

# *The Microcosm Torquer Feedback System, MTFS*

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Magnetic torquers are used on most low-earth orbiting spacecraft for attitude control. Due to their iron core, they are one of the heaviest components on the spacecraft and their linear output range is limited by the natural magnetic saturation. The design of these components has changed very little since the beginning of the space program.

Microcosm developed an innovative torquer system concept to linearize torquer output and, consequently, significantly reduce mass for a given level of control torque\*.

For example, the proposed system can reduce the mass of three 500 Am<sup>2</sup> torquers used on a 1000 kg satellite by a total of 6 kg (for 0.9m length) to 12 kg (for 0.5m length).

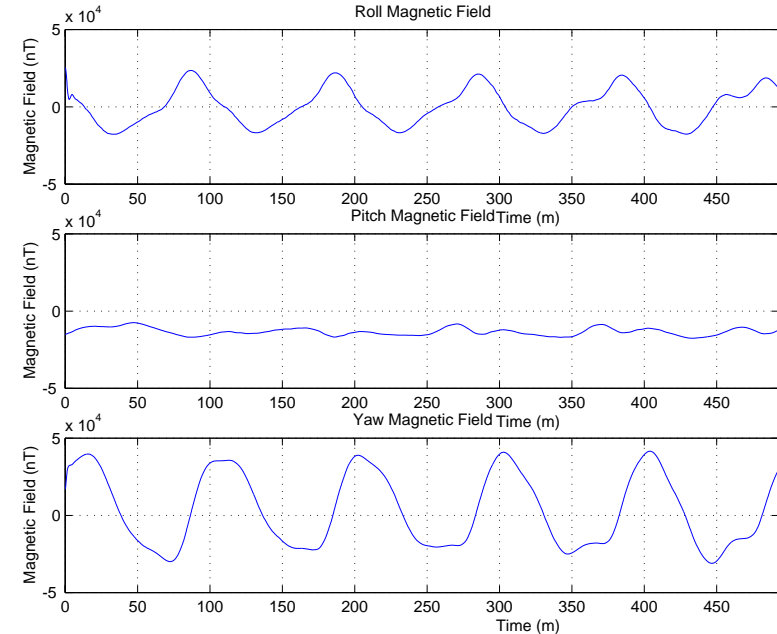
The system consists of a feedback which corrects for hysteresis saturation effects. This translates into enhanced performance, that can provide greater control authority or, for a given level of control, reduce the system mass. Additionally, the feedback system lowers the residual dipole moment.

\* Patent Pending



# Torquer Sizing

- The required dipole moment for a spacecraft in a given orbit is difficult to determine, because the magnetic torque depends on the earth magnetic field vector and the spacecraft's orientation to it. Usually the magnetic field vector varies constantly in body coordinates. The average torque can be determined by simulation or simplified assumptions.
- Torquers are usually used in combination with wheels and or gravity gradient booms, and the momentum capacity, control law implementation and the environmental torques determine the required dipole moment size.



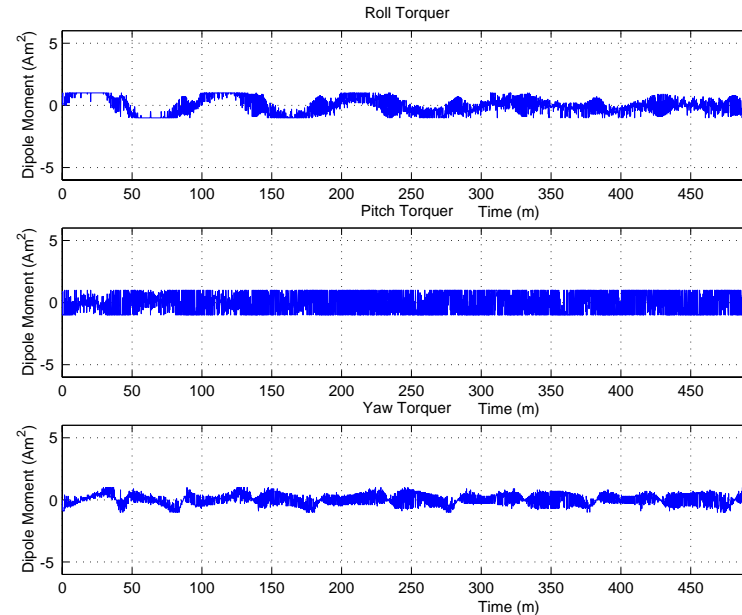
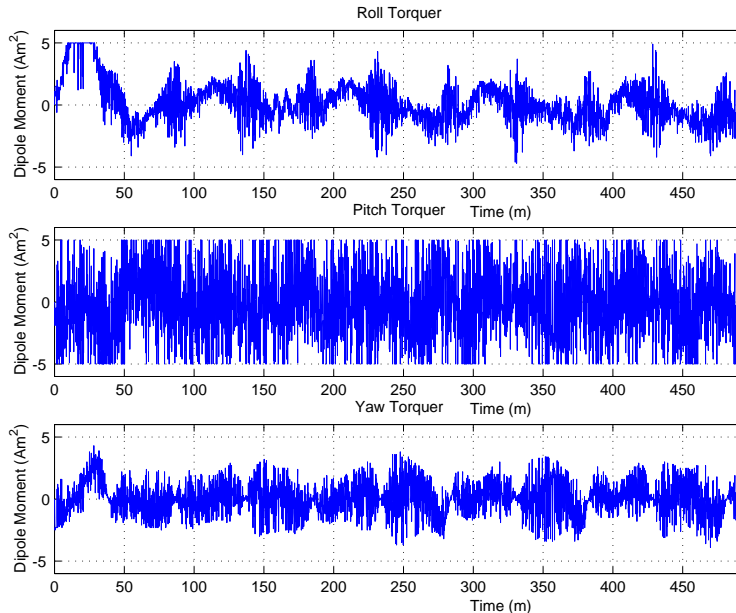
Earth magnetic field in body coordinates for an earth-oriented spacecraft in 700 km high, 56 degrees inclined orbit



- Disturbance torques can be separated into cyclic and secular components (for each axis). If torquers are used in combination with wheels, the cyclic term is ideally compensated by the wheel. The torquer controls the secular terms and controls the angular momentum of the wheels.
- Other factors to determine the torquer dipole requirements could be:
  - Maneuvers to re-orient the satellite, and the time allowed to perform the maneuver
  - Detumbling, after separation from the launcher, and the time allowed to orient the spacecraft before it runs out of battery power
  - Re-orientation, e.g. to turn a gravity gradient oriented spacecraft “upside” down if inadvertently caught in the “other” stable position
- The most accurate sizing is done with an attitude simulator that includes control laws, such as Microcosms AttSim software package.
  - An example satellite with 165 kg mass, momentum bias stabilization (2 Nms), 5 m<sup>2</sup> solar array in a 700 km high, 56 degree inclined orbit has been selected to demonstrate the torquer sizing.



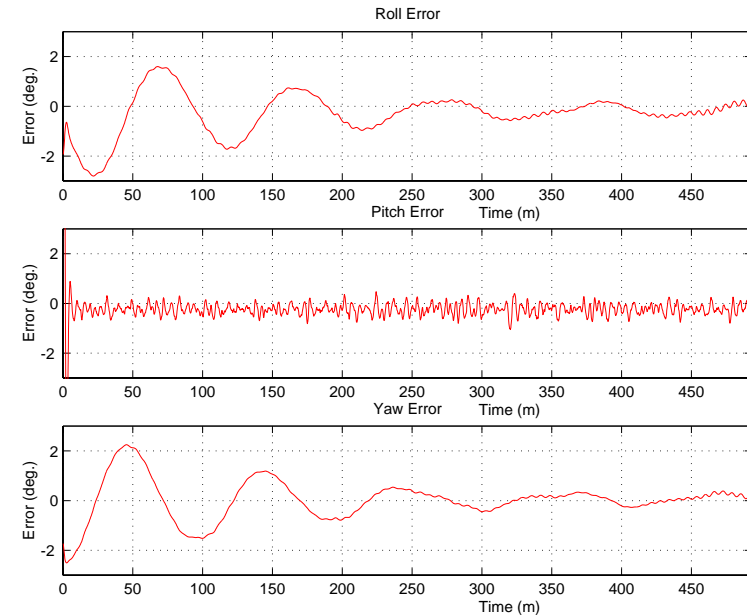
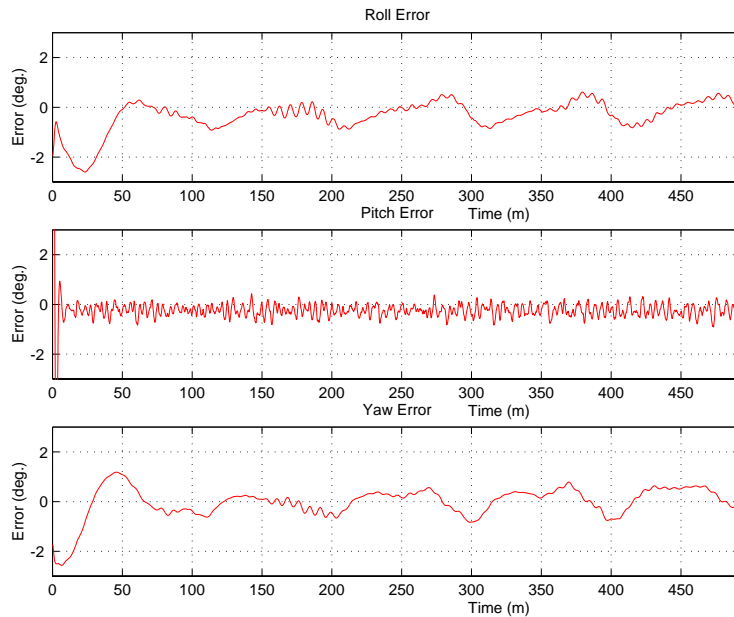
# Simulation Results



- The torquer commanded dipole for a 5  $\text{Am}^2$  torquer (left) and a 1  $\text{Am}^2$  torquer (right) are shown above. The 1  $\text{Am}^2$  torquer saturates in all axes; the 5  $\text{Am}^2$  saturates (mostly) in the pitch axis.
- The simulation results imply that the roll and yaw torquer can be smaller than the pitch torquer. This result could be particularly useful, if the spacecraft has a length restriction in its yaw axis.



# Simulation Results

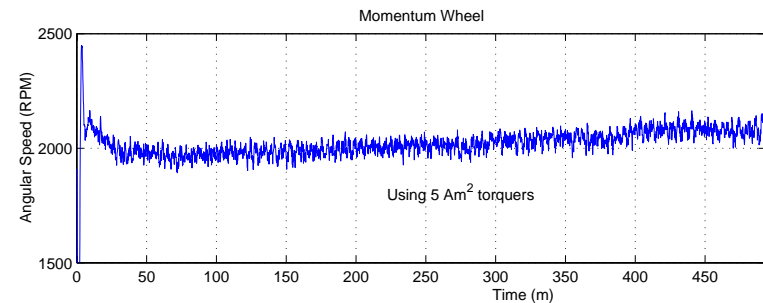
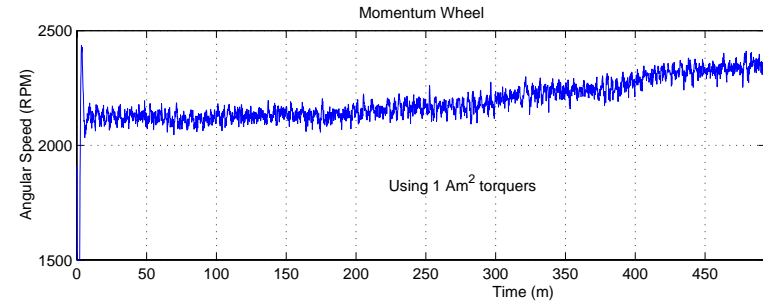


- The key difference between the error of the spacecraft using the 5 Am<sup>2</sup> torquer (left) to the one using 1 Am<sup>2</sup> is the response to the initial error of approximately 2.5 degrees.
- If the transient response is not important for the mission, the 1 Am<sup>2</sup> torquer appears to be sufficient. Note that the pitch axis is primarily controlled by the wheel reaction torque.



# Simulation Results

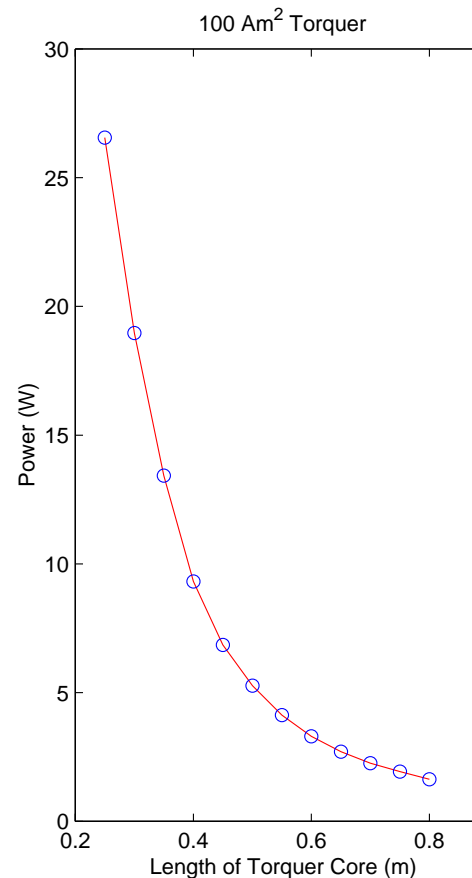
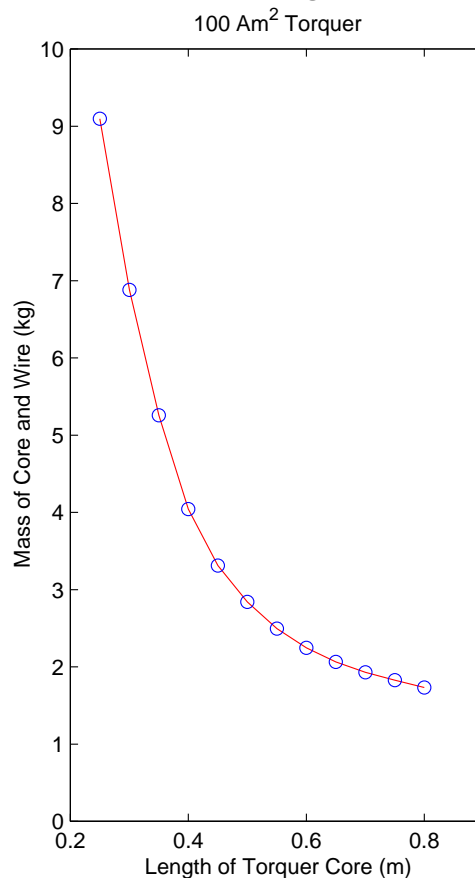
- The torquer has to correct attitude in roll and yaw, but also to maintain the angular momentum in pitch. A long term simulation has to verify if the torquer size is sufficient; in the case of the 1 Am<sup>2</sup> torquer, the wheel speed increases and the torquer is not able to maintain the angular momentum in the pitch axis.
- Gain adaptation could account for this by giving the momentum dumping a higher priority. This would, however, cause a larger attitude error.





# Torquer Design

- A torquer consists of a coil (or two redundant coils) around a magnetically soft iron core. The coil magnetizes the iron core; a long, slender core magnetizes easier and more uniformly than a short, “fat” bar. As a consequence, a longer bar uses less power and requires less coil mass.



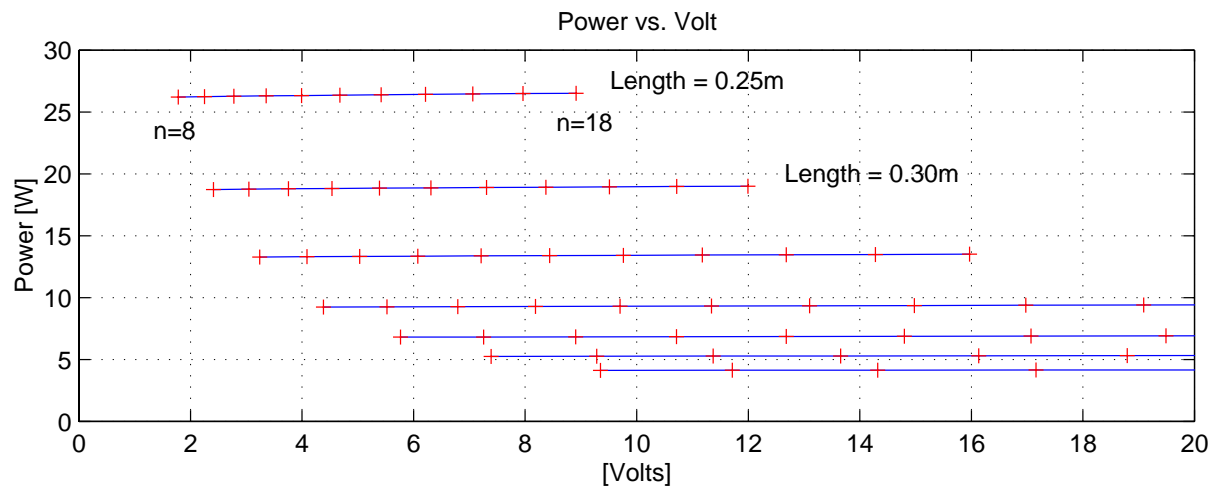
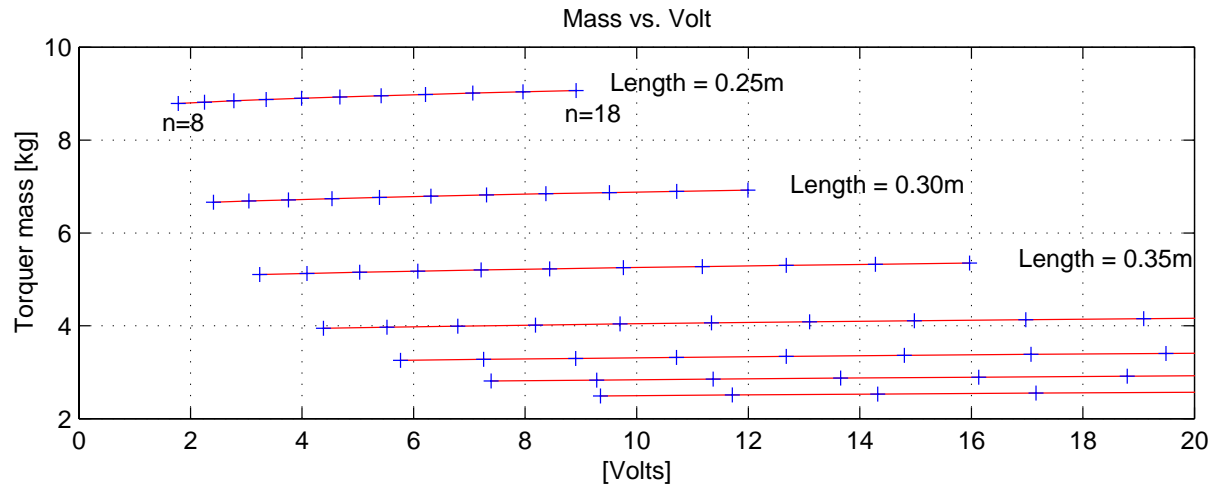


# Torquer Design

- Microcosm’s torquer design tool considers the “mass of power”, i.e. the mass required to generate a certain amount of power. This determines the current density of the coil. Current density is below critical values.
- The trends shows that higher currents and thicker wire is beneficial for the weight of a torquer; however, most power supplies are limited to a certain amount of current.
- To find the optimal torquer design, the length, number of layers (n) and the maximum supply voltage can be varied. The figure below shows the design variations for a torquer with  $100 \text{ Am}^2$ ; each line represents a given torquer length (in 0.05m intervals), and each mark represents a given number of layers between 8 and 18.
- Note that the shortest torquer requires more layers if an operating voltage of 10 V is desired; with a lower operating voltage, the coil is slightly lighter. The main factor that affects the torquer/coils mass and power is the length of the torquer.



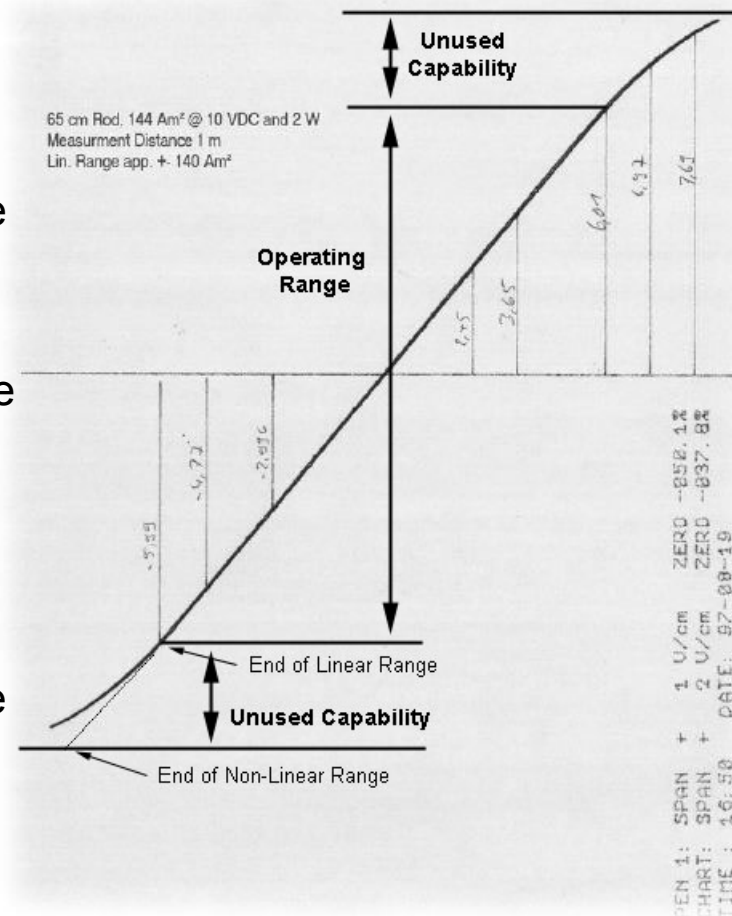
# Torquer Design





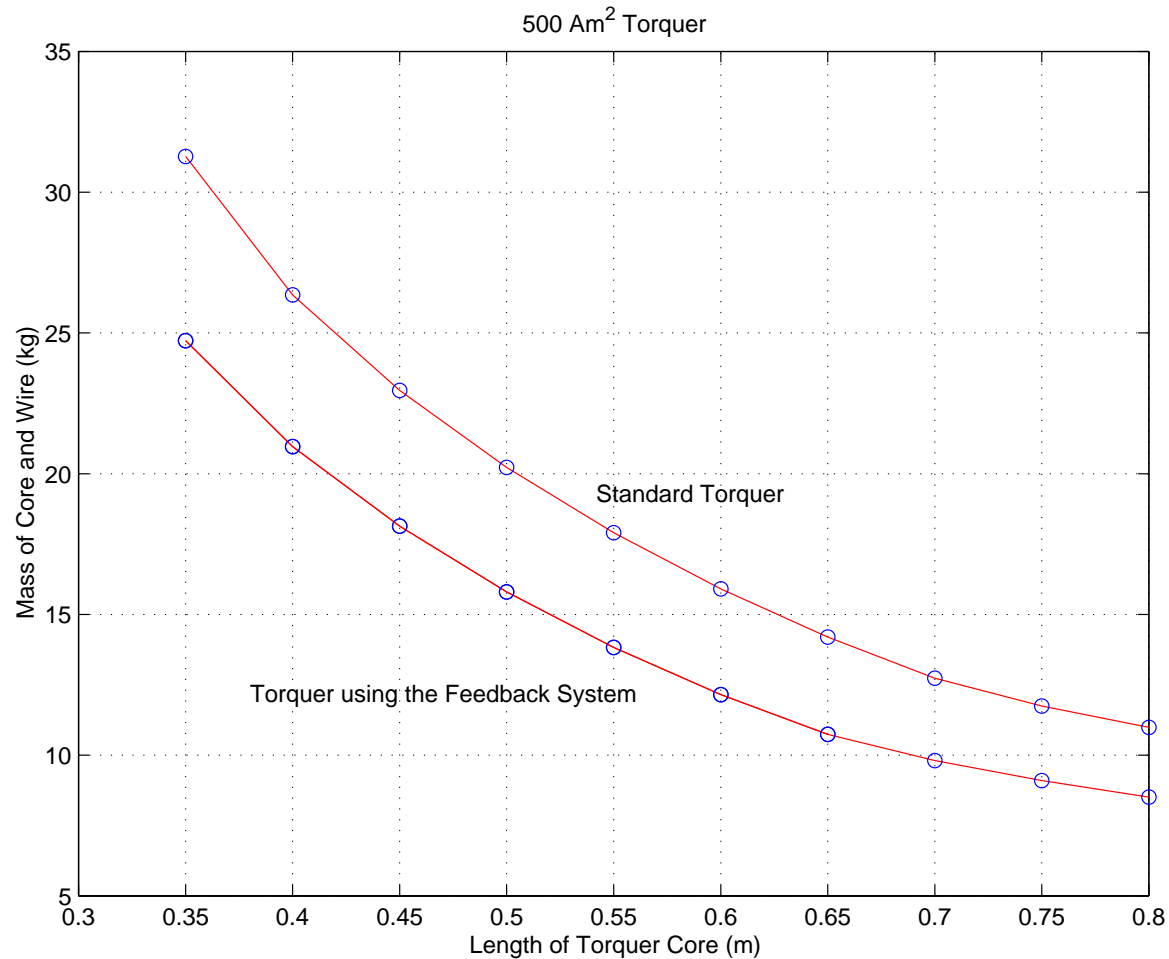
# The Microcosm Torquer Feedback System, MTFS

- The torquer dipole is defined as linear dipole moment; the non-linear part of the hysteresis is usually not used
- The Microcosm Torquer Feedback System corrects the non-linearity of the hysteresis, thus providing a larger linear dipole moment
- Alternatively, a smaller torquer could be used for a given dipole requirement, resulting in substantial mass savings.
- The feedback system is integrated into the torquer command interface
- An alternative approach is to model the torquer performance in the spacecraft computer and linearize the output analytically
- Patent pending





# MTFS Impact on Mass





- Microcosm and ZARM have teamed to design and produce cost-effective, high quality torquers
- Microcosm has also developed a design innovation for torquers. The MTFS can be used to increase performance, save torquer mass or reduce torquer length
  - Example: For a traditional 500 Am<sup>2</sup> torquer, 0.75 m long and 12 kg, we can:
    - Increase performance to 600 Am<sup>2</sup>
    - Decrease mass to 9 kg, or
    - Decrease length to 0.6 m

**The Microcosm Torquer Feedback System can increase performance and provide a level of system design flexibility not previously possible.**