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AN IDEA OF CONDITION MONITORING SYSTEMS

Summary. The paper deals with an idea of intelligent systems, which are intended to be applied e.g. in condition monitoring of turbine-generator sets in electric power plants. The scope, tasks and strategies of the system's actions are outlined. Particular attention is paid to the complexity of data handling within the system.
Keywords and phrases: condition monitoring, machine diagnostics, expert system.

1. Introduction

Recent measuring techniques make it possible to observe permanently and gather multiple signals generated by monitored technical objects. These signals are applied to safety and early warning arrangements. They are mostly analogue electronic devices that can detect if the observed quantities exceed the preset threshold values [5] [4]. Some research centers [1] develop a class of (computer) systems that make it possible to analyse in detail the signals acquired from a machine with the aim of revealing its actual technical state. It has been found that complete results of such an analysis need not be accessible to an end-user (e.g. the machinist), because of the complexity of their interpretation for which an adequate knowledge is necessary. Therefore, values of several signal estimates (symptoms) have been selected in order to show them to the personnel (continually or periodically). All the acquired data are obviously accessible to an expert in machine diagnostics.

Novel microcomputer systems available in Poland and Local Area Networks, which have recently become more popular, make it possible to aid monitoring and diagnostic processes. Research has been undertaken in several centers (including our Chair) in order to develop computer programs which aid diagnostic and maintenance personnel and machinists in their work. Recently the most proper method of aiding machine monitoring and diagnosis is to build an expert system [2]. In the paper we have outlined the scope of problems connected with the application of expert systems to condition monitoring and the diagnostics of rotating machinery.

2. Object of operation of a condition monitoring system

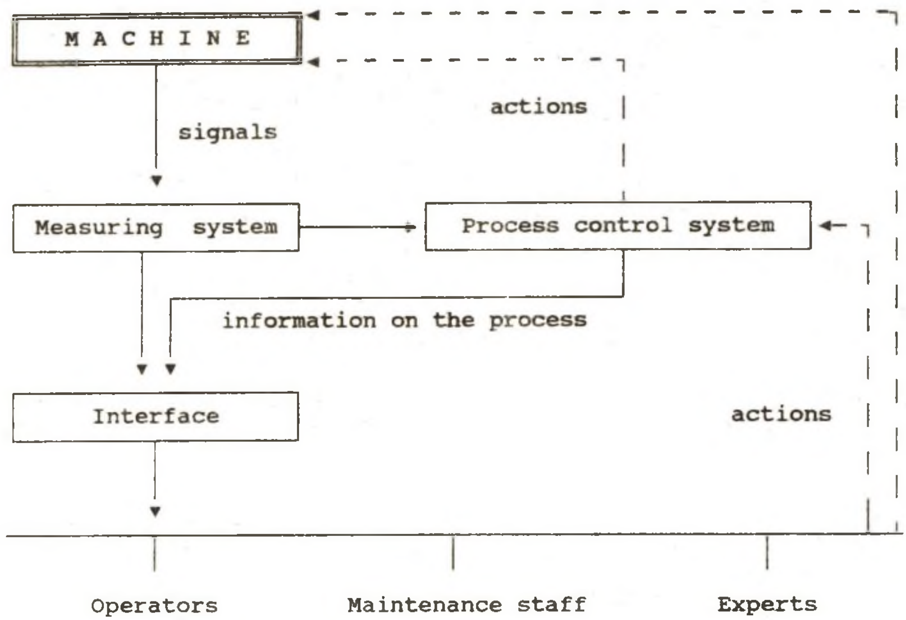

Fig.1 An object of operation of the monitoring system [6]

The object of operation of the described system is a machinery environment (M.F. White [6]) consisting of (see Fig.1):

- the monitored machine - as a (sub)system isolated from its environment;
- the environment of the machine (interactions between the machine and its environment take place through inputs and outputs of the machine only);
- a permanent measuring arrangement (subsystem) that is used for the observation of signals whose estimates make it possible to identify the exploitation condition of the monitored machinery;
- a control (sub)system which is a source of data related to the monitored process carried out by the machine;
- the interface between the described system and its users/operators;
- the personnel (machinists, dispatchers, maintenance staff and experts).

The monitored machine system has several important properties:

- a complex structure of the elements of the system and inter-relationships between them (many elements that can be related to other elements in a complex manner);
- complexity and variety of the applied physical and engineering models (modelling of mechanical, electrical, hydraulic, thermodynamic systems etc.);

- variability of the system features in time, which often can force requirements concerning signal processing rates (eg. real-time processing) that might be necessary in order to make it possible to immediately intervene into the course of process evolution.

Moreover, particular attention should be paid to complex methods of describing the elements and their internal operation (mathematical models, simulation programs etc.).

A permanent measuring arrangement facilitate the observation of signals that are information carriers concerning the exploitation state and condition of operation of the monitored machine. Values of the observed signals are sent to control system and directly to users (through interfaces). The common features of the measuring arrangement are:

- a lot of data acquired in the course of observation of the monitored object (multiple measuring points, considerable amount of feature values gained in each time unit);
- uncertainty/inexactness of measurement results due to variations and/or instability of sensor characteristics, erroneous readings, errors originating from data transmission or noise interfering from the environment of the object;
- redundancy and inconsistency of the collected data;
- possibilities of faults or defects in the measuring channel.

The aforesaid properties of the measuring arrangement require the information processing system to examine the correctness of data (physical, technical, logical etc.). Moreover, the monitoring system must be able to correlate, link and interpret the data.

The system interface should be able to direct, select and extract the feature values which come from the measuring arrangement and the control system, as well as from system databases, in order to present them to the user of the condition monitoring system. The interface works according to a specific set of criteria (human engineering, display of only those features whose values carry essential information on the condition of the monitored machine, ...) within the selected period of exploitation time. Furthermore, the interface enables the user to communicate with the monitoring system, so that is possible to modify the system's actions.

3. Objective of the application of the computerized monitoring system

We expect to accomplish the following aims:

- to assure safety to the power station or monitored equipment;
- to reduce the maintenance costs;
- to maximize the turbine-set availability;
- to improve the production quality (in its broad meaning).

These aims may be attained by means of a permanently operating computerized information processing system. To achieve this goal it is recommended that those signals should be continuously observed and acquired, whose carry information on the exploitation state(s) and control (process) parameters. Moreover, supplementary information should be put into the databases (e.g. arbitrary opinions of the machinist or other personnel) that may be helpful in completing the tasks of the system.

4. Goals fulfilled by a computerized monitoring system

The main goal in the initial stage of building a computer system is to monitor the machine, i.e. identify changes in the reliability condition of the machine. This goal consists in the identification of the moment of exploitation of the machine, when a state of disability for further exploitation has been reached. It is important to identify an early stage of failure, which is equivalent to a change of the technical state from 'ABILITY' into 'DISABILITY'. To achieve this, the monitoring system should operate as an 'intelligent assistant' of the turbine-set operator. It should aid him/her operation in supervising exploitation of the machinery and be able to replace him/her in performing routine tasks (data acquisition, data analysis, interpretation of results, preparation of reports, signalling alarm and dangerous conditions, recognition of the erroneous operation of analog measuring channels etc.). Thus, the developed monitoring system should:

- sample data (e.g. values of signal estimates, values of 'process' parameters) from the measuring arrangement and control system, interpret and collect them (after data compression has been performed) in its databases;
- control machinery operation making it possible to identify abnormal situations;
- manage a dialogue with the operator in order to:
  - gain such data on the process evolution that are inaccessible from 'on-line' control and measuring devices;
  - inform the operator about the state and evolution of the process, arrival of early symptoms of abnormal conditions, alarm situations, critical events etc.;
  - discuss ambiguous situations and possible alternative solutions of the emerged problems;
  - suggest a proper intervention in order to optimize the operation of the monitored machine, its maintenance, repair etc.

Furthermore, many detailed tasks have to be performed:

- signal processing in order to obtain signal estimates of great complexity (especially those requiring greater computing power);
- processing of signal features estimated by simple modules of the described system (eg. clustering, classification of symptoms of the technical state and signal estimates);
- correlation of the collected values of symptoms with the values of 'process' variables;
- collecting the values of signal estimates into dynamically updated databases using advanced methods of data compression, updating and data 'forgetting' etc.;
- aggregate data concerning events that have occurred during the exploitation;
- detection of alarm/hazard situations using advanced methods of symptom analysis;
- analysis of machine behavior in run-up and run-down as well as other non-stationary operating conditions;
- selective display (up-to-date) of machine monitoring results taking into account the system of power-station organization and the scope of tasks and duties, professional training and skills and knowledge of the personnel;
- preparation of selective reports concerning the exploitation of machinery;
- introductory aid of diagnostic work conducted on monitored machinery;
- creation of reports concerning faults together with suitable evidence, e.g. results of signal analysis, conclusions based on the history of exploitation of this machinery, approved statements (in the concluding process);
- forecasting probable changes of the exploitation state of the machine in future;
- performance analysis of the turbine-generator making use of proper computing models.

In future more comprehensive tasks will be solved, as: adaptive preparation of maintenance plans and the repair plan (also aiding the personnel during these repairs), adaptive preparation of a schedule of preventive actions (maintenance, periodical inspections, replacement of elements subject to wear).

A classical exploitation monitoring system act rather passively, indicating the recognition of early symptoms of possible failure in the monitored machine. There are essential problems connected e.g. with 'false alarms'. We assume that the developed system will use active strategy of false alarms elimination, e.g.:

- attempting to evaluate the causes of arising changes (variations) in an exploitation state,
- selection of indicated alarms and alerts,
- correlating and combining acquired symptoms with the values of more important process parameters (e.g. correlated with the outer load as: live steam pressure, temperature of steam measured in different turbine parts, vacuum, current, instantaneous power).

5. Categorie of information in the monitoring system

The computerized monitoring system makes it possible to gather, preserve and output information on the exploitation condition of a machine. Control and process information as well as trend data concerning diagnostic, process and control parameters may be collected as well. All the data may be used for predictive maintenance and diagnostic purposes.

The features of signals observed in stationary and transient conditions of operation are entered into databases of the monitoring system together with the values of 'process variables'. This should be performed for all conditions of operation of the monitored machine. These data make it possible to obtain complex estimates of the exploitation state of the machine. Therefore, no supplementary diagnostic equipment, strip-chart recorders and personnel to record equipment readings manually are required.

It is worth to distinguish the following main data categories:

- information on the machine and its environment (structure of the machine, more important design features as e.g. bearing clearances, ...);
- properties of the measuring arrangement applied to observe the machine;
- sequences of variation of more critical 'process' parameters, in particular those which make it possible to evaluate the temporary conditions of operation of the observed object (e.g. external load);
- data related to residual processes occurring in the machinery system (noise generated by the machine, its vibrations, resonant vibrations of the foundation, temperature of the machine elements, wear products, ...), including sampled signals;
- data on events that occur during the exploitation ('history' of the machine):
  - identified faults, how they manifest themselves by means of adequate symptoms, as well as which methods and remedies were applied to eliminate them, accompanied with information on obtained results of corrective actions;
  - maintenance, preventive treatment and repairs;
  - demand for spare parts, sources of delivery, accessibility, storage methods etc.

The aforesaid data categories may be divided into constant data not subject to change/update during the exploitation of the machine, and variable data that carry information about the varying state of exploitation the machine, about load processes (internal or external) and temporary conditions of operation of the monitored machine. We assume that constant data are entered into a constant database. We further assume that the contents of this database may be modified, but these modifications indicate such significant changes in the properties of the monitored object that is equivalent to determining the properties of a new object of monitoring.

It is worth to stress that information and data are gained 'on-line' (process parameters, values of the estimates of residual processes). The databases of the monitoring system may be also modified 'off-line'. Diagnostic information handled by the system may vary in time - some pieces of information may request updating e.g. due to changes in the structure of a machine caused by its modernization. Of special importance is the method of identifying the moments of time 'macro' when given actions take place (e.g. maintenance, arrival of ALERT message, fault detection of a measuring channel) or when there is an action of some module of the monitoring system (e.g. acquisition of the sampled signal and entering the data into the variable data base). The problem is of great importance, because it is necessary to compare values of signal estimates between them as well as the need to take into consideration a sequence of events in time domain, if diagnostic concluding is being undertaken.

We should take into consideration that information and data that have been handled by the monitoring system belong to different levels of peculiarity, are connected with the structure of the object and, consequently, are 'multilevel' and structured. The structure of data is often not hierarchical. Therefore, we consider frames (see e.g. [2]) as proper means to contain pieces of such information and knowledge for the needs of the monitoring system.

6. An outline of the concept of the monitoring system

We decided to use a model of a system of 'distributed intelligence'. In this model simple signal features are estimated by means of modules (often analogue devices) that directly co-operate with measuring sensors and a computerized system that updates the parameters of a universal (simulated) model of the monitored object. This concept should facilitate modifications and/or the development of the model. It should not be difficult to introduce changes into the discussed model that take into account structural modifications of the machine.

Hence it has been assumed [3] that the monitoring system will be built of primary elements called modules. The general model of a module has been presented in the Fig.2.

The properties of a module may be described using ideas and methods that were introduced in object-oriented programming languages. The use of the 'object' paradigm to describe the essential properties of the modules of the monitoring system makes it possible to model the monitoring system by means of a (micro)computer already in the phase of development of the program. The computer model enables us to review and to test the correctness of the assumed structure and to perform a simulation study taking into consideration the time relations. The latest extensions of the programming language C (e.g. Turbo C++ from Borland, Inc.) are particularly useful for these purposes.

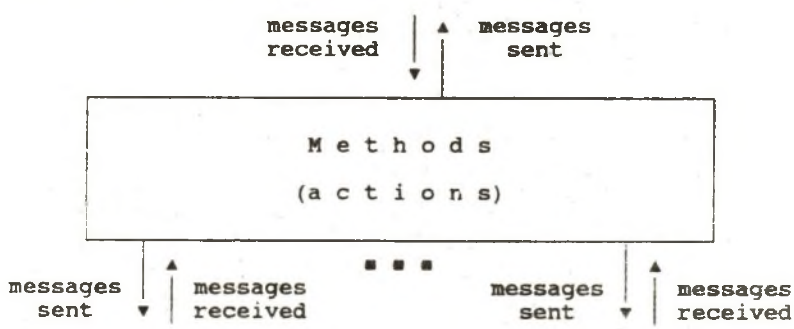

Fig.2. General model of a basic module of the monitoring system [3]

Basic modules of the monitoring system may the have properties of elements of both hardware or software as e.g.:

- an analogue measuring channel that continuously watches some given physical quantity;
- a specific microprocessor board/card that estimates the FFT from sampled data;

- a data base of the monitoring system; different 'methods' may have been assigned to such a module, as: data retrieval, updating, data compression, data 'forgetting' etc.

Basic modules of the system build layers whose number is unlimited. For the needs of the described monitoring system one might in particular distinguish:

- Layer I containing modules that receive signals from transducers, process them using analogue techniques, estimate the values of a specific feature of the observed signal and thus compare it to a suitable pattern (by means of simple methods of evaluation of the symptoms of the exploitation condition of the machine);
- Layer II, where preprocessing and initial analysis of the values of signal estimates takes place as well as their comparison with predefined patterns (it is possible to apply more advanced pattern recognition methods);
- Layer III corresponding to the monitored machinery, where the values of the processed signal estimates are collected and, afterwards, an existing model is adjusted (adopted) making use of these values.

It is reasonable to distinguish subsequent essential layers, as e.g. the layer of monitoring system in the plant (power-station). This method of description of the properties of the elements and (sub)systems of the monitoring system make it possible to define independently the requirements that should meet components of the monitoring system which belong to distinct layers. The assumed method enables us to develop the monitoring system in the 'top-down' manner.

7. Outline of the strategy of operation of the monitoring system

The assumed concept of modules which possess properties of objects contacting each other by means of messages determines at the same time a general strategy of operation of the monitoring system, viz. 'Data- and Event-driven Monitoring'. The strategy might be as follows:

1) Each module becomes active (begins to perform its own tasks) when it receives an activating message. It becomes thus inactive after receiving the message which demands to discontinue the activity;
2) Modules fulfill their tasks in the 'watch-dog' mode. These tasks consist in the observation of the machine by means of signals and the estimation of simple features of these signals. Moreover, symptoms of exploitation state of the machine are evaluated making use of ordinary techniques (e.g. threshold techniques);
3) Once an abnormal situation in the observed machine has been detected, the module sends a message about the detected event to the appropriate module of the precedent layer. Simultaneously, it is possible to change the module's strategy of operation of the monitored machine (another 'method' can be applied as an answer of the module to the received message) to a more 'costly' strategy (e.g. which more intensively engages resources of the module as its memory, communication channels, processor etc.);
4) If a fault occurs in the module (or the module has already received a message NOT_OK from a subordinate module), then a suitable message is sent to the co-operating module(s) and its own action is undertaken by the given module.

The aforesaid strategy of operation enables us to gain noticeable flexibility, because:

- it is possible to distinguish a scope of performed analyses;
- the rate of carrying out analyses may be distinguished (selecting the step in time domain individually and separately for each tasks);
- adaptive methods may be used to evaluate the exploitation state of the machine;
- the user is able to control the modes of operation of the monitoring system (e.g. the monitoring system may operate in the manual mode).

8. Recapitulation

An idea of the intelligent monitoring system has been shown, that uses frames as means of representing data and information concerning a monitored machine. A monitoring system as described here will be developed in our Chair of Fundamentals of Machine Design. This system will be implemented in a Local Area Network environment under the control of Novell NetWare® as an application for MS Windows® using microcomputers equipped with micoprocessors Intel 80386/80386-SX®. Thus it will be possible to run the applications in the enhanced mode of Intel microprocessors. The aforesaid assumptions concerning the hardware and software environment imply the concept discussed in the paper.

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EINE IDEE DER ZUSTANDSÜBERWACHUNGSYSTEMEN

Zusammenfassung

Es wird über eine Idee intelligenter Systeme berichtet, die z.B. zur Zustandsüberwachung eines Turbinen-Generators in einem Kraftwerk entwickelt werden. Aufgaben und Strategien des Systems wurden erläutert. Die Komplexität der Daten- und Informationsbehandlung im Rahmen des Systems wird gezeigt.

IDEA SYSTEMÓW DOZOROWANIA EKSPLOATACYJNEGO

Streszczenie

Opisano koncepcję inteligentnych systemów dozorowania eksploatacyjnego, którą można zastosować np. do monitorowania turbozespołów. Przedstawiono zakres działania, zadania i strategie używane przez system. Szczególną uwagę zwrócono na złożoność zadań związanych z przetwarzaniem danych w systemie monitorującym.

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