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DECISION TREE BASED KNOWLEDGE ACQUISITION AND FAILURE DIAGNOSIS USING A PWR LOOP VIBRATION MODEL

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Abstract

An analytical vibration model of the primary system of a 1300 MW PWR was used for simulating mechanical faults. Deviations in the calculated power density spectra and coherence functions are determined and classified. The decision tree technique is then used for a personal computer supported knowledge presentation and for optimizing the logical relationships between the simulated faults and the observed symptoms. The optimized decision tree forms the knowledge base and can be used to diagnose known cases as well as to include new data into the knowledge base if new faults occur.

Keywords: vibration model, vibration monitoring, fault diagnosis, decision tree, knowledge acquisition, knowledge based systems.

1. Introduction

In German PWR's reactor noise analysis and vibration monitoring of primary circuit components are carried out regularly. Also in this field of diagnostics the tendency is going from the man-power intensive manual analysis to computer supported, "intelligent" (online-) monitoring systems. As well known from other applications of knowledge-based systems, knowledge acquisition is the most difficult task to be treated. The following two main problems have to be solved:

- Due to the high safety standard in German nuclear power stations and the application of vibration monitoring to detect failure in an early stage of development, mechanical faults of reactor structures are very seldom. So the knowledge needed for the implementation and verification of a knowledge-based early failure diagnosis system has to be acquired at least partly by using model calculations.

- The knowledge has to be structured in a computer suitable form (knowledge presentation). A software tool is needed which should form a unity with the special hardware- and software environment and support the different stages of knowledge acquisition, implementation and system application (if possible also with learning capabilities).

This paper describes how an analytical vibration model of the primary system of a 1300 MW PWR can be used for mechanical fault simulation to support, in addition to practical knowledge, the knowledge acquisition task. The decision tree technique in our application is a very practical way for the knowledge presentation and implementation of a case based diagnosis and learning strategy.

2. The vibration model

The vibration model was developed step by step over a period of many years /OES73/. Starting from a six-degree of freedom (d.o.f.) model of the reactor pressure vessel (RPV) a model of the whole primary circuit with nearly one hundred d.o.f. was developed. It was built up by using different modules, one describing the RPV and its internals, one for the main coolant pump (MCP), one for the steam generator (SG) and a finite element model for the piping. In the models of the components the component parts were treated as discret masses coupled by spring and damping elements. By transformation of the coordinate systems of the single modules it is possible to combine the different components and to form a combined model for a three loop resp. four loop primary system. By means of this model the resonance frequencies of all vibration modes - excluding shell vibrations - of all component parts could be calculated. The models were verified by comparing the calculated eigenfrequencies with the measured ones and by fitting these results via changing the model parameters /BAU77a/.

However, for fault simulation it is not sufficient to calculate the resonance frequencies or the change of the resonance frequencies. Analytical eigenfrequencies lay partly quite close together. The influence of frequency changes, above all resonance effects if eigenfrequencies superimpose one another, can therefore not be judged in a sufficient exact manner, if the model calculates the system eigenfrequencies only. Another model is needed, which can calculate the eigenforms as well as the in-operation vibrations of the components. Thus it was necessary to develop also a model of the exciting functions, which simulates the flow caused forces in the state of reactor power operation.

Two sources of information were used to describe the excitations, the measured in-operation vibration and the pressure fluctuation measured at the same time inside the boundary layer of the primary system at different sensor positions /BAU77b/. To define the model of the excitation we need for each d.o.f. the force acting on it and in addition the phase and coherence relation between all the forces acting on the other d.o.f.. Therefore the number of d.o.f. had to be reduced from nearly 100 to a number as small as possible. Criterion was that the model should be able to simulate all the vibration modes of the structure, which can be identified and monitored by means of the signals, used in the Vibration Monitoring System (VMS). Main idea in this connection was to model only one loop in detail and to simulate the influence of the other two resp. three loops by forces acting on the RPV. In this way we came to a 28 d.o.f. model, which was able to calculate the in-operation structural vibrations in a sufficient exact manner. Fig. 1 shows the Auto Power Spectral Density (APSD) of a displacement signal, measured on top of the RPV in comparison with the according APSD, calculated by the model.

3. The simulated faults

This model was used in the succeeding years to simulate the effects of mechanical faults on the PSD functions of vibration signals, measured at the primary components of PWR for vibration monitoring purposes. According to the assumed defects, the stiffness and the damping matrix and if necessary the mass matrix were changed, the modified model was affected by the unchanged excitation matrix and the PSD functions of the model-vibration signals were calculated /BAU86/.

A great number of faults like hold down spring relaxation in the RPV, contact of RPV and core barrel (CB) at CB bottom, top constraint SG, support faults of a SG or a main coolant pump or reduced stiffness of grid plants in the RPV were investigated /BAU87/. From a number of vibration measurements performed at different levels of reactor power or at different temperature/pressure conditions during the heating up phase the influence of the operating parameters on the APSDs of the vibration signals was evaluated too.

Included in the investigations were 38 peaks, which were identified and associated either the flow-excited eigenmode vibrations of the different structures or the forced vibration due to running main coolant pumps and resonance peaks in the pressure flucturations. With respect to peak changes two kinds are to be discerned, frequency shifts (1f - 37f) and changes of the peak magnitude (1a - 37a), which resulted in an over all number of 76 possible deviations. For these deviations thresholds have to be defined for frequency shifts as well as for peak height changes. For the first test with the decision tree based failure diagnosis frequency shifts greater than 2Df (Df = resolution of the frequency analysis of the signals) and peak height deviations greater than +(-) 5dB are taken into account.

With respect to 30 different cases (faults or changed system conditions) a matrix was formed with 76 x 30 elements, showing the number of peaks affected and the kind of deviation, wether frequency increases or decreases and wether peak height increases or decreases.

This procedure worked quite well but not without any problem; e. g. there are cases, where peaks split up into two peaks or peaks move in the spectra to frequencies occupied by other peaks. Such coincidences result normaly in strong resonance effects. The chosen simplified treatment of spectral changes is up to now not able to consider this special cases in a sufficient manner and is to be improved in the future.

4. Knowledge presentation and fault diagnosis using the decision tree technique

The results of the fault simulations are available in form of fault - symptom relationships. If we put the deviations of all the peaks interested in the power density spectra and the related faults together, we get a large decision table. This can be graphically represented a decision tree. Each peak is represented as two nodes in the tree (peak height and peak position) and they can take three states ("0"=unchanged, "+"=increased and "-"=decreased). As a prototype only a part of the simulated cases are investegated. Figure 2 shows a part of the whole (not optimal) decision tree for the RPV vibration as an example.

It is obvious that a lot of redundancies exist in the decision tree. For a better understanding of the logical relationships between the faults and symptoms it is necessary to optimize the tree. One possible optimization technique is reported by Quinlan, Niblett, Bratko et. al. /QUI86/, /NIB87/. From a statistical data pool (sub-)optimal decision trees can be induced according to the maximum entropy criterion. In our case a interactive heuristic optimization is favoured because our simulated data don't have a statistical nature. For this purpose a software package developed for rotating machinery diagnosis, which runs on a PC under MS-Windows is adapted /DIN93/. It is programmed user friendly and the user can optimize the decision tree automatically or interactivlly by changing the order of nodes and eliminating the redundant nodes. After the optimization of the original decision tree the main features of the problem are clearly given by a relatively simple one, Figure 3.

From the view point of the KB system the decision tree builds the knowledge base. Each path beginning from the root to a leaf represents a diagnosis rule. Following steps are necessary for the application to the plant data:

- calculate the APSD from the measured time signals;
- check the peaks node by node beginning from the root of the decision tree;
- if the case passed through the tree then the diagnosis is found;

- otherwise it will be treated as an unknown case. The user have to input the class information, and the new path can be added into the existing tree for applications in the future (supervised learning).

5. Conclusions

For a computer aided diagnosis of mechanical faults on primary circuit components in the PWR's the expert experience and results of fault simulations using a analytical vibration model are structured as decision trees. The graphical presentation of the logical fault - symptom-relationships is very user friendly and easy to verify. New cases can be easily added to the tree to extend the knowledge base. A reimplementation of the KB in rule based form is also possible.

6. Acknowledgement

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7. References

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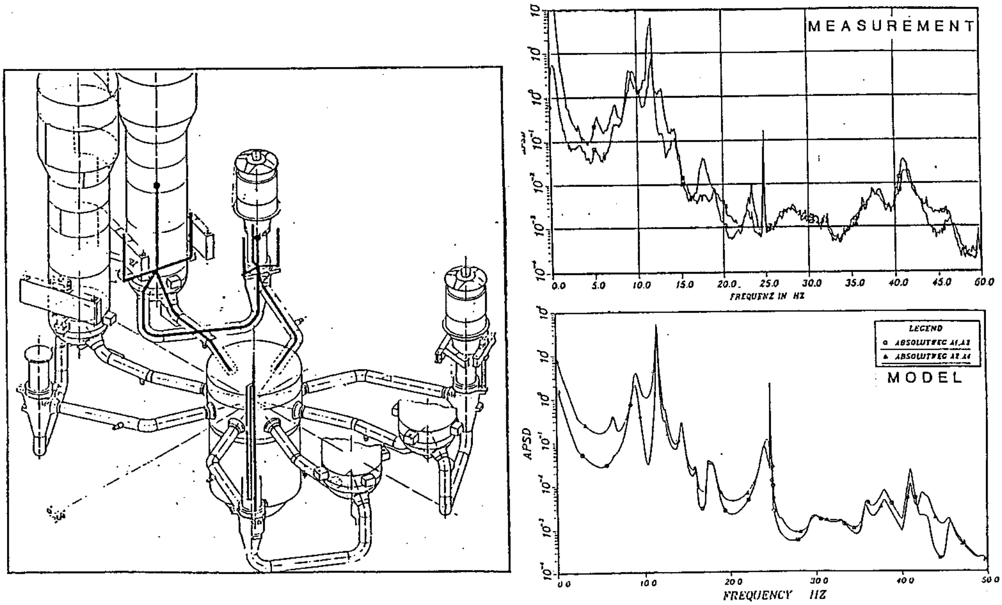
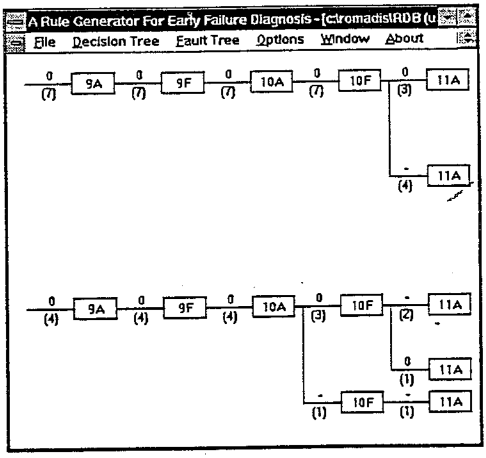


Figure 1: View of the model and comparison of measured and simulated vibration spectra



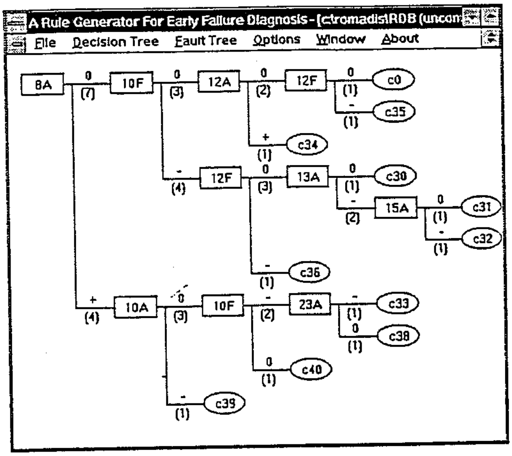


Figure 2: A part of the not optimal decision tree

Figure 3: The optimized decision tree