Study on Knowledge-based Intelligent Fault Diagnosis of Hydraulic System

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Abstract
A general framework of hydraulic fault diagnosis system was studied. It consisted of equipment knowledge bases, real-time databases, fusion reasoning module, knowledge acquisition module and so on. A tree-structure model of fault knowledge was established. Fault nodes knowledge was encapsulated by object-oriented technique. Complete knowledge bases were made including fault bases and diagnosis bases. It could describe the fault positions, the structure of fault, cause-symptom relationships, diagnosis principles and other knowledge. Taking the fault of left and right lifting oil cylinder out of sync for example, the diagnostic results show that the methods were effective.

Keywords: Fault diagnosis, Tree hierarchical model, Object-oriented technique, Database.

1. Introduction
With the frequent application in wartime and its complex structure, there is a high failure rate in the hydraulic system of certain engineering equipment. However the hydraulic system is the core of the whole equipment. Once faults happen, it is difficult to determine where the fault is. The severity of faults affect safety reliability and combat effectiveness of the whole equipment directly. It is an urgent problem to be solved that how to test, diagnose and repair the hydraulic system at high speed. So the general framework of hydraulic fault diagnosis system of the equipment is given in this paper.

A tree model for representing fault knowledge is used to describe the hierarchical structure. According to the relationship of the faults, the corresponding knowledge of all fault nodes are described and encapsulated using object-oriented technique. All the relational database are established including fault fact base, inference rules base and fault model structure knowledge base. Through this all kinds of the knowledge are stored and managed effectively.

2. Research Method
2.1. The general framework of hydraulic fault diagnosis system
The fault diagnosis system in this paper is a real-time artificial intelligence system, which can be used in sudden and complex faults diagnosis. The general framework of hydraulic fault diagnosis system is built in this paper based on usual knowledge diagnosis [1]. The general framework is shown in Figure 1.

The system consists of equipment knowledge base, database, fusion reasoning, knowledge acquisition, explanation mechanism, man-machine interface, interpretation, query and the diagnosis results show. Among them, the diagnostic knowledge processing of equipment knowledge base is one of the key technologies in hydraulic fault diagnosis expert system. How to establish a perfect knowledge base and rational knowledge representation and storage is the first important problem in fault diagnosis system [2]. The following is the key technology in the establishment of knowledge base.

2.2. Establishment and realization of knowledge base
The fault diagnosis knowledge includes the fault position, system structure, the component damage forms, and the severity of the fault, fault cause-symptom relationship,
diagnosis principle, diagnosis methods and other aspects of knowledge. The following will discuss the knowledge model and knowledge base establishment and implementation.

![Figure 1. The general framework of hydraulic fault diagnosis system](image)

**Knowledge model establishment and description.** The correct knowledge model and reasonable expression decide the performance and efficiency of the reason system based on knowledge in the very great degree [3]. In order to organize knowledge clearly, the corresponding diagnostic information is put into the fault model. The tree structure model of fault diagnosis knowledge is established shown in Figure 2.

![Figure 2. The tree structure model of fault diagnosis knowledge](image)

In Figure 2, as a fault unit the diagnosis object is divided into several fault nodes. According to the hierarchical structure of the fault nodes, the nodes are sorted, numbered and give the node properties. The node properties include node number, fault name, fault detection position and name, state characteristic information, parent node information, child nodes information, diagnosis methods, database, knowledge base and so on. All these knowledge can be divided into fault knowledge and diagnosis knowledge. After that, the node properties can be "encapsulated" by object-oriented technique. Thus, a fault unit change, only names of levels of fault nodes, status information, diagnosis methods and other specific information need to change. So the whole knowledge structure need not readjust. It is very favorable for future knowledge expansion and maintenance.

Taking the system pressure fault as an example, the corresponding tree knowledge structure is set up shown as Figure 3.

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Fault nodes knowledge can be described using VC class. Taking Fig 3 for example the fault nodes knowledge can be described as following.
Knowledge base establishment and implement. The knowledge base includes fault knowledge base and diagnosis knowledge base, which store fault knowledge and diagnosis knowledge. The structure of knowledge base in hydraulic system of certain engineering equipment is shown in Figure 4.
Fault knowledge base includes fault fact and fault model structure knowledge such as fault name, fault status information, fault model node numbers [4], node names and so on. Fault diagnosis knowledge base includes fault diagnosis facts and inference rules, such as rules credibility, rules probability, rules threshold value and other expert empirical knowledge.

The Fault knowledge base and Fault diagnosis knowledge base are built by relation database. Several database files are made which save fault facts, reasoning rules and structure knowledge of fault model. The following is the storage format of all kinds of knowledge in the database.

Fault facts base: fault fact predicate + fault fact number;
Inference rules base: (inference rule number) + (fault fact number) + inference rule credibility + inference rule probability;
Fault model structure base: (inference rule number) + input node number + output node number + fault transition threshold + weight + fault transition probability;

Fault fact numbers appear in inference rules base instead of fault facts. Inference rule number can make index between Inference rules base and fault model structure base. Input node numbers and output node numbers are the specific description of fault model nodes [5].

Taking the system pressure fault as an example, the following are the store structures of all kinds of knowledge in database.

Fault fact base. In order to describe the fault symptoms and fault causes, the structure of fault fact base of hydraulic system shown in Table 1. Fault fact is defined as string data characters. And it is give a unique mark (predicate number). Fact _Char(i) which appears in inference rule instead of fault fact.

Inference rules base. In order to store fuzzy production rules of fault symptom-cause [6] the inference rules base is build shown in Table 2.

Fault model structure knowledge base. In order to store fault model structure knowledge, the structure of fault model knowledge base is built shown in Table 3.

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<th>Table 1. The structure of fault fact base</th>
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<th>Table 2. The structure of inference rules base</th>
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<th>Table 3 the structure of fault model knowledge base</th>
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In the programming the above knowledge is expressed as predicate. For internal multiple values the knowledge is expressed with table [7]. For example, system status knowledge can be described as following:

\[
\text{station (num, list1, list2)} ;
\]

Where, num express status number, list 1 express fault symptom fact knowledge, list2 express fault cause fact knowledge.

Fault fact knowledge consists of semantic description knowledge and characteristic numerical parameters. In station, the fact knowledge is arranged by reasoning order. Once the order is defined, the fact knowledge cannot be changed. It can be modified only when the rules change.

3. Results and Analysis

Fault phenomenon: left and right lifting oil cylinder out of sync

Test: The outlet pressure of hydraulic pump (26MPa), the outlet pressure of an electromagnetic valve (20MPa) and the left and the right lifting oil cylinder pressure (16MPa and 14MPa) are tested at the same time.

The data curve, diagnosis and parameters configuration are shown in Figure 5.

Diagnosis: From the real-time data curve can be seen that the outlet pressure of Hydraulic pump is the same to the nominal pressure which shown the hydraulic pump is normal. But the pressures of left and right lifting oil cylinder are significantly different (15MPa and 16MPa). By further observation of the outlet pressure curve of the electromagnetic valve, the pressure is lower than the rated pressure significantly (19MPa < 22MPa). So the electromagnetic valve fault can be determined. The dismountation in the field shows the spool of electromagnetic valve wear seriously.

Figure 5. The data curve, diagnosis and parameters configuration
4. Conclusion
Considering the Complexity and imperceptibility of the hydraulic system fault, the key
technology of knowledge-based intelligent fault diagnosis is studied in this paper. The
corresponding tree knowledge structure of hydraulic fault is set up. The fault knowledge and
diagnosis knowledge of the fault nodes are described hierarchically and encapsulated by object-
oriented technique. The fault knowledge, diagnosis knowledge and rules knowledge are stored
and managed based on relational database. So the hydraulic fault can be detected quickly. The
method can provide theoretical basis for real-time diagnosis. And it can provide effective
solution for electromechanical system and electromechanical system and transmission system.

References
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