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APPLICATION NOTE

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MEASURING ROCK MAGNETISM WITH THE FM300
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INTRODUCTION

This application note describes how to use the FM300 to measure the permanent and induced magnetic dipole moments of a magnetized rock or any other magnetized object.

BACKGROUND

Magnetized objects have static fields which diminish rapidly with distance. Doubling the distance between the object and probe usually results in the measured field magnitude dropping to 1/8 of its original value (the field drops off as $1/r^3$ where r is the distance from the object to the measuring point).

The distortion in Earth’s field caused by a magnetized object extends only a short distance from the object. The stronger the object is magnetized, the further away it can be detected. The fields of permanent magnets can be measured by the FM300 at relatively large distances. Objects which are magnetized by Earth’s field usually have much smaller magnetic fields and must be close to the FM300 to be detected.

MEASUREMENT STRATEGY

Because the magnetized object is immersed in Earth’s field, the field measured by the FM300 is the sum of the Earth’s field and the field produced by the object. We need a measurement technique which will extract the object’s magnetic characteristics from the measurements.

Measurements of the changes in the local Earth's field caused by the presence of the object will achieve this objective. Measuring the changes in the rectangular components is the best way to characterize the magnetic properties of an object. Since the rectangular component values change as the probe is moved in Earth's field, the best strategy for making measurements is to keep the FM300 probe in a fixed position while rotating the object being measured or moving it towards or away from the probe.

INDUCED AND PERMANENT MAGNETIZATION

Objects can have some permanent magnetization and some magnetization induced by Earth's field. The permanent magnetization is not dependent on the presence of a magnetic field for its existence. As the object rotates, the field produced by the permanent magnetization will rotate.

The induced magnetization depends on the direction and magnitude of the Earth's magnetic field vector and the magnetic properties of the object. If the object is magnetically homogeneous and isotropic (same properties in all directions), the induced magnetization will be proportional to and in the direction of the Earth's field. The field caused by the induced magnetization will not rotate as the object is rotated.

The relative contributions of these two magnetization properties can be determined through a series of measurements which involve rotations of the object.

MAGNETIC DIPOLE MOMENT MODEL

If the magnetized object is sufficiently far away from the FM300 probe (at least twice the length of the object's longest dimension), the field it generates can be approximated by assuming that the object may be modeled as two magnetic dipoles: one which represents the permanent magnetization and the other which represents the induced magnetization.

The property of a magnetic dipole, which determines the field that the object generates, is a vector called the magnetic dipole moment. The dipole moment vector is the sum of the permanently magnetized dipole moment vector (mx_p, my_p, mz_p) which is fixed relative to the coordinate system associated with the object, and the induced dipole moment vector (*mx*$_i$, *my*$_i$, *mz*$_i$) which is fixed relative to the Earth's field coordinate system. The items in parentheses are the rectangular components of the vectors in their respective coordinate systems. If the values of these components are known, the field generated by the object can be computed using equations which can be found in standard text books on magnetostatics (see the Reference section). The series of measurements that are described in the following procedure are designed to determine the values of these components.

DATA COLLECTION

The following procedure should be carried out in an area which is free from other magnetic objects that might influence the measurements. You should also remove your belt, keys and any other ferromagnetic material that you may be carrying.

1. Determine the geometric center of the object to be tested. This is the pivot point about which all rotations are to be made.
2. Assign the longest dimension of the object to be the *X* axis (*X* dimension), and draw a straight line on the object to represent this axis with an arrow head at one end of the line.
3. Assign two more axes, called *Y* and *Z*, which are at right angles to the *X* axis and to themselves. Indicate the axes' directions using straight lines with arrow heads drawn on the object. Make sure this reference coordinate system is right-handed.
4. Secure the FM300 probe on a flat horizontal surface with the *X* axis arrow on the top of the probe.
5. Select the rectangular coordinate system and the *X* component.
6. With the object to be measured well removed from the probe, set each of the components in the REL measurement mode. The component readings should now be close to zero.
7. Place the object along the projection of the probe's *X* axis so that the distance, between the center of the object and the crosshairs indicating the center of the X axis sensor, is at least twice the length of the *X* dimension of the object (see Fig. 1). The greater the better.
8. Rotate the object so the *X*, *Y*, and *Z* axes of the probe and the object coincide. The probe and object axes' arrows should be pointing in the same direction (see Fig. 1).
9. Measure and record the distance *s* from the probe *X* axis sensor center to the object's center. Repeat for the probe *Y* and *Z* axes. The crosshairs on the probe indicate the sensor centers.
10. Record the *X* ,*Y*, and *Z* fields measured by the FM300.
11. Rotate the object 180 degrees about its *Z* axis until the object's *X* and *Y* axes' arrows are pointing in opposite directions to those of the probe. Make sure the geometric center of the object remains in the same location.
12. Record the *X*, *Y*, and *Z* fields measured by the FM300.
13. Rotate the object back to its original position. The field values should be the same as recorded in step 10.
14. Flip the object over so that the *X* and *Z* axes' arrows of the object are pointing in opposite directions to the corresponding probe axes' arrows. The *Y* axis of the probe and object should be pointing in the same direction.
15. Record the *X*, *Y*, and *Z* fields measured by the FM300.
16. Move the object one inch away from the probe along the extension of the probe's *X* axis. Place the object so that the *X, Y, Z* arrows of the object point in the same direction as the *X, Y, Z* arrows of the probe, and repeat steps 10 through 15.

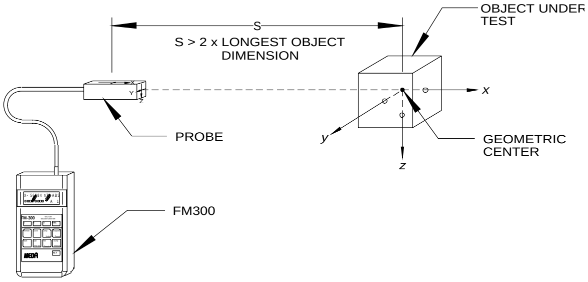

Figure 1 Starting position when measuring the magnetic moments of an object

DATA REDUCTION

The field measurements, at different distances from the probe, are used to verify that the magnetized object can be modeled as a dipole. If the dipole model is correct, a plot of the data will reveal that the strength of the field is diminishing at a rate of $1/r^3$. The distance measured in step 9 for the *X* axis will be 0.5 inches longer than that for the *Y* and *Z* axes, since the *X* sensor center is further away than the *Y* and *Z* sensor center. This must be taken into account when plotting the data.

It is also possible that the geometric center of the object is not its magnetic center. Shifting the origin of the plotted values until the data agrees with a $1/r^3$ relationship will usually reveal where the magnetic center lies. An estimate of the shift can be calculated from two measurements using the following equation:

$$d = \frac{\left(s_2 - s_1 \cdot (R_1/R_2)^{1/3}\right)}{\left[(R_1/R_2)^{1/3} - 1\right]}$$

where R_1 and R_2 are the readings at distances s_1 and s_2, respectively, and *d* is the amount to add to or subtract from the distance measurements to correct for the difference between the magnetic and geometric centers.

Compute the components of the permanent magnetization dipole moment using the following equations:

$$mx_p = (X_0 - X_{180}) \cdot r^3 / 4$$
$$my_p = (Y_0 - Y_{180}) \cdot r^3 / 2$$
$$mz_p = (Z_0 - Z_{180}) \cdot r^3 / 2$$

where X_0, Y_0, Z_0 are the initial field measurements before the object is rotated, X_{180} and Y_{180} are the *X* and *Y* field measurements after the object has been rotated 180 degrees about the *Z* axis (step 11), and Z_{180} is the *Z* axis field measurement after the object has been flipped (step 14). The distance *r* is the distance from the appropriate probe sensor to the object's geometric center.

Compute the components of the induced magnetization dipole moment using the following equations:

$$mx_i = (X_0 + X_{180}) \cdot r^3 / 4$$
$$my_i = (Y_0 + Y_{180}) \cdot r^3 / 2$$
$$mz_i = (Z_0 + Z_{180}) \cdot r^3 / 2$$

The meanings of the *X*, *Y* and Z measurements are the same as described for the permanent magnetization dipole moment component calculations.

SUMMARY

This application note described how the FM300 can be used to measure the magnetization characteristics of rocks or any magnetized object. The FM300 is particularly suited to this kind of measurement. With its 1nT resolution, it can detect the very small changes produced by a magnetized object in the midst of the very large Earth's magnetic field (typically 50,000 nT).

This procedure can be used to measure the permanent magnetization dipole moment of any object. This procedure can also be used to measure the induced magnetization dipole moment of objects with isotropic magnetic properties. A different technique is required for objects with anisotropic (direction dependent) magnetic properties.

REFERENCES

To delve more deeply into magnetic field theory see:

1. Jackson, J. D., *Classical Electrodynamics,* Wiley, New York, N.Y. (1962).
2. Stratton, J. A., *Electromagnetic Theory,* McGraw-Hill, New York, N.Y. (1941).