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Vibration analysis in a rotodynamic system

Análisis de vibraciones en un sistema rotodinámico

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Abstract

In this paper, a study of vibrations for a rotodynamic system connected to a three-phase induction motor with mass imbalance is analyzed. The study is carried out using a test bench interacting with different scenarios of mechanical speed and rotational mass imbalance and translational mass imbalance. The critical rotational mass imbalance causes maximum vibration, then vibration and current signals are measurement in the rotodynamic and motor system respectively, which are processed and analyzed in the frequency domain. The operation scenarios of the rotodynamic system focus on the parametric variation as, separation of bearing, inertial mass unbalance and speed of the induction motor. The instrumentation for data acquisition is made up of accelerometers, current meters, frequency inverter. Open programming in LabVIEW is used to process the signals. Finally, the measured vibration, the faults found, the problems of the faults and the operation of the process are explained.

Rotodynamic system, Out-of-phase, Unbalance

Resumen

En este trabajo se analizan las vibraciones en un sistema rotodinámico conectado a un motor de inducción trifásico, las cuales son causadas por desequilibrio o desbalance de masa. El análisis se lleva a cabo interactuando con distintos escenarios y se induce a una rotación al sistema por medio de un banco de pruebas, donde un desbalance de masa en el disco lleva aun estado de excitación máxima, forzándolo a vibrar de manera desequilibrada, este entrará en un estado desequilibrado, se adquieren las señales de vibración y la corriente del motor. Las cuáles se procesan y analizan en el dominio de frecuencia. Los escenarios de operación del sistema rotodinámico se enfocan a la variación paramétrica de: separación de chumacera, masa de desbalance disco inercial y velocidad del motor de inducción. La instrumentación para la adquisición de datos está constituida por acelerómetros, medidores de corriente, variador de frecuencia. Para procesar las señales se utiliza una programación abierta en LabVIEW. Finalmente, se explica la vibración desequilibrada, fallas que esta misma ocasiona, se expone la importancia de la problemática de este, se detalla el proceso y equipo utilizado para su realización.

Sistema rotodinámico, Desfasamiento, Desbalance

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Introduction

Most rotational machines contain drive systems with motors, clutches, gears, shafts, belts or chains, ball bearings, rollers, oil. Some normal vibrations can be generated by inherent machine oscillations as shaft oscillations, angular velocity, or pulse excitation in the driver. However, changes in these vibrations and additional appearances can be caused by failures. Therefore, vibration analysis is a well-established field in the supervision and monitoring of machines. In this sense, there is a machine transfer behavior between the source of the vibrations and the location of the measurement. This transfer behavior, usually expressed by a frequency response, $Gm(i\omega)$ may contain one or more resonance frequencies $\omega_{res,i}$ de the structure of the machine, as result of different mechanical systems type mass-spring-damper. There are measuring instruments in the machines such as lateral accelerometers in one, two or three directions, this direction can be orthogonal, horizontal, vertical, and axial or rotational in the casing of the machines. The measurement principle of accelerometers is based on the measurement of forces, such as the measurement of force in piezoelectric sensors, or measurement of displacement in a seismic mass using inductive sensors. Usually a high-pass filter is placed after the accelerometer to dampen low-frequency disturbances, with a cut-off frequency 100-200 Hz. Instead of acceleration $a(t)$ you can also measure the vibration speed $v(t)$or vibration displacement $d(t)$. (Isermann, R., 2005).

Machine failures generate additional stationary harmonic signals or pulse signals (Isermann, R., 2005). The former arises due to linearly overlapping effects such as imbalance, inaccurate alignment of electrical flow in electric motors, or changes in the periodic operation of the machine. The resulting signals may appear as additive vibrations, such as

$$y(t) = y_1(t) + y_2(t) + \cdots + y_n(t) = \sum_{i=1}^{n} y_i(t) \quad (1)$$

The Fourier transform is a tool that allows decomposing a function into an infinite series of functions that have different frequencies, and all of them are multiples of the frequency. (Marin, 2012).

The components of a system (bearings, pillow blocks, bearings, etc.) with the overtime suffer some wear or misalignment derived from misalignment or mass imbalance or other cause, causing the system to vibrate in an over-excited manner, then the vibration analysis is important because the failures derived from unbalanced vibration are detected, so a constant vibration wears out the components of the system.

In general, exist two types of maintenance, predictive and corrective. The predictive maintenance identifies the prevailing amplitudes in the vibration signals taken from the system, which are analyzed to determine the causes of the vibration. In this way, a scheduled stop can be established to perform preventive maintenance and correct the imbalance or replace the damaged element, subsystem or system in a timely manner and avoid the propagation of the failure. Corrective maintenance is used based on intervention or interruption in case of failure due to breakdown, which is distinguished by two ways (Blanco-Ortega, 2010) that consist of corrective maintenance by intervention with the elimination of the failure due to breakdown, where in emergency repair, replaces the damaged components of the machine, and corrective maintenance by interruption with elimination of causes, where the damaged components are replaced and the cause that originates the failure is eliminated.

The corrective maintenance it has its advantages and disadvantages, which can maximize the use of the machine or even lower the level of useful life of the same.

Various phenomena can impair the performance of induction motors and cause potential safety risks, this can be detrimental to the critical applications. Deficiencies such as unbalanced voltages due to variations in the electrical, mechanical unbalance system or harmonic grid at the voltage source could lead to problems such as excessive losses, overcurrents, mechanical oscillations, and interference in the electronic control.(Ioannides, M. G., 1995).

Starting a three-phase induction motor with unbalance in both the mechanical and electrical parts, causes vibrations in the system and increases the heating in the mechanical transmission, which propagates to the motor.

The traditional method for analyzing motor operating conditions with unbalanced supply voltages has been the theory of symmetrical components. (W. H. Kersting, March/April 1997).

Common sources that generate mechanical vibrations in rotating machinery are mainly imbalance, resonances, and misalignment. The imbalance occurs when the main axis of inertia does not coincide with the geometric axis of the system, causing vibrations that generate forces that are transmitted mainly to the supports or bearings.

Vibration caused by imbalance is a common problem that occurs in a large number of rotating machineries. To balance the system, various passive and active methods or devices have been proposed with the aim of attenuating the vibrations caused by the imbalance, (Blanco-Ortega, 2010)prior to a vibration analysis.

Fault detection and diagnosis while the system is in operation helps reduce all types of losses. The mechanical failures, the uses, the slack cause different noises and vibrations with different amplitude and frequency compared to the sound and normal movement of the equipment. In this sense, the induction motors are present in all processes and systems and for this it is important to know the types of failures that can occur during their operation(Ágoston, 2015).

The voltage source imbalance and harmonic voltage distortion affect electrical power, torque, and vibrations in induction motors, for example in (Donolo, 2016) the frequency of electrical power, torque, and vibration oscillations due to voltage imbalance and harmonics is calculated. It is also shown that the typical values of harmonic distortion combined with the maximum levels of voltage imbalance allowed by the standards are sufficient to introduce vibration levels under which continuous operation of the three-phase induction motor is not recommended. Nevertheless, also the mechanical vibrations can be used to identify defects arising from defective design, faulty installation, and wear and the frequency of the measured vibration is the same as that of the force causing the vibration (Gopinath, 2010, September).

Measurement and instrumentation

The rotodynamic system or process used in this work is a mechatronic system, which consists of a three-phase induction motor connected and controlled by a frequency inverter (PowerFlex 525), in addition to and shaft or mechanical axis.

Figure 1 shows the rotodynamic system and the frequency inverter used to control the motor speed, it should be noted that the connection of the induction motor is configured in delta with the intention of ensuring the appropriate measurement between phases and dispensing with the neutral wire. In addition, the harmonic 3[ra], in a delta configuration, is not magnified by the motor failure due to loss of insulation or ground fault inherent in the failures in the mechanical system.

Figure 1 Rotodynamic system and PowerFlex 525 driver
Source: UNACAR mechatronics laboratory facilities

Table 1 shows the operating parameters of the three-phase induction motor with which it operates, the data in the frequency driver (PowerFlex 525) is configured through the ethernet type connection.

Motor parameters	
Volts	220 V
RPM	1725 RPM
Poles	4
Frequency	60 Hz
Current	0.9 A
HP	0.37 kW

Table 1 Three-phase induction motor parameters
Source: Own elaboration

The data acquisition (DAQ), is shown in figure 2 and consists of the following equipment:

- Sound and vibration input module NI-9234, 4 cannel, 51.2 KS/s channel ±5V.

- Device USB 6003 de I/O Multifuntion, 8 I (16Bits, 100 KS/s, 2AO (5 KS/s channel), 13 DIO)

- Counter of 32 Bits, el chassis cDA-914

- Two accelerometer PCB of general purpose, 10 mV/g, ICP (EPE) GPTC03

Figure 2 DAQ equipment, target NI 9234, National Instruments
Source: Own elaboration

Methodology

The data collection methodology begins, as shown in figure 3, by programming the initial scenario with the help of the PowerFlex frequency inverter control software through an ethernet connection, subsequently the frequency variation interacts with the induction motor variation and transfers the rotational movement to the rotor, which is connected to the mechanical shaft of the rotodynamic system, an accelerometer or vibration sensor for each bearing, is connected to DAQ which is connected to the PC, where the processing and analysis using LabVIEW software with open source algorithms is developed in this work. Once the test is obtained, subsequent scenarios are carried out to obtain a more complete analysis.

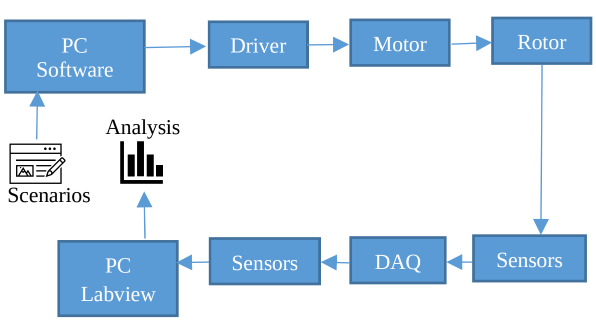

Figure 3 Diagram of data acquisition and control of induction motor speed in open loop
Source: Own elaboration

Below, the used instrumentation equipment for the development of this work is shown.

Figure 4 shows the first part of the instrumentation set equipment: the frequency inverter PowerFlex 525, the induction motor, mechanical transmission shaft, the current meter and oscilloscope.

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Figure 4 First part of instrumental set
Source: UNACAR mechatronics laboratory facilities

Figure 5 shows the second part of the instrumentation set equipment for data acquisition and signal processing (accelerometers, DAQ acquisition card, and data interface HMI).

Figure 5 Second part of instrumental set
Source: UNACAR mechatronics laboratory facilities

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The vibrations are obtained by means of a network of accelerometers, where the signals are processed by a DAQ and through a LabVIEW system engineering software, the signals are analyzed and the data obtained in the frequency domain are extracted, on the other hand, the currents of the induction motor in the oscilloscope are analyzed, where the data obtained are processed by means of mathematical software for engineering calculations.

To analyze the vertical vibration in detail, sensors A and B were placed on the bearing as shown in the following figure 6. Lateral vibrations were not considered in this analysis because the vertical magnitudes give more significant changes experimentally.

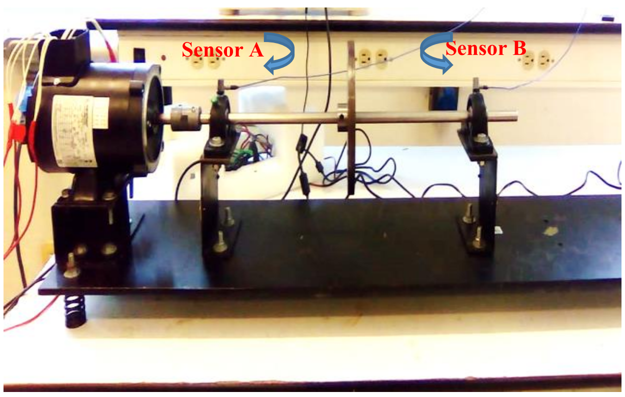


Figure 6 Location of accelerometers A and B on the bearing of rotodynamic system
Source: UNACAR mechatronics laboratory facilities

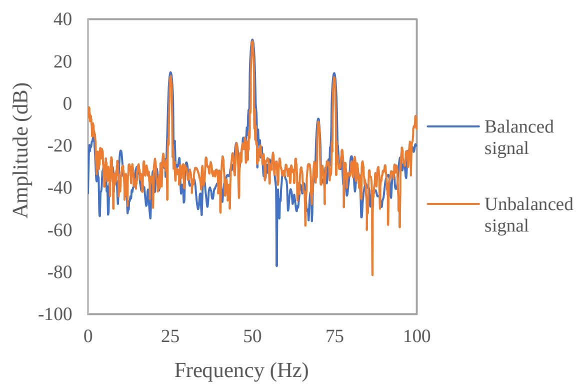
Experimental test

The results of the tests carried out on the rotodynamic system are acquired using two steel transmission bars, one of 0.60 meters and the other of 0.75 meters, which vibrate in a particular way at different speeds. The measurement of motor current disturbances due to the length of the steel transmission bar are post-processed using the Fourier Fast Transformation FFT that the oscilloscope itself has as mathematical tools, resulting in the same frequency spectrum as the methodology that uses accelerators, DAQ, software LabVIEW and PC. The advantage of using accelerometer is the more significant magnitudes relative to the FFT using motor currents.

Test 1

In the first test, a 0.60 m long transmission bar with balanced and unbalanced inertia disc is used. The frequency spectrum of the motor current processed with the mathematical tools of the oscilloscope and the frequency spectrum of the mechanical vibrations with accelerometers are measured with the oscilloscope and the LabVIEW software respectively. The results obtained are shown in Graphs 1 and 2, respectively.

Graphic 1 shows the Fourier spectra of the motor current, where two signals are observed; the first blue signal corresponds to the free-of-load or balanced condition, and the second orange signal, to the under-load or unbalanced condition, both at the same operating speed of 1725 rpm, which were measured by means of a tachometer.



Graphic 1 Fourier spectra of motor currents first test
Source: Own elaboration

Graphic 2 shows the frequency spectra obtained from the mechanical vibrations of the system, where four signals are observed; the first signal in blue and the second in orange correspond to the accelerometers located on the bearing near and far from induction motor, respectively, in a free inertial or balanced load condition with an operating speed of 2,243 rpm. The third signal in gray and the fourth signal in yellow, correspond to the accelerometers located in the bearing near and far from the engine respectively, in condition under inertial load or unbalanced with an operating speed of 2,158 rpm.

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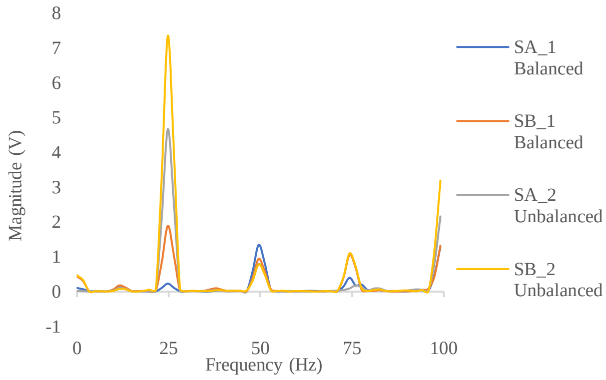


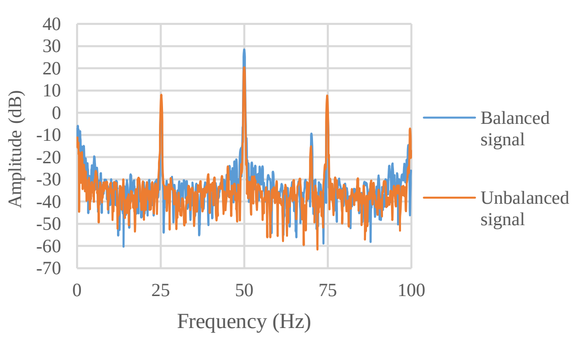
Graphic 2 Fourier spectra of the mechanical vibrations of the system first test
Source: Own elaboration

Test 2

In the second test, a 0.75 m long transmission bar with balanced and unbalanced inertia disc is used. like the first test. the frequency spectra are obtained using the measurement of motor current and mechanical vibrations. The results obtained are shown in Graphs 3 and 4, respectively. The results obtained are shown in Graphics 3 and 4, respectively.

Graphic 3 shows the Fourier spectra of the motor current, where two signals are observed; the first blue signal corresponds to the free-of-load or balanced condition, and the second orange signal, to the under-load or unbalanced condition, both at the same operating speed of 1,905 rpm.

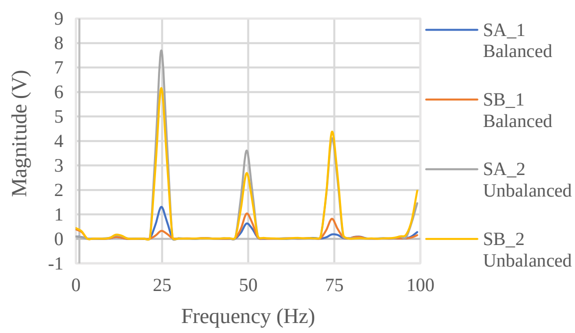
In this test, like the first test, the change in magnitudes is almost negligible in balanced and unbalanced conditions, so it is not possible to adequately analyze different scenarios.



Graphic 3 Fourier spectrum of motor currents second test
Source: Own elaboration

Graphic 4 shows the frequency spectra obtained from the mechanical vibrations of the system, where four signals are observed; the first signal in blue and the second in orange correspond to the accelerometers located on the bearing near and far from induction motor, respectively, in a free inertial or balanced load condition with an operating speed of 1,550 rpm. The third gray signal and the fourth yellow signal correspond to the accelerometers located in the bearing near and far from induction motor, respectively, in free condition under inertial load or unbalanced with an operating speed of 1,905 rpm. In this test,

In this test, like the previous test in Graphic 2, it can be observed that the amplitude variation is much more significant than with the current sensors, so it is more convenient to use this type of instrumentation to determine the severity of the fault.



Graphic 4 Fourier spectrum of system vibrations second test
Source: Own elaboration

Discussion of results

In Graphics 1, 2, 3 and 4 it is observed that the central harmonics correspond to the electrical operating frequency of the motor, which is 50 Hz for Test 1 and 2. Here it is interesting to mention that system shaft speed is a function of operating frequency

On the other hand, the frequency of 25 Hz and 75 Hz for Test 1 and 2, are characteristic of the vibrations produced by the bearings of the pillow blocks. To corroborate these frequencies, it is necessary to know some internal parameters of the bearings, such as the shaft speed and dimensions of the diameters of the pellets, as reported in (Blanco-Ortega, 2010).

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Now, why do we have symmetrical side frequencies? if it is known that the two bearings used are the same. The answer is because vibrations always propagate within the same metal bearing diameter, but transversely. That is, the vibrations are doubled or tripled for each bearing with a different dimension.

The reason why could not operate at full speed of Test 1 and Test 2 could not be selected is because in an unbalanced system with a larger shaft, the vibrations increase to such a degree that the shaft becomes deformed.

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Conclusions

The results obtained from the motor currents and the mechanical vibrations of the rotodynamic system have very similar Fourier spectra.

The detection system can analyze the vibrations of the rotodynamic equipment, sensing a minimum load, but if the load is exceeded, the fault can be immediately propagated to induction motor.

The importance of the length of the shaft is fundamental in obtaining the samples, the greater the length of the shaft, the system experiences greater magnitudes of mechanical vibration and consequently a greater number of samples to be analyzed, Now, the shorter the shaft, the lower the vibration amplitude and the smaller the samples to analyze. So, the shorter the length of the transmission mechanical bar, the less mechanical vibration, and the fewer samples to analyze. This proposal can be improved by adding more sensors, to analyze not only the vertical vibrations but also the lateral vibrations

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