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Characterization of Magnetotorquer Magnetic Moment: magnetometric and fluxmetric methods

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Summary:

Torquer rods for commercial spacecraft need to be characterized for qualification purposes. Very accurate characterization is possible using lengthy methods with accurate mechanical specifications, however, in the commercial environment this is not feasible. Three characterization methods, two magnetometric and one fluxmetric, are evaluated on robustness and uncertainty.

Keywords: Torquer rod, magnetic flux, coil, uncertainty, micro satellite

Introduction

Torque Rods are used on microsatellites, small satellites and cubesats as part of the attitude control systems [1] where the controllable magnetic moments of torque rods interact with the Earth's magnetic field. Torque rods consist of a solenoid winding with soft magnetic material as a core and their characteristic (magnetic moment) need to be verified during qualification.

Motivation and Objective

This paper investigates various methods to characterize torque rods accurately using methods that could be commercially viable in terms of time. We studied three methods: absolute and differential magnetometry using one or two magnetometric readings [1],[2], and an adaptation of a fluxmetric method used for permanent magnets [3]. Motivation for our work comes from the issue of accurately and repeatedly aligning the torque-rod relative to the magnetometer in the "single-point" magnetometric method, where the result uncertainty is dominated by distance uncertainty (tilt up to units of degrees produces negligible errors). Uncertainty due to mechanical placement was evaluated by repeated measurements with the rod removed and replaced, as well as at different axial displacements and orientation angles. The torque rod used in this study has a length of 375 mm and a nominal magnetic moment of 19 Am^2 at 296 mA; we used 200 mA for all measurements. All evaluations were executed in a magnetically quiet environment (<1nT p-p noise) and a fluxgate magnetometer (LEMI-011B) was used.

Magnetic field at specific distance

The classical method involves the measurement of magnetic flux density [1],[2]. The radial component of flux density $\mathbf{B_r}$ is measured when the torque rod of length **L** is energized at a set distance **R** (Fig. 1). This method is, however, extremely sensitive to the accurate distance between the rod and the magnetic sensor (its position in the magnetometer).

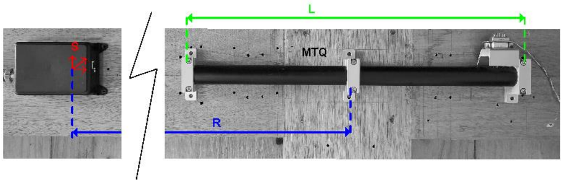

Fig. 1. Torque rod and magnetometer setup

Magnetic moment is calculated from eq. (1) [1].

$$m = \frac{4\pi}{\mu_0} \frac{1}{\frac{\frac{R}{L}-\frac{1}{2}}{\left(R^2-RL+\frac{L^2}{4}\right)^{\frac{3}{2}}} - \frac{\frac{R}{L}+\frac{1}{2}}{\left(R^2+RL+\frac{L^2}{4}\right)^{\frac{3}{2}}}} B_r \qquad (1)$$

Two test points with accurate separation

Given the extreme sensitivity of the previous method regarding distance of placement, obvious from eq. (1), and the chance of human error involved, a variation of this method is proposed where two measurements are taken with the same sensor, at two set distances apart. Only the difference in distances i.e. by a spacer or precise magnetometer movement is required, which can be accurately established. In this case, we do not use the full equation (eq. (1)) but the classical un-corrected point-wise dipole field equation for $\mathbf{B_r}$ eq. (2) (valid only far away).

$$B_{r1} = \frac{\mu_0}{4\pi} \frac{2m\cos a}{R^3} \qquad (2)$$

We can then express the distance **R** and substitute to the same equation with **R+dR**:

$$B_{r2} = \frac{\frac{\mu_0}{4\pi}m}{\frac{\mu_0\ \ m}{4\pi B_{r1}}+3\left(\sqrt[3]{\frac{\mu_0\ \ m}{4\pi B_{r1}}}\right)^2 dR+3\left(\sqrt[3]{\frac{\mu_0\ \ m}{4\pi B_{r1}}}\right)dR^2+dR^3} \qquad (3)$$

Distances of 850 mm and 1000 mm were used, given a separation *dR* of 150 mm. The magnetic moment is calculated by minimizing eq. (3) where $\boldsymbol{B_{r1}}$ and $\boldsymbol{B_{r2}}$ is the magnetic flux density measured at the two positions respectively.

Fluxmetric method

The basis of the fluxmetric method is change in magnetic flux, as detected by a coil enclosing the flux lines of the magnetic dipole source (torque rod). We evaluated various Helmholtz coils as in [3], however, ended up using a solenoid which gave the best signal-noise ratio. The solenoid has a length of 600 mm, 300 turns, 350 mm diameter and a coil constant of 543.23 μT/A. The magnetic length of the torque rod is around 2/3 of the coil length, so we expected large errors as the coil homogeneity has been determined to be below 0.1 % within +-15 cm only. The torque rod was placed in the centre of the solenoid (see Fig. 2) and 200 mA applied. The change of magnetic flux in the coil was measured with a Hirst IFM03 Flux-meter. Magnetic moment is calculated from eq. (4)

$$m = \frac{\Delta\vartheta}{K} \qquad (4)$$

where $\Delta\vartheta$ is the change in magnetic flux in Wb, and K is the coil constant in T/A (543.23 μT/A).

Fig. 2. Torque rod inserted in solenoid centre

Comparative summary of the three methods

Table 1 and Fig 3 shows results for the 3 methods when repeated 5 times (torque rod placed and removed) and also when misaligned. The most robust and most repeatable is the fluxmetric method, insensitive both to angular and axial misalignment; however, it is about +6% off both magnetometric methods. The single position calculation suffers, obviously, from a distance measurement error (+4% at 75 cm), which is suppressed with the differential two-point method. Surprisingly, the differential method works well even with classical dipole field equation eq. (2) uncorrected on rod length.

Tab. 1: Magnetic moments calculated

Criteria	Fluxmetric	Single point	Two points
Mean/5	12.114	11.430	11.432
10°	-1.2%	-1.0%	-0.1%
+1 cm	-0.08%	+4.4%	-

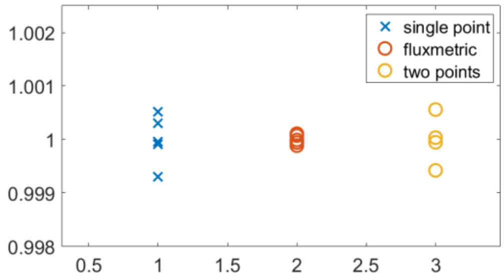

Fig. 3. Spread of 5 repeated measurements for all three methods (relative to the mean value)

Conclusions

The “revived” solenoid fluxmetric method shows the most consistent results, with a correction factor applied, however, a single magnetometric calibration would suffice. Its main advantage is that it does not need precise positioning (a 1 cm misplacement yielded only 0.08% error). The method with 2 magnetometers has potential when employing both equations for radial and tangential field to avoid effects of large angular misalignments, however, resulted in almost the same spread of values due to the small differential distance. Both methods have potential to lessen calibration uncertainty while reducing the alignment time. A promising modification of the two-point method would be a fixed set of two magnetometers where the exact magnetic distance would be precisely determined i.e. with the help of gradient coils.

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