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A Method for Determining the Initial Distance Between the Elevator Cabin and the Shock Absorber

Truong Giang Duong*[1], Ngoc Hai Nguyen[2], Duc Thach Luu[3]

[1,2,3]Faculty of Mechanical Engineering, Hanoi University of Civil Engineering, 55 Giai Phong Road, Hanoi, Vietnam

[1]https://orcid.org/0009-0007-7675-8028

[2]https://orcid.org/0009-0003-7781-0079

ABSTRACT: In elevators, the shock absorber is located at the bottom of the elevator shaft; it is the last line of defense in case the cabin exceeds its permitted travel distance. The initial distance between the cabin and the shock absorber directly affects the impact energy and the braking acceleration. Therefore, research into methods for determining this distance is essential. This research paper determines the initial distance between the cabin and the shock absorber using the energy principle, and the distance constraints based on elevator testing and installation standards. This identification method allows for rapid verification, serving the purpose of initial design and correction. In the experimental example, the paper showed that the dataset represents the optimal correction distance based on a survey of elevator load-related parameters and damping parameters. The calculation method in this paper can be applied to counterweight buffers or other similar devices, and can also be extended to study other types of buffers.

KEYWORDS: energy conservation; cabin; buffer; acceleration, elevator

I. INTRODUCTION

Elevators are an indispensable means of transport in apartment buildings, high-rises, hotels, and hospitals [1], [2]. When installing an elevator, the shock absorber located at the bottom of the elevator shaft serves as the final safety device if the cabin exceeds its permitted travel. According to the structure and working principle, shock absorbers include spring shock absorbers, rubber shock absorbers, and hydraulic shock absorbers. Generally, when the speed ranges from 0.5 m/s to 0.75 m/s, rubber shock absorbers can be used; from 0.75 m/s to 1 m/s, spring shock absorbers are employed; and above 1 m/s, hydraulic shock absorbers are utilized [1-3]. The document in [3] analyzed the working principle, advantages and disadvantages, and technical characteristics of some types of shock absorbers used in lifting equipment and elevators. However, the above studies, textbooks, and documents are only basic guidelines. Manufacturers often provide general selection methods and adjustments during installation, depending on the specific application. In addition, elevators must comply with safety requirements, and the type of product and goods must be strictly controlled from design, manufacturing, installation, and operation [4], [5]. Because of its important role, several studies and regulations related to the issue have already been published.

Studies related to elevators and elevator drive systems have been included in [6 – 8]. The research in [6] helps regulate motion, save energy, and reduce the force applied to the damper by considering a reasonable balance coefficient when using a balancing system in the drive system. The study in [7] presents an elevator dynamics model that calculates the motion of the balancing system in the event of impact with the damper. The 2-degree-of-freedom oscillation model of the elevator system, including the cabin, balancing cable, and cable hoist, evaluates the dynamic tension of the compensating cable caused by impact with the shock absorber. This study aims to investigate the system dynamics with forces on the cable branches, considering the case of impact with the shock absorber. In addition, [8], [9] provide basic knowledge about lifting mechanisms, mechanical details such as springs, thermal deformation, and material elongation under load. It can be said that the above studies do not directly address the meaning and role of the distance between the cabin and the shock absorber at the lowest position during elevator installation and use

Directly referring to the role of the initial distance between the cabin and the shock absorber at the lowest position, as stated in studies [10], [11]. In the invention mentioned in [10], the authors invented a shock absorber placed at the bottom of the elevator shaft. In this invention, an elastic element was designed before the cabin hit the damper, which has the effect of minimizing vibration and also allows increasing the initial distance between the shock absorber and the cabin. Currently, many elevator manufacturers do not consider the actual impact speed during the selection of the shock absorber, which creates safety risks [11]. By analyzing the relevant standard scenarios in [4] [5], study [11] established equations to calculate the impact speed of the elevator cabin or counterweight, determined the corresponding results, and conducted numerical tests. Based on [4], [5], this study calculated the acceleration according to standard regulations, and investigated the calculated damping velocity taken as 115% of the rated velocity. Study [11] indicated that these issues still have many inconsistencies that need to be discussed. To recommend the maximum distance between the cabin (or counterweight) and the damper, the study in [11] had to rely on the elevator's kinematic system for calculation, which would be difficult in the installation and adjustment operation problem due to insufficient data.

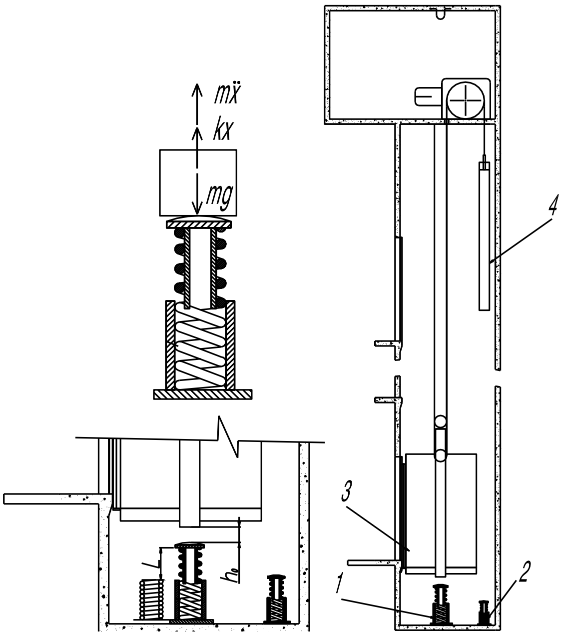

Fig 1. General description of the elevator shock absorber system: 1. The shock absorber for the cabin; 2. The shock absorber for the counterweight; 3. Cabin; 4. Counterweight.

Fig 1 shows a general arrangement of shock absorbers in an elevator. In actual installation, the distance from the cabin to the shock absorber at the bottom position h_o is usually adjusted to ensure that the cabin does not come into contact with the shock absorber during normal operation, but still provides sufficient clearance for the shock absorber to function safely in abnormal situations. The parameter ho directly affects the impact energy and braking acceleration level. Based on the analysis of the aforementioned studies, research into methods for determining this distance is necessary. This paper will investigate a calculation method that does not rely on the elevator kinematic system, with constraints based on standards such as EN 81/TCVN 6396. This determination method allows for quick verification for initial design and adjustment.

Therefore, this paper will present the basis for determining the initial distance between the cabin and the shock absorber based on the energy principle, the constraints on the distance between the cabin and the shock absorber, the results, and a discussion. An experimental example to demonstrate the method will provide a dataset for application in elevator calibration. The calculation method in this paper can be applied to counterweight shock absorbers or other similar devices, and can also be extended to study other types of shock absorbers.

II. METHOD FOR DETERMINING THE INITIAL DISTANCE BETWEEN THE CABIN AND THE SHOCK ABSORBER

A. Initial distance between the cabin and the shock absorber based on energy principle

Let vo be the velocity when the cabin begins to collide with the shock absorber at coordinate x = 0. When the cabin comes to a complete stop, it will have traveled a distance x = s, at which point the velocity v = 0.

Energy at the initial position:

$$E_A = \frac{mv_0^2}{2} \tag{1}$$

Where m is the mass of the cabin and other moving parts, and vo is the velocity of the impact with the shock absorber.

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Work done by gravity in the compressed shock absorber sections:

$$W_s = mgs \tag{2}$$

Where s is the damping stroke, and g is the acceleration due to gravity.

In the general case applicable to all types of shock absorbers, the work dissipated by a shock absorber with a stroke s and the force of the shock absorber F_{gc} is:

$$W_{gc} = \int_0^s F_{gc}(x,\dot{x})dx \tag{3}$$

According to the law of conservation of energy, the total energy will equal the work done by the shock absorber force.

$$\frac{mv_0^2}{2} + mgs = \int_0^s F_{gc}(x,\dot{x})dx \tag{4}$$

In this case, v_o represents the impact velocity when falling through the initial distance between the cabin and the shock absorber ho in the event of an accident such as brake failure, failure of the safety brake, or cable detachment. Consider the problem of the cabin falling freely through the distance h_o:

$$v_0 = \sqrt{v^2 + 2gh_o} \tag{5}$$

Where v is the cabin's speed at a standstill in case of an emergency, for safety reasons, it can be considered the rated speed.

In the case where the shock absorber is a spring, the shock absorber force is $F_{gc} = kx$, substituting (5) into (4) we have:

$$\int_0^s F_{gc}(x,\dot{x})dx = \frac{ks^2}{2}; \frac{m(v^2 + 2gh_o)}{2} + mgs = \frac{ks^2}{2} \tag{6}$$

Where k is the spring stiffness, from (6) we deduce the distance h_0 according to the elevator and shock absorber parameters as:

$$h_o = \frac{ks^2 - 2mgs}{2mg} - \frac{v^2}{2g} \qquad (7)$$

B. *Constraints on the distance between the cabin and the shock absorber.*

The minimum initial distance between the cabin and the shock absorber must be determined so that the cabin does not come into contact with the shock absorber under normal operating conditions, while still ensuring safety requirements are met in the event of a collision. This minimum distance value depends on many factors such as floor stopping error, cable elongation, thermal effects, and installation tolerances…

$$h_o > h_o^{\min} = h_{dt} + h_\delta + h_T + h_{ld} \qquad (8)$$

Floor stopping error according to TCVN 6396-20/ EN 81-20 [4] is usually h_{dt} ≤10mm.

The elongation of the cable h_δ can be determined by the basic formula of strength of materials [8]:

$$h_\delta = \frac{mgH}{nEA} \qquad (9)$$

Where H is the cable length, E is the elastic modulus of steel, A is the cross-sectional area of the steel cable, and n is the number of steel cable strands.

The thermal expansion deviation h_T can be approximately determined by the basic formula [8]:

$$h_T = \alpha H \Delta T \qquad (10)$$

Where α is the coefficient of thermal expansion, with $\alpha = 12.10^{-6}$ for steel, and ΔT is the temperature difference.

The initial distance between the cabin and the shock absorber must be the maximum possible value, h_o^{max}, provided that the allowable acceleration condition is met. Necessary conditions:

$$h_o \le h_o^{\max} = f([a]) \qquad (11)$$

According to the requirements of EN 81-20:2014/TCVN 6396-20:2017 [4], [5] the allowable acceleration [a] has a constraint of average acceleration of 1g, maximum instantaneous acceleration of 6g, which must basically be less than 2.5g; if it exceeds 2.5g, then it must be less than 0.04 s.

For example, with a spring shock absorber, the braking acceleration can be derived from Newton's law:

$$m\ddot{x} = mg - kx \qquad (12)$$

Where a is the braking acceleration $a = \ddot{x}$, condition $a \le [a]$, and shock absorber travel $s \le L$. From (12), we have the condition to choose the shock absorber travel L according to the allowable acceleration.

$$L = \frac{m(\text{g-}[a])}{k} \qquad (13)$$

Substituting (13) into (7), we get the initial distance between the cabin and the shock absorber according to the acceleration condition.

$$h_0^{[a]} = \frac{m([a]+g)^2}{2gk} - \frac{m([a]+g)}{k} - \frac{v^2}{2g} \qquad (14)$$

Therefore, the initial distance between the cabin and the shock absorber at the lowest position for initial design and adjustment purposes is:

$$\begin{cases} h_o^{\min} \le h_o \le h_o^{\max}; \Delta h_0 = h_o^{\max} - h_o^{\min} \\ h_o^{\max} = \min\begin{pmatrix} \dfrac{m(\text{g-}[a])^2}{2gk} - \dfrac{m(\text{g-}[a])}{k} - \dfrac{v^2}{2g}; \\ \dfrac{kL^2 - 2mgL}{2mg} - \dfrac{v^2}{2g} \end{pmatrix} \end{cases} \qquad (15)$$

III.RESULTS AND DISCUSSION

Based on the technical characteristics of the elevator, we determine the minimum distance value. The shock absorber parameters, such as spring stiffness k and travel L, are based on the standard shock absorber installed for the elevator. In another case, the allowable acceleration [a] = 2.5g [4], [5] from (13) can be referred to as Fig 2. The determination of the minimum and maximum distance values according to the travel condition is given by (15). The initial correction value must be within the range $h_o^{\min} \le h_o \le h_o^{\max}$

Table 1. Given parameters

Parameter	*Symbol*	*Value*	*Unit*
Stopping error	h_{dt}	10	mm
Installation error	h_{ld}	10	mm
Coefficient of thermal expansion	α	12.10^{-6}	
Temperature difference	ΔT	20	^{0}C
Permissible acceleration	[a]	- 25	m/s^2
Gravitational acceleration	g	9.81	m/s^2
Elastic modulus of steel	E	210000	N/mm^2

For example, a test with an elevator has a cabin mass and load m = 1200 kg, maximum cabin cable length H = 36 m, rated speed v = 1 m/s, cable diameter d = 12 mm, and number of cables n = 4. The given parameters are shown in Table 1. The shock absorber travel and spring stiffness according to the allowable acceleration are shown in Fig. 2. The damping travel requires increased spring stiffness; the graph serves as a reference in case the manufacturer does not provide sufficient calculation data.

.Substituting the numbers into (9), (10), we have: h_δ = 4.46 mm; h_T = 8.64 mm, and $h_o^{\min}$ = 33.1 mm.

Fig 3 shows the maximum distance between the cabin and the shock absorber that needs to be adjusted according to the travel conditions. The larger the travel of the selected shock absorber, the larger the allowable distance h_0^{max}. From Fig 2 and Fig 3, (14) gives us the following results:

According to the maximum travel condition, with shock absorber L = 700 mm and k = 6.104 N/m, h_0^{max} = 500 mm, and according to the allowable acceleration condition, h0max = 497.8 mm. The distance correction values will be:

$$33.1mm \le h_o \le 497.8mm; \Delta h_0 = 464.7mm$$

and according to the allowable acceleration conditions, h_0^{max} = 419.4 mm. The distance correction values will be:

$$33.1mm \le h_o \le 260mm; \Delta h_0 = 226.9mm$$

Reducing the maximum travel of the shock absorber will lead to an increase in the damping force; if it's a spring shock

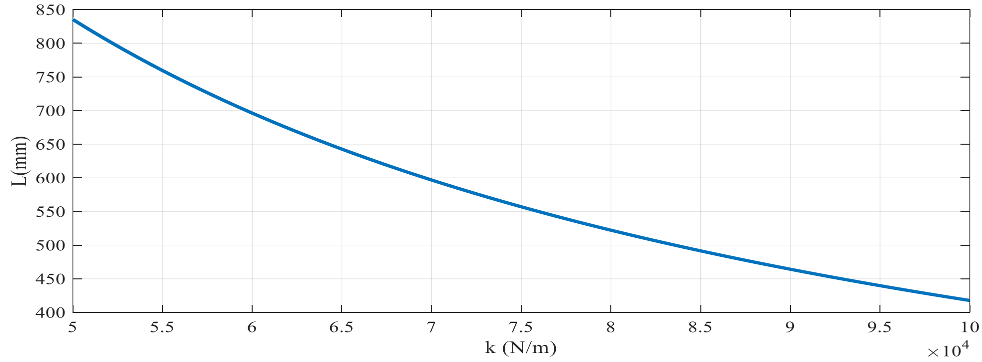

Fig 2. Maximum shock absorber travel and spring stiffness

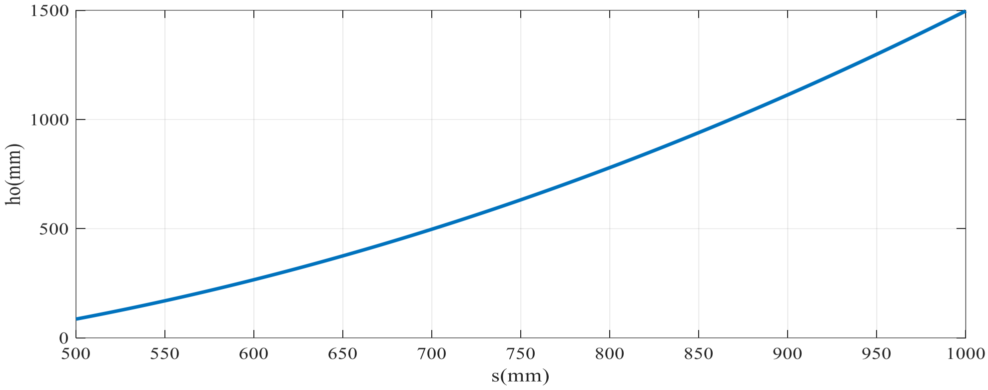

Fig 3. The maximum adjustment distance depends on the shock absorber travel.

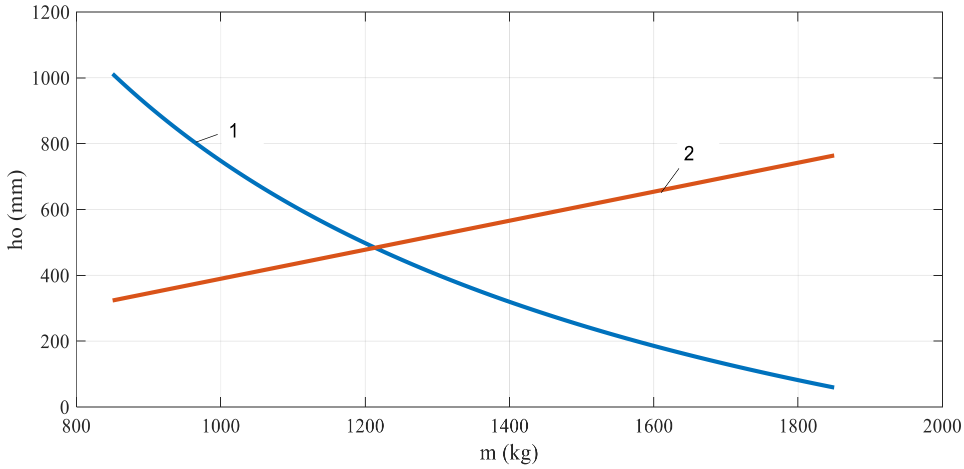

Fig 4. The maximum adjustment distance h_o depends on cabin and passenger mass: 1. Graph according to maximum travel conditions; 2. Graph according to allowable acceleration.

According to the maximum travel conditions, the result with damping L = 600 mm, k = 7.104 N/m, h_0^{max} = 260 mm, absorber, then the stiffness and wire diameter will be larger. Therefore, for large elevators with high-rated speeds, using spring shock absorbers is unsuitable.

Typically, one type of shock absorber can be installed in many types of elevators with different technical characteristics. Fig 4 shows the survey of the maximum adjustment distance between the cabin and the shock absorber with the cabin and passenger weight under the allowable travel and acceleration conditions, m = (850 ÷ 1850) kg. The survey data is with a spring shock absorber L = 700 mm, k = 6.10^4 N/m.

IV. CONCLUSIONS

This paper presents a method for determining the initial distance between the shock absorber and the elevator cabin at the lowest position. The paper develops a method for determining this distance based on the energy principle, with safety constraints based on current elevator industry standards such as TCVN 6396-20:2017/EN 81-20:2014. A test example provides a specific dataset applicable to elevator calibration for a cabin and occupant weight of 1200 kg, a speed of 1 m/s, and a lifting height of 36 m. With a spring damper having a stiffness coefficient of 6.104 N/m and a maximum travel of 700 mm, the initial distance between the damper and the elevator cabin at the lowest position is 33.1 mm ≤ h_o ≤ 497.8 mm, Δh_o = 464.7 mm. The selected shock absorber specifications can be used for elevators with a total cabin and passenger weight of less than 1800 kg; however, the optimal (Δh_o is maximum) adjustment value is 1210 kg.

The calculation method in this paper can be applied to counterweight dampers or other similar devices. In our initial numerical tests, we only applied it to spring dampers; in subsequent studies, we will expand the research to include hydraulic dampers as well as other technical characteristics.

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