APPLICATIONS OF ARTIFICIAL INTELLIGENCE TO CONDITION-BASED MAINTENANCE

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RESUMO

Os autores discutem aspectos interessantes dos sistemas peritos para diagnóstico de máquina e manutenção baseada em condição de máquina. Nas seções que seguem, os autores examinam alguns elementos de manutenção baseada em condição de máquina e suas aplicações, sistemas peritos para diagnóstico de máquina e um exemplo de diagnóstico de máquina. Na última seção, os autores abordam alguns dos problemas a serem resolvidos para que os sistemas peritos aplicados ao diagnóstico de máquina possam ganhar maior receptividade no futuro.

ABSTRACT

In this paper we discuss interesting developments of expert systems for machine diagnosis and condition-based maintenance. We review some elements of condition-based maintenance and its applications, expert systems for machine diagnosis, and an example of machine diagnosis. In the last section we note some problems to be resolved so that expert systems for machine diagnosis may gain wider acceptance in the future.

PALAVRAS-CHAVE

Manutenção baseada em condição de máquina, sistemas peritos, diagnóstico de máquina, Inteligência Artificial, sistemas inteligentes.

KEY WORDS

Condition-based maintenance, expert systems, machine diagnosis, Artificial Intelligence, intelligent systems.

Since the 1980s, several applications of Artificial Intelligence (AI) have been developed in almost every field of engineering and management. Since its conception as a concept in Alan Turing's 1950 article *Computing Machinery and Intelligence*, Artificial Intelligence now has pervasive applications in business functions starting from predicting stocks in investment analysis to making appliances user friendly in product development.

Artificial Intelligence is basically a computer system performing as a substitute for intelligent functions of human beings. It mimics methods of learning and solving problems in human beings through knowledge gathering. Artificial Intelligence includes the following areas of activities:

- Processing of human language
- Image processing
- Intelligent robots
- Expert systems
- Neural networks

Expert systems are highly recognized as the technology directly applicable to the field of machine diagnosis. These systems keep the knowledge of experts and make diagnosis of any abnormality of a given piece of equipment.

In this paper, we discuss interesting developments of expert systems for machine diagnosis and condition-based maintenance. In the following sections, we review some elements of condition-based maintenance and its applications, expert systems for machine diagnosis, and an example of machine diagnosis. The last section comments on some problems to be resolved so that expert systems for machine diagnosis may gain wider acceptance in the future.

CONDITION-BASED MAINTENANCE AND ITS APPLICATIONS

With the progress in automation, the importance of predictive maintenance has increased. Although time-based preventive maintenance has been used as a basic method, condition-based maintenance is being introduced in many working environments. The condition-based maintenance is guided by the maintenance criterion, and the inspection interval does not affect the status of maintenance. The Figure 1 illustrates the advantage of maintaining a machine with respect to a maintenance criterion rather than maintaining the machine at fixed intervals. For example, if we replace a bearing when the vibration exceeds a certain limit rather than being guided by replacing the bearing at a fixed interval, say, at the beginning of each day.

The Figure 1 demonstrates the advantages of condition-based maintenance over preventive maintenance in various deteriorating conditions. In average deteriorating condition, the set interval t_1 guides the preventive maintenance activities where $t_2 - t_1$ is the time incurred in maintenance activities. If the maintenance activities were condition based, there could be a time savings of $t_3 - t_2$ per cycle. In the situations concerning fast deterioration where condition-based maintenance activities are not present, the breakdown occurs at t_5, i. e., before the preventive maintenance schedule t_6. If the condition-based maintenance was performed at t_4, the extra time spent in breakdown maintenance ($t_7 - t_6$) could be avoided. Lastly, when the deterioration is slow, the condition-based maintenance at t_{10} provides a substantive time and cost advantages over the preventive maintenance performed at time t_8 following a set time interval. Thus, as demonstrated, the advantages of condition-based maintenance include:

ARTIFICIAL INTELLIGENCE IS BASICALLY A COMPUTER SYSTEM PERFORMING AS A SUBSTITUTE FOR INTELLIGENT FUNCTIONS OF HUMAN BEINGS.

- replacement period prolongation
- safety improvement
- accident prevention
- reliability improvement

Diagnostic techniques based on machine condition are used to detect degradation of any equipment. In Japan, these techniques have been known since the 1960s, particularly in the steel manufacturing industry. Here are some examples.

Machinery and equipment
- Fluid machines
- Electric rotation machines

- Mills
- Stationary electric machines
- Motors
- Blowers
- Pumps
- Towers
- Drums

Sensing place
- Bearing portions
- Tanks
- Shafts
- Pipes

Condition-based diagnosis techniques have also been used to identify the mode of failure in abnormal vibration, crack by nondestructive examination (ultrasonic or X-ray), corrosion, or degradation of insulation.

A very popular technique is to detect the abnormal vibration in the bearing portions and the shaft of rotating machinery. The level of vibration in the machine axis is measured by using the acceleration pick-up at regular intervals, thus obtaining the tendency of increasing vibration. Many rotating machines are maintained by using this method. The precondition for a condition-based strategy is to make the deteriorating conditions more transparent and predictable. This is where Artificial Intelligence can be used to bring competitive advantages. In the next section, we consider some fundamentals of expert systems for machine diagnosis.

EXPERT SYSTEMS FOR MACHINE DIAGNOSIS

In their early stages, expert systems were designed and developed in laboratories of universities. Most of the work was done without any particular tools. Later on, many expert systems for diagnosis were developed by maintenance engineers, and software tools have been introduced in the U.S. and reconstructed in Japan. Some of them are listed in Table 1.

Figure 1 – The advantages of condition-based maintenance

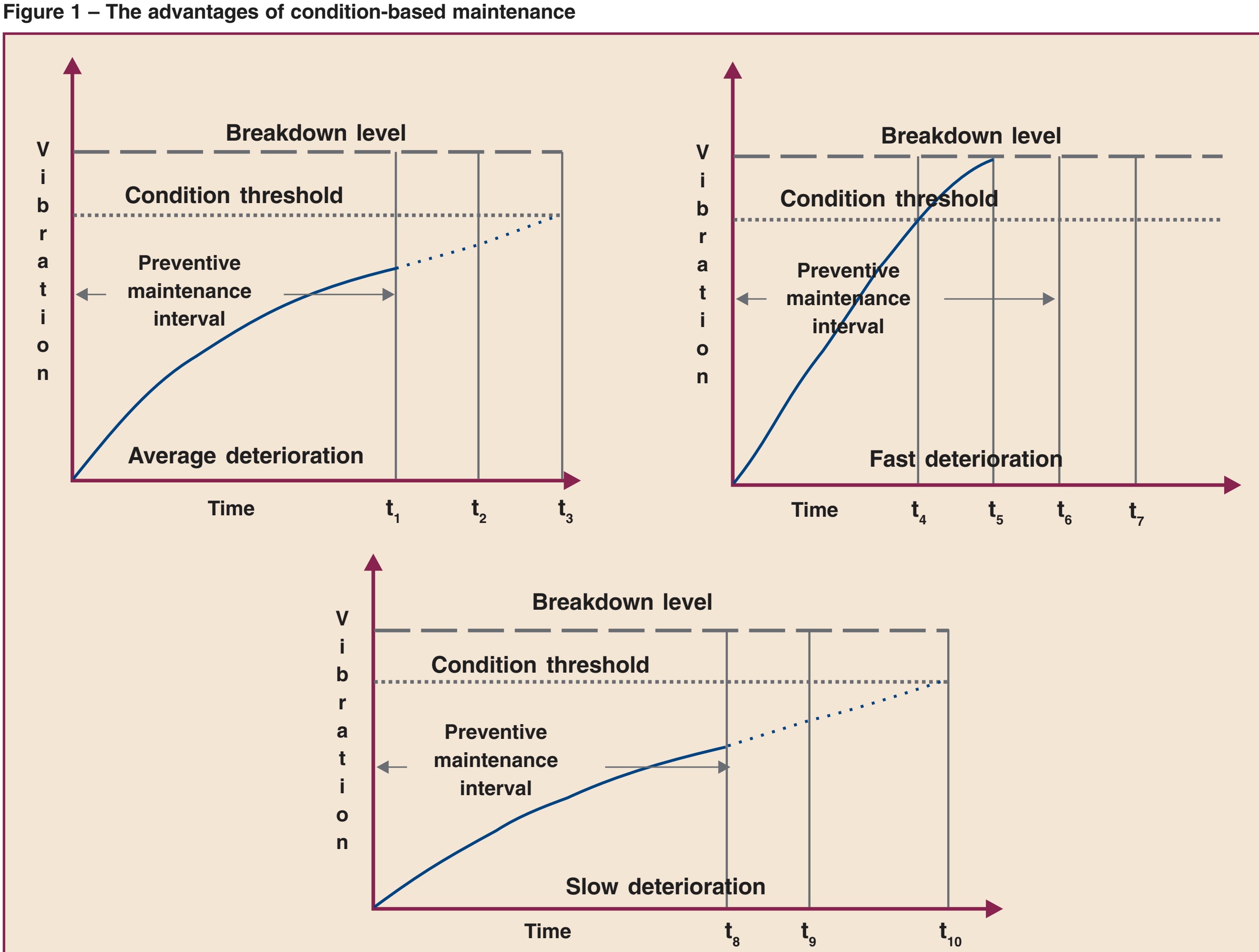


Table 1 – Software tools for expert systems

Name	Developer	Hardware
Interlisp - DJ	Xerox	Xerox 1121
Super BRAINS	Toyo Info. System	IBM 3090
ESHELL	Fujitsu	FACOM S3500 FACOM – f
VM/Prolog	IBM	IBM 3081
MYEXPERT	Toshiba	UX - 700
HPGS	Hitachi	M-200H
EUREKA	Hitachi	HIDIC V90/50
ESHELL	Fujitsu	FM.PC
ES/Kernel	Hitachi	IBM Platform

Figure 2 – Overview of an expert system

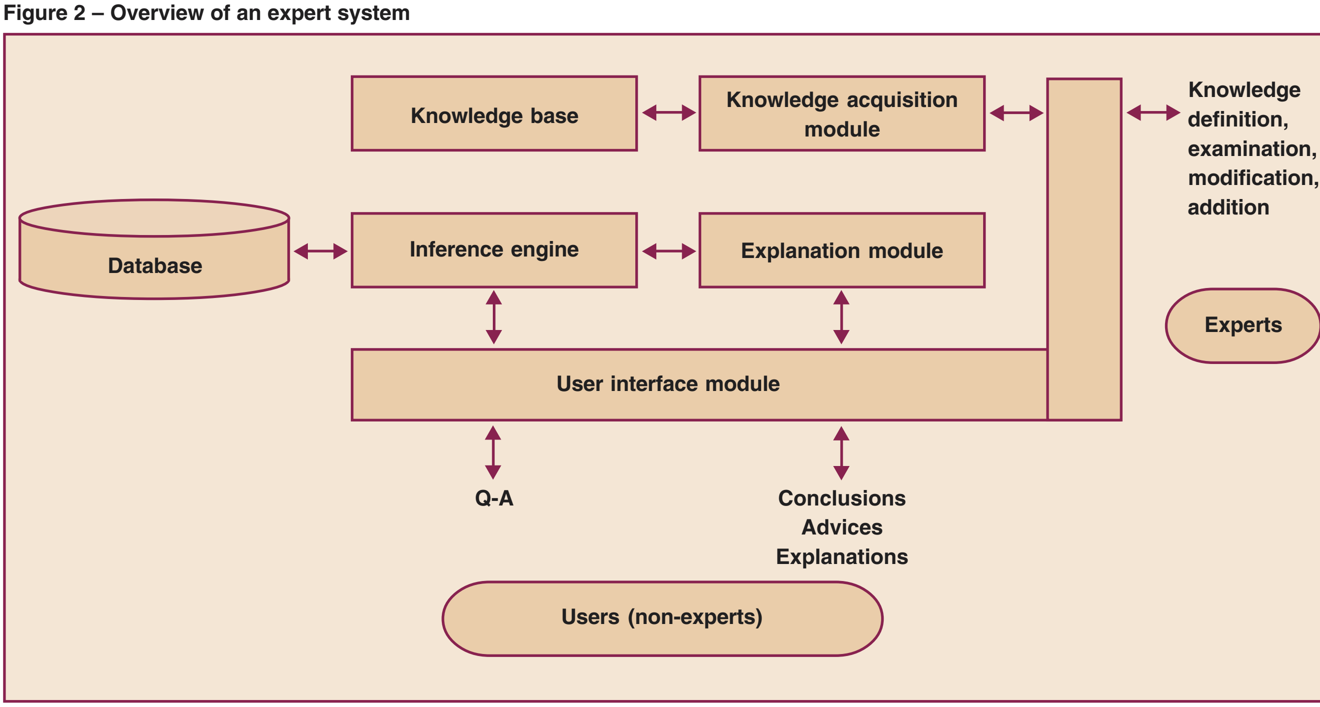
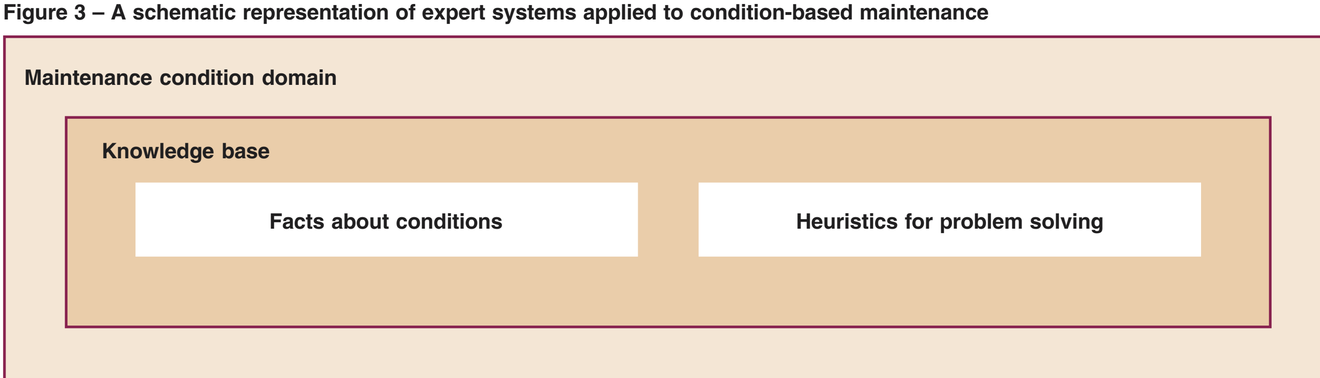


Figure 3 – A schematic representation of expert systems applied to condition-based maintenance



The basic structure of these expert systems is shown in Figure 2. Figure 3 presents a schematic concept of expert system as applied to condition-based maintenance.

An expert system contains a knowledge base and an inference engine. The knowledge required for the diagnosis is expressed by production rules or frame representations. The programming languages used more often are PROLOG or LISP. More recently, object oriented language extensions to LISP-CLOS (Common LISP Object Systems) and PROLOG L & O (PROLOG Logic & Objects) are also used.

Based on given information of the apparatus, the inference engine works to obtain conclusions and give advice. An example of diagnosis for a furnace is shown in Table 2.

The next section lists several expert systems for diagnosis and describes one example.

EXPERT SYSTEMS FOR DIAGNOSIS: AN EXAMPLE

Many expert systems for diagnosis have been developed in maintenance management.

An example of expert system for diagnosing ventilators is described below. Figure 4 shows the object (air fan) to be diagnosed and its possible areas and causes of failure.

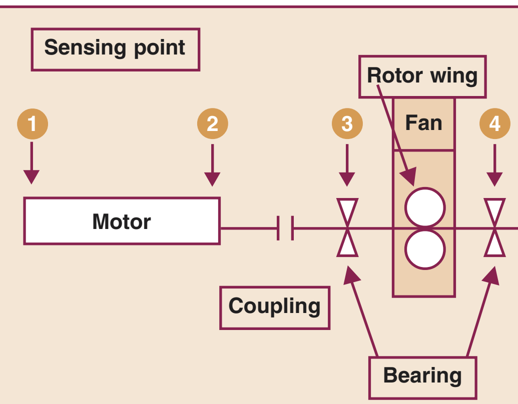
The acceleration and velocity of vibration at the sensing points 1, 2, 3, and 4 are measured. The causalities between these measured values and failures are obtained by using expert knowledge. This knowledge is expressed in a matrix and is transformed into production rules as shown in Figure 5.

The precise diagnosis is carried out based on the spectral analysis of the vibration data. The levels of the fundamental and higher components of the data are calculated. The relationship between the level values and failures is obtained by using

Table 2 – An example of diagnosis (furnace)

Furnace pass metal temperature is high remarkably.
What is furnace pass out temperature in leftside in deg C? 367
What is furnace pass out temperature in rightside in deg C? 379
What is boiler load percentage? 32 : :
What is GMF current in leftside in Amp? 84
What is GMF current in rightside in Amp? 82
What is difference between left and right side on local dampers remarkably? To check setting or actual opening on local dampers and readjust is recommended.
- That's all - The result of diagnose is as follows. Center of burner pattern is low with CF: 1.0 There is difference between left and right side on local dampers with CF: 0.5632

Figure 4 – Failure of air fan

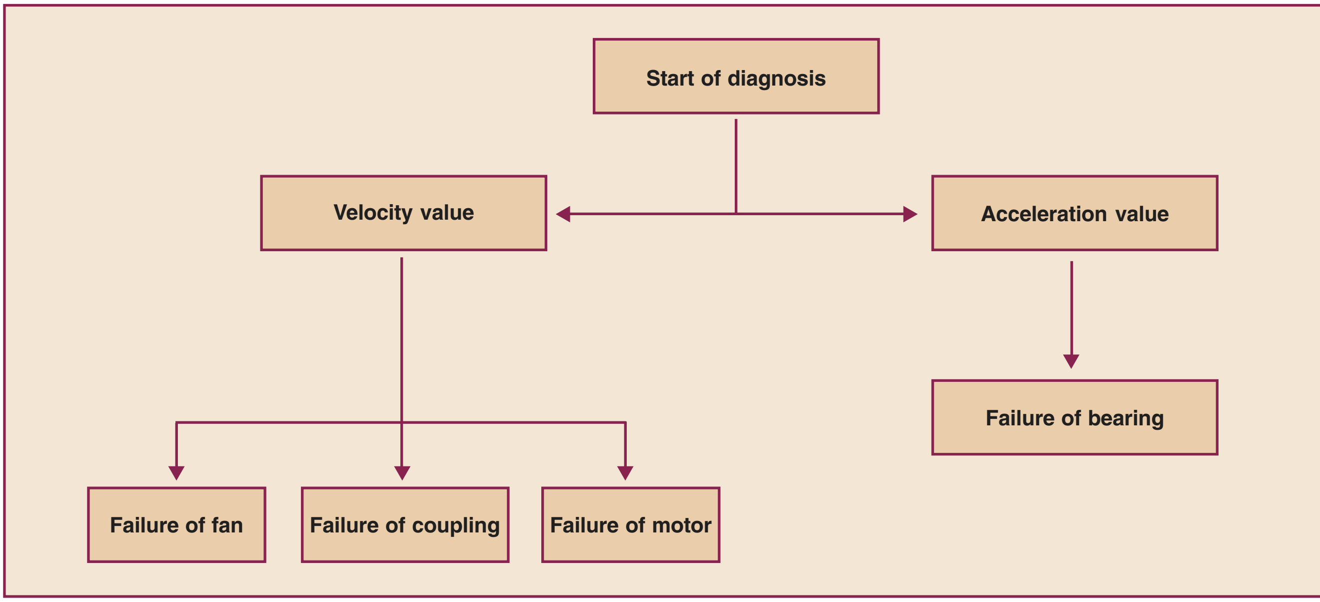


Portion		Failure
Fan	Rotor wing	Unbalance, looseness of bolt, etc.
	Rotor axis	Bending, resonance, etc.
Transmission	Coupling	Misalignment, looseness of bolt, etc.
Motor	Rotor	Unbalance, bending of axis, etc.
	Stator	Unbalance of winding, etc.
	Cooling fan	Unbalance, etc.
Bearing		Bad lubrication, crack, wear, etc.
Base	Frame	Resonance, lack of stiffness, etc.
	Bolt	Looseness, breaking, etc.
	Base	Lack of stiffness, etc.

Figure 5 – Examples of production rules

Rule 1	**If the velocities at measuring points 3 and 4 are abnormal, then failure of fan is expected.**
Rule 2	**If the velocities at measuring points 2 and 3 are abnormal, then failure of transmission is expected.**

Figure 6 – Process of inference



expert knowledge. This knowledge is represented by frames. By using this knowledge source, the process of inference proceeds as shown in Figure 6.

CONCLUSIONS

To date, numerous expert systems for machine diagnosis have been developed in the United States and Japan. They seem to be accepted fairly well by practitioners. However, some problems are still unresolved.

1. It is rather difficult to acquire knowledge about machine failures from experts in the field.
2. It is not easy to organize the obtained knowledge.
3. Although it can be expected that expert systems could use fuzzy information in the future, these systems are still not available.
4. Due to difficulties in constructing expert systems for complicated and ambiguous objects, valuable expert systems are not widely available yet.

The economic merit of expert systems for condition-based maintenance is obvious. They reduce frequency of breakdowns of critical machines resulting in fewer work interruptions which has positive correlation with higher customer satisfaction. The condition-based maintenance, if administered properly through AI, can prevent accidents and increase the resale value of machines. As more expert systems are developed, some of the issues identified above are likely to be resolved in the near future. ❍

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