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Fault diagnosis of hydraulic system in large forging hydraulic press

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ABSTRACT

The leakage is a common fault in the hydraulic system of the large forging hydraulic press. The large forging hydraulic press is usually used in the high temperature situations. Hence once leakage happens, the fire hazard can be caused and the huge economic losses can be taken place. Therefore, detecting and positioning leakage is also of great importance for the fault diagnosis of hydraulic system. A new method of fault diagnosis is proposed based on extracting leakage information in this paper. Firstly, the double inverse limit space is established. Secondly, the leakage information will be mapped into the double inverse limit space via the homeomorphism mapping. The leakage is detected with equicontinuity. The leakage positioning can be realized according to the topological transitivity in the double inverse limit space. Finally, the method of fault diagnosis is feasible according to the simulation results. Hence the fault diagnosis of hydraulic system in large forging hydraulic press is realized by adopting the method proposed in this paper. The leakage can be forecasted in real-time.

1. Introduction

With the development of industry and the progress of the society, the large forging hydraulic press is more and more applied in the national economy and the national defense construction [1,2]. The large forging hydraulic press has many merits, such as higher forging speed, forging precision and the degree of automation. The leakage fault of hydraulic press is inevitable in actual operation. The leakage exists in almost all the hydraulic press, and the whole production process may be affected by the leakage. Therefore, how to exactly extract the leakage information from the huge information needs to be solved.

Up to now, many methods are used to detect leakage. The feature vectors of the pressure signals are derived by wavelet decomposition, and the vectors are inputted to the BP neural network classifier [3–6]; the classification rules of the hydraulic cylinder leakage are obtained by analyzing feature vectors. The surplus error is tracked by Kalman filtering technology [7–9]; the leakage judgment of hydraulic actuator is realized according to analyze surplus error. The System State Monitoring is achieved by analyzing the working parameters of hydraulic loop [10–13], and the problem of poor visibility about the hydraulic transmission is solved; the leakage model of hydraulic pump is established using fuzzy approximation method [14,15]. The leakage detection of hydraulic pump is realized according to this model; the frequency of noise and vibration are analyzed when the leakage happened in the hydraulic system, and the aperture leakage detection is achieved [16]; the changing rule of liquid tested chamber is got using the integral method when leakage occurred. The leakage diagnosis of hydraulic system is achieved with this rule [17–21]. In a word, the leakage diagnosis can be realized through extracting the change of one parameter.

A new fault diagnosis method is proposed based on the developed method. The double inverse limit space is used to extract the leakage information in the hydraulic system

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of large forging hydraulic press. The parameters of this system will be changed when leakage occurred. The leakage feature can be extracted by extracting those changes. According to a comprehensive analysis of several parameters attribute, the purpose of reducing the diagnostic errors are achieved. The structure of the original information space is simplified, hence the efficiency of feature extraction will be raised. The feature is extracted on the basis of information and the fault diagnosis is realized.

2. The leakage of information space

The information of hydraulic system of large forging hydraulic press is described as n set of objects, each object sets is endowed with attribute sets and ranges, hence the leakage information space can be described with quaternion group of information. The space of hydraulic system of large forging hydraulic press can be called the original space. The quaternion group of information is expressed as IS: $IS = \langle D, S, Z, f*g \rangle$. Where D is object set, S is attribute set, Z_s is indicated the domain of attribute set S, $f*g$ is described as the information function of $D \times S \to Z$. D and S are limited and the nonempty. Z_s can be expressed as $Z = \bigcup_{s \in S} Z_s$. Each attribute set of object set will be given a different information value by function $f*g$, namely $\forall s \in S, x \in D, f*g(x,s) \in Z_s$.

According to the quaternion group of leakage information, the leakage information set of the original information space is expressed as Ψ, and the object sets Ψ has n object collections Ψ_1 Ψ_2 Ψ_3. Ψ_i is expressed as the i object set, Ψ_i contains m parameters, such as pressure, temperature, frequency, deformation, flow, and noise. The parameters are expressed as $\psi_i^1, \psi_i^2, \ldots \psi_i^m$, namely, attribute sets. Every attribute has its own range that is called domain and expressed by Z. The relationship vbetween the attribute sets and object sets can be expressed as follows formula:

$$\begin{cases} \Psi_1(\psi_1^1, \psi_1^2, \ldots \psi_1^m) \\ \Psi_2(\psi_2^1, \psi_2^2, \ldots \psi_2^m) \\ \ldots \\ \Psi_n(\psi_n^1, \psi_n^2, \ldots \psi_n^m) \end{cases} \tag{1}$$

The leakage usually relates to the earlier condition. The earlier condition also has parameters change. Hence the leakage information model can be expressed by formula (2):

$$\Psi_{n+1} = f^h * g^k(\Psi_n) = \begin{cases} \Psi_1(\psi_1^1, \psi_1^2, \ldots \psi_1^m) \\ \Psi_2(\psi_2^1, \psi_2^2, \ldots \psi_2^m) \\ \ldots \\ \Psi_n(\psi_n^1, \psi_n^2, \ldots \psi_n^m) \end{cases} \tag{2}$$

The mapping $f^h * g^k$ is a function of information. The information of target sets and attribute sets are mapped to the value sets by $f^h * g^k$. In this way the leakage information space of the original space has been established. This space can be expressed by the quaternion group of information.

$$\begin{cases} \Psi_n \xrightarrow{namely} D \\ (\psi_n^1, \psi_n^2 \ldots \psi_n^m) \xrightarrow{namely} S \\ Z \xrightarrow{namely} Z \\ f^h * g^k \xrightarrow{namely} f * g \end{cases} \tag{3}$$

For convenience, the Eq. (3) can be written as $(\Psi, f^h * g^k)$.

3. The double inverse limit space

The leakage information of the original space is mapped to the double inverse limit space by homeomorphism mapping in the manner of information set. The double inverse limit space is defined as the suppose mappings. The suppose mappings are continuous. The mappings can written as $f: \Psi \to \Psi$, $g: \Psi \to \Psi$. The condition $fg = gf$ is contented in the original information space. The double sequence is described as $\{\Psi, f^h * g^k\}$. And the new set is defined as:

$$\widetilde{\Psi} = \left\{ \tilde{\psi} = (\psi_{i,j})_{i,j=-\infty}^{+\infty} : f^h g^k(\psi_{i,j}) = \psi_{i-m,j-n}, \forall h,k \geqslant 0, \forall i,j \in Z \right\} \tag{4}$$

In the set $\widetilde{\Psi}$, the definition of metric is drawn forth:

$$\tilde{d}(\tilde{\psi}, \tilde{\xi}) = \sum_{i,j=-\infty}^{+\infty} \frac{d(\psi_{i,j}, \xi_{i,j})}{2^{|i|+|j|}}, \ \forall \tilde{\psi} = (\psi_{i,j}), \ \tilde{\xi} = (\xi_{i,j}) \in \widetilde{\Psi} \tag{5}$$

where d is the metric of Ψ, $\widetilde{\Psi}$ is the information set of double inverse limit space. Comparing with the original information space, the double inverse limit space also has target sets. The target sets are $\widetilde{\Psi}_1, \widetilde{\Psi}_2 \ldots \widetilde{\Psi}_n$. Hence the double inverse limit space is $(\widetilde{\Psi}, \tilde{f}^h * \tilde{g}^k, \tilde{d})$. The mapping $\tilde{f}^h * \tilde{g}^k$ of the double inverse limit space can be filed as:

$$\widetilde{\Psi} = \lim_{\leftarrow}(\Psi, f^h * g^k) \tag{6}$$

U is open subset of the original space, and the all open subsets in double inverse limit space both have the following shape:

$$\widetilde{D} = \bigcap_{m=1}^{n} (f^{i_m} g^{j_m})^{-1}(D_m), \ n \in N, \ D_m \subset \Psi_{im,jm} \tag{7}$$

Set $i_0 = \max\{i_m : m = 1, 2, \ldots n\}$ $j_0 = \max\{j_m : m = 1, 2, \ldots n\}$, and $D = \bigcap_{m=1}^{n} f^{i_m - i_0} g^{j_m - j_0}(D_m)$, then D is open subset of $\Psi_{i_0,j_0} = \Psi$. Therefore:

$$\begin{aligned} (f^{i_0} g^{j_0})^{-1}(D) &= (f^{i_0} g^{j_0})^{-1} \left(\bigcap_{m=1}^{n} f^{i_m - i_0} g^{j_m - j_0}(D_m) \right) \\ &= \bigcap_{m=1}^{n} (f^{i_0} g^{j_0})^{-1} o f^{i_m - i_0} g^{j_m - j_0}(D_m) \\ &= \bigcap_{m=1}^{n} (f^{i_m} g^{j_m})^{-1}(D_m) = \widetilde{D} \end{aligned} \tag{8}$$

In addition, the original information space has been mapped into the double inverse limit space. Conversely, the theory is also correct. The useful information in the original information space will be mapped to the double inverse limit space through the one-to-one mapping. Hence