FAULT DIAGNOSIS IN BRAKING SYSTEM OF MINE HOIST BASED ON THE MOMENT CHARACTERISTICS

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ABSTRACT

Fault diagnosis method based on the moment characteristic of system pressure data is presented in this paper. Using AMESim simulation technology, three typical faults of the brake system are studied. After the moment and the percentile characteristics of the pressure curve of the hydraulic system are extracted and used as characteristic parameter, fault information is diagnosed effectively using the BP neural network. The problem that the signal is not synchronized and the characteristic parameters can not be obtained accurately are overcome. It provides some theoretical basis for the intelligent diagnosis and predictive maintenance of the high speed deep well hoist.

KEYWORDS

Moment characteristics; Fault diagnosis; Braking system; Performance degradation; Deep mine hoist

1. INTRODUCTION

Ultra deep mine hoist has large inertia with complex operation conditions and a complex system of electromechanical coupling. Safe and stable operation is related to staff's life and property safety [1-3]. Brake is the last safeguard for safe operation of mine hoisting. It has very important significance to research the fault and performance and to provide the basis theory for intelligent diagnosis and performance evaluation of the braking system.

Nowadays there are a lot of research focusing on disc brake fault diagnosis. literature [4-9] mainly detected the oil pressure on the hydraulic station, opening brake pressure, closing brake pressure，residual pressure, brake clearance, friction coefficient, brake disc runout, and etc. parameters to make fault diagnosis, the literature [10,11] measured the spring pressure, the spring pressure variation, hydraulic pressure, hydraulic pressure variation and brake state detecting switch to make fault diagnosis, and the literature [12,13] detected brake clearance, decomposition and reconstruction of wavelet energy entropy as feature parameters, combined with neural

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network to make fault diagnosis. All of the above methods can get effective fault diagnosis, but there are still some problems: 1) characteristic parameters are not accurate, 2) characteristic parameters can not represent the overall characteristics of the braking system, and 3) other issues. For example, because of the long-term load, the linearity of the signal and the zero drift problems are difficult to solve, regardless of choosing strain gauge or ballast sensors to measure of braking positive pressure; there is no feasible scheme for on-line monitoring of the friction coefficient [14], and the detection of brake clearance is influenced by brake shoe's wear and other factors. To overcome the shortcomings above, this paper presents a new fault diagnosis method. The method extracts moment and percentile characteristics from the brake pressure-time curve as characteristic parameters, then makes fault diagnosis combined with BP neural network.

2. Braking System Performance and Calculation of Minimum Pressure Value of Braking System for Safety Braking

2.1 Brake System Performance Requirements

Coal Mine Safety Regulations and the standard of coal mine mechanical and Electrical Equipment stipulate the following requirements to improve the working performance and working state of the hoist [15].

(1) Idle time of disc brake should not exceed 0.3 s.

(2) The gap between brake shoe and brake disc should not be greater than 2mm.

(3) Braking momentum requirement, i.e. the braking momentum generated by brakes during the work and safety brake should be at least three times the maximum static load momentum.

(4) When safety brake in vertical well, the safety braking deceleration must be less than or equal to 5m/s2 during vessel's ascending with heavy-load, and must be greater than or equal to 1.5 m/s2 during vessel's descending with heavy-load.

2.2 Calculating the Minimum Pressure Value of Braking System when Safety Braking

Coal Mine Safety Regulations stipulates that brake torque generated by hoist during the work and safety brake shall not be less than 3 times the maximum static load torque, i.e.

$$M_Z \geq 3M_j \tag{1}$$

Where M_Z is brake torque, M_j is static load torque.

When a heavy lifting hoist is safely braking, calculated brake pressure value is 4.36MPa [16]. After the performance of brake parts is decreased, in order to meet the requirement that the braking torque is not less than 3 times the maximum static load torque, the minimum pressure value of the braking system is calculated as follows:

According to the principle of Darren Bell, when a heavy lifting hoist is safely braking, the torque balance equation to the hoist drum is [17,18]

$$M_Z + M_J = M_d \tag{2}$$

Where M_J is static and resistance torque, Nm. M_d hoist inertia torque, Nm.

.Where:

$$M_Z = 2(K \cdot x - P_Z \cdot A) \cdot n \cdot \mu \cdot R_Z \tag{3}$$

$$M_J = k \cdot M_j = k \cdot m \cdot g \cdot R_J \tag{4}$$

$$M_d = \sum m \cdot a_3 \cdot R_J \tag{5}$$

Where K is spring stiffness, N/mm. x spring preloading length, mm. $P_Z^{'}$ brake system pressure during safety braking, MPa. μ brake shoe friction coefficient. R_Z brake radius, m. k mine resistance coefficient. If the hoisting container is skip, k=1.15. If the hoisting container is cage, k=1.20. m load mass, kg. g gravitational acceleration, m/s^2. R_J drum radius, m. $\sum m$ mass of hoist equivalent, kg. a_3 lifting load deceleration, m/s^2.

Take k=1.15, combining Eqs. (1),(4) yields

$$M_J = \frac{1.15}{3} M_Z \tag{6}$$

Substituting Eqs. (3),(5)and (6) into Eq. (2) gets

$$P_Z^{'} = \frac{K \cdot x - \dfrac{3\sum m \cdot a_3 \cdot R_J}{8.3n \cdot \mu \cdot R_Z}}{A} \tag{7}$$

Substituting the value of parameters in Tab. 1 into Eq. (7) gets

$$P_Z^{'} = \frac{10328 \times 8.38 - \dfrac{3}{8.3} \times \dfrac{238860 \times 3.5 \times 2.25}{16 \times 0.3 \times 2.45}}{84.2 \times 10^{-4}} = 3.41 MPa$$

When the hoist is safety braking, the braking system pressure value is between 4.36MPa and 3.41MPa, which can meet braking momentum requirement.

3. Simulation and Analysis To The Main Components Performance Decline

In the process of operation, because the brake spring, brake cylinder, piston, seals and other important components work long-term under the condition of high load, the brake performance will gradually degenerate until failure occurs. The following carry out performance simulation of three main components, i.e. the brake spring stiffness reduction, brake shoe friction coefficient decline and cylinder leakage. The simulation only takes into account the heavy lifting condition. And the simulation time is set to a fixed value, that is to set the brake system 1-2s for accumulator charging, 2-5s for the hoist operation, 5-8s for constant deceleration braking, 8-10s system pressure relief. Sampling frequency is set to 100HZ. In order to reduce the length of the article, building simulation platform, reliability verification and the typical fault simulation methods are detailed in the literature [16], which is no longer mentioned here.

3.1 Friction Coefficient Decreased

The normal friction coefficient is 0.3. The simulation results with different friction coefficients are shown in figure 1, 2 and 3:

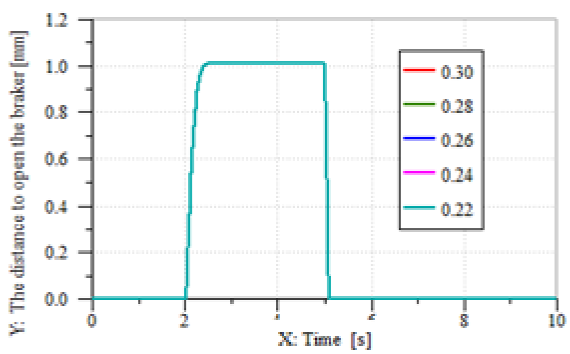

Figure 1 The brake clearance with different friction coefficients

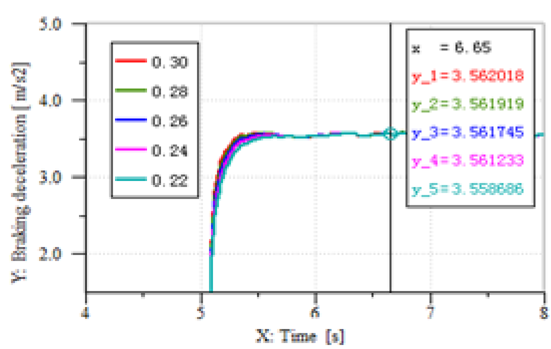

Figure2 Braking deceleration with different friction coefficients

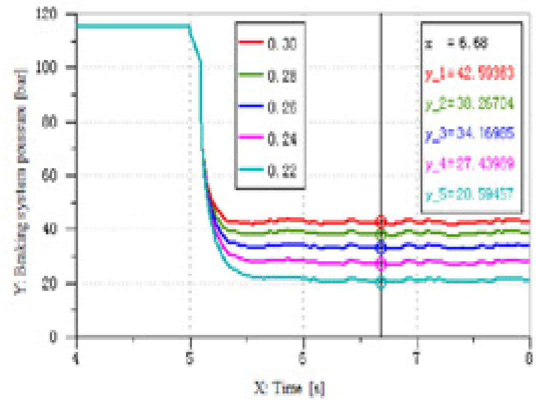

Figure 3 Braking system pressure with different friction coefficients

From the simulation diagram one can obtain that the brake clearance and the idle time of the brake do not change when the friction coefficient is reduced. This meets the requirements that the brake clearance is not more than 2mm and the idle time is not more than 0.3s. Braking deceleration meets the requirements of system deceleration. When the friction coefficient is greater than 0.26, the minimum pressure value of the braking system can meet the requirement of 3 times the maximum static load torque. From the analysis above we can conclude that: When the friction coefficient of braking system is between 0.26~0.3, brake performance degraded, but still meets the Coal Mine Safety Regulations requirements. When the friction coefficient is less than 0.26, the pressure of the braking system is reduced below 3.41MPa, which does not meet the Braking momentum requirements. The failure of brake system friction coefficient declined occurs.

3.2 Spring Stiffness Reduction

The simulation results in different spring stiffness are shown in figure 4, 5 and 6.

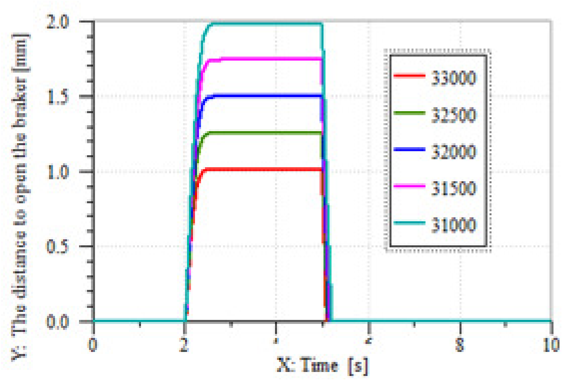

Figure 4 The brake clearance in different spring stiffness

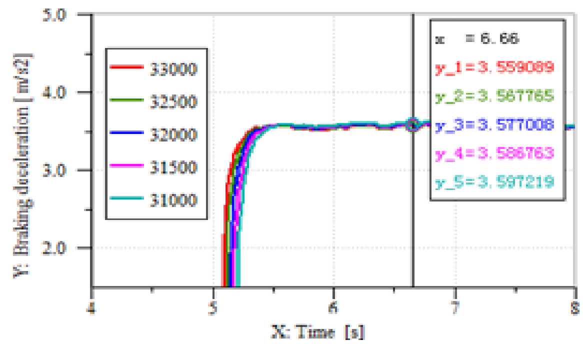

Figure 5 Braking deceleration in different spring stiffness

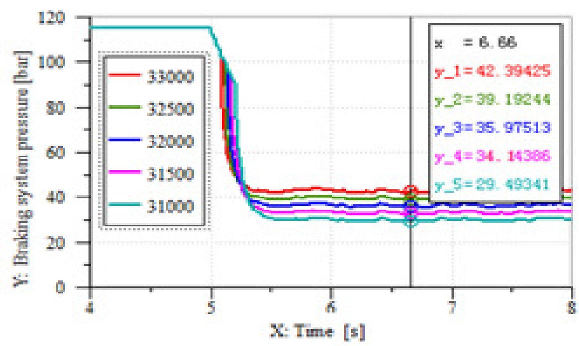

Figure 6 Braking system pressure in different spring stiffness

We can see from the simulation diagram. When the spring stiffness is reduced, the braking deceleration meets the requirements of system deceleration. The brake clearance and the idle time of the brake are gradually increased. When the spring stiffness is reduced to 31000, brake system meets the requirements that the idle time is not greater than 0.3s and the brake clearance is not greater than 2mm. When the spring stiffness is 31500, the pressure of the braking system is reduced to just meet the requirement of braking torque is not less than 3 times the maximum static load torque. The results show that when the spring stiffness is less than 31500, the failure of the spring stiffness reduced occurs.

3.3 Cylinder internal leakage

The simulation results in different cylinder internal leakage are shown in figure 7, 8 and 9:

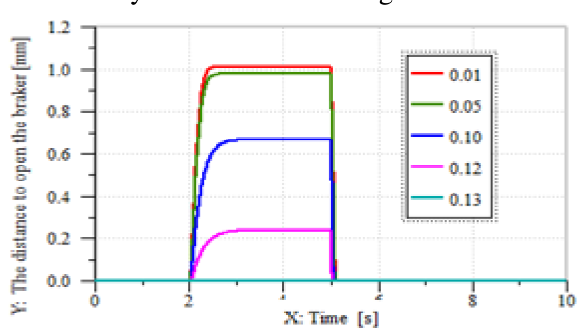

Figure 7 The brake clearance in different leakage

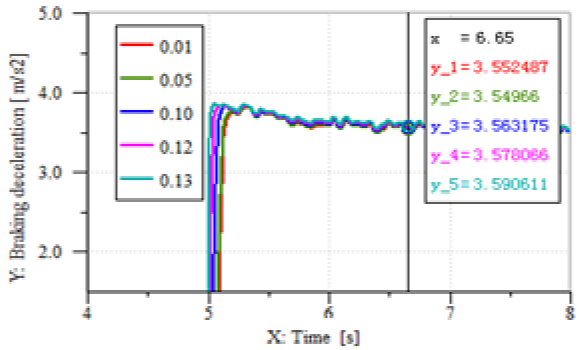

Figure 8 Braking deceleration in different leakage

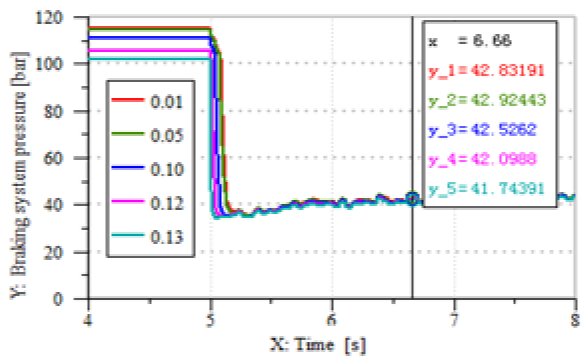

Figure 9 Braking system pressure in different leakage

We can see from the simulation diagram. When cylinder internal is leaked, brake deceleration meets the requirements of the system deceleration. The minimum pressure value of the braking system can meet braking momentum requirement. When the leakage clearance reaches 0.13 , the brake becomes closed, and the failure of cylinder internal leakage occurs.

4. FAULT DIAGNOSIS

We can obtain from the simulations of three main parts performance decline that the time - clearance curve and time-pressure curve of the brake system contain abundant fault information, from which feature parameters can be extracted for fault diagnosis. However, there are many pairs of brakes in the braking system, and the brake clearances are not same. The pressure of brake system can be measured by pressure sensor with highly measurement accuracy, so the pressure of brake system can be used to represent the overall performance of the braking system. In this paper, the time-pressure curve of the system is used to diagnose the fault of the braking system.

4.1 Generate Training Set / Testing set

The simulation platform is used to collect the brake system pressure data of 2-8.2 s as a set of fault data. Each fault is simulated by 30 sets of data, 25 of which are used as training samples, and the other 5 sets as test samples. Then there are 75 sets of training data of 620 dimensions, and the 15 sets of testing data of 620 dimensional. Use these data to extract its 2~7 order statistical moments $m_2 \sim m_7$ and two percentile of p_{50} and p_{51} as characteristic parameter. After normalization, the BP neural network is used to analyze and identify the faults. The normalized training samples are shown in Tabel 1, and the normalized testing samples are shown in Tabel 2.

Table 1 The neural network training samples

Sample number	Network input								Network output	Corresponding fault
	p50	p51	m2	m3	m4	m5	m6	m7		
1	0.0532	0.3581	-0.7939	0.6595	-0.7736	0.5947	-0.6873	0.4829	001	Friction coefficient Reduce
2	0.0103	0.2926	-0.7756	0.6750	-0.7659	0.6140	-0.6910	0.5094	001	
3	-0.9712	-0.9716	-0.9255	0.9976	-0.9523	0.9965	-0.9681	0.9916	001	
…	…	…	…	…	…	…	…	…	…	
26	0.1871	0.8374	0.3677	0.7750	0.1999	0.8395	0.0402	0.8577	010	Spring fatigue
27	0.1890	0.8374	0.2703	0.7796	0.0911	0.8409	-0.0726	0.8545	010	
28	0.1833	0.8374	0.5708	0.7558	0.4428	0.8194	0.3121	0.8409	010	
…	…	…	…	…	…	…	…	…	…	
73	0.6109	0.6216	0.4149	-0.9577	0.6187	-0.9297	0.8125	-0.9043	100	Cylinder Leakage
74	0.5997	0.6058	0.3969	-1.0000	0.6204	-0.9913	0.8349	-0.9812	100	
75	0.5735	0.5830	0.3798	-0.9953	0.6160	-1.0000	0.8406	-1.0000	100	

Table 2 The neural network testing samples

Sample number	Network input								Corresponding fault
	p50	p51	m2	m3	m4	m5	m6	m7	
1	-0.7190	-0.4777	-0.8159	0.8410	-0.8425	0.8106	-0.8415	0.7538	friction coefficient Reduce
2	0.0419	0.4122	-1.0000	0.5504	-0.9016	0.4247	-0.7608	0.2017	
…	…	…	…	…	…	…	…	…	
6	0.1307	0.8294	1.0000	0.6699	1.0000	0.7380	1.0000	0.7594	Spring fatigue
7	0.1446	0.8336	0.7750	0.6538	0.7125	0.7163	0.6445	0.7380	
…	…	…	…	…	…	…	…	…	
11	0.8157	0.8221	-0.2086	0.1158	-0.3030	0.2941	-0.3876	0.3780	Cylinder body Leak
12	0.7398	0.7464	0.0962	-0.3557	0.0547	-0.1740	-0.0148	-0.0387	

4.2 Training and Testing BP Neural Network

The three-layer BP neural network with only one hidden layer can approach any nonlinear function. Therefore, the single hidden layer neural network is chosen in this paper. According to the number of input characteristic parameter, the number of input neurons is chosen to eight. According to the dimension of the output vector, the number of output neurons is chosen to three. And according to the experience, the number of neurons in the hidden layer is choosen to eighteen. The iterations is set to 1000 times, the training accuracy is set to 0.01, and the rest of the parameters use the default value. After finishing the network training, the test data is input for testing, test results are shown in Tabel 3

Table 3 The result of neural network diagnosis

Sample number	Network output			Diagnosis result
1	0.0001	-0.0004	1.0003	friction coefficient Reduce
2	0.0104	-0.0074	0.9970	
…	…	…	…	
6	-0.0005	1.0068	-0.0063	Spring fatigue
7	-0.0005	0.9935	0.0070	
…	…	…	…	
11	1.0005	-0.0034	0.0030	Cylinder body Leak
12	1.0009	-0.0173	0.0164	

It can be seen from the results that the first five fault samples were diagnosed as friction coefficient decreases, the middle five fault samples as spring stiffness decreases, the last five fault samples as cylinder internal leakage. The diagnosed fault type is consistent with the testing fault categories, indicating that the diagnosis method is accurate and effective.

5. CONCLUSION

Firstly, typical faults were simulated on the braking system simulation platform in this paper. It is concluded that the curve of the system oil pressure contains abundant fault information. Then a new method is proposed, in which hoist braking system fault characteristic parameters is extracted, namely statistical moment method. Using this method the characteristic parameters of system pressure-time curve were extracted. Finally, an accurate fault diagnosis of the braking system was obtained using BP neural network. The relationship between the braking system components performance degradation and the overall performance was investigated. It provides some theoretical basis for the establishment of the performance degradation model of the brake system of high speed deep well hoist, and for the intelligent diagnosis and operation maintenance of the hoist. The advantages of this method are as follows:

1) By using the continuous signal collected by the pressure sensor, the characteristic parameters of the fault diagnosis can be obtained accurately, and the problems that the signal is not synchronized and the characteristic parameters can not be obtained accurately is overcome.

2) According to the theory of invariants moment in image processing, the method of characteristic parameters extraction is proposed for the first time.

3) The whole performance of the braking system can be represented only by the signal collected by the pressure sensor, which can not only make fault diagnosis, but also the performance analysis of the braking system

4) The pressure sensor has the advantages of flexible installation position, convenient detection and replacement in time. The problem overcomes that the braking positive pressure sensor is installed inside the brake and is not easy to be replaced.

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