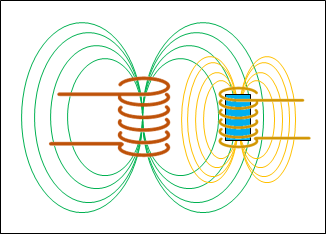
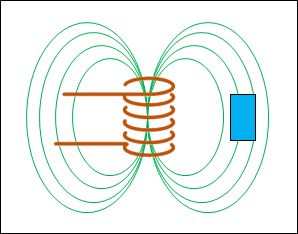
# Using Fluxgate Magnetometers to Detect Ferromagnetic Materials in the Low-Magnetic-Field Environment of the Moon

Ferromagnetic materials can be magnetized by an external magnetic field, and will maintain their magnetization to a certain degree after the field has been removed [A]. On Earth, ferromagnetic materials can be located by detectable variations in Earth’s magnetic field due to the materials, but since the moon lacks a strong magnetic field, locating ferromagnetic materials on the moon is dependent on being able to generate a strong enough magnetization field. This can be done using a solenoid to generate a precise magnetic field strong enough to magnetize ferromagnetic materials on the lunar surface.

Fluxgate magnetometers are instruments capable of detecting very weak magnetic fields (on the order of micro-Tesla), and can be made small enough to fit inside the prescribed payload volume. They cannot be exposed to strong magnetic fields, however, and so must be protected from any field produced to magnetize materials on the lunar surface. A second solenoid can be positioned around the fluxgate magnetometer to cancel out the field generated by the magnetization solenoid at the location of the fluxgate magnetometer.



**Figure 1:** Magnetization solenoid alone exposes fluxgate magnetometer to strong magnetic fields that can ruin the sensor’s operation, but a secondary solenoid can cancel out the magnetization field at the magnetometer's location.

The magnetization solenoid and the secondary protection solenoid can be turned on for a short “burst” to magnetize ferromagnetic materials on the lunar surface, and then turned off to allow the magnetometer to detect whether there has been any significant change in ambient magnetic field after the magnetization burst. If there is, it could indicate that ferromagnetic materials are in the vicinity.

The concept’s feasibility can be evaluated by determining what size the magnetization coil must be to magnetize ferromagnetic materials enough that their magnetization can be detected by the fluxgate magnetometer.

## Magnetization Field Strength at the Lunar Surface

First, to maximize the magnetization field strength at the lunar surface, the solenoid should be oriented with its axis pointing at the surface. In this orientation, the magnetic field at the surface is given by Equation 1 [1a, 1b]:

(1)

Where x denotes the distance between the point of interest and the center of the solenoid; μ is the magnetic permeability of free space, and m is the magnetic moment of the solenoid.

The magnetic moment of a solenoid is given by Equation 2 [B]:

(2)

Where N is the number of turns in the solenoid; I is the current flowing in the solenoid; and r is the solenoid’s radius.

## Degree of Magnetization of Materials on Lunar Surface

For a given material, the degree to which it magnetizes after being exposed to an external magnetic field is described by its magnetic susceptibility property [C]. When the magnetic susceptibility is known, the magnetization strength can be calculated by Equation 3:

(3)

Where M is the magnetization in the material, χ is the magnetic susceptibility, and H is the magnetizing field strength.

## Strength of the Magnetized Material’s Field at the Payload

A few assumptions are made here:

* The shape of ferromagnetic materials on the moon can be approximated as spheres;
* The material particles are uniformly magnetized by the magnetization field;
* The strength of the magnetized particles’ field doesn’t vary significantly between the magnetizing solenoid’s location and the magnetometer’s location in the payload.
* The materials’ magnetization does not decay significantly before the sensor can make its measurement.

The strength of a magnetized sphere’s field at a distance away from it is given by Equation 4 [D]:

(4)

Where r is the vector distance between the sphere and the measurement location, and m in this case is given by Equation 5 [D]:

(5)

Where a is the radius of the magnetized sphere, and M is the sphere’s magnetization defined above by Equation 3.

Another assumption made here is that the vector directions of the magnetic fields and radii are parallel enough that the equations can be evaluated as scalar equations without significantly impacting the validity of the conclusions drawn about the method’s feasibility from the use of the equations.

With these equations, the magnetization solenoid’s geometry and current parameters can be adjusted to determine the minimum particle size that can be detected on the lunar surface by a given magnetometer.

## Magnetization Field Strength at the Magnetometer Location

Finally, to ensure the magnetometer’s protection from the magnetization solenoid’s field during the magnetization burst, the strength of the magnetic field that must be cancelled out by the secondary solenoid can be calculated by Equation 6, assuming the fluxgate magnetometer is positioned along the magnetization solenoid’s equator:

(6)

This is the field strength that must be counteracted by the secondary solenoid. The field strength at the center of the secondary solenoid is given by Equation 7:

(7)

Where N is the number of turns in the solenoid and I is the current flowing in the solenoid.

# References

[A] <http://www.bgu.ac.il/geol/classes/geophysics/Front/Lec12.pdf>

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[1b] <https://thefactfactor.com/facts/pure_science/physics/magnetic-induction/5019/>

[B] <https://en.wikipedia.org/wiki/Magnetic_moment#Magnetic_moment_of_a_solenoid>

[C] <https://byjus.com/physics/magnetic-susceptibility/>

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[2] <http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/magmom.html>

[3] Advice from fluxgate magnetometer expert from GMW Associates (<https://gmw.com/>)

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