Finding the Mechanical Advantage of the Braking System



Link C

Link B

Link A

Pedal

Assumptions: Links A, B and C are two force members

Goal: Find the friction force, , applied to the disc based on an applied force, F.

Calculating Friction Force Required for Ideal Stop Time

Assuming a coasting speed of 4 m/s, an ideal gliding stop time is 1.5 seconds, which implies a stop distance of about 10 ft.

Assuming the average mass of the user is 70 kg and the scooter itself weighs 3 kg, the friction force between the rear wheel and the ground that is required for this stop time is 44 pounds.

Calculating Spring Moment

The spring we use on the foot lever applies a moment about point A (see diagram in following section).

At its initial position, the pedal is at 57.9° above the horizontal, and when the caliper contacts the disc, the pedal is at an angle of 50.2°. Therefore, the change in angle from the pedal’s initial position to its suppressed position is 57.9°-50.2° = 7.7°, or 0.134 radians. Since the spring constant is 4.5 inch pounds or .508 Nm, the total torque applied is only about 0.6 in-lb, as shown below:

0.134) = 0.068 Nm = 0.605 in-lb

Calculating Mechanical Advantage

To calculate the mechanical advantage of our braking system, we analyzed how the force applied by the user would translate to normal force applied to the disc.

F

Pedal FBD Equations

y

x

pedal

y

x

pt. A

FAx

FAy

φ

θ

R

Link A and C Equations

Rx

Rx

Link C

Link A

R

R



Disc

Caliper

Link B

Link C

Caliper FBD Equations

w

pt. B

x

FBz

FBx

z

z

Rx

N

Caliper

Assuming an applied force of 50 lb, when the caliper contacts the disc, the normal force is 168 pounds, giving a mechanical advantage of about 3.3.

Calculating Applied Force Required for Ideal Stop Time

The ideal braking force of 44lb is the friction between the rear wheel and the road. Since the caliper intersects with the disc at a radius of 1.2 inches and the radius of the wheel is 1.9 inches, a ratio of 0.62, the friction between the caliper arm and the disk needs to be multiplied by 1.62, giving us a friction force of 71 lb that needs to be applied to the disc in order to achieve our ideal stop time.

This friction force is dependent on the coefficient of friction (.46) between the disk and the caliper arms. Additionally, since the disk is pressed between the two brake pads, the friction on the wheel is effectively doubled. Therefore, according to the equation below, the normal force needed to achieve our ideal stop time is 77 pounds.

The user has a mechanical advantage of approximately 3.3, so the actual force they need to apply in order to stop in time is a mere 23 pounds. This means that achieving a stop time of 1.5 seconds is completely reasonable, and that if a shorter stop time is required, there is ample room left for the user to apply more force as needed to stop more abruptly.

Table : List of Variables

|  |  |  |
| --- | --- | --- |
| Variable | Description | Value When Caliper Contacts Disc |
| vc | Coasting speed of scooter |  |
| vs | Stopped speed of scooter |  |
| m | Mass of user and scooter |  |
| a | Acceleration |  |
|  | Torque from spring |  |
| k | Spring constant | 4.5 in-lb |
| θ | Angle of pedal from horizontal | 50.2˚ |
| F | Applied force |  |
| R | Resultant force on link A from pedal |  |
| φ | Angle of R from horizontal | 33.6˚ |
| FAy | Vertical resultant force at pt. A |  |
| FAx | Horizontal resultant force at pt. A |  |
|  | Length of pedal from applied force F to pt. A | 2.97 in |
| x | Horizontal distance from R to A | 0.38 in |
| y | Vertical distance from R o A | 0.62 in |
| Rx | Resultant force on Link C |  |
| w | Horizontal distance from pt. B to Link C | 1.72 in |
| z | Vertical distance from pt. B to force N | 1.17 in |
| FBx | Vertical resultant force at pt. B |  |
| FBz | Horizontal resultant force at pt. B |  |
| N | Normal force exerted on caliper from disc |  |
|  | Friction force on disc |  |
| μ | Friction coefficient between disc pad and disc |  |

Table : List of Equations

|  |  |  |
| --- | --- | --- |
| Equation Number | Equation | Description |
| 1 |  | Kinematic equation 1 |
| 2 |  | Kinematic equation 2 |
| 3 |  | Newton’s Second Law |
| 4 |  | Hooke’s Law |
| 5 | ,  | Newton’s Third Law |
| 6 |  | Friction Equation |