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Uncertainty Analysis of Torque Measurement Methods Described in ASTM F2213-17

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Static Field Induced Torque

Magnetically induced torque is a risk associated with medical implants during MRI. To assess this risk, device manufacturers rely on the test standard ASTM F2213-17 [1] which outlines:

- Three test methods to determine if a significant torque is present and further testing is warranted from the following two methods that aim to measure a quantitative value
- **The Torsional Spring Method** – a device is placed on a platform suspended by torsion springs and the deflection angle from induced torque is measured.
- **The Pulley Method** – a device is placed on a low friction surface connected to a force sensor and the force measurement from induced torque is measured.

[1] ASTM F2213-17: *Standard Test Method for Measurement of Magnetically Induced Torque on Medical Devices in the Magnetic Resonance Environment.* West Conshohocken, United States of America: ASTM International; 2017

Objectives

The standard notes that the sources of measurement error associated with each method were not included.

The objectives of this study were:

1. Identify the significance of static friction of the rotating platform described in the pulley method
2. Compare uncertainties between test methods
3. Offer improvements to design and usage of the test apparatuses

This study pertains only to the methods from ASTM F2213-17 that aim to measure magnetically induced torque.

Propagation of Errors in General

For a function,

$$x = f(u_1, u_2, \dots, u_n)$$

The uncertainty based on uncorrelated sources of error is propagated by,

$$\delta_x = \delta_{u_1}^2 \left(\frac{\partial x}{\partial u_1}\right)^2 + \delta_{u_2}^2 \left(\frac{\partial x}{\partial u_2}\right)^2 + \cdots + \delta_{u_n}^2 \left(\frac{\partial x}{\partial u_n}\right)^2$$

The above can be applied to the ASTM F2213-17 torque equations for the torsional spring method,

$$\tau_S = k\Delta\theta$$

and pulley method,

$$\tau_P = R\left(F - F_f\right)$$

Propagation of Errors in ASTM Methods

Torsional Spring Method

$$\tau_S = k\Delta\theta$$

$$\delta_{\tau_S} = \tau_S\sqrt{\left(\frac{\delta_k}{k}\right)^2 + 2\left(\frac{\delta_\theta}{\Delta\theta}\right)^2}$$

τ_S – Torsional spring method torque

δ_{τ_S} – Torsional spring method torque uncertainty

k – Spring constant

$\Delta\theta$ – Deflection angle

Pulley Method

$$\tau_P = R\left(F - F_f\right)$$

$$\delta_{\tau_P} = \tau_P\sqrt{\left(\frac{\delta_R}{R}\right)^2 + 2\left(\frac{\delta_F}{F - F_f}\right)^2}$$

τ_P – Pulley method torque

δ_{τ_P} – Pulley method torque uncertainty

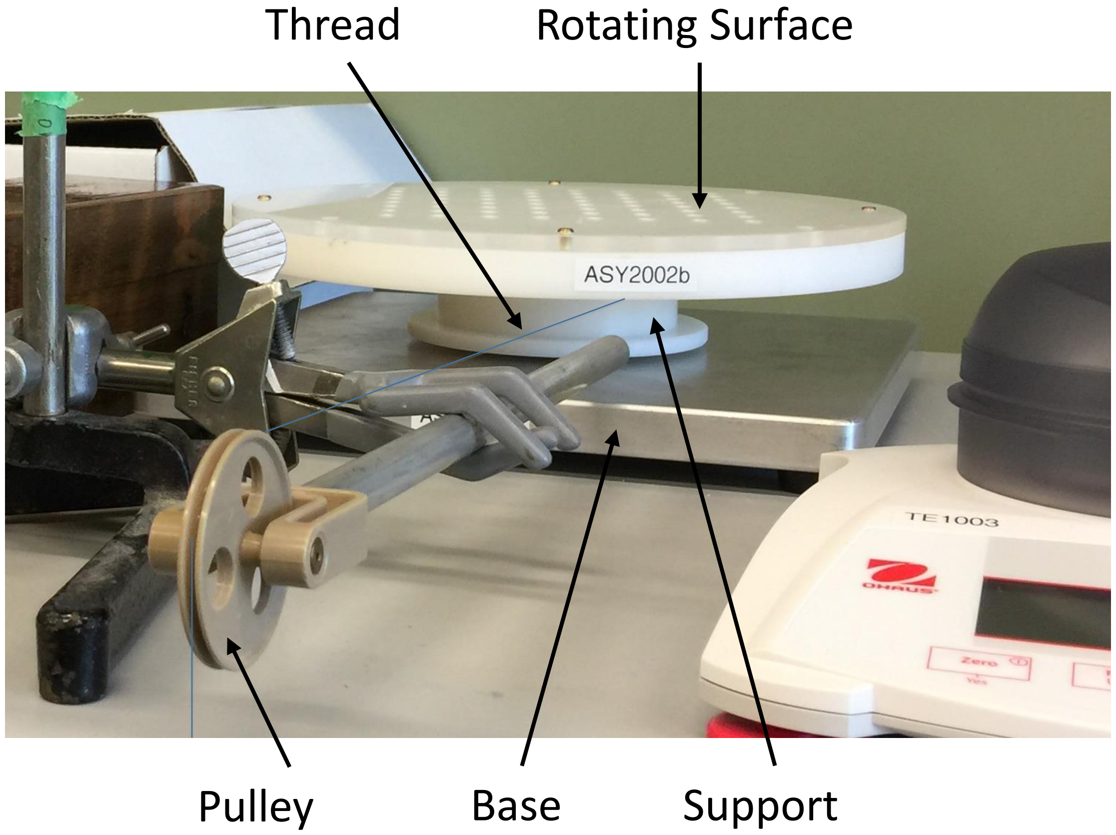
R – Radius of surface

F – Force measurement

F_f – Friction measurement

ASTM F2213-17: *Standard Test Method for Measurement of Magnetically Induced Torque on Medical Devices in the Magnetic Resonance Environment*. West Conshohocken, United States of America: ASTM International; 2017

Experimental Procedure



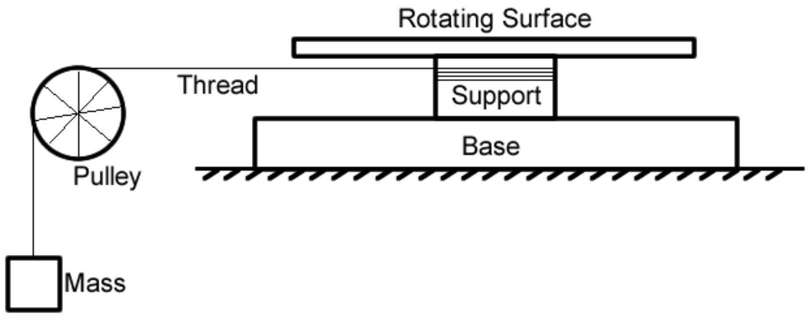
To determine the minimum amount of torque, ‘break torque’, required to set the apparatus into motion:

1. Divide the rotating surface into 30° sections.
2. Attach a mass to a thread hanging over the pulley and anchored to the apparatus. The apparatus should not rotate from the first mass.
3. The mass was incrementally increased until the weight applied allows the apparatus to make a full rotation.
4. Repeat above two steps for each 30 ° section and have a static friction profile of the entire apparatus. There should be 12 measurements for each mass used.

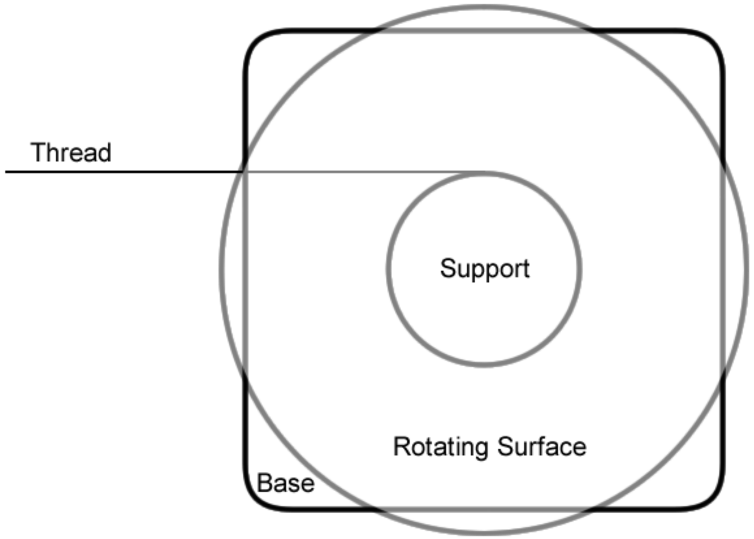
Experimental Apparatus

Schematic

Side View



Top View

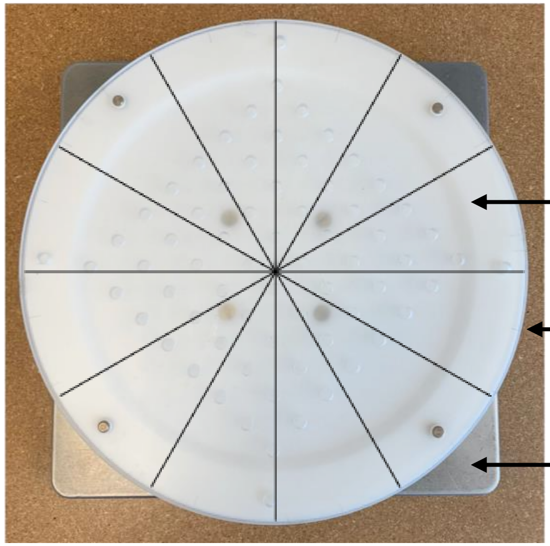


Apparatus

Rotating Surface

Support

Base

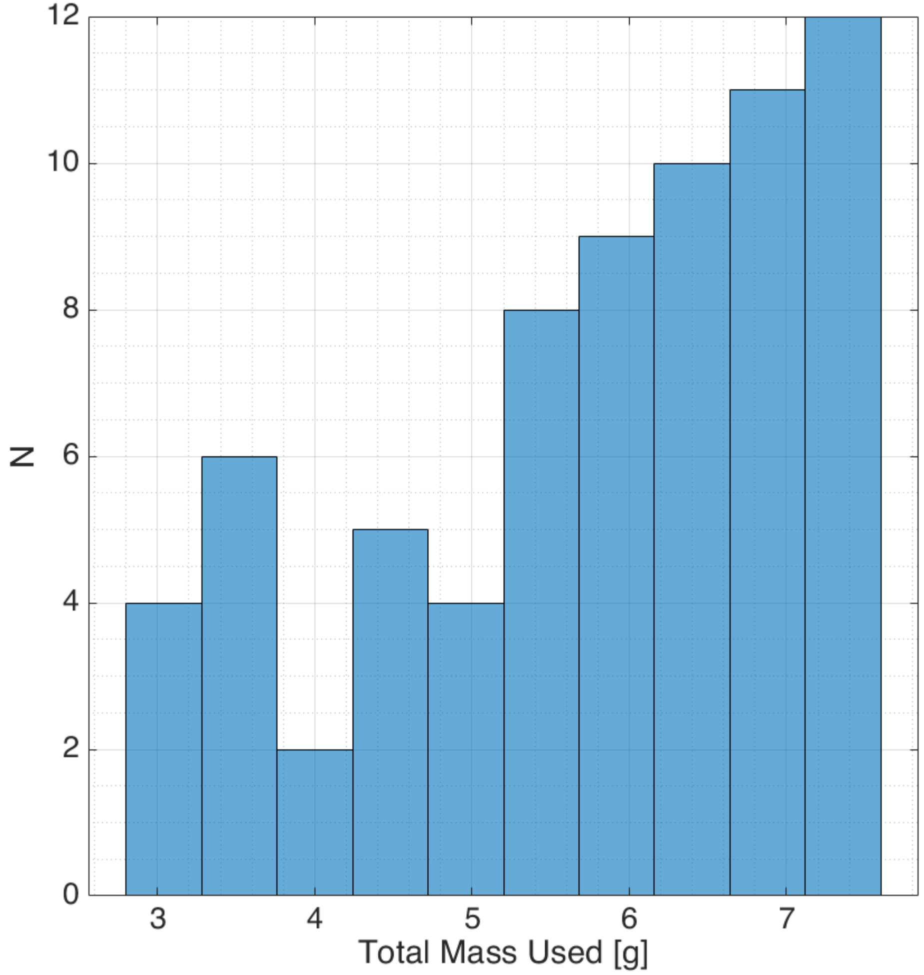


30 ° Sections

Rotating Surface

Base

Static Friction Profile of the Apparatus



It was found that the standard deviation of the distribution of masses allowing the platform to rotate was $1.394\,\mathrm{g}$. The uncertainty in static friction in the rotating platform was calculated to have been,

$$\delta_{F_s} = 0.693\ \mathrm{mNm}$$

This leads to a new error propagation equation for the pulley method,

$$\delta_{\tau_P} = \tau_P \sqrt{\left(\frac{\delta_R}{R}\right)^2 + 2\left(\frac{\delta_F}{F - F_f}\right)^2 + \left(\frac{\delta_{F_s}}{\tau_P}\right)^2}$$

Sources of Measurement Uncertainty

The Torsional Spring Method

$$\delta_{\tau_S} = \tau_S \sqrt{\left(\frac{\delta_k}{k}\right)^2 + 2\left(\frac{\delta_\theta}{\Delta\theta}\right)^2}$$

Torsional Spring Constant	$k = 1.6\ \mathrm{mNm}$	$\delta_k = 0.1\ \mathrm{mNm}$
Angle Measurement [3]	$\theta_{\min} = 1\ °$ $\theta_{\max} = 25\ °$	$\delta_\theta = 0.5\ °$

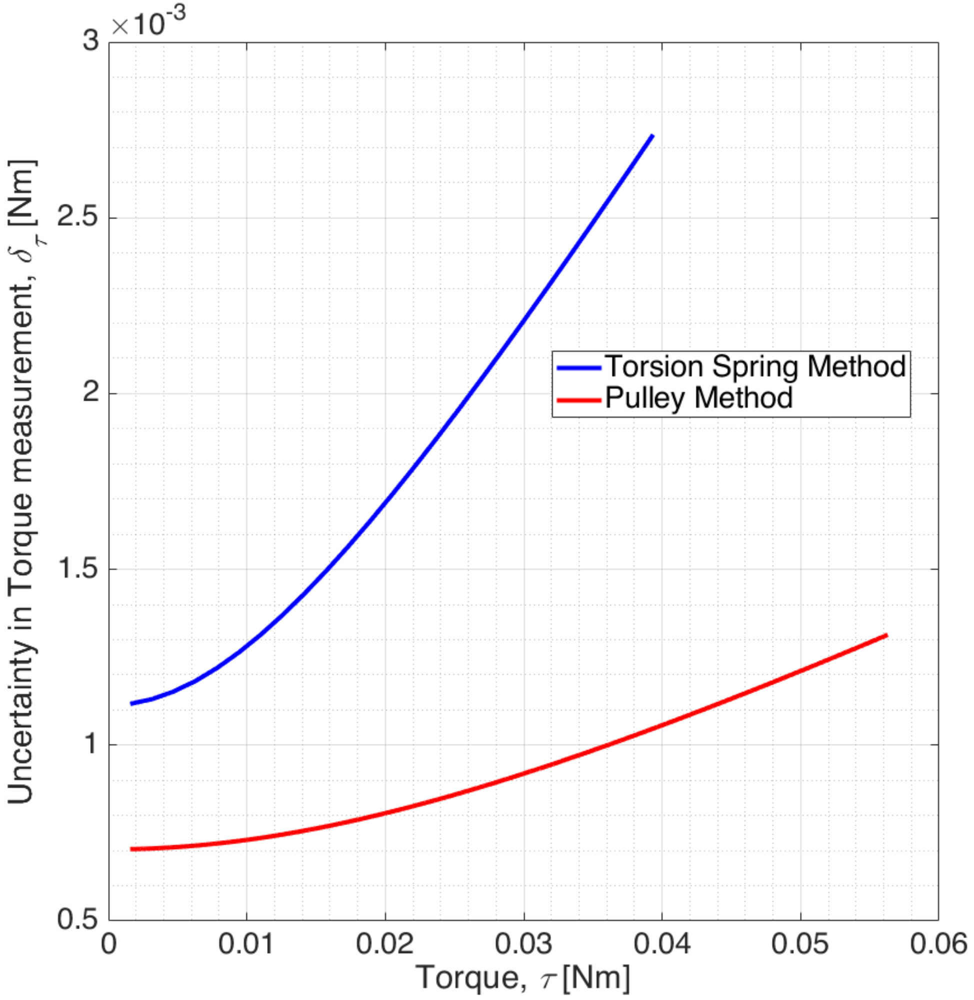
The Pulley Method

$$\delta_{\tau_P} = \tau_P \sqrt{\left(\frac{\delta_R}{R}\right)^2 + 2\left(\frac{\delta_F}{F - F_f}\right)^2 + \left(\frac{\delta_{F_S}}{\tau_P}\right)^2}$$

Radius of Rotating Surface	$R = 5.1\ \mathrm{cm}$	$\delta_R = 1\ \mathrm{mm}$
Force Sensor Measurements [2]	$F_{\min} = 0.03\ \mathrm{N}$ $F_{\max} = 1.11\ \mathrm{N}$	$\delta_F = 1.67\ \mathrm{mN}$
Uncertainty in Static Friction	$\delta_{F_S} = 0.693\ \mathrm{mNm}$	

[2] Mark-10 Corporation, "MR03-025 Force Sensor"
[3] Staedtler Mars, "Staedtler Mars 568"

Comparison Between Measurement Methods



$$\delta_{\tau_S} = \tau_S \sqrt{\left(\frac{\delta_k}{k}\right)^2 + 2\left(\frac{\delta_\theta}{\Delta\theta}\right)^2}$$

$$\delta_{\tau_P} = \tau_P \sqrt{\left(\frac{\delta_R}{R}\right)^2 + 2\left(\frac{\delta_F}{F - F_f}\right)^2 + \left(\frac{\delta_{F_S}}{\tau_P}\right)^2}$$

We propagated the data forward from initial instance where a mass was capable of moving the apparatus.

The pulley method offers a smaller measurement uncertainty than the torsional spring method for comparable measurements.

Discussion and Conclusions

The dominant source of measurement uncertainty were identified for each method. In the torsional spring method, the angle measurement tool capable of measuring at least 1 ° increments. The pulley method, the dominant source of error is the static friction, ‘stickiness’, in the rotating platform from the minimum amount of torque required to set the apparatus into motion

To minimize measurement uncertainty in the two methods we would recommend improving the aforementioned aspects of the test methods. In the torsional spring method, the deflection angle measurement tool should have greater precision than the 1 ° readings as described in test standard. In the pulley method, the break torque should be more consistent around the entire apparatus.

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Conclusions
Discussion
Results
Methods
Introduction