FAULT DIAGNOSIS METHODOF MECHANICAL HYDRAULIC SYSTEM BASED ON ARTIFICIAL INTELLIGENCE

Peng AN [1,a]

ABSTRACT: To solve the problems that the working condition of the hydraulic system is poor, the parameters are difficult to obtain, and the faults are multiple, uncertain and hidden, various hydraulic system fault diagnosis technologies and methods are comprehensively analyzed. According to the characteristics of the hydraulic system fault, a fault diagnosis model for hydraulic system based on artificial neural network expert system (ANNES) is constructed. In addition, the detailed structure and design method of system components are discussed. Finally, the fault diagnosis based on ANNES is realized for the hydraulic system of excavator, and the feasibility of the fault diagnosis method is proved. The simulation results showed that the system completely realizes the expected functions. At last, it is concluded that the system has strong intelligent behaviors.
KEY WORDS: Hydraulic system; neural network; expert system; intelligent diagnosis.

1 INTRODUCTION

The modern engineering machinery hydraulic system develops towards high performance, high precision and complex direction. The reliability of the hydraulic system has become a very prominent problem. In addition to the reliability design of the hydraulic system, hydraulic system fault detection and diagnosis technology has been paid more and more attention to and become an important direction of the development of hydraulic technology [1]. Intelligent diagnosis is the application of artificial intelligence technology in the field of equipment fault diagnosis field. It is the result of the combination and development of computer technology and fault diagnosis technology [2]. The essential feature of intelligent diagnosis is to simulate the function of human brain, to effectively acquire, transfer, process, regenerate and utilize the fault information, and to successfully identify and predict the state of the object [3]. The research of intelligent fault diagnosis technology at present is mainly carried out from two aspects [4]: knowledge based intelligent fault diagnosis technology and intelligent fault diagnosis technology based on neural network. Artificial neural network expert system (ANNES) based on neural network is an organic combination of the fault diagnosis expert system and neural network diagnosis system. It not only has the expert system's logical thinking ability, but also has the experience of thinking ability of neural network [5].

[1] College of Electronics and Information Engineering, Ningbo University of Technology, Ningbo,Zhejiang, China

E-mail: [a] pmbdcd@163.com

Based on the analysis of artificial neural network and expert system, in-depth study of the combination approaches and methods of the two is carried out. In addition, combined with the research on the fault characteristics of the hydraulic system, a hydraulic system fault diagnosis model based on ANNES is constructed, and according to the excavator hydraulic system, the intelligent diagnosis based on ANNES is achieved.

2 NECESSITY OF COMBINING NEURAL NETWORK WITH EXPERT SYSTEM

The intelligent diagnosis system based on knowledge expresses and stores the functional or event type knowledge obtained by domain experts according to certain rules in a specific symbol. The knowledge system obtained is the knowledge base of expert system [6]. In the process of system fault diagnosis, the knowledge processing system carries out logical reasoning according to the input state signals and a certain reasoning mechanism and reasoning strategy, and judges and determines the running state of the system. Although the traditional knowledge processing system, in some respects, indeed has the ability that the intelligent system has, and it achieves a considerable successful application in the field of equipment fault diagnosis, because of the inherent defects of the expert system itself, its application has obvious limitations [7]. In the process of developing an expert system, we are faced with the bottleneck problem of knowledge acquisition, the "narrow step effect" of knowledge, the contradiction between the storage capacity of knowledge and the speed of operation and so on. Therefore, the knowledge-based fault diagnosis expert system has the limitations of poor

adaptability, poor learning ability and poor real-time performance. These problems make it difficult to develop an expert system, the development cycle is too long, and the practical application ability is poor.

The intelligent diagnosis technology based on the neural network makes use of the learning function, the function of associative memory, distributed parallel information processing function and strong nonlinear mapping ability of the neural network [8], to solve the knowledge representation, acquisition and parallel reasoning problems of diagnosis system. Compared with the traditional diagnostic method and expert system, the application of neural network in fault diagnosis shows obvious superiority, which opens a new way for the development of intelligent diagnosis technology. Compared with other diagnostic technologies, although the intelligent diagnosis technology based on neural network has many obvious advantages, it also has the following problems to be solved: the training samples are difficult to obtain, it is easy to ignore the experience knowledge of experts in the field, the representation of the weight knowledge is difficult to understand and so on.

The fault diagnosis expert system simulates human's logical thinking on the basis of human expert's knowledge, and neural network fault diagnosis system simulates human's experiential thinking on the basis of fault instances. These two diagnostic methods have their own advantages and disadvantages, and their advantages and disadvantages can complement each other. For example: a neural network method is used for fault diagnosis, which neither needs a lot of rules knowledge, nor needs the search reasoning. The network can conduct self-organization and study, which provide solutions for the most difficult problem of the traditional expert system: knowledge acquisition and reasoning problems. The expert system has quite strong process analysis and interpretation ability. As long as the calculation process of the neural network is reflected as certain rules, data and results are qualitative, the overall scheduling and interpretation of the neural network can be carried out, and singular cases encountered in practice can be further analyzed and judged. The neural network is combined with the expert system. The establishment of fault diagnosis expert system based on neural network has become the research direction of artificial intelligent fault diagnosis system.

3 METHOD

At present, the fault diagnosis in hydraulic system is mainly subjective diagnosis based on human, FDD method based on mathematical model and diagnosis method based on intelligent technology, specifically introduced as follows:

Subjective diagnosis based on human: subjective diagnosis based on human is mainly based on simple diagnostic instruments, with the practical experience of experts in the field, to judge the location and causes of the fault, and to propose the corresponding troubleshooting methods.

Diagnosis method based on mathematical models and information processing: the diagnosis method is to use certain mathematical method to describe the relationship between system's measurable characteristics in amplitude, phase, frequency and correlation with the fault source, and then through the measurement, analysis and processing of the signal to determine the fault source. The fault diagnosis methods based on mathematical model and information processing usually include state estimation method, parameter estimation method and so on.

Diagnosis based on intelligent technology: diversity, suddenness, complexity of causes, knowledge needed for fault diagnosis depend on experts' practical experience and diagnosis strategy. As a result, the development of intelligent fault diagnosis of hydraulic system has become the current trend. Artificial intelligence has the characteristics of simulating the human brain function, effectively acquiring, transferring, processing, regenerating and making use of the fault information and so on.It can use a large number of unique expertise and diagnostic strategies to identify and predict the diagnosis object. At present, the fault diagnosis methods based on intelligent technology are mainly: diagnosis method based on the neural network, diagnosis method based on expert system and so on.

The diagnosis method based on expert system is the knowledge system established by depending on the experts' existing knowledge. It applies artificial intelligence technology and simulates the thinking process of human experts to solve problems, so as to solve various problems in the field and to reach or close to the level of experts. For the diagnosis method based on the neural network, the neural network can be applied in fault diagnosis mode recognition includes perception device, multi layer perception device, and self-organizing feature mapping. The multi layer

perception device is quite helpful for complex and multi-mode fault diagnosis. While self-organizing feature mapping is very suitable for fault diagnosis of large machines or engineering systems that cannot carry out the supervised learning. When the neural network is used for knowledge processing, the knowledge is stored by the system weight matrix.

In this paper, a serial connection method neural network fault diagnosis expert system (hereinafter referred to as ANNES) is used to conduct the faults diagnosis simulation experiments of hydraulic system. The knowledge of ANNES comes from the experience summary of maintenance experts in long-term maintenance practice, which is actually an abstraction of the structure and function of the diagnosis objects. An irrational structure division destroys the integrity of diagnostic knowledge and eliminates the inherent link between failure phenomena and causes. Therefore, the division of diagnostic objects, systems, functions, and structures requires maximum retention of the system characteristics and functional paths. The block diagram of the system is shown in figure 1.

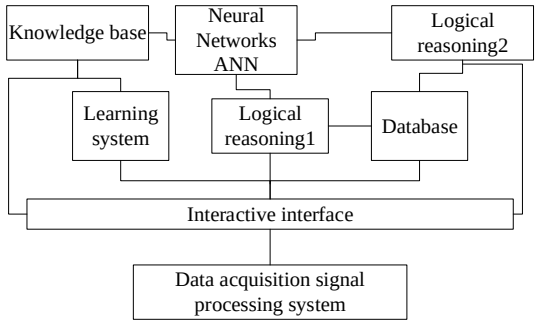

Figure 1. Block diagram of a serial connection method neural network fault diagnosis expert system

In ANNES design, the method of hierarchical classification is the most widely used, easy in implementation and having better effect. Hierarchical classification methods of the main diagnostic object are mainly structure decomposition, function decomposition and fault decomposition three kinds. The structure decomposition refers to the decomposition of the system from the structure. The overall structure is divided into sub structure to the next level, and each sub structure can be further divided into sub structure to the next level, until decomposed to the lowest level's components. The functional decomposition decomposes the system from the functions. The overall function of the system is decomposed into sub function of the next level, and each level can also be further decomposed into sub function of the next level, until decomposed to the most basic function. The decomposition depth of system function depends on the useful degree of the decomposition of the next level for the diagnosis. The fault decomposition is to decompose the type of fault diagnosis of objects.The next level child fault is the special case of the upper level father fault, and the upper level father fault is the summary of the next level child fault. This decomposition can be applied to the most specific failure point.

The process of fault diagnosis is the process of "collecting fault phenomena - detection - judgment and decision" for every point in the diagnosis model. Whether the expression of fault knowledge is scientific and reasonable directly affects the accuracy and efficiency of diagnosis. In ANNES, the expression of fault knowledge consists of 6 nodes: fault level, level number, fault number, fault phenomenon, fault cause and fault solution.

There are two ways for ANNES reasoning diagnosis: one is that the users choose the corresponding fault phenomenon and fault severity in fault list according to the actual situation. The system will give the system fault causes and corresponding treatment suggestions. The fault severity is also called fault level, which is the severity degree of impacts of failure modes on the system level. The other one is: the system asks the users in the way of human-computer interaction, the user chooses the answer according to the actual situation, and finally achieves the purpose of diagnosis, and gives the corresponding diagnosis explanation.

In order to prove the feasibility of ANNES for fault diagnosis of hydraulic system, the hydraulic system test circuit (open circuit) is designed: the output flow of hydraulic pump is 15L/min, the set pressure of pilot type relief valve is 12MPa. Pressure sensor 1 and a pressure sensor 2 use AK-3d type strain pressure sensor, whose main technical indicators are: the analog output is 0~5V, the working temperature is -10~60 DEG C, the range is 0.5~100MPa, and the accuracy grade is 0.2. The pressure sensor 1 is used to measure the pump outlet pressure, the pressure sensor 2 is used to measure the hydraulic cylinder cavity pressure. The flow sensor uses LWGY type turbine flow sensor, and its main technical indicators are: the flow range is 0.1~50L/min, the working temperature is -20~50 DEG C, the working pressure is 25MPa, and the accuracy grade is 0.5. The flow sensor is used to measure the positive cavity flow of the hydraulic cylinder.

4 RESULTS AND DISCUSSION

Three kinds of faults are set for the hydraulic system: pilot relief valve orifice plug (fault I), the solenoid valve to maintain the position in not reversing (fault II) and serious leakage of hydraulic cylinder (fault III). And it is set that when a fault occurs, the other two kinds of failures do not occur. Because these three kinds of faults will cause that the hydraulic cylinder cannot drive the load movement, the measurement value of pressure sensor 1, pressure sensor 2 and flow sensor is taken as the input vector of ANNES. The measured data is shown in table 1.

Table 1. Neural network input vector

Fault types	The input vectors		
	Pump outlet pressure (MPa)	Positive pressure of hydraulic cylinder (MPa)	Positive flow of hydraulic cylinder(MPa)
	The input node 1	The input node 2	The input node 3
Fault I	0.5	0.5	0
Fault II	12	0	0
Fault III	5	5	15
Normal	11.5	11.5	7.5

The target output (desired output) of the neural network is shown in table2.

Table 2. The target output of neural network

Fault type	The target output			
	The input node 1	The input node 2	The input node 3	The input node 4
Fault I	1	0	0	0
Fault II	0	1	0	0
Fault III	0	0	1	0
Normal	0	0	0	1

It can be seen that, for the corresponding input vector and the desired output vector (target output vector), the corresponding fault node value in the actual output vector is close to 1, and the non fault node value is close to 0. This shows that the network has good learning ability, and the convergence speed is relatively fast.

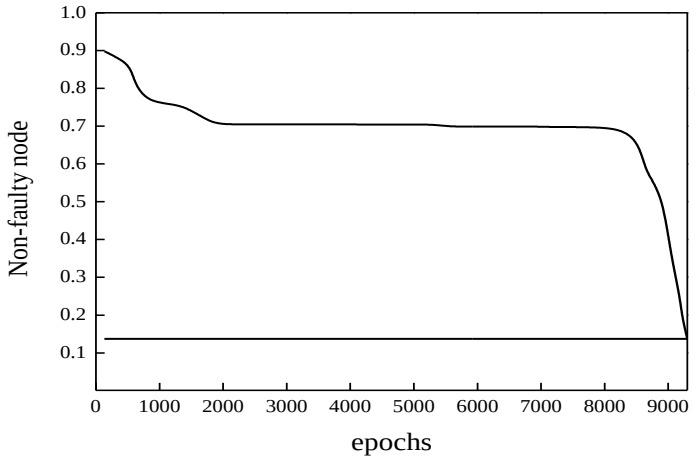

Figure 2. Training effect diagram

From the results, it can be seen that the system fully realized the expected function, and showed a strong intelligent behavior. When the unknown fault occurs, based on the signal analysis, technical personnel can make a correct judgment. As long as the fault names and solution are input into the computer database, other things (such as the identification of fault signal, the memory of fault

characteristic signal and so on) can be done by computer. As long as the knowledge base is not lost, this knowledge will remain in the computer forever. When the fault occurs, the computer can automatically identify, and tell the staffs the solutions, no requiring technical personnel to guide in the field. This process accords with the theory of expert system, namely: when the data in the repository is enough, and the hydraulic system troubles, it may not need relevant experts in the field, and the staffs can provide clues according to the computer, remove troubles, and to ensure smooth and continuous operation of production.

5 CONCLUSION

After the author's work, this paper has completed the theoretical research of hydraulic fault diagnosis based on neural network expert system, and has done some concrete research work in the following aspects:

On the basis of the comprehensive analysis of the current various fault diagnosis methods of hydraulic system, the characteristics of the hydraulic system are combined, and the fault diagnosis expert system based on neural network is put forward for the fault diagnosis of hydraulic system;

The database is used to deal with a large number of complex data information, easy to manage and maintain data and so on. And the knowledge representation of hydraulic system fault based on database is realized;

Various development tools(Visual Basic, Visual C++, Visual Prolog, Matlaband so on) are adopted, to develop ANNES software based on Windows platform. The software operation interface is simple and clear, easy to maintain. And it has strong practicability and expansibility that it can be used in practical auxiliary diagnosis;

The feasibility of ANNES used in fault diagnosis is proved, and the simulation experiment of hydraulic system failure is carried out. The test results show that the system completely achieves the expected function and shows strong intelligence behavior.

The modern computer technology, detection technology, and information technology change rapidly, which provides the technical foundation for the emergence and development of intelligent fault diagnosis technology. The intelligent fault diagnosis technology has great advantages. In recent years, at home and abroad, a lot of researches and developments are done on intelligent fault diagnosis technology, and it has been widely used in all walks of life. The artificial intelligence is introduced into the hydraulic fault diagnosis system, and the fault diagnosis model is established by using this method, which can better and faster analyze the faults and eliminate the faults. Through the research on the fault diagnosis method of mechanical hydraulic system based on artificial intelligence, a better way to solve the fault diagnosis of hydraulic system is found, which has a certain practicability.

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