AN APPLICATION OF MCSA ON PREDICTIVE MAINTENANCE OF TERMOPE'S INDUCTION MOTORS

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Abstract. The main objective of this paper is to present a procedure to acquire and analyze electrical signals for condition monitoring of electrical machines through motor current signature analysis in order to get the best possible results in an industrial environment. As secondary contributions, the paper intends to disseminate important concepts to guide companies that have their own predictive group or want to hire consultants or specialized service to obtain good results through general predictive maintenance practices and, especially through electrical signature analysis. For this purpose, the paper presents a discussion between Condition Monitoring and Troubleshooting, pointing the differences between both approaches and the main benefits and problems involved with each one. Keywords: Electrical signature analysis, Predictive maintenance, Motor current signature analysis, Condition monitoring, Induction Motors.

1. INTRODUCTION

Nowadays there is great concern about the reduction of production costs and the increase of productivity in the industrial area. In addition, the reliability of the pieces of equipment that are part of the productive process becomes more and more important in industrial plants. This is result of the new global reality that doesn't permit waste and compromise in the quality of the final product. In order to keep up with this new global tendency, many companies have been trying to increase the reliability of their productive process through new maintenance techniques. The highlights of the moment are predictive maintenance techniques. These techniques consist of using continuous monitoring systems. Their use is justified in the presence of general randomly failures of complex equipment with a large amount of components. Such failures usually have serious economical or human consequences. The predictive maintenance is based on analysis of data supplied by a continuous monitoring system. Depending on the condition of the equipment, some kind of corrective maintenance can be applied. Since induction motors are often critical components in industrial process, they deserve special attention from the plant maintenance department. This work consists of applying a specific technique of predictive maintenance in three-phase-induction Motors among several other existent techniques. The chosen technique is the stator current signature analysis to detect induction motor faults (Bonnett & Soukup, 1992). The choice of this approach stems from the success that it has been having in international publications and also from the advantages obtained with the use of this method. The developed monitoring system in this work is divided in four parts: • Acquisition of the stator one-phase current signal; • Treatment of the acquired signal, e. g., amplification, analog filtering, etc; • Digital signal processing; • Presentation of the output data: spectrums, frequencies of interest, tendency graphs, etc. The most important tool used in the digital signal processing is the Fast Fourier Transform (FFT). The characteristic frequencies of failures are very well known. All this makes this technique very attractive to be implemented and tested. The following mechanical faults have been monitored: air gap eccentricity, load unbalances, broken bars, and bearings failures. The success of practical tests has confirmed the technique efficiency in monitoring the health of three-phase-induction motors and hasopened the way to several other studies.

2. TYPES OF MAINTENANCE

The motors are the center of the majority of the industrial production processes. Therefore, these machines deserve concerns to increase the reliability of the productive process. In this sense, many techniques have been developed for an on-line motor monitoring of the behavior and performance. Monitoring condition of electric machines is an evaluation continuous process of the health of equipment during all its useful life. The main function of a monitoring predictive system is to recognize the development of failures in an initial state. For the maintenance department, each failure must be detected as soon as possible in order to promote a programmed stop of the machine. The process of continuous monitoring of the condition of vital electric machines for the production process brings significant benefits for the company. The main benefits are: bigger efficiency of the productive process, reduction of the losses for not-programmed stops, increase of the useful life of the equipment, and build a historical of failure (Legowski et al., 1996; Tavner & Penman, 1997; Thomson & Fenger, 2001). A continuous monitoring system must observe parameters that give to the maintenance team trustworthy information for the decision-making. The more usual monitored parameters are: voltage and current of the stator; temperature of the nucleus; level of vibration; instantaneous power; level of contamination in the lubricant of the rolling; speed of rotation; flow of escape; and so on. In such a way, it can be noticed that this area of the technology demands knowledge of the functioning of electric machines, instrumentation, microprocessors, processing of signal, analysis of materials, chemical analysis, analysis of vibrations, etc.

2.1 Classification of the Maintenance Activities

"Maintenance" can be understand as the action to repair or to execute services in equipment and systems. It can have its activities classified in four main groups: a) Corrective maintenance: this is the more primary form of maintenance. It occurs after a failure carried out. Usually, it becomes the unavailable equipment for use. Many disadvantages of this type of maintenance are clear. As examples, the systematic occurrence of not-programmed stops, lesser time of useful life for the machine, bigger consumption of energy (since with the presence of the failure the engine needs more current keeping the Constant torque) can be cited. b) Preventive maintenance: this is the name that receives a set of actions developed with the intention of preventing the occurrence of unsatisfactory conditions, and consequently, reducing the number of corrective actions. When preventive maintenance plan is elaborated, a set of technical measurements must be created in order to increase the machine reliability and decrease the total cost of the maintenance. A preventive maintenance program can still choose for one of the three types of activities: continuous monitoring; periodic measurements; or predictive techniques. c) Predictive maintenance: as it can see previously, the predictive maintenance can be a sub-area of the preventive maintenance. However, the predictive maintenance presents some proper characteristics as: • Support in not invasive techniques, that is, it is not necessary to stop the operation of the machine for its application • Elimination of corrective maintenance; • Not consideration of information as the durability of components; • On-line or off-line can be effected through techniques. d) Systematic maintenance: characterized for the substitution of components of the equipment or for the substitution of the equipment as a whole [B4].

2.2 Abnormalities in Three-phase Induction Motors

The main focus of problems in three-phase induction motors are in the stator and the supports. The main causes of failures are: superheating, imperfections in the isolation, mechanical bearings and electric failures. Figure 1 presents a division of the failures in threephase induction motors with squirrel steamer and power of 100 HP or higher [B3].

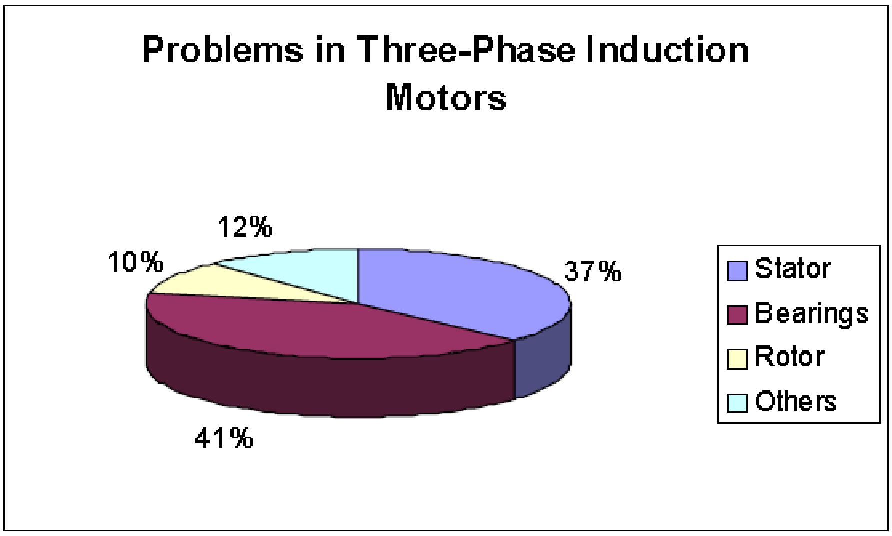

Figure 1: Main Problems in Three-Phase Induction Motors

In one hand, the main source of electrical problems in induction motor is in stator that totalizes 37% of the total of failures. Figure 2 details different type of problems in the motor stators.

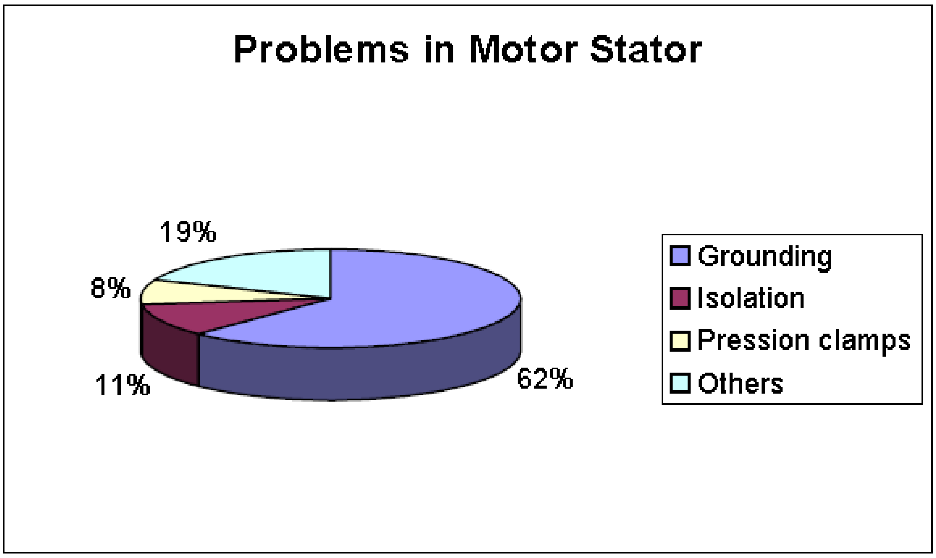

Figure 2: Main Problems in Motor Stator

In the other hand, problems in the motor rotor totalize 1 0% of the t otal of motor failures, and they are shown in Figure 3.

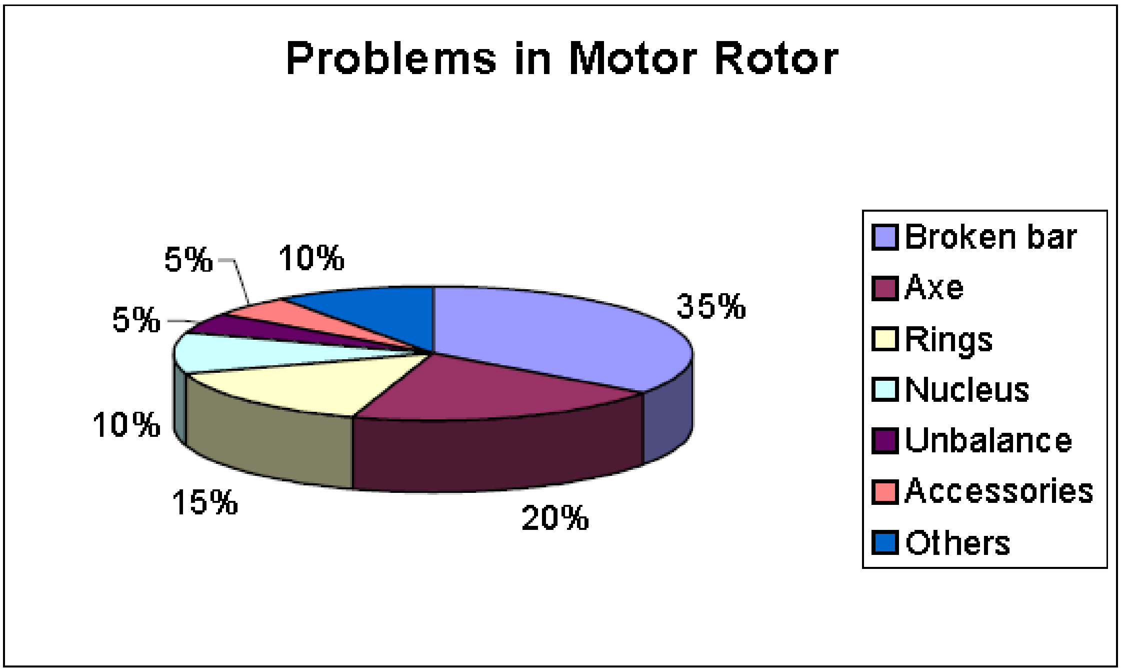

Figure 3: Main Problems in Motor Rotor

3. RELATION BETWEEN MOTOR SPECIFICATION AND FAILURE MECHANISM

Many failures can be deriving of incorrect specifications. The specification of a motor must consider the mechanical and electric conditions, and the environment in which the machine goes to work. The monitored parameters to be will be affected by these operational conditions. In terms of the mechanical conditions, the failures will appear as resulted of the behavior of the load. Amongst the main problems they are distinguished: • Successive overloads that can cause superheating and/or damages to the rolling; • Pulsing load that can cause damages to the rolling; • Repeated departures that can damage the machine rolling; • Vibration that can be transmitted to the machine causing damages to the rolling. In terms of the electric conditions, the failures can result of the electrical Power system characteristics or the load feeder by the motor. Amongst the main problems they are distinguished: • Slow fluctuations of voltage being able to cause loss of stop power and of the machine. • Brusque fluctuations of voltage being able to cause failure in the isolation. In terms of the environment conditions, the failures can result of the characteristics of the process in which the machine is being used. Amongst the main problems they are distinguished: • High temperatures that can cause the deterioration of isolation. • Humidity and pollution that can respectively cause imperfections and contamination of the isolation. Thus, it is clear that the failures that occur in electric machines depend on the type of machine and the environment where it is working. What it is really important to observe it is that the failure mechanism happens in gradual way, leaving of an initial defect and arriving until a real failure. The time of propagation of the failure depends on some factors. However, the major parts of the failures present initial pointers of its presences and are exactly in these initial indications that the predictive maintenance must act [B5].

4. ELEMENTS OF A MONITORING SYSTEM FOR PREDICTIVE MAINTENANCE

A sophisticated monitoring system can read the entrances of hundreds of sensors and execute mathematical operations and process a diagnosis. Currently, the diagnosis is gotten, most of the time, using artificial intelligence techniques [GG]. Considering the previous statements, a monitoring system can be divided in four main stages: • Transduction of the interest signals; • Acquisition of the data; • Processing of the acquired data; • Diagnosis.

Figure 4 presents a pictorial form of this process.

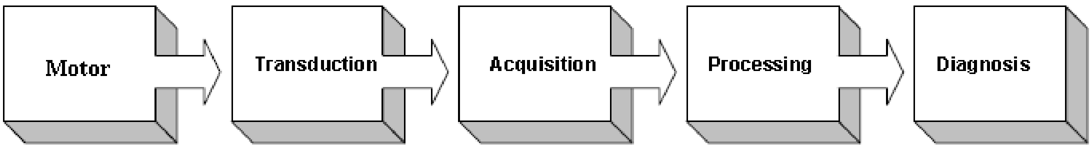

Figure 4: Steps of the Monitoring Process

4.1 Transduction

A transducer is an equipment that has in its entrance an input value to be monitored (current, voltage, acceleration, temperature, etc), whereas in its output it has a signal that He will be conditional and envoy to the acquisition system and processing. The main transducers used in the monitoring processing of electric machines are: • For measurement of temperature: they are the three main methods of measurement of temperature: thermocouple, thermister, and RTD (Resistance Temperature Detection). • For the measurement of vibration: two types of transducers for the vibration analysis exist: the absolute transducers or with contact and the relative ones or without contact. The absolute transducers measure the real movement of the machine, whereas the relative ones measure the movement of an element of the machine in relation to the other element. The accelerometer is the main and more used existing absolute sensor in the market. •

For measurement of force: the most common is the strain gauge, that it is a device that understands a resistance that will have its modified size and transversal area in function of the application of a force. Then, the force can be measured through the variation of the resistance. • For measurement of electric and magnetic values: the electric values are measured from transforming of voltage and current those always are presented as part of the protection system. However, it can still have the necessity an extra measure, the density of magnetic flow in the machine, using itself a hall-effect device. 4.2 Data Acquisition The data acquisition is a stage with fundamental importance; because it needs to guarantee the integrity and precision of the collected data. The precision of the data demanded of the acquisition is determined by the future mathematical manipulations that Will be applied to the data set. The collection and the transmission of the data must be made in order to minimize to the maximum the effect of the noise, being become the sufficiently consistent data. In complex systems with many entrances, it is oriented that the processing system is remote, that is, located to a certain distance of the inspected process. Figure 5 presents an example where some engines are being monitored. A group of adjacent machines is connected to a point of collection of data that digitalize the signal and sends for the remote central office of processing and diagnosis

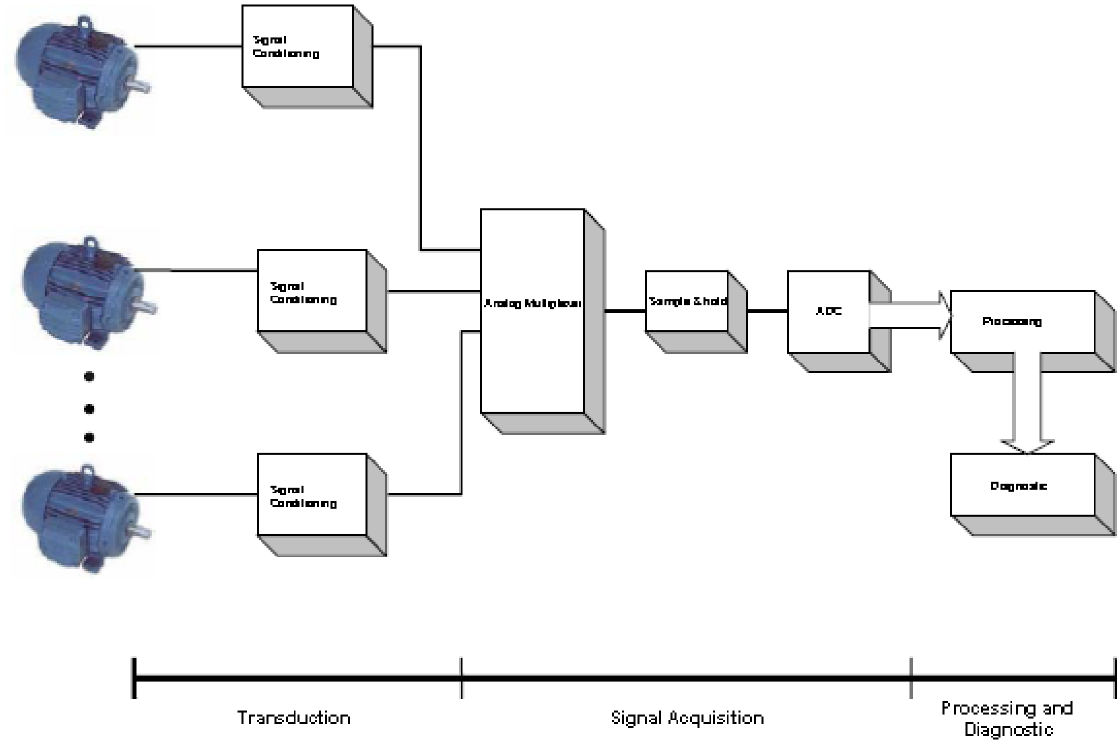

Figure 5: Example of a Monitoring System

The multiplexer is essential when a great number of channels must be monitored. Moreover, it also is recommended for a small number of channels, since it allows the use of only one converter A/D. Already converter A/D is the heart of the acquisition system and must be specified in function of the time of conversion and precision.

4.3 Processing

The task of the processing must be to catch the collected data and to manipulate them and/or to transform them, aiming at the agreement of these for the system of diagnosis in af faster and easy form. The processing can be made on-line or off-line. The choice depends on the process that are being monitored and on the speed with that the characteristics of interest of this process if modify. There are different techniques of processing to monitor electric machines. One of the simplest of them, it examines the amplitude of the signal of entrance of the function in the time, and compares it with a predetermined value. Elaborated techniques are currently possible due to the new computers, such as: spectral analysis, correlation, averages, cepstral, envelope analysis, etc.

4.4 Diagnosis

Diagnosis is the part most critical of the system, because it involves decisions and consequently money. Currently, many techniques of artificial intelligence as expert systems and neural nets are being used [B6].

5. MONITORING THE FREQUENCY SPECTRUM

This is the main technique of detention of failures using vibration analysis, mainly after the new techniques and the instrumentation for spectral analysis. The spectral analysis does not identify only the general condition of the machine. It has as objective to point specific problems, being necessary to investigate certain components of frequency, or even though, certain groups of frequency. In the particular case of induction engines, the spectral resolution must be sufficiently high; because the rotation speed is sufficiently close to the feeding frequency. This makes with that the failures appear with lateral bands spaced of s or 2s of the feeding frequency, where s is the slipping of the machine (Lambert-Torres et al., 2003). The process of the spectral analysis if initiates with the acquisition of the signal of vibration for intermediary of an accelerometer. This signal, into the domain of the time, will be transformed for the domain of the frequency becoming fulfilled itself FFT (Fast Fourier Transform) (Bonaldi et al., 2007). No longer domain of the frequency, analyzes the signal looking for the peaks more bulging than they can constitute an indicative of failure of na element of the machine in particular. Table 1 presents the vibration frequencies related to the specific failure of the machine (Benbouzid , 2000).

6. CONCLUSIONS

The industries currently look for products and outside services for predictive maintenance. In many cases, the outside service company or even the industrial plant predictive group make mistakes that can compromise the whole condition monitoring and failure diagnosis process. In this increasing demand for prediction technology, a specific technique referred as Electrical Signature Analysis (ESA) is calling more and more attention of industries. Considering this context, the presented paper intends to disseminate important concepts to guide companies that have their own predictive group or want to hire consultants or specialized service to obtain good results through general predictive maintenance practices and, especially through electrical signature analysis. The result of the proposed discussion in this paper is a procedure of acquisition and analysis, which is presented at the end of the paper and intends to be a reference to be used by industries that have a plan to have MCSA as a monitoring condition tool for electrical machines

Table 1: Vibration Frequencies related to the Specific Failure of the Machine

Nature of the Failure	Vibration of Frequency
Unbalanced rotor	$1xf_r$
Unbalanced axe	$1xf_r$ $2xf_r$ $3xf_r$ $4xf_r$
Bearing elements	External path: $f_e = \frac{n}{2} \cdot f_{im} \cdot \left(1 - \frac{BD}{PD} \cdot \cos\beta\right)$ Internal path: $f_i = \frac{n}{2} \cdot f_{im} \cdot \left(1 + \frac{BD}{PD} \cdot \cos\beta\right)$ Rolling element: $f_{re} = \frac{PD}{BD} \cdot f_{im} \cdot \left[1 - \left(\frac{BD}{PD} \cdot \cos\beta\right)^1\right]$ Where: β = contact angle; BD = diameter of the rolling element; PD = primitive diameter; n = number of rolling elements; f_{im} = relative frequency enters the paths in Hz
Boost glide or recesses in carcasses.	Sub-harmonics of axe rotation: 1/2 and 1/3 of f_r
Whirl of the boost glide oil film in bearing	A little less than the axe rotation: 42% til 48%
Damages or consuming in gears	$f_{eng} = f_r \cdot Z \cdot i$ Where: Z = path of the gear; i = 1,2,3,4...
Mechanical recesses	$f_{fm} = i \cdot 2 \cdot f_r$ 1.2x, 2.5x, 3.5x Where: i = 1, 2,3...
Imperfections in drive leather straps	$f_{correia} = i \cdot \frac{\pi \cdot D \cdot N}{60 \cdot L}$ Where: D = pulley diameter; N =pulley RPM; L = pulley perimeter; i = 1, 2 , 3 ...
Induced vibrations for electric problems	$1xf_r$ ix60 Hz; i = 2,3, ... In case of induction motors: $f = i \cdot RPM \pm j \cdot s$ Where: s = machine slipping; j = 2, 4, 6, ...

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