3Dwheel - Attitude Control of Small Satellites Using Magnetically Levitated Momentum Wheels

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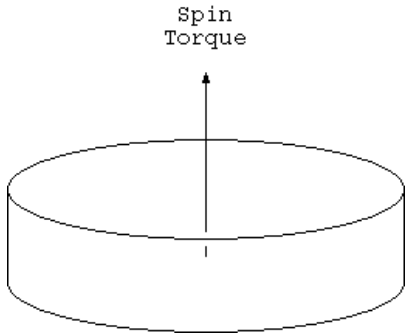
Overview

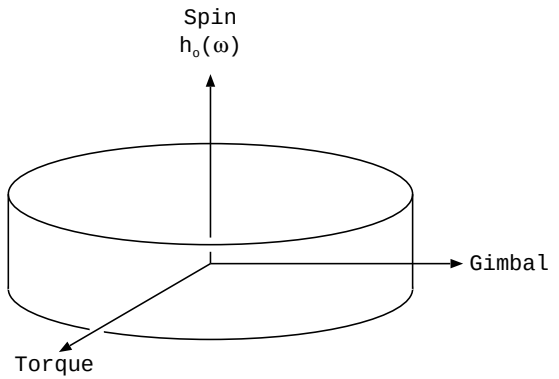
- Momentum wheels, CMGs and magnetic bearings
- 3Dwheel Principle
- Simulation Results
- Experimental Results
- Power Consumption and further work
- Conclusions, novelty and publications

Momentum Wheels/CMGs

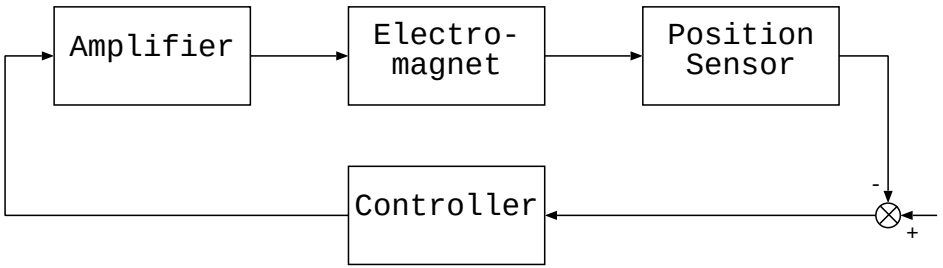
- Reaction/Momentum Wheel (MW)



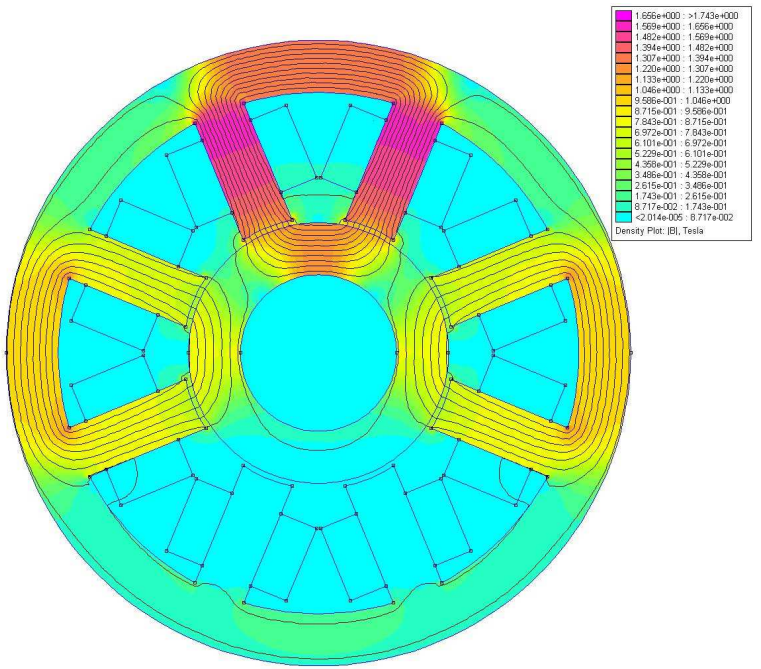
- Control Moment Gyro (CMG)



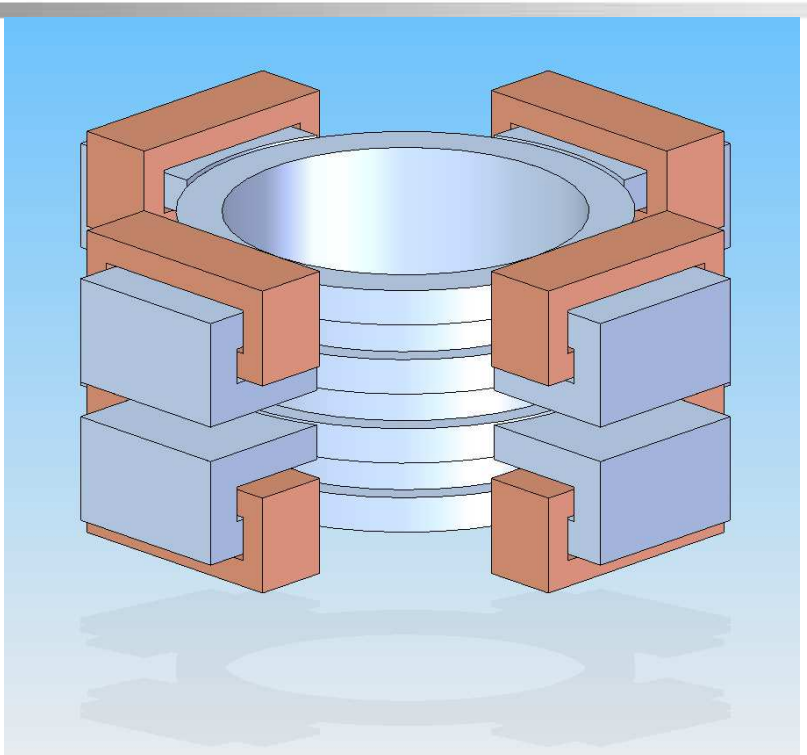
Active Magnetic Bearings (AMBs)



Position sensors measure the rotor position and feed-back, through a controller, to set the coil currents and control the rotor position



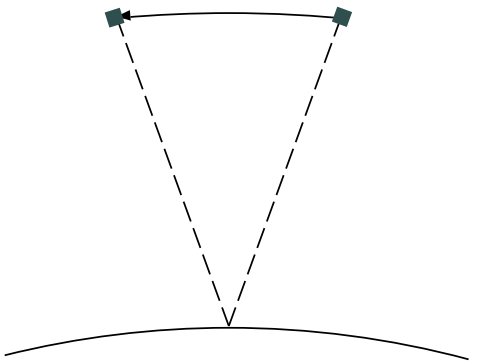
3Dwheel



- Conventional torque about spin axis and gyroscopic torque about axis on plane normal to spin axis
- Cancellation of static mass imbalance and dynamic couple imbalance

Reference Mission - TopSat

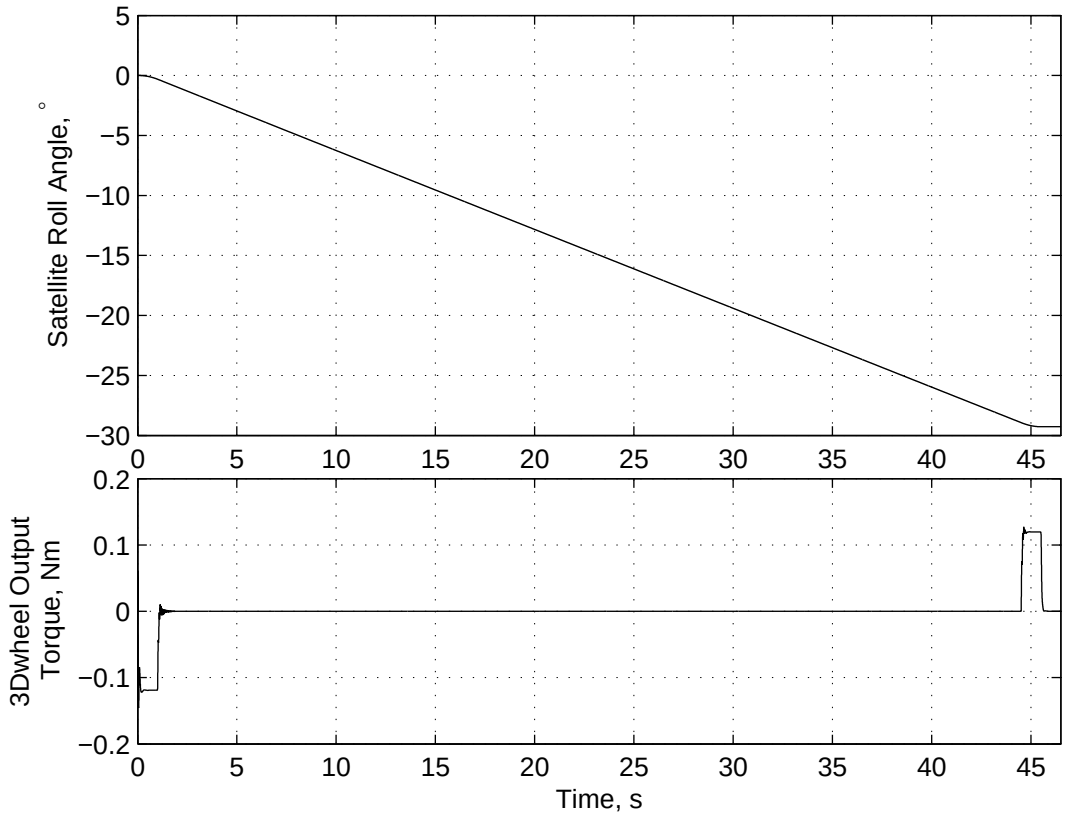
- Launched by SSTL in 2005, 113 kg mass
- Image Motion Compensation imaging mode
- Roll $\pm 30^\circ$ for off track imaging



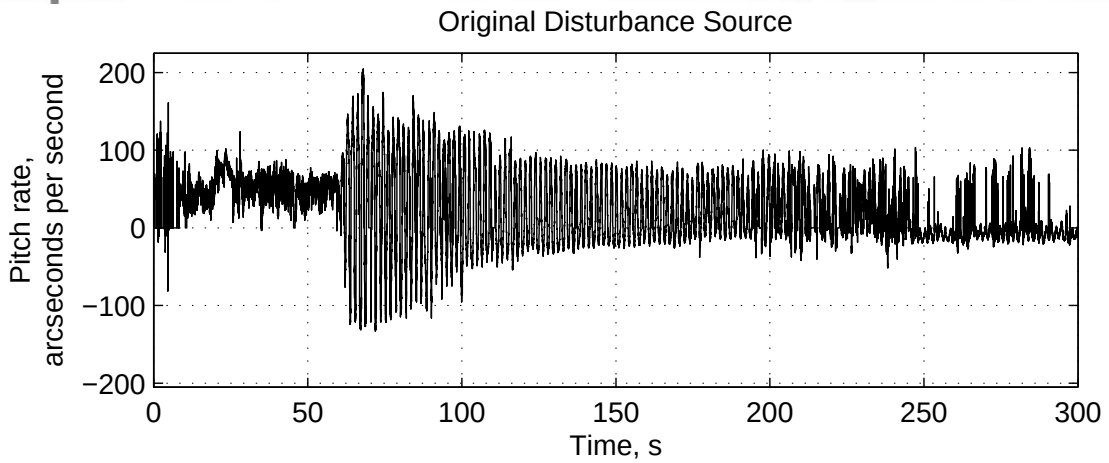
Design Process

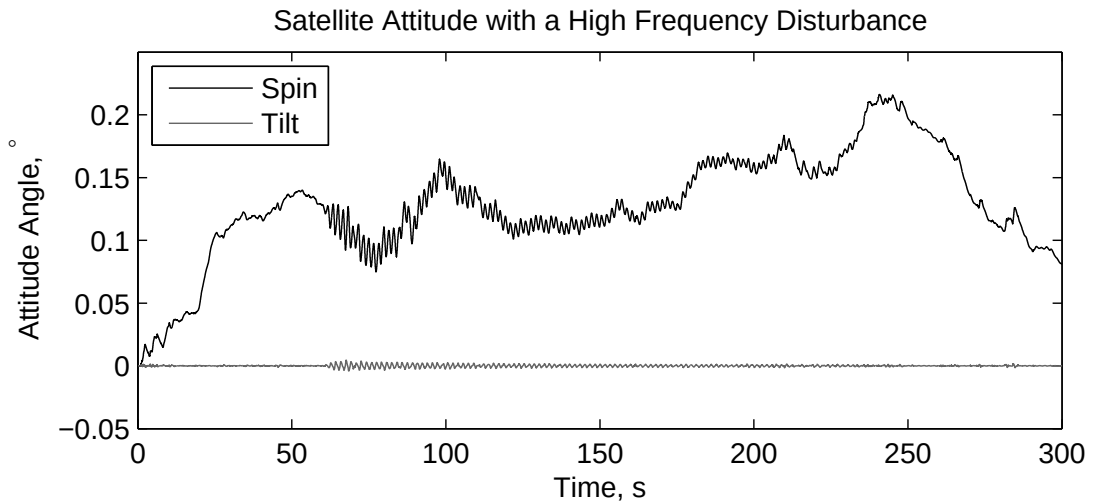
- Literature review
- Materials
- Magnetic Modelling
- Dynamic Modelling
- Controller Design
- Engineering Models

Simulation Results



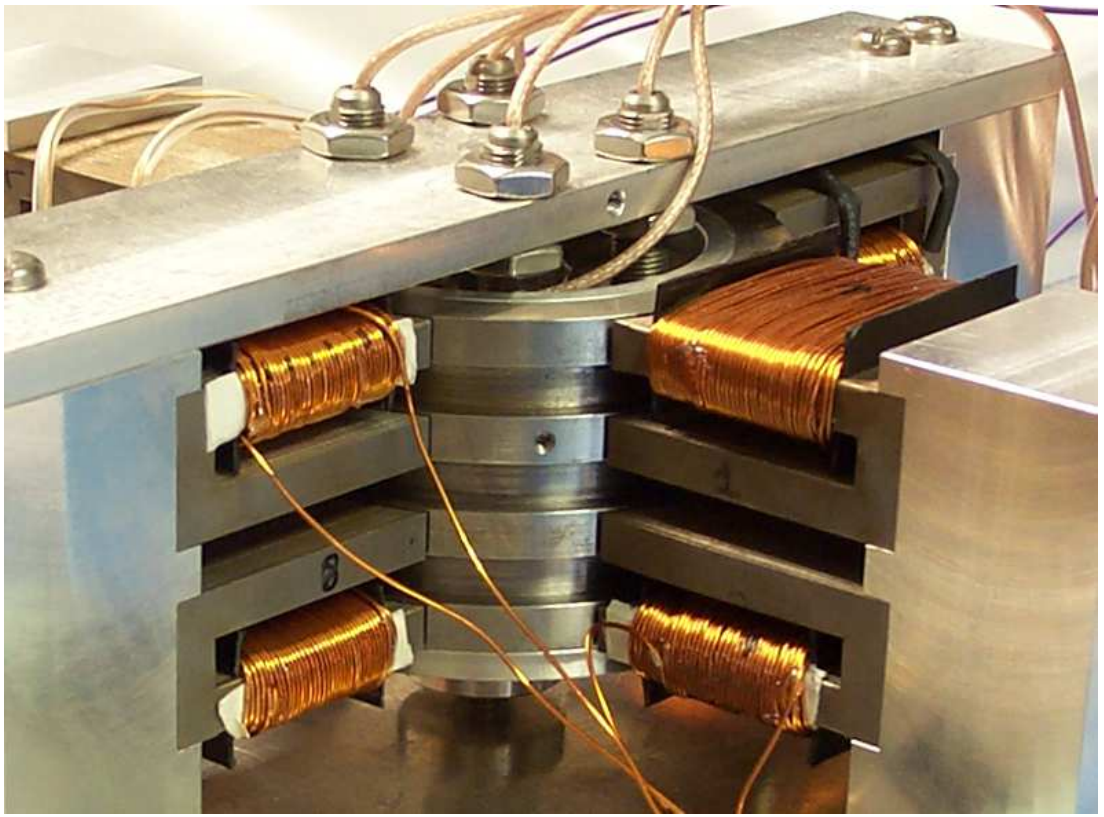
Simulation Results





Engineering Model

- Uses the electromagnetic principle
- Laminated steel stator poles made using wire erosion
- Contact free eddy current sensors - 2 μm resolution
- Low noise linear audio amplifiers
- Real time PC controller



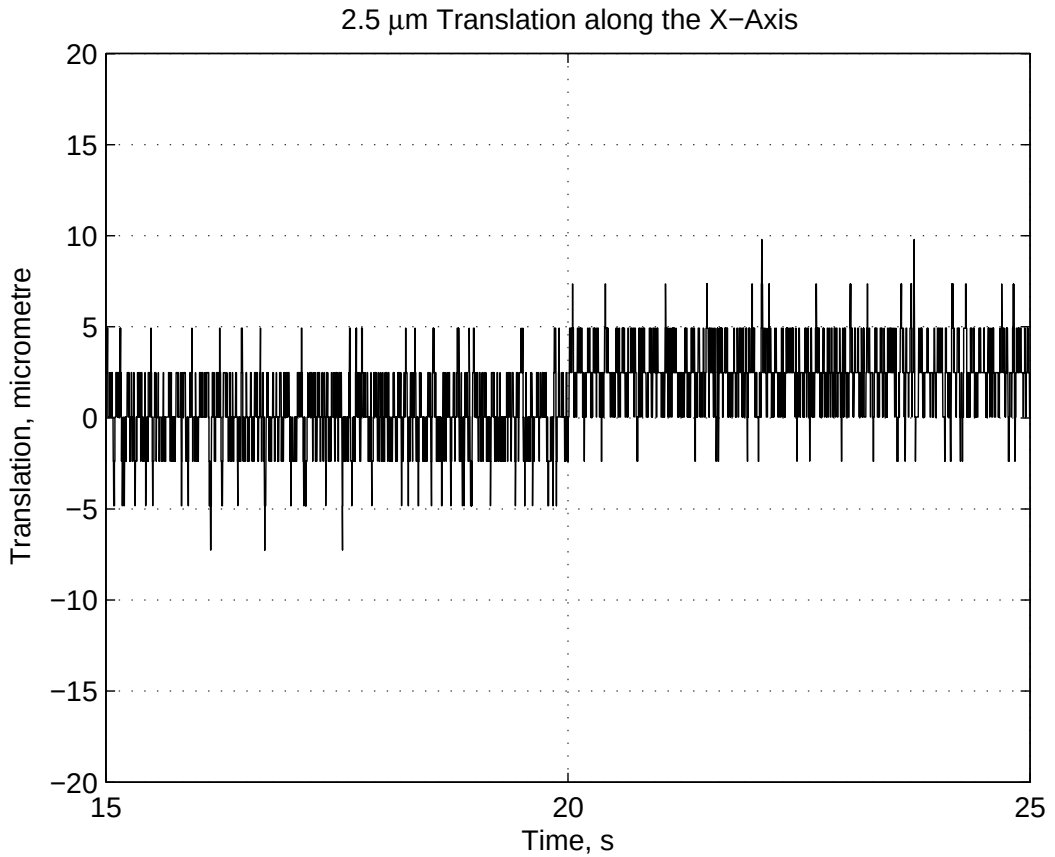
Engineering Model

Rotor radius	50 mm
Rotor height	56 mm
Rotor mass	1.3 kg
Moment of inertia	2.326×10^{-3} kgm^2
Angular velocity	5000 rpm, 524 rads^{-1}
Angular momentum	1.22 Nms
Tilt range	$\pm 3.0^\circ$
Air gap width	1.4 mm
Radial stiffness	1.6×10^4 Nm^{-1}
Axial stiffness	3.6×10^3 Nm^{-1}

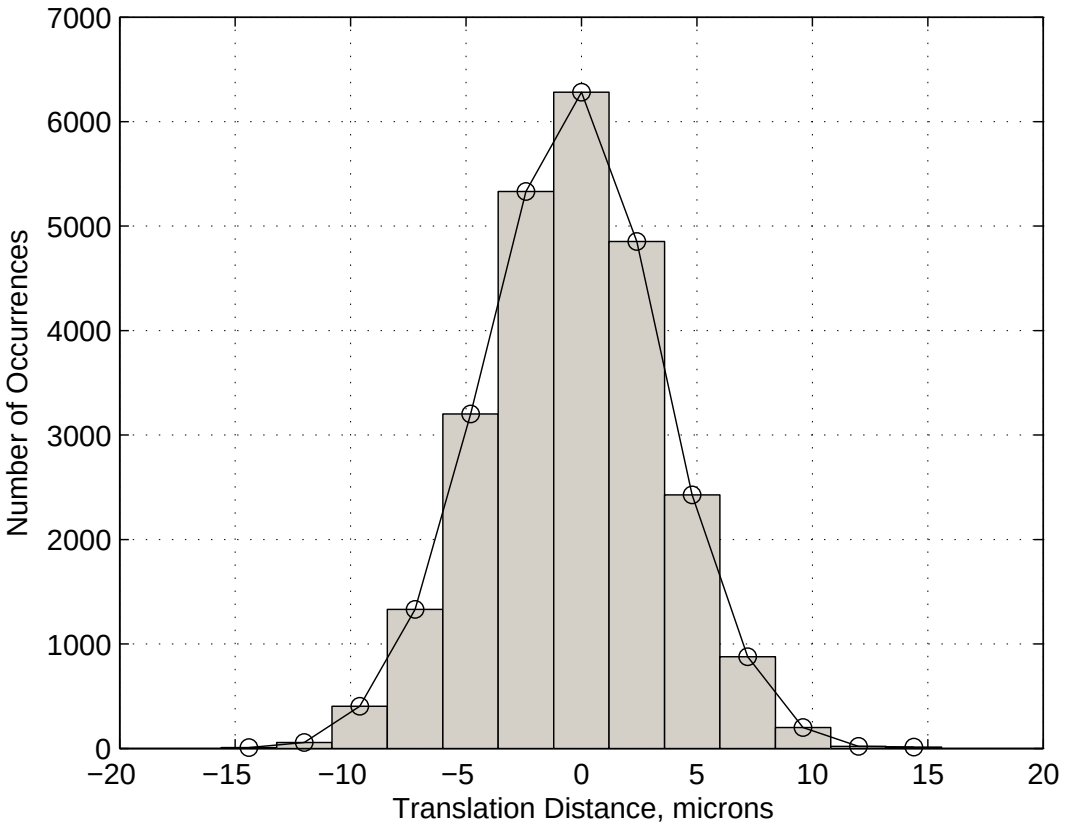
Experimental Results

(Loading 3Dwheel.m4v)

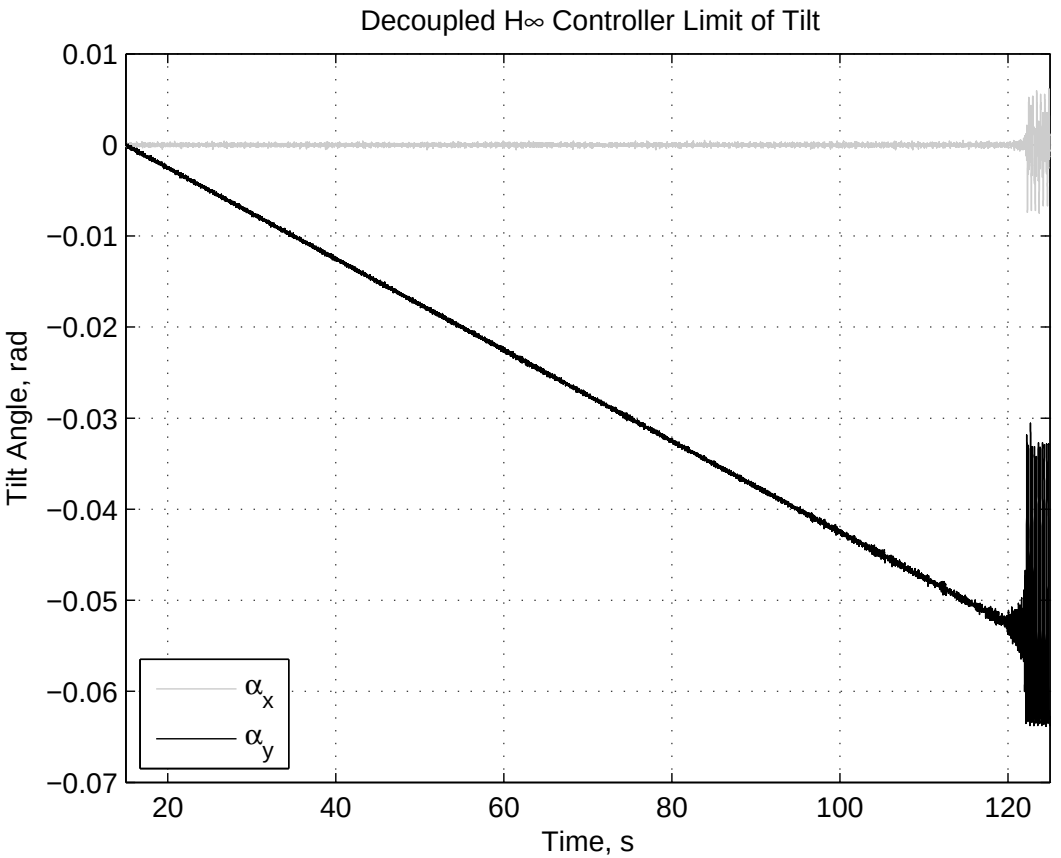
Resolution


2.5 µm Translation along the X−Axis
Translation, micrometre
Time, s
20
15
10
5
0
−5
−10
−15
−20
15
20
25

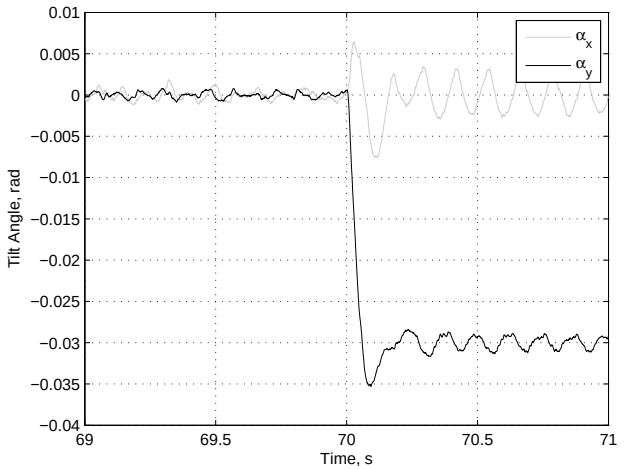
Accuracy

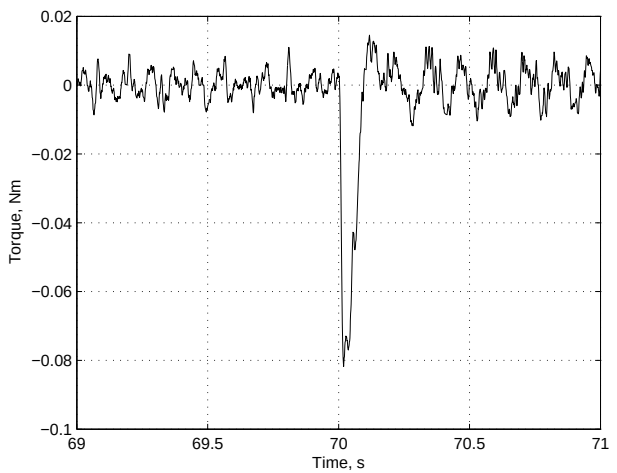

7000
6000
5000
4000
3000
2000
1000
0
Number of Occurrences
−20
−15
−10
−5
0
5
10
15
20
Translation Distance, microns

Tilt Range

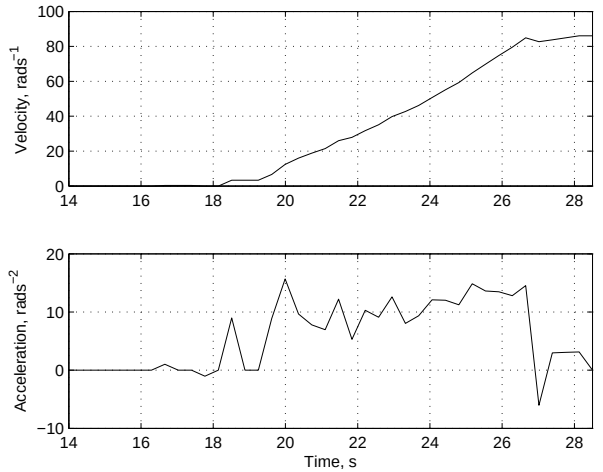

Decoupled H∞ Controller Limit of Tilt
Tilt Angle, rad
Time, s
0.01
0
−0.01
−0.02
−0.03
−0.04
−0.05
−0.06
−0.07
20
40
60
80
100
120
α_x
α_y

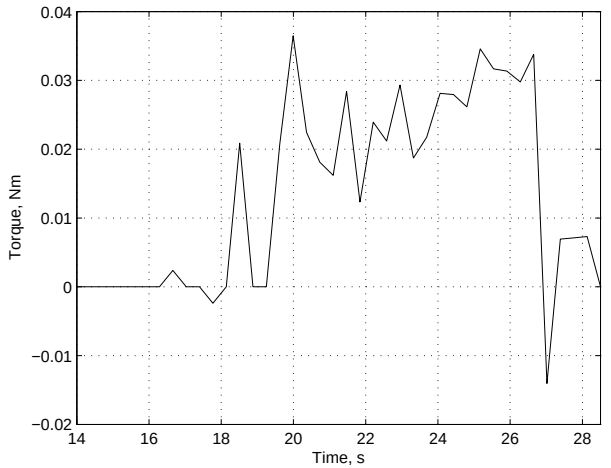
Gyroscopic Torque



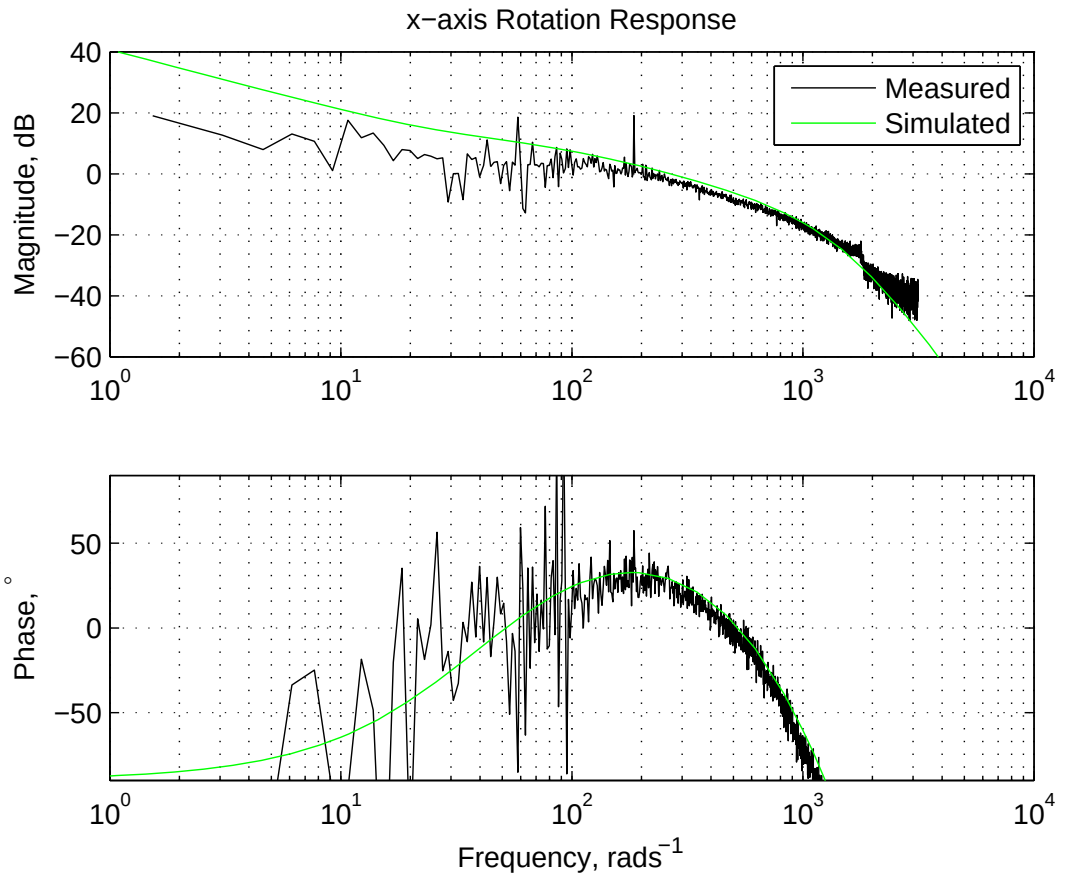


Conventional Torque





Frequency Response



Power Consumption

- Using the electromagnetic principle is very power inefficient
- Need to get bias flux from permanent magnets
- Control current 2.8 A at 28.0 V = 78 W
- Air gap width determines power consumption
- Non-tilting designs use 2.5 to 23 W for levitation

Controller Development

- Decoupled Lead-Lag
- H∞ Decoupled
- H∞ Multi-Variable
- State Feedback

Additional Design Aspects

- Launch Lock Mechanism
- Magnetic Shielding
- Touch Down Bearings
- Gravity Compensation
- Rotor Critical Frequencies

Conclusions

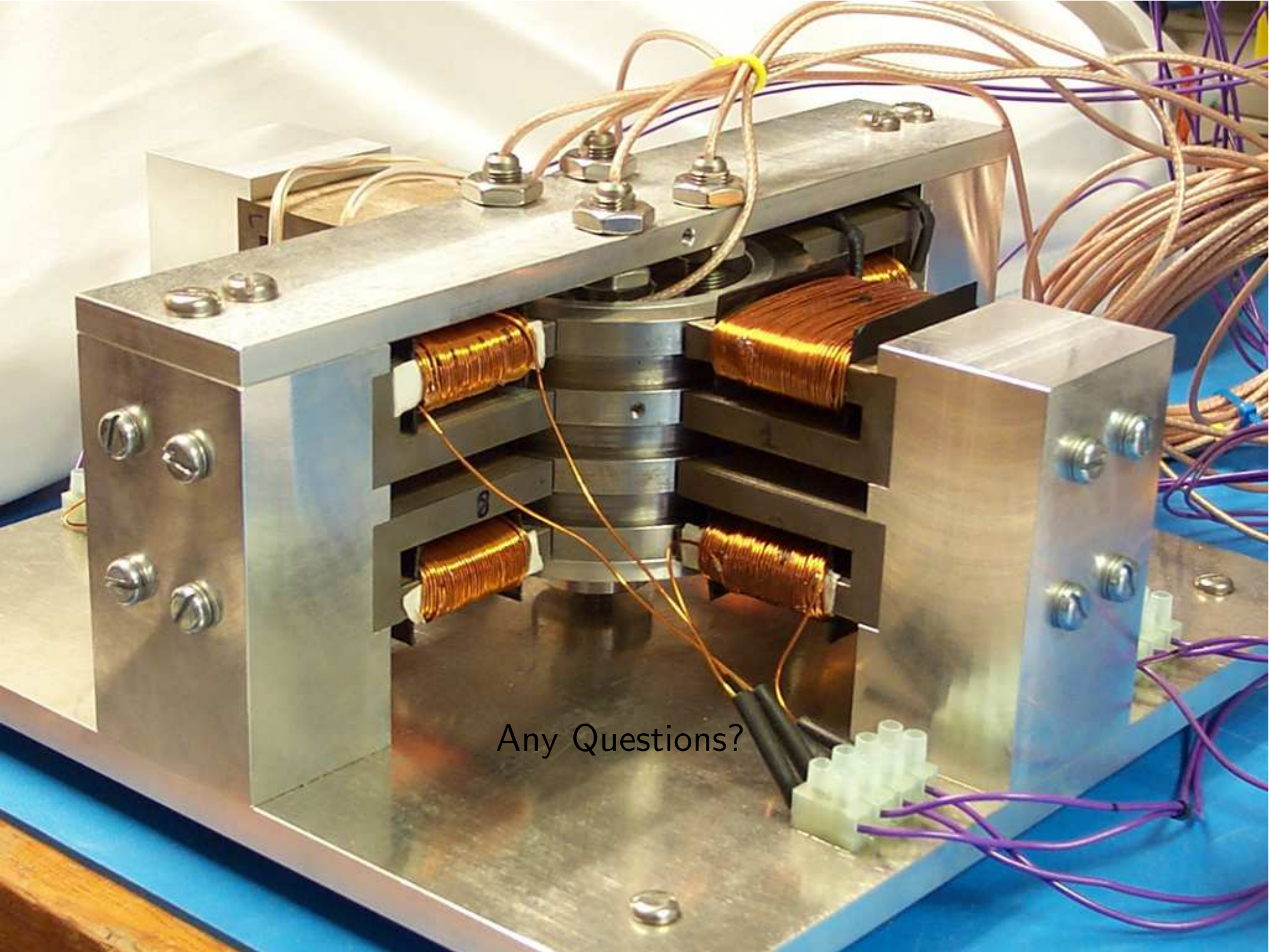
- 3Dwheel concept has been successfully demonstrated in the laboratory
- 3Dwheel overcomes higher bandwidth disturbances
- Active control prevents wheel jitter being transferred to the spacecraft
- Active control allows damping of static and dynamic imbalance
- Direction of the output torque is controllable
- 3-axis attitude control is possible with a single wheel: improved mass and power consumption or improved reliability
- Tilting increases the power consumption

Novelty

- A 3Dwheel sized for a small satellite has been designed, built and demonstrated in the laboratory
- It's been tilted through $\pm 2.9^{\circ}$ in the laboratory, which is a factor of three greater than other designs
- First tilting momentum wheel that is capable of a torque about all three axes that can reorientate a small satellite
- A scalable design methodology for such a wheel is now available
- Performance, costs and benefits of a tilting rotor in have been examined

Publications and Awards

- Jon Seddon, Alexandre Pechev, *3Dwheel - A Single Actuator Providing 3-Axis Control of Satellites*. Accepted by AIAA Journal of Spacecraft and Rockets
- Jon Seddon, Alexandre Pechev, *3Dwheel: 3-axis low-noise, high-bandwidth attitude actuation from a single momentum wheel using magnetic bearings*. 23rd AIAA/USU Conference on Small Satellites, Utah, USA, 10-13 August, 2009
- Jon Seddon, Alexandre Pechev, *A low-noise, high-bandwidth magnetically-levitated momentum-wheel for 3-axis attitude control from a single wheel*. 13th European Space Mechanisms and Tribology Symposium (ESMATS), Vienna, Austria, 23-25 September, 2009
- Royal Aeronautical Society Aerospace Speakers' Travel Grant
- Royal Academy of Engineering International Travel Grant


Any Questions?