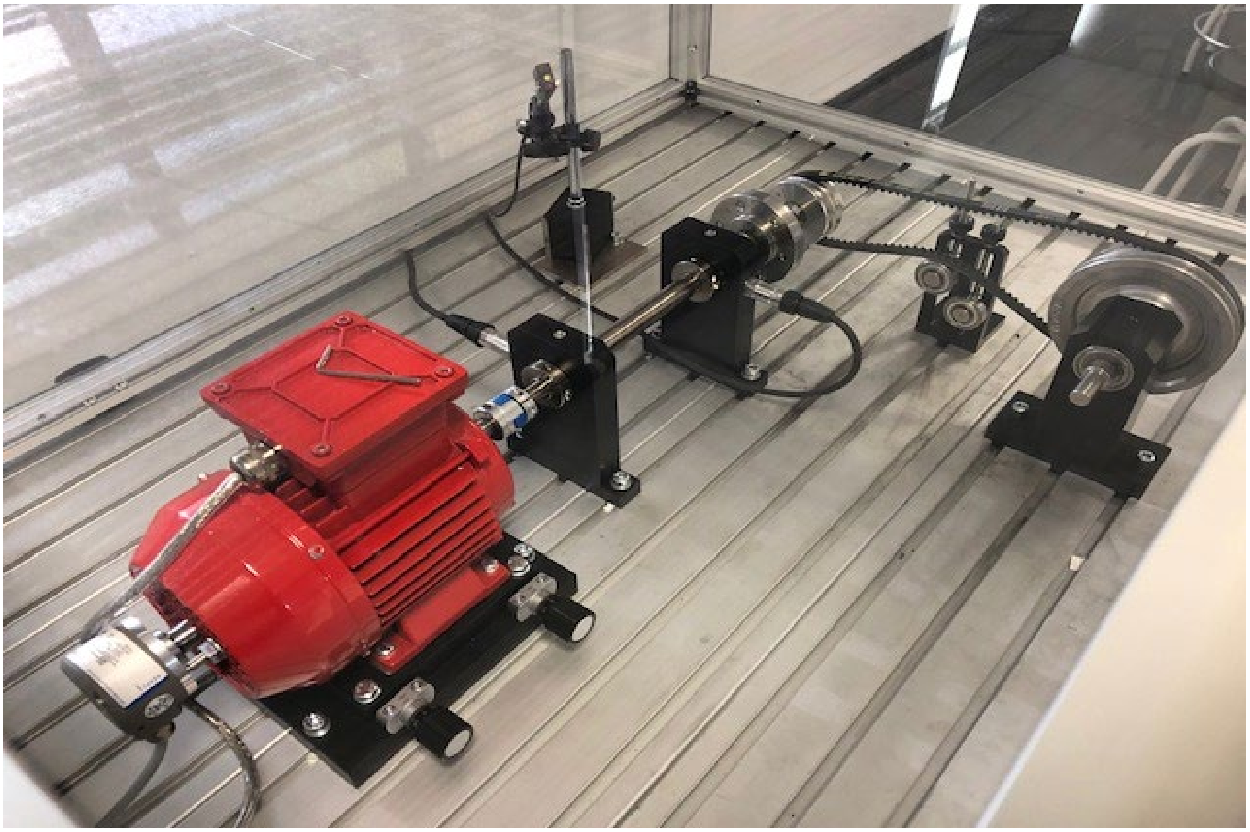

Figure 1. Vibration testing training platform

The system has a three-phase current motor module, which is mounted on a base plate with an alignment device, which allows the motor shaft to be aligned horizontally. The activation of the motor is carried out by the control unit, where there is also a frequency converter and indicator to regulate the number of revolutions without steps.

The objective is to detect possible damage in order to carry out maintenance and repairs, thus reducing machine downtime. For these operations, the vibrations of the machine have been taken into account, since the more vibrations, the worse the condition of the machine. The vibrations produced are measured from a reference transducer with magnetic support, showed in Figure 2, which is an optical reflection sensor and whose mission is to acquire the number of revolutions that occur. To do this, the vibration spectra have been visualized using a computer-assisted vibration analyzer, model PT500.04, since the machine diagnostic system allows us to simulate different damages and observe their behavior in the vibration spectrum. Likewise, the amplitude of vibrations, the speed of vibrations and the acceleration of vibrations in the time and frequency range have been measured.

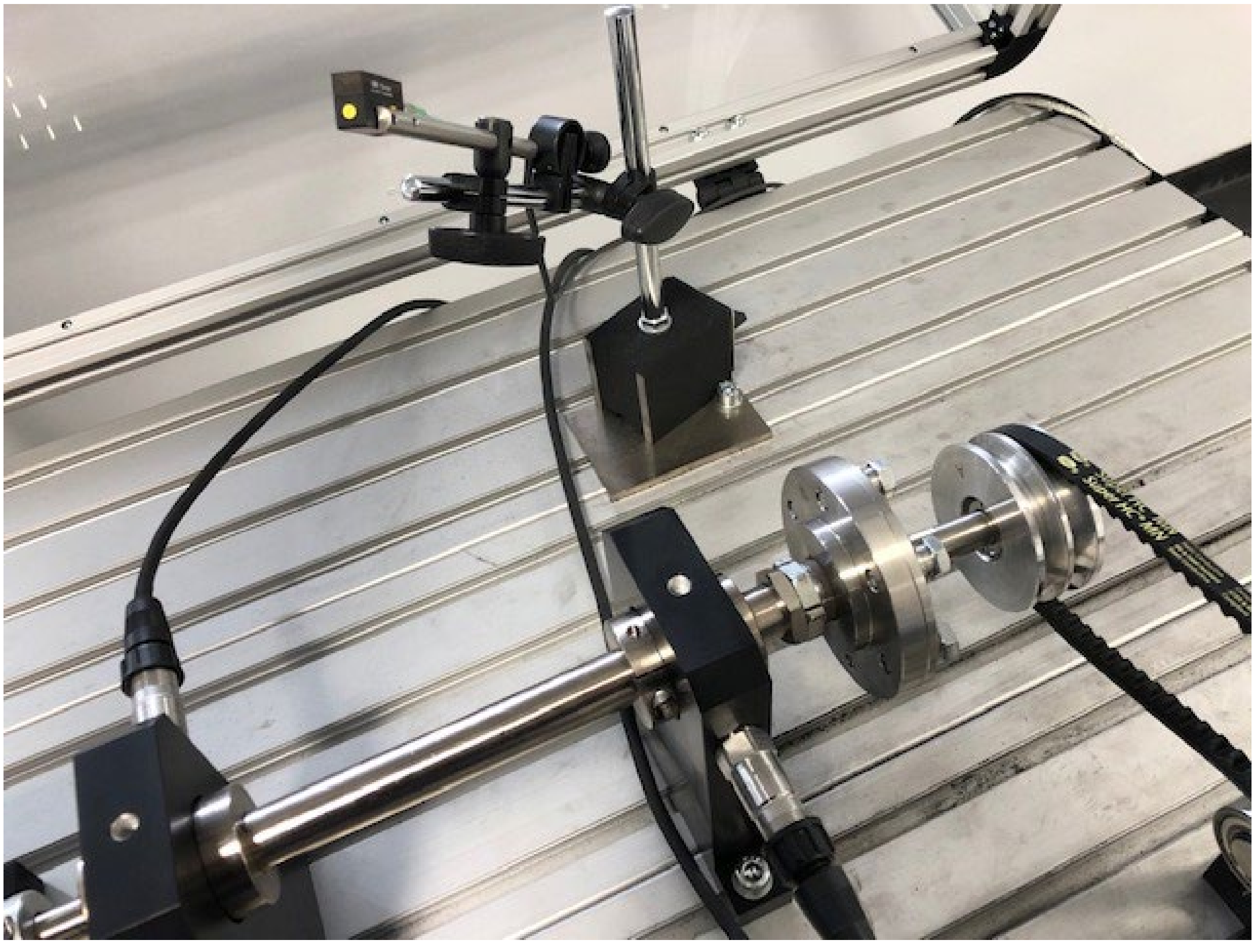

Figure 2. Vibration sensing

All these measurements have been made under the standards and directives to standardize and make the measurements comparable. These standards prescribe that the effective value of the vibration speed should preferably be measured at the bearing points of the machine, that is, in the horizontal, vertical and axial directions at each of them.

Therefore, measurements have been made for the harmonic vibrations in which the measurements of the vibration speed and the analysis of the frequency spectrum have been carried out. For the vibrations caused by shocks, the envelope analysis was also carried out for belt transmission defects and the 2nd order inertia analysis for the crack in the shaft.

The main utility of the equipment is the study and observation of the different damages produced by vibrations, thus reaching the exhaustive behavior of the different effects produced in the machines and being able to mediate a solution in which the downtime is as short as possible. Since generally it is not possible to directly measure the cause, but only the effects. In addition, it also allows practicing balancing rigid rotors in operation.

To carry out the assembly and training, the distances to be able to lower the protective cover, the good adjustment of the system and its correct alignment are taken into account, in addition to bringing the engine to zero revolutions before raising the protective cover.

The diagnosis of the machine is carried out both while it is stopped (disassembly and visual inspection, wear measurements and crack checks) and during operation (measurement of vibrations and noise, displacement, measurement of process parameters and lubricant analysis).

To qualify the type of vibration of the system and whether or not they are harmful to the operation itself, since these can increase or create a crack, in addition to increasing the load and wear, it must be known when the vibrations are admissible, based on the following Figure 3, in group K.

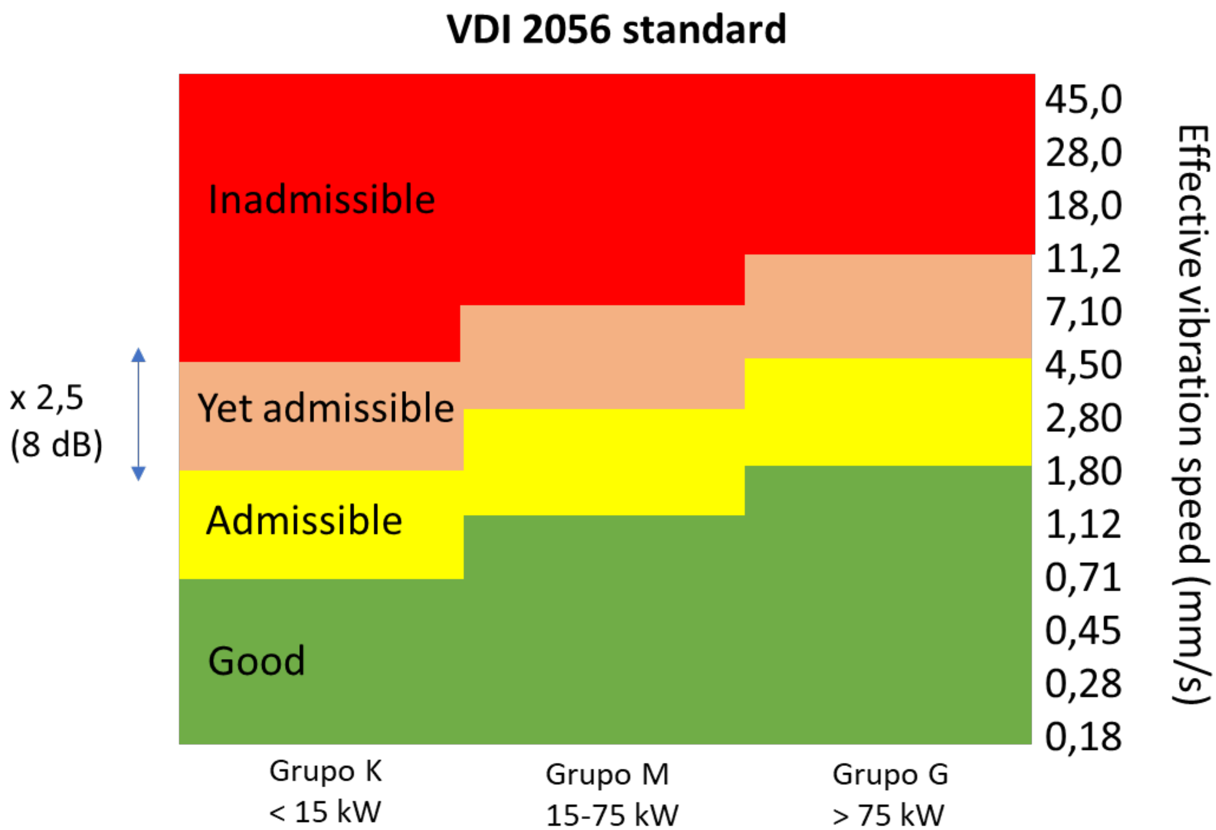

Figure 3. Vibration norm

Next, first training phase is described. Cracks due to material fatigue are very dangerous in rotating machines, as they often cause ultimate failure. A crack in a shaft causes a change in stiffness and thus influences the vibration behavior of the shaft.

Through the first activity it is intended to analyze the variation of the characteristic vibration behavior. Identification of the crack through the variation of the vibration spectrum, detection of cracks in trees, learning to interpret frequency spectra.

For the simulation of the cracked shaft, a union system is assembled in which two shafts of equal dimensions are fixed, one straight, with a slot to couple a tamper plate by means of a pressure thread system. The other shaft has a plate-like end that is connected by holes to the take-up plate connected to the other shaft, as shown in Figure 4.

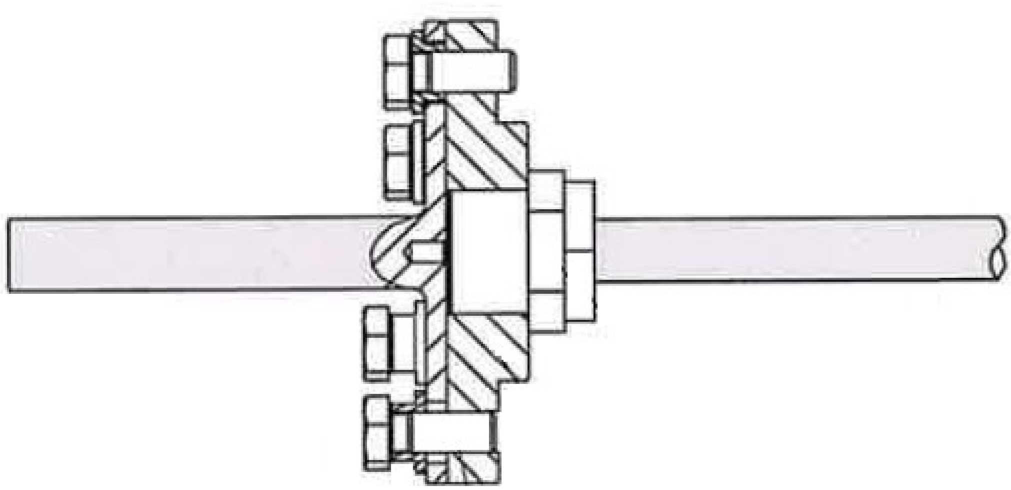

Figure 4. Simulation of training 1

Regarding the simulation of the crack, the connection between the two plates is made by means of screws. These screws have two possible positions, tight or loose, depending on the number of loosely connected screws, the crack is greater or less, In Figure 5, A refers to tight screws.

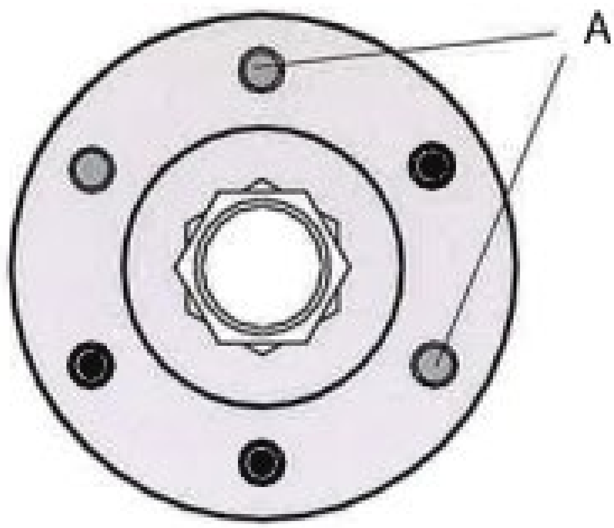

Figure 5. Screws diagram

The second activity focuses on the detection of the different faults in bearings. Defects in bearings are manifested by the fact that the operation gradually worsens. In the analysis, the frequencies of the vibrations produced are compared with the theoretical frequencies. Although the failure frequencies in bearings are normally provided by the manufacturers, it is interesting that future technicians know the fundamentals of one of the most common failures in rotating machines.

The performance of this activity simulates five different cases of bearing failure as is shown in Figure 6. The characteristic frequencies of faults in bearings depending on their location are as follows.

Inner ring error frequency: $f_i = 7{,}324 \cdot \frac{n}{60}$
Inner ring error frequency: $f_D = 4{,}676 \cdot \frac{n}{60}$
Inner ring error frequency: $f_r = 4.313 \cdot \frac{n}{60}$

Figure 6. Training activity 2

4. Results and Discussion

To evaluate the activities in this training, next rubric is developed, Table 1. In this table different rates are considered, according to the competences developed in the fields of organization and writing quality, content, methodology, conclusions.

Table 1. Evaluation rubric

	Organization and writting quality.	Content.	Methodologies.	Conclusions.
0,00 to 2,49	Lack of structure, illegible and/or careless with figures and citations.	Serious mistakes (scale of magnitude, concepts, etc) lack of content (less than 50% of required tasks).	Inadequate methodology for detecting issues.	Results do not provide any conclusion.
2,50 to 4,99	Swallow or badly structured and/or careless with figures and citations.	Serious mistakes (scale of magnitude, concepts, etc) and/or important lack of content.	Do not apply some methods for calculus or estimation of the problem.	Results provide conclusions that do not enable to determine the mechanical problematic.
5,00 to 6,99	The structure is clear enough and figures and citations visible and correctly organized	Not relevant mistakes.	Correct methodology for calculus or problem detection. Not evaluation of different alternatives.	Conclusions enable to define the 50% of the mechanical problematic.
7,00 to 8,99	Correct structure and figures and citations are visible and correctly organized	Without mistakes. All tasks are fulfilled.	Correct methodology for calculus or problem detection. All mechanical aspects are analyzed.	Conclusions enable to define the 100% of the problematic.
9,00 to 10,00	Excellent structure and elaboration.	Without mistakes. All tasks are fulfilled and the student implements new methodologies	The applied methodology means a development of new skills for the student.	Very interesting conclusions.
%	15	40	30	15

Applying this rubric, results are obtained as follows in next graph, Figure 7.

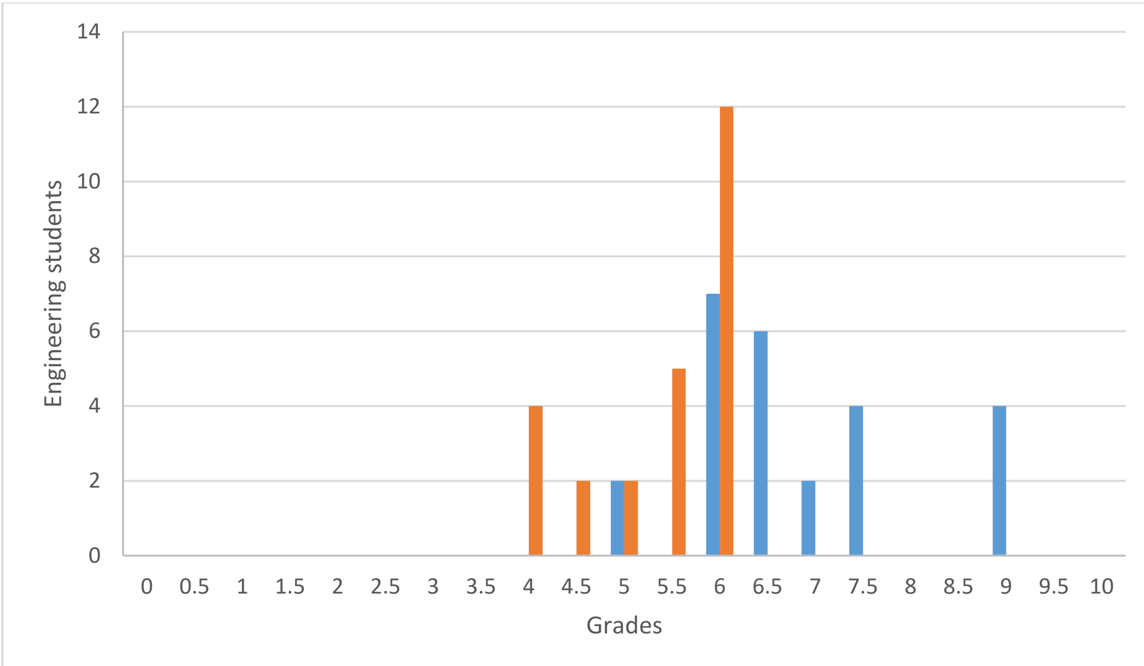

Figure 7. Results from vibration training

In Figure 7 we can see the grades that the students have obtained in the two vibration practices that they have carried out during the academic year. The study was carried out with a total of 25 students. Blue color would be the one corresponding to practice 1, which is in which the vibrations of a tree with a crack are observed. Orange color is the one corresponding to practice 2, which is in which the defects in the bearings are looked at.

In practice 1 it can be seen that none of the students have failed said practice as the lowest grade is 5. 60% of the students have obtained a passing grade (5-6.99), 24% have obtained a mark of remarkable (7-8.99) and 16% of the students an outstanding (9-10).

In practice 2 it can be seen that there is a difference from the first practice in this case 24% of the students have failed (0-4.99) while 76% have obtained the passing grade (5-6.99). In this practice, no student has obtained the qualification of remarkable or outstanding. With this we can see that the average grade has dropped quite a bit between the first practice and the second. Therefore, a new approach is required for the second phase of this training.

5. Conclusion

The practical knowledge acquired results in an improvement in professional skills, which means a great competitive advantage, both for students and for future companies that employ them. Regarding the results, worse than expected results have been obtained, especially in the second practice in which no improvement has been obtained with respect to the errors that had been made in the first. Regarding the difficulty of this practice, it was higher in the second than in the first. The different maintenance techniques, mainly predictive maintenance, allow the reduction of costs derived from inefficient operating practices, so having qualified personnel is crucial in today's companies.

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Biographies

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