

# EXPERIMENTAL STUDY OF THE EFFECT OF BRAKE DRUM COOLING GROOVES ON MOTORCYCLE BRAKING PERFORMANCE

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## Abstract

Some important indicators in the braking system performance on a motorcycle are the braking temperature and stopping distance. High temperatures due to frictional heat in the drum brake can decrease the braking force and cause a slip. To improve braking performance, an effective strategy is needed to reduce the drum temperature and shorten the stopping distance. This study aims to analyze the effect of cooling grooves on the standard brake drum to decrease the drum brake temperature and the length of stopping distance. The measurements were compared to the standard drum brake as a reference, and two types of the modified ones to increase the braking performance by adding the slant-grooved and a straight grooved on brake drum. Braking is performed by providing a compressive load of two kg on the brake pedal for three cases of motorbike speed: 20, 40, and 60 km/hour. The results show that the brake drum with straight cooling grooves provides better braking performance compared to other drum brakes. For a speed of 60 km/h, the temperature of the straight grooved brake is 3.5 °C. The stopping distance is 29.1 % shorter compared to the standard one. It shows that adding cooling grooves on drum brake can increase the effectiveness of motorcycle braking performance at various speeds. The results show that the brake drum with straight cooling grooves provides better braking performance compared to other drum brakes.

**Keywords:** motorcycle braking system, grooved drum brake, braking temperature, stopping distance.

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## 1. Introduction

The braking system is a very important device in a motorcycle design as safety prevention for riders [1]. Faulty brakes cause the vehicle to have a high risk of accidents. A survey shows that the faulty braking system is one of the main factors causing accidents in Indonesia between 2015 and 2017 [2]. The number of motor vehicle accidents in Indonesia caused by poor brake function was quite high [3].

In 2012, around 27 % of the total traffic accidents that occurred in Indonesia were caused by the faulty of the vehicle's braking system [4]. The Republic of Indonesia Government Regulation Number 44/1993 on Vehicles and Drivers draws up a rule on a roadworthy vehicle. A vehicle is roadworthy if it has a good braking system with the following requirements: the speed must be controllable; the brakes work on all wheels, or at least on two wheels side by side to balance the vehicles [5].

As a safety driving device on a motorcycle, braking systems can be classified into two main types; drum brake system and disc brake system [6]. The fundamental differences between them are the system's operation and the components of the braking system. For economic reasons, drum brakes are widely used in lightweight vehicles [7], such as motorbikes. Drum brakes have several benefits: cheaper and easier to maintain, simple to construct, capable of providing self-energizing effects, etc. [8]. Another advantage of the drum brake system is that it produces bigger stopping power if given the same amount of force on the pedal compared to the disc brake system [9]. However, there are some disadvantages in using drum brakes: brake noise, vibrations on the vehicle, excessive trapped heat, weak braking power, etc. [10, 11]. Moreover, the drum brake system has a closed construction that makes the temperature of the brake drum hotter because low convection cooling.

Drum brakes work based on the mechanical pressure principle between the brake lining attached to a fixed plate with the drum rotating along with the rotation of the wheels. Brake linings move radially against the drum so that there is friction between the two materials. This friction is slowing the vehicle following the given braking power. The stopping power is dependent upon the weight of the vehicle, the applied force, friction coefficient, the distribution of pressure on the surface of the brake lining, etc. [12, 13].

During the braking process, the friction on the surface of the material will reduce the vehicle's kinetic energy. Friction between the brake shoe and the drum brake will produce heat [14], which can increase the temperature of the brake lining and the drum [15]. A very high braking temperature will decrease the friction coefficient as well as the braking system performance [16] and cause thermoplastic deformation of brake materials [17, 18]. This condition is commonly called the braking fade [19, 20]. On the other hand, the heat generated during the braking process can cause material overheating and evaporation of the brake fluid. To avoid slipping and the decreasing of the coefficient of friction, this heat must be released immediately to the environment. Furthermore, inhomogeneous temperatures distribution on drum and brake shoes cause high-temperature gradients between surfaces called hot spots [21]. Uneven heat concentration in the material can cause high local stress and increase the fragility of the material [22]. In improving the braking performance, a cooling system is needed to release the trapped in the brake drum.

The braking temperature depends on the friction between drum brake and brake lining, the strength of the braking force, etc. A numerical study shows that the temperature of the drum brake parts rubbing directly with the brake lining can reach up to 120 °C, while the central and outer parts of the brake drum that do not rub the brake lining have a much lower temperature [23]. Other numerical studies show that the temperature of the drum brake during braking can reach up to 32.8 °C [24] and 85 °C [25].

Another important parameter that becomes an indicator of brake performance is the stopping distance. Stopping distance is the distance required for a vehicle to from starting braking until it completely stops. Stopping distance depends on several factors: vehicle characteristics (drag coefficient, vehicle weight), speed, and road conditions [26] and the type of brake and vehicle [27]. The stopping distance is directly proportional to the braking time. For safety reasons, the minimum braking time needed is 3 seconds [28]. Thus, the safe stopping distance for 60 km/h of speed is 40 m. The shorter the stopping distance, the better the performance of the brakes in avoiding crashes. A study shows that by using drum brake systems on both wheels, the stopping distance of Honda EX-5 is 14.31 m for riders without passengers. Similarly, Yamaha LC that uses disc brakes as the braking system has 13.36 m stopping distance for the same conditions [27]. Braking distance is closely related to braking time. Braking time is the accumulation of the driver's brake reaction time to respond when it sees obstacles and the time needed until the vehicle completely stops. The driver's reaction time ranges from 0.82–1.78 seconds [29]. On the other hand, the rims also influence the braking time and distance [30].

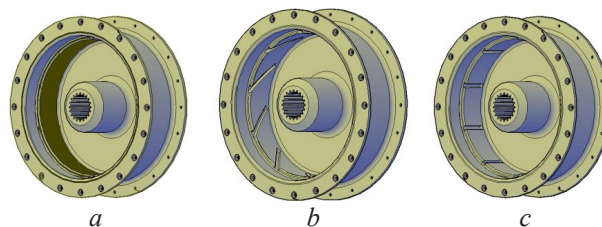
Some methods to improve the performance of motorcycle brakes have been performed. A drum brake design that maximizes the cooling effect can significantly prevent the brake fade. There are several techniques to accelerate heat transfer from the braking chamber to the environment: spraying water into the brake drum [31], cooling using other fluids [32], adding grooves to the drum or brake lining, etc. [33, 34]. However, direct spraying of cooling water into the brake drum can shorten the service life of the brake drum [31]. A study on thermal analysis of motorbikes braking systems showed that the brake systems with air ventilation holes on its discs have better heat dissipation than the brake with solid disc [35]. Besides, the braking method also significantly influences the brake fade in the vehicle brake system [36]. Braking optimization, from various parameters such as aerodynamic effects and vehicle maneuvering techniques, have been studied [37]. However, improper braking techniques can cause damage to the drum brake: depth color change, worn out drum brake lining, permanent scratch marks, varying wall thickness on brake panel, and brake panel material peel off [16].

Another technique in reducing the braking temperature is the addition of grooves on the brake drum that serves as the air cooling ventilation duct and release the braking friction dust. Heat dissipates from drum brake by conduction, convection, and radiation. Several previous studies regarding the addition of grooves to brake linings are presented in literature studies [33, 34]. However, adding grooves on drum brake accelerates brake shoe wear. During braking, the grooves on the drum brake will scrape the surface of the brake lining and make it worn out faster.

This experimental study aims to analyze the effect of the cooling groove on the brake drum on the braking performance. The groove on the brake drum functions as a cooling air inlet to remove excess heat and dispose of residual brake dust into the environment to reduce braking temperature. Braking performance is measured based on two indicators; brake drum temperature and stopping distance of the braking. Measurements of brake drum temperature and stopping distance are performed on a standard drum brake and two modified ones; a slant-grooved brake drum and a straight-grooved brake drum.

## 2. Materials and Method

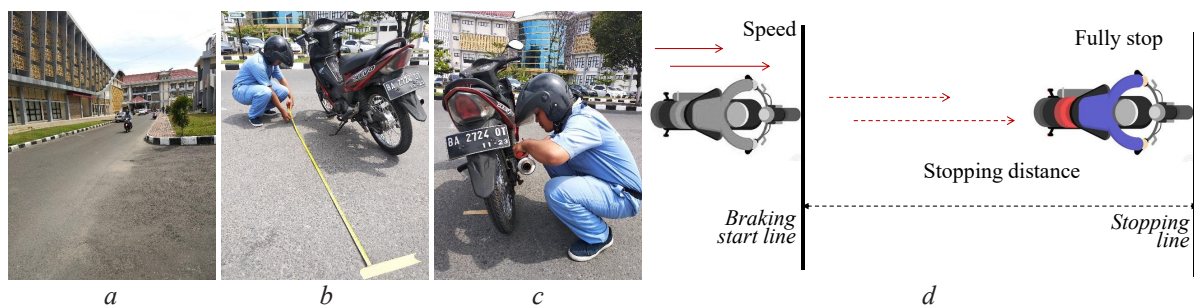
Performance parameters analyzed in this experimental study are (1) the outside surface temperature of the brake drum just after the braking and (2) the stopping distance of the braking (**Fig. 2, d**). The object of research is three brake drums with identical geometry and size. All brake drums have identical dimensions, with outer diameter  $D_{out}$  170 mm, inner diameter  $D_{in}$  130 mm and a thickness ( $t$ ) of 45 mm (**Fig. 1, a**). The measurement of temperature and braking distance is carried out on a motorcycle with a standard drum brake without modification (**Fig. 1, a**) and two other drum brake modified by adding a cooling groove with diameter  $D_g$  of 5 mm inside the drum with two different patterns: slant grooves with inclination  $45^\circ$  (**Fig. 1, b**) and perpendicularly straight grooves (perpendicular to brake lining's rotation) (**Fig. 1, c**). The number of grooves on each modified drum is 10, so the distance between the grooves is  $\pm 40$  mm. The diameter of grooves is not significant compared to the thickness of the drum material, so the presence of grooves has no important effect on the strength of the drum.



**Fig. 1.** Case studies with several drum conditions: *a* – unmodified brake drum, *b* – slant-grooved brake drum with  $45^\circ$  inclination, and, *c* – straight-grooved brake drum (perpendicular to brake lining's rotation)

The experiment was carried out on a straight road in Universitas Negeri Padang (**Fig. 2, a**). The road is made from dry asphalt, flat, and clean from the sand. The studied vehicle is Honda

Revo made in 2007. The types of brakes in the vehicle are the leading and trailing brakes. The tire pressure during the experiment was 30 psi. Based on the L-type motor vehicle brake testing method following SNI-4404 [38], measurements were carried out at three different speeds: 20, 40 and 60 km·h<sup>-1</sup> [38]. These speeds are determined based on the average speed of motorcycle in Indonesian cities and the maximum allowable vehicle speed according to the Indonesian transportation regulation [39–41]. The braking process is carried out by giving a 2 kg load on the brake pedal. The distance of the vehicle before braking is 400 m. Braking distance is measured using a manual roll-meter with accuracy  $\pm 5\%$  (Fig. 2, b) while the outside temperature of the drum brake is measured using a digital infrared thermometer IR 60i with  $-50$ – $600$  °C range of temperature and the accuracy is 1 °C (measurement below 100 °C) or 2 % (measurement above 100 °C). The temperature is measured on the outer surface of the brake drum as shown in Fig. 2, c. Another tool used in this research is the toolset for removing the drum brake from the motorcycle. To minimize errors, measurements were carried out three times for each different speed and brakes. The results of braking temperatures and stopping distance measurements are the average values obtained in each case.



**Fig. 2.** The experiment process: *a* – the road for experiment condition; *b* – the process of braking distance measurement; *c* – temperature measurement; *d* – the stopping distance of the braking

### 3. Results and Discussion

The results of the drum brake temperature and stopping distances measurements for the three types of drum brakes with different speeds are shown in **Table 1**. The data shown in **Table 1** is an average value of three measurements.

**Table 1**

The brake temperature and the length of the stopping distance for the three different drum brake and speeds

| Case study                             | Speed (km·h <sup>-1</sup> ) | Temperature (°C) | Length of Stopping distance (m) |
|--|-----------------------------|------------------|---------------------------------|
| Case-1: Unmodified standard brake drum | 20                          | 33.9             | 7.4                             |
|  | 40                          | 35.7             | 19.1                            |
|  | 60                          | 40.8             | 37.5                            |
| Case-2: Slant-grooved brake drum       | 20                          | 32.3             | 6.1                             |
|  | 40                          | 35.2             | 16.8                            |
|  | 60                          | 39.6             | 31.8                            |
| Case-3: Straight-grooved brake drum    | 20                          | 31.3             | 4.4                             |
|  | 40                          | 33.6             | 11.4                            |
|  | 60                          | 37.3             | 26.6                            |

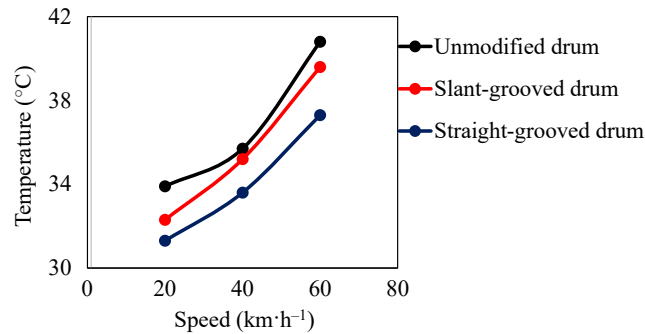
#### 3.1. Temperature profile on the brake drum

The braking temperature for each brake lining for different speeds is shown in **Fig. 3**. For all types of brakes, the braking temperature increases as the speed increase. The faster the movement of the vehicle, the higher the kinetic energy converts into heat. The standard brake temperature increased from 33.9 °C to 35.7 °C and 40.8 °C for speeds of 20 km·h<sup>-1</sup> to 40 and 60 km·h<sup>-1</sup>.

From the comparison of temperature measurements on the three types of drum brakes, the highest braking temperature is on the standard drum brake without modification. At a speed of

60 km·h<sup>-1</sup> the braking temperature reaches 40.8 °C. By adding cooling grooves, the temperature has reduced significantly. At the same speed, the temperature dropped to 39.6 °C on the slant-grooved drum brake, and 37.3 °C on the straight-grooved drum brake (**Table 1**).

In the thermal aspect, the cooling grooves are able to increase the convective cooling on the inner surface of the brake drum. Heat in the brake lining and drum will be evacuated to the environment by convection along with air circulation in the grooves.



**Fig. 3.** Braking temperature profile at different speeds

The straight-grooved drum shows the best cooling performance compared to the other two drum brakes. The braking temperature can be reduced by 3.5 °C compared to the unmodified drum brake. This temperature drop is caused by the convective heat transfer through the cooling groove hole. The environment air, with a lower temperature than the brake lining, will flow naturally into the grooves and dissipate heat trapped in the drum into the environment. The straight grooves on the drum allow air to circulate properly from one side to another. The sloping groove produces less air circulation and dissipates less heat to the environment.

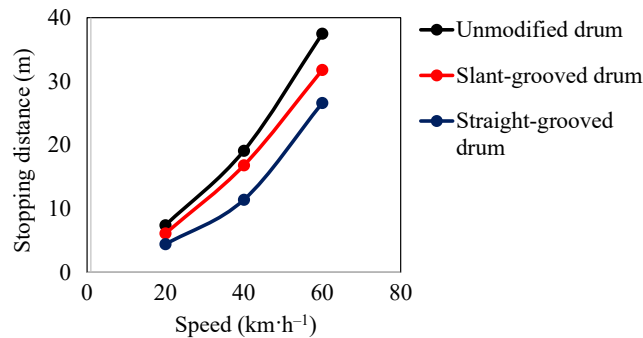
### 3. 2. Braking stopping distance

Based on the measurement results obtained that for all types of drum brakes, stopping distance increases as the speed increase. The change in the kinetic energy on a moving vehicle explains this issue. The higher the speed, the greater the kinetic energy. When kinetic energy and speed increase with a fixed braking force, the stopping distance will be longer. For the unmodified drum brake, stopping distance of the one with 20 km·h<sup>-1</sup> of speed was 7.41 m (**Table 1**), whereas, for the 40 and 60 km·h<sup>-1</sup> of speed vehicles, this distance increased significantly to 19.1 m and 37.5 m. At 60 km·h<sup>-1</sup> of speed, the slant and straight grooved drum brake show 16.8 and 11.4 m braking distance, consecutively (**Table 1, Fig. 4**). Furthermore, for the 60 km·h<sup>-1</sup> of speeds, the stopping distances for the three types of drum brakes are 37.5, 31.8, and 26.6 m (**Table 1**). The riders need to be aware of the changes in stopping distance to help them estimate the minimum distance allowed in the braking process, especially if obstacles suddenly appear in front of the vehicle.

In **Fig. 4** it is possible to observe that the increase in stopping distance is not similar to the increase in speed. This exponential increase of stopping distance explains how the brake fade occurs due to an increase in temperature during the braking process. The heat on the surface will make the brake lining and the drum saturated, and reduce the coefficient of friction between the two.

The comparison of stopping distance for the three cases of drum brakes can be observed in **Fig. 4**. The motorcycle with an unmodified brake drum requires a longer braking distance compared to the other two types of grooved drums. At a speed of 20 km·h<sup>-1</sup>, the stopping distance required for the motorbike to completely stop is 7.4 m (**Table 1**). The stopping distances for the other two drum brakes that have been modified are shorter. The distances are 6.1 m for the slant-grooved brake and 4.4 for the straight-grooved brake. The decrease in stopping distance in the grooved drum brake happens due to an increase in surface roughness. Therefore, it will also increase the frictional force. When turning, the grooves on the drum will hit the surface of the brake lining and increase the friction significantly. The measurement results for all three-speed levels (20, 40, and 60 km·h<sup>-1</sup>) are convergent. Regardless of the speed, the stopping distance in

the standard drum brake is always longer than the grooved drum brakes. It shows that the addition of the groove can increase the surface friction force and reduce the slip between the drum and the brake lining.



**Fig. 4.** Variation of stopping distance according to motor cycle speed for different types of brake drum

The reduction in stopping distance due to the influence of grooves compared to the unmodified drum brake can be seen in **Table 2**. The reduction in stopping distance in the slant-grooved brake drum compared to the reference drum brake is between 1.3 and 5.7 m which is equivalent to 12 % to 17.6 % reduction (**Table 2**). Whereas in straight-grooved brake drums, the decrease in stopping distance length ranges from 3 m to 10.9 m, which is equivalent to have a 29.1 % to 40.5 % decrease (**Table 2**). The significant decrease in stopping distance for the straight-grooved drum brake case due to the perpendicular direction of the grooves to the direction of the drum rotation. The perpendicular scrubs on the grooved drum brake will reduce the risk of the brake lining slips.

**Table 2**

The reduction of stopping distance for grooved drum brake

| Speed (km·h <sup>-1</sup> ) | Stopping distance           |                    |               |                      |               |
|-----------------------------|-----------------------------|--------------------|---------------|----------------------|---------------|
|                             | Unmodified drum (Reference) | Slant-grooved drum |               | Stright-grooved drum |               |
|                             | Length (m)                  | Length (m)         | Reduction (%) | Length (m)           | Reduction (%) |
| 20                          | 7.4                         | 6.10               | -17.6         | 4.4                  | -40.5         |
| 40                          | 19.1                        | 16.8               | -12.0         | 11.4                 | -40.3         |
| 60                          | 37.5                        | 31.8               | -15.2         | 26.6                 | -29.1         |

This study describes the advantages of modifying the brake drum by adding a cooling groove on the inner surface of the drum. This research can be used as a practical benchmark for motorcycles used in urban areas with a maximum speed limit of 60 km/hour. For motorcycles with high speed, it is necessary to carry out further experiments by increasing the maximum speed of the motorcycle. In addition, the results of this research are limited to small light-weight motorcycles.

#### 4. Conclusions

The results of measurements conducted on the three types of drum brakes present the advantages of adding cooling grooves on drum brake on the braking performance. The cooling grooves function as a cooling air inlet to remove excess heat and dispose of residual brake dust into the environment and give a positive effect on decreasing the braking temperature and stopping distance. It happens because of the increase in the coefficient of friction caused by the high sanding friction of the groove in the brake lining reduce the slip to both surfaces. Furthermore, in terms of thermal, adding grooves increase the convective cooling effect of natural circulating airflow in the

grooved-drum brakes. Air that passes through the groove hole will carry heat trapped in the drum to the environment. When compared with the other two types of drum brakes, the straight-grooved drum brake shows a better performance in providing a cooling effect which is able to reduce the braking temperature and stopping distance up to 3.5 °C and 40.5 % compared to the unmodified one, respectively. Since the grooves are perpendicular to the drum rotation direction, it provides a higher friction effect on one side and increases the cooling effect through maximum air circulation on the other side. Besides, the braking dust causing braking fades can be disposed of through the drum brake's groove gap. However, further research has not been discussed in this study related to the effect of drum grooves on brake endurance is needed.

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