Performance of a fully mechanical parking brake system for passenger cars

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Abstract. In order to ensure that a vehicle remains stationary when it is parked at a certain road slope, the driver has to apply sufficient pulling force on the handbrake lever. Otherwise, the vehicle will start to rollaway where the torque generated by the parking brake system is lower than the torque required by the vehicle to remain stationary. This poses a danger situation not only to the vehicle’s occupants but also to the people surrounding it. Thus, this paper aims to investigate performance of a typical parking brake system used in passenger cars. A theoretical model of drum-type parking brake system is derived and later being validated by test data that measured from the parking brake test bench. A good agreement is achieved between calculated and test results. Results from the model show that the parking brake system used in this work can hold the vehicle stationary at 11 degree slope less than 200 N of the applied force and thus it meets the regulation requirement, and also the vehicle will not rollaway even though there are four adult passengers inside it.

1. Introduction

In a ground vehicle, mechanical parking brake unit is a mechanism that used to hold the vehicle stationary either on the even or slope road. It consists of a cable (usually adjustable for length) directly connected to the brake mechanism on one end and to a mechanism that can be actuated by the driver on the other end. This actuating mechanism is often a hand-operated lever on the floor on either side of the driver, or a pull handle located below and near the steering wheel column or a (foot-operated) located far apart from the other pedals [1].

European Economic Community (EEC) regulation [2] specified that the handbrake system of a laden vehicle in class M1 (passenger cars comprising no more than eight seats in addition to the driver's seat) must be able to hold vehicle in 20% gradient. FMVSS 135[3], on the other hand, stated that the vehicle should able to stay stationary on 20% grade road for 5 minutes in both forward and reverse direction with 400N or less force applied at hand control mechanism.

To date, there is wealth information available in the open literature to evaluate braking performance for the service brakes [4-8], but very limited studies have been done on the parking brakes. For instance, McKinlay et al [9, 10] investigated conventional parking brake performance in term of vehicle rollaway for the disc brakes through laboratory tests and theoretical approaches. In the theoretical approach a one-dimensional (1-D) model of disc-type parking brake system using simple linear spring element had been proposed and analyzed to predict clamping force. A laboratory parking brakes test rig had been developed to measure clamping force of the parking brakes system which is
used to validate results from the 1-D model. In the studies, they considered thermal effects on the braking torque and subsequently vehicle rollaway. To authors’ knowledge, there is no information available in the public domain to investigate performance of on drum-type of parking brakes system through theoretical and laboratory test approaches. Thus, this paper attempts to establish mathematical model of parking brake and develop reliable laboratory parking brake test bench in order investigate and assess parking brake performance.

2. Theoretical Model

In order to study performance of the parking brake system, a mathematical model is derived based on diagrams given in figure 1(a) and 1(b). Thus, it can be deduced that the torque produced by the drum-type of parking brake in the forward and reverse directions are given in Eqs. (1) and (2), respectively.

\[
T_{\text{forward}} = \mu * r_d * F_{hb} * 8.8333 \left[ \left( \frac{l_d * l_f}{l_e + \mu * l_h} \right) + \left( \frac{l_m * l_j}{l_e - \mu * l_h} \right) \right] \tag{1}
\]

\[
T_{\text{reverse}} = \mu * r_d * F_{hb} * 8.8333 \left[ \left( \frac{l_d * l_f}{l_e - \mu * l_h} \right) + \left( \frac{l_m * l_j}{l_e + \mu * l_h} \right) \right] \tag{2}
\]

where \( \mu \) is coefficient of friction, \( F_{hb} \) is handbrake force and \( r_d \) is radius of the drum.

![Diagram](image1.png)

(a) Hand lever mechanism

![Diagram](image2.png)

(b) Drum brake

**Figure 1.** One-dimensional parking brake model.
The torque required to hold a passenger car stationary on a slope road can be estimated based on the free body diagram as shown in figure 2. Thus, the required torque to hold the vehicle can be given as follows;

\[ T_{req} = \mu_c \cdot F_r \cdot r_{wheel} = mg \sin \theta \cdot r_{wheel} \]  \hspace{1cm} (3)

where \( m \) is the vehicle weight, \( \theta \) is the road slope, \( g \) is the gravity and \( r_{wheel} \) is radius of the wheel.

Figure 2. Free body diagram of a vehicle on the slope

3. Experimental Work

The experiment is conducted using parking brake test bench as shown in figure 3 and all data are captured and recorded by Dewetron data logger[11]. The bench consists of a set of parking brake mechanism connected to a pair of rear-drum-brake unit, two hydraulic pumps, an actuator, a flywheel, a 5.5 kW motor with speed controller, and one load cell. The parking brake unit is taken from one of the national passenger cars. One of the hydraulic pumps is used to supply brake pressure to the drum brake and to heat up the brake unit, whilst the other one is connected to the actuator which is used to pull a cable that connects to the flywheel and the load cell. This will measure brake torque produced by the drum brake unit when the hand lever is being pulled. In order to engage the parking brake, force on the hand lever is applied using deadweight by connecting them through a cable.

Figure 3. Parking brake test bench.
4. Results And Discussion

It can be seen in figure 4(a) and 4(b) that there is good correlation achieved between model and test results within 200 N of the applied force. It is also shown that the parking brake torque is increased with the increase of applied force. It is noticed that the torque in the forward direction is slightly lower than the torque in the reverse direction. This is due to design of the leading-trailing type of a drum brake unit [1]. Table 1 shows value of the parameters used in this work.

Table 1. Value of the parameters used in the model and experiment

| Parameter | Model Value | Parameter | Experiment Value |
|-----------|------------|-----------|-----------------|
| $\mu$     | 0.25-0.28  | $M$       | 1150 kg         |
| $r_d$     | 0.091 m    | $r_{wheel}$ | 0.289 m       |
| $l_c$     | 0.022 m    | $G$       | 9.81 m/s$^2$   |
| $l_d$     | 0.113 m    |           |                 |
| $l_e$     | 0.068 m    |           |                 |
| $l_f$     | 0.112 m    |           |                 |
| $l_h$     | 0.070 m    |           |                 |
| $l_j$     | 0.135 m    |           |                 |

(a) Forward direction

Figure 4. Correlation of the parking brake torque between model and experiment.
4.1. Effect of road slope

It is interesting to see performance of the parking brake with various road slopes. FMVSS 135 [3] stated that a vehicle must be stayed stationary for five minutes at 20% slope (or 11 degree slope) with 400 N applied force. Figure 5(a) and 5(b) show that the vehicle is not rollaway at 400N because the torque at 11 degree is very much lower than the torque produced by the parking brake (PB Torque). It is also shown that the minimum forces required to hold the vehicle stationary are 60N (4 degree), 120N (8 degree) and 180N (11 degree) for forward direction and 58N (4 degree), 110N (8 degree) and 160N (11 degree) for reverse direction.

(b) Reverse direction

Figure 4 (continued). Correlation of the parking brake torque between model and experiment

Figure 5. Parking brake performance at different road slopes.
4.2. Effect of passenger weight
The effect of passenger weight is also studied up to four adult passengers with 70kg each. It can be seen in figure 6(a) and 6(b) that the vehicle remains stationary up to 4 passengers when the force applied by the driver is 400N. The minimum force needs to be applied with 4 passengers is 220N in the forward direction and 200N in the reverse direction.

(a) Forward direction
Figure 6. Parking brake performance with various number of passengers.

(b) Reverse direction
Figure 5 (continued). Parking brake performance at different road slopes.
Figure 6 (Continued). Parking brake performance with various number of passengers.

5. Conclusion
From the study, it can be deduced that:
- The parking brake model is valid where good correlation is achieved between calculated and measured results,
- Due to design of the leading-trailing type of drum brake unit, the torque produced in the forward and reverse direction is slightly different,
- The parking brake system is complied with FMVSS 135 regulation,
- The vehicle will not rollaway at 11 degree slope and with 4 passengers inside it.

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