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Final Report

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DC Magnetics Measurement System Design

This report will detail the updates to the magnetics measurement system design and testing procedures that are required for performing static (DC) magnetics testing of future flight hardware. An older magnetics testing system had to be integrated with new procedures and hardware to meet the demands of future testing programs and accommodate an upcoming magnetics tests. The next test will be for the Geostationary Operational Environmental Satellite R-Series (GOES-R), which will verify that the SAFT Battery component meets its specifications for magnetic cleanliness. The satellite is scheduled to launch in 2015 with magnetics testing to be completed on the battery in November 2012.

The concern for magnetic compatibility on the GOES-R stems from the scientific magnetometers used on board the satellite. While the main objective for the GOES-R is detecting weather patterns on Earth such as hurricanes, monitoring severe weather in space is also critical to mission goals (Mission Overview). By the use of magnetometers, GOES-R can gather data for scientific use and provide alerts for satellite operations. Even Earth based operations like “[c]ommunications, transportation, and electrical power systems can be disrupted and damaged by space weather storms” (FAQ). In fact, previous GOES missions found that the magnetometer data collected was “among the most widely used spacecraft data by the national and international research community” and GOES-R will continue to contribute using

tri-axial fluxgate magnetometers similar to those flown on the Cassini orbiter, JUNO, and other missions (MAG). Because of the importance of the mission, NASA/NOAA will need to be certain they are receiving accurate ambient magnetic field data not corrupted by spacecraft subsystems. Therefore, thorough magnetics testing will characterize any potential magnetic inference so mission operations can analyze and/or adjust the data correctly.

DC magnetics testing requires certain hardware and testing apparatus. Figure 1 shows the Magnetics Instrument Rack on the right and the G3 Mac computer on the left. The three Schonstedt magnetometers on the top detect the change in magnetic field of the device under test. On bottom, the power supplies provide current and voltage for the Helmholtz coil to nullify Earth's magnetic field to put the component in a predictable, low and stable magnetic environment. The Macintosh and the interface box at the bottom of the rack coordinate the devices and collect and analyze the incoming data.

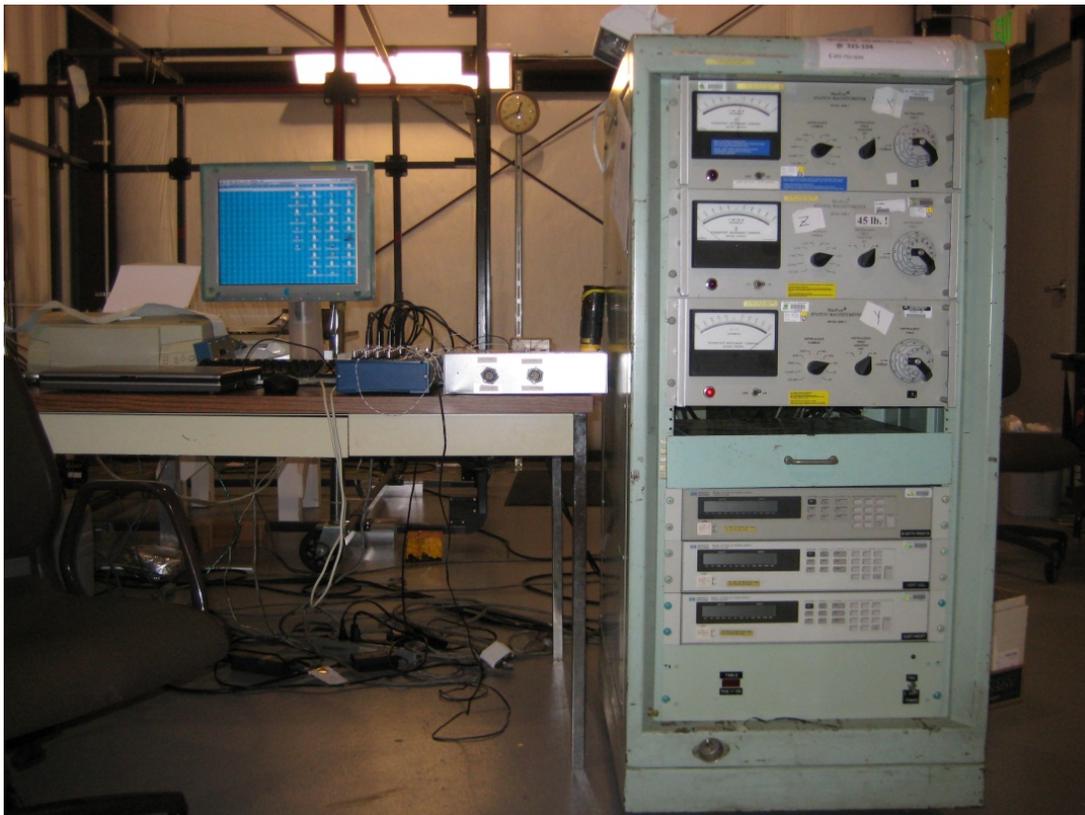
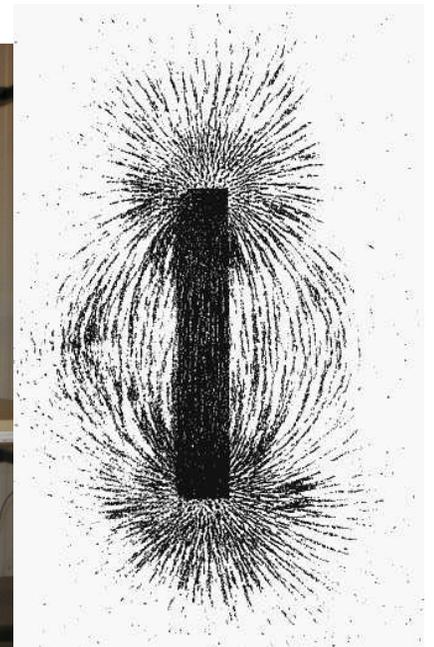


Figure 1

Figure 2 shows the testing setup. Because an object's magnetic moment and field strength depend on an object's orientation relative to the magnetic dipoles, the object must be rotated to be fully characterized. Figure 2a demonstrates this effect visually. The denser clusters of iron filings represent a stronger field. Therefore, the turntable shown was proof-loaded to 1500 lbs, qualifying to hold hardware up to 500 lbs. The aluminum stand and wooden block (non-magnetic) is the sensor fixture. Since testing requires a tri-axial measurement, three sensors needed to be placed orthogonally to one another; one up/down, north/south, and east/west. The following guidelines are what certain orientations generally read: the vertical sensor should read a constant field and the sensor perpendicular to the device under test should read half the amplitude of the sensor facing the test object for any given degree.

**Figure 2****Figure 2a**

The main objective for the summer project was to confirm that the magnetics measurement system was compatible with the goals for DC magnetics testing of the SAFT Battery. As detailed in the Sabre-Co Proposal, the battery required as little handling as possible to ensure that there was a small potential for damage. The Electromagnetic Compatibility/Magnetics group proposed a tri-axial measurement system to minimize the amount of battery configurations from six to two. Figure 3, below, is a tri-axial plot and analysis of a known magnetic source. The tri-axial magnetometer method, only used once before, requires a unique setup that uses different software.

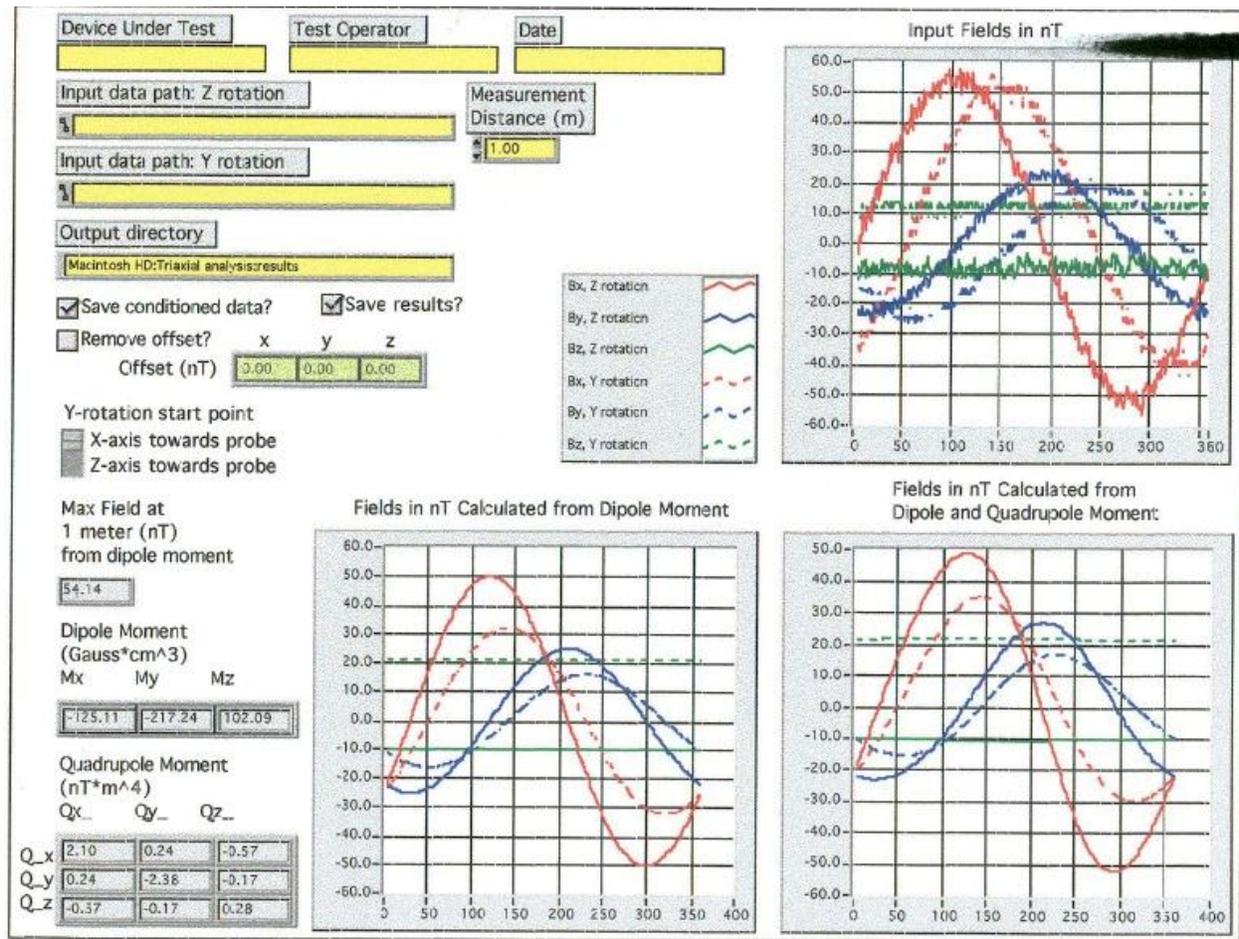


Figure 3

To validate this process, a known quantity was measured to ensure the measurement system's accuracy. This graph calculates a dipole moment of 270 Gauss*cm³, compared a recorded dipole of 310 Gauss*cm³. The difference observed would be generated by an offset of about 10 nano-Teslas; easily accounted for by magnetic variation in a magnetic unclean testing facility. To ensure the elimination of this variation, testing of the SAFT battery will be completed in a magnetically clean testing facility. Testing will also occur only during night to remove magnetic variations caused by movement of vehicles and personnel.

The importance of the dipole moment lies in this mathematical relation:

$$B = \frac{2M\cos\theta}{r^3}$$

Here, B, or the magnetic field strength decreases for a specific magnetic dipole moment M by the cubed distance from the source of the field. Theta represents the degrees around the dipole, with theta equals zero at the magnetic north pole. This scalar value relates the relative field strength depending on the location from a pole, as discussed above with Figure 2a.

Spacecraft engineers have recognized this relation and therefore put magnetometers as far away from the main body of the spacecraft as possible. For example, both Voyagers used a 13 meter long boom to ensure there was little magnetic interference in the magnetometers' data (Instrument). However, even with the strength dropping off at the cubed distance away, stringent magnetic requirements are required for the best data.

The dipole moment is also useful for finding the net magnetic effect on very complex magnetic systems. Rarely does engineered hardware produce a perfect magnetic dipole similar to the known test magnetic in Figure 3. System demands like electric current and magnetic metals can produce many individual fields in varying directions. Often these magnetically

complex components will produce fields better approximated by quadrupoles, octopoles, and beyond. However, unlike the net dipole moment, a quadrupole alone will drop off at the distance to the fifth power. Therefore, approximations of the net dipole are the most relevant because they are generally the only fields seen at far away distances such as 10 meters. To analysis the data gathered, the dipole is calculated in vector form by:

$$B_x = \frac{3(M_x x + M_y y + M_z z)}{r^5} x - \frac{M_x}{r^3}$$

$$B_y = \frac{3(M_x x + M_y y + M_z z)}{r^5} y - \frac{M_y}{r^3}$$

$$B_z = \frac{3(M_x x + M_y y + M_z z)}{r^5} z - \frac{M_z}{r^3}$$

Whereas the quadrupole is described by:

$$B_x = \frac{5(Q_{xx}x^2 + Q_{yy}y^2 + Q_{zz}z^2 + 2Q_{xy}xy + 2Q_{xz}xz + 2Q_{yz}yz)}{2r^7} x - \frac{Q_{xx}x + Q_{yy}y + Q_{zz}z}{r^5}$$

$$B_y = \frac{5(Q_{xx}x^2 + Q_{yy}y^2 + Q_{zz}z^2 + 2Q_{xy}xy + 2Q_{xz}xz + 2Q_{yz}yz)}{2r^7} y - \frac{Q_{xy}x + Q_{yy}y + Q_{yz}z}{r^5}$$

$$B_z = \frac{5(Q_{xx}x^2 + Q_{yy}y^2 + Q_{zz}z^2 + 2Q_{xy}xy + 2Q_{xz}xz + 2Q_{yz}yz)}{2r^7} z - \frac{Q_{xz}x + Q_{yz}y + Q_{zz}z}{r^5}$$

Additionally, Helmholtz coils are needed for general magnetics testing to facilitate the most accurate readings of an object's magnetic field. By producing a stable, predictable, and near zero field at the center, the sensors are able to detect only the strength of the device under test unaffected ambient fields. A Helmholtz coil is a pair of coiled electromagnets along a common axis. Each coil mimics the north or south magnetic dipole, with field lines either moving out of the magnetic north coil and into the magnetic south coil. The field strength in the center can be calibrated to very few nano-Teslas by applying specific voltages and current. The distance between the pair, for maximum magnetic uniformity, is at the coils' own radius.

However, to allow for more room inside the coil while limiting the total size, the coil pairs can have their diameter's distance between them at the cost of magnetic uniformity away from the exact center. Helmholtz coils can be simple, one pair systems, or 3 pair systems like in Figure 2 for tri-axial uniformity.

The coil system also possesses a critical function in correctly measuring the SAFT battery. While a coil system is mainly needed in testing to nullify Earth's magnetic field as described previously, the importance for the SAFT testing is to prevent induced effects. The nickel material in the battery system is extremely vulnerable to induced magnetic effects. Without a Helmholtz coil to isolate the hardware from Earth's magnetic fields, engineers would not be able to measure the magnetic moment and field strength on the battery; the nickel material would take on characteristics of Earth's magnetic field.

The coil system also became more automated. The Apex-CS controller, the manufacturer's automated nulling device, did not perform as desired. This forced a return to three individual power supplies that required manual control of the voltage and current into the coils. However, the JPL programmed data acquisition software also had an algorithm that automatically generated enough current and voltage through the coils needed to produce a roughly zero magnetic field. Wiring issues that prevented this function in the past have been corrected and now the system can reach negligible fields quicker.

In another effort to create a magnetically clean testing process, non-magnetic testing apparatus were built and used using SolidWorks CAD software. An aluminum stand was designed and built to house a wooden sensor holder (Figure 4). This setup functions as a permanent, non-magnetic, and adjustable fixture to collect data at the right height as the device under test rotates. Aluminum lifts were also designed and built for the Helmholtz coil.

Keeping the structure off the ground, the lifts provide stability, contribute to cleanliness, and reduce potential for wear and tear.

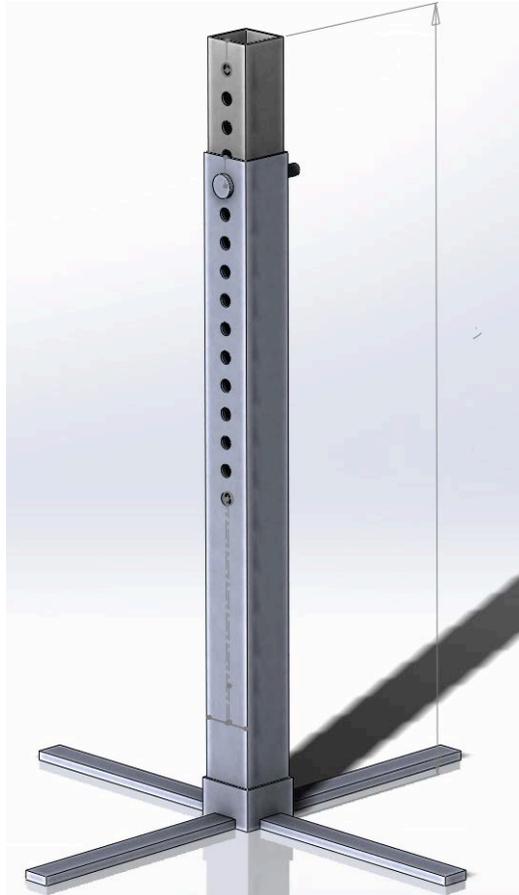


Figure 4

Finally, the single-axis magnetics system was also updated. Although not required for upcoming SAFT Battery testing, the single axis testing has historically been the most often used magnetic measurement system. Figure 5 below, shows a graph of the Y-axis rotation on the standardized magnet. Note the peak to peak value, or twice the amplitude, is very close to the value found with the tri-axial data acquisition program on Figure 3.

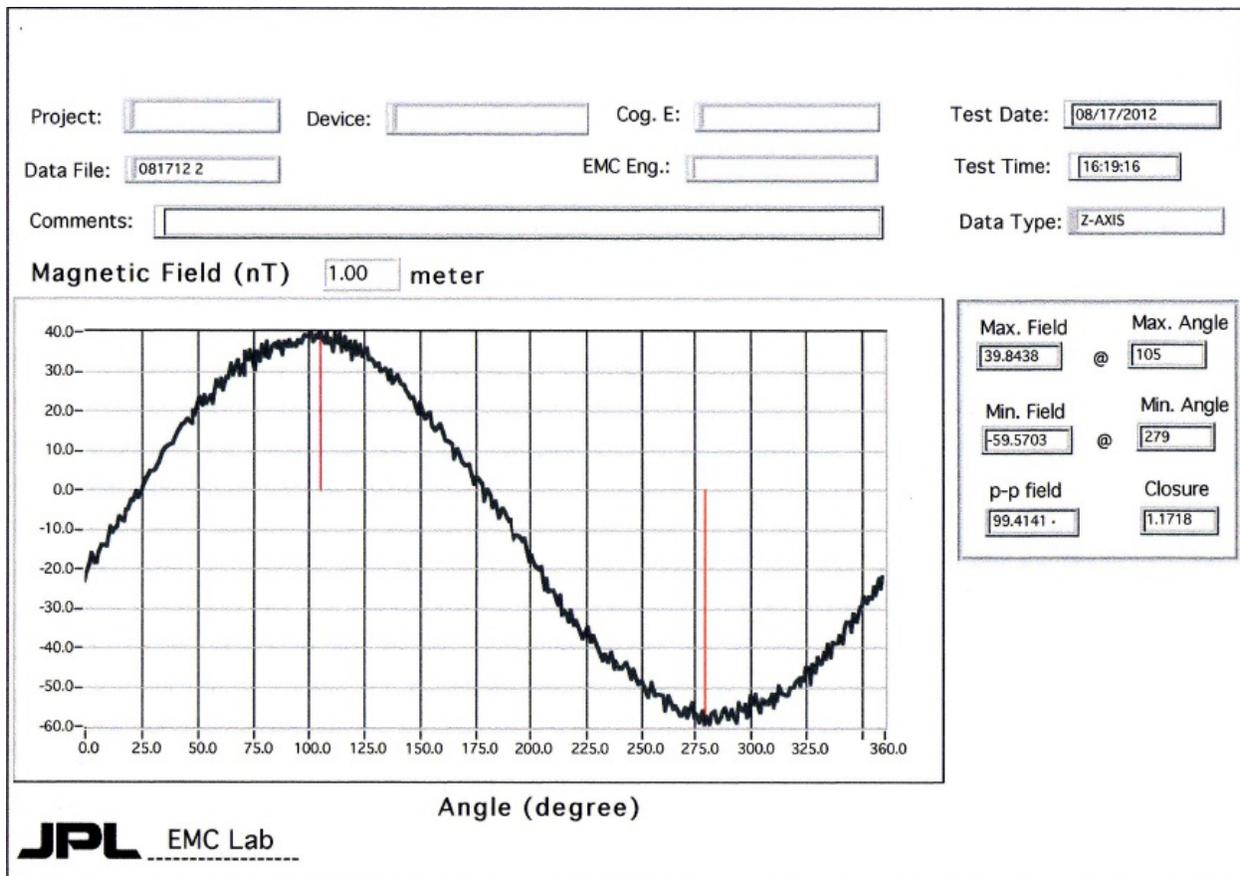


Figure 5

Efforts to prepare this system over the summer have been a huge success. Testing now is more assured since all data gathering and analysis tools have been tested and verified against known sources. Although to ensure complete functionality for all future missions, a new commanding document that completely covers all magnetics testing and hardware still needs to be written. However, updates to the SAFT Battery Testing Procedure have been implemented to reflect current goals for the upcoming tests, as well as descriptions of all processes that have been updated. Due to aging hardware and the appearance of infrequent computer crashes, software backups have now been put in place. A complete upgrade from the old system to a newer computer is to be completed shortly.

Acknowledgements

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