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Comparison of braking performance between mechanical and dynamic braking for Electric Powered Wheelchair

S M Asyraf[1,2], P M Heerwan[1,2*], I M Izhar[1,2], I M Zulhilmi[1,2], I M Sollehudin[1,2]
[1]Automotive Engineering Centre (AEC), Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
[2]Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

*Corresponding author: mheerwan@ump.edu.my

Abstract. Braking is the necessary system need to install as the safety feature for the moving transportation. Using the mechanical braking only as primary braking system in Electric Transportation (ET) is insufficient due to some issues such as low strength users hand gripping and abruptly tire locking during braking especially on wet surface condition. In this paper, the performance between mechanical and electrical braking which is by using dynamic braking concept is proposed to enhance the braking performance of Electric Powered Wheelchair (EPW). The experiments were conducted during descending on the slope under wet and dry pavements. From the results of slip ratio, the slipping time between mechanical and dynamic braking in dry pavement is recorded 0.9 seconds and 0.7 seconds respectively. Meanwhile, it is observed that tire is fully locked-up for mechanical braking under the wet surface. However, by using the dynamic braking, the wheel does not lock-up and the slipping time was recorded 1.4 seconds. It can be considered that, mechanical and dynamic braking give their own merit. The high braking torque from mechanical braking is suitable to use under the dry pavement for the short stopping distance. The other sides, braking under the wet pavement, dynamic braking is more efficient compare to the mechanical braking in term of short slipping time and does not cause tire to lock-up while braking.

1. Introduction

The used of wheelchairs are increasing every year due to the increase numbers of disabled people and elderly. From the "World Population Prospects: The 2012 Revision" conducted by the UN estimating that the population is 65 and above is 16.5% by 2060 [1]. Moreover, there are almost 200 000 disabled people use wheelchairs as transportation in daily [2]. Meanwhile, in Japan, electric powered wheelchair (EPW) sales reached 530 00 units at the end of 2008 and sales continued to rise due to the age and ability factor [3].

EPW used electric motor as a drive system. There several advantages of the electric motor such as small size but powerful output, can generate the electric motor braking force and the motor torque can be controlled individually. Based on these advantages, the research related to the EPW are becoming popular and led many researchers to improve of the functionality, dynamic and stability [4,5].

Another most important thing in dynamic control of transportation is the braking control system. Nevertheless, research related braking for Electric Powered Wheelchair (EPW) is still in small amount. In general, the braking system is one mechanism to create retarding torque to stop the tire rotation with sudden or slow stop depending on the situation. Development of efficient and effective braking system for transportation applications has been a subject of continuous study over the years. A number of braking techniques used in electrical transportation has been reported in literature [6–9]. The technique of braking system can be divided into two types; frictional braking and electrical braking. Frictional braking such as mechanical braking system is the basic component for the wheelchair. While the electrical braking system is the additional braking system for the EPW and it can be divided into three systems; dynamic, plugging ad regenerative.

For the mechanical braking system, the users need to grasp the braking lever to control the speed of EPW especially during descending on slope. In fear condition, users tend to give the sudden braking that also known as panic braking which 100% hand gripping is applied to the brake lever. Thus, the EPW will stopped abruptly. However, when panic braking is applied under the wet pavement, the tire of EPW will be locked up and EPW will skid. This will cause an accident as well as injuries to the users.

In this study, since the EPW is drive by the electrical motors, it is practical to implement the electrical braking in EPW system. The dynamic braking concept is proposed as the alternative braking for EPW during descending on the slope. The mechanical braking system is compare with the dynamic braking system to analyse the efficient braking performance.

2. Electric Powered Wheelchair (EPW) model

Electric Powered Wheelchair (EPW) is made up with many parts and equipped with various type of sensors. Figure 1 and Table 1 shows the parts and specifications of EPW that used in this experiment.

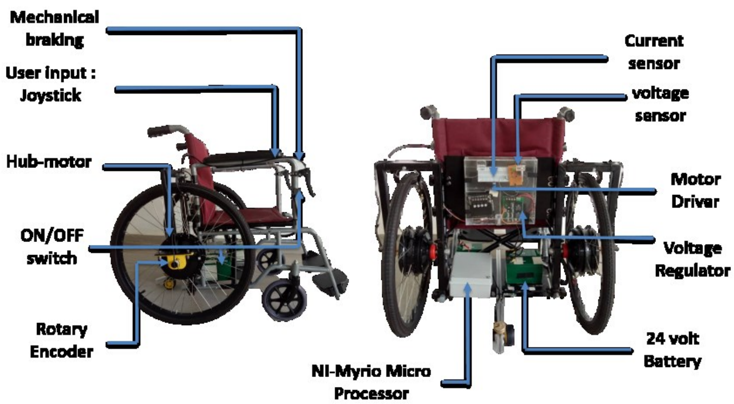


Figure 1. Parts of Electric powered wheelchair (EPW).

Table 1. Specification of EPW

Feature	Specification
User input	Two step speed joystick
Type of motor	In-wheel Brushless DC
Maximum speed (m/s)	2.7
Operating voltage (Volt)	24~36
Mass without patient (kg)	25
Type of battery	Lithium Ion
Dimension (m)	L0.4 x W0.6 x H0.4

2.1 EPW sensors

There are several sensors that equipped in EPW. In this experiment, there are two type of sensors that used in this experiment which are rotary encoder sensors which is to acquire the speed of tire and the third wheel tire is to acquire body speed as shown in Figure 2(a) and 2(b).

(a) (b)

Figure 2. (a) Tire speed sensor (b) Body speed sensor

2.2 Braking system in EPW

2.2.1 Mechanical braking. This braking concept is to reduce the speed of tires by applying friction to the rotating part such as a rotor. There are two common types of mechanical braking for low speed transportation which are disk and caliper. Equation 1 and Figure 3 shows the standard mechanical braking equation and the caliper braking parts that used in EPW.

$$\frac{T_g - T_f - T_{mb}}{J} = \frac{T_g - T_f - (F_{grip} x R_{clamp})}{J} = \frac{d\omega}{dt} \quad (1)$$

T_g : Torque generation due to gravitational pulling force

T_f : Frictional Torque (N.m)

T_{mb} :Mechanical Braking Torque (N.m)

J :Tire Inertia (kg.m^2)

$\frac{d\omega}{dt}$: Rotational acceleration (m/s^2)

The brake caliper will grasp the rotating tire and produces the braking torque from the friction between braking pad and tire rim when the brake lever is gripped. The more gripping is given to the lever, the more braking torque produce and caused EPW stopped immediately.

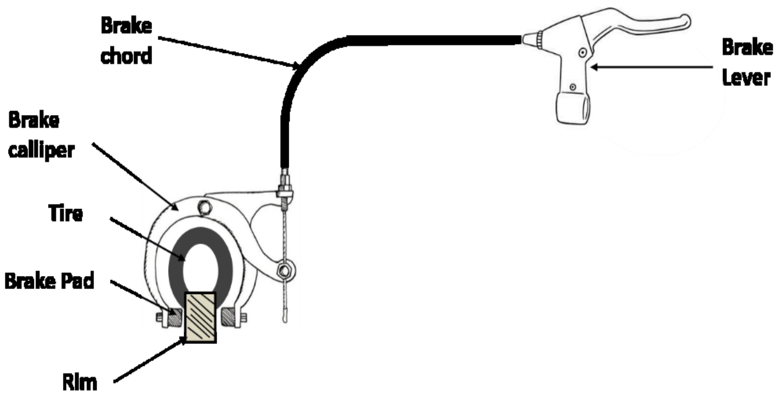


Figure 3. Mechanical braking system.

2.2.2 Dynamic braking. The concept of this braking is by resisting the current flow by using internal resistor inside electrical motor itself. As shown in Figure 4, when voltage supply is cut off (switch S1 cut off), the motor operation is changed into generator that generate the voltage (back EMF) as shown in Equation 2. The current will be flowing reversely when the switch 2 (S2) is closed. As result, the current is resisted and dissipated into the internal resistance inside the motor that caused braking torque is produced and the rotational speed reduced as shown in Equation 3. Thus. when the internal resistor is higher, the rotational speed will reduce faster.

$$V_{emf} = -K_b \omega = Ri \tag{2}$$

$$\frac{T_g - T_f - T_{eb}}{J} = \frac{T_g - T_f - (K_t i)}{J} = \frac{d\omega}{dt} \tag{3}$$

T_g : Generation torque due to gravitational pulling force
K_b :back EMF constant
R : Resistance (Ω)
i : Current (Amp)
T_f : Frictional Torque (N.m)
T_{eb} :Electrical Braking Torque (N.m)
J :Tire Inertia (kg.m^2)
$\frac{d\omega}{dt}$: Rotational acceleration (m/s^2)

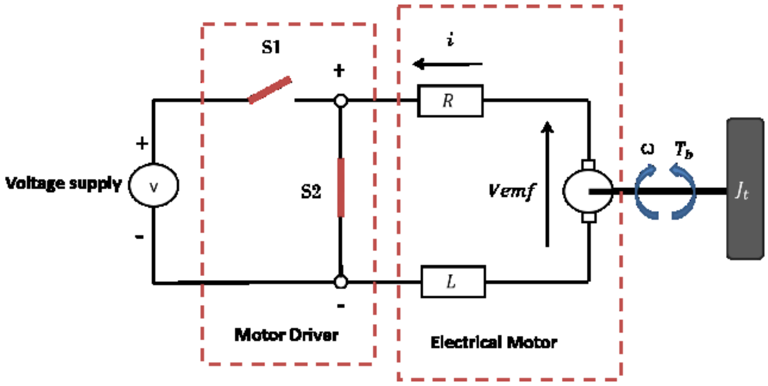


Figure 4. Dynamic braking conceptual.

3. Experimental setup

3.1 Slope condition setup

The experiment is conducted on the slope for wheelchair that located at Students Activity Centre in Universiti Malaysia Pahang (UMP). First, the condition of experiment site need to be identify such as degree and length of slope. According to American Disability Acts (ADA), there are several standards for slope of wheelchair need to be follow.

The first requirement is the slope percent that not more than 1:12 ratio. Then, the rise of slope is not more than 22 inch (0.76 meter) [10]. However, in this experiment the degree of slope is already set more than ADA requirement that equal to 7.8 degree average that had been measured by using tilt sensor. Thus, the length of slope is set 4.5 meters based on the maximum rise standardized by ADA. The condition surface of slope is setup in two condition which are dry and wet mosaic. The details of slope are shown in Table 2.

Table 2. Slope condition setup for experiment

Specification	Requirement
Slope	7.8 degree
Rise	0.56 meters (ADA requirement)
Length base on maximum rise	4.5 meter
Surface condition	Dry and wet mosaic

3.2 Mechanical Braking procedure

The mechanical braking will be analysed at the slope as state in Table 1. In the dry surface condition analysis, EPW will be drive at constant speed 1 m/s. The voltage supply is cut off when the EPW entered the slope and at the same time the 100% gripping level is applied to the brake lever which same as panic braking as shown in Figure 5 until the EPW stopped or reach more than 4.5 meter slope length. Next, For the braking analysis in wet surface condition, the experiment is repeated same as dry surface condition braking analysis procedure.

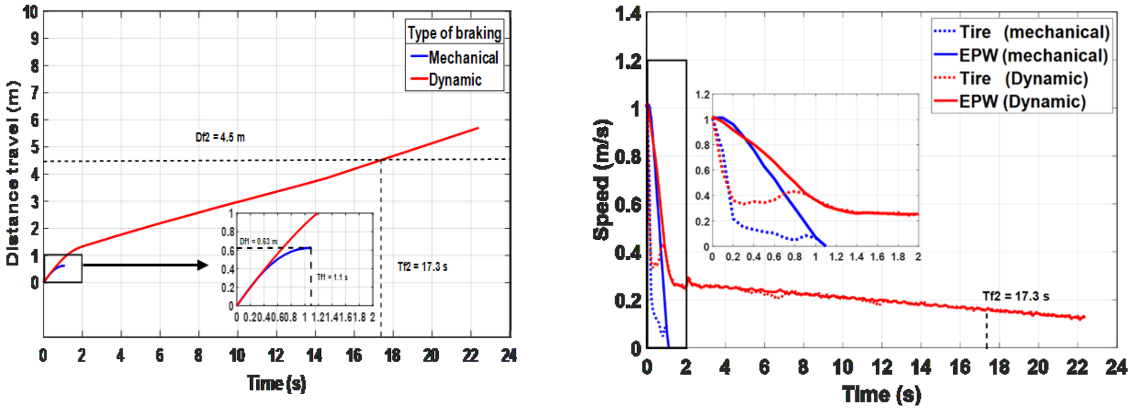
Figure 5. 100% hand gripping.

3.3 Dynamic braking procedure

The EPW will be drive at constant speed 1 m/s by switch on the S1 switch. The voltage supply is cut off (switch S1 open) when the EPW reached on the slope condition and dynamic braking is applied by closing the switch S2 until the EPW stopped or reached more than 4.5 meter slope length. Lastly, the experiment is repeated at wet surface condition same with the previous dry condition procedures. The experiment need to be repeated in several times for the accuracy and precise tabulate data analysis acquired.

4. Results and discussion

Figure 6(a) shows the distance travel of EPW when braking is applied at speed 1 m/s in dry surface condition. Solid blue line indicates the distance travel of EPW when the 100% hand gripping mechanical braking is applied. From the plotted graph, it is shown the EPW is stop before reaching 4.5 meter of slope length. The stopping time and distance was recorded 1.1 second and 0.63 meters respectively. Solid red line indicates the distance travel of EPW when dynamic braking is applied at speed 1m/s in dry condition. As shown in graph, the distance travel of EPW is exceeded the requirement length by ADA and the time was recorded 17.3 s at distance 4.5 meters.



(a) (b)

Figure 6 (a) Distance travel during braking at 1 m/s in dry surface (b) speed of EPW during braking at 1 m/s in dry surface

Figure 6(b) shows the speed of EPW and tire when braking is applied at speed 1 m/s in dry surface condition. At speed 1m/s, it seems the speed of tire which represent as blue dotted line is quickly dropped and the speed of EPW (solid blue) decelerated until stopping in 1.1 s when the mechanical braking is applied. Meanwhile, when the dynamic braking is applied, the speed of tire (red dotted) does not shows abruptly decrease as mechanical braking. This is because the dynamic braking produced the small braking torque than mechanical braking. The speed of EPW (solid red) is quickly decelerated However, in 1.4 s the EPW is still moving descending on slope with the lower deceleration. This is happened because of the gravitational force that pulled the EPW downward is more than braking torque produced by dynamic braking.

Slip ratio plot is used to show the behavior of tire and EPW when brake was applied. Tire will defined as sliping when the slip ratio is exceed than 0.2. This is the optimal slip ratio value which the tire at the higher gripping force with the surface of road. Figure 6(c) shows the slip ratio between mechanical and dynamic when braking on dry surface condition at speed 1m/s.

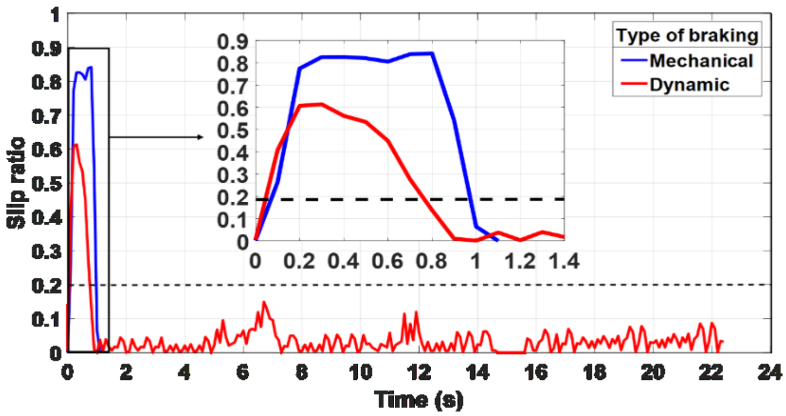


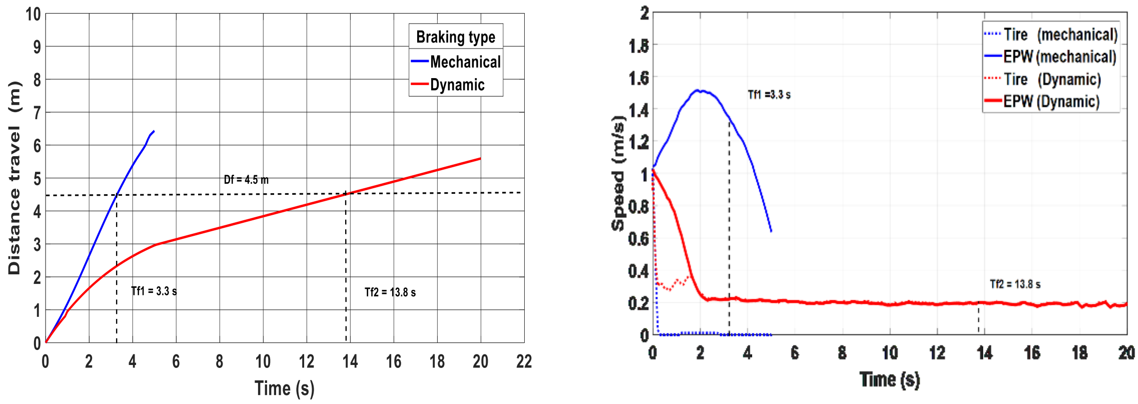
Figure 6(c) Slip ratio of braking by using different braking type at dry condition.

Blue and red line is indicate the slip ratio when the mechanical and dynamic braking respectively. From the both plots, it is shows the tire slipping for mechanical braking is longer than dynamic braking.

The value of slip ratio also shows the mechanical braking is higher than dynamic braking which is 0.8 that almost in "tire locking" condition.

Figure 7(a) Shows the distance travel of EPW when braking is applied at speed 1 m/s in wet surface condition. Solid blue line is indicated the distance travel of EPW when the 100% hand gripping mechanical braking is applied. From the plotted graph, it is shown the EPW is still moving and exceeded the 4.5 meter of slope length. The stopping time and distance was recorded 3.3 second at distance travel 4.5 meters. Solid red line indicates the distance travel of EPW when dynamic braking is applied at speed 1m/s in wet condition. As shown in graph, the distance travel of EPW also exceeded the requirement length by ADA and the time was recorded 13.8 at distance 4.5 meters.

Figure 7(b) shows the speed of EPW and tire when braking is applied at speed 1 m/s in wet surface condition. When the mechanical braking is applied at speed 1m/s, it seems the speed of tire which represent as dotted line abruptly stopped which known as tire lock. However, the speed of EPW (solid blue) keep accelerated until 2 s and then decelerated. This is happened because the weight is transferred during braking and produce momentum of inertia. The larger of weight of user will cause the largest momentum of inertia produced. Meanwhile, when the dynamic braking is applied, the speed of tire (red dotted) also shows quickly decrease but does not lock-up as mechanical braking. The speed of EPW (solid red) is quickly decelerated However, in 2.1 s the EPW is still moving descending on slope with the lower deceleration. This is also because the gravitational force that pulling EPW downward is more than braking torque produced by dynamic braking as previous discussed.



(a) (b)

Figure 7 (a) Distance travel during braking at 1 m/s in wet surface (b) speed of EPW during braking at 1 m/s in wet surface

Figure 7(c) shows the slip ratio between mechanical and dynamic when braking on wet surface condition at speed 1m/s. Blue and red line is indicate the slip ratio when the mechanical and dynamic braking respectively. From the both plots, it also shows the slipping time for mechanical braking is longer than dynamic braking. In this condition, at time 0.2 seconds tire is start locking until reaching 4.5 meters. For dynamic braking, the slipping time interval is only happened in 1.4 seconds and tire does not shows tire lock during braking. This is happened because of lower friction contact between tire and wet pavement. Thus, tire will be skidding when higher and constant braking torque is applied from the mechanical braking. Meanwhile, even dynamic braking produce higher torque braking, the braking torque does not apply constantly that caused tire to lock-up even braking under wet pavement.

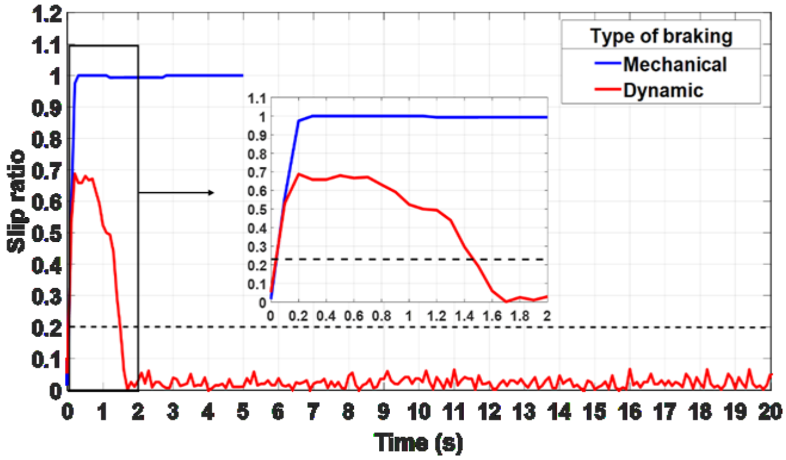


Figure 7(c) Slip ratio of braking by using different braking type at dry condition.

5. Conclusions
From the experimental had been done, it is observed the braking performance between mechanical and dynamic braking shows their own merits. In dry condition. Mechanical braking is more suitable to use since it gives the short time and distance stopping even produce the higher slip and deceleration. Meanwhile the dynamic braking gives the lower deceleration than mechanical but the EPW seems does not fully stop when descending on slope. In the wet surface condition, the mechanical braking is unsuitable to used which caused tire abruptly stopped (lock) and EPW still moving (skidding) more than 4.5 length slope and dangerous to the users. Besides that, Dynamic braking gives the better braking result which produce lower braking torque that does not cause tire to abruptly stop or locking when descending on wet slope.

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