

Parking Brake System

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1. Overview

The parking brake system serves two purposes. One is to provide redundancy in the event that the primary braking system unexpectedly fails. The other is to allow the vehicle to park on inclines without rolling away due to gravity.

The braking system allows the Solar Car to apply a frictional torque on the front and back wheels. This system contributes to the vehicle's safety and performance metrics because it is the means of decelerating the car. The driver will need to brake the car in order to navigate corners on the Formula Sun Grand Prix (FSGP) and American Solar Challenge (ASC) tracks. The driver will also need to brake the car in order to avoid catastrophic collisions with other vehicles, people, or landscape. An effective braking system also involves redundancy and a way to lock the wheels in a parked position even after the driver exits the vehicle; these two brake system requirements are fulfilled by the parking brake system.

2. Functional Requirements

The parking brake system's main function is to convert the driver's hand motion into a clamping force on the rear wheels to cause frictional torque. This clamping force should remain engaged without additional driver effort until the driver decides to finally disengage the parking brake. A functional architecture is shown in Fig. 1. Additionally, our parking brake (and the entire vehicle) must meet the specifications expected of all vehicles participating in the ASC and FSGP races. To meet specification, all the hardware and software in the final vehicle must be compliant with all the rules and regulations of the ASC and FSGP [1].

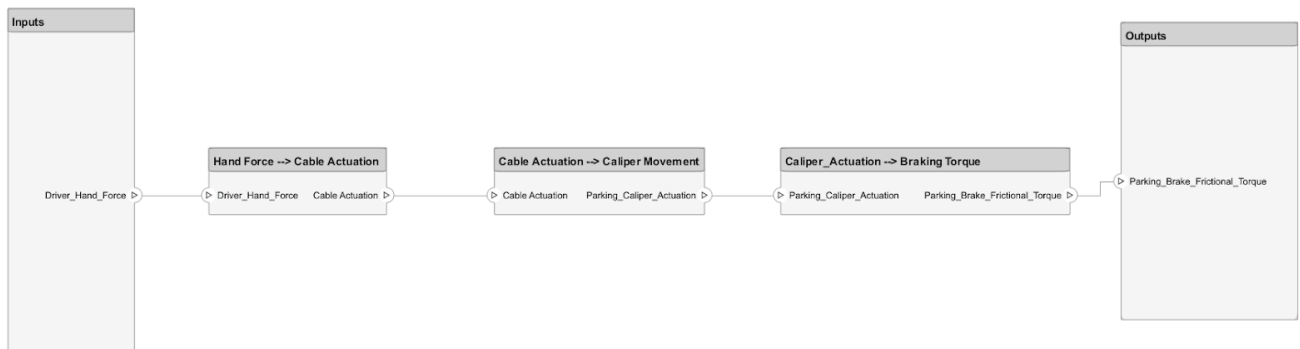


Fig. 1.

To best accomplish the design objectives of being reliable, affordable, and effective while also meeting the ASC Rules and Regulations [1], the system should satisfy the following functional requirements outlined in Table 1:

Metric No.	Relevant ASC Regulation	Requirement Metric	Comments
1	10.6.A	“The Parking Brake shall be able to hold the car in place without wheel chocks on dry pavement under either a forward or rearward force equal to 10% of the car’s weight in fully loaded condition.	10% of car’s weight roughly translates to 50-60 lbs as of recent estimates
2	10.6.C.3	Parking brake lever shall require no more than 10 lbs of effort by the driver to actuate	Driver ergonomics
3	N/A	All parking brake equipment shall be able to withstand 3Gs of force	3g’s of acceleration is typical for a bump found on a race track
4	N/A	Parking brake hand lever shall be able to withstand a worst-case scenario of 50 lbs laterally	In case the driver accidentally kicks the lever or falls on it
5	10.6.C.2	Parking brake handle shall be within 2 feet of the driver’s hips	Driver ergonomics

Table 1.

3. Parking Brake Notional Design

The notional parking brake design shown in Fig. 2 uses a ratcheting hand lever with a mechanical cable as the means of converting the driver's hand force into caliper clamping.

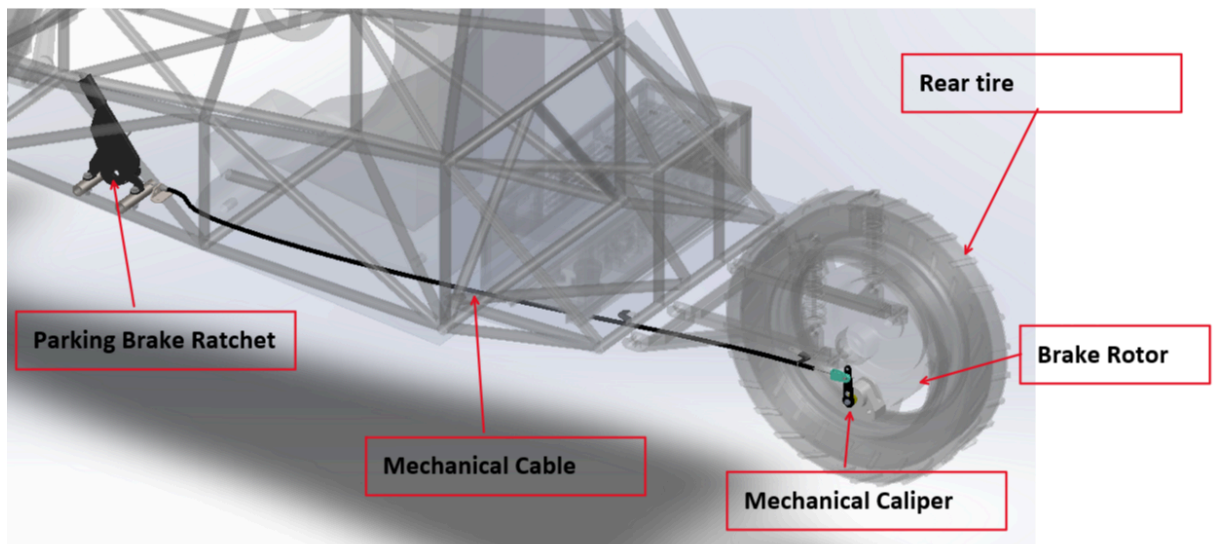


Fig. 2.

Other concepts for parking brake designs include using hydraulic or electrical actuation instead of a mechanical cable. However, a mechanical cable-actuated parking brake design was ultimately chosen due to cost, mass, ease of installation, and performance.

4. Down Selection of Parking Brake Actuation Strategy:

Cost:

A mechanically actuated system includes a mechanical parking brake ratchet, mechanical cables, and a mechanical caliper. The costs for these components are around \$22, \$30, and \$40 respectively. The overall cost of a mechanically actuated system can be estimated as \$92, not including fasteners and mounting hardware which can be assumed as standard across other actuation strategies [4] [5] [6].

A hydraulically actuated system includes a hydraulic ratcheting lever, a master cylinder, hydraulic brake lines, and a hydraulically actuated brake caliper. The costs of these components are \$35, \$35, \$30, and \$173 respectively. This comes out to a total estimated cost of \$273 [7] [8] [9] [10].

An electrically actuated system includes a driver interfacing switch, wiring harnesses, an electronic parking brake control unit, and an electrically actuated parking brake caliper. These components cumulatively cost \$1,034 [11].

Mass:

The total mass of the mechanically actuated system can be calculated as per Table 2.

Component	Mass
Parking Brake Ratchet [4]	.447 kg
Mechanical Cables [5]	1 kg
Mechanical Parking Brake Caliper [6]	.54 kg
Total Mass	~2kg

Table 2.
Mass of Mechanical Actuation Strategy

The total mass of the hydraulically actuated system can be calculated as per Table 3.

Component	Mass
Hydraulic Ratcheting Lever [7]	1.17 kg
Master Cylinder [8]	1.3 kg
Hydraulic Brake Lines [9]	.6 kg
Hydraulic Brake Caliper [10]	.68 kg
Total Mass	3.75 kg

Table 3.
Mass of Hydraulic Actuation Strategy

The total mass of the electrically actuated system can be calculated as per Table 4.

Component	Mass
Electronic Caliper	2.26 kg
EPB Control Unit	~1.5kg

EPB cables	~.5kg
Switch	Negligible
Total Mass	~4.26 kg

Table 4.
Mass of Electrical Actuation Strategy

Ease of Installation:

The mechanically actuated parking brake system is the easiest to install due to its low part count of three. The hydraulic parking brake system would require more effort to install due to higher part count as well as the need to bleed and flare hydraulic lines. The electronically actuated parking brake system requires the most effort to install due to its very large part count as well as its need to interface with other components in the car such as the battery.

Performance:

To assess the performance of various parking brake actuation strategies, it is necessary to check if the selected actuation strategies can keep the vehicle stationary when a load equal to 10% of the vehicle's weight is applied parallel to the ground and in a forward direction, as per ASC regulation 10.6.A.

Assumptions for calculations:

Wheel rotor diameter = 8.66 in. [12]

Tire effective diameter = 22 in. [12]

Solar Car Vehicle Nominal Total Weight = ~400 lbf [12]

Coefficient of friction between brake pads and rotor = .4

Performance Analysis:

When 10% of the car's weight is acting in the forward direction parallel to the ground while the vehicle is parked, the rear wheel is responsible for resisting this forward force. This is because the front tires are free to rotate in a parked configuration. 40 lbf acts on the rear axle while a 40 lbf frictional force acts on the tire contact patch in the exact opposite direction, as shown in Fig.3. Taking a moment balance, the frictional force a caliper must exert to keep the car stationary can be derived, as shown in Eq. 1.

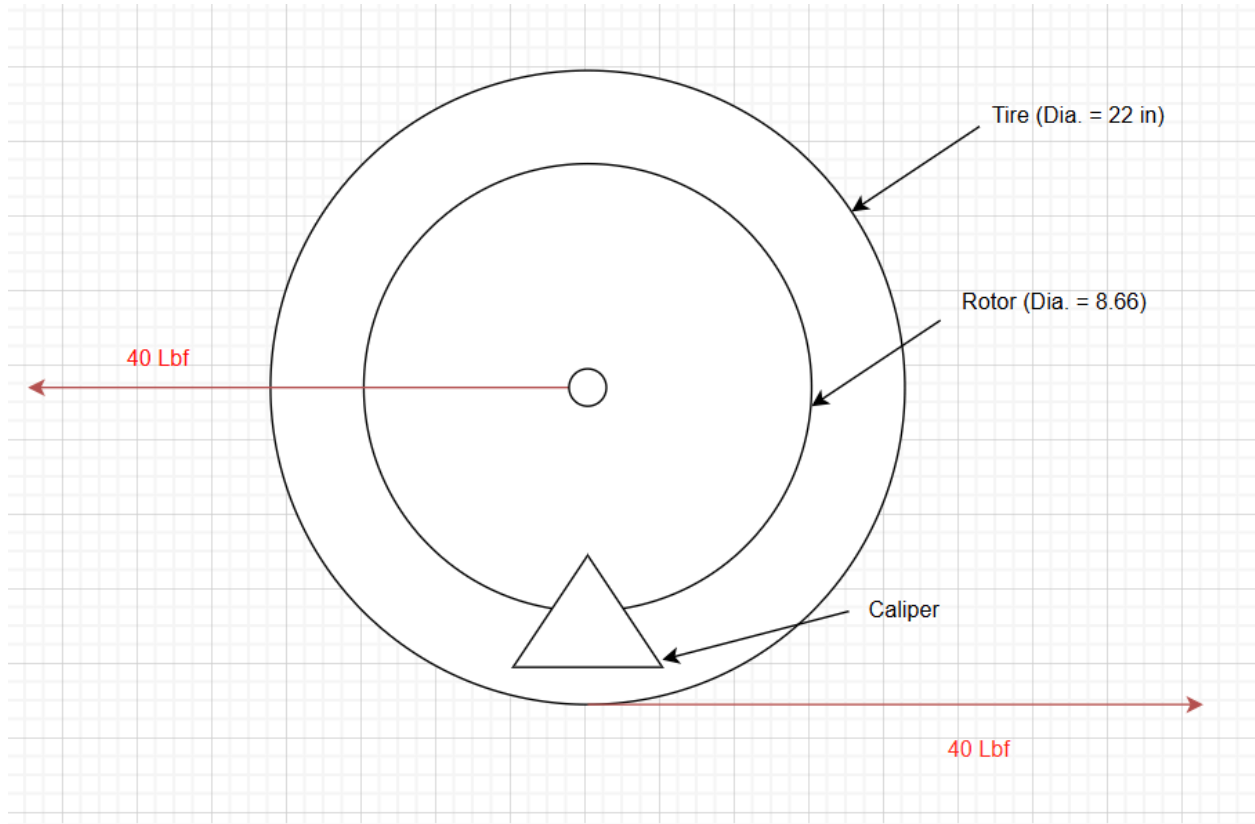


Fig. 3.

$$\Sigma M_{axle} = 40\text{lb}f \times 11\text{in} - M_{caliper} = 0$$

$$40\text{lb}f \times 11\text{in} = M_{caliper} = 440\text{lb}f \cdot \text{in} = F_{friction} \times 4.33\text{in}$$

$$F_{friction} = 101.62\text{lb}f$$

Eq. 1

A prospective mechanical caliper chosen for a mechanically actuated parking brake system is able to exert a maximum frictional force of ~960 lbf, much more than the 101.62 lbf required to resist 10% of the car's weight [6].

A prospective hydraulic caliper [10] chosen for a hydraulically actuated parking brake system is able to exert around 800 psi through its brake pads, according to a Wilwood engineering representative [13]. Given a brake pad area of 1.88 in², the brake pads are able to exert 1,504 lbs of clamping force. The frictional force generated by the hydraulic caliper's brake pads is:

$$F_{friction} = F_{clamp} \times \mu_{static\ friction} \times 2 = 1,504lbf \times 0.4 \times 2 = 1,203.2lbf$$

The expression of $F_{clamp} \times \mu_{static\ friction}$ is multiplied by two because the clamping force occurs on two surfaces of the rotor. The 1203 lbf of frictional force generated is more than the 101.62 lbf required to resist 10% of the car's weight.

A prospective electric caliper chosen for an electrically actuated parking brake system is able to exert a clamping force of 2400 lb [11]. As a result, the frictional force exerted by this electric caliper can be calculated as:

$$F_{friction} = F_{clamp} \times \mu_{static\ friction} \times 2 = 2,400lbf \times 0.4 \times 2 = 1920lbf$$

Therefore, the electric caliper is able to exert a frictional force well above the required 101.62 lbf.

Weighted Pugh Matrix

The down selection for the parking brake actuation strategy can be quantified by the following weighted pugh matrix shown in Table. 5. Mass of the overall parking brake system and whether or not it can meet performance requirements outlined in ASC reg 10.6.A were the most important attributes, and this was reflected in the weighting of the pugh matrix. Overall, the mechanically actuated parking brake system had the best score and will be picked as the parking brake actuation strategy.

Attributes (-5 to +5)	Weighting (1-5)	Mechanical Actuated (Fig. 2)	Hydraulically Actuated (Datum)	Electrically Actuated
Cost	3	+2	0	-3
Mass	5	+2	0	-1
Ease of Installation	2	+1	0	-3
Performance	5	0	0	0
Total Score	—	+18	0	-20

Table. 5.

5. Structural Analysis of Handle Mount

A component that needs to be built to spec is the mount that structurally grounds the parking brake hand ratchet to the car. The following analysis attempts to predict which fasteners will be able to survive loads experienced in normal parking brake operation.

Mounting Concept

A simple mounting method involves adding additional chassis beams, which the lever is then mounted to using traditional fasteners. This configuration is shown in Fig. 4.

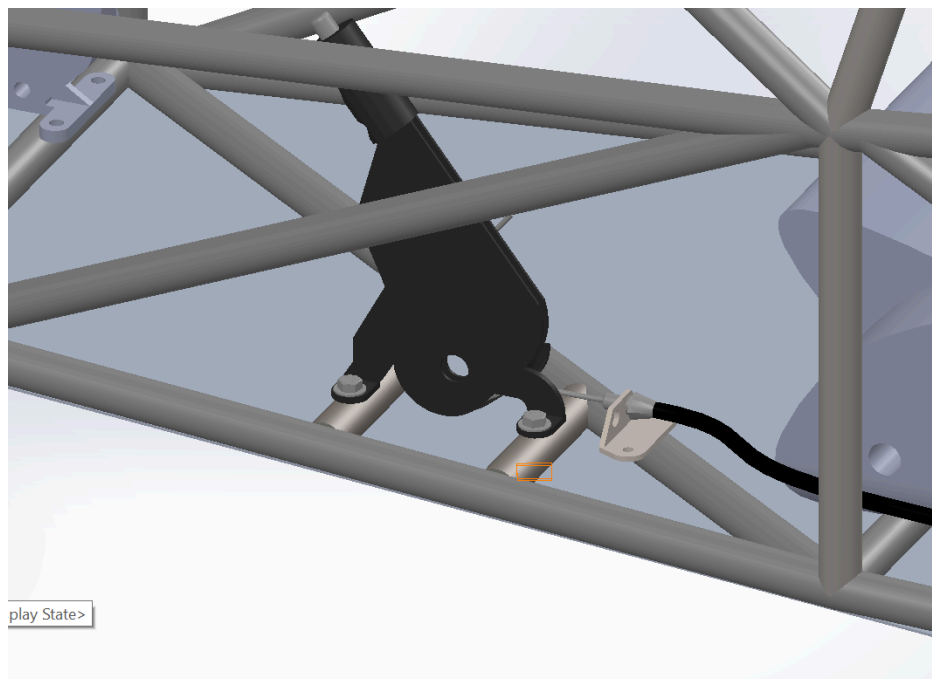
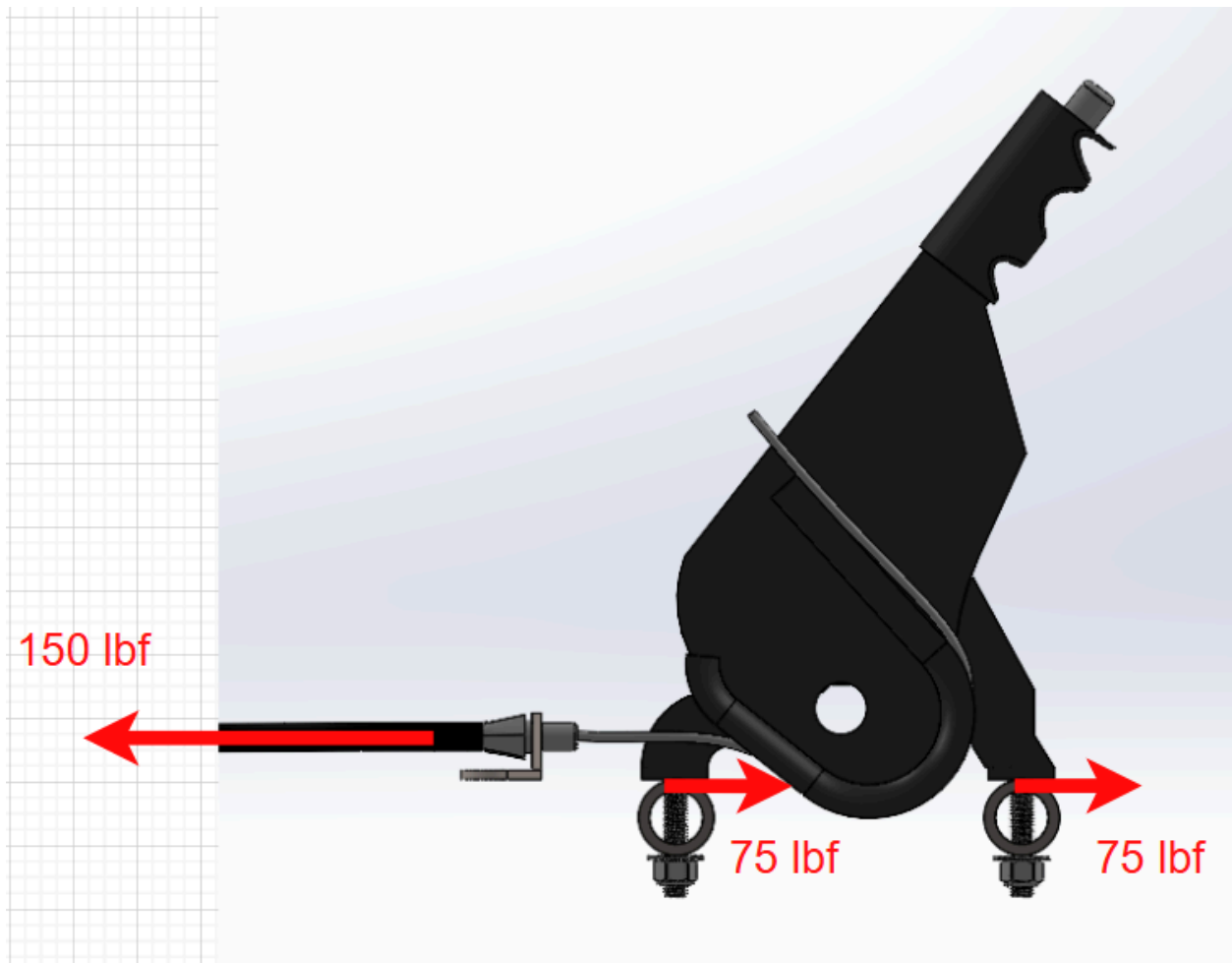


Fig. 4.

Free body diagram



Assumptions:

- Cable feels 150 lbf of tension when parking brake is fully engaged and operating at max clamping force [6]
- The bolts will likely experience more shear stress than the chassis members because they have a smaller cross sectional area. Additionally, the chassis members would be in double shear whereas the bolts are not.
- Bolt Material = Steel
- Tensile strength of steel bolt = 150,000 psi
- Shear yield strength of steel = tensile yield strength * .75 [14]
- Factor of Safety (FOS) = 1.5

Calculations:

$$\sigma_{shear-yield} = .75 \times \sigma_{yield-tension} \quad [14]$$

$$\sigma_{shear-yield} = .75 \times 150,000psi = 112,500psi$$

$$\sigma_{shear-allowable} = \frac{75lbf}{(\pi D^2/4)} = \frac{300}{\pi D^2}$$

$$FOS = 1.5;$$

$$\frac{\sigma_{shear-yield}}{\sigma_{shear-allowable}} = FOS = 1.5$$

$$\frac{(112,500psi)\pi D^2}{300} = 1.5$$

$$D = 0.0357in$$

A bolt diameter of .0357" is needed to withstand the expected loads with a factor of safety of 1.5.

Therefore, the original plan of using 5/16" - 24 threaded bolts to fasten the parking brake hand ratchet is still reasonable.

6. References and appendix

- [1] American Solar Challenge Rules and Regulations:
<https://www.americansolarchallenge.org/regulations/2024-american-solar-challenge-regulations/>

- [2] Industrial Metal Supply in Irvine:
<https://www.industrialmetalsupply.com/>

- [3] McMaster-Carr
<https://www.mcmaster.com/>

- [4] Parking Brake Ratchet from Amazon.com
[Link](#)

- [5] Mechanical Cables for Parking Brake from Amazon.com
[Link](#)

- [6] Mechanical Parking Brake Caliper from Comet ©
[Link](#)

- [7] Hydraulic Ratcheting Lever from Amazon
[Link](#)

- [8] Master Cylinder from Amazon
[Link](#)

- [9] Hydraulic Brake Lines from Amazon
[Link](#)

- [10] Hydraulic Brake Caliper from Wilwood ©
[Link](#)

- [11] Electronic Parking Brake Components from Wilwood ©
[Link](#)

- [12] Solar Car Cloud Drive

- [13] Wilwood Sales Representatives (805) 388-1188
Person of Contact: Chase D.
Date contacted: 11/25/2024

- [14] [Calculation of steel shear yield strength](#)