Physics: Braking System with Spikes

Group 3

Department of Science, Technology, Engineering, and Mathematics

SEPTEMBER 2024

The Mechanism

The researchers intend to introduce a new safety mechanism to address brake failures, a leading cause of road crashes in the Philippines. The safety device, a **spiked emergency brake system**, integrates spikes into the brake pads attached to the calipers of vehicle brakes as a backup in case the primary hydraulic brakes fail. The device utilizes hollow steel spikes, similar to police spike strips, attached to the inner part of the rubber wheels to quickly deflate tires in a controlled manner and allow the vehicle to decelerate safely.

The Physics Behind the Mechanism

Normal braking systems utilize friction to stop tires. Brake pads attached to a center-pull caliper system applies frictional force to the tire, converting total kinetic energy to thermal non-mechanical energy. The spiked emergency braking system works similarly. The present section will analyze the forces acting on the different parts of the mechanism at the moment of triggering.

1. The driver applies a force (F_a) to a brake lever attached to the inside of a car. The lever transmits a force of tension (F_T) to the braking cable. The mechanism at the top of the brake lever pulling on the cables (F_{LonC}) should be equal to the normal force exerted by the weight of the caliper at the bottom of the cable (F_{ConC}).

2. The caliper arms will then rotate at an angular motion, pivoting around a central bolt that causes them to clamp together. Once these clamp together, they apply a normal force (F_{NonT}) on the tires. Antiparallel to the direction of motion (A) and perpendicular to the normal force applied, a frictional force ($\vec{F_f}$) is generated.

3. Once the spiked brake pads inelastically collide with the tires, the spikes quickly puncture the tires. The friction generated by the spikes on the tires is greater than the tires' ability to rotate, thus halting the vehicle to a stop. In this scenario, the kinetic friction ($\vec{F_{fk}}$) is converted back into static friction ($\vec{F_{fs}}$), and the kinetic energy (KE) present in the wheels is converted into non-mechanical thermal energy.

4. The mechanism is released when the tension force generated by the cable brought about by the brake lever is brought back to equilibrium at rest.

Computations

The purpose of this section is to compute the values of the concepts used and discussed above. The car dimensions to be evaluated in this section will be that of a Toyota Vios. The Toyota Vios is the most commonly bought car in the Philippines and thus can be used to exemplify the braking dimensions of the emergency system.

The measurements below assume the perfect functioning of all involved parts; a completely flat and straight road with minimum but nonzero friction; and the maximum reaction time of the driver.

The Toyota Vios' dimensions, measurements, and technical specifications are outlined as follows:

- Mass (M) = 1,460kg
- Weight (W) = 14,308N
- Maximum speed (v) = 170kmph

- Acceleration from rest to start (a) = 12s

---

1. *Kinetic energy of the car in motion*

   The formula for kinetic energy (KE) is as follows:

   $$KE = \frac{1}{2}mv^2$$

   Assuming maximum velocity, substitute the values:

   $$KE = \frac{1}{2}(1,460)(170)^2$$
   $$KE = \mathbf{21.1mJ}$$

2. *Total time until complete deceleration*

   The formula for acceleration is given as follows:

   $$a = \frac{v_f - v_i}{t}$$

   Suppose that the maximum deceleration that a vehicle can produce for safety is 1.2G. The car can then slow down from its maximum speed of 170kmph to rest in:

   $$1.2(9.8) = \frac{-170}{t}$$
   $$t = \mathbf{14.46s}$$

3. *Distance traveled until total deceleration*

   The formula for distance traveled is given as follows:

   $$d = \left(\frac{v_f + v_i}{2}\right)t$$

   Given the computed values above, solve for the distance traveled from maximum acceleration to rest.

   $$d = \left(\frac{170}{2}\right)14.46$$
   $$d = \mathbf{1.2km}$$

4. *Force required to be applied on the brake pedal to trigger mechanism for deceleration*

5. *Normal and frictional force exerted on wheel by brake pads and vice versa*

   Referring to the image above, first, calculate the tension force (F_T) generated at $\bar{GC}$.

   $$\sqrt{9.06^2 + 8.15^2} = \sqrt{148.81^2}$$
   $$\mathbf{12.9\ in}$$
   $$\sum F_y = 355 - 2T\left(\frac{9.06}{12.19}\right) = 0$$
   $$T = \mathbf{238.82}kN$$

   Given the tension force exerted on the calipers, calculate for the normal force exerted by the brake pads onto the tires.

   $$\sum M_A = -238.8\left(\frac{8.15}{12.19}\right)(3.62) - 238.8\left(\frac{9.06}{12.19}\right)(8.15) + 16.3F_{NonT} = 0$$
   $$F_{NonT} = 124kN$$

6. *Inelastic collision and total momentum conserved*