ARTIFICIAL NEURAL NETWORKS APPLIED TO GEARBOX FAULT DETECTION

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Abstract. *With the insertion of new concepts, as economy of energy, improvements of the control process, increase of the efficiency and reduction of the maintenance costs, has increased the interest in the development of new techniques and tools for the detection and the diagnosis of faults. Actually, the monitoring of the machines has an essential paper so that if it guarantees a good functioning of any set. Following this trend, it has been used, each time more, the techniques of artificial intelligence in set with the traditional predictive techniques, increasing the reliability of diagnosis. In this context, the focus of this work is the study and the characterization of flaws in gearboxes using Artificial Neural Networks (ANNs), trained from signals of vibration obtained experimentally. Through a Selective Filter it was possible to reduce the number of parameters capable to represent the signals used for training of the nets. The use of ANNs in set with the vibration analysis allows that the maintenance team executes planned interventions, therefore allows the diagnosis of the defects when still they are in initial phase. Through this new tool the excitement due can be classified the misalignment, mechanical looseness, pitting, consumings, teeth flaws and geometric imperfections, beyond the normal condition of functioning. In short objective to extend the reliability and the availability of these equipments in the industrial plants, beyond perfecting the conditions of project and assembly of gears.*

Keywords*: Artificial Neural Networks; Gearboxes; Vibration Analysis*

1. INTRODUCTION

The growths of the competitiveness and the new challenges related with the increase of productivity between the industries have demanded more complex and sophisticated machines each time. Therefore, the condition monitoring of these machines if has become very important.

A trustworthy machinering condition monitoring system provides the following benefits: reduction of the faults number and not planned maintenance interventions, reduction of the machines stopped time, reduction of the maintenance costs, and consequently, increase of the equipment useful life and the level of components security.

These reasons have made possible the sprouting and the fast development of new techniques and methods for mechanical faults diagnosis. Diverse they are the methods of diagnosis of flaws, amongst them; we can cite the vibrations analysis, termography analysis, oil analysis among others.

The application of Artificial Intelligence techniques in detection of faults makes possible the accomplishment of machines diagnosis on line, being able to present a minimum interaction with the user and, in many cases, being capable to diagnosis flaws without the aid of the maintenance specialists, Brito (2002).

In its more general form, a neural network is a projected machine to absorber the way as the brain carries through a particular task or function of interest. The net is, normally, implemented using electronic components, or is simulated by computer programming.

The objective of this work is the main faults diagnosis occurred in gearboxes through an alternative methodology, using the vibration analysis to quantify the amplitude of vibration in these machines, in order to construct an extensive data base, which will be used by Artificial Neural Network, characterizing the faults.

Constituting, thus, a complementary tool to the current predictive maintenance techniques, making possible planned interventions in the monitored equipment, increasing the availability and the reliability of the gearboxes operation gifts in the industrial plants.

2. EXPERIMENTAL BENCH

The experimental tests were held using an experimental bench, represented in Fig. 1, set up in LASID – Laboratório de Sistemas Dinâmicos of the Departamento de Mecânica of the Universidade Federal de São João del-Rei.

Before starting the tests, the bench was balanced dynamically and aligned with laser technology to eliminate the undesirable vibration sources. The flexible bench structure turned possible that the induced defects became more perceivable in the collected signals.

The faults were induced in a FLENDER helical geared motor [1], coupled in a SEW geared motor[2], that serves as load of the system.

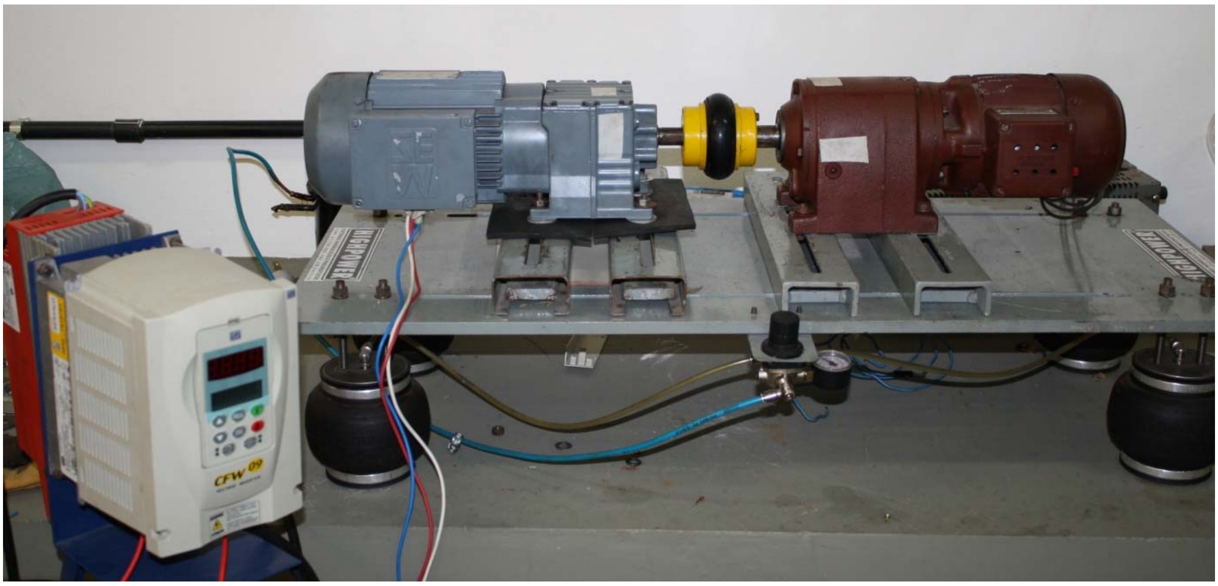

Figure 2. Experimental Bench.

Fault real vibration signals were collected using the data collector/analyzer SKF *Microlog* GX and an accelerometer SKF CMSS2200, Fig. 2, the signals are transmitted to the computer through the support program SKF @ptitude Analyst. This procedure allows to carry analyses more detailed, to build databases and to generate technical reports.

Figure 2. SKF Microlog GX.

This procedure allowed to more carrying through detailed analysis of the specters, validating the theory of vibration analysis on gearboxes machines, and later it assisted to elaborate the data base.

The signals had been gotten in the radial plan (vertical and horizontal position) and axial of the FLENDER geared motor. It was used Hanning window with resolution of 1600 lines and 4 averages, varying the band of frequency between 0 and 2000 Hz, in order to analyze the entire frequency band in which the above-mentioned faults are identified.

3. METHODOLOGY

The detention of faults when they are still in development phase, through the comparison of specters of magnetic flow, vibration and electric chain, makes possible the maintenance engineer to plan a corrective action with regard to the foreseen defect, Lamim Filho (2007).

The most viable form to conceive an applicatory one that detects imperfections in gearboxes machines, was using the Artificial Neural Networks through the Matlab. Of this form was opted to using the Neural Network Toolbox (NNTOOL), to develop the network in a more versatile and friendly environment.

The first stage of the work is the development of the experimental tests, through which if it constructed an ample data base of vibration signals as FFT specters.

As second stage of the work, a selective filter was implemented, in Matlab environment, for the election of the interest signals for training and validation of the network. After the selective filter development, the neural network was developed in the NNTOOL until the attainment of a satisfactory topology.

3.1. Experimental Development

A neural network can be trained using great amounts of significant examples, what it contributes for the high performance attainment. That is, the evaluation is shaped through examples of well or badly succeeded applications, through objective models or quantified of this operation, Brito (2002).

The main objective of the work is to use Artificial Neural Networks (ANNs) for Gearboxes machines faults diagnosis, the first stage for the ANN development is the elaboration of a significant vibration signals data base that characterizes the studied faults.

This register of the vibration signals must be organized, in order to supply given clear and concise the RNA, so that it is efficient and has the lesser index of possible error.

For the data base confection, diverse types of flaws had been introduced in the experimental bench, aiming at an ample understanding of the faults types as well its characteristic vibration specters.

3.2. Mechanical Faults

Evaluating the flaw types could be introduced in the experimental bench; the main faults found in gearboxes machines are delimited, as being: misalignment, mechanical looseness and gear faults.

Of this form the faults had been introduced initially separated and later combinations of the same ones had become, seeking compose the data base with industry common situations.

The misalignment excitement was gotten unlevelling the bench geared motors through fine plates introduced between the base of the bench machines. In Figure 3, is had the misalignment vibration characteristic specter.

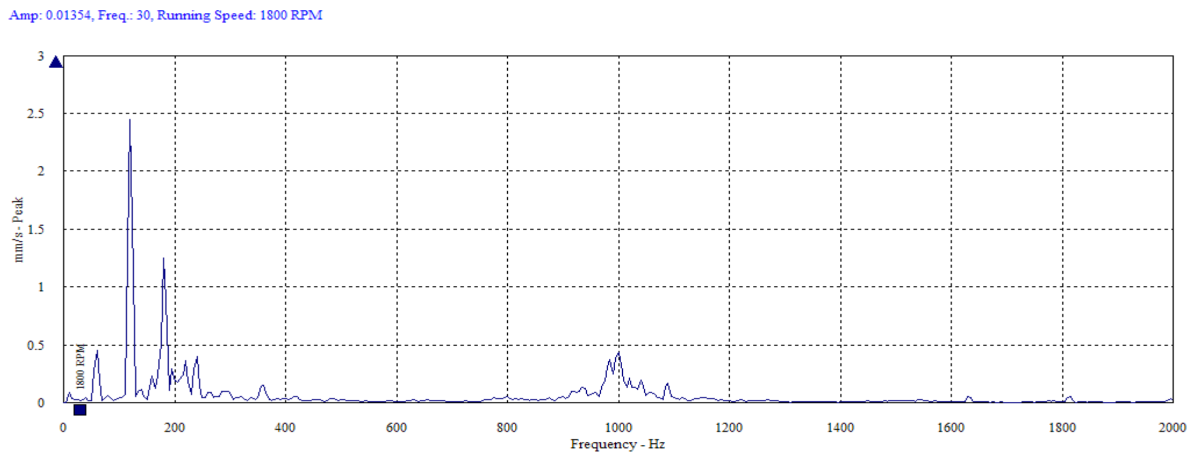

Figure 3. Misalignment fault characteristic specter.

Was introduced Mechanical Looseness through the loosen of the screws of setting of the geared motor to the base of the experimental bench. The Figure 4 shows a Mechanical Looseness Fault characteristic specter.

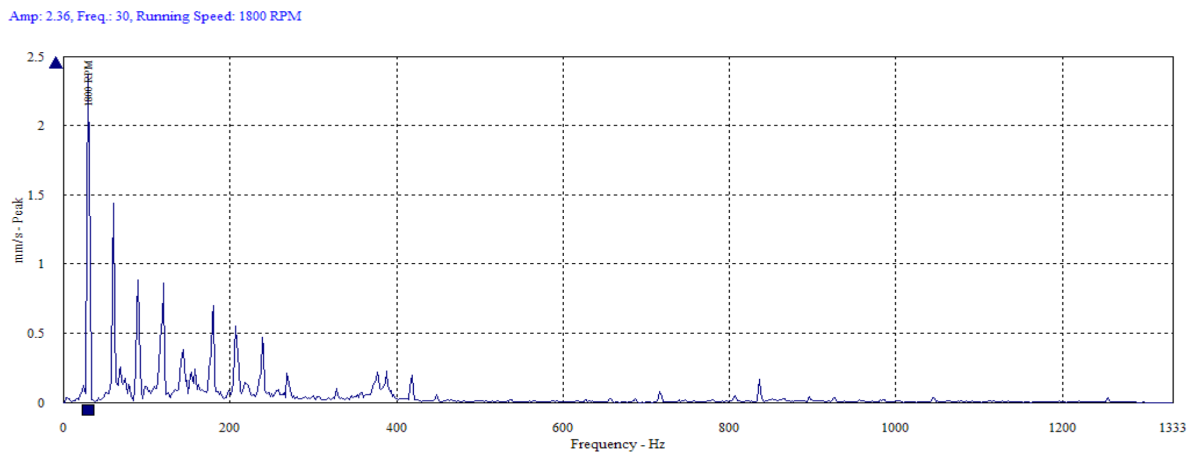

Figure 4. Mechanical Looseness fault characteristic specter.

The gears flaws introduction received special attention for if dealing with a destructive process, in which the used gear lost its condition of use. A wimble was used to simulate the effect of pitting and defects in teeth of the gear. The Figure 5 shows a gear fault characteristic specter of vibration.

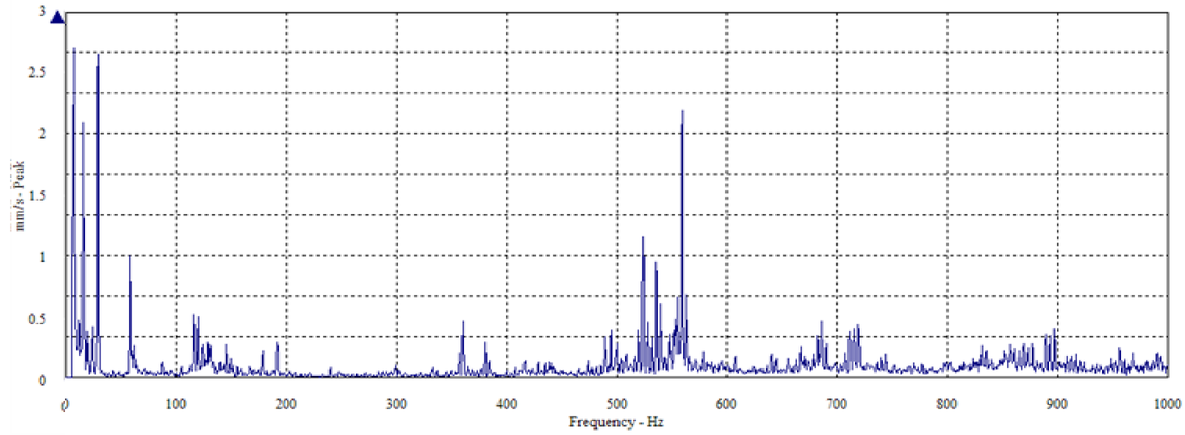

Figure 5. Gear fault characteristic specter.

3.3. Application of Artificial Neural Networks to the detection and diagnosis of faults

The application fields for the neural networks are ample: analysis and processing of signals, control of processes, data classification, standards recognition, images analysis, medical diagnosis, among others. In the industrial area, neural networks has been used in the processes shunting lines prevention and in hybrid systems are distinguished, associates to the nebulous logic techniques and specialist systems, for detention of maintenance problems. They are treated of problems with difficult quantification mathematical, inefficacious or even though impossible, Brito (2002).

The main stage for the development of the ANN for gearboxes faults detention and diagnosis was the determination of the best mathematical parameters and the ANN architecture.

It was stipulated that the neural network input would be the amplitude collected in the radial plan (vertical and horizontal position) beyond the gear frequency of the machine, inserted parameter numerically (from the tooth number of the gear and the rotation of the same one). Already the output would be the fault detected in matricidal form.

Of this form, using the Haykin (2001) methodologies, had been trained and compared three ANNs architectures, 3x3x1, 3x6x1 and 3x12x1, with desired error of 0,5%, learning tax of 0.01, constant and moment 0,1, random weights initialize and a times maximum number of 500.

The topologies had been developed using the backpropagation training method through the supervised learning and being optimized for the Levemberg-Marquardt method.

It was used sigmoid function, as activation function of the input and hidden neurons, for the output neuron was used the linear function. The used activation speed was 0,001.

It was divided the neural network conception in two phases, initially the training phase, in which we satisfactorily use 60% of the specters of the data base and after the training conclusion, we insert the remaining specters seeking the ANN validation.

4. ANALYSIS OF THE EXPERIMENTAL RESULTS

During the neural network development can be observed that some parameters modified more significantly the ANN performance, valley to point out the learning tax case, which was hardly modified during the network conception, therefore a band of values that made the ANN easily converge, of this form did not meet was observed that this parameter in the practical one does not obey no theoretical criterion.

The data input format was very varied also, until it was arrived at the conclusion of that a matrix of three lines, having represented the collected vibrations in the two plans of measurement of the machine, in which the columns represented the amplitude of vibration made possible the best one result.

Analogous definition the data output format is very varied, until which was arrived at the most viable form, that would be a matrix of a line with four columns, represents the studied faults and the condition without flaws.

Other variable are still studied, as the rotation and the engine power coupled to the gearbox, that can become the Artificial Neural Network developed in a general purpose application in any type of set engine-gearbox, eliminating the disadvantage of that to be applied ANN would take a significant time to confection a data base.

To follow, the results gotten from the ANNs architectures implementation and training are presents, with the algorithm backpropagation, using real parameters as network inputs.

In Figure 6, it is had success individual tax for each fault type in each artificial neural network architecture studied during its learning (training).

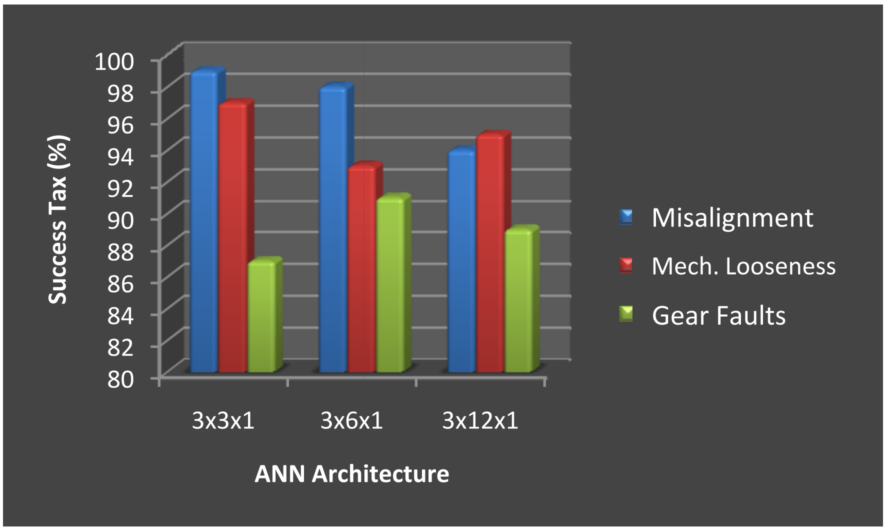

Figure 6. Artificial the Neural Networks Success Tax during the training.

Already in Fig. 7 it is had individual success tax, for the three faults types studied, in the three network models during its simulation (validation).

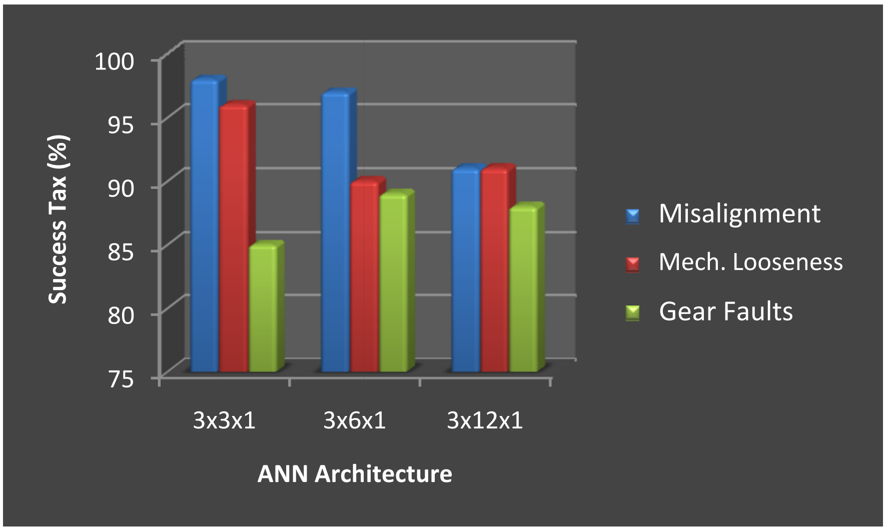

Figure 7. Artificial the Neural Networks Success Tax during the validation.

The Table 1, presents the global results (average of the success tax, for the studied faults) of the three network architecture developed.

Table 1. Global results of the ANN architectures.

Architectures	Success Tax (%) Training	Success Tax (%) Validation
3x3x1	94,33	93,00
3x5x1	94,00	92,00
3x10x1	92,67	90,00

Analyzing the results previously presented, it can be concluded that the three developed architectures had been efficient with success taxes higher than 90%. However case must be stranded out that for a perfect diagnosis the ANN must present the best success tax, which is in ours the 3x3x1 network, presented optimum global result.

5. CONCLUSIONS

Artificial Neural Networks are one of the tools that great interest of researchers has raising in recent years, for being a tool that makes possible the predictive maintenance on-line monitoring aiming at the time minimization enters the act of receiving of the information and the problem detention and diagnosis.

Ahead of the presented results, it was observed that amongst many theoretical and practical aspects that they are part of neural network project, the architecture choice and the ANN training parameters does not follow predefined rules, the knowledge and experience of the designer in relation to the faced problem is more important.

The definition phase is delicate; therefore it involves, beyond the choice of the network topology, the attainment of significant set variable for the problem resolution. This attainment involves, beyond the variable identification that are related with the problem, the removal of not trustworthy process variable, or whose use is impracticable for economic and technical reasons.

Additionally, it was observed that the sensitivity and the neural network reply time in relation to others faults diagnosis techniques are important aspects and that they can be evaluated and improved during the ANN implementation, training, test and validation phases.

The results show, the capacity and viability of neural networks application as sufficiently efficient tool in the gearboxes faults detention and diagnosis.

In short, it is distinguished that the experimental development of artificial intelligence combined with the traditional predictive maintenance techniques provides fault detention and diagnosis almost that immediate for the monitored equipment, beyond consisting a low cost tool, and with its constant implementation and development, could be in the future the most viable answer for a competitive maintenance.

6. ACKNOWLEDGEMENTS

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8. RESPONSIBILITY NOTICE