Application of Simulation to Mechanical Fault Diagnosis by Pattern Matching with Parity Equations

Ferreiro Garcia R, Pardo Martinez X. Vidal Paz J.
Dep. Electrónica e Sistemas, Universidade da Coruña
E.S. Mariña Civil, Paseo de Ronda 51, 15011
ferreiro@udc.es; pardo@udc.es; vidal@udc.es

Abstract

The operation of technical processes requires increasingly advanced supervision and fault diagnosis procedures to improve reliability, safety and global efficiency. Simulation associated to signal analysis techniques offers an alternative solution to the field of detection and diagnosis. This paper deals with a basic method in supervision and fault diagnosis of mechanical equipment using simulation procedures to determine both, the ideal dynamic pattern and the faulty dynamic pattern. Then comparison of actual vibration spectrum with both patterns for extract a valid conclusion is the aim of this.

1. Introduction

Supervisory functions serve to indicate undesired or unpermitted process states, and to take appropriate actions in order to maintain the operation and to avoid damage or accidents. Some relevant supervisory functions are:

- **Monitoring**: measurable variables are checked with regard to tolerances.
- **Automatic protection**: the monitoring function automatically indicates an appropriate counteraction
- **Supervision with fault diagnosis**: information supplied from measured variables permits the calculation of features, symptoms are generated via change detection, a fault diagnosis is performed and decisions for counteraction are made.

The classical methods based on monitoring and automatic protection are suitable for the overall supervision of processes. Therefore, the method based in the association of supervision with fault diagnosis is needed. It must satisfy some requirements:

- early detection of faults with abrupt or incipient time behaviour.
- diagnosis of faults in the process equipment such as actuators, sensors or process components
- supervision of processes in transient states.

The goal for early detection and diagnosis is to have enough time to counteractions included maintenance and repair. Figure 1 shows a general scheme for all supervisory functions and resulting actions.

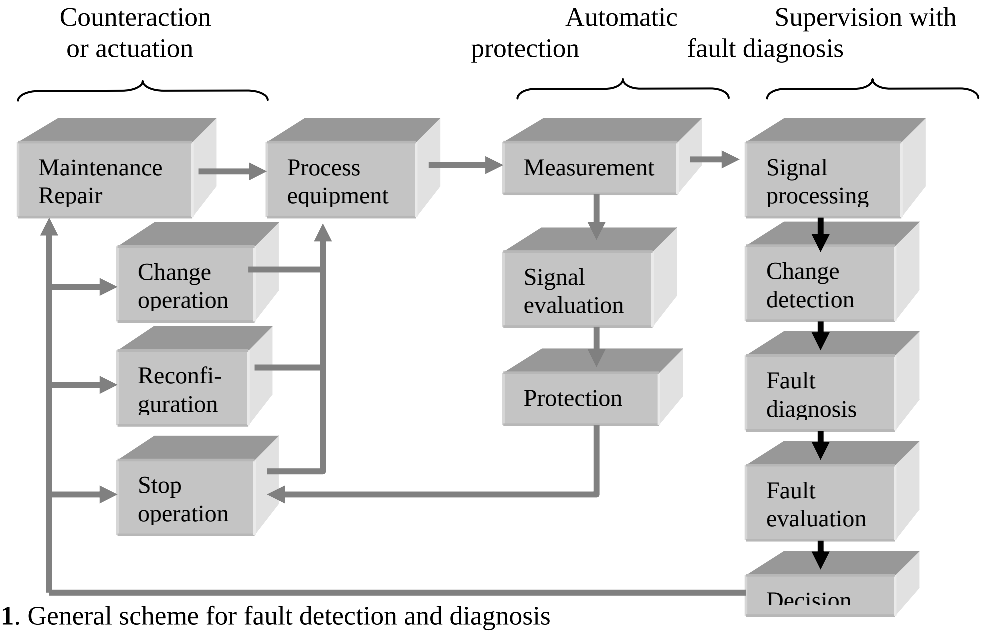

Figure 1. General scheme for fault detection and diagnosis

The main tasks encountered in an overall diagnostic problem can be subdivided into fault detection by analytic and heuristic symptom generation and fault diagnosis

1.1 Analytic symptom generation

The analytical knowledge about the process is used to produce quantifiable, analytical information. To do this, data processing based on measured process variables has to be performed, to generate first the characteristic values by means of

- limit value checking of direct measurable signals
- signal analysis of directly measurable signal by the use of signals models like correlation functions, frequency spectra, autorregresive moving average or characteristic values.
- process analysis by using mathematical process models together with parameter estimation, state estimation and parity equation methods.

In some cases, special features can then be extracted from this characteristic values, defined process coefficients or special filtered transformed residuals. These features are then compared with the normal features of the non-faulty process. The methods of changes detection and classification are applied. Resulting changes or discrepancies in directly measured signals and signal models are considered as analytic symptoms. Signal models have been generated by simulation. Two signal model are used to generate behaviour patterns:

- the signal model of an ideal pattern
- the signal model of a faulty pattern

1.2 Fault diagnosis

The task of fault diagnosis consists of determining the type, size and location of the fault based on the observed analytical and heuristic symptoms. Classification methods can be applied which allow a mapping of symptom vectors into fault vectors. Geometrical classification and fuzzy clustering among others such as statistical classification or neural nets are used. Finally a fault decision indicates the type, size and location of the most possible fault

1.3 Model-based fault detection

During last twenty years, different approaches for fault detection using mathematical models have been developed (Willsky, 1976; Himmelblau, 1978; Iserman, 1984, 1993; Gertler, 1988; Frank, 1990). Generally, the most relevant methods are concern to:

- fault detection with parameter estimation
- fault detection with state estimation and observers

- fault detection with parity equations
- fault detection with signal models

From the point of view of mechanical fault diagnosis, the method of fault detection based on signal models becomes particularly interesting.

This paper deals with a basic method in supervision and fault diagnosis of mechanical equipment using simulation procedures to determine both, the ideal dynamic pattern and the faulty dynamic pattern. Then, comparison of actual vibration spectrum with both patterns for extract a valid conclusion is the aim of this paper. In section 2 the main task of fault detection and fault diagnosis are considered. Then implementation of the method is given in section 3 and finally results and conclusions are presented in section 4

2. Fault detection with signal models

The contribution of this work on fault detection of mechanical equipment based on vibration analysis consists in determine the relation between measured signals and fault model signals. Faults model signals are generated by simulation based on a-priori knowledge about mechanical dynamic behaviour of the process. If changes in these signals are related to faults in the mechanical equipment, a signal analysis procedure will be a further source of information. About machine vibration, sensors are used to detect for instance, imbalance and bearing faults. The extraction of fault-relevant signal characteristics can in many cases be restricted to the amplitudes or amplitude densities within a certain bandwidth of the signal.

Other possibilities are the determination of autocorrelation functions or the Fourrier Transform in the form of Fast Fourrier Transform (FFT). Correlation functions and spectral densities are specially suited to separating stochastic and periodic signal components. If the frequencies are known, crosscorrelation with the known basic and higher-order harmonics can be performed.

Analytic symptom generation can be achieved by matching the current value of an actual frequency spectrum with the ideal frequency spectrum using a deterministic or a fuzzy methodology.

The task of fault diagnosis consists of the determination of the type of fault with as many details as possible such as fault size and location in order to extract its origin. Classification methods are used in fault diagnosis. Based in the information supplied by ideal operating pattern and faulty-operating patterns, a classification method known as pattern recognition or pattern matching can be used. Here a reference vector or ideal operating pattern, which represents the normal behaviour, is generated by simulation. Another reference vector, which consists in an operating fault pattern, is generated by simulation. The relationship between the actual measured vector and the ideal pattern is the base for symptom generation. The consequent search is based in the relationship between the actual measurable vector and the fault pattern as in figure 2.

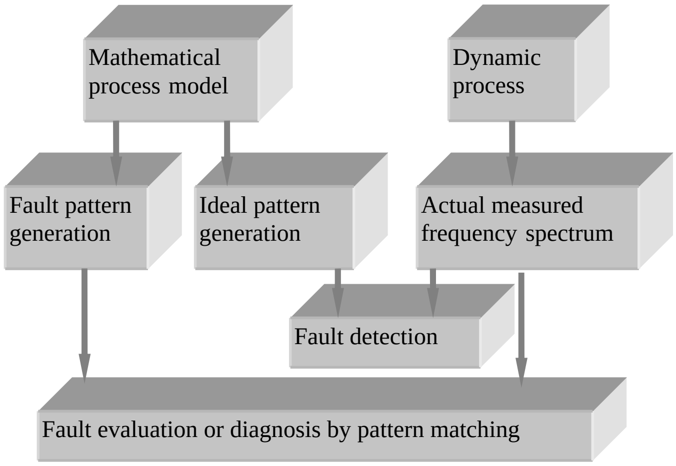

Figure 2. Mechanical fault diagnosis by pattern matching

3. Implementation of the method

In this contribution, are considered as special features the spectrum of measured vibration frequencies. These features are then compared with the normal features of the non-faulty process, that is the ideal spectrum pattern or non-faulty pattern. Resulting discrepancies between measured signals and signal models or non-faulty pattern signals, are considered as analytic symptons, which is interpreted in terms of the evidence of fault existance.

In order to acquire some knowledge about qualitative aspects of faults, more information can be extracted by comparing the spectrum of vibration frequencies with a pattern of the faulty process. Resulting coincidences between measured signals and signal model of faulty process or faulty pattern spectrum, are considered as deterministic faults.

For every process there exist an ideal pattern spectrum and at least a faulty pattern spectrum. Both patterns are achieved by simulation of the dynamic behaviour with some a-priori knowledge about process characteristics. If the characteristics of a process change, for instance due to speed changes, then another faulty and non-faulty patterns are needed. In this work it is considered a constant speed and consequently, two signal models are used to generate behaviour patterns:

- the signal model of an ideal pattern
- the signal model of a faulty patern

Based in the information supplied by ideal operating pattern and faulty-operating patterns, a clasification method known as pattern recognition or pattern matching can be used. Here a reference vector or ideal operating pattern which represents the normal behaviour is generatd by simulation. Another reference vector which consist in a operating faults pattern is generated by simulation. Both paterns are stored into a knowledge base. The information extracted from the data base is applied in the task of fault diagnosis. The main phases of the pattern generation task by simulation is shown in figure 3

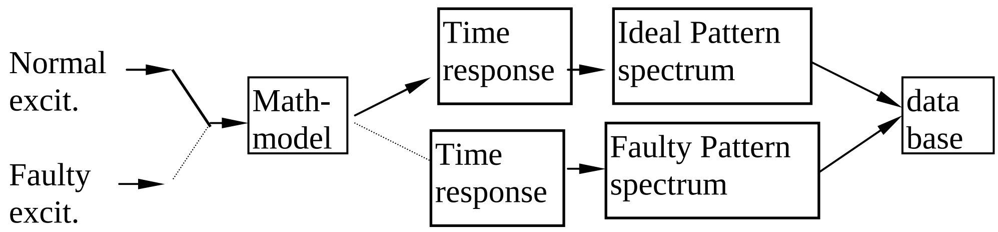

Figure 3. Pattern generation by simulation

The task of diagnosis is performed by detecting differences between an ideal pattern and the actual spectrum. Comparison of both spectrums is carried out by means of parity equation procedures. The result of processing both spectrums by means of parity equations is a spectrum that highlights faults in the system (faulty spectrum). If differences exist, obviously at least a fault exist. A diagnostic task on the type and place of faults is then performed by pattern matching, that is, a task based in the comparison of an actual faulty spectrum with the faulty pattern. Amplitudes/frequency matching are associated to faults in particular frequencies of the spectrum.

4. Results and conclusions

To implement the diagnostic task, an application based on a virtual engineering environment tool has been developed. Figure 4 illustrates the view panel of such application where it is shown at the left side an ideal spectrum, an actual spectrum, and at right side of the view panel it is shown the faulty pattern

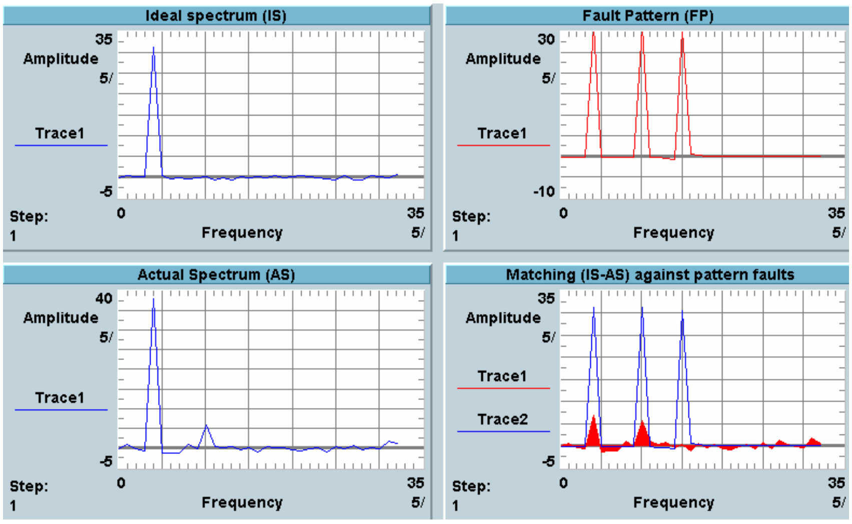

Figure 4. The spectrums for a diagnostic task

and the result of pattern matching. Visual inspection of left side graphs at figure 4 shows that there are faults.

Matching that faults against the faults pattern spectrum (right side and down in figure 4), results in some coincidences that identify the existing faults.

To conclude, simulation procedures are a good way to find patterns based in knowledge gained by experimentation or by mathematical models. Nevertheless, diagnosis, that is the final objective, is performed due to the existence of such patterns and consequent algorithmic manipulation. Mechanical fault diagnosis as well as diagnostic tasks in many other environments could be possible without too much effort.

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