A New Automatic System for Quality Control of Compressors on Production Lines

C. Cristalli
AEA s.r.l

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Cristina Cristalli

AEA s.r.l. Via Fiume 16, 60030 Angeli di Rosora (AN) Italy

ABSTRACT

A novel system that automatically detects the mechanical defects on the production line of compressors has been developed. The testing device is aimed to look for vibrations determining a large gamma of noises, different the one from the other for amplitudes and frequencies. The developed self-standing testing workstation works in parallel with already existing lines and different sequential tests took place over each compressor. In order to quantify the amplitudes of the measured vibrations, a quartz accelerometer has been applied to the external structure of the compressor. Advanced techniques of Artificial Intelligence have been adopted and integrated into complete systems for data acquisition and classification in order to give an objective and accurate assessment of product quality. As classifier, the Kohonen Self Organizing Map has been used, obtaining the 100% rate of success.

INTRODUCTION

Quality control of finished products is an essential part of the manufacturing process. Even though manufacturing has benefited from recent advances in automation and robotics, quality control of the emitted noise and vibrations largely still relies on human operators and expertise. This is partly due to the nature of the problem, which is quite complex and requires the combination of advanced sensor technology and highly sophisticated data analysis techniques. Recently however, thanks to measurement system development and while Artificial Intelligence is maturing, advanced and performing automatic quality control systems are becoming part of standard production line [Meier et al. 1994].

On-line quality control of compressors represents an interesting test case for diagnostic systems. These products are in fact characterized by mass production; they are designed to reduce costs as much as possible and they are sold in a very competitive market, which is demanding more reliable products with reduced vibro-acoustic emissions. Therefore, manufacturers in order to meet such needs are constantly improving production process controls and strongly rely on 100% on-line quality control.

At present, on a production line different automatic tests are performed, like the current absorption test, the pumping test, the leakage test, the electric insulation test. The noise and vibration detection due to mechanical defects are still relying on human judgement and this shows limits, in particular for the accuracy and repeatability of measurements in a noisy factory environments. Furthermore the interpretation can vary from operator to operator and human factors such as training and fatigue can influence the results.

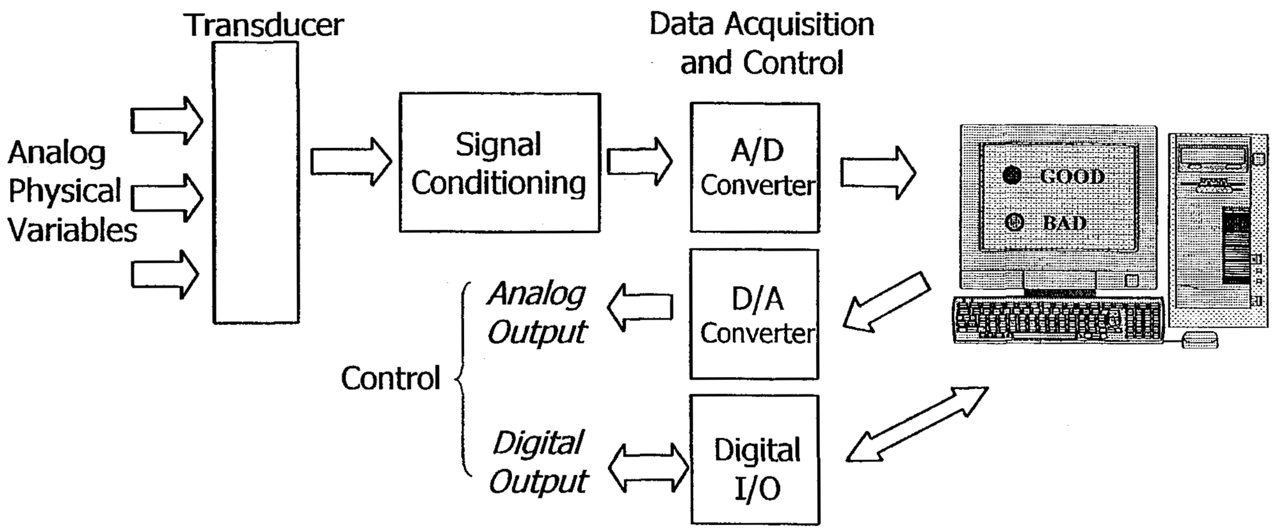

Figure 1 Block Diagram of a Data Analysis System.

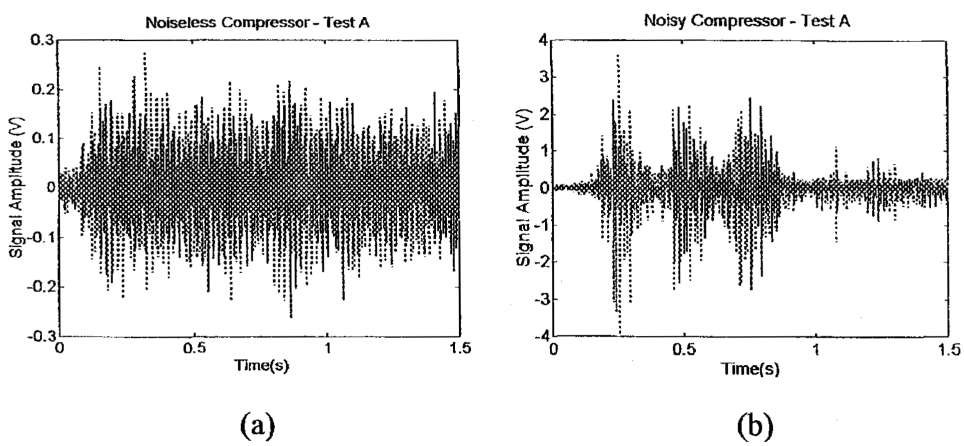

Figure 2 Signal acquired by an accelerometer in the time domain for a noiseless (a) and noisy (b) compressor during one phase of the testing procedure.

DATA ANALYSIS

Data processing and manipulation is central and is the power of such a system. Since each manufacturing operation is unique, interpretation carried out by humans may be highly operator dependent. An Artificial Intelligence (AI) system enables the judgement to be carried out faster, more reliably and robustly [Pouliezos and Stavrakakis, 1994].

A self-standing testing workstation that could work in parallel with already existing lines has been developed in order to detect noisy compressors for refrigerators at the end of the assembly lines. The testing device performs all the tests listed before and furthermore the system checks the vibrations emitted by the compressor in order to determine a large gamma of noises, different from each other both for amplitudes and for frequencies. Different noises were due to different constructive and assembly defects such as plays, compressor shocks, defective coils and suspensions.
In order to automatically classify the compressors as good or faulty, a spectral analysis and Kohonen neural network algorithm have been developed. This new neural approach has been compared to the previous fuzzy one to detect noisy compressors, for household appliances, at the end of the production line. The analyzed compressors were affected by more then one kind of manufacturing and assembly defects.

INSTRUMENTATION AND METHODS

Mechanical diagnostics are traditionally performed by vibration and acoustic measurements. The measurement techniques employed for data extraction will have to satisfy several requirements and specifications and need to cope with the production system in terms of environment and logistics. In large industrial plants working at full regime, only few seconds will be available for testing each product. During the testing procedure the product will approach the test station on a pallet, then it will stop and be prepared for functionality tests. Testing time has to be divided into three main phases: product set-up and connection to the actuators and sensing system; product operation during test according to a prescribed sequence, and finally stopping of the product and disassembling from the test station.
The production line environment is very hostile and characterized by extremely high levels of acoustic noise. Vibration may also be high. Humidity and temperature range in normal values, but electromagnetic disturbances, both radiated and conducted, may be high due to the many electrical and electronic devices operating on the production line.
A typical data analysis system includes sensors or transducers, signal conditioning and amplification circuitry, data acquisition system, input trigger channels, relay output channels, a processor or microcomputer and software to analyze the data. Systems are available with multiple channels and with different types of signal conditioning to handle different sensors. The software is designed to acquire the data and then to perform the analysis on the measured or computed waveforms. Depending on the outcome of the analysis, the system can take appropriate actions such as displaying data on a video screen, activating a control output, sending signals to a PLC (Programmable Logic Controller), or saving data to a disk file.
A block diagram in Figure 1 illustrates the different parts of a data analysis system.
Different sequential tests, characterized by different operative conditions, took place over each compressor starting from its switching on phase. The testing device has been coupled to the existing testing line just to receive the starting trigger signals.
In order to quantify the amplitudes of the measured vibrations, a quartz accelerometer applied to the external structure of the compressor has been used. The analog signals from the sensors are then amplified and digitized.
An example of the time course of the signals acquired by the accelerometer in a noiseless compressor and in a noisy compressor are reported in figures 2 (a) and (b), respectively.

The phases of a diagnostic procedure can be formulated in the terminology of Pattern Recognition techniques. A pattern class is a group of patterns with certain common properties. Each pattern element is just a number that is called feature. Feature definition and selection is largely application dependent although generic feature sets applicable over a wide range of applications can be defined. Once the feature vector has been obtained, the classifier that operates on this vector produces a classification decision based on prior knowledge, which describes at least the normal operating conditions.

In the definition of the classifier a certain number of samples are used for the training of the system; this means that the labeled samples are presented to the system sequentially and the decision rule is altered by a "teacher", which corrects any errors in the classification of the current sample. Once the system has been trained by the labeled samples, it can then be used in the testing phase to classify new samples of unknown classification.

Acquired signals have been analyzed both as time-series and in the frequency domain by use of spectral analysis. In the frequency domain, either Fast Fourier Transform (FFT), to the stationary components of the signals, and Short Time Fourier Transform (STFT), to evaluate the spectral components that changed over time, have been applied. An example of the acquired signals in the time and frequency domain for a noisy and a noiseless compressor is reported in Figure 3.

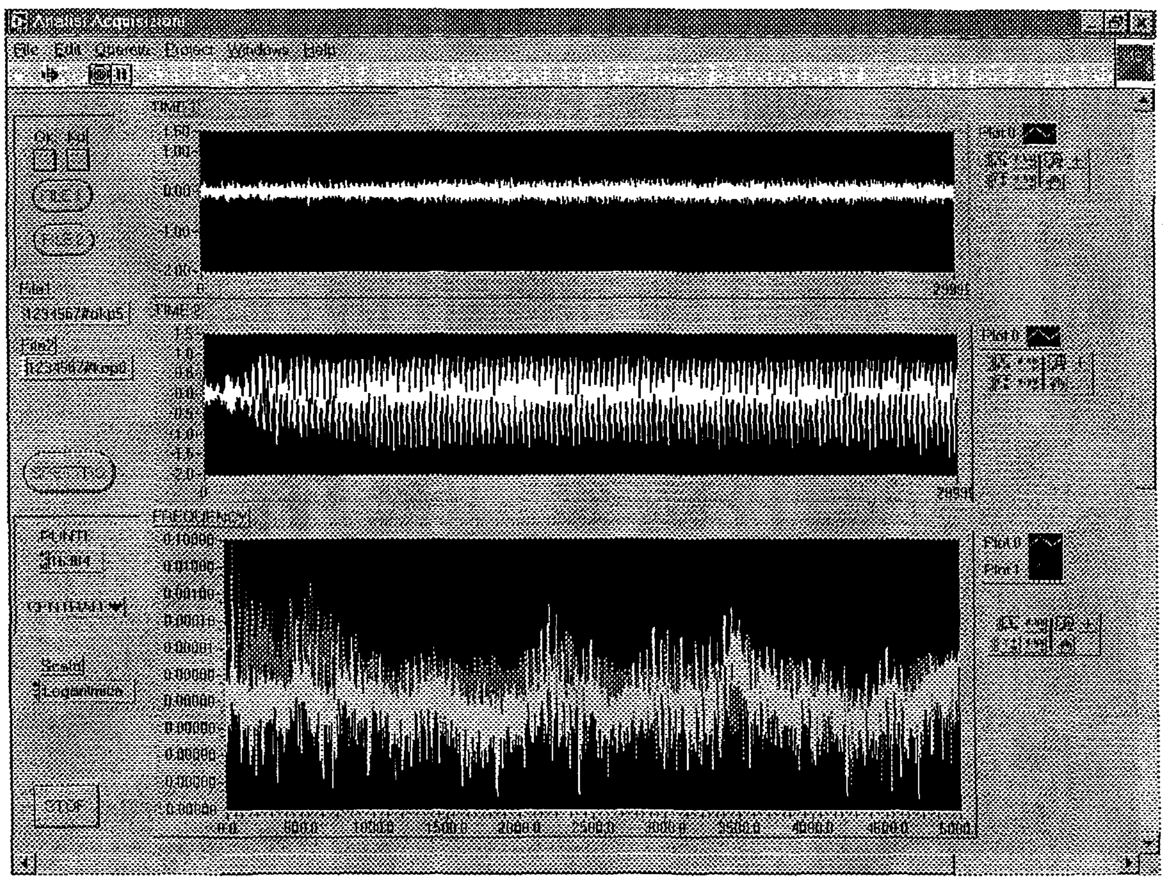

Figure 3 Evaluation panel with signals acquired from a noiseless and noisy compressor in the time and frequency domain.

To properly classify compressors as noisy or noiseless two different clustering approaches, fuzzy C-means and Kohonen neural network, have been performed.
Fuzzy C-means is an algorithm that partitions a collection of data points into a number of subgroups (classes). The objects inside a cluster show a certain degree of closeness or similarity (membership values). The assignment of these objects to the above mentioned classes is done in a fuzzy sense, i.e. each object is assigned to a special degree.
The Kohonen network is a neural network which is used to find classes in a multidimensional feature space. These classes are crisp so that the objects are assigned to crisp classes.
Deviating from the fuzzy C-means, the number of clusters has not to be predetermined and the cluster shape can differ from a hyper sphere. Using Kohonen network the number of classes for the classification comes in the procedure only in a second step. The classification result is strict membership to just one class.
Both fuzzy logic and neural network assisted data analysis involve the assessment of features. Seven features have been selected in order to properly classify the compressors: two derived from time-based signal analysis, three from the FFT analysis and two from the STFT analysis.
The extremely different vibration behaviors of the tested defects in terms of spectral signals caused the use of such a big number of features characterizing the test.

RESULTS

The testing procedure has been applied over a total number of two hundred (coming from assembling line) and twenty (noisy) compressors. The twenty noisy compressors, characterized by hand made defects, were introduced randomly among the two hundred compressors from the line. The same features sets have been used to compare the Kohonen network based classifier (K-Classifier) and the fuzzy C-means based classifier (F-Classifier).
Different results, showed in Table I, characterize the performance of the two classifiers. K-Classifier has 100% of success, while F-Classifier has 94% of success in classifying the total number of compressors. Both the classifiers show to be very good in detecting noiseless compressors (100% of success), but F-Classifier has only 38% of success in detecting noisy compressor. K-Classifier has 100% of success with noisy compressors, too.
To test the repeatability of the classification procedure, both noiseless and noisy compressors have been submitted to the classification procedure more than one time. They always provide the same results.
The obtained results show that in situations where more than one defect has to be grouped in a single class, the neural network approach gives best results than fuzzy logic approach.

Test Results		Percentage of Success	
Noisy: 21	Noiseless: 199	Noisy:	Noiseless:
K-Classifier: 21/21	K-Classifier: 199/199	K-Classifier: 100%	K-Classifier: 100%
F-Classifier: 8/21	F-Classifier: 199/199	F-Classifier: 38%	F-Classifier: 100%

Table I

CONCLUSION

The methods and results described in the present work show how the developed Data Analysis System composed of appropriate transducers, data acquisition system and Pattern Recognition algorithms can be successfully applied to mechanical defect diagnostics for compressors.

In order to properly classify compressors as noisy or noiseless the Kohonen Neural Network technique has been chosen as the most powerful for this application.

The attributes of the method developed are robustness, ability to operate in diverse production environments, adaptation to different products and real time operations. In all the described applications, the mechanical tests are fully integrated with the traditional functional tests in order to obtain a comprehensive quality control solution.

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