

CONSIDERATION REGARDING THE MONITORING AND DIAGNOSIS OF MANUFACTURING SYSTEMS

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Key words: monitoring, diagnosis, applied methods, maintenance, manufacturing systems.

Abstract: This paper summarizes some aspects of current methods used in monitoring and diagnosis of machine tools and the importance of this in preventive maintenance of manufacturing systems.

1. NEEDS AND ROLES OF MONITORING SYSTEMS

Considering the trends of manufacturing developments, the following reasons can be pointed out to explain why monitoring technology is becoming more and more important in modern manufacturing systems:

- (1) Large-scale manufacturing systems should be operated with high reliability and availability because the downtime due to system failure has a significant influence on the manufacturing activity. To meet such a demand, individual unit processes should be securely operated with the aid of reliable and robust monitoring systems. Monitoring of large-scale systems is already beyond the capability of humans.
- (2) Increasing labor costs and shortage of skilled operators necessitate operation of the manufacturing system with minimum human intervention, which requires the introduction of advanced monitoring systems.
- (3) Ultra-precision manufacturing can only be achieved with the aid of advanced metrology and the technology of process monitoring.
- (4) Use of sophisticated machine tools requires the integration of monitoring systems to prevent machine failure.
- (5) Heavy-duty machining with high cutting and grinding speeds should be conducted with minimum human intervention from the safety point of view.
- (6) Environmental awareness in today's manufacturing requires the monitoring of emissions from processes.

The roles of the monitoring system can be summarized as shown in Figure 1.

First, it should be capable of detecting any unexpected malfunctions which may occur in the unit processes. Second, information regarding the process parameters obtained with the monitoring system can be used for optimizing the process.

For example, if the wear rate of the cutting tool can be obtained, it can be used for minimizing the machining cost or time by modifying the cutting speed and the feed rate to achieve adaptive control optimization [5]. Third, the monitoring system will make it possible to obtain the input-output causalities of the process, which is useful for establishing a databank regarding the particular process [6].

The databank is necessary when the initial setup parameters should be determined.

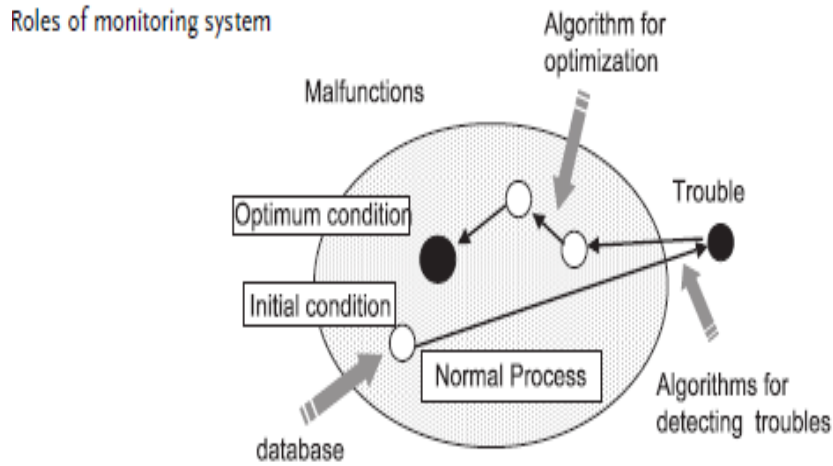


Fig. 1 Roles of monitoring system [2]

2. MACHINE TOOL MONITORING AND DIAGNOSIS

The growing investment machine tools and production systems requires their maximum availability. The complexity of such systems, which are highly automated and consist of many modules which are linked and have to work together without failure, increases the risk of breakdowns.

Monitoring is the automatic supervision of machine tool functions (or of processes). The monitoring system has to ensure that a machine works correctly without malfunctions. The result of its operation is a corresponding message about the machine state. This test can be performed according to a plan, periodically or continuously. A diagnosis system goes further, identifying the incorrect function and the reason for this malfunction. It gives an indication of the reasons and it is initiated when an incident occurs or upon demand.

Different methods can be applied for M & D (monitoring and diagnosis):

- signal-based M & D (heuristic);
- model-based M & D with signal prediction;
- model-based M & D on parameters;
- feature recognition or classification;
- knowledge-based M & D.

Heuristic signal-based systems use experienced states and the respective signals of machine components, eg, a temperature signal, and compare them with a threshold value of the signal which is set by former experience.

Model-based M & D systems need a description of the system to be monitored. This description or model is a parametric algorithm or another input-output correlation of the system which is experimentally determined. The model is able to predict the relevant behavior of the machine. Figure 2 shows as an example the model structure of a DC drive of a machine tool table. The model is given by the system describing differential equations or the state variables. Not a single signal is considered in feature recognition or classification systems but the constellation or cluster of different measured values or multi-dimensional information such as images is analyzed.

Knowledge-based methods store information about the system behavior and error symptom relations. They are used to identify the causes of disturbances, failures, or interruptions.

The knowledge representation is made by different methods; Figure 3 shows examples. An often applied method is the failure tree representation. The failure tree is a graphical

description of logic links between the failure entrances leading to a defect (Figure 4). The figure shows the malfunction of a valve. Cause chains for all sources or consequences of the failure are stored in failure trees. The knots in the tree may be assigned a probability for different errors. The tree entrances, ie, the elements in the bottom level, are classifications of observable process or machine states or extracted features.

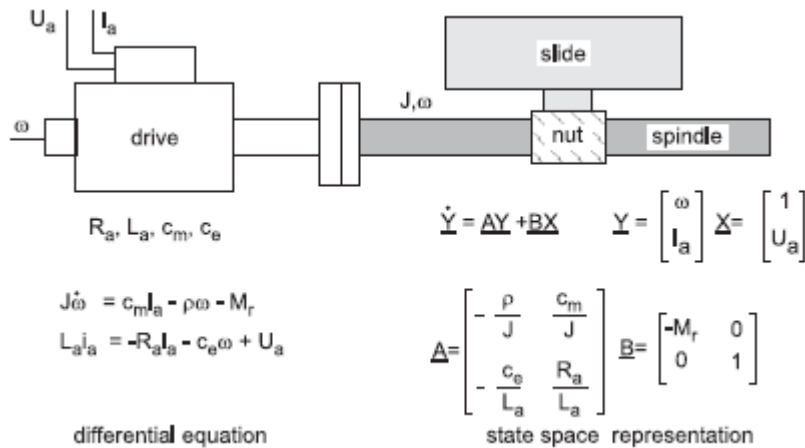


Fig. 2 Model structure of an NC axis.

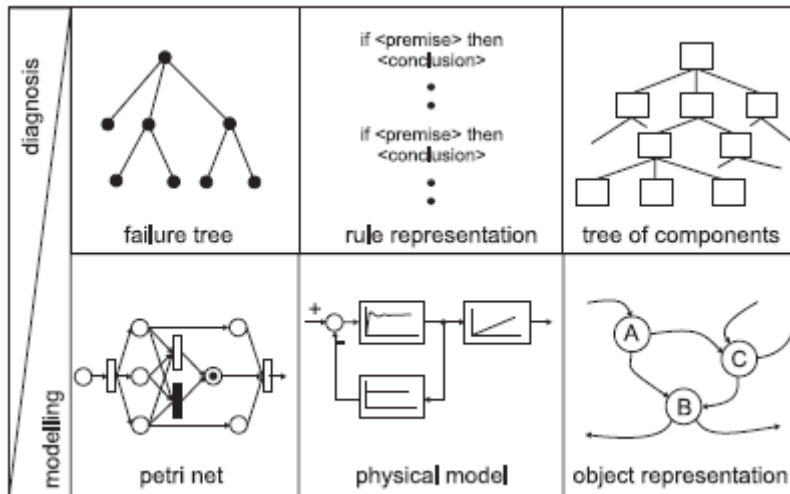


Fig. 3 Methods of knowledge representation.

The advantage of a knowledge representation by a failure tree is that it can be easily applied in practice. Further, there is no need for an engineer with special knowledge to generate a failure tree normally. The failure tree can be easily transformed into algorithms for computers. The main disadvantages are the statistical representation of the knowledge and the limited appropriation for dynamically transmitting failures. The time dependence cannot or only with difficulty be introduced in failure trees. Also, only known failure descriptions can be considered in those trees. This might lead to problems for complex systems.

The formulation of heuristic knowledge in rules, i.e., 'if-then', representations is also widespread. It is often preferred because the experience and knowledge of service technicians and machine operators can be easily modeled. It is similar to the failure tree

representation applied to post-failure analysis, which means assisting the operating or service personnel to find out the cause of failure in case of malfunction. Compared with failure trees, the rule-based representation is more flexible but it is not simple for more complex applications. Another disadvantage of the rule-based representation is that the run time depends on the number of rules and hence it might not be applicable to on-line diagnosis of larger systems.

The speed of rule-based knowledge systems can be accelerated by dividing the knowledge basis and by import and export of rules, by efficient inference algorithms, and by using compilers for the knowledge basis.

M & D systems should be well integrated into the control system of a machine tool. Nevertheless, the machine should be able to operate even if the M & D system fails. This means that the M & D functions have to work independently and parallel to the machine functions but they have to be synchronized with them. Set data of the control and additionally status and sensor signals of the machine are used for the synchronization. The following criteria should be taken into consideration under the prerequisites of flexibility, modularity, and extensibility:

- the data processing functions should be implemented in small independent and reusable modules;
- data and data processing functions should be clearly separated;
- the mechanism to control the data processing functions should be interchangeable to be able to apply different methods with variable flexibility;
- the architecture must be multiprocessor treatable and multicomputer applicable.

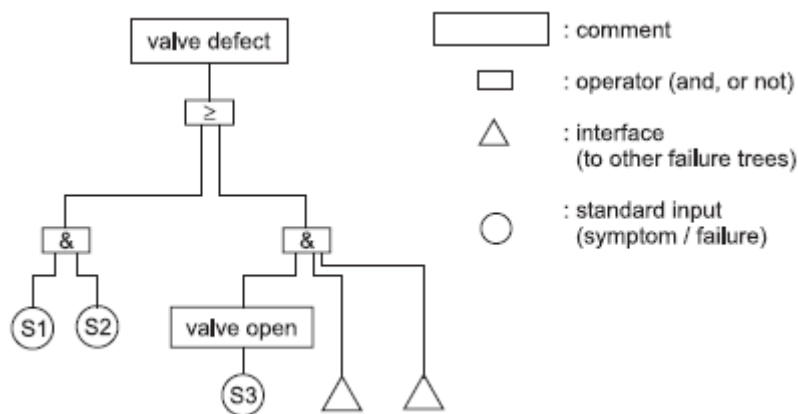


Fig. 4 Example of failure tree representation

Figure 5 shows the internal structure of a system which follows these requirements. The complete system is built up as a network of separate, equally structured run-time modules which act autonomously.

The internal elements of a run-time system and the interfaces between them are shown in Figure 6. In addition to the communication interface the run control is the central kernel which determines the data processing functions according to stored data of the knowledge base and the actual state of the machine. The data processing functions are implemented in separate program modules in which algorithms for signal processing tasks, communication functions, and functions to switch on sensors and actuators are integrated.

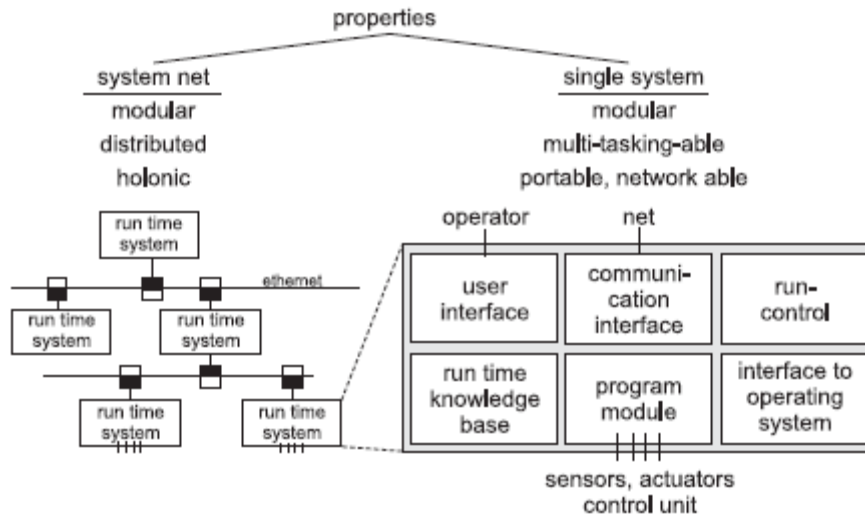


Fig. 5 Internal structure of the M & D kernel system.

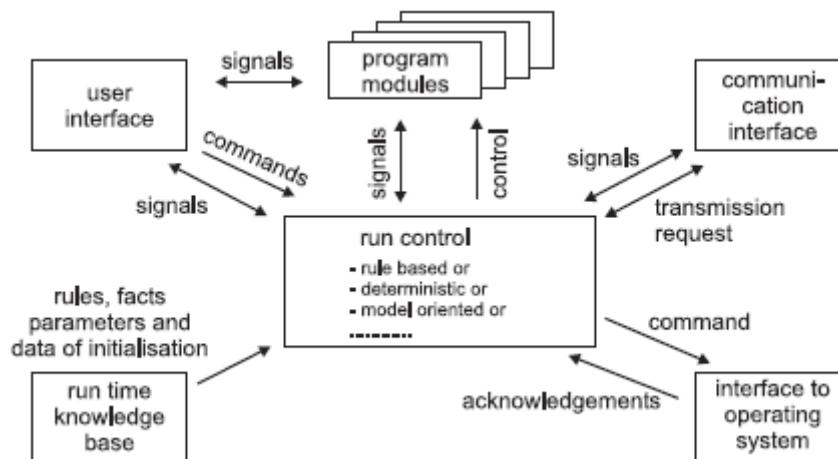


Fig. 6 Information exchange between elements of the run-time system.

Demands on the availability of machine tools grow with the investment. Their complexity needs specific know-how to maintain or repair them. The consequence is that tele-service and tele-diagnostics are of growing interest. The economic benefits result from the fact that M & D systems may be expensive. It is interesting to use them only if they are necessary by telecommunication and not to place them locally. Several machine tool manufacturers already offer tele-M & D systems. Via an RS-232 interface the service personnel can communicate with the machine over long distances. The test can be run by a local machine operator in collaboration with the service technician at the manufacturer's office. It is also possible to run a part program to repeat critical states of the machine. Some machine control units are provided with ISDN interfaces. The service center can load specific diagnosis programs and evaluate the test results.

3. CONCLUSIONS

Monitoring tools cover a wide range of measurements:

- vibration measurements with FFT signal analysis and automatic evaluation of results;
- shock pulse measurements to determine the conditions of lubrication of bearings and early detection of wear;

- measurements of speed;
- temperature measurements;
- measurements of analog signals;
- determining the resonance frequencies of the machine;
- orbit calculation for sliding bearings.

Monitoring and diagnostic devices are an interesting approach to increase the availability of a machine tool by decreasing the mean time to repair (MTTR).

The advantages of implementing a maintenance system based on periodic measurements and analysis of vibration signal:

- Saving of materials and spare parts;
- Shortening the residence time in repair;
- Increasing the availability of equipment for production.

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