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EXTRACSION : UN SYSTEME DE CONTROLE AUTOMATIQUE PAR COURANTS DE FOUCAULT DES TUBES DE GENERATEURS DE VAPEUR DE CENTRALES NUCLEAIRES

EXTRACSION : A SYSTEM FOR AUTOMATIC EDDY CURRENT DIAGNOSIS OF STEAM GENERATOR TUBES IN NUCLEAR POWER PLANTS

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SYNTHÈSE :

Améliorer la rapidité et la qualité des contrôles non destructifs par courants de Foucault des tubes de générateurs de vapeur conduit à automatiser tous les processus qui contribuent au diagnostic.

Cette note décrit notre utilisation du traitement du signal, de la reconnaissance de formes et de l'intelligence artificielle, en vue de développer un logiciel capable de fournir automatiquement un diagnostic efficace.

EXECUTIVE SUMMARY :

Improving speed and quality of Eddy Current non-destructive testing of steam generator tubes leads to automatize all processes that contribute to diagnosis.

This paper describes how we use signal processing, pattern recognition and artificial intelligence to build a software package that is able to automatically provide an efficient diagnosis.

EXTRACSION : a system for automatic Eddy Current diagnosis of steam generator tubes in nuclear power plants.

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1. INTRODUCTION

In order to improve both safety and cost effectiveness of nuclear power plants, steam generator tubes Eddy Current In-Service Inspection must face the following challenges : increasing number of tubes being checked, huge quantity of data to analyse and store, evolutivity of the flaws and of the criteria to use, intrinsic difficulty of the filtering and classification tasks,...

Electricité de France has defined a research and development project one of the main objectives of which is to realize a prototype of *an automatic system of diagnosis*. During the first phase of this project, we have mainly focused on the feasibility of an off-line software package (EXTRACSION*), easy to maintain and to upgrade and providing automatically an efficient diagnosis.

After a short statement on Eddy Current testing of tubes, this paper defines the problem of Eddy Current diagnosis automatization and describes which solutions we have developed and used. The architecture of the EXTRACSION software is briefly presented. Finally, some results of diagnosis obtained from real world signals are given.

*EXTRACSION is a registered trademark of EDF.

2. THE EDDY CURRENT AUTOMATIZATION PROBLEM

2.1 Issues in Eddy Current testing of tubes

Testing a steam generator implies to collect about 3,000 to 5,000 signals. With each tube is associated a three megabyte long complex signal. Eddy Current testing signals are often corrupted by three kinds of noise : electronic noise, probe offset noise and flattening noise. Whereas the two first kinds of noise corrupt systematically the source signal, the deterioration by flattening noise mainly depends on tube manufacturing process. A spectral analysis stated that each kind of noise have a specific spectral support and that the flattening noise have the same spectral distribution than the signal. This property will lead us to use sophisticated digital signal processing techniques [1] to restore the useful information needed to elaborate a diagnosis.

2.2 The automatization problem

Steam generator tubes diagnosis involves a large number of sophisticated operations such as signal restoration, feature extraction, pattern recognition or neural networks for classification and the "know-how" of human experts for diagnosis. As a matter of fact, diagnosis is basically a mixed numeric/symbolic treatment. Moreover, diagnosis of a tube is an undefined function of testing context, localization of current tube in steam generator, history of the tube,... Thus, to automatize a diagnosis process implies to solve three problems : i) to decide how each algorithm should be chosen and applied with the right set of parameters, ii) to define, with human experts in eddy current tube diagnosis, the expertise rules and iii) to design the global strategy of cooperation between numeric and symbolic treatments.

The solution must take into account the general constraints of open architectures allowing the future addition of new functionalities.

Note that another project, AITRAS [2], aims to elaborate a diagnosis from noiseless signals only. Unfortunately, it is not our case.

3. THE EXTRACSION EXPERT SYSTEM

In this context, we have developped the EXTRACSION mock-up. The main original features of this software are on one hand its open architecture via object-oriented modeling and on the other hand its expert capabilities in Eddy Current signal processing and in diagnosis via a rule-based language. EXTRACSION main functionalities cover data transfer, conditionning, restoration processing and automatic diagnosis elaboration on the straight part of a tube (see figure 1). For each important step of the process, quality of obtained results is checked to insure the best automatic running order to the software. The operator can, with full rights required for final diagnosis decisions, verify, show up and complete the correctness of proposed diagnosis by the software. The weaknesses and limitations of machine procedures are then palliated.

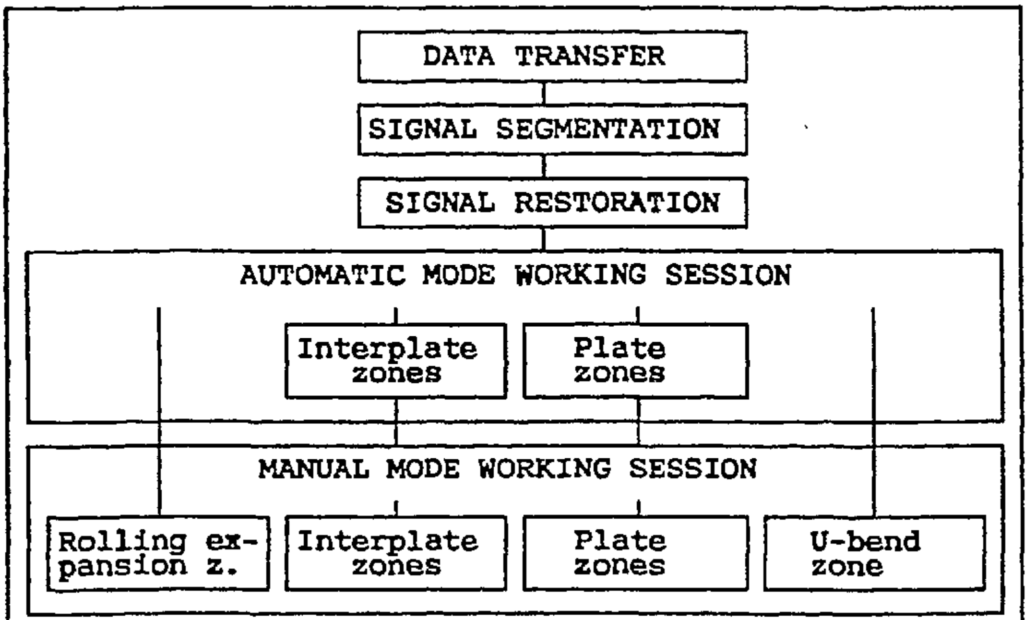


Figure 1 : EXTRACSION main functionalities

3.1 An Eddy Current signal processing expert system

To warrant a sufficient automatic running order, we have developped for EXTRACSION some original rules in signal processing working up and control. The digital processing module restores noisy signals, avoiding thus erroneous diagnosis : EXTRACSION decides on setting and driving of the algorithms and on the quality of their results.

To illustrate this original feature, we present how the flattening noise problem is solved. We suppose that we have eliminated electronic and offset noises. We follow the original solution proposed in [3] based on adaptive filtering with noise reference. The high frequency signal F1 is used as a noise reference for F2 and F3 restoration. F1 cannot be filtered with this technique (a whitening Least Mean Squares technique [4] is then applied instead). In the automatic mode, the EXTRACSION Eddy Current signal module is able to answer the three following questions :

. *Question 1* : should the current signal be restored ?
. *Question 2* : when necessary, which restoration technique should be used ?
. *Question 3* : when achieved, is the restoration process successful ?

To perform that, EXTRACSION involves mixed numerical/symbolical treatments. For example, to decide if the flattening noise should be reduced (answer to question 1), EXTRACSION compute the narrow band/wide band ratio, r(nb/wb), compute the signal to noise ratio, r(s/n) and apply the decision rule : "*if r(nb/wb) exceeds a given threshold S1 and if r(s/n) does not exceed a given threshold S2 then the current signal must be restored regarding the flattening noise*". Concerning question 2, we distinguish two cases : if restoration of F1 is needed, only the whitening Least Mean Squares technique is available and is applied. But, if restoration of F2, F3 is needed then the system verifies if the F1 signal have the required properties to be used as a noise reference. If yes, an Eddy Current dedicated adaptive filtering with transversal structure is applied. Finally, if FI cannot be used as noise reference or if the results obtained with the adaptive filtering technique are bad, the restoration process is repeated with the whitening LMS technique. Regarding question 3, the restoration process is considered successful if the r(nb/wb) has decreased of a given (band) rate and if the r(s/n) has increased of a given (power) rate. As these rates depend on frequency, restoration techniques used, types of treated area,... mixed treatments are needed. Note that these rates can be interpreted as improvement measures.

The principle of separation between numeric and symbolic treatments consists in dedicating a numerical treatment when the process to realise a required functionality is *indisputable*. For example to compute the spectrum of a signal, use the FFT algorithm or a AR Burg algorithm. Conversely, choices of appropriate algorithm according to situation, signal nature, number of points, AR order, etc, are subject to discussion and are better managed by symbolic treatments.

3.2 An Eddy Current signal diagnosis expert system

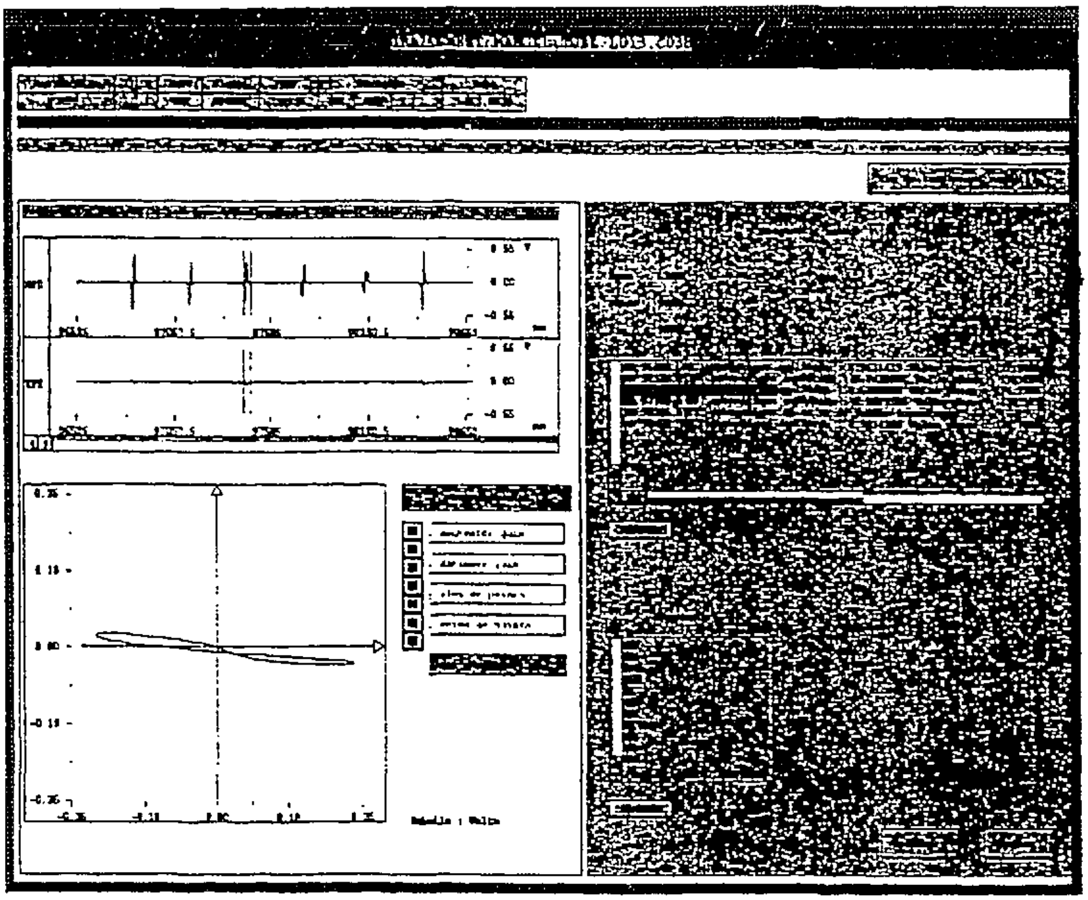
Automatic diagnosis EXTRACSION module is limited to interplate and plate zones. After human expertise collecting and analysis, automatic diagnosis rules can theorically output a diagnosis for all kinds of defects in interplate zones. The system outputs for each diagnosis a self evaluation regarding diagnosis coherence taking into account statistics on defects. Pattern recognition is applied to binary classification of plate signals into two classes : "with defect" or "without". The method performs in two major steps. The preliminary step consists in learning from 13 parameters describing the shape of normal signal. The second step discriminates between "with defect" or "without defect" : a K-Nearest Neighbors rule with a reject option using the Mahalanobis distance is applied [5].

3.3 An example of obtained results

The Man-Machine interface below shows the obtained results. EXTRACSION outputs mostly efficient diagnosis with a well-restored signal. Sometimes, the diagnosis process fails : the abnormality is mentioned to the operator who can elaborate himself the right diagnosis.

4. CONCLUSION

Improving Eddy Current non-destructive testing means making all processes involved in diagnosis automatic. For that, we have designed and realised the EXTRACSION mock-up to show the feasibility of an automatic and evolutive software. The quality of results obtained, the capability to change easily digital modules and to upgrade EXTRACSION leads us to validate the principles applied in our approach. The EXTRACSION testing bench will allow us, owing to the experience we will acquire, to prepare and define the features of future systems of steam generators tubes eddy currents diagnosis.



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