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# Modeling and Performance Testing of Anti-Lock Braking System (ABS) with Variation of Road Friction Coefficient to Braking Distance

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## ABSTRACT
*Automated vehicles are increasingly being researched and developed to reduce accident rates. The braking system is an integral part of the safety factor in the vehicle. One of the development systems in braking on vehicles is the Anti-lock Braking System (ABS). ABS is a vehicle b that prevents the wheels from locking during sudden braking. The research was conducted by modelling and designing the ABS braking system using SIMULINK software on MATLAB. This research was conducted by varying the coefficient of braking friction on dry asphalt, wet asphalt, dry soil, and wet soil by paying attention to the braking distance. In the first test, the first test of the non-ABS system sets 0.9. The results were obtained with the shortest braking distance of 20 meters and the farthest, 34.5 meters. As for the results with ABS, the shortest braking distance is 17.95 meters, and the farthest is 27 meters. From the analysis that has been done, it is found that the ABS is better than the non-ABS system. This is because ABS regulates the braking calliper and is adjusted to the vehicle's dynamics instead of statically.*

***Key words** : modelling, braking distance, coefficient of friction, calliper, automatic vehicles*

## INTRODUCTION

One of the focuses of the development of automatic vehicles is the level of safety because most accidents are dominated by human error or unruly drivers (Sam et al., 2016). In Indonesia, accidents are caused mainly by human factors (Herawati, 2019), (Saputra, 2018). The development of automatic vehicles uses a lot of electric vehicles; besides being more environmentally friendly, energy efficiency and the required energy costs are much more affordable (Patriawan & Putra, 2021). Under development by the Society of Automotive Engineers (SAE), automatic vehicles have five levels of automation (Shi et al., 2020). The tiers start at the level that which current vehicle requires. At the same time, it requires a fully automatic vehicle without the need for human intervention as a controller (Szikora & Madarasz, 2017).

Automated vehicle development can be very complicated because it requires many sensors, fast communication transmission systems and precise navigation (Patriawan, Natakusuma, et al., 2021), image processing and massive computational calculations (Rasheed et al., 2020). In terms of vehicle dynamics, a good steering system is also needed (Setyono et al., 2019), an Active suspension that can support vehicle handling with driving comfort (Patriawan, Irawan, et al., 2021), a strong and light frame (Prasetyo et al., 2020), comfortable and safe braking system. The target of this research is to be able to build automatic vehicles, but the current focus is to develop the braking system.

The development of the braking system can start with the materials used. Material with bamboo fibre composite (Purboputro, 2016) and teak wood powder (Purboputro, 2020) can be a choice of materials and materials in making brake pads. The development of natural materials, in this case bamboo fiber and sawdust, has the feature of being more environmentally friendly and non-toxic. Anti-lock Breaking System (ABS) is one of the safety standards of the current braking system. The system is straightforward here. This braking does not allow the wheels to lock while the vehicle is still moving.

The development of the ABS braking system has

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been widely carried out, among others, by adding a solenoid vibrator component to produce 10 Hz when braking (Zakaria et al., 2018). The research is interesting, but closing the callipers every 10 Hz or every 0.1 seconds is still considered slow if the vehicle travels at high speed. In addition, if the system is only constant by closing the callipers every 0.1 seconds, the braking distance can be far even when the vehicle is moving slowly. The improvement of the 10 Hz vibrator solenoid system is that it can add a control system. With the addition of a solenoid control system, the vibrator is not only statically functioning at 10 Hz. However, it can adjust each frequency by comparing the vehicle's speed with the wheels. Proportional-integral-derivative (PID) control can be applied to ABS systems (Alaboodi et al., 2019).

ABS braking system can be designed by modelling with Matlab. Modelling will make it easier to design the ABS braking system. In addition to making it easier to design the ABS system, modeling and simulation are also a safer way before the results of the ABS system design are tested in the real world. In addition to the design in Matlab, it can also be used to analyze the ABS braking system. Adding a control system to ABS braking improves results, especially with the PID controller (Pradeep Rohilla et al., 2016). In addition to using a PID controller, fuzzy logic and multiple-model switching controllers can also be used as ABS breaking controllers (Dousti et al., 2015; Mauer, 1995).

## RESEARCH METHOD

The method used is to design an ABS with MATLAB. This modelling will be varied with the road conditions. This modelling will be varied with road conditions. The effectiveness of the control system design can be observed under different road conditions. The observed effectiveness is how far the braking distance is with variations in road conditions and comparing the system that is given a control system and that which is not. Braking distance which is a parameter of the quality of the ABS braking system design. Several parameters that can be observed to obtain breaking distance are temperature, slip ratio and pavement surface characteristics (Tang et al., 2017) The first part of modelling the braking system is to create data specifications for the type of vehicle used. Vehicle specification data can be seen in Table 1. Apart from the specification data in table 1, the modelled vehicle is filled with four passengers. The presence of passengers causes a shift in the vehicle's centre of gravity. The following process is to find a calculation to get the centre of gravity in the vehicle by adding four passengers. Figure 1 shows the free body diagram of the vehicle.

Table 1. Vehicle specification data

| Part of Vehicle | Dimension |
|---|---|
| Total Weight | 2005.5 kg |
| Front Weight | 1031 kg |
| Rear Weight | 834.5 kg |
| Brake Pedal Distance to Pedestal | 0.18 m |
| Push Rod Distance to Pedestal | 0.04 m |
| Calliper Piston Diameter | 0.05 m |
| Disc Brake Diameter | 0.26 m |
| Master Cylinder Inner Diameter | 0.02 m |
| Wheel Diameter | 0.432 m |

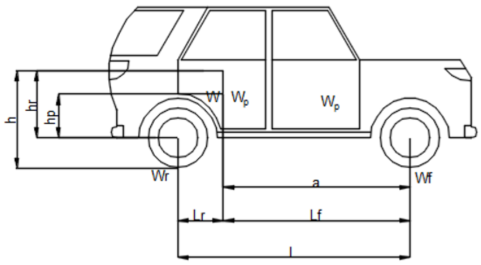


Figure 1. Free body diagram of the vehicle

Where $W$ is the net weight of the vehicle in newtons (N), $Wr$ is the weight of the rear vehicle (N), $Wf$ is the weight of the front of the vehicle (and N), $Wp$ is the weight of the passenger (N), $L$ is the length of the vehicle in meters (m), $Lf$ is the distance from the front wheelbase to the centre of gravity (COG) (m), $Lr$ is the distance from the rear axle to the centre of gravity (m). Distance from the passenger's centre of gravity to the front axle (m), $h$ is the centre height concerning the ground without passengers in (m), and he is the centre of height on the rear axle without passengers (m). The distance from the centre of gravity of the cross-section to the wheel axis so(m). So the equation for the wheelbase with COG becomes

$$Lf_1 = \frac{Wp.a + W.Lf}{Wt} \dots\dots\dots\dots\dots.(1)$$

There are three kinds of variations in the coefficient of friction used, namely: tire material with cast iron $\mu_1 = 0.2$, with wood $\mu_2 = 0.3$, sintered alloy $\mu_3 = 0.5$, and mould material $\mu_4 = 0.6$. The four friction coefficient variations are used to compare the performance of the ABS braking system. In addition, variations in the coefficient of friction are also used to test a control system's ability. This study did not include a vehicle suspension system, because it is considered an ideal vehicle suspension system. However, the suspension system on the vehicle also affects the dynamics of the vehicle, especially the vibrations that occur in the vehicle (Patriawan, Ulum, et al., 2021). Friction in braking occurs when the driver steps on the brake pedal. Assuming the driving force of the driver one$F_1$) is 242.5 newtons. So that the force obtained from stepping on the brake pedal can be calculated by

$$F_k = F_1 \left(\frac{a}{b}\right) \ldots\ldots\ldots\ldots\ldots (2)$$

Where $F_k$ is the force of the brake pedal, $a$ is the pedal length distance, and $b$ is the distance from the pedestal to the rest of the pedal length. In simple terms, the braking force can be seen in Figure 2.

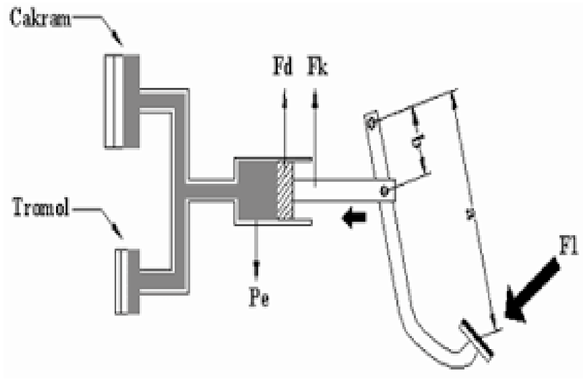


Figure 2. The braking system on the pedal

The result of equation (2) is entered into the equation to get the pressure obtained in the hydraulic master cylinder. The equation is as follows :

$$P_e = \frac{F_k}{0.25 \times \pi \times d^2} \ldots\ldots\ldots\ldots.. (3)$$

Where $P_e$ master cylinder hydraulic pressure, $d$ is the diameter of the brake piston. The pressure on the calliper is caused by the hydraulic master cylinder, which provides thrust on the brake pads. This pressure causes friction between the pad and the brake. So that the $P_e$ equation can calculate the force on the calliper (Fp):

$$F_p = P_e \times 0.25 \times \pi \times d^2 \ldots\ldots\ldots\ldots\ldots. (4)$$

The force on the calliper is converted into the frictional force between the brake lining and the disc brake. Calculation of the friction force ($F_{bf}$) is

$$F_{bf} = \mu \times F_p \ldots\ldots\ldots\ldots\ldots.. (5)$$

Where $\mu$ is the coefficient of friction between the disc brake and the brake pads, after $F_{bf}$ is obtained, the following is to find the braking torque. The braking torque following with R is the radius of the disc brake, and $r$ is the calliper piston radius.

$$T = F_{bf} \times (R - r) \ldots\ldots\ldots\ldots\ldots. (6)$$

Modelling is done to find out how the slip occurs first part is to find the vehicle's speed concerning the wheel's radius ($\omega_v$). The equation can obtain the speed of the vehicle concerning the radius of the wheel:

$$\omega_v = \frac{V}{R} \ldots\ldots\ldots\ldots\ldots\ldots.. (7)$$

$V$ is the vehicle's linear speed, and $R$ is the wheel radius. If the wheel's angular velocity is $\omega_w$, the equation for slipping can be obtained as follows.

$$slip = 1 - \frac{\omega_v}{\omega_w} \ldots\ldots\ldots\ldots\ldots. (8)$$

From equation (8), it is shown that the slip value should not be one or the value is too small. If the slip value is one, the wheels on the vehicle will be locked; if the slip value is too small, the vehicle will not stop immediately. The following section determines the parameters of the modelling in Matlab. Parameter determination can be seen in Table 2.

Table 2. Simulation parameters

| Vehicle Parameters | Value |
|---|---|
| Vehicle Mass (m) | 2005.5 kg |
| Moment of Inertia ($I_R$) | 76,49 kg.$m^2$ |
| Gravity Constant (g) | 9,81 m/$s^2$ |
| Braking Torque (T) | Varied |
| Vehicle Speed (V) | 100 km/h |
| Slip Value (λ) | 0.2 |

There are five parameters modelled in this study. The torque generated from braking is varied to test the control system on braking. ABS Modelling the vehicle while performing and braking has the same approach. Three factors affect the vehicle when accelerating or braking. These factors include the coefficient ($C_{of\ drag\ (R\_a)}$), the coefficient of friction on the front wheel ($C_{s\ (R\_rf)}$) and the coefficient of friction on the rear wheel ($C_{s\ (R\_rr}$). In simple terms, the free body diagram (FBD) of the vehicle when experiencing acceleration or braking can be seen in Figure 3

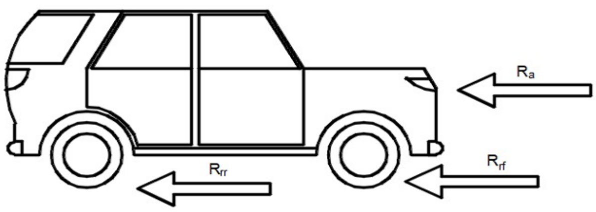


Figure 3. FBD braking on vehicles

The following process is to do the modelling by utilizing the Simulink feature in Matlab. The parameters that have been determined are then assembled in a braking system. The results of connecting parameters into modelling can be seen in Figure 4. The vehicle speed of 100 km/hour was used in the test. The shorter the braking distance, the better the braking system. In this ABS system modeling the braking caliper is only set to produce a predetermined slip ratio of 0.2. In the next development the braking process can fully use artificial intelligence to produce safe and comfortable braking (Lizamanihi et al., 2020; Rigas et al., 2014).

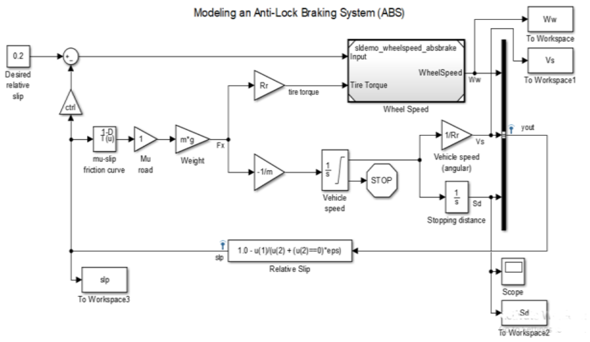


Figure 4. ABS Modelling in Matlab

## RESULTS AND DISCUSSIONS

The test is carried out when the vehicle travels 100 km/hour. After the vehicle reaches 100 km / h, the delivery begins. The first test was carried out on asphalt roads in dry conditions. The results of the test can be seen in Figure 5

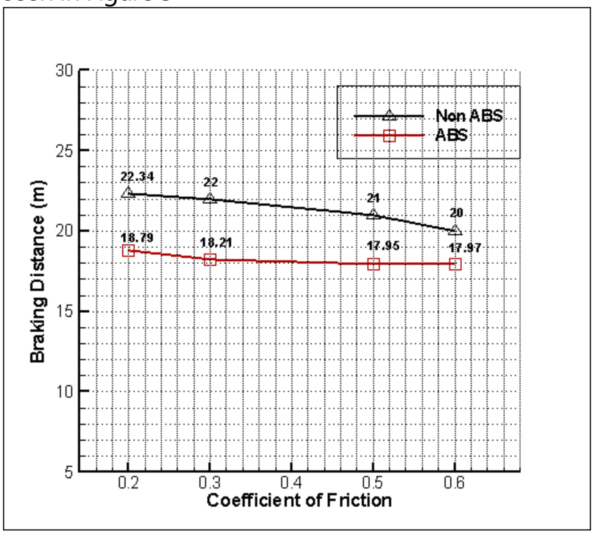


Figure 5. Braking test on dry asphalt

Figure 5 shows that braking with ABS has a shorter braking distance if the braking conditions are ideal, like the first test where the dry asphalt condition should be non-ABS having a short braking distance. A moment when there is a slip increases the vehicle's braking distance. When the friction coefficient is added of inertia may occur in the braking system, it hardly affects the ABS, while non-ABS shortens the braking distance.

The second test was carried out when the asphalt road was wet. The variation of the braking friction coefficient is still the same, namely 0.2, 0.3, 0.5, and 0.6. In this test, it can be seen that the average braking distance is longer than the dry asphalt condition. The complete results can be seen in Figure 6. Testing on wet asphalt adds to the difference in braking distance between ABS and non-ABS. When the asphalt is dry, the shortest difference is 2.03 meters in braking. While in wet conditions, the difference in braking distance is 3.97 meters.

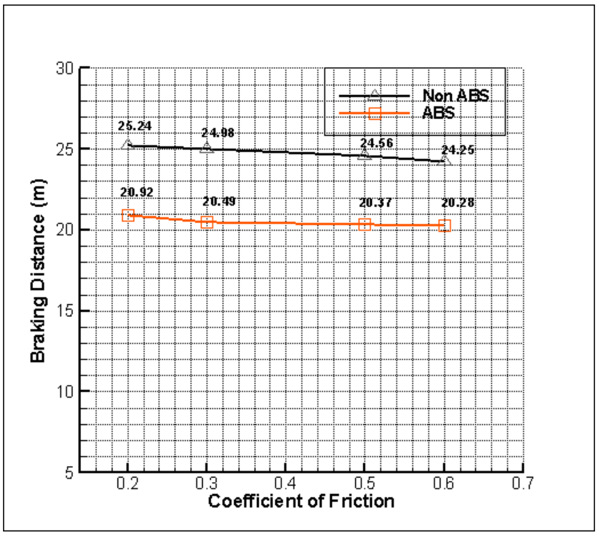


Figure 6. Braking test on wet asphalt

The test results in Figure 6 show that both types of braking experience an increase in distance. In non-ABS, the addition of the average distance is 3.42 meters. While the ABS only increased by 2.29 meters. So ABS performs nos better than ABS and gets better when wet asphalt conditions. The next test is on the condition of the dirt road. This test is carried out to determine how the vehicle's braking distance is in non-ideal road conditions or when the vehicle is on the ground. This test is carried out with two scenarios, the first is dry dirt road conditions, and the second is wet dirt road conditions. The dry dirt road test can be seen

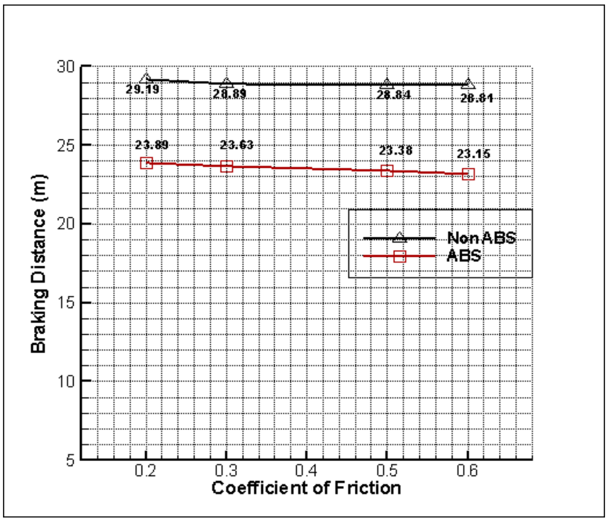


Figure 7. Testing of braking on dirt roads

In Figure 7, it can be seen that braking with ABS has a much better performance. The mileage required for the vehicle to stop at the best value for non-ABS is 28.81 meters, while the ABS only needs 23.15 meters. The difference in braking distance is 5.66 meters. The difference is even more sig when compared to wet asphalt conditions. In this case, using significant ABS when on a dirt road is beneficial in the braking process until the vehicle stops. The next test is a dirt road when the conditions are wet. Testing with an actual vehicle is unsafe, so it needs to be tested by modelling. Moreover, the vehicle was tested at a speed of 100 km / h. The test results on dirt roads with wet conditions can be seen in Figure 8.

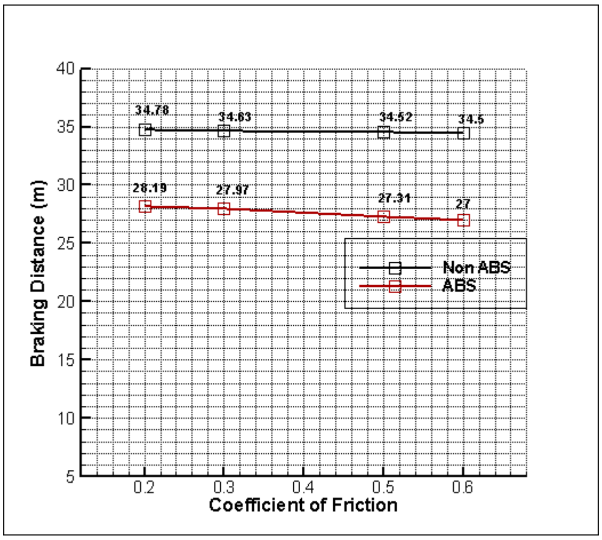


Figure 8. Testing of braking on wet dirt roads

Testing on wet dirt roads showed that braking with ABS further shortens the braking distance. The difference in braking distance with non-ABS is also getting further from the dirt road condition; the difference is 5.66 meters to 7.5 meters when the dirt road is wet. This test proves that ABS braking is a good choice for those who want to break with the shortest distance when road conditions are not ideal (dry asphalt).

## CONCLUSIONS

The test results found that the ABS braking system has the shortest distance compared to non-ABS. Testing on ideal conditions where the road with dry asphalt is still good with ABS with a distance difference of 2.03 meters. This difference is even more remarkable when testing dirt roads in wet conditions. The difference from the test was obtained at about 7.5 meters. The distance is quite far, almost one vehicle more. The initial estimation results of non-ABS braking will perform better under dry asphalt road conditions. However, the results obtained by ABS braking get the best results in each test. An intelligent braking system can be developed from the ABS, where each calliper can work independently according to the required needs.

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