

*Article*

## Identification of Handbrake Patterns of Young Motorcycle Riders in Thailand Using a Newly Invented Force Measuring Device

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**Abstract.** The paper aims at identifying handbrake control behavior of young Thai volunteer riders by focusing on small underbone-type of motorcycle using a newly developed force measuring device. The device has been invented to measure the handbrake force using the potentiometer through the fulcrum of hand control lever. Through calibration with the discrete static loads, the relation between the rotational hand control lever and the handbrake force has been determined. This technique is applicable for both hydraulic or cable handbrake systems. It has been employed to measure each rider's handbrake force against both handbrake levers during brake application. Our sample included thirty volunteers and a professional rider. We conducted the tests based on transportation standard regulation of the United Nations Economic Commission for Europe (UNECE) regulation No. 78, under speed of 40 km/hr. Three types of handbrake patterns have been identified from these tests. Consequently, the force response characteristics from hydraulic and cable systems in motorcycle are notably different. The number of rider's finger actuation and various patterns applied at the hand brake levers have been revealed to improve the brake skill from young motorcyclists.

**Keywords:** Handbrake force, motorcycle handbrake patterns, handbrake measurement.

ENGINEERING JOURNAL Volume 22 Issue 5

Received 26 December 2017

Accepted 25 July 2018

Published 30 September 2018

Online at <http://www.engj.org/>

DOI:10.4186/ej.2018.22.5.185

## 1. Introduction

Thailand has high number of road accidents. Based on the record of WHO, in the year 2015, Thailand has the second highest accident death rate in the world, with 14,059 fatalities on the road, representing 36.2 per 100,000 population, with an annual estimate of over 24 000 deaths or 66 deaths every day. Moreover, 73% of road accident deaths are motorcyclist (2 or 3 wheel motorcycles), while the rests are pedestrians (8%), passengers of 4-wheel cars (7%), drivers of 4-wheel cars (6%), cyclists (2%), drivers and passengers of buses (1%), and others (2%) [1]. Even though the government realizes and releases road safety plans and road safety actions, the number of road traffic injuries and crashes are still high. Along with the safety policy, users have to know how to ride safely, as a basically requirement of every rider.

In this paper, we focus on the braking behavior of motorcycle riders, since it has a big impact on road accidents. Corno, et al. [2] stated that “The ability of a driver to achieve an optimal braking can make the difference on the lap-time. Even few milliseconds per braking hence can be crucial.” Moreover, in many cases of accidents the riders usually make poor use of the braking capacity of their machines, which will lead to more accident frequency and severity [3]. However, the literature on the motorcycle braking behavior are still limited. There are some previous works on the motorcycle braking. Juniper and Good [3] reviewed a literature related to braking stability and handling of motorcycles. They provided relationships between motorcycle characteristics and accidents, with investigations of motorcycle dynamics, and the effects of accessories, tires, and machine modifications. Corno, et al. [2] discussed an optimal braking strategy through a simulation-based study of the braking maneuver in high-performance (racing) motorcycles. The control strategy using the front brake and rear brake of motorcycle were analyzed in which the role of aerodynamics and how to select and modify the control objective during the brake application are highlighted and studied respectively. More literature on braking stability and behavior are reviewed and conducted [4]-[6]. However, most of previous works tried to determine the effective braking control. As a different point of view, in this research, we try to identify the braking pattern of motorcyclists, since it is essential information for motorcycle trainers that will help users control their motorcycles more effectively; stable, in time, or in stopping distance.

The input handbrake behavior is the key to dominate the stopping distance of motorcycle. There are many types of braking service systems. Here we classified braking service systems based on their control operation. The first one is the split service brake system that independently operates the brakes on each axle, where a front wheel and a rear wheel brake can operate independently by left hand, right hand, or by foot. Another is the Combined Brake System (CBS) that dependently controls the brakes on each wheel by single actuated input. It was found that results of the braking test from motorcycle with CBS and Antilock Brake System (ABS) showed high performance in deceleration [7], [8]. Furthermore, motorcycles with optional ABS appeared to be effective in preventing the crash in comparison with their non-ABS [9]. In the emergency straight-path braking behavior, less-skilled volunteer riders attempted to stop the motorcycle through early “lock-up” of the rear wheel. By contrast, the skilled riders realized to actuate the brake proportion between the front and rear wheels to utilize the available road friction. To stop motorcycle more efficiently, the integrated and/or anti-lock braking system could be equipped for the less-skilled riders [10]. However, the split service brake system is commonly used in the budget motorcycle. Therefore, the stopping distance of motorcycle is dependent on the amount and duration of each wheel brake force application. The other factors such as rider, speed, pavement condition, braking strategy, and motorcycle also affect the stopping distance of motorcycle [11]

To actuate the handbrake control, the hand grip capacity is the result of forceful flexion of all finger strengths. In medical and ergonomic research, Jamar dynamometer was used to measure grip strength under standardized positioning and instructions. It was found that the highest grip strength scores were found in the 25 to 39 age male groups with the mean strength of 121.8 and 112.9 pounds (55.25 and 51.21 kilograms) for the right and left hands respectively [12]. For mean 61.1 age male groups in South Africa, the mean hand grip strength was 37.9 kilograms [13]. However, individual finger force was investigated using a linear force summing strain gauge dynamometer, which resulted in forces from the index and middle fingers were more than 3 N greater than that from the ring and small fingers [14]. The control of handbrake lever and usage of finger strength are dependent on the rider skill and habit under the emergency situation.

For this reason, the objective of this study is to monitor the handbrake force and identify the handbrake patterns on the budget motorcycle in Thailand under the UNECE Regulation No.78 requirement from young volunteer riders in Thailand.

## 2. Methodology

### 2.1. Apparatus

The invented device was developed to measure the force and pattern on the hand control levers of motorcycle. Using the potentiometer through the fulcrum of hand control lever, the actuated rotation can be detected as shown in Fig 1. With this technique, either hydraulic or cable handbrake systems can be equipped through this invented device. It consists of the potentiometers and data acquisition unit. The National Instruments USB-6008 model was used as data acquisition unit to monitor and record the handbrake forces at 16 Hz of sampling rate. Therefore, the right and left handbrake inputs can be measured with time dependence during the brake application.

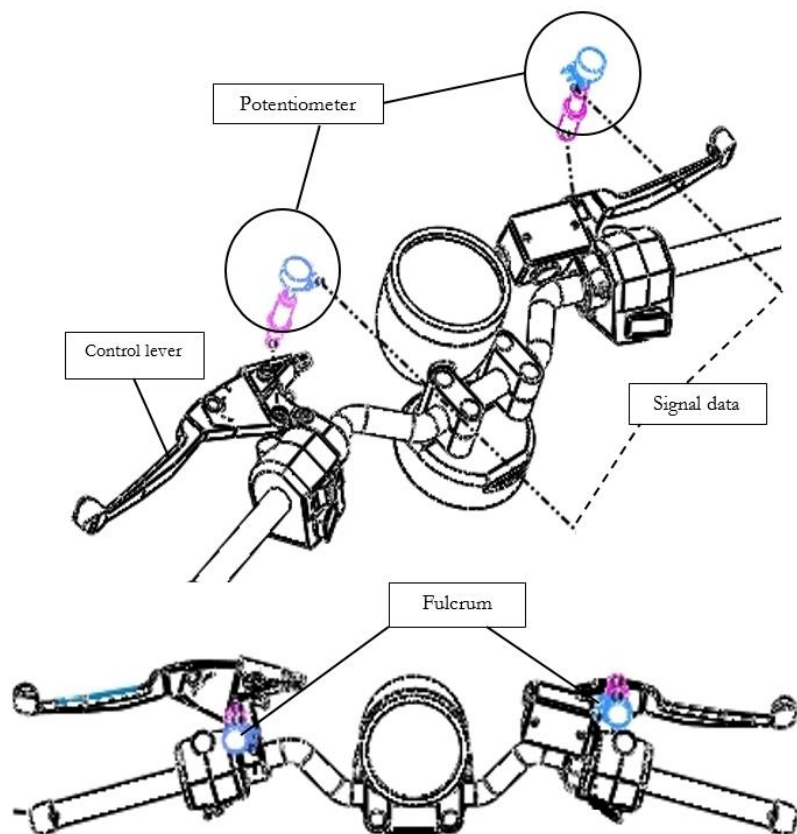


Fig. 1. Invented device with potentiometer at the fulcrum of the control lever.

### 2.2. Experimental Vehicle

We used the Yamaha motorcycle Mio 125 GT, 2011 model for our road test, since it is one of the top three models that have been used in Thailand. The model is considered as a small underbone motorcycle that is affordable. Note that the model is classified as a budget motorcycle with the price range between 20,000 to 40,000 baths. It has a specification of dimensions (width x length x height): 685 x 1,850 x 1,060 mm, engine type: 4 Step, Single Over Head Cam (SOHC), weight: 99 kg, transmission: automatic v-belt, with rear drum and front disc brake systems. The breaking system is actuated by left and right handbrake levers, which separately control the rear and front wheel brake systems respectively.

### 2.3. Determining Relationship between Voltage and Force

The objective of this section is to determine the relation between the voltage from potentiometers and the handbrake force at levers. A potentiometer is commonly used to control electrical devices such as volume

controls. In this case, we applied it to measure the handbrake force. The potentiometer can detect the rotational degree changing on the handbrake lever, and yield the value of voltage. So to measure the handbrake force, the relationship between the voltage and the force can be determined. Once we have that relationship, the handbrake force by changing rotational degree can be measured.

To calibrate the invented device, the additional tool was installed with 75 discrete gravity loads from 10 N to 250 N, which incremented by 3 N. Note that the maximum force of 250 N was the limitation of the rotational movement. Figure 2 showed the installed tool for calibration with discrete gravity loads through the cable (marked in red) under UNECE No. 78 requirement. So, we obtained the pairs of force and voltage on both right and left hand control levers. Next, we fitted the simple linear regression line to represent the relationship between rotation degree and each handbrake force. For the right hand force the regression line is  $Y=0.101+0.00174*X1$ , where Y represents the rotation degree (voltage) and X1 represents the right handbrake force (N) with the  $R^2=0.971$ . For the left hand force the regression line is  $Y=0.0785+0.00109*X2$ , where Y represents the rotational degree (voltage) and X2 represents the left handbrake force (N), with  $R^2=0.994$ . The relation between the rotational hand control lever and the handbrake force showed in Fig. 3. The maximal lever span that is equivalent to the 23.4 degree of rotation at its fulcrum can be proportionally related to the output of 0.55 volts from the invented device. Furthermore, the number of finger usage to activate the brake system on the hand control lever were monitored through video recording device as shown in Fig. 4.

The right handbrake is controlled by hydraulic system with internal friction part through the stick-slip motion of the tubular rubber seals, while the left handbrake is controlled by cable system with constant spring stiffness [15]. From Fig. 3, we will see that to reach the same amount of force, the right hand control required more effort on the handbrake lever (voltage) than the left hand control.

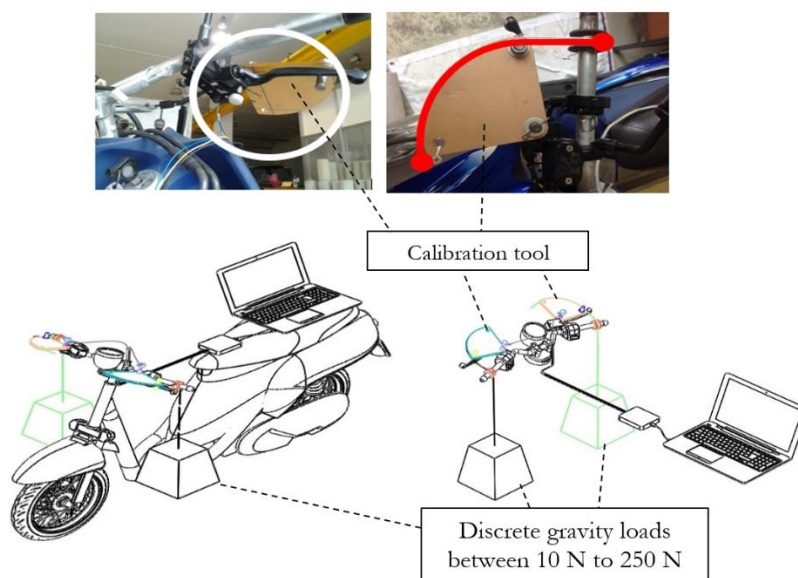


Fig. 2. Installed tool for calibration with discrete gravity loads.

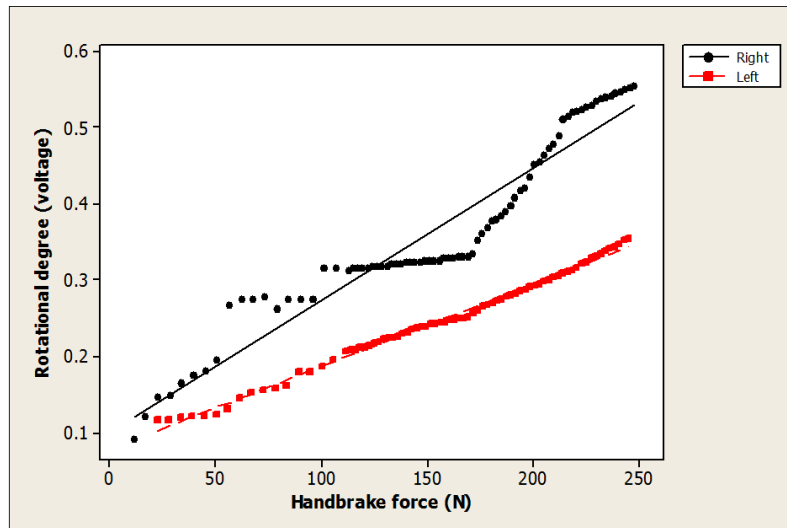


Fig. 3. Linear relationship between rotational degree (voltage) and left hand brake force (N).



Fig. 4. Video recording device to monitor the number of finger actuation.

## 2.4. Experimental Design

The experiments are conducted based on the transportation standard of motorcycle with regard to the braking performance from United Nations Economic Commission for Europe (UNECE) regulation No. 78. This regulation has been widely used for sustainable transport safety in many countries including Europe, Canada, the Central Asian republics, Israel, and the United States of America. The detail of the UNECE No. 78 can be seen in this regulation [16]. The tests were followed the regulation such as speed before brake application, hand brake force, stopping distance, road condition, temperature, etc.

The input force ( $F$ ) at the handbrake lever is measured with time dependent on the control lever's forward surface perpendicular to the axis of the lever fulcrum at a point located 50 mm. from the outermost point of the control lever. The handbrake actuation force is allowed up to 200 N, which covers force range of riders. The test speed is controlled as the following; the initial speed is 50 km/h or lower, the final speed is in the range of 5 to 10 km/h. The maximum vehicle speed before a rider actuates the control of handbrake levers is set at 40 km/h. The maximum braking distance is set at 16.25 meters, which allows enough clearance to avoid rear end collision. All the road tests are performed on the dry asphalt road in Thai Yamaha Riding Academy. The temperature on the test day was in the range of 36°C to 38°C (UNCCE Regulation No.78 set the temperature range of 4°C to 45°C). Based on the test speed and the temperature, tests we conducted are suitable for Thailand traffic situation in which the vehicle mostly moves with low speed condition.

To prepare the dry stop test, the motorcycle is equipped with the invented device and the data acquisition

unit. The tire pressures are set to the manufacturer's specification at 29 and 33 Psi for the front and rear wheels respectively. The lightly loaded condition should be applied together with the laden condition from the riders. To perform the test, the rider should speed up from zero to 40 km/h and maintain the constant speed before actuating the both handbrake levers at the brake actuated point as shown in Fig 5. In this case, the riders are realized the limited stopping distance to simulate the emergency conditions. So, they have to perform the dry stop within the stopping distance limit using the brake control on both hands, which independently controlled and monitored.

To perform the brake test, thirty Thai volunteers under 25 years old including one professional rider should wear the safety suits and helmet. These volunteers with the motorcycle driving licenses have experienced in riding motorcycles more than five years. The professional rider has over twenty years old with the well-trained riding skill. In this dry stop test, we controlled independent variables, which are speed; pavement condition; and stopping distance. The dependent variables that we measured and monitored are the amount and duration of force applied on both handbrake controls; the stopping distances. In addition, usage of finger actuation from riders is recorded during the brake application.

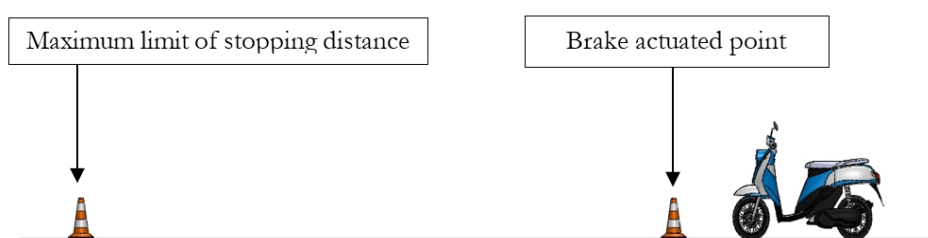


Fig. 5. The beginning of brake application and the maximum limit of stopping distance for the brake test.

### 3. Results

#### 3.1. Study Sample

There are 31 licensed riders participated the road test. The participants consisted of 26 college students, 4 university officers, and 1 professional rider. Among them, 26 were males and 5 were females. Age range was between 15-20 years (65%), 21-30 years (19%), and less than 15 years (16%). The riding experience was between 5-10 years (71%), less than 5 years (16%), and more than 10 years (13%). The riding frequency was less than 10 times per week (42%), between 10 to 20 times per week (45%), and more than 20 times per week (13%).

#### 3.2. Classification of Handbrake Patterns

Based on the brake test of 31 volunteer riders, the results showed the maximum handbrake forces ( $F$ ) between the right and left hands as in Fig 6; where (a) represented the histogram of maximum right handbrake forces, (b) represented the histogram of maximum left handbrake forces. The overall mean of handbrake forces for the right and left hand sides were 57.14 N (SD = 26.54) and 82.00 N (SD= 46.81), respectively. In addition, the average peak brake time of maximum handbrake forces were 1.37 sec. (SD= 1.31) and 1.21 sec. (SD=0.75) for the right and left hands respectively.

Cluster analysis was performed in order to classify the handbrake patterns. The data set included 31 observations, which is from our samples and the selected professional rider. We classified the handbrake pattern with respect to 3 key variables, which are the period of stable force, the period of decreasing force, and the number of peaks during brake application. Since the samples applied the brake with two hands, it totals of 6 variables. Three clusters were identified based on the Euclidean distance and the average linkage method. Figure 7 showed the dendrogram of the clustering. The statistics of each cluster are also provided in Table 1. Note that one sample (No.24) applied no force on the left handbrake, which results in 0.000 in the minimum value. The first cluster is identified as stable pattern, with the average stable force of left hand and right at 1.379 and 1.589, respectively. Sample No. 13 and No. 31 (professional rider) are represented this group. The second cluster is identified as oscillated pattern, which applied unstable force with some peaks. The average numbers of peaks on the left hand and right hand are 2.714 and 2.571, representatively.

Sample No. 17 is represented this group. The third cluster is identified as gradually decreasing pattern, which applied unstable force with some peaks. The average decreasing force on the left hand and right hand are 1.860 and 3.120, representatively. Sample No. 14 is represented this group.

In the experimental tests, the mean braking distance of all volunteer riders is only 10.02 meters long (SD=2.48) which are under the limitation of UNECE regulation No. 78. The longest and shortest braking distances from samples were found at 15.3 and 6.6 meters respectively. In the longest distance, the rider used four and two fingers to actuate the left and right handbrake levers respectively. For the shortest distance, four fingers from both hands were used similarly to the professional riders. Their braking distances are independent on the amount of handbrake force and the peak brake time in each side as shown in Table 2. However, the braking distance from the professional rider was found at 6.71 meters with higher force in left hand side and longer peak response time in both hands. Therefore, the input patterns to control the levers during the brake application are significant to the brake distance.

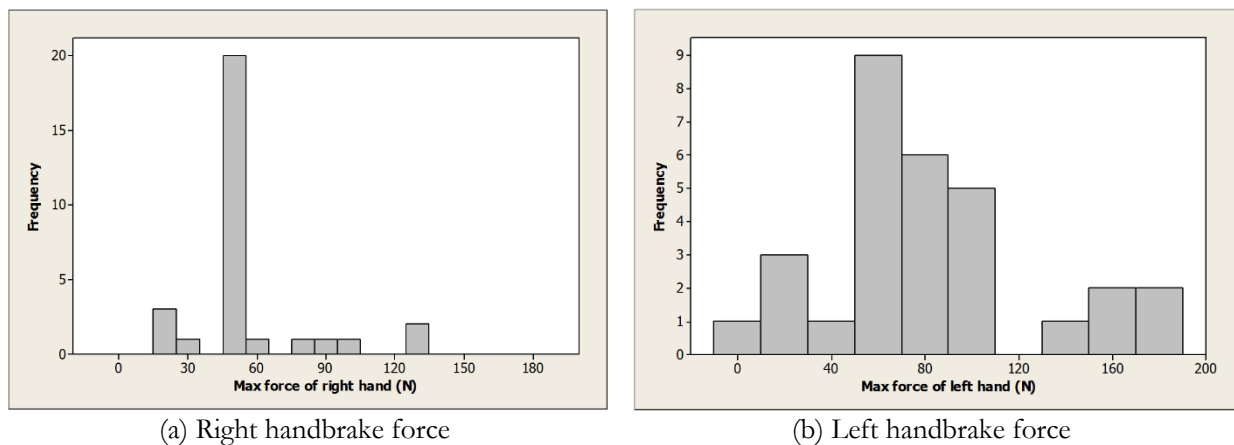


Fig. 6. Histograms of maximum handbrake forces of 30 volunteer riders.

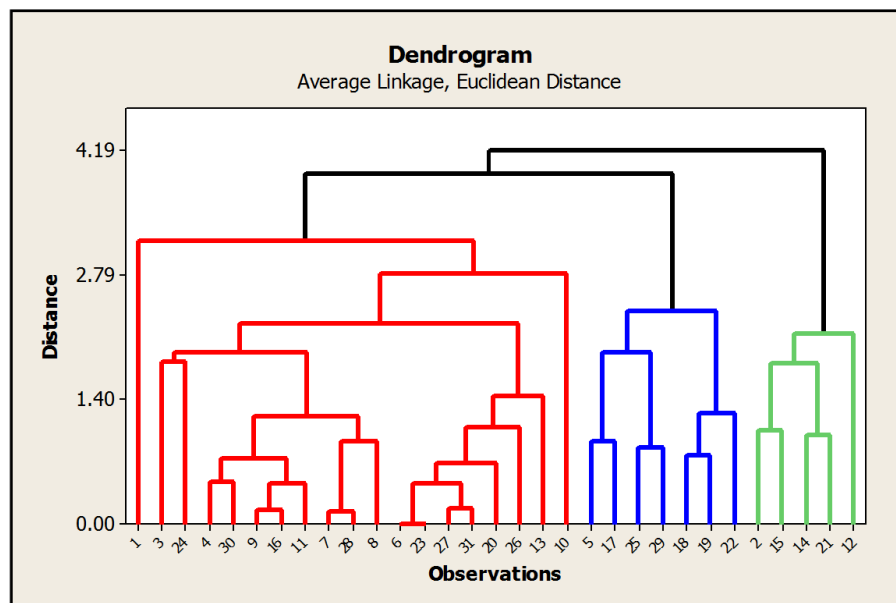


Fig. 7. Dendrogram of three handbrake pattern clusters.

Table 1. Statistics of three handbrake pattern clusters.

Cluster 1 (n=19)	Average	SD	Min	Max
Period of stable force (Left)	1.379	0.857	0.000	3.500
Period of stable force (Right)	1.589	0.660	0.500	2.600
Period of decreasing force (Left)	0.350	0.248	0.000	1.000
Period of decreasing force (Right)	0.505	0.408	0.200	2.000
Number of peaks (Left)	0.105	0.459	0.000	2.000
Number of peaks	0.000	0.000	0.000	0.000
Cluster 2 (n=7)	Average	SD	Min	Max
Period of stable force (Left)	0.421	0.227	0.200	0.800
Period of stable force (Right)	0.557	0.207	0.300	0.800
Period of decreasing force (Left)	0.486	0.367	0.200	1.000
Period of decreasing force (Right)	0.357	0.310	0.100	1.000
Number of peaks (Left)	2.714	1.113	1.000	4.000
Number of peaks (Right)	2.571	1.134	1.000	4.000
Cluster 3 (n=5)	Average	SD	Min	Max
Period of stable force (Left)	0.660	0.313	0.200	1.000
Period of stable force (Right)	0.900	0.141	0.800	1.100
Period of decreasing force (Left)	1.860	0.581	1.000	2.500
Period of decreasing force (Right)	3.120	0.804	2.000	4.000
Number of peaks (Left)	0.200	0.447	0.000	1.000
Number of peaks (Right)	0.000	0.000	0.000	0.000

Table 2. Test results of the longest and shortest braking distances from the samples and professional rider.

Rider Sample No.	Braking distance (Meters)	Peak right hand brake force, F (N) @ Time (sec.)	Peak left hand brake force, F (N) @ Time (sec.)
05	15.30	78.66 N @ 1.20 sec.	58.39 N @ 1.00 sec.
11	6.60	47.76 N @ 0.63 sec.	32.00 N @ 0.63 sec.
Professional	6.71	50.97 N @ 1.49 sec.	120.72 N @ 1.74 sec

To observe the number of finger usage during the brake test, the records from video camera showed that there were 10 samples that used the number of finger in the left hand more than that in the right hand. And 80% of these 10 samples applied four fingers to actuate the brake lever. Only three samples applied the right hand more than the left hand. It reveals that the riders require the handbrake force on the left hand more than that on the right hand. However, there were 17 out of 30 samples in which the equal number of finger usage in both hands was used i.e. 13, 3 and 1 samples for 4, 3 and 2 finger usages respectively. Based on the human hand dexterity, equal fingers from both hands do not indicate the equal hand force. There are 21 samples applying the left hand forces more than the right hand forces.

#### 4. Discussion

It also reveals that the samples averagely applied the left hand forces with shorter duration time more than another, even though only five riders are dexterous with the left hand. Therefore, the training skills of brake application for young motorcycle riders in Thailand under the emergency brake situation are necessary. However, the brake factor between the input hand level and the wheel brake force is dependent on the designs of brake systems in motorcycles. In the tested motorcycle, the left hand lever is longer than the right hand lever by 9 millimeter, resulting in the mechanical advantage. The brake test results from Thai professional rider over twenty years well-trained riding skill showed the same actuated time of brake application in both hands with the same rotated degrees through the output voltage of potentiometer at the fulcrum of handbrake lever as shown in Fig. 8. It shows typical stable pattern with equal grip span of well-trained rider. However, these results can be converted into the input hand forces as shown in Fig. 9. It



revealed that professional rider was intended to exert force on the left hand more than the right hand in order to complete the span of both handbrake levers. Therefore, it is generally necessary for riders to do trial brake tests for different brake systems in order to realize the braking distance through the mechanical advantage of handbrake levers from motorcycles.

From the brake test, 61% of samples showed the stable pattern with unequal grip span in the handbrake levers during the brake application. With this pattern, the front wheel was potentially subjected to high brake force more than the rear wheel. This is because the riders in this pattern were possibly attempted to exert equally both handbrakes. But the tested motorcycle has less brake factor in the left handbrake lever as shown in Fig. 9. Representative of the stable pattern in rotational degree of hand levers with unequal grip span of sample No. 13 is shown in Fig. 10. However, the control of the handbrake levers can be oscillated with unequal grip span as shown in Fig. 11. This pattern can be found for 23% of samples. This pattern reveals that the riders attempted to avoid both wheel lock conditions. There were 16% of samples attempted to increase rapidly and decrease gradually both lever spans during the brake application. Example of this pattern is shown in Fig. 12. It implied that the majority of samples do not understand how to utilize the road friction throughout the emergency brake application.

Based on the hand-force actuation against the various physical objects, the force measurement at the hand's rider on the brake lever in motorcycle is different from the force measurement in the clinical area which normally uses Rolyan, Jamar dynamometers and Martin vigorimeter [17] [18]. These devices are used to assess the grip strength of human being by occupational therapists in a range of clinical settings [19]. Therefore, the data from the measurement of hand force in this research are found to be lower than the grip strength. Furthermore, the handle dimension of cylinder bar such as motorcycle grip was found to have influence on the hand grip force [20]. Thus, the newly invented force measuring device in this research is developed to identify the handbrake pattern and force actuating on the lever with the potentiometer technique.

However, the invented device cannot measure the actuating force more than the certain value due to the limited rotation of the fulcrum of handbrake lever. To overcome this limitation, a silicon-based force sensor in a flexible package for finger-mounted applications can be used [21]. Alternatively, a new type of tactile sensor using pressure-conductive rubber with stitched electrical wires can be applied at the handbrake lever because it is thin and flexible and can cover object geometry [22].

In this research, the measurement of the left hand force was found to be higher than the right hand force. The volunteer riders also get used to apply the rear wheel brake on the left hand side with cable system which requires more force than the hydraulic system on the right hand side. And different usage of fingers and four different grip patterns were found in the volunteer riders. This might be the influence of mentally practicing a motor skill and cognitive task [23]. Furthermore, the driving experience and skill-oriented driving have more fluent in handling the vehicle, but lower in safety aspects of driving [24]. Young males and females involve in the frequency and accident likelihood of the risky behaviors [25]. Therefore, the safety value of education and training programs might prove to be effective in reducing collisions under the concern of critical age and experience related factors [26].

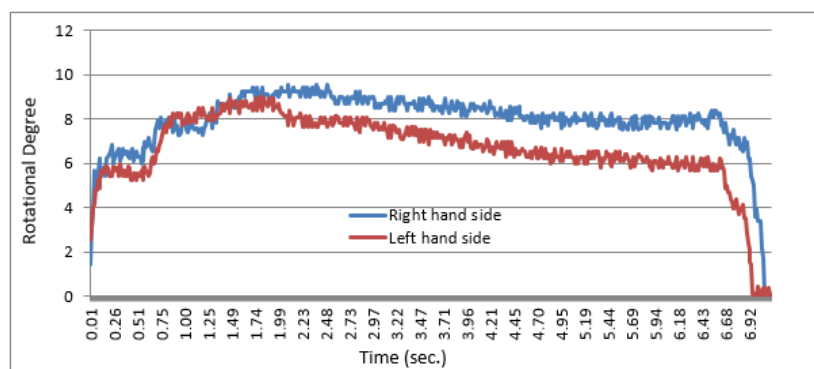


Fig. 8. Rotational degree at fulcrum of the handbrake levers from the professional rider under brake application.

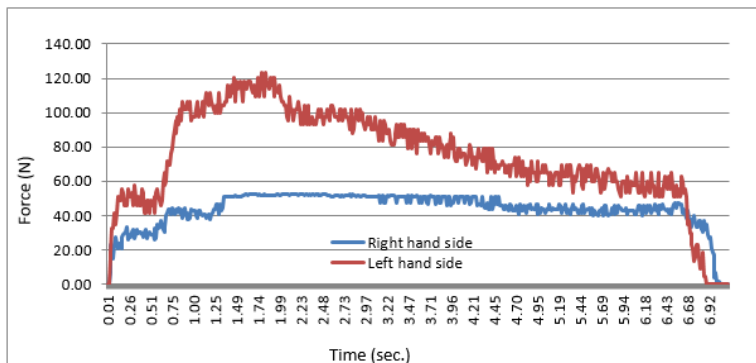


Fig. 9. Handbrake force inputs of the professional rider under the brake application.

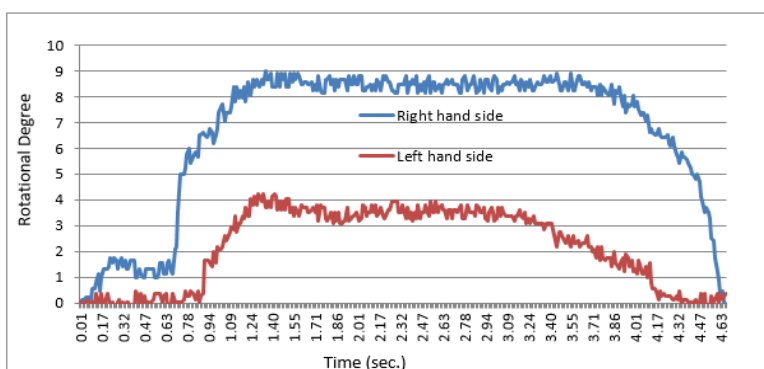


Fig. 10. Representative stable pattern in rotational degree of hand levers with unequal grip span of sample No. 13.

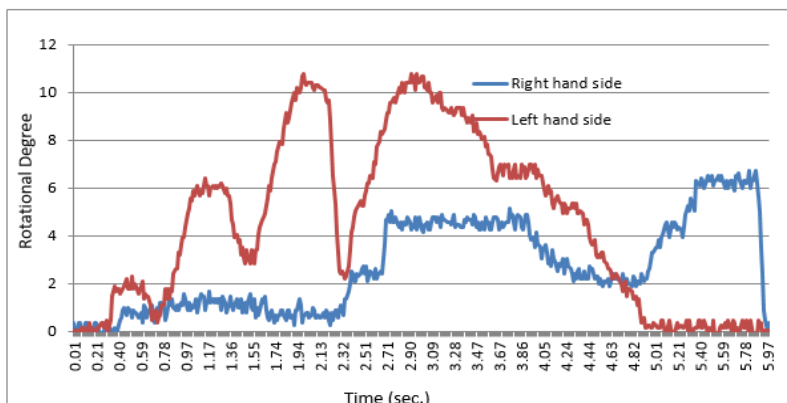


Fig. 11. Representative oscillated pattern in rotational degree of hand levers with unequal grip span of sample No. 17.

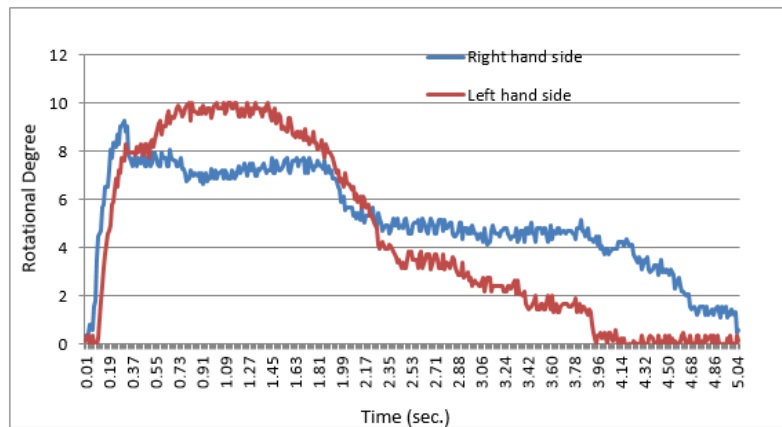


Fig. 12. Representative high and gradually decreased pattern in rotational degree of hand levers of sample No. 14.

## 5. Conclusions

- The invented device can be used to measure and monitor the rider behaviors in either hydraulic or cable handbrake systems. The distributed handbrake force can be converted to the input force according to UNECE Regulation No. 78
- Even though thirty volunteer riders are dexterous with the right hand, the mean of left hand force is more than the right one. This is because the tested motorcycle is equipped with the cable handbrake system on the left hand side to actuate the rear wheel brake. And the riders are familiar with the rear wheel brake on the left hand side. Therefore, the type of motorcycle brake system for each wheel is the key to exert the rider hand force for maintaining the same braking distance.
- Different usages of fingers in both hands of samples were found in the volunteer riders applying more number of fingers in the left hand side than that in right hand side in order to increase the handbrake force. However, over 50% of samples used the equal number of finger usage in both hands during the brake application.
- Four different grip patterns such as stable with equal and unequal grip spans, oscillation and initial peak can be used to represent the handbrake controls of Thai volunteer and professional riders. Such patterns and the response time affect the brake distance of motorcycle which is independent on the amount of handbrake force during the brake application.

## Acknowledgment

The authors would like to acknowledge Faculty of Engineering project No. 56-04-06-027, KMUTNB for financial support. Thanks also to Yamaha Riding Academy (Thailand) for supporting staffs and the brake testing area and especially to volunteers participated in the study.

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