Universidad Continental

FACULTAD DE INGENIERÍA

Escuela Académico Profesional de Ingeniería Mecánica

Tesis

Development of a Thermographic Vibratory Test Bench for Predictive Maintenance in Asynchronous Motors

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Para optar el Título Profesional de
Ingeniero Mecánico

Huancayo, 2021

Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: K Vilchez *et al* 2021 *J. Phys.: Conf. Ser.* **1877** 012005

Development of a Thermographic Vibratory Test Bench for Predictive Maintenance in Asynchronous Motors

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Abstract. The predictive philosophy contributes to improving productivity, reducing system failures and reducing unplanned downtime in a non-invasive way to the machine, for which the test bench is based on the German standard VDI2221, using mathematical models to select the materials and the design of the final prototype. The development of the project consists of applying vibration analysis, thermographic analysis and the quality of energy in which each measurement and the correlation that exist between them is shown; in addition, the inverse Fourier transform was used to demonstrate the amplitude and frequency ranges according to the theoretical equation proposed in the Matlab program, it can also be seen the higher order vibrations of 22.1 is located at the same critical point of the SP7 measurement with a temperature of 34.6 ° C and an emissivity of 0.95, likewise the Power quality measurements are within the allowable limits according to ISO 50001; On the other hand, this analysis made it possible to determine the existence of a positive linear correlation between thermography and vibration analyzes with a correlation coefficient equal to 0.828.

1. Introduction
The industrial maintenance is one of the fields of greatest interest in engineering capable of having an economic impact [1], it also develops organizational techniques in advanced industrial maintenance, such as Reliability Centered Maintenance (RCM) and Total Productive Maintenance (TPM). Currently, the machines are involved in 90% of the industrial production and only the remaining 10% is carried out by production personnel; therefore, technified companies are obliged to invest in the preservation and maintenance of their equipment. [2]
On the other hand, the possibility of performing predictive maintenance contributes to improving productivity, reducing system failures, minimizing unplanned downtime, increasing efficiency in the use of financial and human resources, and optimizing the planning of interventions. maintenance, mainly the arrival of the fourth industrial revolution or also known as Industry 4.0, mainly generated the creation of digital presentations of the physical processes to obtain a better understanding of the early signs of an anomaly and to be able to change a reactive repair for a planned [3], for which there are non-destructive methods. In asynchronous motors that require the use of sensors capable of collecting data

on operating parameters, without the need to generate equipment shutdowns to perform predictive analysis [4], such is the case of vibratory analysis, thermographic analysis and power quality.

2. Materials and Methods

The method applied in the research is based on the German standard VDI 2221, which indicates the requirements, conceptual model and the preparation stage for the test bench [6]. For the selection of materials and dimensions, an analysis was carried out on the most critical elements of the project that could generate possible problems in functionality and it was also carried out according to the studies of mechanical properties and concepts of resistance of materials, which was concluded that the design will have a 22 mm diameter shaft made of hot-rolled AISI 1020 steel according to the fatigue failure analysis, in the same way the type of number of the bands were determined, the selection of bolts for the variable motor support and pillow blocks using the load-life-reliability relationship.

Figure 1. Prototype of the 3D design of the vibratory and thermographic test bench designed in Solidworks software.

Figure 1 shows the prototype that has a 4-channel Fluke 810 vibration analyzer that includes triaxial accelerometers with electromagnetic sensitivity of 100 μg/gauss which will provide measurements of the system applied to the ISO 10816 standard, a FLIR T440 thermographic camera with -20 ° C to 1200 ° C intervals [8] on a rotating base, capable of capturing the hottest surface points that occur in critical elements such as the asynchronous motor, bearings, shaft, etc.; it is clear that 15 critical points were considered throughout the prototype.

The segmentations of thermographic images and deterministic signals emitted by mechanical vibrations are displayed in real time on the seven-inch Display Touch screen programmed with the Raspberry Pi4 3b processor, it will also have a pulley alignment system by means of the SKF TKBA brand 40 which it will have magnetic infrared sensors located on both the driving pulley and the driven pulley; the alignment will be possible, since it has a motor fixing plate with variable lateral supports capable of rotating 180°, this system allows aligning and tensioning the drive belt.

In vibrations, the analysis of spectra is related to the transformation of a signal from the domain function in time to the function of the frequency domain, for which the Fourier serie was used in order to represent the vibrational signals in equations.

$$\mathrm{X(t)} = \frac{1}{2}a_0 + \sum_{n=1}^{\infty}[an\cos(nwt) + bn\ sen(nwt)] \qquad (1)$$

Where the Fourier coefficients are defined as a mathematical conversion from the time domain to the frequency domain of the original form, it can be reconstructed from the frequency coefficients: a_0, a_K y b_K will be defined in the following equations.

$$a_0 = \frac{2}{T}\int_{-T}^{T} X(t)dt \qquad (2)$$

$$a_K = \frac{2}{T}\int_{-T}^{T} X(t)\cos(nwt)\,dt \qquad (3)$$

$$b_K = \frac{2}{T}\int_{-T}^{T} X(t)\,\text{sen}(nwt)\,dt \tag{4}$$

Replacing the general equation in coefficient values the following equation is obtained:

$$X(t)=\sum_{n=1}^{\infty}[+\frac{2}{n\pi}[1-(-1)^n]\,sen(nt)]$$

Likewise, the preventive philosophy is also applied in the measurements of electrical parameters, where behaviors of the different energy quality variables were obtained, when the system operates under normal conditions or under fault conditions. Therefore, the monitoring allowed to investigate more in depth the conditions that are being presented, from the power supply in the electrical power supply such as the behavior of the voltage and current RMS, THD, the frequency, the cosine of fi, the factor of power. In addition, the behavior of the active, reactive and apparent powers, the flikers and the harmonics that are generated by the variable speed drive.
In addition, measurements were made at the input of the drive, for the part of the AC power that enters the controller from the power supply, also at the output of the drive, where the AC to DC converter is located, also in the filter DC and in the DC to AC inverter which provides the three-phase power to the asynchronous motor.

3. Results

3.1. Power Quality

By analyzing harmonic distortion records using the NI Crio NI 9023 CPU power quality equipment, with NI 9225 Voltage Measurement, NI 9227 Electrical Acquisition Modules and NI 9227 Current Measurement which works with software, which helps to prevent the increase of temperature and the useful life of asynchronous motor. In addition, the resulting unbalance causes permanent voltage fluctuations (high/low) on single-phase lines, also affecting the asynchronous motor.
3.1.1. Current harmonics, current distortion is displayed, measured on the power supply in the dyno system, harmonic distortion is in odd amounts in the limit range of 0.0001A to 1A.

3.1.2. Fundamental voltage unbalance, as the quality of energy detected by the test bench is essential in the energy alteration that occurs in the tests according to the regularity of frequency and voltage; That is why, it shows its diagram of percentage of voltage, which is incorporated new charges to the electrical system, therefore there are changes of sine waves, in this case we can interpret that the highest peaks occur at 6.4%; that is to say, that they have different load levels greater than that established which is 3% according to the ISO 50001 stand.

3.1.3. Current measurement, according to the power quality measurements of asynchronous motors, it is determined by active power, reactive power in which asynchronous motor unbalances are determined on the test bench.

In figure 4 the current is shown in ranges from 1.42A to 1.56A, which means that it is limited to asynchronous motor conditions, that is, there are physical changes that alter the equipment.

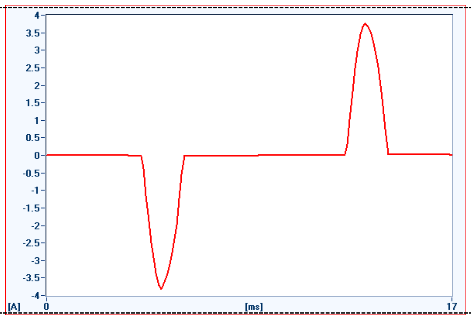

Figure 2. The test bench measurement is shown with respect to the current distortion that was detected relative to the ideal sine wave.

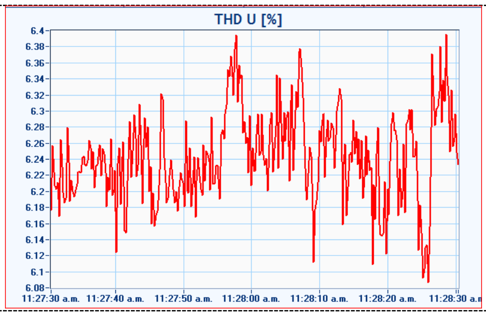

Figure 3. Fundamental voltage unbalance out of range; there are overloads due to asynchronous motor.

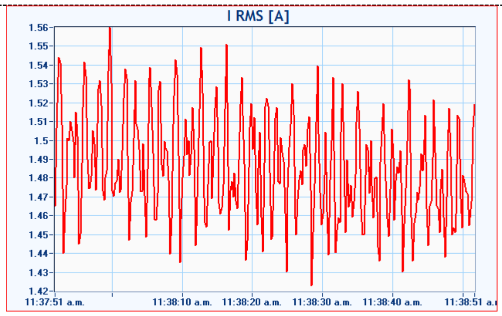

Figure 4. Power quality, the current intensity is shown according to the signals of the asynchronous motor being measured, the voltage is out of range; that is, there are overloads due to an asynchronous motor.

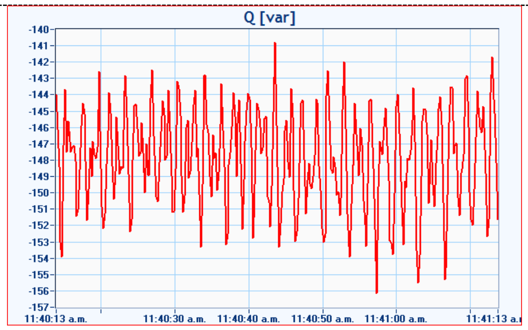

Figure 5. Shows the reactive power of the phase difference with respect to the voltage, out of ranges due to magnetic field conditions, therefore there is transformation of the effective work of the asynchronous motor that fluctuates through the network between the generator and the receivers.

3.2. *Mechanical vibration analysis*.
The following figure shows the measurement performed by the triaxial accelerometer and the ranges predetermined by the ISO 10816 standard are observed, also showing the natural frequency and its present harmonic faults.

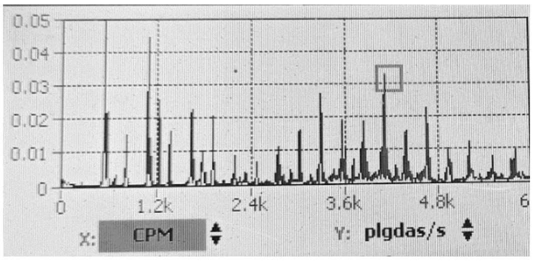

Figure 6. The peaks measured by the test bench in compound sine waves are shown in amplitude factors and cycles per minute.

In the theoretical demonstrative process, we use the Fourier series mentioned above, to check the amplitude and frequency ranges according to the theoretical equation proposed where it is parameterized in time factor, for this the simulation was carried out in the Matlab program.
Figure 7 shows the behavior of the sum of simple harmonic signals in amplitude factor and time, where the amplitude is in ranges from 0inch/s to 0.05inch/s, that is, it complies with the range of data obtained by the bank. asynchronous motor testing.

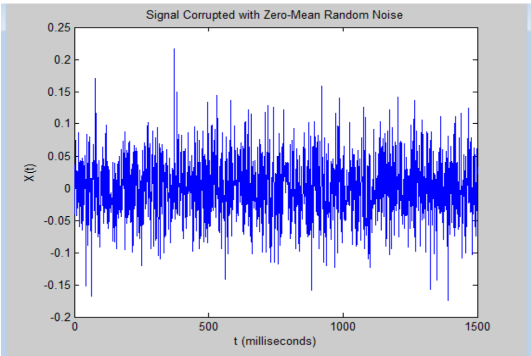

Figure 7. Measurement and theoretical simulation of the test bench in the Matlab software of the asynchronous motor where the average amplitude is 0.03 inch/s in the order of 6.68, thus determining the low level that exists in the measurement of the asynchronous motor.

3.3. Thermographic Analysis

The temperature display reflects the measurement of heat or thermal energy to determine the index of mechanical problems, in the developed test bench it contributes to the measurement of thermography with the Flit T440 camera, thus helping to interpret the causes and relationship between temperature. and vibrations.

In figure 8 the application of the thermography technique is observed, as well as the different temperatures throughout the system, which is intended to be continuous monitoring.

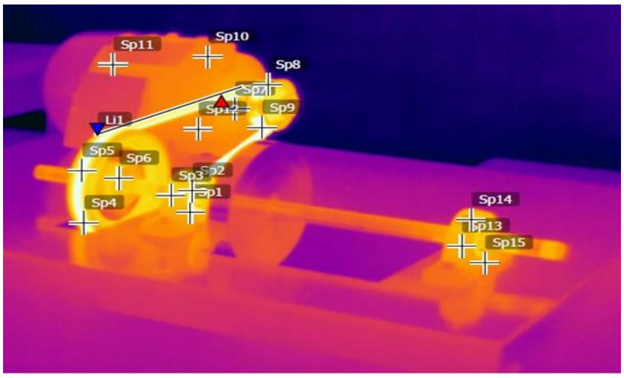

Figure 8. Thermography measurement of the asynchronous motor through the Flit T440 camera, it is observed that the maximum temperature is 34.6 ° C in the transmitted pulley.

In the measurement of thermographic data obtained by the test bench, it shows the temperature ranges and the emissivity of temperature levels, which are related to the vibration process that exists in the asynchronous motor.

3.4. Variable Correlation

In the correlation that exists between thermography and vibrations shows that the measurement range of the asynchronous motor has an average of 0.023 inch in amplitude, this agrees with the temperature of 26.96 ° C, we show that at higher vibrations there is detection of calorific images which gives us the testing bench. The amplitude and temperature correlation are within the ranges of the ISO 10816 standard, this determines conjugated results showing direct data of what happens in the test bench.

Table 1. Unified data on temperature and vibrations.

Measurements	Thermography	Vibrations		
	Temperature(°C)	Amplitude(inch/s)	Order	Level
SP1	26.8	0.03	3.5	Low
SP2	26.7	0.02	6	Low
SP3	32.4	0.02	3	Low
SP4	30.6	0.01	4	Low
SP5	22.4	0.03	8	Low
SP6	23.4	0.01	7	Low
SP7	34.6	0.01	22.1	High
SP8	22.4	0.03	2.26	Low
SP9	23.6	0.03	7.5	Low
SP10	26.5	0.04	3.5	Low
SP11	23.4	0.01	6	Low
SP12	25	0.03	8	Low

SP13	26.89	0.01	3.5	Low
SP14	32.3	0.04	12	Low
SP15	27.4	0.03	4	Low
Total average	26.96	0.023	6.69	Low

The data obtained by the test bench in thermography and vibrations correlating in instantaneous tests of the variable.

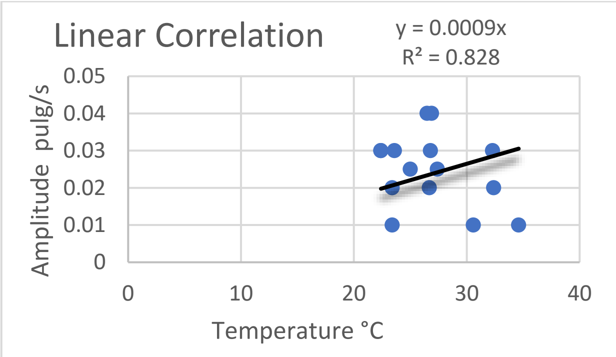

Figure 9. Correlation between vibration and thermography variables in unified asynchronous motor data.

4. Discussions

Most induction motor problems cause a reduction in machine speed, higher current consumption and especially economic losses. In general, a relationship of vibrations, thermography and power quality was determined in which the highest temperatures and vibrations located in the main bearing of the asynchronous motor and high current peaks at the time of ignition were detected due to the anomaly in the Bearing; In the Electric Energy Research Institute (EPRI), studies of failures in induction motors were carried out, where 41% of failures are caused by bearings and bearings, 37% of failures by the stator winding, 10% by failures in the rotor and 12% various failures [12], this reflects that an analysis with more processes integrated in the PdM (Predictive Maintenance) turn out to be more precise and reliable, adapting to the new challenges of Industry 4.0 [1].

It should be noted that, to reduce current consumption, a fractional PI controller must be used which reduces the steady state error from 2.4 to 11 and in the same way reduces the stabilization time of the motor near the ranges of 1.93 to 0.85 [13].

Likewise, it is important to mention that to choose a thermal camera in PdM the thermal sensitivity, precision, spatial resolution and frequency of the image must be taken into account [14].

5. Conclusions and recommendations

The results have shown that the supply voltage, the current and the frequency in real time, generate electrical parameters in current and voltage according to the phase shift distortion that exists in an asynchronous motor. According to the results obtained, the current increase is shown; Therefore, it generated overloads in the system, causing distortion in the effective work; Likewise, it was verified that the levels of THD U, I RMS are within the admissible limits according to the ISO 50001 standard.

The practical results obtained in vibrations by the fluke 810 equipment was supported by Fourier transform analysis, this led to the development of variables and coefficients with respect to time, thus determining the similarity of the measurements with an average of: practical of 0.023 in/s and theoretical 0.02 in/s in amplitude, for the simulation Matlab software was used which showed the composite sinusoidal graph in the parameters of 0.01 in/s to 0.04 in/s similar to the graph of the vibration equipment.

In the thermographic measurement, the radiometric parameters were found at the points where there is greater vibration, where it could be concluded that the results of the vibration and thermographic analyzes are related through the positive linear correlation with a correlation coefficient of 0.82; that the system reliability model assumes analytically and numerically to quantify the impact of component failures according to ISO 10816 and NEMA MG 1; where the admissible parameters of 0.28 in / sec and 40 ° C in maximum operations were determined, this will allow a diagnosis with a lower percentage of error, facilitating the formulation of predictive solutions with non-destructive and non-invasive methods [15].

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