Sun Devil Braking Co.

Phase 1 Report: Car Braking System

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Executive Summary:

For this project, Sun Devil Braking Co decided to work on developing a braking system for a car. Cars are a critical factor in modern societies and provide people with the most reliable form of transportation to travel from one point to another. There are many working parts that go into building a functional and safe car, with one of the most important features being a braking system. Braking systems ensure that a car can safely stop within a certain time and distance, which makes them crucial for the safe operation of a motor vehicle. Since the braking system is such an important part of a motor vehicle, our group, Sun Devil Braking Co is going to research and study braking systems to see how braking systems ideally operate, withstand failure, perform optimally, and function inside motor vehicles. With these considerations, a model of a performance braking system for a single rotor will be designed, tested using simulations, and a 3D-printed prototype will be constructed.

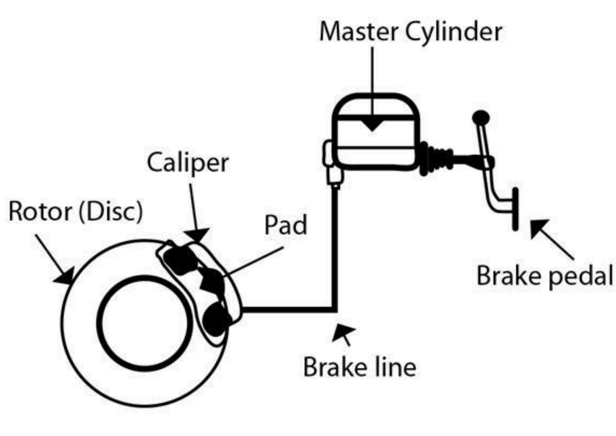
System Description and Functional Overview:

A braking system is a hydraulic, friction-based system designed to safely decelerate a vehicle by converting the vehicle's kinetic energy into thermal energy. This works by the driver of the vehicle applying a force to the brake pedal, which transforms this mechanical input into hydraulic pressure by the brake master cylinder. Inside brake lines, there is brake fluid that is pressurized, which is transmitted into the brake caliper. Inside the caliper, hydraulic pressure forces the pistons outwards, which push the brake pads against the brake rotor, creating friction. This friction produces a braking torque that opposes the rotation of the wheel, which consequently decelerates or stops the vehicle. A braking system allows controlled braking by applying different forces to the brake pedal, allowing different rates of deceleration or stopping of a vehicle. Additional considerations external to the brake system itself include the weight of the car and the tires. As a car slows down, its weight is shifted forward, leading to the front brakes of the car providing the majority of the braking power, leading to the need for front rotors to be larger to produce a greater brake torque. Additionally, the braking power of a car is limited by the traction between the tires and the road. This means that factors such as the tread, contact patch, temperature of the tires, and road surface conditions can all limit the ability of the braking system, as the wheels will “lock up” if traction is lost.

Component Breakdown:

- Brake Rotor:
    - Rotates with the wheel
    - Absorbs heat that is generated from braking and dissipates it
    - A rigid disc attached to the wheel hub
- Brake Pedal:
    - Mechanical input device
    - Allows the driver to control the force of the braking system

- Brake Pads:
    - o Made out of high-friction composite materials
    - o Generate friction by pressing against the rotor
    - o Designed to withstand substantial wear and high temperatures
- Brake Caliper (Pins & Pistons):
    - o Supplies pistons that are actuated by hydraulic pressure
    - o The pistons push the brake pads toward the rotor
    - o The caliper pins allow calipers to auto-align for even wear on the pad
- Brake Lines:
    - o Carry pressurized brake fluid from the master cylinder to the brake caliper
    - o Maintain system integrity by withstanding high temperature and pressure
- Brake Master Cylinder:
    - o Converts force from the brake pedal into hydraulic pressure
    - o Ensures proportional braking force relative to the input into the brake pedal



Kinematic Description:

The braking power of a car is dependent upon the torque created from the frictional force generated between the brake pads and the brake rotor. The material of the brake pads and the rotor determines the coefficient of friction. The clamping force of the pads on the rotors is determined by the force of the piston(s) pressing on the pads.

$$F_{friction} = \mu_k F_{piston}$$

This force is determined by the area of the piston being acted upon by the pressure of the hydraulic fluid within the brake lines.

$$F_{piston} = P_{brake\,fluid} \cdot A_{piston}$$

$$F_{piston} = P_{brake\,fluid} \cdot \frac{\pi D_{piston}^{2}}{4}$$

When the brake pedal is depressed, this limits the volume occupied by the brake fluid, which then increases its pressure, which forces the piston to expand. This creates a system in which the driver of a vehicle can control the brake response to slow the vehicle by pressing the pedal. Combining these equations results in the torque, T_{brake}, acting on the wheel to slow the vehicle.

$$T = lever\ arm \times force$$

$$T_{brake} = \frac{\mu_k P \pi D_{piston}^{2} R_m N}{4}$$

Where R_m represents the lever arm taken as the average of the inner and outer radii of the brake pads, and $\frac{\mu_k P \pi D_b^{2} N}{4}$ represents the frictional force between the pads and rotor.

$$R_m = \frac{R_0 + R_i}{2}$$

Additionally, the variable N is implemented to account for the number of brake pads clamping on the rotor, which is two $N = 2$ in the case of this single rotor braking system. When the wheel's speed is zero, the coefficient of kinetic friction instead becomes the coefficient of static friction μ_s, resulting in the following equation.

$$T_{brake} = \frac{\mu_s P \pi D_{piston}^2 R_m N}{4}$$

Preliminary Failure Modes:

- Total hydraulic failure:
  - Loss of pressure, or inability to hold/generate pressure
  - Without adequate pressure, calipers cannot exert enough force on pads to create a significant frictional force
  - Caused by leaks, trapped air in the system, or contaminated brake fluid
- Pad glazing/loss of friction:
  - Pad surfaces become smooth and shiny (glazed) due to extreme heat
  - The surfaces don't have enough grip to create a significant frictional force
- Pedal/lever fracture:
  - The brake pedal becomes broken or detached
  - Inability for driver to create input to the brake system
- Brake fade/thermal runaway:
  - The brake system becomes increasingly less effective at extreme temperatures

- Excessive hard braking heats up the system, reducing the amount of friction the pads and rotor can produce
- Extreme heat can lead to deformation, such as warped rotors, or cause the brake fluid to boil

- Uneven braking:
  - Applicable to a brake system with more than one rotor
  - Causes vibrations, noises, sluggish or pulsating brakes
  - Usually caused by a lack of maintenance or warped rotors
  - Pads or rotors are unevenly worn or below wear specs and need to be replaced
  - Caliper pins need lubrication; a seized caliper preventing piston from properly compressing/retracting

Design Considerations:

- Materials:
  - Rotors need a material with good thermal conductivity
  - Pads need a material that has high friction and can withstand the expected temperature range (metallic, ceramic, or organic)
  - Material to consider weight such as aluminum
  - Brake line material needs to withstand high temperature and pressure
- Seals and Fluids:
  - The seal must be compatible with the brake fluid

    - Must consider the fluid's properties
- Tolerances:
    - Must understand the tolerances for size specifications and material selection
- Safety/Redundancy:
    - Fail-safe measures, such as master cylinder residual pressure valves, only if needed
- Assembly:
    - Installation must be simple and repeatable to prevent errors during assembly
- Dimensions:
    - Rotor with a diameter of 260-300 mm and a thickness of 22-26 mm
    - Brake pad with a length of 110-125 mm, a height of 50-60 mm, and a thickness of 12-15 mm
    - 3-Piston Caliper with a length of 140-150 mm, a height of 70-85 mm, a depth of 110-130 mm, and a piston diameter of 30-42 mm
    - Brake line with a diameter of 4.75 mm
    - Master Cylinder with a bore size of 22-28 mm
    - Design must be a ¾ scale model of a common braking system for 3D-printing

References

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