inwheel

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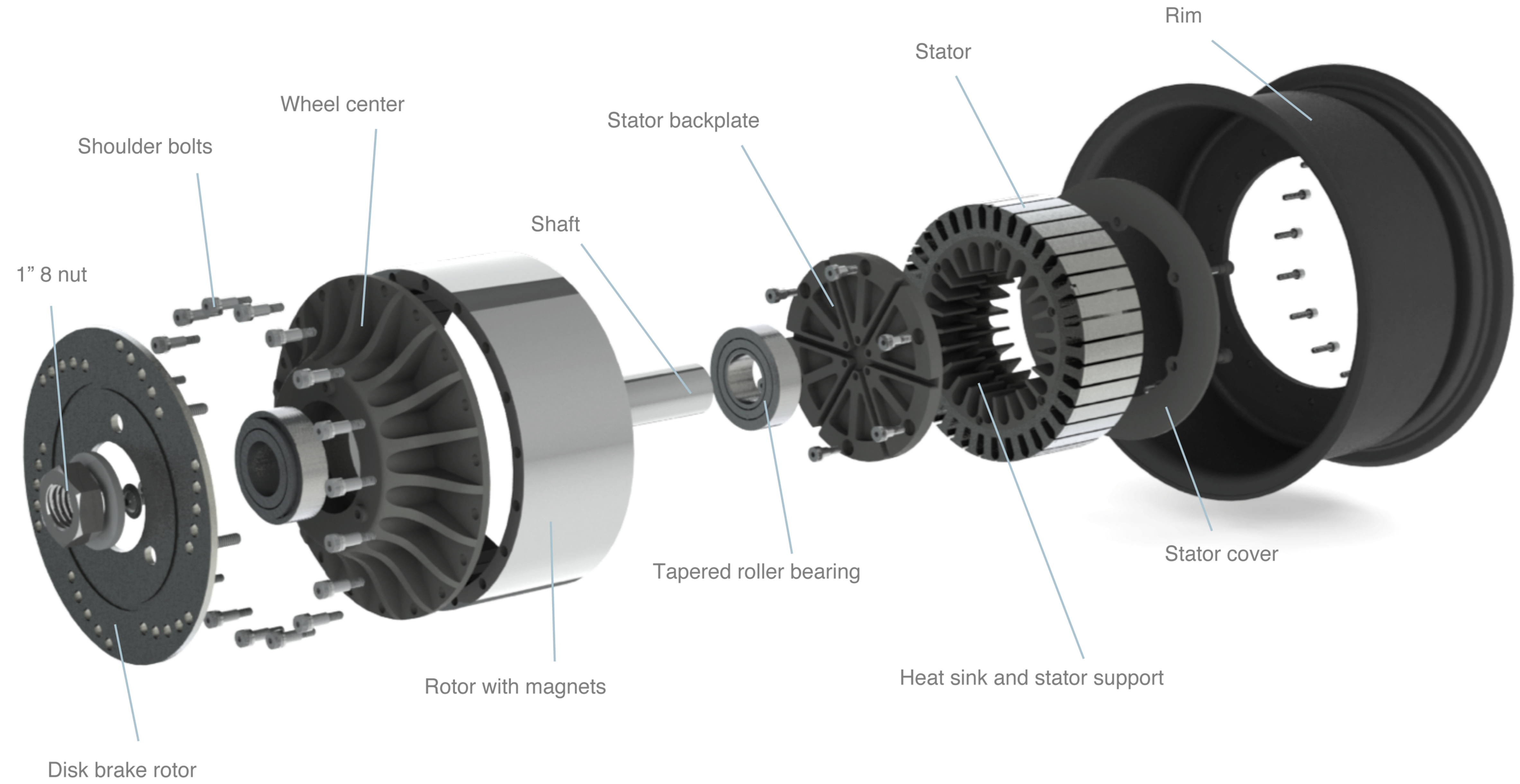
Given the recent trend toward battery-electric and hybrid vehicles, there is a wide open space for innovative electric powertrain design. Through this project, we have explored the powertrain architecture of an in-wheel motor, which involves housing the electric motor directly within the wheel. Our goal was to build a functional brushless direct current (BLDC) motor to fit a commercial scooter (i.e. Honda Ruckus). The prototype is a real world test platform for future in-wheel motor development for use in the next Penn Electric Racing project. Our final prototype is a BLDC motor that is designed to operate at a peak power of 5.9kW and produce a peak torque of 107 Nm. The motor incorporates an innovative heat sink design, which greatly increases the power density of the motor and protects the magnets and windings from thermal damage.



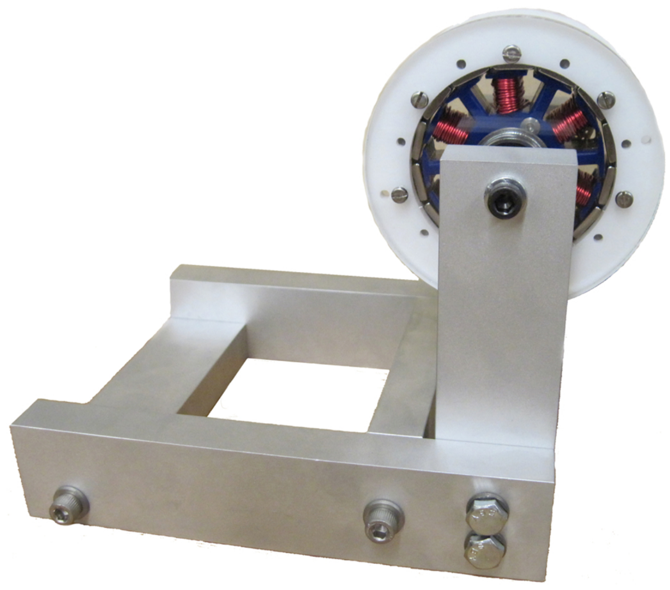
What is a BLDC Motor?

A BLDC motor is an electric motor that uses an electronic controller to drive the commutations of the motor, rather than mechanical brushes.

Key Features:
- -High power density
- -High Efficiency
- -Uses permanent magnets which consume no power
- -Low friction losses due to lack of brushes
- -Longer life than Brushed DC
- -Can be controlled with off the shelf controller

In Wheel Architecture

-Regenerative braking on all wheels – a range increase of 6%-27%
-Weight reduction of powertrain – no drive shaft, differential, gears
-Reduced mechanical losses
-Increased interior space – cars can have more room or be made smaller
-Advanced dynamics through independent torque control



Design Requiremenets

The first step in designing a motor is to characterize the motor by the torque constant, which is determined by the dynamic requirements of the vehicle. We can determine the target performance by defining how the motor should perform in three specific scenarios:

Using this model, we were able to determine that the motor would need to have a peak torque at 107 Nm and a rated speed of 539 rpm.

In order to verify if we could construct a working BLDC motor, we spent the first semester designing a small scale prototype.

Case 1:
- Max acceleration from standstill

$$F_{tractive\ effort} = F_{rolling\ resistance} + \cancel{F_{aerodynamic\ drag}} + \cancel{F_{hill\ climbing}} + F_{acceleration}$$

Case 2:
- Climbing a hill at a constant velocity

$$F_{tractive\ effort} = F_{rolling\ resistance} + \cancel{F_{aerodynamic\ drag}} + F_{hill\ climbing} + \cancel{F_{acceleration}}$$

Case 3:
- Travelling at max speed
- Only drag and rolling resistance acting on bike

$$F_{tractive\ effort} = F_{rolling\ resistance} + F_{aerodynamic\ drag} + \cancel{F_{hill\ climbing}} + \cancel{F_{acceleration}}$$

First Order and FEA

The 1st order model and FEA results were verified using empirical results from the fall semester prototype. These results assisted in guiding the design for the final prototype.
The 1st order model allowed us to roughly determine a torque constant that would characterize our motor. The model also allowed us to determine the number of windings per phase that would be required to get the correct torque constant. The magnetic FEA that was performed, allowed us to confirm potential saturation points on the motor, and more importantly allowed us to confirm the approximation of the first order model. Shown below is a calculation of the torque constant from the first order model for the final prototype:

Kt First order DC estimate	Value	Units
Number of turns per phase	72.00	
Rated field strength of magnets	1.32	T
Thickness of magnet	3.18	mm
Air gap thickness	0.76	mm
Field Strength across air gap (B)	1.06	T
Active Length (L)	0.0495	m
Radius at the air gap (R)	0.0812	m
Torque constant (wye) = 4NBLR	1.233	Nm/A

Testing and Validation

We conducted two main tests to verify the models used to construct the motor. To determine the torque constant, we needed to know current and torque, or back EMF and speed.

Dynamic testing
- -Run the motor at no-load speed
- -Measure speed and calculate back EMF

Static testing
- -Load motor with known weight
- -Drive 2 phases with high current
- -Slowly decrease current
- -Measure current when weight falls. This gives maximum torque at a given current.

The results for the empirical and analytical torque constants are shown below for the fall semester prototype. Note how the analytical results agree closely with the empirical.

1st Order Model	0.115
Dynamic FEA average	0.085
Dynamic Testing average	0.102
Static FEA average	0.107
Static Testing average	0.099

Mechanical Design

The mechanical design of the motor accommodates a singly supported architecture that is adaptable to both two wheel and four wheel vehicles. The design also takes in consideration the lessons from design for manufacturability, by minimizing the total number of components and using common yet appropriate material for the design. The robustness of the final design would prevent external particles from entering the air gap, and protect the windings and sensor wiring as well.

Electrical Design

In order to design the final motor, the interactions between the electrical circuits, the magnetic circuits and the material properties need to be taken into account. Magnetic flux leakage and slot leakage for example, must be avoided to increase the efficiency of the motor. Using the results from the FEA and optimization models, we determined a design and winding configuration that were specific to our needs and adaptable for future projects for Penn Electric Racing.