Brake Rotors 2020

Rotor Design

Our brake rotors undergo a large amount of thermal stress during the braking process. Since in previous years we have had problems with our rotors thermally compromising, it is especially important to our team that the rotors are able to withstand very high temperatures and the mechanical stress at these temperatures due to forces from the callipers will not compromise the rotors.

As a result of this, our main design goal for the 2020 rotors was to ensure that they are robust and can withstand the high temperatures experienced during braking. Additionally, we wanted to try to reduce the mass of the rotors as much as possible by incorporating through holes. Unfortunately, these two goals interfere with each other; as the mass of the brake rotors decreases it is less likely to be able to endure the heat transfer.

Materials

We chose 4340 steel for our rotors this year. What we were mainly concerned about for materials choice was choosing a robust material that was easy to machine but was also capable of withstanding the heat transfer. We also wanted to consider cost. We could have really reduced the weight of our rotors by choosing a material like titanium, but couldn't justify the high cost. Our main criteria in choosing a material was heat capacity. This is because when the car brakes, the kinetic energy of the car is translated into thermal energy that goes into the brake rotors. If we assume that all of the kinetic energy of the car goes into each of the rotors equally, then we can model that by the equation
$\frac{1}{2}mv^2 = 4m_{rot}C_p\Delta T$.
Since we know the values for m and v during a max braking event, when finding the temperature the main constraining factor is the heat capacity of the material. Looking through different materials in our cost range, we found that carbon and nickel steels were very good in terms of heat capacity. We narrowed our materials down to 4340 steel, a robust nickel steel, and cast iron, a carbon steel. Given that they both had a good heat capacity, we made the decision based on ease of machinability and robustness. Given that cast iron can be extremely brittle, we ultimately made the decision to go with 4340 steel for our rotors.

Physical Validation

In order to verify our calculations, we considered using multiple contactless infrared temperature sensors, brake temperature indicating paint, and embedded thermocouples. Brake temperature indicating paint was one we eliminated quickly due to the controversy around its reliability for high temperatures, but it would have been a good preliminary tool to find a temperature range of the rotors within 5 minutes of testing. (Insert something about IR sensors). We decided to use a rubbing contact thermocouple because it has a large enough measuring range with an accuracy of $\pm 1.5°C$ and it is a low cost, direct method that is specifically designed for high vibration, high temperature environments.

The front and rear axles should both have thermocouples installed on the same side of the car and at relatively the same radius and position with respect to the brake pads and center of brake rotor while taking into account the position of the holes in the rotor.

Tests should include accelerating the car to 60 mph before engaging in full deceleration braking to a stop as well as sequenced brake maneuvers with close to maximum braking pedal force. To factor into brake pad degradation, this cycle will be repeated for three trials to monitor thermomechanical deformation from pads. This will help understand and map the physical degradation of the pads as well.

If the results are lower than expected, then in future designs, we should consider further weight optimization, but if the results are higher than desired, we should optimize the rotor's thermal capabilities through change in it's geometry.