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Effect of operating conditions on vehicle braking efficiency Part 1: Effect of vehicle braking speed

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ABSTRACT: *The purpose of this paper is to study the effect of operating conditions on vehicle braking efficiency. In order to investigate the effects, a longitudinal dynamic model of the vehicle is proposed during braking on a flat road surface. The indicators such as braking distance and braking time are selected to investigate the effect of vehicle operating conditions on braking efficiency. The investigation results indicate that the operating conditions such as adhesion coefficients of road surface, vehicle braking speed have a great effect on vehicle braking efficiency, especially when the vehicle brakes on the road surfaces with low adhesion coefficients, and vehicle braking high speeds.*

KEYWORDS: *Braking system, Braking force, Operating condition, Braking efficiency*

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I. INTRODUCTION

The automobile industry is growing day by day, every year tens of millions of vehicles of all kinds are produced, put on the market and circulated all over the world. In Vietnam, there are many companies such as Toyota, Mazda, Honda, Hyundai, Mercedes.... constantly launch new generation models with diverse types, improved comfort and demand for buying vehicles. of the Vietnamese people more and more. Like other countries in the world, Vietnam is facing an increasing number of traffic accidents, causing great loss of life and property. And vehicle-related accidents account for no small part. In which, about 70% of accidents are due to subjective causes, the rest is due to the technical system. Therefore, it is extremely necessary to promote research and development activities on automobile systems to improve vehicle safety. In particular, the brake system on a vehicle is an extremely important system in ensuring movement safety and increasing the efficiency of vehicle operation.

Given the economic importance of the automobile industry and its impact on modern society, much research has focused on improving vehicle performance [1]. The brake system is essential to operating the vehicle in safe conditions for both the driver and other road users. As a result, the brakes are sent to tight legal conditions. The efficiency and reliability required for braking systems over time have implied their continual improvement [2]. The process of vehicle braking is to create frictional force for the purpose of reducing the movement of the vehicle until the vehicle stops. To evaluate the braking system, four criteria are used to evaluate the braking efficiency, which are deceleration when braking, braking time, braking distance and braking force or specific braking force. The development of the system should be based on this experience, so as not to repeat the same weaknesses in the structure of the system, and strive to achieve comprehensive quality and reliability [3]. Continuous improvement is needed to achieve a high-performance braking system that ensures safe and stable braking at any speed. One such improvement to the system brakes, is the addition of ferrite magnets to the disc brakes, to increase the vehicle's stopping force. As such, both mileage and braking time are significantly reduced, for smooth and stable braking at high speeds [4]. The occurrence of squealing and other phenomena in the brake system can be reduced by reducing the coefficient of friction, but with its reduction, the performance of the brake system decreases [5]. In addition to influencing factors such as the structure of the brake system, during braking, the kinetic energy of the vehicle will convert a part to generate heat. At that time, the temperature of the friction brake mechanism components increases, which can lead to deformation or cracking of the disc, decrease in the coefficient of friction between the brake pad and the brake disc, evaporation of brake fluid, abrasion of the working surface. ,... all lead to a decrease in the efficiency of the vehicle's brakes. Nikit Gupta et al [6] studied, analyzed the heat distribution in different regions as well as changed the brake disc materials and used ANSYS software to analyze with different brake disc surfaces. Choi and Lee [7] used the finite element method to analyze the thermal expansion in the disc brake system, the process of analyzing the thermal expansion problem when connecting between the components of the disc brake structure when the temperature is high. caused by friction. Aleksander A. Yevtushenko et al. [8] also used the finite element method to find a solution for the thermodynamic balance of friction and wear for materials used to fabricate cheeks. disc brake. From there, determine the change in braking time, friction coefficient, braking torque, engine speed, average temperature in the area of brake pads in contact with brake discs and wear due to surface friction.

Therefore, to ensure the safe operation of the vehicle, one of the requirements is the quality of the braking process to ensure the highest efficiency. The quality of the braking process is expressed through the criteria such as the braking distance, the braking time,… and the directional stability of the vehicle when braking. The main goal of this paper is to investigate the effect of the braking initial speeds of vehicle with the different adhesion coefficients on braking efficiency, a longitudinal dynamic model of the vehicle is proposed during braking on a flat road surface. The indicators such as braking distance and braking time are selected to investigate the effects.

II. VEHICLE LONGITUDINAL DYNAMIC MODEL

The process of vehicle braking is to create frictional force for the purpose of reducing the movement of the vehicle until the vehicle stops. To investigate vehicle braking efficiency, a longitudinal dynamic model of vehicle is established when the vehicle brakes on a flat road surface, as shown in Figure 1.

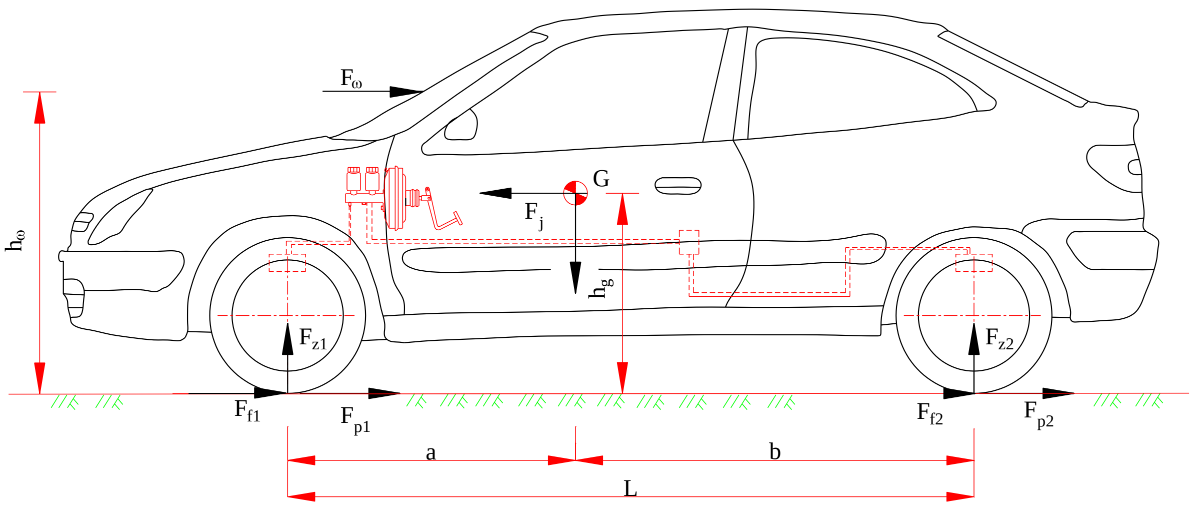

Fig 1. Dynamic model of the vehicle when braking

Interpretation of symbols on Figure 1, G is the vehicle weight; F_{p1}, F_{p2} are the braking forces at the front and rear wheels, respectively; F_ω is the air resistance force; F_j is the inertia force during braking; F_{z1}, F_{z2} are the vertical reaction forces of road surface on the wheels, respectively; a,b, and L are the distances, respectively and h_ω, h_g are the heights, respectively.

Based on Figure 1, total longitudinal braking force could be determined by the following formula

$$F_p=F_{p1}+F_{p2} \quad (1)$$

The total longitudinal braking maximum force is obtained as below

$$F_p=\varphi.G \quad (2)$$

where, φ is adhesion coefficient of road surface.

Total rolling resistance force of vehicle could be determined by the following formula

$$F_f = F_{f1}+F_{f2} = f.G \quad (3)$$

where, f is rolling resistance coefficient.

The air resistance force could be determined by the following formula

$$F_\omega=KFv^2 \quad (4)$$

where, K is the coefficient of air resistance; F is the front bumper area of the vehicle; v is the relative velocity of movement between vehicle and longitudinal wind during braking

The force of inertia could be determined by the following formula

$$F_j = \delta_i \frac{G}{g}\frac{dv}{dt} \quad (5)$$

where, δ_i is the coefficient taking into account the influence of the rotating mass on the vehicle; t is the braking time; g is the acceleration due to gravity.

The longitudinal force balance equation of vehicle could be determined by the following formula

$$F_j=F_p+F_w+F_f \quad (6)$$

If the values of forces F_f, F_ω, F_i are small, it could be neglected. Eq. (6) could become below

$$F_j=F_p \quad (7)$$

Combining Eq. (2) with Eq.(5), Eq. (6) could become below

$$\delta_i \frac{G}{g}.\frac{dv}{dt} = \varphi.G \tag{8}$$

From Eq.(8), the deceleration of acceleration during braking could be determined by the following

$$J_p = \frac{dv}{dt} = \frac{\varphi.g}{\delta_i} \tag{9}$$

From Eq.(9), the braking time is determined by Eq.(11)

$$t_p = \int dt = \int_{v_2}^{v_1} \frac{\delta_i}{\varphi.g} dv \tag{10}$$

$$\Rightarrow \quad t_p = \frac{\delta_i}{\varphi.g}(v_1 - v_2) \tag{11}$$

where, v_1 is the initial speed of the braking process, v_2 is the speed of the end of the braking process.

The braking time when the vehicle comes to a complete stop, v_2=0, Eq. (11) could become below

$$t_p = \frac{\delta_i}{\varphi.g} v_1 \tag{12}$$

From Eq.(9), multiplying boths sides of an equation by ds

$$\frac{dv}{dt} ds = \frac{\varphi.g}{\delta} ds \Rightarrow vdv = \frac{\varphi.g}{\delta} ds$$

$$\Rightarrow \quad ds = \frac{\delta}{\varphi.g} vdv \tag{12}$$

The braking distance is determined by Eq.(13).

$$s_p = \int ds = \int_{v_2}^{v_1} \frac{\delta}{\varphi.g} vdv = \frac{\delta}{2\varphi.g}\left(v_1^2 - v_2^2\right) \tag{13}$$

The braking time when the vehicle comes to a complete stop, v_2=0, Eq. (13) could become below

$$s_p = \frac{\delta}{2\varphi.g} v_1^2 \tag{14}$$

From the above expression, we see that the minimum braking distance also depends on the speed of the vehicle, depends on the coefficient of traction and the factor taking into account the influence of the rotating masses, so the braking distance will be decrease when disengaging the clutch and then braking. The coefficient of traction depends on the load of the vehicle. As the load increases, the coefficient of tractionwill decrease, then the braking distance will increase. Therefore, the braking distance of different types will be different even though the initial braking speed is the same. We consider the effect of the initial speed when braking at different coefficients of traction on the minimum braking distance.

III. RESULTS AND DISCUSSION

In order to investigate the effect of vehicle operating conditions on braking efficiency**,** the braking initial speeds of vehicle such as v_1=[2.78 5.55 8.33 11.11 13.89 16.67 19.44 22.22] m/s is selected to investigate the its effect on braking efficiency with the different adhesion coefficients of road surface φ=[0.3 0.4 0.5 0.6 0.7 0.8]. The effect of the braking initial speeds of vehicle with the different adhesion coefficients on braking time is shown Figure 2.

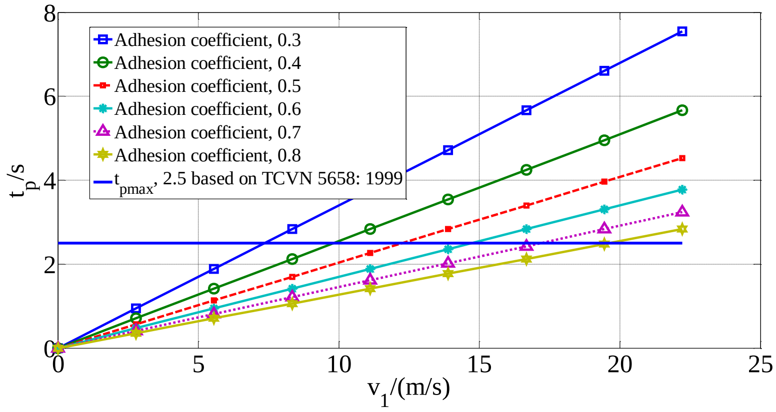

Fig 2. The effect of the braking initial speeds of vehicle with the different adhesion coefficients on braking time

From the results on Figure 2, we show that the value of the braking initial speeds of vehicle increases, the braking time increases very quickly, especially, when the vehicle brakes at the low adhesion coefficients of the road surface φ≤0.4 and the high braking speeds $v_1 \geq 20$m/s. Thus, in order to achieve the minimum braking time on roads at low adhesion coefficients, it is necessary to reduce vehicle speed when braking. The limited braking time according to Vietnamese standard TCVN 5658: 1999 [9], $t_p \leq 2.5$s, the range of values $t_p \geq 2.5$s, the operating conditions do not satisfy good braking performance.

The effect of the braking initial speeds of vehicle with the different adhesion coefficients on braking distance is shown Figure 2.

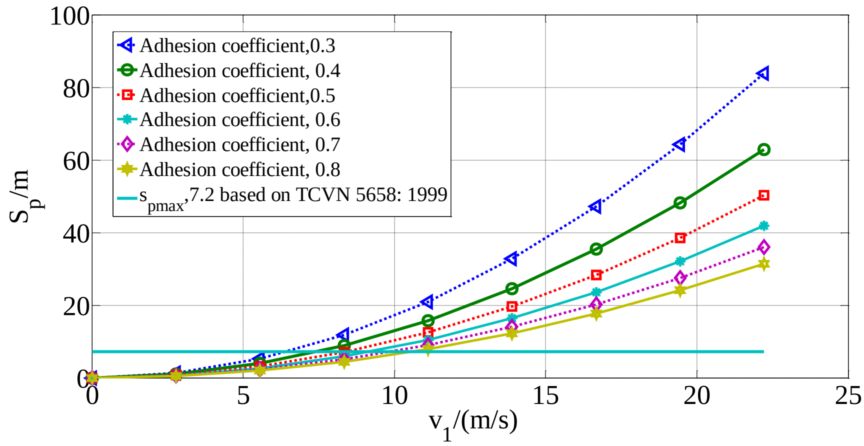

Fig 3. Effect of the braking initial speeds of vehicle with the different adhesion coefficients on braking distance

From the results on Figure 3, we show that the value of the braking initial speeds of vehicle increases, the braking distance increases very quickly, especially, when the vehicle brakes at the low adhesion coefficients of the road surface φ≤0.4 and the high braking speeds $v_1 \geq 15$m/s. Thus, in order to achieve the minimum braking distance on roads at low adhesion coefficients, it is necessary to reduce vehicle speed when braking. The limited braking distance according to Vietnamese standard TCVN 5658: 1999 [9], $s_p \leq 7.2$m, the range of values $s_p \geq 7.2$m, the operating conditions do not satisfy good braking performance.

IV. CONCLUSION

In this study, in order to investigate the effect of the braking initial speeds of vehicle with the different adhesion coefficients on braking efficiency. A longitudinal dynamic model of vehicle was established when the vehicle brakes on a flat road surface. Some conclusions drawn from the investigation results: (i) The value of the braking initial speeds of vehicle increases, the braking time increases very quickly; (i) The value of the braking initial speeds of vehicle increases, the braking distance increases very quickly, especially when the vehicle brakes on the road surfaces with low adhesion coefficients, and vehicle braking high speeds. Therefore, in order to ensure effective braking of vehicles during traffic on different types of roads and loads, there should be appropriate maximum speed regulations.

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