A Reaction Sphere for High Performance Attitude Control

Matthew P. Wampler-Doty (matt@w-d.org) John P. Doty (noqsi@noqsi.com) Noqsi Aerospace, Ltd.

Introduction

Our research introduces a novel method for spacecraft attitude control. We replace conventional systems of momentum wheels with a single spherical induction motor, which we refer to as a *reaction sphere*. Our patent pending innovation has a number of advantages over the existent technology. We hope that our reaction sphere will enable nano-satellites to do scientific research demanding precision orientation.

Components

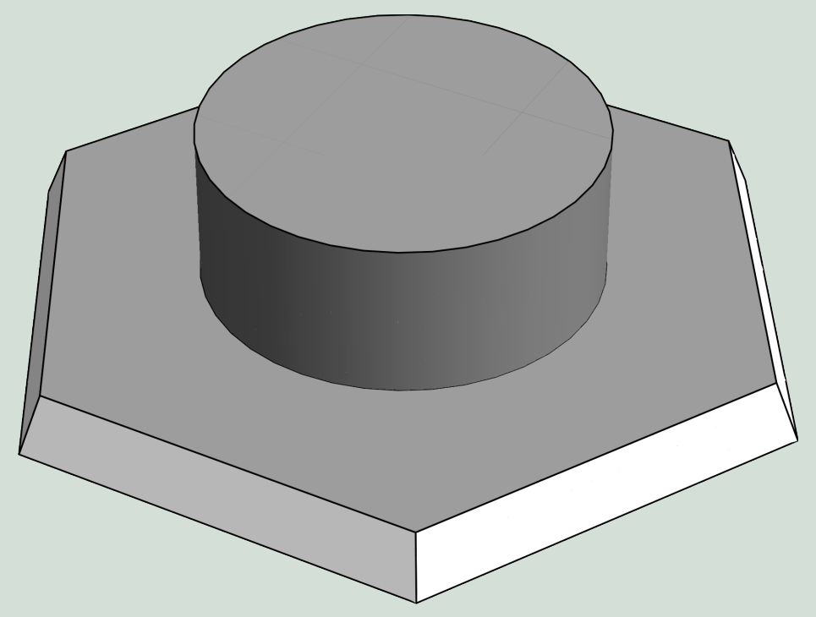
- *Rotor* – a solid copper sphere
- *Stator* – copper magnetic coils on pole pieces
- 20 *Pole Pieces* – hexagonal ferrite structures
- 8 *Optical Sensors* – placed all around the rotor

Operation

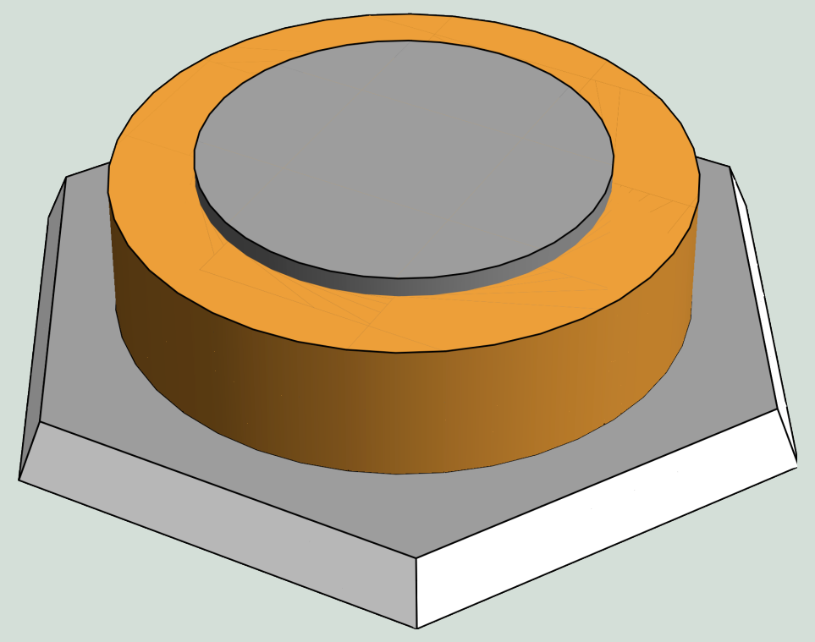
The reaction sphere is a rotary induction motor. A rotating magnetic field induces a trapped field in the rotor, torquing the rotor into corotation. A superimposed oscillating magnetic field repels the rotor, suspending it within the stator. Optical sensors measure rotor velocity and distance relative to the stator. A microcontroller calculates the required field and drives the stator using pulse width modulation.

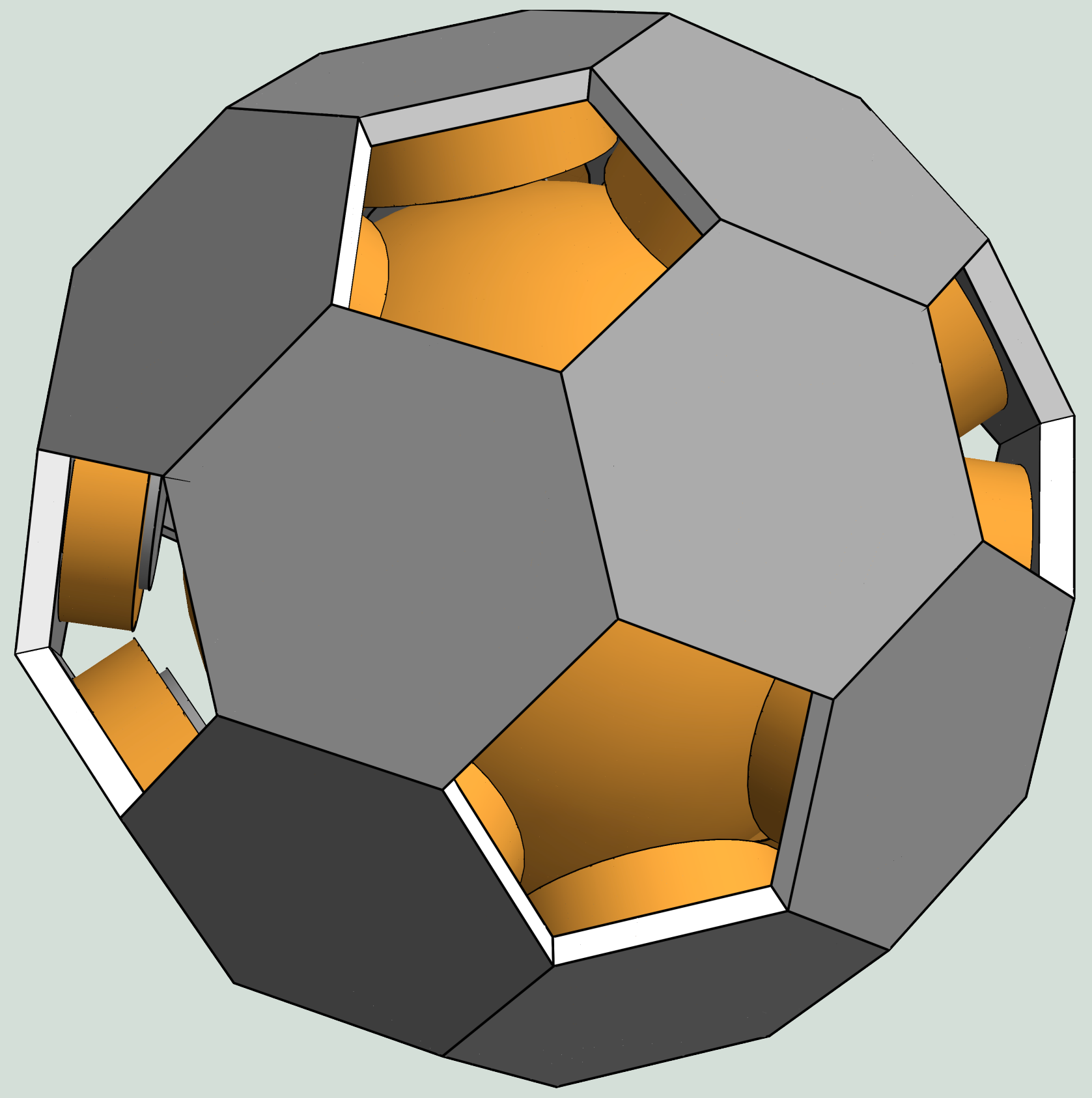
Design

The stator is composed of 20 ferrite pole pieces



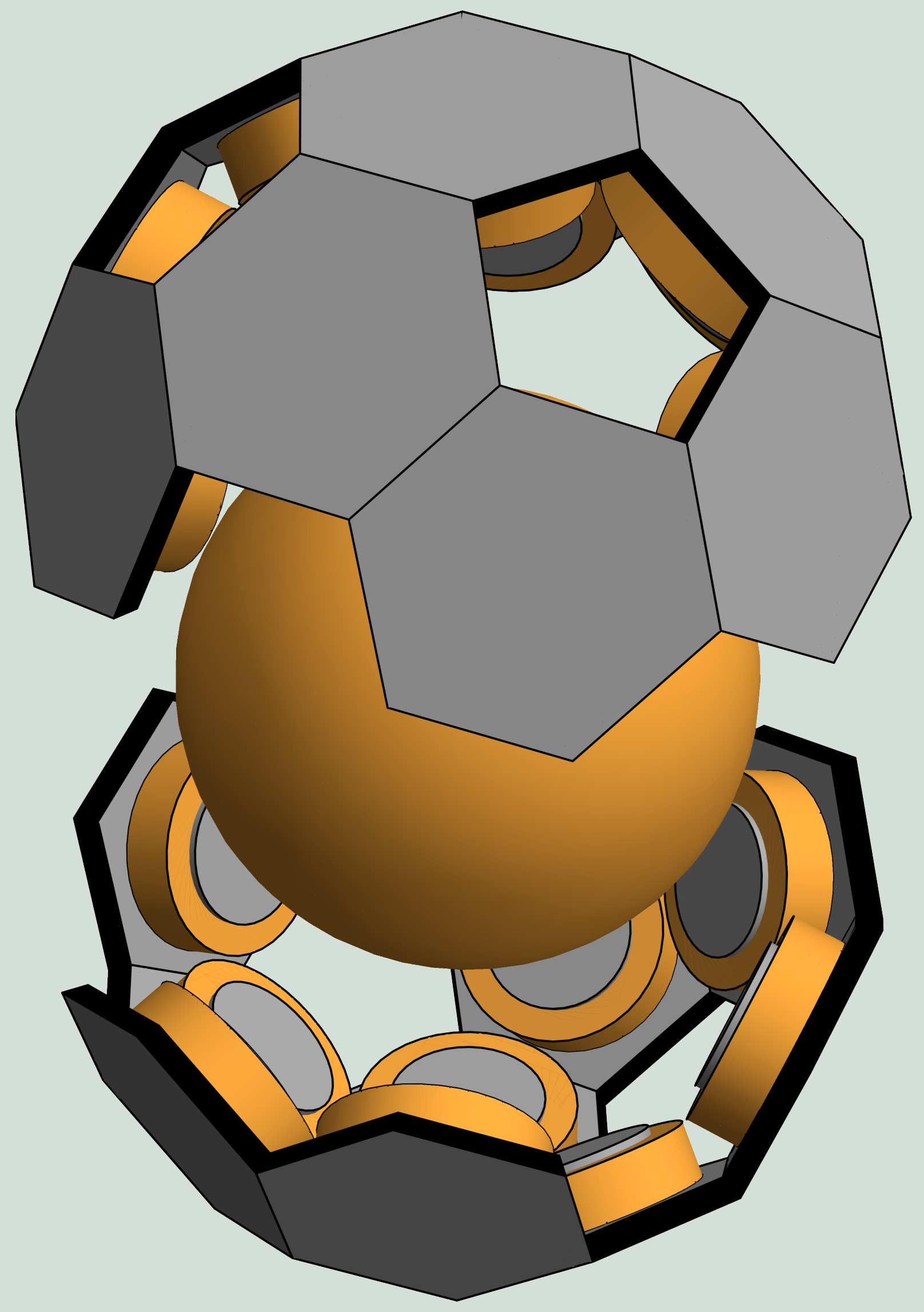
Each pole piece has a copper wire winding





Tachometers will be placed in openings (not shown)

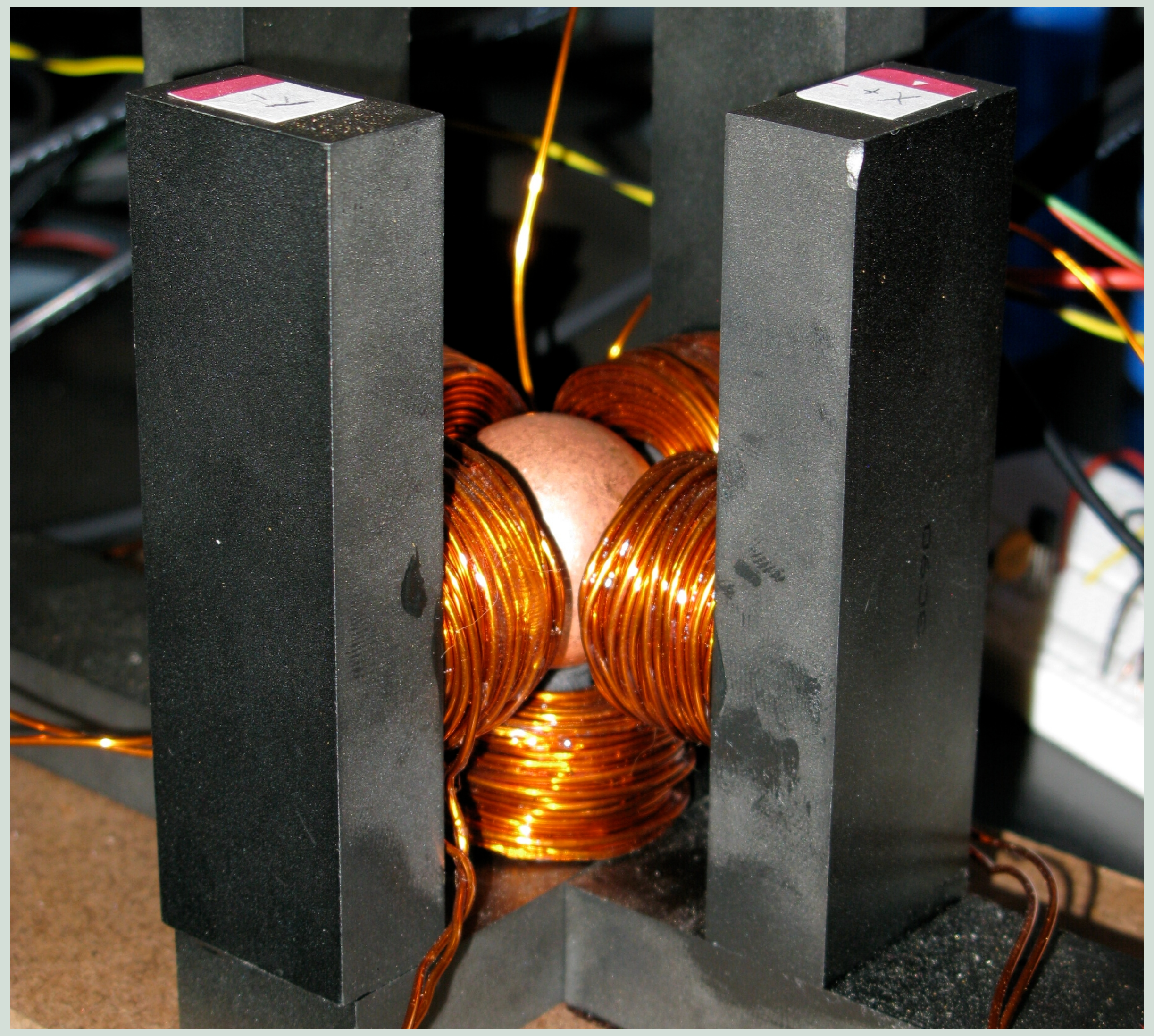
The 20 pole pieces form a truncated icosahedron about the rotor, a solid copper sphere



Comparison

Difficulties with conventional reaction wheels	**How the reaction sphere resolves them**
Torque can only be exerted in one direction. $\geq$ **3** wheels are necessary for full control.	Spherical induction allows for torque in any direction. **Only one** sphere is necessary!
Gyroscopic precession, referred to as *nutation*, complicates control.	The sphere moves freely in inertial space, so the axial constraint that drives nutation is absent.
Mechanical stress leads to component failure. Redundant backup systems are often necessary.	The sphere levitates; mechanical failure is impossible.
Energy is lost of from friction on the bearings.	There is no friction, hence no energy wasted.
Bearings stick at slow rotation rates and chatter at higher rates.	Because there is no contact, there is no sticking. The only chatter comes from imperfections in the magnetic field.
Reaction wheels cause vibrations.	Vibration is negligible, because no contact is made with the sphere, and the oscillating suspension field is very small in microgravity.

Prototype



Performance Goals

Mass	< 400 g
Power	< 200 mW
RMS Jitter	$< 1\%$ of torque
Max Torque	0.00005 NM
Maximum Momentum	0.002 NMs
Device Dimensions	$5 \times 5 \times 6$ cm^3

These goals are intended to enable subarcsecond pointing and large scale maneuvers in $\sim$1 minute for spacecraft at the Cubesat scale.

Simulation

We are developing a simulation. Our approach uses the magnetic diffusion equation:

$$\frac{1}{\sigma\mu}\nabla^2\vec{\mathbf{B}} = -\frac{\partial\vec{\mathbf{B}}}{\partial t}$$

This is easy to solve numerically with convolution, which in turn is well suited to fast, parallel implementation. In the rotor, σ is the conductivity of copper. For the vacuum between the rotor and stator $\sigma = 0$. There, we assume a low but nonzero value. This insures rapid, stable convergence.

We solve this equation on a mesh that is fixed to the rotor, so in the electromagnetic part of the calculation the stator rotates. We compute two different values for the field:

1. $\vec{\mathbf{B}}$ approximates the actual field. We compute it using the field at the pole pieces as a boundary condition.
2. $\vec{\mathbf{B}}_f$ is the field assuming the pole pieces are absent, computed using $\vec{\mathbf{B}}$ at the surface of the rotor as a boundary condition.

We use $\vec{\mathbf{B}}_f$ to compute the back reaction of the field on the pole pieces, and thus the force and torque on the sphere.

Funding

This work is currently supported by NASA SBIR Phase 1 contract NNX11CF07P.