FAULT POINT STATE MONITORING OF ELEVATOR DOOR BASED ON MODULUS MAXIMUM WAVELET TRANSFORM

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Abstrac: In order to reduce the occurrence of elevator door system failure and avoid the casualty of passengers, a detection system based on wavelet transform modulus singularity detection theory was proposed. Wavelet transform was a time-scale analysis method. It was widely used in local singularity detection and time-frequency joint information distribution. The results showed that the wavelet transform modulus maxima detection theory detected the sudden change of torque current. Thus, it effectively distinguishes the fault and its corresponding time.

Keywords: Wavelet transform maximum theory, elevator door system, fault

1. Introduction

With the progress of electronic in-formation technology and data processing theory, the maintenance of mechanical equipment is developing from the traditional fault diagnosis to intelligent maintenance and early warning. The research focus of elevator door system maintenance and processing is also gradually shifting from the field of gate crane fault diagnosis to the research of portal crane intelligent maintenance based on state monitoring, predictive maintenance and performance degradation analysis. In fact, the door machine experienced a measurable performance degradation process, despite the sudden failure of the door machine (Yang et al., 2015). Based on the theory of artificial intelligence, advanced information technology and remote network monitoring technology, the elevator door machine system is modeled. The potential feature signals of the system are extracted, processed and analyzed. The abnormal parts of the elevator door machine are tested. At present, the reliability of the operation performance of the gate machine is judged. The service life of the system is predicted. The corresponding measures are taken to maintain the normal operation of the system, so as to realize the intelligent monitoring and maintenance of the gate machine. The intelligent maintenance system transforms the traditional post fault maintenance mode into a new type of state prediction and maintenance. It can avoid accidents, save a lot of unnecessary maintenance resources, prolong the lifespan of the elevator, and realize the maintenance service of near zero fault (Tjirkalliset al., 2016).

From the principle of motor and elevator door operation, the torque current in the elevator door controller is proportional to the electromagnetic torque of the motor, and the electromagnetic torque is an active force source for the opening and closing of the door. Therefore, the operation of the elevator door can be indirectly reflected by measuring the change of torque current. The number of the encoder pulses in the output of the motor is proportional to the number of rotor rotations. The door motor rotor runs through a conveyor belt to drive the door leaf. The number of the pulse of the encoder is proportional to the displacement of the door leaf. The displacement and speed parameters of the door leaf can be identified by the encoder pulse.

These parameters reflect the running state of the door system. In the system state detection platform, the opening and closing experiments are carried out.

The excitation current, torque current, the number of encoder pulses and the friction force data of the door system are processed and analyzed. The current state and performance degradation of the door system can be analyzed indirectly. In recent years, there are many studies on the direction of multi-information fusion (Shinomiya et al., 2015); Pan, 2016). This project can also consider a number of parameters fusion analysis of the state of the door system.

2. Current Monitoring and Fault Identification

The status monitoring platform of the elevator door system can monitor the current size and position information of the motor torque in real time. In addition, it monitors changes in position and drive current during door opening and closing. The operation state, performance and fault location of the door system are analyzed. The fault warning threshold is obtained. The portal maintenance system is constructed by comparing the signal characteristics of the normal operation state and the fault state of the door system. According to this idea, a large number of experiments are carried out to compare the difference of excitation current, torque current and the acceleration of door leaf's running direction under normal conditions and various faults or performance degradation. Then, the characteristics of the performance degradation of the sign door system are counted. According to the common fault type door machine, simulation of door system status is set as follows: screen, screen failure caused by the failure of clamping fault, closing device failure, the friction between the door rail in-creases, normal. Through the system experiment platform, in the different state of the door system, the characteristics of the acceleration, torque current and excitation current in the time and frequency domain are statistically analyzed. The specific statistical characteristics are shown in Figure 1.

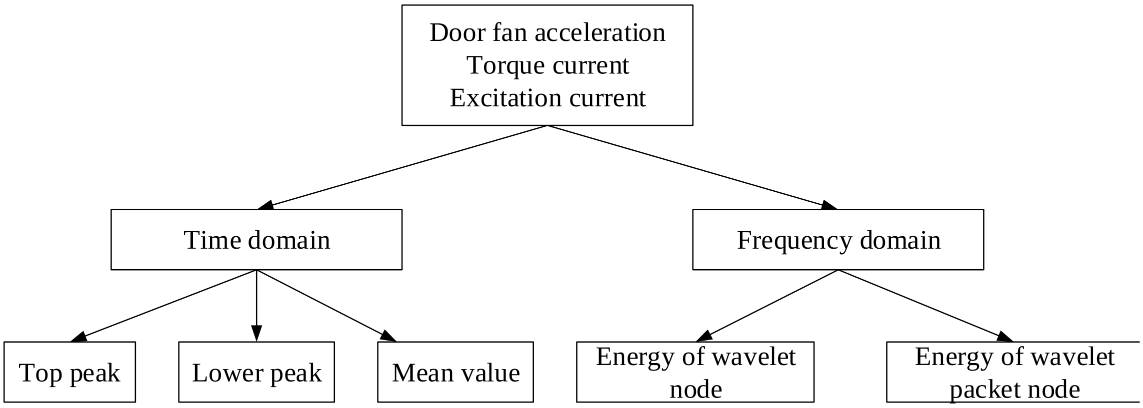


Figure 1. Experimental statistical characteristics

The statistical characteristics (especially energy) of wavelet and wavelet packet decomposition have been widely discussed and applied as signal characteristic quantities. The energy of wavelet packet is regarded as an important statistical characteristic.

Then, the different system state is set. Dozens of closed door loops are executed. The signal is collected and the distinct characteristics of different states are counted. After a large number of experiments, in five cases, the time-domain characteristics of the excitation current and torque current are shown in Table 1 and table 2, respectively.

Table 1. Time domain characteristic statistics table of excitation current

	Maximum peak value	Second peak value	Minimum	Mean
Screen failure	0.549	0.212	-0.0482	0.0458
Screen failure, cause the elevator door clamping accident	0.637	0.245	-0.0474	0.0518
Failure of forced closing device	0.583	0.288	-0.0641	0.0366
Friction increase between gate guide way	0.625	0.254	-0.0555	0.0492
Normal condition	0.635	0.271	-0.0668	0.0557

Table 2. Time domain characteristic statistical table of torque current

	Maximum peak value	Second peak value	Minimum	Mean
Screen failure	2.854	-1.233	-4.087	0.353
Screen failure, cause the elevator door clamping accident	2.745	-1.591	-4.335	0.107
Failure of forced closing de-vice	2.419	-1.298	-3.716	0.213
Friction increase between gate guide way	2.854	-1.216	-4.069	0.268
Normal condition	2.760	-1.205	-3.964	0.233

From the two aspects of time domain and frequency domain, the three kinds of signals, the excitation current, the torque current and the acceleration of the door leaf in the running direction, are calculated in different states of the door system. According to the different states of the door system, ten switching door cycles are respectively executed.

The time domain characteristic of the exciting current is taken as the mean value, as shown in Figure 2:

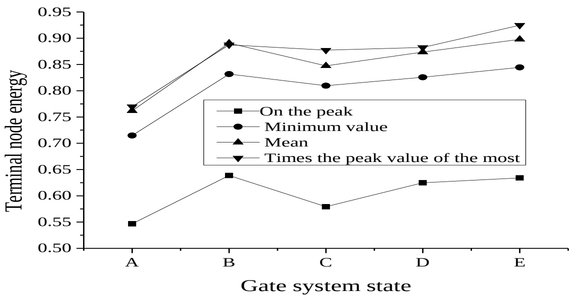


Figure 2. Excitation current time domain feature statistics

As shown in Figure 2, A is the light curtain failure. B is the light curtain failure caused by pinch accident. C is the forced closing device failure. D is the door friction between the rails increased. E is the normal situation. The maximum peak value of the excitation current is an important feature that distinguishes the state of the gate system. The experimental settings are the same as above. The maximum peak value of the torque current and the minimum peak value are the important features that distinguish the state of the gate system. The maximum value and mean value of the acceleration data in the running direction of the door are more obvious.

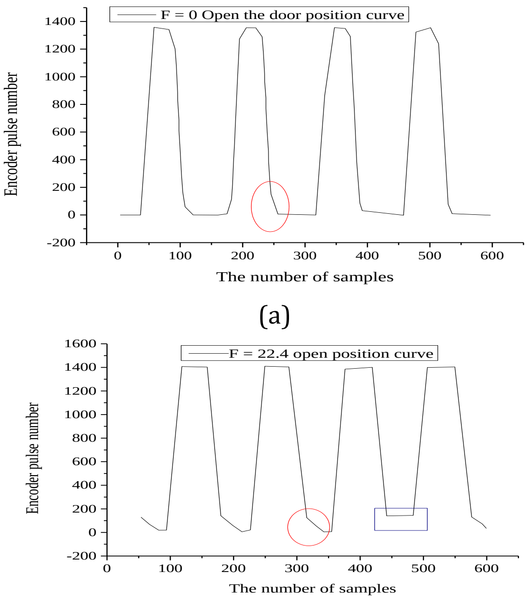
3. Test and Analysis of the Performance Decline of Elevator Door Machine System

The door motor takes on the driving force of the elevator door. Once the failure occurs, it will bring serious consequences. The gate pulley is worn seriously, and the door guide is deformed or loosened. There is too much dust or sundries in the sill of the floor. The door lock roller is not close to the door knife. The gap is large, which will cause the resistance. The vibration of the door fan and the noise increase when the door is closed. There are many kinds of energy loss in the motor, such as electric, magnetic and mechanical. The energy of these losses is emitted in a hot way. If the temperature rise is exceeded, the motor will accelerate the aging of the insulation material, reduce the material strength and insulation performance, and shorten the service life of the motor. The main cause of the heating of the motor is two kinds of electrical and mechanical. Most of the reasons for the failure are not in the motor itself. If the resistance of the elevator door switch is detected, the cause of the potential failure can be found effectively and the failure time of the elevator door can be improved.

Under the ideal condition, it is as-sumed that the sliding wheel wear is ignored. The door guide rail is not deformed without loosening and deflection. The resistance of the door lock roller is close to the door knife. The resistance of the elevator door switch is equivalent to the friction force of the gantry crane system. In order to describe the performance degradation of the door system, a fixed pulley is installed on the test bed of the door and the weights are hung outside. At external forces F=0, 2.5N, 5N, 7.5N, 10N, 12.5N, 15N, 15.8N, 16.6N, 17.4N, 17.5N, 18.2N, 19N, 19.8N, 20N, 20.8N, 21.6N, 22.4Nrespectively, the door opening position, excitation current, torque current and door opening and closing resistance are monitored in real time. Data of various working conditions are recorded. According to the opening resistance, the corresponding friction at each sampling point is calculated.

3.1 Opening position

In the course of the change of F=22.4N without external force, the opening position curve has changed obviously, as shown in Figure 3 (a).When F changes from 0 to 22.4N, the time of closing the door with the increase of F is gradually extended. The phenomenon of being unable to be put into place at the time of F=22.4N, as shown in Figure 3 (b).



(a)

(b)

Figure 3. When adding different external force F open the door position curve

3.2 Torque current

The change of instantaneous torque current is difficult to capture in real time. However, the maximum and minimum value of the torque current in the opening and closing period can be quickly determined. They correspond to the peak torque current of the door and the door, respectively, as shown in Table 3.From table 3; Figure 4 and Figure 5 are obtained. They are the curve of torque current changing with the external force, that is, the performance degradation curve of torque current.

The change of the opening torque peak current with the external force is not obvious, as shown in Figure 5.When the peak torque peak current varies with the external force, the point of failure is compared with the peak torque peak current without external force. The rate of change was 28.53%.It is considered to be the process of performance degradation when the resistance is increased. For closing the door, the added weight is to increase the friction. With the increase of the external resistance, it is difficult to close the door and the absolute value of the peak current of the closing torque is increased.

Table 3. External force and switching torque peak peak current corresponding table

External force F (N)	0	2.5	5	7.5	10	12.5
Torque peak current of open door I_{max}	2.194	2.191	2.164	2.167	2.179	2.157
Torque peak current of close door I_{min}	-1.126	-1.275	-1.261	-1.248	-1.326	-1.385
External force F (N)	15	15.8	16.6	17.4	17.5	18.2
Torque peak current of open door I_{max}	2.169	2.156	2.155	2.145	2.110	2.154
Torque peak current of close door I_{min}	-1.412	-1.412	-1.424	-1.409	-1.315	-1.411
External force F (N)	19	19.8	20	20.8	21.6	222.4
Torque peak current of open door I_{max}	2.123	2.093	2.211	2.137	2.186	2.185
Torque peak current of close door I_{min}	-1.429	-1.433	-1.444	-1.429	-1.471	-1.489

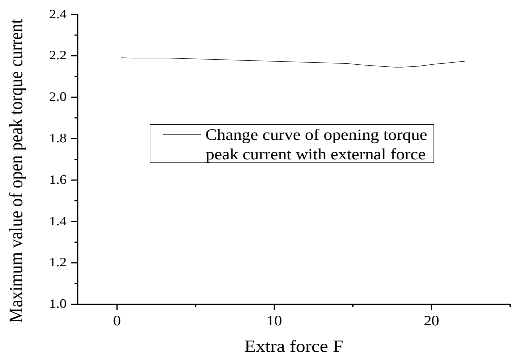


Figure 4. Performance degradation curve of torque peak current during opening

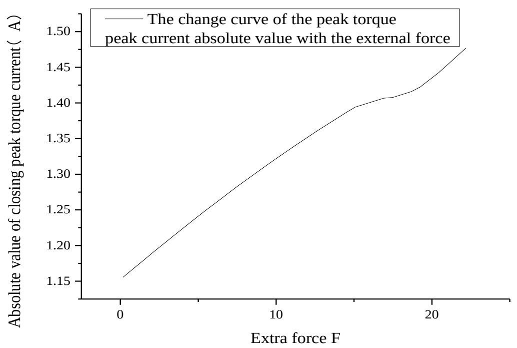


Figure 5. The performance degradation curve of the absolute value of the torque peak current in the closing process

3.3 Keeper current of close

The keeper current is one of the performance indicators to measure the performance degradation of the elevator door system. The closing current is not zero during the normal operation of the door system. Once the door is closed to keep the current to zero, it can easily pull the door open and trouble.

This indicates that the motor control of the elevator door system is in the open loop state. It cannot achieve the state of keeping the door closed.

3.4 Resistance curve of opening and closing the door

The effect of the external weight on the resistance of the switch door is very significant. According to the experimental data, the relationship between the maximum and the minimum of the external force is obtained, as shown in Table 4. In the process of opening the door, the extra weight plays a dynamic role. Therefore, the peak resistance of the door decreases with the increase of the external force. In the process of closing the door, the counterpoise plays the role of resistance. The absolute value of the peak resistance increases with the increase of the external force. The external force corresponds to the peak resistance table of the switch door is shown in Table 4.

Table 4. The external force corresponds to the peak resistance table of the switch door

External force F (N)	0	2.5	5	7.5	10	12.5
Peak resistance of open door F_{max}	98.61	97.11	94.55	93.59	94.14	94.68
Peak resistance of closing doors F_{min}	-14.61	-25.79	-23.80	-27.07	-35.42	-39.51
External force F (N)	15	15.8	16.6	17.4	17.5	18.2
Peak resistance of open door F_{max}	98.43	96.45	89.33	95.64	95.08	95.75
Peak resistance of closing doors F_{min}	-41.80	-39.73	-40.23	-40.14	-41.38	-39.95
Peak resistance of open door F_{max}	19	19.8	20	20.8	21.6	222.4
Peak resistance of closing doors F_{min}	70.51	93.89	93.55	91.11	75.08	75.11
Peak torque current of closing the door I_{min}	-43.09	-42.56	-47.46	-46.31	-45.44	-45.28

From table 4, Figure 6 and Figure 7 are obtained. They are the curves of the resistance to the opening and closing of the door with the external force, that is, the performance degradation curve of the door opening and the closing resistance under the external force. As shown in Figure 6, when the failure occurs, the rate of change is 21.43% compared to the peak resistance of the normal state.

As shown in Figure 7, when the fault occurs, compared with the peak resistance of the normal state, the absolute change rate of the peak resistance of the close is 171.99%.

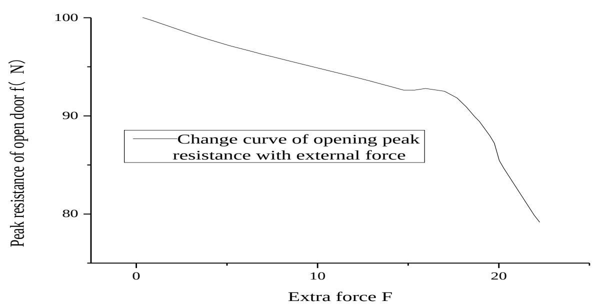


Figure 6. Resistance performance degradation curve of open door

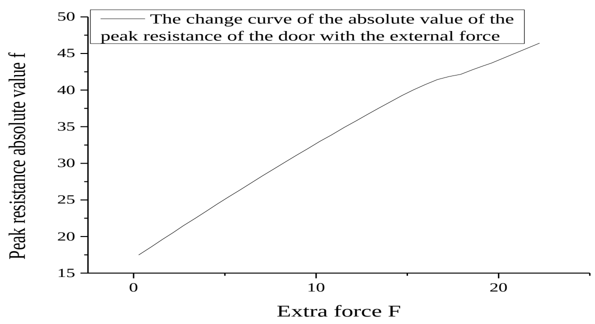


Figure 7. Gate resistance performance degradation curve

4. Result Analysis and Discussion

In recent years, wavelet and wavelet packets have been widely used in signal feature extraction.

The statistical features of nodes (especially energy) decomposed by wavelet and wavelet packets, especially energy, have been discussed and applied in a large amount (Qin et al., 2016; Prakash et al., 2015; Hao et al., 2015; Kong et al., 2017). The research shows that the wavelet analysis can be successfully used to analyze and detect the non-stationary signal and the signal with strong noise (Wang et al., 2017; Horikoshiet al., 2016). In reference to literature, there have been many applications of the detection of signal singular mutations by using the local characteristics of the wavelet in the time and frequency two domain to highlight the local characteristics of the signal (Horikoshi et al., 2015;Tobitaet al., 2015). The torque current extracted from the elevator door controller is a non-stationary signal. The screen will cause the failure of elevator door clamping fault. It will cause a sudden change in the torque current.

According to this, wavelet analysis is used to identify the singular mutation principle of the signal to distinguish the fault of the system. A brief overview of wavelet transform modulus maxima analysis signal singular mutation theory is introduced.

4.1 Wavelet transform module maximum principle

A very important application of wavelet transform is to represent the singularity of the function. In general, the local singularity of a function is described by the Lipschitz exponent α.

The definition of the Lipschitz exponent α is given.

Let n be a positive integer, n<α<n+1, If there are two constants A and h0 (> 0) and an n-th order polynomial Pn (h), the formula (1) is satisfied for any h <h0.

$$\left|f\left(x_0+h\right)-p_n\left(h\right)\right| \leq A\left|h\right|^{\alpha} \quad (1)$$

The function f (x) is the Lipschitz exponent α at point x0. If (2) holds for all x∈ [a, b], then f (x) is called a consensus Lipschitz α in [a, b].

For wavelet transform, its local Lipschitz exponent α is defined as: let f(x)∈L^2(R), [a,b] is the closed interval on R, 0<α<1, for ∀ε>0, f (x) is a uniform Lipschitz exponent α in (α + ε, b-ε). If and only if there exists a constant Aε, s> 0 is for all x∈ (a + ε, b-ε) and on any scale.

$$\left|Wf\left(s,x\right)\right| \leq A_s s^{\alpha} \quad (2)$$

The above theorem shows that wavelet transform can be used to estimate the local singularity of a function. However, in the actual numerical calculation, it is difficult to calculate the Lipschitz exponent of the function.

Generally, the point of zero or extreme value of wavelet transform is used to detect the mutation point of the signal. Let θ (t) be some low-pass smoothing function, and any low-pass smoothing function is θ(t) , $\left(\int \theta\left(t\right)dt \neq 0\right)$ the derivative of each order must be a band pass function. When w=0, they are 0. According to the differential theorem of Fourier transform, their frequency characteristics must have zero at w = 0. Therefore, the calculation method is as shown in formula (3):

$$\psi^{(1)}\left(t\right)=\frac{d\theta}{dt},\psi^{(2)}\left(t\right)=\frac{d^2\theta}{dt^2} \quad (3)$$

If $\psi^{(1)}$(t)is the first derivative of some low-pass smoothing function θ(t), $\psi^{(1)}$(t) can be wavelet transformed by x(t). At this point, the extreme point of wavelet transform is (dy／dt=0). (y(t) is the result of x(t) being smoothed by θ(t), that is, the turning point of y(t).

If $\psi^{(2)}$(t) is the second derivative of the smoothing function θ(t), $\psi^{(2)}$(t) can be wavelet transformed by x(t). At this point, the zero crossing of the wavelet transform is the turning point (dy／dt=0) of y (t). These conclusions also apply to the expansion and contraction of the basic wavelet.

For effective detection of local mutations, appropriate conditions must be met. First, $\psi^{(1)}$(t), $\psi^{(2)}$(t) should be the first and second derivative of a smoothing function. Second, scale a must be appropriate. On the one hand, the abrupt point of y (t) basically reflects the abrupt point of the analysis signal X (t). On the other hand, wavelet transform caused by each mutation point can avoid overlapping interference only on a proper scale.

4.2 Experimental analysis

Through the test bed, 53 closing and opening periods are performed. 282 points are collected for each cycle. At the 8, 15-21, 26-27, 37-39 and 46-48 cycles, the failure occurred. Due to the inclusion of a large number of harmonic components in the current and the wide frequency band of the information, it is very difficult to identify the fault information and the location of the fault mutation by the FFT transform. Using the db4 wavelet with tight support orthogonally, the torque current data was analyzed and decomposed into five layers. The information of singular mutation is mainly concentrated in the high frequency section, so the mutation information should be found from the detail decomposition details of the wavelet. From the wavelet coefficient distribution diagram of the high frequency detail D2, the five extreme mutations can be resolved clearly.

5. Conclusion

The parameter characteristics statistics of different system fault conditions are introduced.

Through the system state monitoring experimental platform, excitation current, torque current, encoder pulse data are collected. Then, the added force is described. From the position, torque current and drag, the influence of elevator door system is quantitatively analyzed. Finally, the theory of wavelet transform modulus maximum value discrimination function mutation is introduced. The application of this theory in identifying fault conditions is discussed. The statistics of the performance degradation of the system should be studied in depth. System performance degradation assessment and maintenance should be improved.

Based on theoretical analysis and multi group experiments, and through the elevator door system status monitoring platform, the results show that the change of closing position, closing torque, peak current and peak resistance is obvious. The failure of the elevator door system is determined to prevent the accident. The safety and efficiency of the equipment are improved, to achieve the purpose of realizing the intelligent prediction and maintenance of the equipment.

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