Experiment Method of Tribology Performance of Braking Material for High Speed Elevator

Yinge Li [1], Xi Shi [1], Simo Makimallila [2]

[1]School of Mechanical Engineering, Shanghai Jiao Tong University, 800 Dong-chuan Road, Shanghai 200240, P. R. China;
[2]KONE KUNSHAN PARK, 88 Middle Gucheng Road Kunshan, Jiangsu 215300, P. R. China

Keywords: Testing rig, experiment method, high speed braking, friction coefficient.

Abstract. As a crucial brake component of the elevator, the braking performance of the safety gear is extremely important for the safety and reliability of the elevator. In this paper, an elevator safety gear braking testing rig based on disc brake model was established to simulate the actual high speed braking working condition, and some preliminary results have been obtained.

1 INTRODUCTION

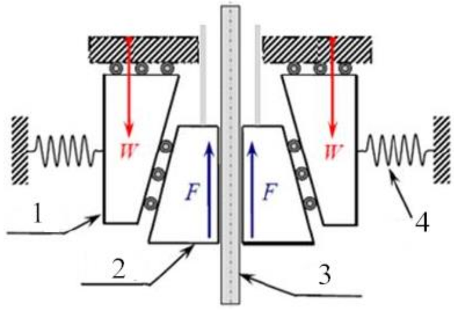
High-speed elevators generally refers to elevators operating at speeds greater than 3m/s so far, which are widely used in vertical transportation for high-rise buildings because of their high transport efficiency[1]. In consideration of the high operating speed, the technical requirements, especially the braking performance, should be more demanding than the conventional elevator. Thus, the safety gear, as a crucial brake component of the elevator [2], whose braking performance is extremely important for the safety and reliability of the elevator, should be emphatically studied. The friction interface problem of the safety gear is mainly to study the influence of the wedge material on the friction performance of the friction interface. Ao et al. study the braking process on progressive safety gear [3]. Chuan Jin reports a numerical simulation model for the safety gear frictional temperature rise [4]. Xiong X et al. study the impact of brake pressure on the friction and wear of carbon/carbon composites [5]. Therefore, the development and testing of wedge materials for the safety gear has become the concern of many elevator companies. Besides, Hyung-Min Ryu built a mechanical structure of high-speed elevator system for a dynamic load simulator [6], and Hussam et al. did a series of experiments on C/C–SiC brake pads for high-performance elevators [7].

In this paper, an elevator safety gear braking testing rig based on disc brake model was established to simulate the actual high speed braking working condition, and thus obtain the effective friction coefficient of the corresponding material.

2 ELEVATOR SAFETY GEAR

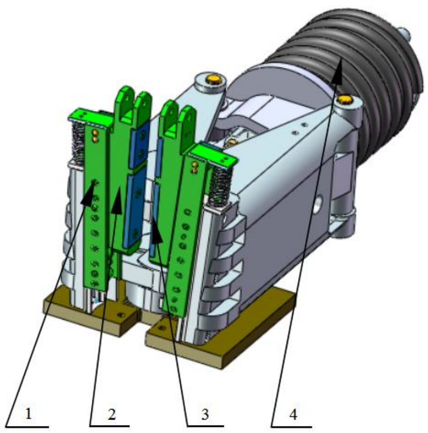
2.1 Elevator Safety Gear

For low-speed elevators, if emergency situations such as wire rope fracture, car over-speed operation, and car drop happen, the speed governor will trigger elevator safety gear by simultaneously lifting the wedges on both sides of safety gear, and the wedges will lock the rail because of the force acting by the springs. Fig.1 illustrates the structural diagram of low-speed elevator safety gear. For high-speed elevators, the spring is placed on the rear side of the safety gear, at the same time a leverage mechanism is introduced to amplify the rear spring force, and thus larger normal loads can be applied to the wedges. Fig.2 illustrates the structural diagram of a high-speed elevator safety gear.



1- gear 2- wedge 3- rail 4- spring

Figure 1 Structural diagram of low-speed elevator safety gear



1- bearing 2- wedge 3- breaking material 4- spring

Figure 2 Structural diagram of high-speed elevator safety gear

2.2 Theoretical model

Since setting the braking test in the vertical hoistway would cause operating risk and safety threat because of the shock on test tower caused by high initial velocity and inertia, the disc braking model is used to establish the testing rig. Fig.3 shows the dynamic analysis of these two models. Thus, the coefficient of fiction of the braking material can be derived according to the force analysis of the brake disc, as shown in Eq. 1.

$$\mu = \frac{F_t}{F_n} = \frac{M}{2 \cdot p \cdot A \cdot R} = \frac{J\alpha}{2 \cdot p \cdot A \cdot R} = \frac{Ja}{2p \cdot A \cdot R^2}$$

Where μ represents the COF (coefficient of friction); F_t represents the friction force during braking; F_n represents the normal pressure during braking; *A* represents the contact area; *J* represents the total inertia; α represents the angular deceleration of the brake disc; *R* represents the distance from the center of the brake pad to the center of the brake disc; *a* represents the linear deceleration at *R*; *M* represents the total mass of the actual car and passengers; *p* represents the surface pressure to the brake pad.

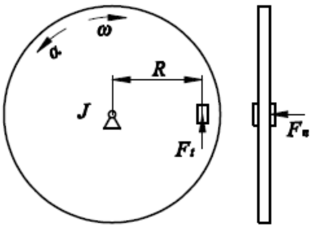
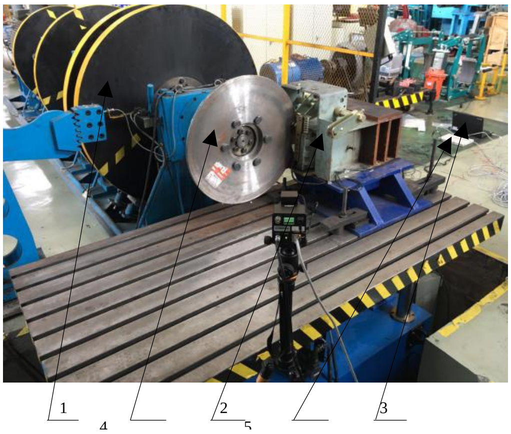


Figure 3 Dynamic analysis of these two models

2.3 Testing rig

The high-speed elevator safety gear testing rig is established as shown in Fig.4, which includes the driving system, the braking system and the data collection system.

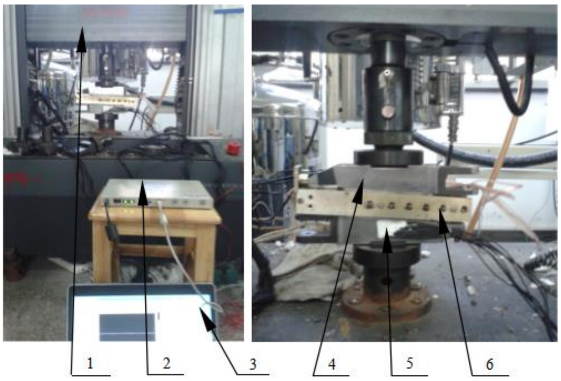


1- inertia disc 2- braking disc 3- safety gear 4- dynamic strain indicator 5- computer

Figure 4 High-speed elevator safety gear testing rig

The driving system mainly includes the motor, the load inertia, and the fixture of devices. The initial speed and load inertia are provided by the driving system. The braking system includes a brake disc and the safety gear. The normal load to the brake pad is exerted by the safety gear, so that a braking torque opposite to the direction of motion is generated in the contact area between the brake disc and the pad, which stops the whole system. The data collection system includes speed and braking pressure data collection systems. The speed data collection system is to collect the motor speed via the encoder during braking process, and thus the angular deceleration can be obtained by doing the discrete derivative of the angular velocity. The braking pressure data collection system is to dynamically monitor the pressure between brake disc and the material pad, the main method is collecting strain data from the wedge surfaces, then obtaining the braking pressure using the pressure-strain calibration curve.

The pressure calibration device is shown in Fig.5. Pressure is applied on the surface of the wedge, and the pressure and strain data simultaneously recorded during the compression process, so that the pressure-strain curve can be obtained.



1- compression testing machine 2- dynamic strain indicator 3- computer 4- wedges

5- bearing 6- strain gages

Figure 5 The pressure calibration device

3 RESULTS AND DISCUSSION

3.1 Braking deceleration

Fig.6a) and Fig.6b) show the linear velocity and the linear deceleration at the center of the brake pad respectively. The linear deceleration increases rapidly after a relatively smooth period, indicating that the braking material starts to get in touch with the brake disc when t>0.33s. Besides, due to the instability of braking pressure, the linear deceleration may fluctuate greatly during the braking period. The smooth period between t=0s and t=0.33s can be considered as the consequence of the system damping after the motor has been cut off. Thus, the average deceleration a_{av} of the braking process can be calculated according to these two periods, as shown in Eq.2. It can be told that the average deceleration a_{av} meets the technical requirement for braking average deceleration from the national standard GB7588-2003, that is, the average deceleration of progressive safety gear should be 0.2g~1.0g with a free-falling car equipped with rated load.

$$a_{av} = \frac{V_s}{T_e - T_s} - \frac{V_i - V_s}{T_s} = \frac{9.362}{2-0.33} - \frac{9.582-9.362}{0.33} = 4.94 m/s^2$$

Where V_s represents the linear speed at the beginning of braking; V_i represents the linear speed at the beginning of recording; T_s represents the time when braking starts; T_e represents the time when braking ends.

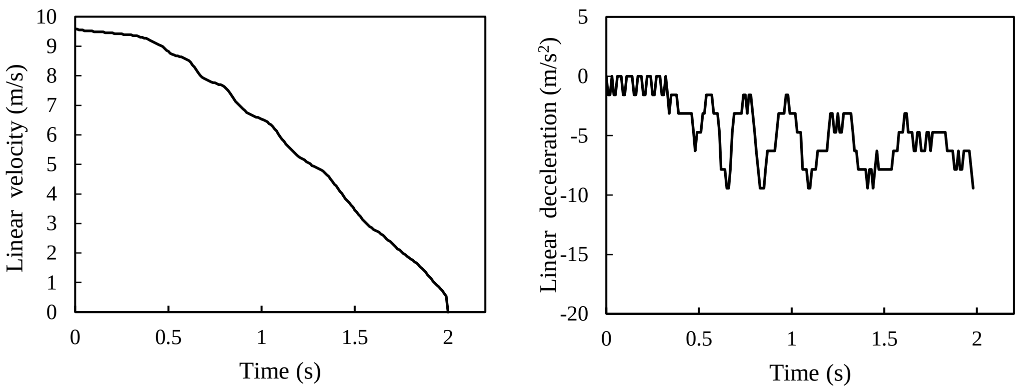


Figure 6 (a) linear velocity (b) linear deceleration

3.2 Braking pressure

Fig.7a) shows the pressure-strain calibration curve; it can be approximately considered as proportional relationship. The strain curve during the braking process is shown as Fig.7b). The impact stress wave caused by the contact and the quickly touching down of the wedges and brake disc lead to the instantaneous increase of the surface strain. The strain value fluctuates inevitably after entering the stable braking period mainly because of the differences of the pad- disc contact conditions at different areas, and accordingly the period of strain fluctuation is the rotation period of brake disc. Besides, due to the wear loss of the brake pad, the braking pressure curve will certainly show a damping trend during the braking period, as shown in Fig. 7b).

The average braking pressure $P_{av} = 18.5MPa$ can be obtained by the mean strain of the braking period $\varepsilon_{av} = -339\mu\varepsilon$ and the pressure calibration curve.

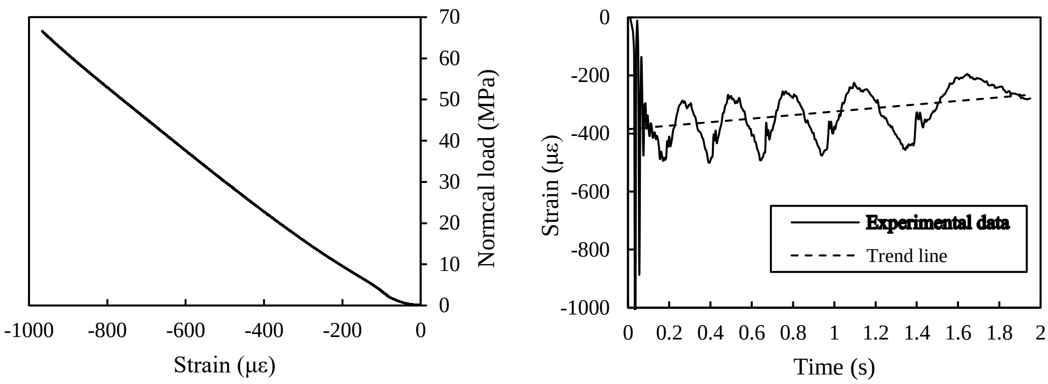


Figure 7 Curves for (a) Pressure-strain calibration and (b) Strain

3.3 Coefficient of friction

According to Eq.1 and data above, the COF of brake material can be obtained, as shown in Eq.3. The COF is 0.198, which is close to the theoretical friction coefficient. Thus, the experimental method proposed in this paper can effectively measure the COF of the brake materials.

$$\mu = \frac{J \cdot a_{av}}{2 p_{av} \cdot A \cdot R^2} = \frac{200 \times 4.94}{2 \times 18.5 \times 10^6 \times 0.0015 \times 0.3^2} = 0.198$$

REFERENCES

[1] Zhu Chang Ming. *Elevator and Escalator*. Shanghai Jiao Tong University Press, (1995).

[2] MA Pei-zhong. *Model Features of Safety Gear and Analysis of Its Function——Talking about Elevator Safety Device.* China Elevator, (1996), 7:9-15.

[3] AO Hai-ping, WANG Wen-shui. *Research of braking process on progressive safety gear based on SolidWorks.* Journal of Mechanical ＆ Electrical Engineering, (2015), 32(9):1218-1221.

[4] Jin Chuan, Shi Xi. *Finite Element Analysis of Temperature Rise Caused by Braking Friction Safety Gear in High- speed Elevator.* Machine Design and Research, (2015)(2).

[5] Xiong X, Li J, Huang B. *Impact of brake pressure on the friction and wear of carbon/carbon composites*. Carbon, (2007), 45(13): 2692-2694.

[6] Ryu, Hyung Min, et al. *Dynamic load simulator for high-speed elevator system.* Power Conversion Conference, 2002. PCC-Osaka 2002. Proceedings of the IEEE, (2002):885-889 vol.2.

[7] Abu El-Hija, Hussam, W. Krenkel, and S. Hugel. *Development of C/C–SiC Brake Pads for High-Performance Elevators.* International Journal of Applied Ceramic Technology 2.2(2010):105-113.

BIOGRAPHICAL DETAILS

Yinge Li received the B.Sc. degree in mechanical engineering from Chongqing University, China, in 2016. She is currently pursuing the Master degree at the School of Mechanical Engineering, Shanghai Jiao Tong University, China, under the supervision of Prof. Xi Shi. Her research interests cover many aspects of friction interface applied to elevator.

Prof. Xi Shi received his Ph.D. in Mechanical Engineering from University of Illinois at Urbana-Champaign in 2005. Currently, he is the director of Elevator Test Center at Shanghai Jiao Tong University. His research interests span from intelligent elevator technology and interfacial mechanics, to tribology. He has been the PI for tens of research projects sponsored by NSFC, MOST, MOE and international renowned enterprises, and published tens of journal papers. Prof. Xi Shi won the ASME K.L.Johnson Best Paper award in 2007.

Dr. Simo Makimattila received his Ph.D. in Physical Metallurgy (Material Science) from Teknillinen korkeakoulu-Tekniska högskolan in 1988, and currently work with KONE as leading expert in global research and development of elevators and escalators.