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Development of electro-hydro automatic parking braking system for automotive system

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Abstract--- ***A parking brake is an important tool of any automotive system. Conventional parking brake systems requires the driver to manually pull the lever if the brakes are to be applied. To some extent, the vehicle is left without applying the parking brake due to the insensibility, which could make the vehicle in danger if there any gradient of the road and strong wind. The aim of this manuscript is to present an automatic electro-hydro parking braking system which brakes once the vehicle park. This is developed by associating the wheel speed sensors, accelerator proximity sensors, controller, and a linear actuator. This electro-hydro automatic parking braking system automatically brakes the vehicle when it parks. It ensures the vehicle to remain stationary when it is parked and prevents vehicle rollaway or any unwanted movement that might occur. It increases the safety of the vehicle as well as others around it. The linear actuator displacement is controlled in this study by the auto-clamping system when the vehicle park. The model has been tested considering the road gradient 2-25%. The automatic parking braking system requires hydraulic pressure 383.66 kPa to ensure the vehicle park on 25% gradient, which is 11% less than the vehicle to brake from speed of 35 km/h.***

Keywords: Parking brake; Sensors; Linear actuator; Master brake cylinder; Microcontroller.

1. INTRODUCTION

The braking system is one of the most important safety equipment of any automotive vehicle. The two function of braking system is to slow down or decelerate the speed of the vehicle and to hold the vehicle at rest while parking, both on flat or sloped grounds. The second part is the primary function of the vehicle parking brakes also known as emergency brakes or hand brakes. In the conventional system pulling a mechanical lever, which is usually located at the side of the driver seat, does this. Without pulling or pushing the lever the parking brakes cannot be engaged or disengaged. Since this requires human effort sometimes we forget to apply it in case of any rush or emergencies or even plain negligence. Many of the drivers are used to only leaving the gears in park without even applying the parking brake. The function of the parking brake is to stop the car from moving while it's parked on any flat roads or grounds, and also to stop it from rolling away when parked at a slope.

It is advisable by all the vehicle safety experts to turn on the parking brake as well as putting the gear on park when parking the vehicle for both the automatic and manual transmission vehicles [1,2]. In some places it is required by law to leave the parking brake on when parking. However, many people still ignore such instructions. Parking vehicles on hills or inclines surface without engaging the parking the parking brake can cause the vehicle to roll back and damage other vehicles or structure behind [. In such cases in some countries, like Germany the insurance company is not required to cover such damages [3]. The parking brakes should always be used when we want the vehicle to remain motionless. Using the parking brakes to stop or slow down a speeding car when the foot-operated brakes are still functional is a very bad idea. It's only other use is during emergency when the foot operated brakes fail and should only be used in a controlled manner [4]. The force by the parking brake is very small, so it is unwise to apply while the vehicle is in motion, as it will likely damage the brakes. In our project we want to create a system that minimizes the human interaction in applying and disengaging the parking brakes when required thus minimizing the safety hazards of forgetting or not using them. We aim to achieve this by using Displacement sensors, a control unit and the master cylinder of the braking system and a linear actuator [5,6].

The parking brake linkages use control cables, transfer cables and application cable (Figure 1). The control cables attached to the parking brake pedal, lever, or hand inside the vehicle. The transfer cable transmit force to an intermediate lever or equalizer to the application cables. The application cables use the force passed through the linkage to apply the rear brake assembly. The parking brake cables are subject to damage from water, dirt, and other debris thrown up under the vehicles by tires. In most cases of the parking brake it is obvious that the amount of physical force a driver can apply to the parking brake control is often not enough to apply the parking brake especially when the vehicle is in slope [7-9].

In some parking brake linkage, the pulling cables assemblies are adjusted separately. If the adjustment are unequal, one brake apply before the other, preventing full lining–to-drum contact at the opposite wheel and greatly reducing the holding power of the parking brake. Furthermore, the rusting parking brake cable can keep the brake applied even though the parking brake has been released. This can cause dragging brakes, reduced fuel economy, and possible vehicle damage due to overheated brakes. In the current automotive industry most vehicles require human effort in the engagement and disengagement of the parking brakes.

This leads to infrequent use of the system and thus

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increasing the chance of the vehicle rolling away while on slopes or due to some external horizontal force in flat grounds. This may lead to unwanted situations and accidents [10-12].

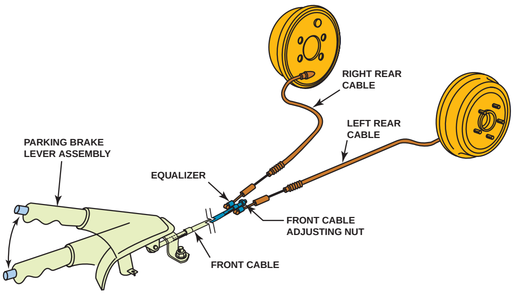

Fig.1: Typical parking brake.

The objective of this study is to develop an automatic parking system with associating wheel speed sensors, accelerator proximity sensors, controller with set-up coding and a linear actuator. The significance of the system is to make ensure the vehicle parking in any road to minimize the human effort and increase the safety of the automotive vehicle. The automatic parking has been developed in such a way that it activates as long as vehicle brake. It will be not activated as it the wheels of the vehicle are in rotation.

2. MATHEMATICAL MODEL

Consider a vehicle of weight 14.715 kN of wheelbase 2.2 m is to be parked on the road of gradient maximum 15%. The vehicle CG is located a_1 from the behind of front axle and that from the rear axle a_2 as shown in Figure 2.

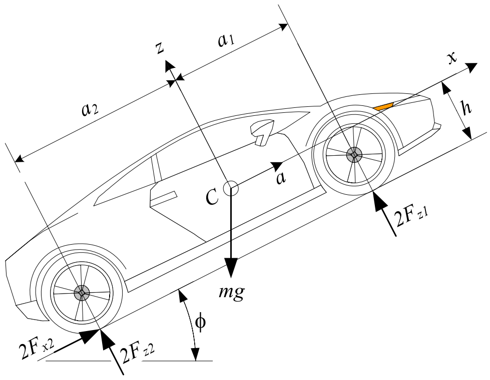

Fig.2: Vehicle parked on a slope road

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Performance characteristics of a road vehicle refer to its capability to decelerate and stop. However, the weight during deceleration event the maximum braking force that the maximum braking force needs to develop by the braking system can be estimated by modifying the mathematic models [13-14]:

$$F_{bf(d)}(t)=\mu_p * W_{f(d)}(t)=\mu_p * \left(W_{f(s)}+W_{T(d)}\right) \quad (1)$$

$$F_{br(d)}(t)=\mu_p * W_{r(d)}(t)=\mu_p * \left(W_{r(s)}-W_{T(d)}\right) \quad (2)$$

with $W_{T(d)}=\left(\frac{a_d}{g}\right)*\left(\frac{h_{cg}}{L}\right)*W$ and $L=\frac{W_r}{W}*L+\frac{W_f}{W}*L=CG_{f(x)}+CG_{f(r)}$,where, h_{cg} is height, L the wheel base, a_d deceleration, $CG_{f(x)}$ location of centre of gravity from front axle while $CG_{r(x)}$ from the rear axle, μ_p is the road adhesive coefficient, $F_{bf(d)}(t)$ and $F_{br(d)}(t)$ are the instantaneous dynamic braking force, $W_{f(d)}(t)$ and $W_{r(d)}(t)$ the instantaneous dynamic load distribution, $W_{f(s)}$ and $W_{r(s)}$ the static load distribution at the front and rear axle, respectively.

The percentage of instantaneous weight transfer which determine the hydraulic pressure distribution from the master cylinder to the axles can be estimated,

$$Percent\ front\ axle\ weight,\ x_f=\frac{W_{f(d)}(t)}{W}*100\%$$

$$Percent\ rear\ axle\ weight,\ x_r=\frac{W_{r(d)}(t)}{W}*100\%$$

The force required to actuate the caliper against the rotation of the braking rotor can be estimated [7]:

$$F_{a(f)}(t)=x_f*\frac{P_{mc}(t)\theta}{2}*\left(r_o^2-r_i^2\right) \quad (3)$$

$$F_{a(r)}(t)=x_r*\frac{P_{mc}(t)\theta}{2}*\left(r_o^2-r_i^2\right) \quad (4)$$

where, $F_{a(f)}(t)$ is the actuation force at the front calipers and $F_{a(r)}(t)$ at the rear wheel's rotor calipers, r_o and r_i the outer and inner radius of the brake pad from the centre of the braking rotor, $P_{mc}(t)$ instantaneous master cylinder pressure into the fluid pipe, and $x_f + x_r$ =100%. The braking torque required to decelerate or stop the vehicle can be estimated [11-12]:

$$T_{b(f)}(t)=\frac{\mu_m * x_f * P_{mc}(t) * \theta}{3}\left(r_o^3-r_i^3\right) \quad (5)$$

$$T_{b(r)}(t)=\frac{\mu_m * x_r * P_{mc}(t) * \theta}{3}\left(r_o^3-r_i^3\right) \quad (6)$$

where, $P_{mc}=\frac{F_{p(a)d}+F_d}{A_{mc(p)}}$, μ_m is the friction coefficient of the braking pad, θ is the angular position of the braking pad on the brake rotor, A_{mc} is the cross-sectional area of the master cylinder piston, $F_d(t)$ instantaneous force applied by the driver to the brake pedal, $F_{p(a)d}(t)$ is the amplified force developed by the DC motor based on the policy making by the controller with the response of the WSS and accelerator sensor $T_{bf}(t)$ and $T_{br}(t)$ are the instantaneous braking torque of the front and rear rotor during the vehicle deceleration, respectively.

It could be mention that if $T_{bf}(t)+T_{br}(t)<T_t$ the vehicle will be decelerate and

if

$T_{bf}(t)+T_{br}(t) \geq T_t$ the vehicle will be in full stop, T_t is the traction torque of the vehicle. The force required on the master cylinder to stop the vehicle in time *T* at distance *S*,

$$F_d * \frac{l_2}{l_1} + F_{p(a)d} = \frac{mv^2}{2S*T} \tag{7}$$

The power ($P_{p(a)d}$) required the DC motor to develop the amplified force,

$$P_{p(a)d} = \left[\frac{mv^2}{2s*T} - F_d * \frac{a_2}{a_1}\right]\left(\frac{S}{T}\right) \tag{8}$$

The energy required for the motor to develop the amplified force in time T,

$$e_{p(a)d} = V_b * I_b * \eta_m * \frac{T}{3600} \tag{9}$$

where, $e_{p(a)d}$ is the energy consumption in Wh, *S* is the stopping distance in m, and *T* is the stopping time in sec, V_b and I_b are the battery terminal voltage and current delivered to the DC motor, η_m efficiency of the motor. However, in this study the by using an automated clamping system the energy consumption of the system makes zero.

3. BRAKE FORCE ANALYSIS

If the car is parked on the hilly road (Figure 2) of slope θ and adhesion coefficient μ and the car optimum slip is considered as i_{opt}. The parking braking force F_b can be formulated as

$$F_b = \mu W \cos\phi / \left(1 - i_{opt}\right) \tag{9}$$

with $i_{opt} = 1 - \left[\left(i_w - i_c\right)v_w / \left(1 - i_c\right)v_w\right]$ and $i_w = \left(v_w - v_c\right)/v_w$

where, i_{opt} optimum brake slip of the wheel on the road surface in %, i_w and i_c are the slip of wheel and caliper in % and v_w and v_c slip speed of the wheel and caliper in m/s

The excessive slip of the wheel can be avoided if the high quality abrasive material for the braking pad is used. It is a ratio of stands inertial mass ε_{ABS} for braking with ABS acting, to maximum deceleration of these mass ε_{max} in time of braking without ABS. The adhesion utilization can be estimated if the car is equipped with anti-lock braking system [15]:

$$\varepsilon_{st} = \frac{\varepsilon_{ABS}}{\varepsilon_{max}} = \frac{\left[\left(\omega_{40} - \omega_{20}\right)/\left(t_{40} - t_{20}\right)\right]_{ABS}}{\varepsilon_{max}} \tag{10}$$

The equation indicates that if slope of the road, θ = 0, then $F_b = 0$. Therefore, the parking braking force is necessary to apply and it is good enough to stop the vehicle with braking and release. However, little amount of force needs to for the safety. By using the highest gradient of the road, ϕ = 15. If we consider a vehicle weight, W = 14715 N on a slope of road, ϕ = 15 and static friction coefficient, μ = 0.2, the parking brake force can be computed as 762 N. The pressure ($P_{p(c)}$) needed to develop this force at the brake caliper piston is given by the equation: $P_{p(c)} = \mu W \cos\phi / \left(1 - i_{opt}\right) A_{p(c)}$ where $A_{p(c)}$ is the area of the piston of the brake caliper. By using the brake caliper cylinder diameter, d = 0.08 m, the area of the brake caliper cylinder can be computed as 0.05 m^2 and the pressure required at the caliper cylinder can be computed as, $P_{p(c)}$ is 152.34 kPa. This pressure is to be given by the master cylinder $P_{m(c)}$ to the piston. So the force needed at the master cylinder (F_m) is given as, $F_m = P_{p(c)} \times A_{p(mc)}$.

If the diameter of the master cylinder piston is $D_{p(mc)} = 0.1$ m, the cross-sectional area of the master cylinder, 0.0078 m^2, the computed value of F_m is 1196.5 N. To develop the 1196.5N, the required torque of the linear actuator DC motor can be estimated as, $T = F_m \times R_m$, where the R_m is the radius of the motor. If the diameter of motor pinion, $d_{m(p)} = 0.03$ m, the computed torque of the motor, 17.95 Nm. The power (P_m) required to produce the motor torque of 18 Nm can be estimated as, $P_m = T_m \omega_m$ where, w_m is angular speed of the motor. If the linear velocity of the actuator is 0.025 m/s, the motor speed, $\omega_m = \frac{v_m}{r_{m(p)}} = 0.833 rad/s$, the computed power of the motor is 15 W. The 12 V battery is required to supply current to the actuator motor is 3.0 A.

4. AUTO PARKING BRAKING MODEL

The automation of the parking brake in this study has been developed with the integration of sensors (wheel speed sensor, acceleration-off sensor and brake pedal-off sensor), controller, linear actuator and DC power [Figure 3]. The wheel speed sensor is fitted at the front wheels and acceleration-off sensor (AOS) is fitted closed to the acceleration paddle such that it make signal when the pedal is depressed. Infrared sensor (IS) is used as AOS. The range of the AOS can be adjusted so that it can accurately detect when the accelerator pedal is pressed. It is directly connected to the control unit. The wheel speed sensor (WSS) is connected to a relay switch which is connected to the power supply of the Arduino Uno. The microcontroller is connected to a 2-relay switches that can control the polarity of the power supplied to the linear actuator. The relay switches are also connect to the wires of the motor of the linear actuator. The linear actuator is collinearly lined with the piston of the Master cylinder oft he braking system.

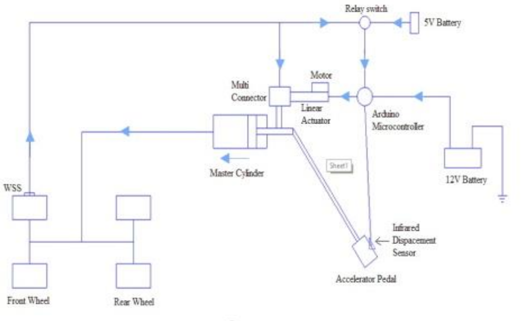

Fig. 3. Pulling cable less auto parking brake system model.

When the vehicle is stationary, the wheel speed sensor sends signal to the relay switch. The relay switch activates the controller with the 5V DC battery. The controller activates the ultrasonic displacement sensor (UDS). When the accelerator paddle is not pressed the UDS sends signal to the controller. The controller maintain the 12V DC power supply to the linear actuator. Thus the motor of the linear actuator turns in the anti-clockwise direction and the shaft of the linear actuator extends and pressurizes the piston of the master cylinder (MC). The master cylinder thus develops fluid pressure $P_{h(mc)}$. The pressure $P_{h(mc)}$ remains same throughout the tube. On the disc brake the hydraulic fluid from the master cylinder is forced into the caliper where it is pressed against a piston. The piston in turn squeezes the two brake pads against the rotor of the disk, which lock prevents the rotor from turning thus engaging the parking brakes. When the wheels are not moving, the WSS not get any signal so that the 5V-relay switch connected to the controller is turned off and the controller turned off power to the sensors. This causes the relay switch that is connected to the controller to remain in closed condition. In this situation the negative terminal of the battery is connected to the positive terminal of the linear actuator and vice versa. This causes the shaft of the linear actuator to retract back and thus master cylinder piston does not get pressed. So, the parking brakes remain disengaged. When the vehicle is started and the acceleration pedal is pressed, The UDS sends signal to the controller and the controller stops power flow to the relay switch and the switch moves to its naturally closed condition and the linear actuator wires polarity is reversed. This retracts the shaft of the linear actuator and the piston of the master cylinder depressurized. This mode disengages the parking brakes and thus the vehicle can be driven. In order to keep the car in braking mode on the hilly, the parking brake force (F_b) has to be equal or higher than the traction force of the car. However, the parking braking force would be,

$$F_{b(p)} = \begin{vmatrix} f_r W & if \quad G = 0 \\ \mu W_d \cos\theta & if \quad 0 < G \geq 15 \end{vmatrix} \tag{11}$$

The parking braking force ($F_{b(p)}$) required 176.5 N if the vehicle is parked on level ground with considering f_r = 0.012. However, parking braking force is required 11593 N to park the vehicle on 15% gradient with considering μ = 0.8..If the road adhesion coefficient (μ) is considered to be 0.8 and vehicle weight (W) 14715 N, the computed The master cylinder pressure required 35 kPa to keep the vehicle braking on level ground.

5. MOTOR AMPLIFIED TECHNIQUE

The continuously growing need for better comfort and safety of automotive, it is almost impossible to imagine without intelligent systems. The researchers from all around the world have been working hard to invent intelligent devices consisting of not only sensors, but also controller, among other devices, that incorporate a certain amount of intelligence to the sensors themselves, transforming their response to the controller to make the system intelligent and auto pitched system [16 -17].

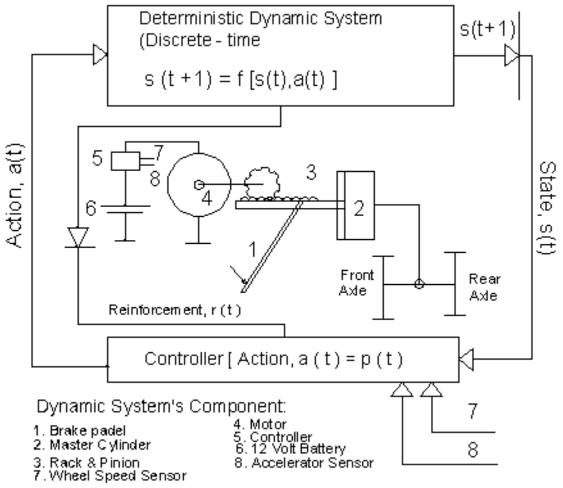

Fig. 4: Makrov decision process model

The Markov Decision Process (MDP) model (Figure 4) have been considered in this study to develop the DC motor amplified intelligent system with integrating the WSS and accelerator sensors. It is assumed that the Markov property effects of an action based in a response (i.e., state) of sensors (wheel speed sensor, accelerator sensor and SOD sensor oft he battery). The model contains:

- A set of possible states, ’S’. The state (S) of the MDP model in this study is referred as the force developed by the motor F_{pd} with the help of the rack-pinion to active the master cylinder for the additional pressure of the braking devices.
- A set of possible action ,’a’ based on the sensor response of the dynamic components not on any previous response. The controller action in this study has been referred as supply current (I_b) to the DC motor by the controller action to develop the necessary applied force tot he master cylinder through the rack and pinion.
- A real valued reward function R(s,a)
- A description,’t’ of each action of controller in each state is called the instantaneous action of the controller based on the sensor response.

The task of the controller is to make an action (or policy, P) to active the Dc motor on creating an effort, $P : S \rightarrow A$ to amplify the mechanical-hydraulic braking system to provide the additional safety of the car during braking. For the instantaneous effort of the motor the controller take a policy, based on the signal of the WSS and accelerator sensors, $P(s_t) = a_t$.The deterministic dynamic system actions of the MDP is stated in this study as, $t : s \times a \rightarrow s$, for each action of controller based on the sensors response. The MDP policy mapping can be made based on *s* and *a* [18].

6. RESULTS AND DISCUSSION

Figure 5 shows the laboratory scale cable-less auto parking braking system by integrating the WSS, UDS, UIS and controller with power pack. The auto parking braking system performance has been investigated by considering the slope of the road in the range of 0-15^0. The braking force for the vehicle parking on 0^0 slope is found equivalent tot he rolling resistance of the vehicle. The required braking force has found to increase with increasing the road slope. It is also tested that the barking force of the system is found to be constant if the road slope increases to more than 15^0. This is because of the linear actuator has maximum force developed capacity is maximum 2500 N.

Notification: 2: Circuit Bread Board, 3: Arduino Circuit Controller, 4: L298N DC Motor Driver, 5: 6V Battery, 6: Brake Pedal, 7: DC Motor embedded linear actuator, 8 : Gearbox, 9: Distance Sensor, 10: Brake Fluid Hose and tank, 11: Brake pad, 11: Brake Disc (Rotor), 12: Brake Caliper, 13: Hydraulic valve, 14: Hydraulic Pressure, 14: Master Pump, 15: Rotating Shaft, 16: Shaft bearing, 17: Bearing Support, 18: Pinion, 19: Rack.

Fig. 5: Laboratory scale automatic parking braking system.

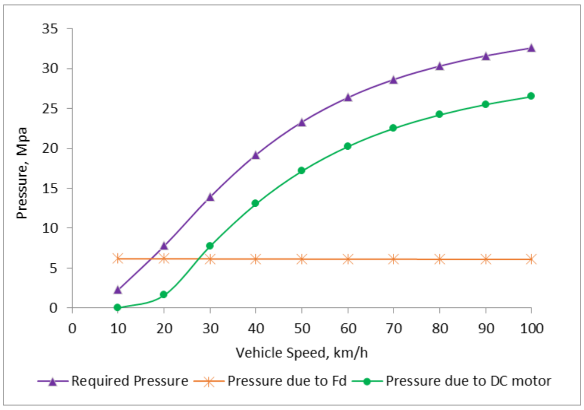

Fig.6: Hydraulic pressure against vehicle speed

Braking performance has been conducted theoretically by using Microsoft EXCEL to show the results of stopping distance, braking force and hydraulic pressure in graphical analysis. Some parameters are determined throughout the simulation process [Figures.6-7]. The vehicle mass, m=1500 kg, road adhesion, μ_p = 0.6, frictional coefficient of brake pad, μ_b = 0.46, lever ratio of 8:1 and master cylinder bore of 2.85 cm. It also could be mention that the vehicle braking force needs based on the speed. In addition, the braking distance of the vehicle is determined based on the vehicle speed as well. Result shows that the stopping distance increases as it stops at higher speed. Once the stopping distance is known, the braking force, F_b can be found. However, once the vehicle stops the automatic parking system activates in 0.5 s. The delay of the electronic system is very low which is about 100 ms. The automatic electro-hydraulic parking system performance has been measured in laboratory by using the vehicle normal load on the road different gradient and presented in the Table 1.

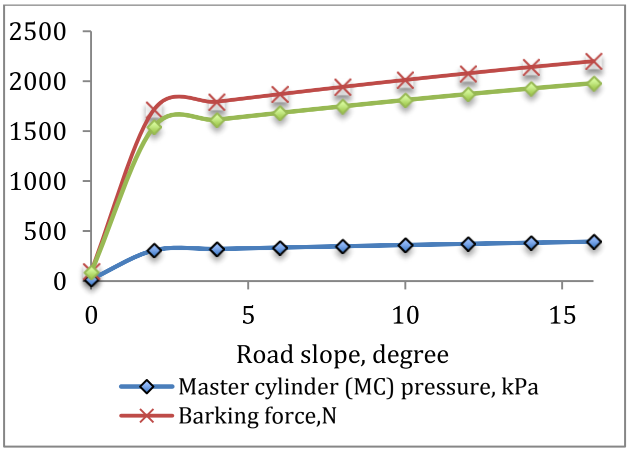

Fig. 7: Parking braking force.

7. CONCLUSION

A laboratory automatic electro-hydro parking braking system has been developed from this study in order to replace the cable-pulling hand braking system and its problems associated. The model has been tested considering the road gradient 2-25%.

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The automatic parking braking system requires hydraulic pressure 178.24 kPa to ensure the vehicle park on 25% gradient, which is 11% less than the vehicle to brake from speed of 35 km/h. The linear actuator displacement is controlled in this study by the auto-clamping system when the vehicle park. Therefore, the power consumption of the linear actuator motor has been made about zero. The further research needs to make the system validation on any road surface.

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Table 1: Braking parameters for changing slope with considering $f_r = 0.012$ and $\mu = 0.4$

Parking Surface Gradient (%)	W (N)	F_b (N)	A_{mc} (m^2)	Performance parameters of APBS P_{mc} (kPa)	F_m (N)	T_m (Nm)	P_m (Watt)	I_b (A)
0.00	14715.00	176.58	0.03	5.52	98.10	1.96	1.63	0.14
3.5	14715.00	5827.14	0.03	182.10	1715.70	34.31	28.58	2.38
6.98	14715.00	5956.63	0.03	186.14	1794.12	35.88	29.89	2.49
10.45	14715.00	6589.38	0.03	205.92	1869.95	37.40	31.15	2.60
14.5	14715.00	6630.58	0.03	207.21	1942.91	38.86	32.37	2.70
17.63	14715.00	6674.72	0.03	208.59	2012.70	40.25	33.53	2.79
20.7	14715.00	6718.87	0.03	209.96	2079.05	41.58	34.64	2.89
24.15	14715.00	6733.58	0.03	210.42	2141.69	42.83	35.68	2.97
27.56	14715.00	6760.07	0.03	211.25	2200.33	44.01	36.66	3.05

Notification: APBS= Auto parking braking system, W= Vehicle total weight, N; Amc = Master cylinder cross sectional area, m^2; Pmc = Master cylinder pressure, kPa; F_m=Force required to apply to the master cylinder, N; T_m=Torque required of the linear actuator motor, Nm; P_m= Power required of the motor, W; I_b = Current supplied to the motor.

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