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Fault Diagnostic Tests in Induction Machines

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ABSTRACT
Currently in the industry, induction motors represent more than 60 [%] of consumption energy of the country so it is necessary to schedule preventive maintenance to avoid interruptions in service. Within these maintenances tests are carried out that help to detect possible electrical or mechanical failures, to carry out these tests it is necessary to follow a standards-based protocol. The standards used are international standards, because the Mexican standard that corresponds to this issue is in disuse. In addition, for the In carrying out this work, different specialists dedicated to the area of maintenance, sales and regulations of electrical machines, in order to obtain results Reliable based on your industry experience. Electrical and mechanical tests are performed on low power motors that are found in the laboratory "Tests to the industry" of the Section of SEPI in Heavy II of the race of Electrical Engineering at ESIME Zacatenco.

KEYWORDS;- induction machine, test to the industrie, diagnostics.

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I. INTRODUCTION

The main function of diagnosis is to determine the general condition of a machine, there are different faults that can be found when making the diagnosis, they are divided into two types: electrical tests and mechanical tests as can be seen in the table, where each fault belongs. In the table of fig. 1., the classification of the faults that an induction motor can present is found.

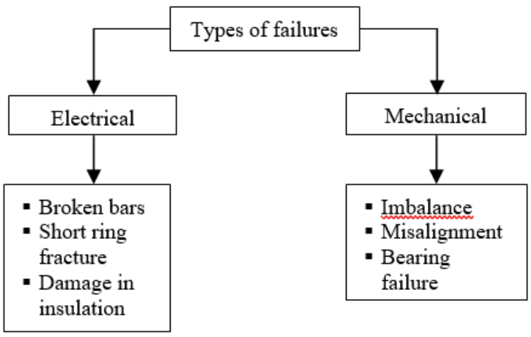

Fig. 1. Scheme of types of motor failures.

- **Electrical failures**

The causes of insulation failures are classified into five groups [8]:

a) Damages of electrical origin: overvoltage phenomena and voltage drops.
b) Damages of mechanical origin: start-up and stop cycles (especially frequent) and unbalance.
c) Damage of chemical origin: the proximity of chemicals such as oils, corrosive vapors and dust affect the insulation performance of the materials.
d) Damage related to temperature changes: expansion and / or contraction affect the characteristics of insulating materials. Exposure to extreme temperatures is a factor in the aging of materials.
e) Contamination in the environment: mold and the accumulation of particles from humid and hot environments cause the degradation of the insulation.

Commonly, motor winding faults start as shorts between turns within the coils which generate hot spots and so-called "beads" that will degrade the insulation which can take a long time to manifest as a ground fault. . In fig. 2 shows a stator with inter-turn damage, causing pearl formation. For a better visualization one of the formed pearls is enlarged.

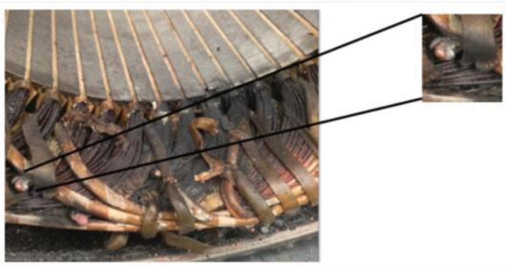

Fig. 2. Burnt insulation fault in the stator

Due to starting under load, high starting currents, the difference in the electrical resistances of the individual bars causes heating and expansion in the rotor bars. Heating and expansion are uneven, so cracking occurs in the shorting ring which is where the bars are welded. In a squirrel cage rotor, the presence of asymmetry is due to manufacturing issues or transitory operating or performance factors. The latter is caused by high temperatures reached by the rotor itself, by the centrifugal forces that bars and rings support. The fractures in the bars can cause sudden variations in rotation speed, consequence of their operation.

- **Mechanical failures**

a. **Eccentricity**. The rotor of a motor must be centered, there is a space called the air gap, if it is not well distributed in the 360 ° of the motor, unequal magnetic fields are produced. The adverse effect of these uneven magnetic fields that will eventually result in insulation failure and bearing failure has been widely discussed. This problem is known as eccentricity, there are basically two types, the static in which the rotor is misaligned but fixed in one place and the dynamic that happens when there is no uniformity in the weight of the rotor causing unbalance generally this type of problem is caused when the bearing housings are misaligned, due to improper alignment or the motor shaft was twisted when installed in its base. [7]

b. **Vibrations.** A vibration is an oscillating movement in any direction in space, starting from a point of balance; In general, in rotating machines, vibrations are of a periodic nature, that is, they repeat from time to time, below is a list of the most common problems that cause vibrations: [7]

1. Unbalance of rotating parts.
2. Misalignment of couplings or bearings.
3. Expired axles.
4. Worn or damaged eccentric gears.
5. Drive belts or chains in poor condition.
6. Bearings.
7. Torque deviations.

The main unit for diagnosing vibration problems in rotating electrical machines is speed; if the machines have low speeds, displacement or acceleration are used as a unit. The vibration signals are not pure sinusoidal, but it is a combination of harmonics with different amplitude and frequency. As mentioned above, there are three parameters for the measurement of vibrations, these will depend on the type of transducer used and to choose the appropriate transducer the application must be taken into account. Transducers, which can be accelerometers, are made up of piezoelectric materials that transform mechanical energy into a voltage signal. Acceleration behaves over a wide frequency range, from low to high frequencies that cannot be captured with the speed parameter. The displacement parameter is the opposite of acceleration, it picks up low frequencies. To find faults due to broken bars, it is analyzed at low frequencies [23]. On the other hand, when it is required to observe failures due to unbalance, misalignment, mechanical backlash, among others, the speed parameter is used, because this type of failure is within 10 [kHz]. If it is required to check the state of bearings, gears, etc., it works with frequencies ranging from 0 to 40 [kHz] [22].

II. METHODOLOGY

- **Electrical tests**

Measurement of ohmic resistance. This test identifies resistive unbalances, which allows you to evaluate your windings. High resistive imbalances indicate that, during operation, the motor will present hot spots due to high resistance connections. The way in which this resistance value is obtained is done with the help of the Kelvin bridge or a micro-ohmmeter, connecting the tips of the instrument to the terminals where it is desired to measure, taking care not to leave loose points that could affect this measurement. The connection diagram is shown in fig. 3.

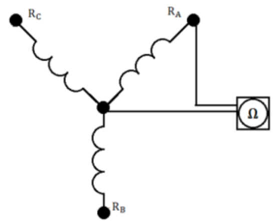

Fig. 3. General electrical diagram of ohmic resistance measurement.

Insulation resistance test. The reliability of the motor depends on the integrity of its insulation system, so this is an important part. The motor insulation system is subject to various mechanical, thermal and electrical stresses. This test detects the presence of moisture and / or contaminating substances on the surface of the windings. It can be seen in fig. 4, these factors together with others less harmful to insulation.

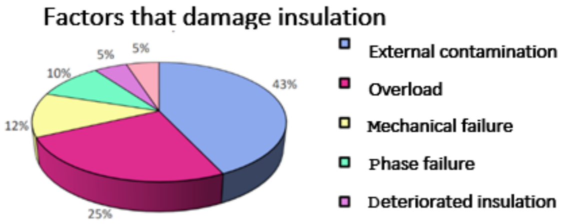

Fig. 4. Graph of the factors that damage the insulation [8]

This test determines the polarization indices (IP) that indicate the variation of the insulation resistance to earth with respect to time and the dielectric absorption index (DAR) that indicates the humidity of the machine. It should be mentioned that this test is not destructive because the energy is limited.

The insulation resistance measurement results in a value expressed in [kΩ], [MΩ], [GΩ] and even in [TΩ]. This resistance expresses the quality of the insulation between two conductive elements. The instrument used is an insulation resistance meter also called a megger.

Impulse test. Megohmmeter direct current (DC) insulation resistance tests are not able to fully establish the condition of the insulation between turns, typically formed by an enamel film (at most it will detect the presence of moisture inside the windings). On the contrary, the impulse comparison test, which is performed offline, is the most used way to evaluate the condition of the insulation between turns, which detects defects in the insulation, turn-turn, coil-coil or phase- phase (faults that cannot be detected by the other tests). The equipment used injects voltage pulses into the motor coil and the resulting reflected pulses are the response of the coil's inductance. An impulse is a surge caused by a voltage pulse with a rise time of very short duration (in the range of micro-seconds), applied to a winding [12].

Vacuum test. This test is carried out with the machine in operation at the nominal voltage and frequency without any type of load on the rotor, thus the values of friction and ventilation losses are achieved; the input temperature, voltage, current and power values are recorded. By recommendation of the IEEE std. 112-2017 "Test Procedure for Polyphase Induction Motor and Generators", measurements are made between 125 [%] and 75 [%] of the nominal voltage, with a point close to 100 [%] of the nominal voltage and three or more voltage values between 50 [%] and 20 [%] of the nominal voltage or to the point where there is a greater reduction in voltage. To obtain the losses in the copper, it is done with the help of the ohmic resistance measurement, as the losses in the copper of the rotor are negligible due to the low current, only the losses of the stator represented by R_1 are considered. The sum of the losses is represented as follows [13]:

$$P_0 = P_{Fe} + P_m + P_{Cu} \qquad 1$$

Where:
P_0= Total losses or vacuum power
P_{Fe}= Iron losses
P_m= Mechanical losses
P_{Cu}= Stator copper losses

To determine the values of the mechanical losses and the losses in the iron, it is fed with a variable voltage source. The connection required for the test is shown in Fig. 5, where a network analyzer is used to replace voltmeters and ammeters and obtain the values in a single instrument.

Locked rotor test. It should be recognized that testing induction machines under locked rotor conditions with polyphase power involves high mechanical stresses and high heating rates. Therefore, the following needs to be considered [13]:

a) The mechanical means to secure the machine and lock the rotor may be of adequate mechanical strength to avoid possible personal injury or equipment damage.
b) The direction of rotation is established before the test.
c) The machine is at approximately room temperature before the test starts.

Current and torque readings should be taken as quickly as possible and, to obtain representative values, the temperature of the machine should not exceed the nominal temperature rise plus 40 ° C. The magnitudes of voltage and current will gradually increase, however, care must be taken not to exceed 115 [%] of the nominal current, because they can cause damage to the motor under test. Shown below in fig. 6, the connection diagram, which is very similar to the vacuum test, but with the characteristic of the locked rotor. The aforementioned tests are for the verification of the design of the machine.

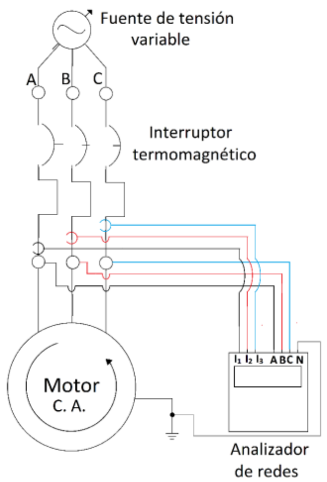

Fig. 5. Connection diagram for vacuum rotor test.

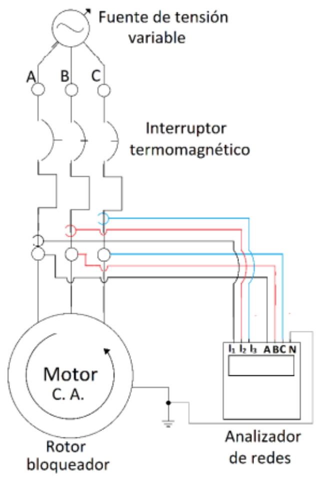

Fig. 6. Connection diagram for locked rotor test.

Motor current pattern analysis test. The Motor Current Signature Analysis (MCSA), applied to the diagnosis of faults in the squirrel cage rotor, is a non-invasive method; This test is based on the analysis of the high-resolution frequency spectra of the motor supply current operating in line, under nominal load conditions. Rotor cage status or failure detection can be determined by: rotor bar breakage; ring on induction motors in operation. It also allows studying the eccentricity effects in the air gap, which affect the behavior of the motor [7]. This method is carried out through an analysis of the frequencies that induce the field harmonics due to rotor failure, reflected in the currents, because some harmonics caused by the fault do not induce electromotive forces [10].

The Fast Fourier Transform (FFT) is the name of the algorithm for the approximate calculation of the discrete Fourier transform. With this method the sinusoidal current signals, in the time domain, are converted into the frequency domain; In this way, the state of the squirrel cage rotor can be evaluated using the lateral band methodology. [17]. The sideband method consists of tracking two harmonics, which are called the lower side harmonic and the upper side harmonic. They are located on both sides of the fundamental harmonic. The separation between the two is represented as [7]: -2sf and + 2sf. Where f is the power frequency. The amplitude of each harmonic is related to the degree of rotor asymmetry. Here are some considerations that must be taken into account in relation to harmonics and the degree of rotor failure [17]: a) The amplitude of all current harmonics is a function of the load applied to the motor Therefore, it is not possible to define an amplitude for the lateral harmonics to consider a degree of failure. b) Current harmonics are present in a motor in good condition, and the amplitudes of the harmonics depend on the construction of the motor. With the above considerations, it is determined that for a diagnosis of an induction motor the amplitude of the harmonics present is not taken into account, that is why a method is used that aims to normalize the measurement of the amplitudes. In this case, the method used is to measure the amplitudes in a spectrum of decibels [dB]. This is done by relating the difference in amplitudes of the fundamental current harmonic between the characteristic harmonics of a fault, on an algorithmic scale. Thus, the results obtained are validated for any type of squirrel cage induction motor. When the process of broken bars begins in an induction motor, the resistance between the union of the bar and the ring rises, this means that the motor has points of high resistance. In this way, the degree of failure is distinguished, ranging from the presence of high resistance points to the existence of several broken bars [7]. However, the criteria used to decide whether a motor has rotor asymmetries are based on statistical studies on a large number of motors. Next, table 1 shows the relationship that exists between the amplitude of the lateral harmonics with the progressive increase of broken bars. [33] [17]

Table 1. Amplitude difference between the lower lateral harmonic and the fundamental one for different degrees of failure.

Decibel difference [dB]	Engine condition
≥ 49	Engine in good condition
46-49	Some high strength point
44-46	Multiple high strength points
39-44	Many high strength points or a broken bar
35-49	At least one broken bar
<39	Several broken bars

For this test the engine is online; use is made of current transducers, where the conductor that energizes the motor of the study case is passed through the center of the transducer. This is done for each of the phases. For the study of this work, three current transducers are used, one for each line. For the test it is recommended that the motor be coupled to a load. In fig. 7, you will find the electrical diagram for the test connection.

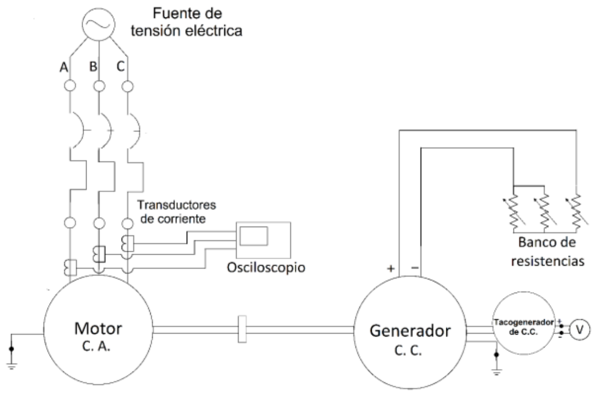

Fig. 7. Electrical diagram of connection for MCSA test.

Slip test. A meter that can be a digital tachometer or a tacho generator is used to determine speed and slip. When using a tachogenerator, the voltage at terminals is measured using a voltmeter and according to the data plate of the tachogenerator, the conversion is made from volts to revolutions per minute. In the case of the digital tachometer, a reference point is used that is marked with a shiny tape that must be included with the instrument.

- **Mechanical tests.**

Vibration test. This test is based on two stages that involves the acquisition and interpretation of the data related to the vibration of the machine, its purpose is to determine the mechanical conditions of a machine and to accurately point out the eventual specific mechanical or functional defects, due to the fact that there is a strong relationship between frequency, machine components and spectrum [9] [22]. Before and after performing maintenance on the machine, it is advisable to take measurements and after carrying out a repair it is measured again, and the results are compared with each other to validate that the repair really worked [9]. By means of the accelerometer a signal is obtained that can be seen in the oscilloscope connected by means of a mil-BNC cable.

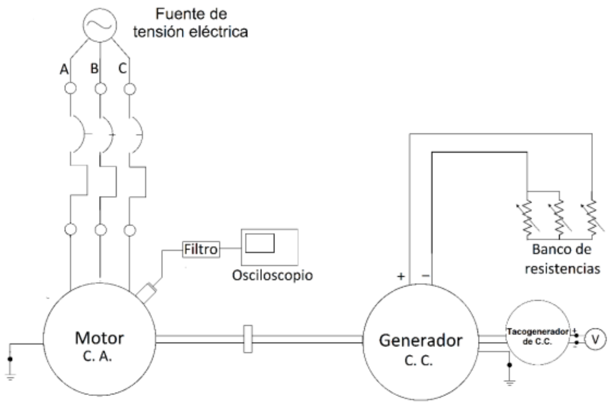

Fig. 8. Electrical connection diagram for vibration test.

The measurement is made by placing the sensor directly on the motor so that it is fixed to it. The engine must be operating under load conditions. To validate the results obtained in the vibration tests, the ISO 10816-2014 Standard "Mechanical vibrations - Evaluation of machine vibrations by measurements on non-rotating parts" is taken as a reference. In fig. 9, the graph is shown with the allowed values according to this standard.

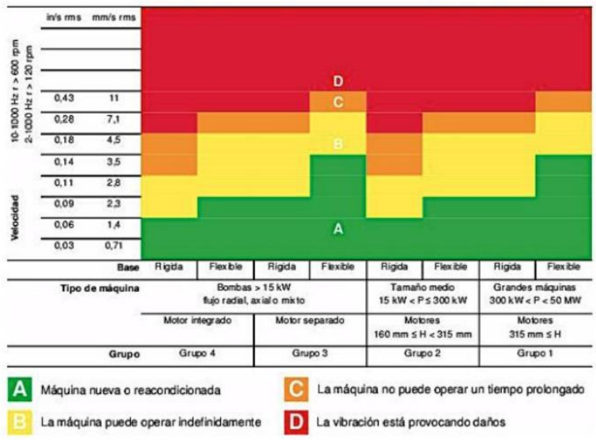

Fig. 9. Vibration limits allowed by ISO 10816-2014 standard

Thermography test. This test is done as part of predictive maintenance with the help of a thermal imaging camera, as its name indicates, it allows the temperature of an object to be visualized by means of an infrared sensor, which indicates the hot spots of a machine that will be indicators of failure that they can be some of the following [29].

1. Lubrication problems
2. Alignment errors
3. Suspicious rollers
4. Overloads
5. Bad bearings

To start the test it is necessary to have a firm surface to place the camera, the recommended distance between the camera and the object under test is one meter as shown in fig. 10. [29] [13]. In thermography, the interpretation of results is based on the association of light colors at high temperatures and dark colors at low temperatures. When taking temperature readings on the case, it is necessary to mention that these readings are not the temperature of the motor windings; According to some specialists, the temperature varies between 15 and 20 [° C] between the casing and the windings, this value varies according to the ambient temperature. The heat transfer in motors also depends on the size of the frame, its shape and type, as well as the mass of the motor. [31]

The photograph taken by the equipment must be taken when the machine is operating, in case the equipment is only started for this test, wait until the temperature in the casing is stable. The temperature in a device in good condition must be homogeneous over its entire surface as shown in fig. 11. [29]

Fig. 10. Thermography test.

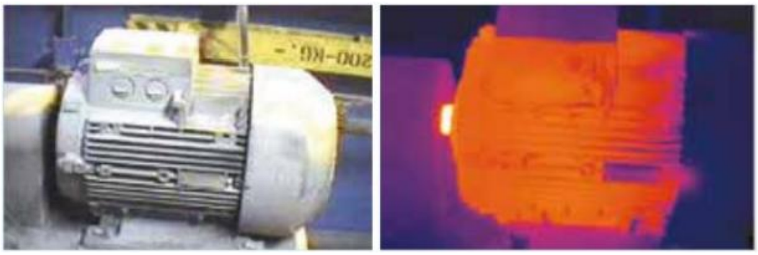

Fig. 11. Engine in good condition

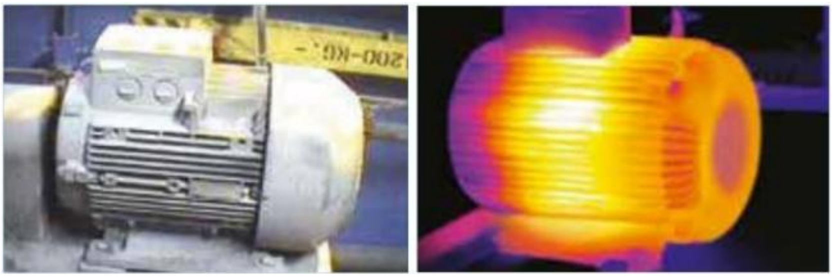

Fig. 12. Motor with damaged winding [29]

When the temperature is not homogeneous and has hot spots, they indicate a problem, depending on the area in which these spots occur, the fault will be as shown in fig. 12, where hot spots can be seen in lighter shades [29] Case study. Squirrel cage type motor mode induction machine.

Off-line and on-line tests are performed to carry out fault diagnosis on squirrel cage induction motors. In addition, before carrying out these tests, an inspection is carried out and the motors are disassembled. See fig. 13.

Fig. 13. Squirrel cage induction motor, case study.

Fig. 14. Motor under test data plate

- **Electrical tests.**

Measurement of ohmic resistance. In this measurement a micro-ohmmeter with its respective tips is used. See fig. 15 and table 2.

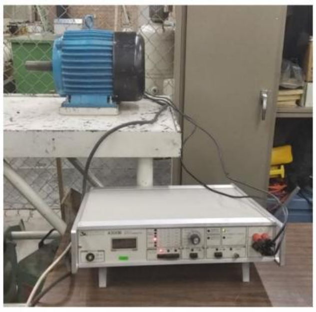

Fig. 15. Physical connection for ohmic resistance measurement

Table 2. Values of obtained in the ohmic resistance measurement

Phase	Terminals	Electric Resistance [Ω]	Percentage difference from the average [%]
A	1-7/-4-5-6	0.463	4.27
B	2.8/-4-5-6	0.434	2.02
C	3-9/-4-5-6	0.435	2.25
Average		0.444	
Corrected average resistance [W] a 20°C		0.55733	

Insulation resistance test. The proposed test voltage is 500 [V] so special care must be taken to use safety equipment and discharge the equipment properly to avoid accidents. In this case, the megger included includes a program that can automatically plot the insulation resistance measurements during the ten minutes, plotting time versus resistance. You can see the connection that was followed for the test in fig. 16. And fig. 17.

Fig. 16. Physical connection of insulation resistance test

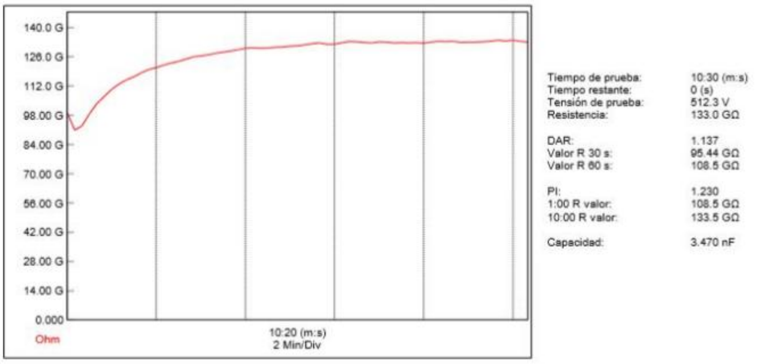

Fig. 17. Graph of the state of the insulation with the values measured by the instrument.

Impulse test An AVO Multi-Amp model DS-13 Winding Tester is used in this test. This equipment is designed to analyze stator windings; looking for a balance between the two waves displayed on the oscilloscope. Although the instrument has its own 71 oscilloscope to interpret the waves, an external digital oscilloscope is used to store the waveforms, of the Tektronix model TDS-2014C brand.

The results obtained are shown in the following graphs, it is worth mentioning that the values are not included, because it is only intended to compare the waveforms. The waveforms obtained after the impulse test are shown below.

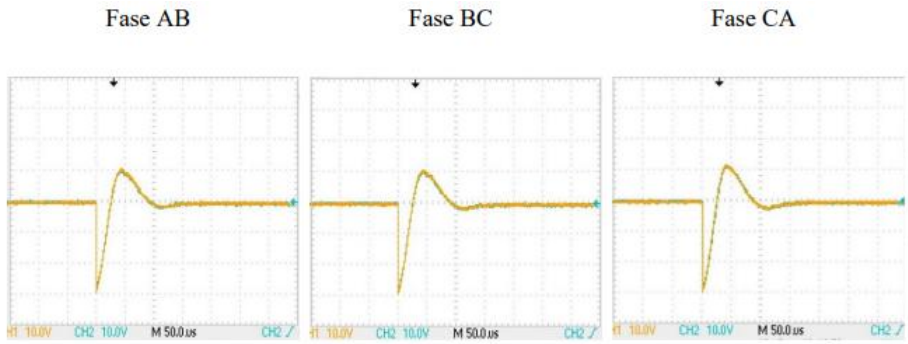

Fig. 18. Waveforms obtained in the impulse test.

Vacuum test As described earlier in this work, the vacuum test, or also known as free rotor test, the latter, allows to determine parameters such as: vacuum voltage (VV), vacuum current (IV), vacuum power (PV), vacuum impedance (ZV), as well as vacuum resistance and reactance (RV, XV). In this test the slip in the motor 74 is close to 0, because it has no load, this causes a low current and a high rotor resistance.

Locked rotor test. With this test the following parameters can be determined: Locked Rotor Voltage (VRB), Locked Rotor Current (IRB), Locked Rotor Power (PRB), Locked Rotor Impedance (ZRB), as well as Locked Rotor Resistance and Reactance (RRB, XRB) and stator and rotor reactance (XS, XR, respectively).

Motor current pattern analysis test. By means of the voltage provided by the current transducers shown in fig. 19, in the oscilloscope the frequency spectra are obtained. The fundamental frequency must be established, that is, the reference to the frequency of the motor being studied is obtained, in this case, the reference is to 60 [Hz] to make the difference in decibels with the lower side band.

Obtaining the data was done in the same way as in the impulse test with one of the oscilloscope functions, in this test three channels are used, through the FFT function the oscilloscope shows an average of the input of the three signals, one for each phase of the motor. As an additional configuration, the oscilloscope gives the option of "Window" in this case a "Hamming" type window is established, this choice is made based on the display of the frequency spectrum. The “Cursors” function sets the references to 0 [Hz] for cursor 1 and 60 [Hz] with cursor 2 to indicate the fundamental frequency. From there, cursor 2 can be varied to check how often the study is analyzed. In figs. 19, 20 and 21, the oscilloscope screen is shown pointing to the aforementioned settings.

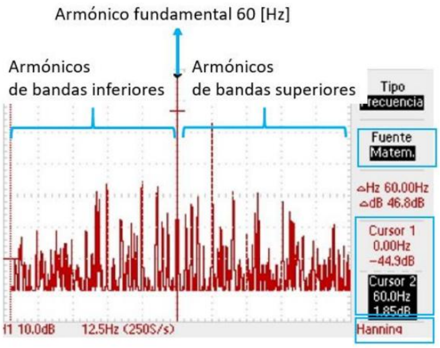

Fig. 19. Oscilloscope setup for MCSA test

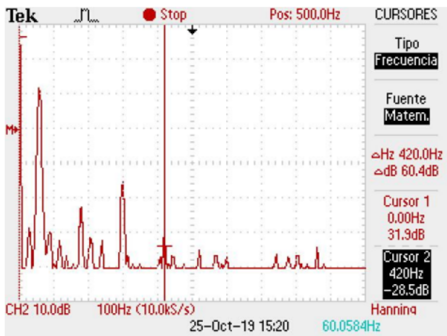

Fig. 20. No-load motor frequency spectrum.

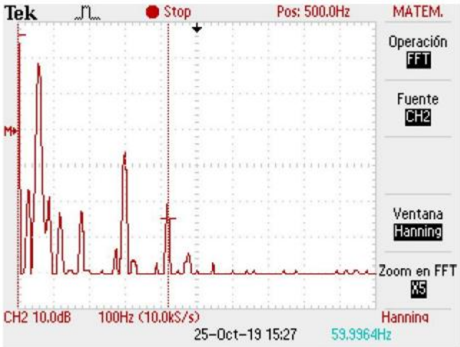

Fig. 21. Motor frequency spectrum with load.

- **Mechanical tests**

Vibration test. For this test an accelerometer is used which is a piezoelectric sensor, fig. 22, as mentioned above. The case study engine has a magnitude of 101.53 [dB], with a frequency of 35 [kHz]; given in speed, this value is 1,188 [mm / s], that is, it is in an optimal state in terms of bearings.

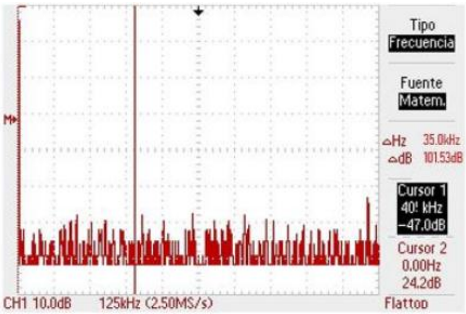

Fig. 22. Vibration spectrum of the motor case study.

III. ANALYSIS OF RESULTS

Diagnosis: The imbalance obtained in the ohmic resistance test is less than 5 [%] recommended by the IEEE Std. 1415-2006. Regarding the isolation, it presented damages; although the insulation level is within the range of [GΩ] its IP is below 2 and like the DAR is at a lower value than recommended in accordance with IEEE Std. 43-2013. It is recommended to keep track of the insulation status of the machine, it cannot be defined as a fault because when performing the impulse test the graphs obtained indicate that the windings are in good condition. The aforementioned standards continue to apply, making these procedures valid. Once its starting performance has been tested and it operates under nominal conditions, the sideband test is carried out with the MCSA method, with which it is determined that the rotor is in an optimal state, since the difference in decibels between the main harmonic and its lower side band is above the 49 [dB] recommended by the reference consulted. However, the motor slip exceeds 5 [%], this means that the motor design is not suitable for the nominal values recommended by the manufacturer. Finally, the vibration test complements the diagnosis in the mechanical part of the engine, specifically, in its bearings. The test determines that they are in good condition, according to the ISO 10816-2014 standard, which establishes a range of 0 to 3 [mm / s], the motor is at 1,188 [mm / s], therefore Therefore, it is acceptable.

According to the insulation tests performed on this motor, it can be determined that the state of the insulation is corrupted, since both the IP and the DAR are are below 2, following the recommendations of the IEEE Std. 43 standard. complement of this test, the impulse test was also applied and as a result have the graphs in table A.1 in which the phase shift between the signals: the input signal and the output signal of the motor windings. When applying the current pattern analysis test at different load percentages (no load, 80 and 100 [%]), the damage to the rotor is checked, because the difference in decibels between the harmonics is less than the recommended value. Indicating that there are several broken bars, which causes an imbalance in the flow of currents causing overheating in the motor, likewise, causes a slip greater than allowed between the speeds of the components of it. Finally, in table 3, the diagnosis of each of the engines under test in this work in accordance with the regulations consulted. Being case 1 the engine in good condition and case 2 refers to the engine in poor condition.

Table 3. Comparison of results obtained with respect to national and international standards

Test	International Standard	Mexican standard	Standard Section	Case 1		Case 2	
				Results	Observations	Results	Observations
Ohmic resistance	IEEE Std. 1415-2006. Guide for induction machinery maintenance testing and failure analysis. In section 4.3.40 it establishes that the resistive unbalance must be between 3% and 5% of the average resistance.	NMX-J-075/2-ANCE-1994. Electrical appliances, Rotating machines. Part 2 Short-circuited rotor-type alternating current induction motors at large powers. Specs. NMX-J-075/3-ANCE -1994 Electrical apparatus, Rotating machines, Part 3. Test methods for induction motors of alternating current, of the rotor type in short circuit, in powers from 0.062kW.	does not apply	4% unbalance	According to the standards, the motor is in the permitted range of resistive unbalance	-	For fault diagnosis it is not considered as a mandatory test
Insulation resistance	IEEE Std. 43-2013. Practical recommendations for resistance measurement tests on rotating machines. In section 5, table 3, he recommends a minimum IP value of 2 for a machine with type B design.		In NMX-J-075/2, section 5.1.12 establishes that the insulation resistance value depends on the nominal voltage of each motor, which must not be less than the nominal voltage value measured in kV + 1.	IP = 1.23 DAR = 1.1327	The motor presented an IP with a value below the established one, so it is recommended to perform maintenance on the stator.	IP = 1.46 DAR = 1.16	The motor presented an IP with a value below the established one, so it is recommended to perform maintenance on the stator.
Electrical impulse	IEEE Std. 522-2004. Guide to Testing Stator Winding Insulation for AC Electrical Machines. In figure A.4 of Annex 3, the waveforms under normal conditions are shown.		does not apply	The two input and output signals must be in phase.	The signals obtained are in phase with a slight difference in the output signal since it presents a small deformation.	Input and output signals of the two test windings are out of phase.	I have visible distortion in the input and output signals
Vibrations	ISO 10816 IEC-60034-14-2003 Rotating electrical machines-part 14: Mechanical vibration of certain machines with shaft heights of 56 mm and above. Measurement, evaluation and limits of the severity of vibration. In section 8, table 1, the maximum allowed vibration limits are established.		does not apply	V=1.118 [mm/s]	The value obtained is within what is allowed by the standard.	-	-
Temperature with thermography	IEEE Std. 112-2017 Standard tests for induction motors and generators, section 3.3.2. test procedure		does not apply	-	-	20.4 ° C increase in less than half an hour	The test could not be completed due to eccentricity in the rotor causing

IV. CONCLUSION

During the course of this project, electrical and mechanical tests were carried out in order to perform the analysis of results to base a diagnosis on a low power motor mode squirrel cage induction machine. The tests were carried out according to the standardized recommendations, so that with the results obtained, a general report on the state of the engine of the case study can be generated as described in chapter 3. Based on this report, it is determined that The case study is in good operating condition at full load, however, it is recommended that preventive maintenance be carried out, in order to observe that there are no significant changes in the results of the applied tests and thus avoid possible failures. On the other hand, to have a reference to the parameters of the induction machine, the vacuum rotor and locked rotor tests were carried out for its characterization; Although these tests are not for fault diagnosis because the initial parameters of the machine are not always accessible; It is necessary to have knowledge of the manufacturing design of the induction machine since in some occasions the failures can start from its design and construction. The vibration test can be carried out at low, medium and high frequencies, which identifies electrical and mechanical damage; To do this, the type of sensor to be used is chosen and then what type of damage is to be identified, in order to have a reference to the frequency at which the test is to be carried out. Likewise, it must be known with which parameter it is going to work: displacement, acceleration or speed; having these considerations improves the quality of the measurements in the test. If done correctly, vibration analysis complements electrical tests, reducing costs and time in maintenance and / or diagnostics. This test can also prevent failures when performed as part of preventive maintenance and in cases where equipment cannot be taken out of operation it works as predictive maintenance. Another test that is part of predictive maintenance is the temperature using a thermal imaging camera, this technique has several advantages over others, such as faster data collection, since its use does not interfere with the engine process. Despite this, this test is defined as complicated for the interpretation of results, because if the necessary experience is not available, the cause of a failure in the machine cannot be determined, because the test only indicates the existence of the problem.

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