

Mechanical Faults Diagnosis in Induction Motors based on Neural Networks and Vibration Patterns

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Abstract. The importance of this project takes root in the aptitude to recognize some types of mechanical faults across a new algorithm as neural networks are, with little margin of mistake that will allow the users of small, medium and big companies, to become free of the technician specializing in vibrations and signs, and to realize an alone investment for the constant monitoring of their engines. The patterns generated for the training and operation of the back propagation neural network, not only is able to also diagnose the type of fault but that so severe is this one, existing the possibility of predicting future behavior of the machine with the obtained results.

1 Introduction

In the industrial automatic processes, one of the electric parts of major application, they are the engines of induction of fall, medium and high tension. If the used engine was presenting a sudden fault, there might be generated serious consequences that would cause losses in the production. For the previous reason, it turns out necessary to assure the operative continuity of the engine by means of the detection of incipient faults generated by the efforts to which it is submitted, and to give it maintenance of an opportune way [1].

Anyone that is the strategy used in the maintenance is necessary to identify the variable of operation that will provide to us the readings of the machine's condition, to be able to generate a diagnosis by means of an automatic algorithm. In this article, the variable to measuring will be the mechanical vibrations produced in different points of the engine and the algorithm to analyze the vibration readings involves the neural networks.

Traditionally in industry, the maintenance has developed on the base of two fundamental strategies [2]. On one hand, the machinery; as part of an automated process, it works in a constant way and its breakdowns are attended until these appear [2], [3]. This strategy is known as Corrective Maintenance. In other types of machines the maintenance is applied in certain intervals of time that can be established on the basis

of the recommendations of the manufacturer or the frequency of failures, which is known as strategy of Preventive Planned Maintenance [4].

Nevertheless, from the 40's, the world has come implementing and perfecting the predictive technologies, whose conceptual base takes root in the intervention of the machinery when it is justified by the presence of objective symptoms of the deterioration of its mechanical condition [1], [5], [6].

The PPM (Program of Predictive Maintenance), it is that one who contemplates in an effective way three indispensable stages: Detection, Identification and Correction [6]. In general, the PPM helps at first, to incipient faults detect simultaneously that allows to have the necessary tools to analyze the reason of the problem that is developing, being achieved to determine finally, the opportune moment to correct effectively detected problem. Across the years, the operators of rotating machines in the different industrial sectors have used technologies of auditory checking to verify if the behavior of their engine is normal or not [7]. Traditionally and probably in unconscious form, the vibrations have been used as an indicator of the technical condition of the engines, being able by means of the measurement and analysis of these, detect and identify different types of faults. Besides, the frequencies and magnitudes of the signs of vibration of the engine, they will allow identifying what this one badly, and so severe what is the problem, to take opportune action before the damage produces irreversible losses of production.

2 Mechanical Vibration

The forces that cause the vibration are usually generated on the parts of the engine that they are in movement, or in which ones this movement is transmitted. Due to the fact that these forces change direction or magnitude in agreement to the rotational speed (RPM) of the machine, it is possible to deduce that the majority of the problems of vibration will have frequencies directly related to its speeds [1].

The frequency response of vibration has been so useful, that could have rejected many faults so much electrical as mechanics of the engine, the Fig. 1 shows the frequencies of the characteristics harmonics signals of different kind of mechanical faults [1], [2], [3], [8].

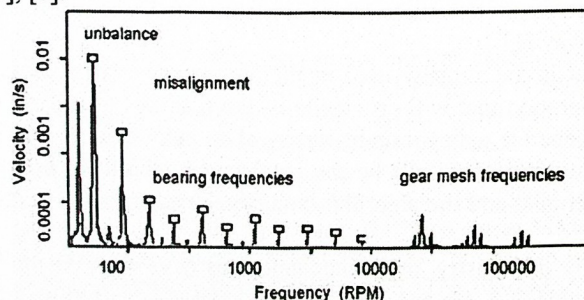


Fig. 1. Frequency response of mechanical faults in induction motors. This shows the characteristic harmonics of different kind of faults in electrical engine.

The diagnosis of the type of present fault in the engine is realized searching harmonic in frequencies multiple of its speed. This way, the degree of severity of the fault is evaluated by the magnitude of the harmonic one and the comparison by international procedure of monitoring of electrical machines [8].

3 International Standards of Mechanical Condition

International organizations as the American National Standards Institute (ANSI), Engineers' German Association VDI 2056 or International Standards Organization ISO 10816-1 1995 (replaces to the ISO norm 2372 and ISO 3945), and the BS 4675, they all stipulate the positions of measurement as well as the maximum permissible limits for class of equipment. These indicators contemplate the measurement of the total level of RMS speed inside a specific range of frequencies. The vibrations considered by these standards to evaluate the severity of the vibrations, are those measures in the surface of the machines, on its rests or in the points of assembly, in the range of frequencies of 10 Hz to 1000 Hz [9], [10].

18 - 28					1.102 - 1.772
11.2 - 17	Non Permissible				0.709 - 1.101
7.1 - 11.1					0.441 - 0.708
4.5 - 7.0					0.280 - 0.440
2.8 - 4.4		Limit			0.177 - 0.279
1.8 - 2.7					0.110 - 0.176
1.12 - 1.7		Permissible			0.071 - 0.109
0.71 - 1.11					0.044 - 0.070
0.45 - 0.70					0.028 - 0.043
0.28 - 0.44	Normal				0.018 - 0.027
0.18 - 0.27					0.011 - 0.017
	Group K (<15 KW)	Group M (15 KW - 75 KW)	Group G (>75 KW rigid base)	Group T (>75 KW flexible base)	

Fig. 2. Standards levels of mechanical vibrations. The figure shows normal, permissible, limits and non permissible levels of mechanical vibration in different kind of engine. Motors of the group K has power level's lower than 15 000 Watts, group M greater than 15 000 Watts and lower than 75 000 Watts and group G and T for power level's greater than 75 000 Watts with rigid and flexible bases respectively.

It thinks that a significant change takes place in the vibratory response, when this one changes in the reason 1:1.6 meaning that the vibratory level changes in 60%. Increases of the levels of vibration in 2.5 times indicate a change of condition Me-

chanics of the engine. Increases of the levels of vibration in 10 times constitute an alarming change.

4 Data Acquisition

The piezoelectric accelerometer can be fixed to the surface where it is desired to carry out the measurement with the aid of different elements such as: the steel bolt, the wax of bee, the permanent magnet, glues and the sharp shooting well-known. The sensor used for the construction of the System of Predictive Maintenance of Motors of Induction of this project, were the MA11 of the Honeywell mark, with one frequency of operation located in the rank of 2Hz - 10kHz. The MA11 is a piezoelectric accelerometer with stainless cover and system of magnetic fixation and a Sensitivity of 100 mV/g.

For the acquisition of the mechanical measures of vibrations in the induction motor, the tool of graphical programming LabVIEW 7 Express was used, with the use of card PCI - 4452 of National Instruments. This card specifically is designed for the acquisition of signals of sound and vibrations. It counts on Applications package that works for signals associated with accelerometers, microphones and some other types of transducers with an ample dynamic range. Card PCI - 4452 also count on four channels of integrated analogical entrances in the accessory of acquisition of dynamic signals BNC - 2140 and whit the frequency of sampling equals to 204.8 kS/s, each channel of entrance can sampling to a frequency of 51.2 kS/s in case that the four channels of simultaneous way are used. This frequency is sufficient since he was necessary that outside greater to 10 kHz.

For the acquisition of the vibration signals, accelerometers were placed on guard axial, vertical and horizontal [11], [12], [13] according to the type of fault that was hoped to find, as it is in Fig 3.

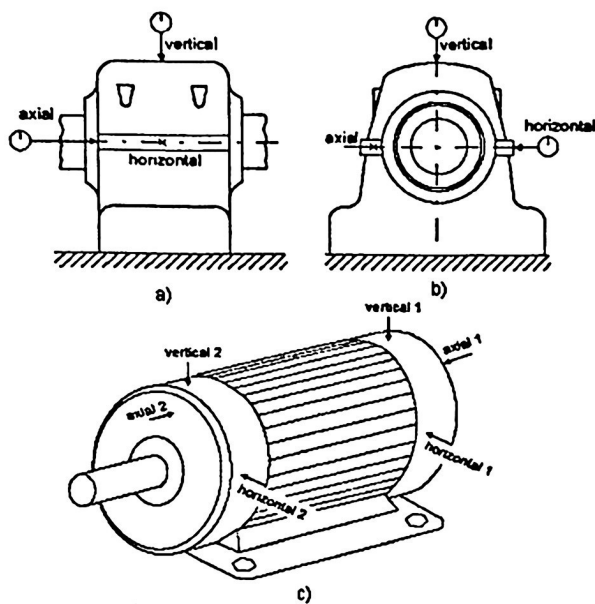


Fig. 3. Location of the piezoelectric accelerometers. The accelerometers must be placed simultaneously in the positions that the figure shows, of simultaneous way or one depending on the type of fault

5 Fault Recognition Using Neural Networks

The artificial neural network that was used in this project is based on the architecture of back propagation. This is a learning rule that is used for the training of the network, has like main characteristics, more able containing one or intermediate between the layer of entrance and the one of exit, and its operation consists of a learning pre-defined by a data set of entrance related to its corresponding exit [14].

When one works with back propagation neural networks, first a pattern of entrance like excitation is applied to the network, the data propagate layer after layer, and a percentage of calculated error is returned, to readjust the training patterns, in order that the difference between the wished values "targets" and the values of exit, are minimum. This procedure is made in cycles known like epochs [14].

Although the network is only trained to recognize four types of mechanical faults, the patrons of entrance to undercoat were planned to detect any type of well-known mechanical fault at the present time.

5.1 Generation of Patterns

In order to train to the neural network 50 signals in LabVIEW of each one of the following mechanical faults were simulated: unbalance, bent shaft, angular misalignment and parallel misalignment; with Normal, Permissible, in the Limit and Non Permissible level vibration.

Table 1. Mechanical Faults. It shows the characteristic harmonics for the different types of faults.

Frequency (RPM)	FAULT
$< 0.5 \times \text{RPM}$	Oil whirl instability.
$1 \times \text{RPM}$	Unbalance.
$1 \times \text{RPM}$	Weakness of machine feet.
$1 \times, 2 \times \text{RPM}$	Bent Shaft.
$0.5 \times, 1 \times, 2 \times, 3 \times \text{RPM}$	Mechanical Looseness.
$1 \times, 2 \times, 3 \times \text{RPM}$	Misalignment.
$1 \times, 2 \times, 3 \times, 4 \times \text{RPM}$	Mechanical Looseness.
$0.5 \times, 1 \times, 1.5 \times, 2 \times, 3 \times, 4 \times, 5 \times, 6 \times, 7 \times, 8 \times, 9 \times, 10 \times$	Mechanical Looseness.

Reason why altogether, 12 overtones looked for: $0.5 \times, 1 \times, 1.5 \times, 2 \times, 3 \times, 4 \times, 5 \times, 6 \times, 7 \times, 8 \times, 9 \times$, and $10 \times \text{RPM}$. Each significant overtone of a fault is observable in a bandwidth of approximately 10 Hertz, reason why the vectors of training of the neural network were constructed as it is in Fig 4. What means that, the vector of the vibration signal is of length 132, independently of the frequency or engine's speed.

The samples for unbalance, for example, generate an overtone in frequency 16 of the training adjustment, in amplitude that vary of 0,28-28 mm/s equivalent to the amplitude of the speed.

The neural network that was used contains 132 neurons of entrance for each one of the elements of the generated patterns, two intermediate ones, one that the entrance transmits and a second that classifies the twelve harmonics characteristic of the faults, and finally layer of exit of seven neurons one for each one of the four faults detected by the three different levels from severity (Fig. 5).

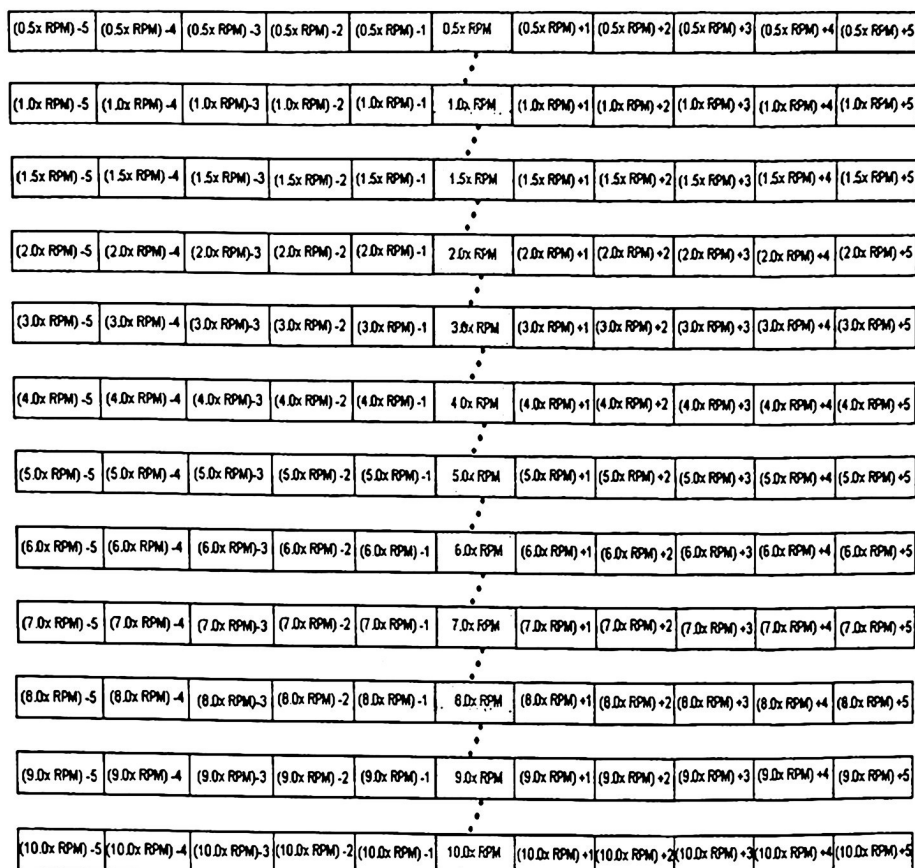


Fig. 4. Patterns of entrance to the neural network. Figure shows the 132 significant readings to identify all kind of mechanical fault.

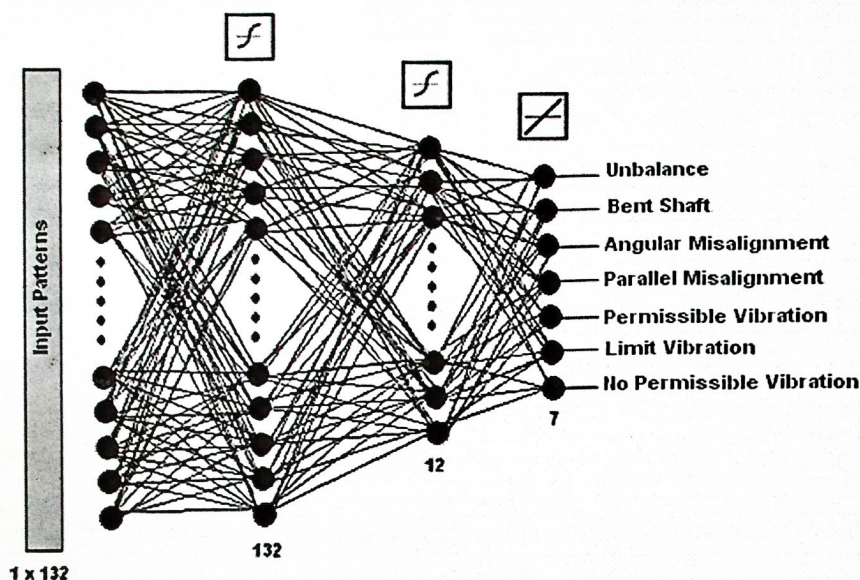


Fig. 5. Neural network topology. The neural network has the input layer with 132 neurons, 2 hidden layers with 132 and 12 neurons and the output layer with 7 neurons, 4 for fault's kind and 3 for severity level.

6 Results

The training of the described neural network was reached at 5682 epochs with algorithms established in MATLAB under the following code:

```
p=[PP1 PP2 PP3 PP4];
t=[tt2];
net=newff(minmax(p), [132,12,7], {'tansig','tansig','pure
lin'}, 'trainrp');
net=init(net);
net.trainParam.show = 10;
net.trainParam.goal = 1.4e-4;
net.trainParam.epochs = 6000;
net.trainParam.delt_inc=1.2;
net.trainParam.minstep =1.0000e-4;
net.trainParam.min_grad=1.0000e-18;
[net,tr]=train(net,p,t);
```

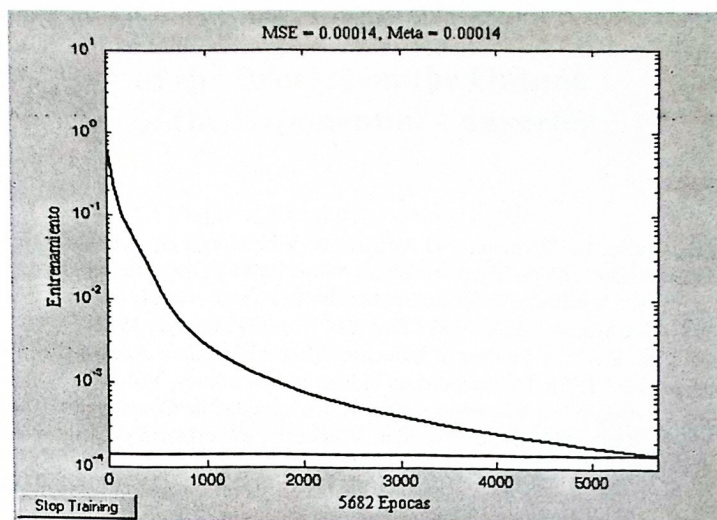



Fig. 6. Training of the neural network. Number of epochs x-axis against error in the y-axis.

The results of only some of tested with the neural network are in Table 2.

Table 2. Neural Networks Results. The most of the experiments does almost 100% recognition.

Pattern	% Recognized
Permissible Unbalance	99.3966
No permissible Parallel Misalignment	99.6066
Permissible Bent Shaft	99.7288
No Permissible Angular Misalignment	99.3653
Permissible Parallel Misalignment	99.1234
Limits Angular Misalignment	97.8126

Conclusions

Not only incipience's faults of a motor are detected of induction by means of the implementation of neural networks, but also it is possible to emit objective diagnoses, with low levels of error, on the existence of more severe faults.

At the present time, there are systems of no detection of mechanical faults based on algorithms of artificial intelligence, so this system can be implemented with facility and good results, reflecting its utility in economic gains and improvements in the production levels, as long as opportune action of maintenance is taken, when some fault is detected. This system is limited the detection of mechanical faults in induction

motors, so that although it is possible to detect some electrical faults by means of he himself procedure, has been verified that exist greater success in the use of other techniques.

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