Research Article

Technical Effectiveness of ABS, Non-ABS and CBS in Step-through Motorcycles

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Abstract
In Thailand, step-through motorcycles with engine sizes of 110 and 125 cc are very popular due to affordability and mobility. Fatalities of road accidents from such motorcycles are a very high proportion in comparison with other vehicles. Common accident scenarios from Thai motorcyclists are rear-ended and overtaking collisions. For these reasons, safety technologies in motorcycle brake systems are very significant to prevent road accidents for motorcyclists. However, there are various technologies that are affordable or available in the Thai market. Road safety assessment for motorcycles from the International Road Assessment Programme (IRAP) is also very poor in Thailand. To increase motorcyclists' awareness of such safety technologies, the brake performance of ABS, Non-ABS, and CBS in step-through motorcycles were conducted with different protocols under controlled hand brake force in UN Regulation R78 and accident scenarios in Thailand. Consequently, the experimental results reveal that under the condition of the high friction surface, the braking distance of ABS motorcycle is up to 9.7% longer than those from the motorcycle with Non-ABS and CBS. Conversely, under the condition of the low friction surface, the braking distance of CBS motorcycle is up to 26.5% extension from those of the motorcycle.

Keywords: Step-through motorcycle, Motorcycle braking test, ABS, CBS

1 Introduction

In Thailand 2018, there are 1,942,494 new motorcycles based on the statistic registration record from the department of land transport [1]. From 2009 to 2018, there are not less than 1,600,000 new motorcycles yearly on road in Thailand. Therefore, the proportion of deaths from the riders of motorized 2-and 3-wheelers increases from 73% to 74% from Global status report on road safety 2015 and 2018 by WHO [2], [3]. In 2018, WHO estimated and reported road traffic fatalities based on data in 2016, which are 22,491 and 21,745 respectively. Due to the compact dimension, a motorcycle is the highest mobility among other people transportation modes. The motorcycle can also easily speed up in comparison to passenger cars due to the higher power-to-weight ratio. For example, in an urban area with uncontrolled T-intersections, motorcycles travel approximately 10% faster than car mean speed of 34.97 km/h in New Zealand [4]. Elliott *et al*. reviewed that 80% of all motorcycle collisions were found in the front direction [5]. Therefore, a head-on collision is the leading cause of head injuries in motorcycles [6]. The brake system in a motorcycle is also the key to control

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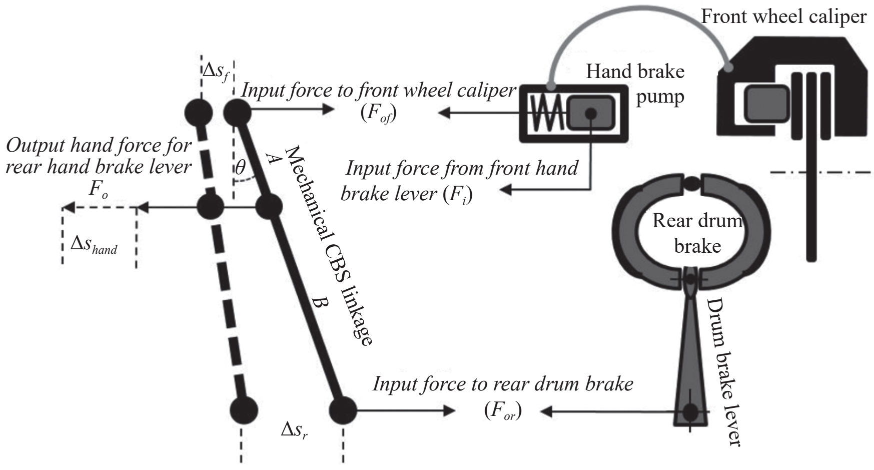

Figure 1: Schematic diagram of mechanical CBS in motorcycle.

the brake distance or the headway which can prevent the rear-end collision of the vehicle.

Typically, there are various available brake systems in a motorcycle e.g. Single Brake System (SBS), Combined Brake System (CBS) and Antilock Brake System (ABS). SBS means that a brake system applied on a single wheel can be actuated by a single control unit. CBS means that a brake system applied on all wheels can be actuated by a single control unit. CBS means that a brake system applied on all wheels can be actuated by a single control unit. The basic principle of budget CBS in the step-through motorcycle is based on mechanical linkage as shown in Figure 1. The output hand force (F_o) from the rear brake lever can generate the force (F_{of}) in the front wheel through the mechanical CBS linkage. F_{of} can be calculated from the geometry design of CBS linkage as shown in Equation (1). Therefore, the input forces to the hand brake pump in the front wheel consist of the output force from CBS (F_{of}) and the force from the front hand brake lever (F_i). However, the angle (θ) of mechanical CBS linkage is dependent on the wear or the adjustment of drum brake shoes. This causes the different strokes between the front hand brake pump (Δs_f) and drum brake lever (Δs_r) under the limited input stroke (Δs_{hand}) from the hand brake lever as shown in Equation (2). Consequently, the brake distribution from CBS is dependent on the hand brake forces from a rider, wear, and adjustment of the drum brake. This can minimize overall motorcycle deceleration due to reduced brake force in the front wheel [7]. To overcome the disadvantage of mechanical CBS, the hydraulic brake system in both front and rear wheels with controlled brake distribution was developed [8].

$$F_{of} = \frac{F_o B}{(A+B)} \tag{1}$$

$$\Delta s_{hand} = \Delta s_f + \left[\frac{(\Delta s_r - \Delta s_f)}{(A+B)} A \right] \tag{2}$$

Where F_{of} = Output force from CBS (N)
F_o = Output hand force (N)
A, B = Mechanical CBS linkage (mm)
Δs_{hand} = Limited input stroke (mm)
Δs_f = Front hand brake pump (mm)
Δs_r = Drum brake lever (mm)

For the motorcycle ABS, the controller unit regularly monitors the hydraulic pressure (P_{o2}) and the wheel angular (ω) as shown in Figure 2. It can deactivate and activate the anti-lock modulator to control the pressure output (P_{o2}) in the wheel caliper based on the value of the wheel slip (δ). The wheel slip dominates the tire force behavior and governs the vehicle dynamic conditions [9].

From Huang and Shih research work, the limited wheel slip (δ) can be set up to 20% in order to achieve high lateral and longitudinal adhesive coefficients [10].

When the control unit deactivates the anti-lock modulator due to low wheel slip, the hand brake pressure output (P_{o1}) can directly pass through and control the wheel caliper. However, if the value of the

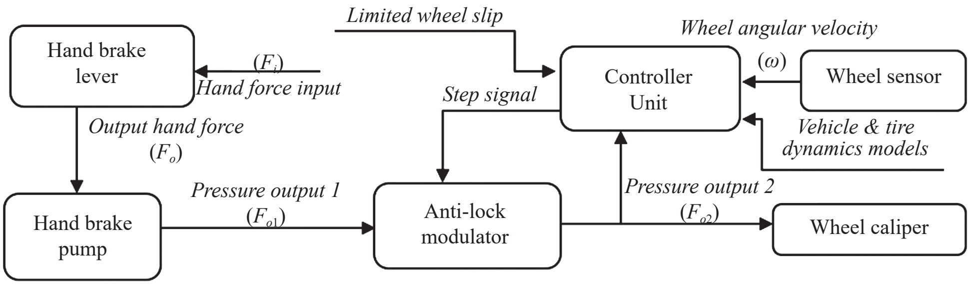

Figure 2: Schematic diagram of ABS in motorcycle.

wheel slip is higher than the limited value, the anti-lock modulator can be activated to control the pressure (P_{o2}). The controller unit identifies the wheel slip based on Equation (3). The estimated vehicle velocity can be technically calculated from the wheel angular velocity (ω) and the pressure (P_{o2}) [10].

$$\delta = \frac{(v - \omega r)}{v} 100\% \quad (3)$$

Where δ = Wheel slip
v = Estimated vehicle velocity (m/s)
ω = Wheel angular velocity (rad/s)
R = Dynamic tire radius (m)

To obtain the technical effectiveness of brake systems, the development of brake test protocols should be established under the traffic riding situations for motorcyclists in Thailand. These situations are related to global plan with a decade of action for road safety such as pillar 2: safer roads, pillar 4: safer road users, and pillar 3: safer vehicles [11]. Therefore, the brake performances from motorcycles with ABS, Non-ABS and CBS system based on UNECE R78 and the braking maneuver condition are evaluated using the experimental brake test protocols on simulated different friction surfaces. The procedure in the development of standard brake test protocols is obtained from the simulation of road conditions and riding behavior with the various brake systems of popular motorcycles in Thailand. The context situations from various road safety pillars are also considered. These factors and approaches are summarised as shown in Table 1.

Table 1: Motorcycle context and response situation

Motorcycle Situation in Thailand		Approach
Pillar 2: Safer roads	There is a poor rating of road safety assessment for motorcycles from the International Road Assessment Programme (IRAP) [12].	- Simulate different road conditions related to the utilization of motorcycle tire forces
Pillar 4: Safer road users	In 2001, the rear end collisions from motorcycles are found to be common road accident scenarios in Thailand [13]. From 2015 to 2018, overtaking motorcycle by another vehicle is also found as the 2nd type of motorcycle crash [14].	- Simulate driving conditions related to the accident scenarios i.e. straight forward braking and maneuver conditions.
Pillar 3: Safer vehicles	There is no standard brake test for a motorcycle as a mandatory requirement for active safety.	- Adopt partial standard brake test from UNECE Regulation No. 78 by controlling hand brake force and vehicle speed
	In 2018, the step-through types with engine sizes of 110 and 125 cc were very common modes of transportation with 541,372 and 458,246 units respectively that were sold in Thailand [15]. In 2001, there were 339 cases of the step-through type from all 723 accident-involved motorcycles. From these data, the scenario with motorcycle impacting rear of the other vehicles was the top accident configuration [13].	- Use the step-through type of motorcycles to identify the technical effectiveness of ABS, Non-ABS and CBS brake systems
	There are various brake systems in motorcycles i.e. Non-ABS, ABS and CBS in Thailand.	
	There is no technical effective information from various brake systems related to the step-through motorcycles with a small size of an engine under the road and typical accident scenarios.	- Integrate the standard brake test and accident scenarios to assess the technical effectiveness of brake systems for step-through motorcycles

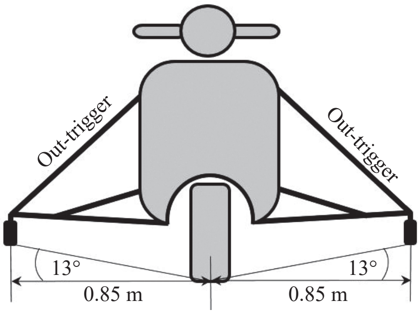

Figure 3: Out-trigger design for the avoidance of motorcycle instability.

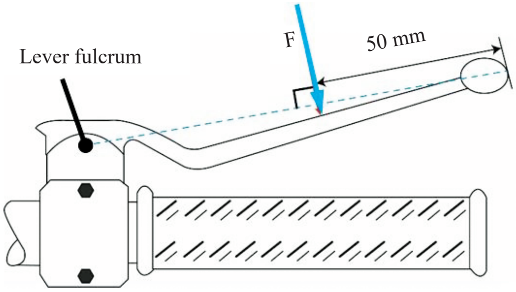

Figure 4: Location of the input force on the hand brake lever from UN Regulation R78.

To evaluate the effectiveness of motorcycle brake systems, the standard brake test with different road frictions and overtaking scenarios on the step-through type of motorcycle in Thailand should be considered in this approach. Three different brake systems i.e. ABS, Non-ABS, and CBS are also evaluated.

2 Methods

2.1 *Target motorcycle*

Brand-new Honda "Click 125i" and Yamaha "Grand Filano" 2018 models were selected to represent CBS, ABS and Non-ABS brake systems respectively. The specification of the selected motorcycles is summarized in Table 2. Honda "Click 125i" model uses a mechanical CBS brake system to activate only the brake service in the front wheel from the actuation on the hand brake lever of the rear wheel. There is no vice versa for the hand brake lever of the front wheel to control the rear wheel.

Table 2: Tested motorcycle specification

Specification	Honda*	Yamaha**
Model Name [Year]	All New Click125i: Spoke [2018]	New Grand Filano Hybrid [2018]
Engine size	124.88 cc	125 cc
Structure type	Under-bone	Under-bone
Wheelbase	1280 mm	1280 mm
Gross weight	113 kg	102 kg
Front brake system	Disc Brake (CBS)	Disc Brake (ABS)
Rear brake system	Drum Brake	Drum Brake
Front tire	80/90-14M/C 40P	110/70-12 47L
Rear tire	90/90-14M/C 46P	110/70-12 47L

Data information *https://www.aphonda.co.th/honda2017/motorcycle/automatic/new-click-125i-2018
** https://www.yamaha-motor.co.th/commuter/new-grand-filano-hybrid-2018/feature

The out-trigger with 0.85-metres long is developed to stabilize motorcycle during the wheel locking condition as shown in Figure 3. When the out-trigger is installed in the target motorcycle, the tested motorcycle can be tilted up to 13 degrees maximum for braking maneuver conditions. Furthermore, it can stabilize the motorcycles and prevent a fall while braking from a high speed under high and low friction surface conditions.

2.2 *Measurement devices*

Based on UNECE Regulation No. 78, the hand brake force (F) must act perpendicularly on the ideal line between the lever fulcrum and the outermost point of the lever. It is also located at 50 mm from the outermost point along which the control lever can be rotated as shown in Figure 4. To actuate the hand brake force from the rider on the tested motorcycle, the extra hand grip device and the rigid rod are developed and installed on the hand brake lever as shown in Figure 5. The rigid rod is fixed on the hand brake lever through which the extra hand grip device can be freely moved. Therefore, the hand brake force from the rider (F1) can be measured from the load cell with reaction force (F) through the rigid rod.

Load cells with an accuracy of 0.3% and a maximum load limit of 500 N are installed on the extra hand grip device to measures the force (F) from the rider hand force. The GPS unit for a speedometer with 0.1 km/h accuracy averaged over 4 samples and position with ±10 cm accuracy is installed at the top of the toolbox behind the rider position. The measured time with 0.01-second accuracy is used during the test. Therefore, the time-dependent position and velocity data with 20 Hz are collected in the data acquisition unit as shown in Figure 6.

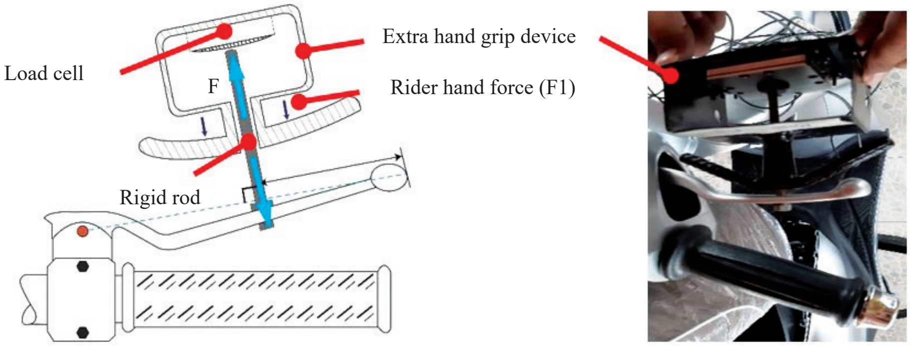

Figure 5: Extra handgrip device with the rigid rod.

Figure 6: Installation of measurement Units in test motorcycle.

2.3 *Testing procedure*

Based on the previously mentioned approach, three different protocols of braking performance are developed and complied with UN Regulation No. 78 using a hand-actuated control lever to actuate both front and rear brakes. The motorcycle brake testing was performed at the test track in King Mongkut's University of Technology North Bangkok, Prachinburi Campus with the engineering measuring instruments and data acquisition system of the National Metal and Materials Technology Center, a member of the National Science and Technology Development Agency. The 1st protocol of the brake performance under a high friction surface (maximum nominal peak braking coefficient of 0.9) is evaluated by controlling hand brake force less than 200 N and a maximum speed of 60 km/h before brake application as shown in Figure 7.

The 2nd protocol of the brake performance under maximum low friction surface (maximum nominal peak braking coefficient of 0.55) is evaluated by controlling hand brake force less than 200 N and a maximum speed of 60 km/h before brake application as shown in Figure 8. For the 3rd protocol of the braking maneuver condition, the controlled area under the width of 2.8 m and braking condition of 12 m long before the obstacle is constructed under maximum

Figure 7: Braking performance test on high friction surface with a nominal peak breaking coefficient of 0.9 (1st Protocol).

Figure 8: Braking performance test on low friction surface with nominal peak breaking coefficient of <0.55 (2nd Protocol).

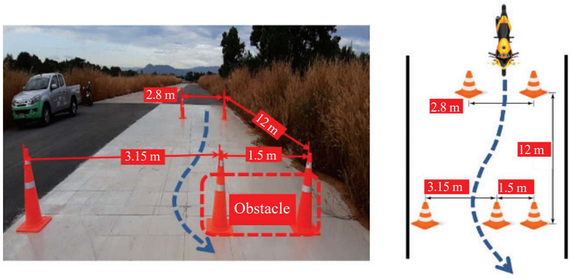

Figure 9: The controlled area for 3rd protocol of the braking maneuver condition.

low friction surface (maximum nominal peak braking coefficient of 0.55) as shown in Figure 9. The controlling hand brake force less than 200 N and a maximum speed of 50 km/h before brake application are constrained in evaluation. For all three protocols, the best and average values of braking distance and Mean Fully Developed Deceleration (MFDD) from six attempts are used from the same professional rider. Three different brake systems of ABS, Non-ABS, and CBS from the available and most popular step-through type motorcycles with 125 cc of engine size are used with the out-trigger device for safety mandatory requirement.

3 Results and Discussion

The stopping distances and the Mean Fully Developed Deceleration value (MFDD) from Equation (4) were measured during the tests. Each protocol was conducted up to six times for Non-ABS, ABS, and CBS. In the 1st protocol on the high friction surface, each brake system revealed the same trends as shown in Figure 10.

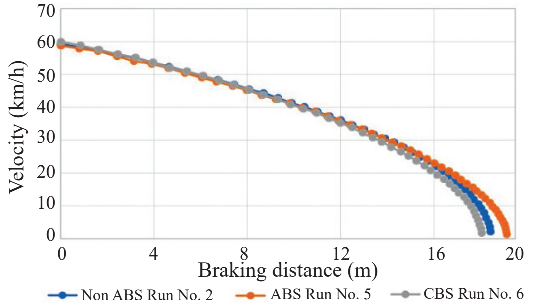

Figure 10: Velocity and braking distance profiles of best results for each brake system on high friction surface.

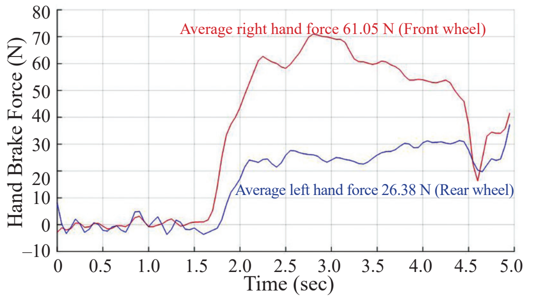

Figure 11: Hand brake force profiles of CBS during the 1st protocol on the high friction surface.

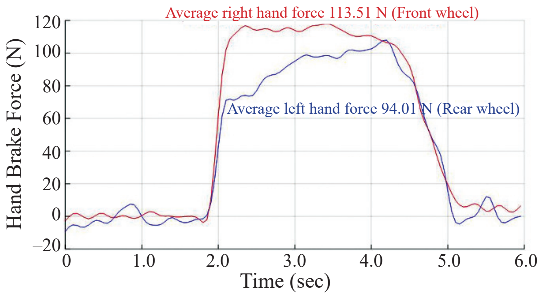

Figure 12: Hand brake force profiles of ABS during the 1st protocol on the high friction surface.

The best and average results for each brake system with both hand brake forces below 200 N are presented in Table 3. It reveals that CBS achieves the shortest braking distance of 18.17 m on the high friction surface, although the average hand brake profiles of CBS in the best result are lower than ABS as shown in Figures 11 and 12 respectively.

Therefore, the values of hand brake force are not significant indicators to identify the braking distance. However, various hand brake patterns and forces in Thai young riders can be found to control the braking distance [16]. To gain the best braking distance, the design algorithms of the brake system with consideration of motorcycle geometry and dynamic load should are significant [7]. If the rider attempts to increase the hand brake force in the rear wheel, the additional force (F_{of}) from CBS can increase the pressure in the hand brake pump. This can cause the locking condition in the front wheel because the increment of brake force is beyond the limitation of road friction. The locking condition is related to motorcycle geometry and tire that involve the decreased vertical load and the wheel slip in the rear wheel respectively [7]. In addition, the influence of wear in drum brake can decrease the braking distance because of the effect of longer stroke in the drum brake lever (Δs_r) as shown in Equation (1).

The best and average run No. of ABS from the 1st protocol provided the longest braking distance, even though the rider attempted to apply higher hand brake forces in ABS than those in CBS as shown in Figure 12. And no significant lateral deviations of the brake systems are found. However, the overall results of braking distances and decelerations performance of Non-ABS, ABS, and CBS complied with UN Regulation No. 78 Annex 3. This performance requirement for stopping the vehicle on a high friction surface with a test speed of 60 km/h shall be less than or equal to 22.68 m with MFDD more than 0.62 g.

The results in the high brake friction surface reveal the same trend of the ABS brake system in both wheels in sport and touring segment of motorcycles at a test speed of 48.3 km/h [17]. These are due to the influence of control algorithms of CBS and ABS control strategies. One of them uses front and rear wheel sensors together with the horizontal and vertical accelerations to identify the vehicle reference speed and deceleration for recognition of over braking and tilt angle status [18]. In other algorithms, the fuzzy controller utilizes wheel speed and its change rate as input to control wheel locking condition or the intelligent controller can be used to calculate the slip ratio of wheels in real-time [19], [20]. In the CBS algorithm, the braking force adjustment of another wheel from the actuated brake wheel is dependent on the increment rate of master cylinder pressure in comparison of predetermined value [21]. Therefore, the effectiveness of ABS and CBS in a motorcycle are dependent on the design of control algorithms.

In the 2nd protocol on the low friction surface, the best shortest and average braking distances with both hand brake forces below 200 N were found in the ABS brake system at the value of 26.62 and 27.86 meters respectively as shown in Table 4.

Table 3: The best and average results for each brake system in 1st protocol on high friction surface

Parameters	Shortest distance of brake systems (1st Protocol)			Parameters	Average value of brake systems (1st Protocol)		
	Non-ABS	ABS	CBS		Non-ABS	ABS	CBS
Best test value				**Average value from test run No. 1-6**			
Time (s)	2.17	2.42	2.13	Time (s)	2.28	2.46	2.31
Best Braking distance (m)	19.01	19.93	18.17	Avg. Braking distance (m)	19.61	20.48	19.85
Lateral deviation (m)*	–0.03	–0.01	0.02	Lateral deviation (m)*	–0.09	–0.04	–0.14
MFDD (g)	0.79	0.72	0.81	MFDD (g)	0.76	0.72	0.75
				Standard deviation of Braking distance (m)	0.47	0.56	1.35

* Lateral deviation means the distance between the initial test path and the position at which motorcycle travelled.

Table 4: The best and average results for each brake system in 2nd protocol on low friction surface

Parameters	Shortest distance of brake systems (2nd Protocol)			Parameters	Average value of brake systems (2nd Protocol)		
	Non-ABS	ABS	CBS		Non-ABS	ABS	CBS
Best test value				**Average value from test run No. 1-6**			
Time (s)	3.81	3.13	3.81	Time (s)	3.57	3.28	4.56
Best Braking distance (m)	29.79	26.62	33.67	Avg. Braking distance (m)	30.02	27.86	38.97
Lateral deviation (m)*	0.21	0.04	–0.05	Lateral deviation (m)*	0.16	0.04	–0.31
MFDD (g)	0.49	0.52	0.45	MFDD (g)	0.50	0.51	0.39
				Standard deviation of Braking distance (m)	0.34	0.98	4.4

* Lateral deviation means the distance between the initial test path and the position at which motorcycle travelled.

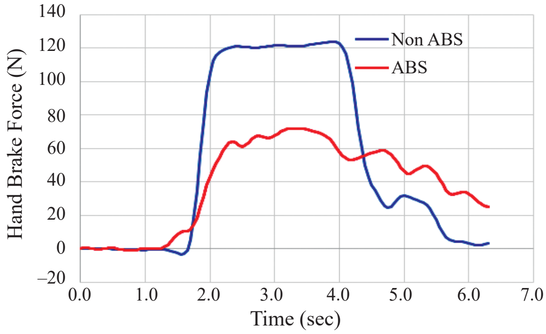

Figure 13: Force responses of Non-ABS and ABS from the load cell at the right hand brake lever.

In theory, the main objective of ABS is to achieve longitudinal and lateral adhesive coefficients where the wheel slip is limited up to 20%. As the system operates, the ABS modulator does decrease and increase the brake fluid pressure in the caliper to maintain the desired wheel slip. In such fluctuation of brake fluid pressure, the operation of ABS can be monitored by the vibrating force of the related hand brake lever. For the example of such characteristics, the hand force of Non-ABS is rather smooth than that of ABS as shown in Figure 13.

Furthermore, there were high signification different results among six run tests in CBS as shown in high values of standard deviation and lateral deviation. This was because the rider attempted to achieve the test requirement for non-touching of out-trigger on the test surface in each test by controlling the hand brake lever. In addition, the influence of wheel slip in the front wheel is prone to cause the wheel locking condition and lose control of the direction in CBS. However, Non-ABS showed better braking results in comparison with CBS because the rider can independently control the hand brake forces on the front and rear wheels. In addition, the influence of CBS can create the input force (F_{of}) in the front wheel, while the rider attempted to control the force (F_o) in the rear hand brake lever for the avoidance of wheel locking condition. Therefore, the standard deviation of braking distance is the best in Non-ABS. Consequently, CBS and Non-ABS require more skill of rider during the brake application on the low friction surface.

In the 3rd protocol of the braking maneuver condition on the low friction surface, the results revealed that the motorcycle with ABS system can avoid the allocated obstacle without losing control of motorcycle as shown in Table 5. This is because the influence of wheel locking control algorithm and the slide angle can develop the lateral side force in the front wheel. The slip angle is the orientation of the local velocity vector relative to the wheel symmetry plane [22]. The lateral force is also related to the wheel slip [23]. Therefore, the slip angle and wheel slip can occur at the same time during the braking maneuver condition. For this reason, the design of ABS in a motorcycle can play a significant role in vehicle stability control [20]. Optimum design of motorcycle suspension under such conditions is also related to the braking distance because the vibration of suspension causes variable vertical dynamic load in motorcycle tire [24].

$$d_m = \frac{(V_b^2 - V_e^2)}{25.92(S_e - S_b)} \quad \text{m/s}^2 \tag{4}$$

Where:
d_m = Mean Fully Developed Deceleration (MFDD) (m/s^2)
V_1 = vehicle speed when rider actuates the control (km/hr)
V_b = vehicle speed at 0.8 V_1 (km/h)
V_e = vehicle speed at 0.1 V_1 (km/h)
S_b = distance travelled between V_1 and V_b (m)
S_e = distance travelled between V_1 and V_e (m)

Table 5: Test results in 3rd protocol for braking maneuver condition on the low friction surface

Braking Systems	Initial test speed: 50 km/h Brake actuation force for both hand control ≤ 200 N	
	3rd Protocol: The obstacle avoidance maneuver on the roadway on the low friction surface with a nominal peak breaking coefficient of 0.55	
	Test Result	**Motorcycle Maneuver**
Non-ABS	Unable to swerve obstacles and lose vehicle stability during braking application	Figure 14
ABS	Able to swerve obstacles and keep vehicle stability during braking application	Figure 15
CBS	Unable to swerve obstacles and lose vehicle stability during braking application	Figure 16

Figure 14: Non-ABS-equipped motorcycle during the braking maneuver (from left to right).

Figure 15: ABS-equipped motorcycle during the braking maneuver (from left to right).

Figure 16: CBS-equipped motorcycle during braking maneuver (from left to right).

4 Conclusions

In the 1st protocol, the braking distance from ABS was the longest. The main reason is from the algorithm-controlled strategy of the hydraulic brake system in ABS to utilize the maximum high friction surface. This algorithm is dependent on the vehicle design and development on the target motorcycle. Therefore, the braking distance of ABS motorcycle is 1.76 m longer than those from the motorcycles with Non-ABS and CBS. Furthermore, the experimental results showed the braking distances were related to the motorcycle deceleration obtained from road surface utilization. However, braking distances from all brake systems satisfied UNECE Regulation No.78 requirement in Annex 3 (Topic 9.3). The standard braking distance and deceleration of this requirement should be less than 22.68 m and more than 0.62 g respectively.

From the brake performance under low friction surface in the 2nd protocol, the motorcycle with CBS system utilized the longest braking distance of 7.05 m among all brake systems because the rider controlled the hand brake forces to avoid the wheel locking condition and reach the optimal braking distance based on the standard requirement.

In the last protocol, the braking maneuver condition can typically reflect the driving situations such as obstacle avoidance, emergency braking situation of the lead vehicle with a short headway, vehicle passing the junction with a poor vision of clear zone in Thailand. The experimental results revealed that the motorcycle with ABS system can avoid the allocated obstacle without losing control of the motorcycle. However, the Non-ABS and CBS brake systems cannot pass the protocol due to loss of lateral force at the front wheel from wheel locking condition.

Acknowledgment

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