Analysis on mechanical characteristics of brake wheel and brake shoe of elevator traction machine

Tao Jiang\textsuperscript{1,a}, Ziwei Wang\textsuperscript{2,b}, Zhaolin Ren\textsuperscript{1,c}, Guangjun Liu\textsuperscript{2,d*, and Facai Ren\textsuperscript{1,e}}

\textsuperscript{1}Shanghai Institute of Special Equipment Inspection and Technical Research, Shanghai 200062, PR China
\textsuperscript{2}School of Mechanical Engineering, Tongji University, Shanghai 201804, PR China
\textsuperscript{a}email: jiangtao@ssei.cn, \textsuperscript{b}email: wang_ziwei1996@163.com,
\textsuperscript{c}email: renzhaolin3@163.com, \textsuperscript{d*}email: caifaren@163.com
\textsuperscript{d*}Corresponding author email: gjliu@126.com

Abstract. This paper analyzes the change of brake torque during normal stop and emergency braking of elevator. Taking the permanent magnet synchronous elevator traction machine as an example, the mechanical characteristics of the brake wheel and brake shoe on the brake under emergency braking are analyzed. According to the finite element analysis and calculation results, the impact and stress of the elevator are the largest at the moment of emergency braking, reaching 270.3MPa, and the strain increases gradually. The analysis results can provide reference for the design and verification of brake wheel and brake shoe of elevator traction machine.

1. Introduction

With the continuous advancement of China’s urbanization, high-rise buildings have sprung up like bamboo shoots after a rain. In high-rise buildings, elevators play an important role in transporting people and goods. Therefore, the design of elevators puts forward requirements for safety, reliability, riding comfort, and energy saving [1-3]. The traction machine is the power device of the elevator, which controls the up and down movement of the elevator. When an emergency occurs, in order to ensure the safety of the passengers in the elevator, the traction machine needs to be braked urgently. In this process, the brake plays a vital role, so it can be said that the reliability of the brake will directly affect the safety of the elevator [4, 5].

At present, the most commonly used brake is the shoe brake. This brake realizes elevator braking through the friction between the brake shoe and the brake wheel. The shoe brake is normally closed. When the elevator stops running, under the action of the brake spring, the brake shoe and the brake wheel lock the elevator to stop the elevator [6]. Brake wheel and brake shoe are the core components, and their stress will have an important impact on the braking effect. Therefore, it is very important to analyze the mechanical characteristics of brake wheel and brake shoe. In this paper, a permanent magnet synchronous traction machine is taken as an example to analyze the mechanical characteristics of the brake wheel and the brake shoe during emergency braking.
2. Brake Torque Calculation

In the elevator system, it mainly includes the elevator car, the counterpoise and the traction wheel, and its simplified model is shown in Fig. 1.

![Simplified model of elevator system](image)

Figure 1. Simplified model of elevator system.

In Fig. 1, $P$ represents the weight of the elevator car, $W$ represents the weight of the counterpoise, $R$ represents the radius of the traction wheel, $V$ represents the operating speed of the elevator car, and $M_f$ represents the braking torque of the brake. If the influence of the weight of the traction rope on both sides of the elevator car and the counterpoise is not considered, when the load of the car is the rated load, the force balance should satisfy the formula:

$$W = P + kQ$$  \hspace{1cm} (1)

In formula (1), $k$ represents the balance coefficient of the elevator, and $Q$ represents the rated load weight of the elevator. In elevators, usually the value range of the balance coefficient $k$ is between 0.4 and 0.5. Then, according to formula (1), the weight of the counterpoise can also be obtained.

When the elevator stops normally, the running speed $V$ of the elevator car is 0, and the braking torque of the brake is used to maintain the balance between the elevator car and the counterpoise. In terms of torque balance, the formula (2) should be satisfied:

$$M_f + W \cdot R = (P + Q) \cdot R$$  \hspace{1cm} (2)

The formula (2) is transformed, when the elevator stops normally, the braking torque can be expressed as:

$$M_f = (P + Q - W) \cdot R$$  \hspace{1cm} (3)

When the elevator descends suddenly due to a malfunction, the brake will brake urgently, and the elevator car and the counterpoise will decelerate at this moment. The deceleration value is represented by $a$, and the range of deceleration is usually between $0.2g$ and $1.0g$ ($g$ is the gravitational acceleration). Then, during emergency braking, the torque balance equation is:

$$M_f + \frac{W}{g} \cdot (g - a) \cdot R = \frac{(P + Q)}{g} \cdot (g + a) \cdot R$$  \hspace{1cm} (4)

The formula (4) is transformed, when the elevator stops in an emergency, the braking torque is:

$$M_f = \frac{(P + Q)}{g} \cdot (g + a) \cdot R - \frac{W}{g} \cdot (g - a) \cdot R$$  \hspace{1cm} (5)

Formula (5) can be simplified to formula (6):

$$M_f = (P + Q - W) \cdot R + \frac{2}{g} \cdot (P + Q + W) \cdot R$$  \hspace{1cm} (6)

Comparing the expressions of braking torque in formula (3) and formula (6), it can be seen that the braking torque of the brake during emergency braking is greater than that during normal stopping.
During the normal start and stop of the elevator, the elevator accelerates and decelerates to the set speed value under the control of the traction machine. But when the elevator breaks down, in order to make the elevator stop urgently, the brake needs to be braked urgently, which puts forward higher requirements for the performance of the brake. For this reason, it mainly analyzes the mechanical characteristics of the brake in the case of emergency braking.

3. Establishment of Finite Element Model
Assuming that the traction wheel radius \( R = 0.245 \text{m} \), the elevator rated load \( Q = 1000 \text{kg} \), the elevator car weight \( P = 300 \text{kg} \), the balance coefficient \( k = 0.45 \), the deceleration \( a = g \). According to the limit conditions stipulated by the national standard, the elevator is braked urgently under the rated load of the elevator car at 125%.

Substituting the above data into the formula (1), the weight of the counterpoise is calculated as:

\[
W = (300 \times 0.45 \times 1000 \times 1.25) \times 10 = 8625 \text{N}
\]  

When this elevator is in emergency braking, the braking torque can be obtained according to formula (6):

\[
M_f = \left(3000 + 1000 \times 1.25 - 8625\right) \times 0.245 + \frac{9.8}{9.8} \times \left(3000 + 1000 \times 1.25 + 8625\right) \times 0.245 = 7.595kN \cdot m
\]  

Since the braking process is a very complex process, the influence of many physical factors needs to be considered. Therefore, for the simplicity of the analysis, the following assumptions are made:

1. In the braking process, the value of deceleration \( a \) is constant;
2. In the braking process, the friction coefficient between the brake wheel and the brake shoe remains unchanged;
3. In the braking process, the braking torque is evenly distributed on the brake wheels;
4. In the braking process, the deformation of the brake wheel and brake shoe are both elastic deformation;
5. The initial temperature during braking is normal room temperature.

In the assumption (3), the braking torque is evenly distributed on the brake wheel, so the positive pressure \( N \) on the brake shoe can be calculated as:

\[
N = \frac{F_f}{\mu} = \frac{M_f}{R\mu}
\]  

In formula (9), \( \mu \) represents the friction coefficient between the brake wheel and the brake shoe.

In the emergency braking process, the main force objects are the brake wheel and brake shoe. Therefore, in order to accelerate the convergence process and improve the calculation efficiency, only the brake wheel and brake shoe are analyzed by finite element method. Fig. 2 shows the three-dimensional model of a permanent magnet synchronous traction machine.

Figure 2. Three-dimensional model of permanent magnet synchronous traction machine.
In Fig. 2, the radius of the brake wheel and the traction wheel are the same, which is 0.245m. The single-side brake shoe wrap angle is 50°, and the brake shoe width is 55mm.

The three-dimensional models of brake wheel and brake shoe are imported into the ANAYS software, and finite element analysis is performed.

(1) Mesh division:
The hexahedral network is used to mesh the brake wheel and brake shoe, as shown in Fig. 3. Among them, the total number of units of brake shoe and brake wheel is 4571, and the total number of nodes is 9251.

(2) Material parameters:
The material of the brake wheel is HT200, the density is 7250kg/m³, the modulus of elasticity is 1.48E+11Pa, and the Poisson's ratio is 0.3. The material of the brake shoe is a composite copper mesh plate, the density is 2150kg/m³, the modulus of elasticity is 2.2E+9Pa, and the Poisson's ratio is 0.3. The friction coefficient between the brake shoe and the brake wheel is $\mu = 0.3$.

(3) Load setting:
The pressure is evenly distributed on the outer surface of the brake shoe, and the positive pressure $N$ on the brake shoe can be calculated by formula (9) as:

$$N = \frac{7.595}{0.3\times0.245} \text{ KN} = \frac{310}{3} \text{ KN} \quad (10)$$

(4) Boundary conditions:
The displacement of the brake wheel and brake shoe in the X, Y, and Z directions is zero.

(5) Initial conditions:
The initial speed of the brake wheel is 10rad/s, and it rotates clockwise. In the emergency braking process, the speed is set to zero within 1s. The initial temperature is room temperature, which is 25°C.

4. Mechanical characteristic analysis
Fig. 4 shows the stress change of the brake wheel during emergency braking of the traction machine.

Figure 3. Grid division of brake wheel and brake shoe.

Figure 4. Stress change of brake wheel during emergency braking.
It can be seen from the data in Fig. 4 that in the emergency braking process, as time goes by, the maximum stress of the brake wheel gradually increases, and the maximum stress decreases and stabilizes after 600ms. In this process, the maximum stress of the brake wheel occurs at the shaft connection, and the minimum stress occurs at the friction edge of the brake wheel.

Fig. 5 shows the change of brake shoe stress during emergency braking.

Analyzing Fig. 5, it can be seen that the stress change of the brake shoe is more complicated. The maximum stress fluctuates increased before 200ms, and the maximum stress decreases from 200ms to 400ms, and then the maximum stress slowly increases with a smaller amplitude. Further analysis shows that at the beginning of friction braking, the stress is unevenly distributed on the brake shoe, and then gradually evenly distributed. Due to the continuous rotation of the brake wheel, the stress on the brake shoe is equivalent to the pulsating cyclic stress, so that the maximum stress and the minimum stress on the brake shoe also cyclically change.

According to the data obtained from the finite element analysis, a comprehensive analysis of the maximum and average stress changes on the brake wheel and brake shoe is carried out, as shown in Fig. 6.

In Fig. 6, the red solid line represents the maximum stress on the brake wheel and brake shoe, and the blue dashed line represents the average stress on the brake wheel and brake shoe. The data in Fig. 6 show that the stress value on the brake wheel and brake shoe reaches the maximum at 12ms, which is 270.3 MPa. Obviously, the stress is increased sharply due to a large impact at the moment when the brake wheel and brake shoe contact. As the friction deceleration progresses, the impact gradually stabilizes, and the maximum stress and the average stress increase in a smaller range. Finally, as the brake wheel gradually stops rotating, the maximum stress and the average stress increase during the period from 600ms to 800ms, and then remain basically unchanged.

Due to the brake wheel keeps rotating during the braking process, the strain change cannot be accurately analyzed. Therefore, only the strain analysis is performed on the brake shoe, as shown in Fig. 7.
Figure 7. Strain change of brake shoe during emergency braking.

It can be seen from Fig. 7 that the maximum strain on the brake shoe basically remained unchanged before 600ms, but it has been increasing since then. This is due to the continuous increase in deformation caused by friction, and the maximum strain is basically at the place where the brake shoe enters the friction, which is the upper side of the brake shoe.

5. Conclusion
Calculating the braking torque of the brake during normal stop and emergency braking of the elevator, and analyzing the mechanical characteristics of the brake wheels and brake shoes in the emergency braking process, the following conclusions can be obtained:

(1) During emergency braking, the braking torque of the brake is relatively large, so the stress change in this situation should be considered when designing the brake;

(2) The maximum stress of the brake wheel is at the joint between the brake wheel and the traction wheel; The stress on the brake shoe is a pulsating cyclic stress, so the problem of fatigue damage needs to be considered;

(3) The friction between the brake wheel and the brake shoe causes the strain to increase continuously, which will cause the braking effect to gradually deteriorate, so the life test is very important.

Acknowledgments
The authors are grateful for the support by Shanghai Bureau of Quality and Technical Supervision Research Project (No. 2019-26).

References
[1] Hamad, Q. S., Ali, Y., Fadhil, H. A., Al-Janabi, M., Ahmed, F.. (2020). Elevator Exhaustion Time Reduction by Eliminating Fake Demands. 2020 International Multi-Disciplinary Conference Theme: ‘Sustainable Development and Smart Planning’.
[2] Ongun, E., Demir, A.. (2017). Improving the performance and energy efficiency of elevators by direct-landing elevator position control system. International Conference on Electrical & Electronic Engineering. IEEE.
[3] Hamad, Q. S., Croock, M. S., Qaraawi, S. A.. (2014). Efficient infrared sensor and camera based monitoring system. 2013 International Conference on Electrical Communication, Computer, Power, and Control Engineering (ICECCPCE), IEEE.
[4] Peng, Q., Li, Z., Yuan, H., Huang, G., Li, S., Sun, X.. (2018). A model-based unloaded test method for analysis of braking capacity of elevator brake. Advances in Materials Science and Engineering, 2018: 1-10.
[5] Durak, E., Yurtseven, H. A.. (2016). Experimental study of the tribological properties of an elevator's brake linings. Industrial Lubrication & Tribology, 68(6): 683-688.
[6] Pan, G., Lei, C.. (2018). Impact analysis of brake pad backplate structure and friction lining material on disc-brake noise. Advances in Materials Science & Engineering, 2018: 1-9.