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Design And Fabrication of Electromechanical Parking Brake System

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Abstract: **An electromechanical parking brake system for a vehicle consists of an electric motor, reduction gear train associated with the motor for transmitting motion from the motor to a lead screw, which pushes the brake pads. This project provides a new concept design of the EMPB system that has simple and low-cost characteristics. This paper deals with designing, analysis and fabrication of EMPB system.**

Electromechanical parking brake system also referred to as brake by-wire, replace conventional parking braking systems with a completely electrical component system. This occurs by replacing conventional linkages with electric motor-driven units. The braking force is generated directly at each wheel by high performance electric motors and gear reduction, which are controlled by an ECU.

INTRODUCTION

Conventional parking brake actuation involves the human interference. Without pulling or pushing the lever, the parking brake will not work. Also, sometimes due to negligence or in emergency conditions, we humans often forget to apply parking brakes. This may lead to rolling of vehicle in case of slopes and collision with other vehicles in parking area. Constant enhancements in active safety and improvements with respect to the reliability and comfort of operation mean that mechanical handbrakes are increasingly being replaced by electromechanical systems. This gave birth to ideas of electric parking brake techniques. The fundamental function of the electric parking brake (EPB) is to activate and release the parking brake when the vehicle is at a standstill. In first generation of electric parking brake fitted, a switch on the instrument panel replaces the traditional handbrake lever used to operate the mechanical parking brake. This switch utilizes an electronic control unit (ECU) to trigger electromechanical actuators within the wheel brakes or a central actuator that operates the rear wheel brake via a Bowden cable.[1]

Further, for reducing drivers effort and reminding for application of parking brake, there was a demand for a completely automated parking brake system, which will be fulfilled by the upcoming ideas of mechatronic. This paper is based on the development of one such system, involving the concepts of automobile, mechanical and electronics, known as Electromechanical parking brake.

Hence, there is great demand for an electronic applied mechanism, with automation for actuation of the parking brake. It should also save space, reduce overall weight, complication in linkages, less mechanical parts prone to wear and tear, good responsive technique, high durability, very less or no involvement of human, easy to repair and economic. The EMPB system helps to enhance driving safety and comfort and provides greater freedom in interior design and packaging. EMPB eliminates the need for a parking brake lever or pedal and improves vehicle styling, space management and crashworthiness.[2]

The EMPB system is composed of one electro-mechanical actuator integrated into the disc brake caliper and a controller with redundant connections to the power supply, which is controlled inside the vehicle's cabin by a simple rocker switch. EPB is electronically controlled, and features can be designed easily through software giving an enhanced level of freedom for driver comfort- and safety functionality.

SYSTEM DESIGN CONCEPT DESCRIPTION

An electromechanical parking brake system for a vehicle consists of an electric motor, reduction gear train associated with the motor for transmitting motion from the motor to a lead screw, which pushes the brake pads.[3] The lead screw and thrust nut are used which pushes the brake pad against disc when rotated. The gears are used to increase the torque of the motor. The actuation of brake is dependent on the engine ignition conditions.[4]

The weight of the vehicle is assumed as 350 kg and road gradient as 30^o throughout the calculations. For prototype fabrication, structural mild steel (A36) material is considered and analysis were made for same. Instead of force sensors, the control method consists of a simple control structure which approximately detect the initial contact point between brake pads and a brake disc with the angular velocity of motor and the clamping force was estimated with the function of angular displacement from the maximum angular velocity.[5,6]

Hardware components required

1. Caliper
2. Gears
3. Motor
4. Lead screw and thrust nut
5. Microcontroller
6. 2-Channel Relay

7. Ignition switch and keys for operation

8. Wiring and harness

9. 12V DC supply source

10. Brake disc

Design

Design of the prototype is done using CATIA V5 and Autodesk Inventor 2012.

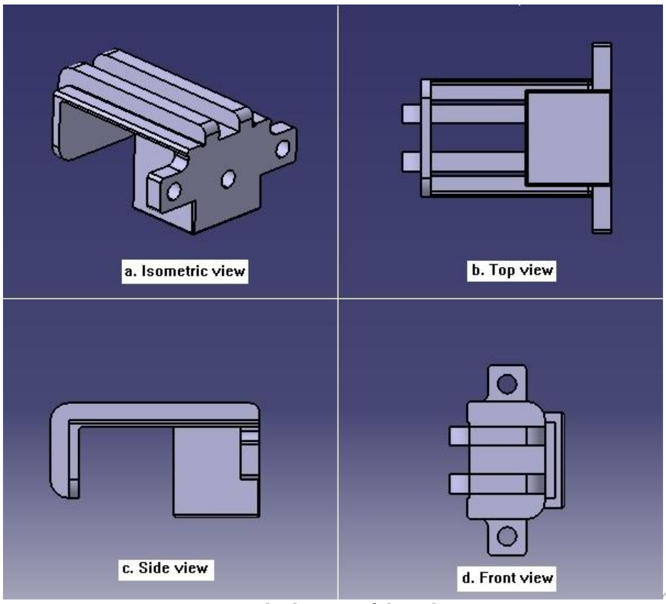


Figure 1 Standard views of the caliper pot

Shown in Figure 4.1 are the different views of the caliper pot model. This is the basic housing for the caliper assembly with other parts namely lead screw, thrust nut, gear train and DC motor. A hole is created for fixing the lead screw on caliper pot base.

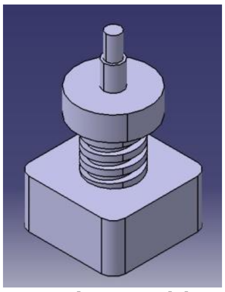


Figure 2 Lead screw and thrust nut

Analysis of caliper

Analysis is made for clamp load to check the safety of the design using ANSYS 14.0 .

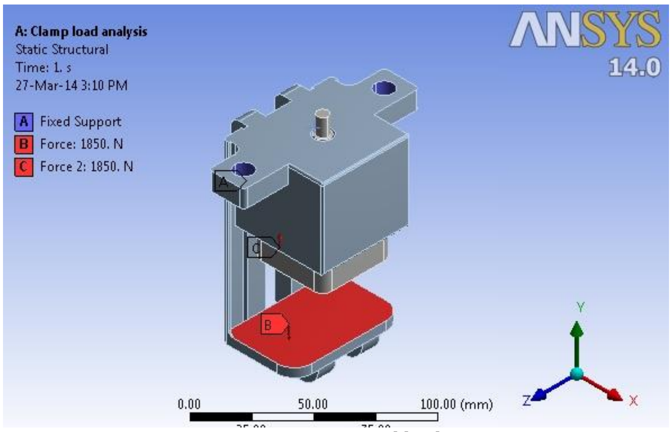


Figure 3 Constraints and loads

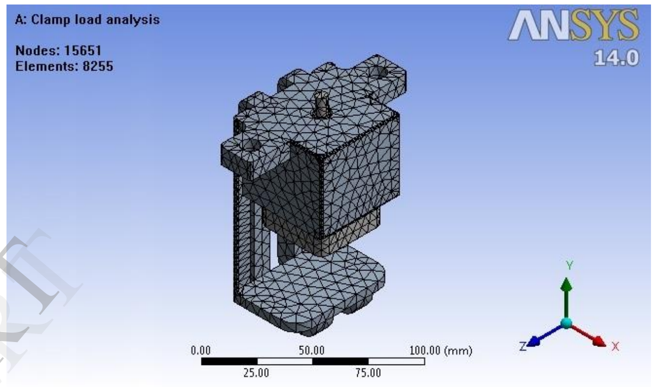


Figure 4 Mesh view

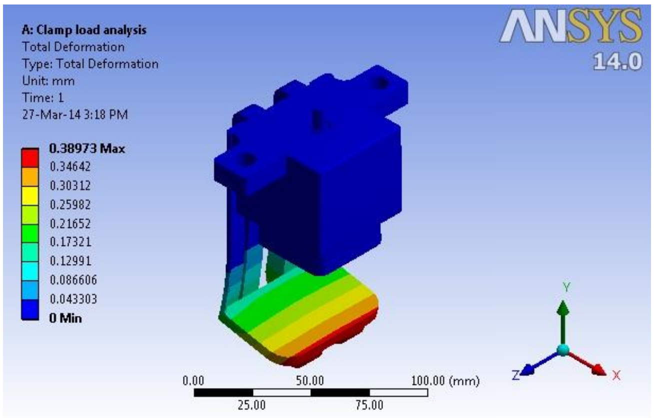


Figure 5 Total deformation

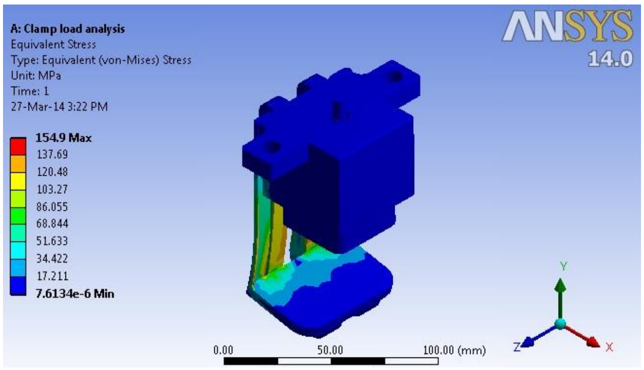


Figure 6 Equivalent stress (Von-mises stress)

The design is first checked by applying a force of 3700N on both the faces as shown in Figure 4.3. The analysis is done using the finite element method and hence mesh view of the model is shown in Figure 4.4. The results of the analysis is as shown in Figure 4.5 and Figure 4.6, where the former indicates total deformation (max. of 0.38mm) and the latter indicates stress (max. of 154.9MPa). The yield strength of mild steel is 250 MPa. Hence, the design was found safe.

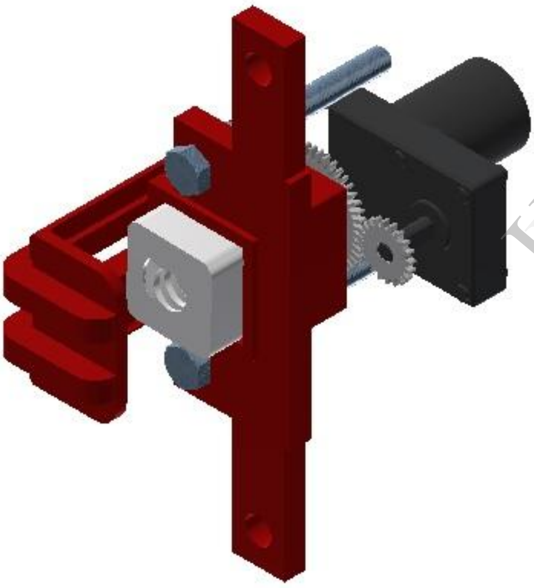


Figure 7 Assembled view

Circuit design

As shown is below figure, microcontroller is always supplied with 5V DC and sends the actuating signal of range 0V to 5V to relay based on the ignition condition of engine. Relay is supplied with 12V DC and switches the motor to rotate either clockwise or anticlockwise. As the motor rotates, it produces some electrical noises and high voltage. So to prevent microcontroller components from damage due to this noise and high voltage, we are using opto-coupler in between microcontroller and relay board.[7,8]

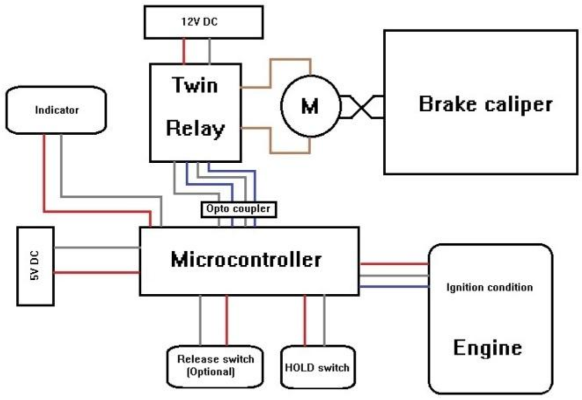


Figure 8 Circuit design of EMPB system

WORKING PRINCIPLE

The EMPB system is a semi automated system in which motor rotates as per the signals from an ECU. Considering engine ignition is on and vehicle is at rest, as soon as the engine is turned off, microcontroller senses this and sends actuating signal to motor relay. As the motor starts to rotate (Anticlockwise), the rotary speed of motor is reduced, hence torque is increased using gear trains and its output is supplied to lead screw which rotates in a nut, in turn converts rotary motion to linear motion, hence pushing the brake pad against the disc and parking brake is hence applied.

In other hand, when engine is started, the microcontroller senses this and actuates the motor to rotate in opposite direction(Clockwise), hence releasing the parking brake.

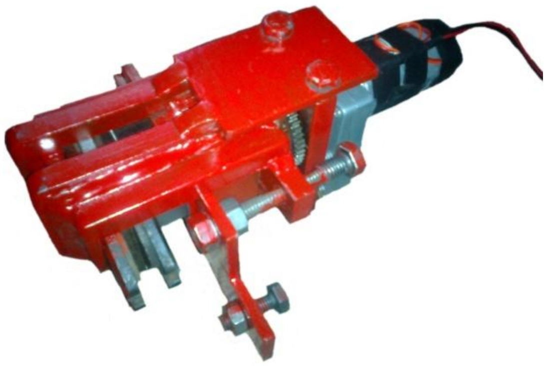


Figure 9 Fabricated caliper unit

Figure 10 EMPB (complete system)

RESULTS

The design is made so that it can be applied to 350 kg vehicle. The EMPB system works satisfactorily on ignition conditions. The HOLD and release functions also works in an acceptable manner. It is seen that the average response time of the EMPB system is 600-700 ms.

Table 1 Test results

Sl. No	Ignition	Hold function	Release function	Indicator	Motor rotation direction	Parking brake condition
1	OFF	-	-	ON	Anticlock wise	Applied
2	ON	-	-	OFF	Clockwise	Released
3	ON	ON	-	ON	Anticlock wise	Applied
4	ON	OFF	-	OFF	Clockwise	Released
5	OFF	-	ON	OFF	Clockwise	Released

CONCLUSION

- The electromechanical parking brake help with automatic parking brake application based on engine ignition condition.
- Safe braking is assured in slopes and hill starts with the help of "HOLD" function.
- EMPB has complete automatic operation for easy drivability and safety.
- This system also gets some advanced options like hold function in head to head traffic and inclined roads, which would promise the drivers and vehicle owners with a safe pleasure drive and stops.
- The response time of EMPB system is good. Hence, applies and releases the parking brake in very short time period.
- The EMPB system has greater relative advantages over the conventional parking system and will find maximum application in the future because of its significance.

APPENDIX

List of symbols

W = Weight of vehicle

θ = Angle of slope

h = Height of center of gravity

b = Wheelbase

l = Distance of CG from rear axle

R_f = Load on front axle

Rr = Load on rear axle

F_r = Brake force required between road and tyre

μ = Coefficient of friction between road and tyre

r_e = Effective radius of disc

C = Clamp load

α = Helix angle

Ø = Friction angle

d_o = Outer diameter of lead screw

p = Pitch of lead screw

d = Nominal diameter of lead screw

P = Tangential force

T= Torque to operate screw

T_m = Torque required by motor

I = Current

N = Speed in rpm

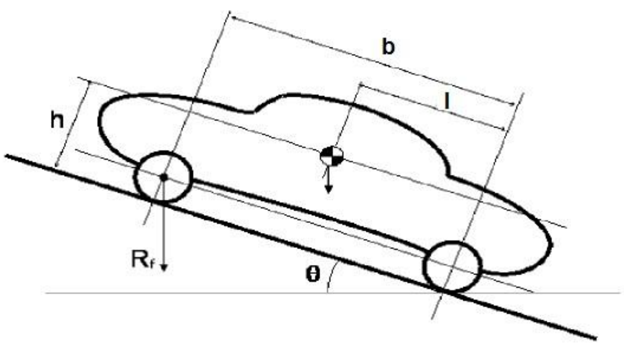
V = Velocity

A = Amperes

Calculation

Brake force:

When parking on an inclined road, the lower axle has a higher load than it does on the level road.



As per our assumptions (above sketch)

h = height of center of gravity (CG) = 285 mm

b = wheelbase = 1570 mm

l = distance of CG from rear axle = 500 mm

R_f = load on front axle

R_r = load on rear axle

W = weight of the vehicle assumed = 350 kg = 3433.5 N

θ = angle of slope = 30^o

Now, $R_f = \frac{W(l - h\tan\theta)}{b} = \frac{3433.5(500 - 285\tan 30)}{1570}$

$\therefore R_f = 733.62\ N$

Now, $R_r = W - R_f = 3433.5 - 733.26$

$R_r = 2699.88\ N$

Brake force required between road and tyre is

$F_r = \mu\ R_r$ where, μ = coefficient of friction between road and tyre = 0.8

$\therefore F_r = 2159.9\ N$

The value of F_r is for two rear tyres.

$\therefore$ for single tyre, $F_r = \frac{2159.9}{2} = 1079.95 \simeq 1100\ N$

Now, Brake torque $T = F_r \times R$ where, R= radius of tyre = 215 mm

$T = 1100 \times 215$

$\therefore T = 236500\ Nmm \simeq 236.5\ Nm$

Disc effective radius (r_e)

$$r_e = \frac{D+d}{4} = \frac{210+110}{4}$$

$$r_e = 80\ mm = 0.8\ m$$

Clamp load C

$$C = \frac{T}{r_e \mu_b n} = \frac{236.5}{0.08 \times 0.4 \times 2}$$

$$C = 3695.3125\ N \simeq 3700\ N$$

Clamp load required:

$W = 3700\ N$

Power screw dimensions: Assuming the specifications of lead screw

Outer diameter $d_o = 20\ mm$,

Pitch of thread (Square) $p = 5\ mm$,

Nominal diameter $d = d_o - \frac{p}{2} = 17.5mm$

$Tan\alpha = \frac{p}{\pi d} = 0.0909$

$Tan\phi = 0.2$ (intermediate workmanship)

1) Tangential force (P) calculation:
   Tangential force required at circumference to produce force W =3700 N

   $i.e.$ P=$W\tan(\alpha + \phi) = W\left[\frac{\tan\alpha + \tan\phi}{1 - \tan\alpha\tan\phi}\right]$

   $\Rightarrow P = 3700\left[\frac{0.0909 + 0.2}{1 - 0.0909 \times 0.2}\right]$

   $\therefore P = 1096.26$ N

2) Torque (T) required to operate the screw

   i.e. $i.e\ T = p \times \frac{d}{2} = 1096.26 \times \frac{17.5}{2}$

   $\therefore T = 9592.275\ Nmm \simeq 9.6\ Nm$

3) Two gears i.e. a gear and pinion is selected to increase the torque from motor for application of brake.
   Gear = 48 teeth and pinion = 20 teeth

   $\therefore$ Gear ratio $= \frac{48}{20} = 2.4:1$

   Torque required is 9.6 Nm
   Hence, torque to be produced by motor is

   $T_m = \frac{9.6}{2.4}\ Nm = 4\ Nm$

   Or

   $T_m = 4\ Nm = 40.77\ kgcm$

4) The motor having torque more than 40.77 kgcm is selected,

Motor selected has $T_m = 47.19\ kgcm$

speed of $N_m = 200$ rpm

5) Due to gear train, speed reduces to 83.33 rpm at full current i.e. I = 10.6 A

If current I=6.3 A, speed $N_m = 110\ rpm$

(As per motor specification)

Speed reduces to 45.833 rpm

$$\therefore N = \frac{v}{p} \quad \Rightarrow \quad V = N \times p$$

@ full current $V_1 = 83.33 \times 5 = 416.65$ mm/min

$For\ 5\ mm \Rightarrow 0.72$ sec

@ $I = 6.3$ A $V_2 = 45.83 \times 5 = 229.15\ mm/\min$

$For\ 5\ mm \Rightarrow 1.309$ sec

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