Regenerative Braking: A Study on Efficiency

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Regenerative Braking

Regenerative braking is an energy recovery mechanism that converts a moving vehicle's kinetic energy into storable electrical energy. This system uses an electric vehicle's motor as a generator to convert much of the kinetic energy lost when decelerating back into stored energy in the vehicle's battery. Therefore, when the car accelerates again, it can use much of the energy previously stored from regenerative braking instead of tapping back to the original energy reserve. Figure 1 shows a simplified model of the acceleration versus deceleration of the car and how that motion translates to a from the electric motor.

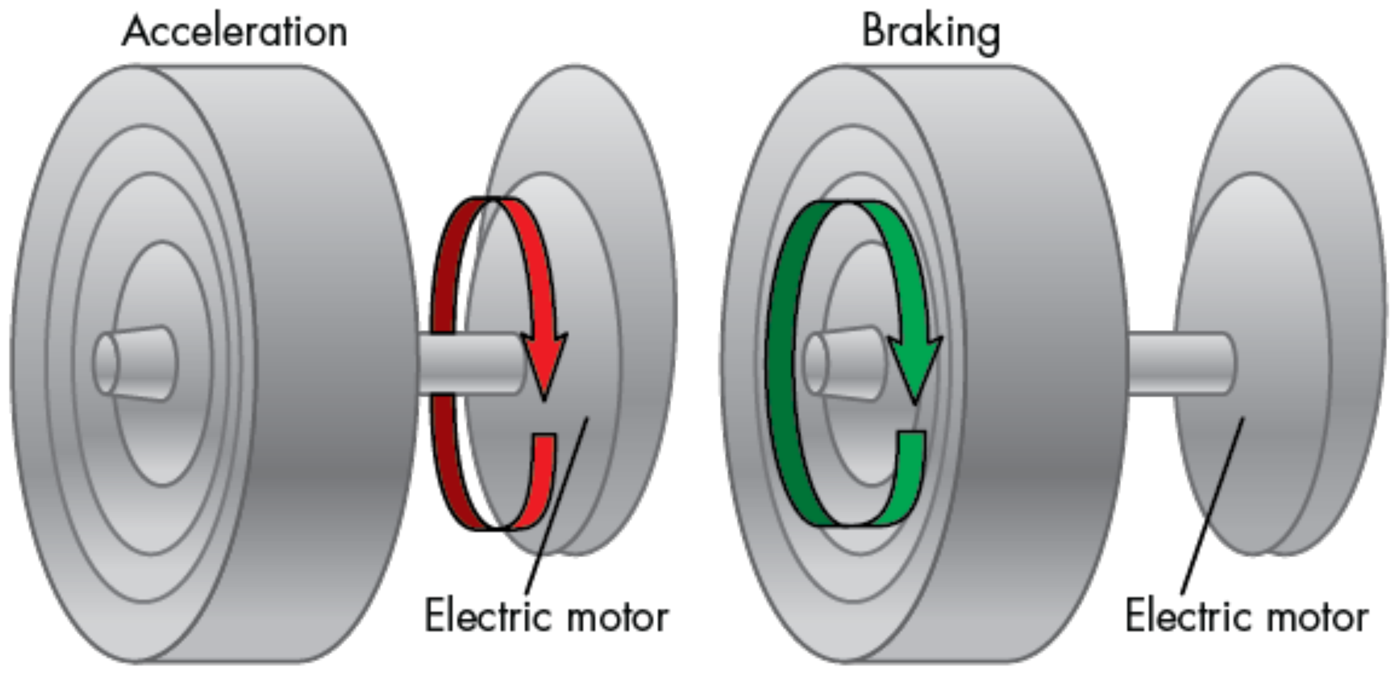

Figure 1. Regenerative Brakes [1]

Investigation

Our team investigated how to improve the efficiency of a regenerative braking system. We thought about how a brake system works (see Figure 2) and how to harvest extra energy from the system. Our thoughts immediately led towards harvesting the heat lost from the brake pad rubbing against the rotor. The team investigated taking this heat and finding a way to convert it to energy that could be stored back in the batteries on top of what the regenerative braking system already does. This led us to thermoelectric generators, such as Peltier devices.

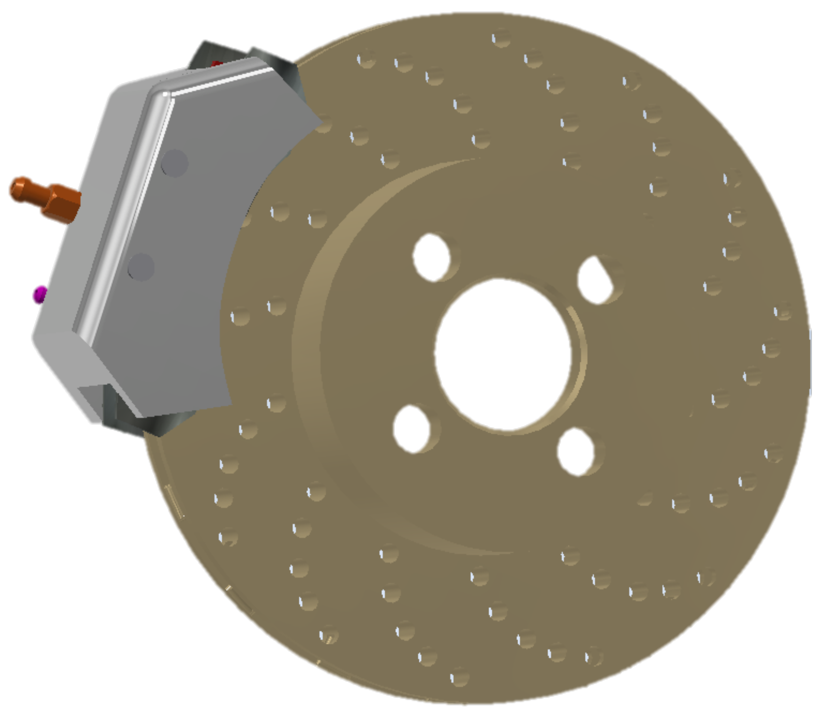

Figure 2. Standard Brake System [2]

Peltier Devices and the Seebeck Effect

The Seebeck effect was discovered by Thomas Johann Seebeck, a Baltic German physicist. This effect is a phenomenon in which two dissimilar materials in contact with one another produces a voltage difference. When heat is applied, the electrons become excited. The electrons start moving to the cooler side of the two semiconductors, producing a current in the circuit. The voltage produced by the Seebeck effect for one of these thermocouples is very small, however, when many of these devices are connected in series, the voltage adds up. For example, one 40x40mm Peltier device might contain 128 of these thermocouples. Connecting many of these Peltier devices together in series will greatly increase the amount of voltage able to be harvested [3]. An example of a Peltier device is shown in Figure 3. This specific device is a 40x40mm high-temperature TEG (thermoelectric generator) that will generate up to 3W at a 100˚C temperature difference and down to 0.22 W for a 20˚C temperature difference.

Figure 3. Peltier Device [4]

Solution

Our team decided to create an array of 24 Peltier devices close to the surface of the rotor on both sides (Figure 4). The hot side of the Peltier faces the rotor while the cool side is exposed to ambient temperature. Fins can be implemented to ensure the cool side of the device remains at ambient temperature. When braking occurs, the remainder of the kinetic energy not removed from the regenerative braking system is dissipated into the rotor, thus increasing the rotor surface temperature. As this occurs, radiative and convective heat transfer take place between the rotor's surface and the hot side of the Peltier. This thermal energy is then converted into electrical energy via the Seebeck effect. These devices are largely inefficient. The thermal energy recovered using these devices, however, is already wasted. Recovering any portion of this energy is beneficial.

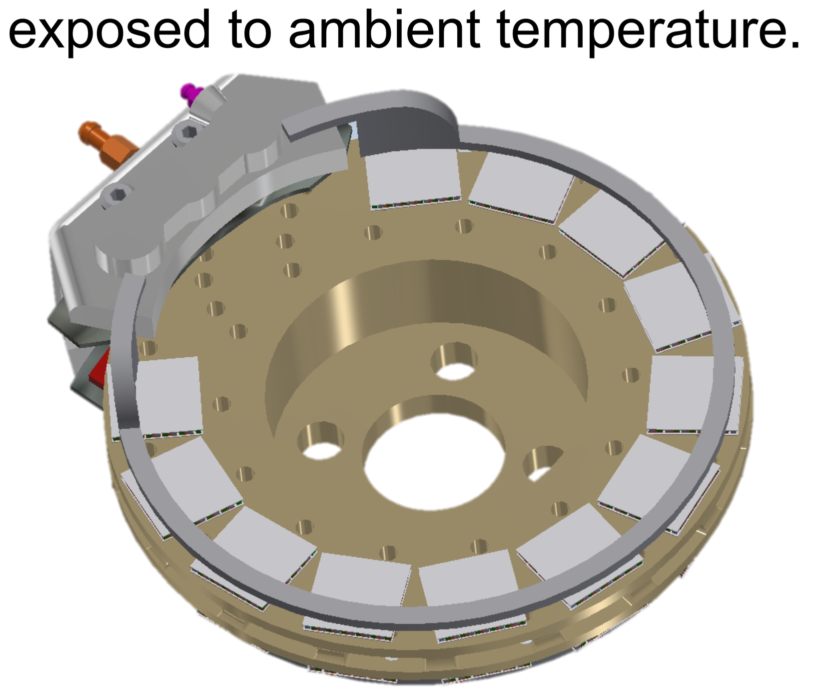

Figure 4. Brake System with Peltier Devices

Results

To model the thermal energy transfer to the rotor from the clamping of the brake pads, COMSOL Multiphysics software was used. Excel was then used to compute the thermal energy from the rotor to the Peltier devices (Eq. 1). The assumptions made in the model include: using a Tesla Model 3 as reference, the regenerative braking system has an efficiently of 60%, most of the thermal energy to the Peltier is due to radiation, the Peltier can be placed 2mm from the rotor, and the car is initially traveling at

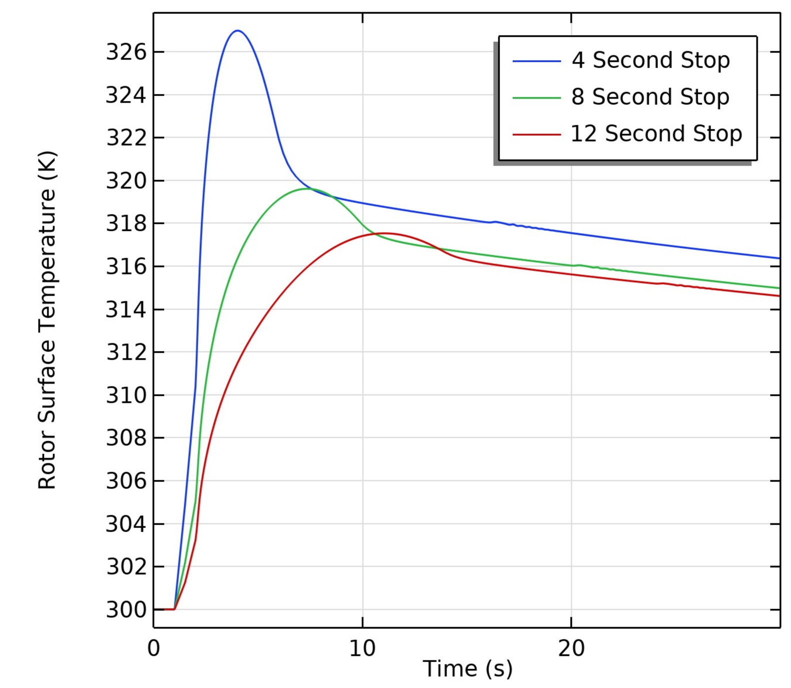

Figure 5. Rotor Surface Temperature v. Time

$$Q_{into\ Peltier} = \Sigma\left[\sigma\epsilon FA\left(T^4_{rotor,i} - T^4_{Peltier,i}\right)\Delta t\right]. \qquad (Eq. 1)$$

56 mph. Three different brake times were tested: 4, 8, and 12 seconds (Figure 5). An average of the temperature on the surface of the rotor was computed during braking, while stopped, and while speeding back up. The efficiency of the regenerative braking system with the Peltier devices is shown in Equation 2. Taking

$$\eta_{Peltier} = \frac{60\% * KE_{car} + Q_{into\ Peltier}}{KE_{car}} \qquad (Eq. 2)$$

the average efficiency increase over each brake time results in an overall efficiency of 60.25%. For our Tesla Model 3 traveling at 56 mph, this corresponds to an increase of 1.6 kJ per stop over its standard regenerative braking system. If implemented this device seems to have promising results for energy savings.

References

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