Disturbing Effect of a Magnetic Object on the Absolute Measurement of the Magnetic Field

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Abstract
Ground magnetic surveys are carried out over small areas on a previously defined target. Many observations are spoiled by a magnetic object the observer is carrying while observing. It is not easy to estimate how far away a magnetic object should be kept from the point of measurement. To investigate this, a theoretical formulation of the magnetic field for a small magnetic object in an external magnetic field was calculated having a look at the influence of an arbitrary shaped magnetic body at any point in space in the presence of an external field $H$. The nuclear prescission (proton) magnetometer was used for the field work. An estimation of anomalies for given weight for round and elongated bodies was considered. The result shows distances for some common objects at which an anomaly is 1nT with safety pin having the least the distance of 0.6m and Autobus the highest distance of 76.0m. However, the best way of avoiding the disturbance due to a magnetic body is checking the surroundings of the measurement point with a proton magnetometer.

Keywords: magnetic survey, magnetometer, disturbance, magnetic object, magnetic body

INTRODUCTION
Ground magnetic surveys are performed usually over small areas on a previously defined target. Consequently, the spacing of the stations should be the order of 10-100m, although smaller spacing may be employed where the magnetic gradients are high (Landau and Lifshitz, 1957).
Many observations are spoiled by a magnetic object the observer is carrying while observing. Readings should not be taken in the vicinity of magnetic objects such as penknife, screwdrivers, Keys, fountain pen, railway lines, cars, roads fencing, houses etc. Operators of magnetometers should not carry any magnetic objects while observations are going on (Breiner, 1993).
It is not easy to estimate how far away a magnetic object should be kept from the point of measurement. This is because the effect of magnetic object on the magnetic field depends on many factors. According to Jankowski (1992), include:
1. The distance between a magnetic object (source position) and the point of measurement.
2. Magnetic parameters and the volume of a magnetic object.
3. Geometrical shape
4. An angle between the component to be measured and the direction of magnetization.
5. The past history of magnetic body.
The strength $F_i$ of the measured magnetic field is directly proportional to the frequency of the signal ($f$) and is given by:

$$F_i = \frac{(2\mu_0 \gamma p)}{\mu} f$$

Where $\mu$ = permeability

Theoretical Formulation
To carry out effectively a theoretical formulation of the magnetic field for a small magnetic object in an external magnetic field was calculated having a look at the influence of an arbitrarily shape magnetic body at any point in space in the presence of an external field $H$.

Solving Laplace equation for magnetic scalar potential $\Phi$ having boundary condition of magentic induction normal component $B_n$ and tangential component of magnetic field $B_c$, continuity on boundary of magnetic body, we have
\[ \Delta \varphi = 0, \dot{\varphi} = \nabla \varphi \]  
(1)
The solution can be solved by having a look at a very small magnetic object of spherical shape. In the spherical coordinate system \((r, \theta)\) the solution is
\[ \begin{align*}
\mathbf{H}_r &= \frac{\mathbf{H}_0}{r} - \frac{\mathbf{J}_I}{r} \\
\mathbf{H}_\theta &= \frac{\mathbf{H}_0}{r \cos \theta} - \frac{\mathbf{J}_I}{r} \cos \theta
\end{align*} \]  
(2)
Inside the sphere
\[ \begin{align*}
H_r &= \left( H_0 + \frac{J_I}{r} \right) \cos \theta \\
H_\theta &= \left( -H_0 + \frac{J_I}{r} \right) \sin \theta
\end{align*} \]  
(3)
The origin of the coordinate reference system is at the centre of the sphere.
\[ \begin{align*}
\alpha &= \text{radius of sphere} \\
\mathbf{H}_0 &= \text{external magnetic field along vertical axis} \\
\mu &= \text{permeability} \\
\kappa &= \text{susceptibility} \\
J_I &= \text{induced magnetization}
\end{align*} \]  
(4)
There exist an additional field (from equation 3) of
\[ 0.17 \]  
(5)
\[ 0.11 \]  
(6)
\[ 0.8 \]  
(7)
\[ \text{in Figure 2 and some values listed in Table 1.} \]

**Demagnetisation Factor and its Calculation**

Equation (2) can be rewritten in a generalized form as
\[ J_I = \kappa (H_0 - N J_I) \]  
(5)
\[ N = \text{demagnetisation factor. For a sphere} \]
\[ N = \frac{4}{3}(\text{cgs}) \text{ or } \frac{1}{3} \text{ (SI)} \].

For more complex shape the formula becomes more complicated and instead of scalar factor \( N \) it is necessary to introduced demagnetization tensor. For the ellipsoid, the magnetization along the main axis can be expressed by the formulae.
\[ \begin{align*}
J_{IX} &= \kappa (H_0 X + N_{IY} J_I X) \\
J_{IY} &= \kappa (H_0 Y + N_{IZ} J_I Y) \\
J_{IZ} &= \kappa (H_0 Z + N_{IX} J_I Z)
\end{align*} \]  
(6)
Here, the magnetisation is homogeneous but its direction is not the same as induced field. The ellipsoid with axis \( a = b < c \) is the coordinate system \( x, y, z \) had the magnetization factor.
\[ \begin{align*}
N_{IY} &= \frac{4\kappa a(1-a^2)}{2\kappa^2} \left[ \ln \left( \frac{1-a^2}{1+e^2} \right) - 2e \right] \\
N_{IY} &= N_{IY} = \frac{1}{12} (4m - N_{IY}) \quad \text{(cgs)} \\
N_{IY} &= N_{IY} = \frac{1}{12} (12m - 2e^2) \\
N_{IY} &= N_{IY} = \frac{1}{12} (1 - N_{IY}) \quad \text{(SI)}
\end{align*} \]  
(7)
where \( e = \sqrt{1 - \frac{b^2}{a^2}} \).

For the ellipsoid with axis \( a = b > c \) yield:
\[ h_{IY} = \frac{4\kappa a(1-a^2)}{2\kappa^2} (m - n_{YY}) \quad \text{(cgs)} \]  
(8)

Figure 2: Dependence of the magnetization factor of the elongation of the ellipsoid body (cgs units). to get in SI units, \( N \) is divided by \( 4\pi \).

The magnetization factor tends to zero with growing elongation of the body and equals \( 4\pi \) (cgs) or 1 (SI) for a thin layer. The demagnetisation ratio is in the interval \( (0, 4\pi) \) in cgs units and \( (0, 1) \) in SI units (Polivanov, 1957). A graph of demagnetization factor calculated with equations 7 and 8 is presented in Figure 2 and some values listed in Table 1.

<table>
<thead>
<tr>
<th>( \lambda )</th>
<th>( \lambda )</th>
<th>( \lambda )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.19</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>2.18</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>1.37</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>0.95</td>
<td>14</td>
</tr>
<tr>
<td>5</td>
<td>0.70</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>0.54</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>0.43</td>
<td>17</td>
</tr>
<tr>
<td>8</td>
<td>0.36</td>
<td>18</td>
</tr>
<tr>
<td>9</td>
<td>0.30</td>
<td>19</td>
</tr>
<tr>
<td>10</td>
<td>0.25</td>
<td>20</td>
</tr>
</tbody>
</table>
Induced and Remanent Magnetization of the Magnetic Body

The induced magnetization could be calculated using equation (5)

$$I_I = \frac{kN H_o}{1 + kN}$$

(10)

The quantity \(\frac{kN}{1 + kN}\) is called the apparent or shape susceptibility.

When \(kN >> 1\), we have

$$I_I = \frac{I_R}{N} H_o$$

(11)

The magnetization in this case does not depend on susceptibility but only on the demagnetization factor and external field.

When \(kN << 1\),

$$I_I = k N H_o$$

(12)

Applying equations 10, 11 and 12 induced magnetization could be calculated if \(k\) is known.

The total magnetization is a vector sum of the induced and remanent magnetization.

$$I = I_I + I_R$$

(13)

Equation 12 can be used for any iron body, provided that it is not very elongated. \(I_I\) and \(I_R\) are not parallel but during rotation of the magnetic non-spherical body in an external field, \(I_I\) is not changing while \(I_R\) has a constant value.

Practical Simplified Formulae for Calculation of Disturbing Effect of a Magnetic Object

In considering the disturbing effect of a small magnetic object in the site a magnetic measurement, an important role is played by an angle between an additional field \(\Delta H\) and the main field \(H_o\). The vector sum of these two quantities according to Jankowski (1992).

$$H = H_o + \Delta H$$

If

\(\Delta H \ll H_o\) \ king have

$$\Delta H = (H_o + 2 H_o \Delta H + \Delta H^2)^{1/2}$$

(14)

If

\(H_o / \Delta H\)

$$H = H_o + \Delta H$$

And, if

\(H_o \perp \Delta H\)

$$H = H_o$$

Assumptions which led to the formulae for estimation of the disturbing field.

(a) The disturbing field can be represented by the magnetic field of a magnetic dipole. This assumption is valid if the dimension of the source is much smaller than the distance between source and an observer.

(b) The external field, magnetic moment and the direction of magnetization are parallel to one another, and was in the direction of magnetic moment passing through the source. This assumption overestimates the amplitude of disturbing field.

(c) The total intensity is twice the induced magnetic field. This in some cases leads to value of anomaly, while in other case may give too high a value.

$$\frac{H_o}{H_o} = 50.000nT$$

(undisturbed total field)

$$H = 40nT$$

Figure 3: Addition of External and Anomalous Fields

(For Total Component Of Geomagnetic Field)

After all simplifications the disturbing effect can be expressed as

$$\Delta H = \frac{m k B_o}{\pi m^2} (1 + kN)$$

(14)

In SI units, the dimensions are

$$\text{[m]} = \text{kg}, \ [k] = \text{SI units}, \ [H_o] = \frac{m k B_o}{\pi m^2} [\text{m}] = \text{m}$$

$$\Delta H = \frac{m k B_o}{\pi m^2} \left[\text{m}^2\text{kg}^{-1}\right] = \text{mT}$$

Using equation (14), the computations depicted in figures 4 and 5 were carried out. Figure 4 is for estimating anomalies for given weights for round bodies while Figure 5 is for estimating anomalies for given weights for elongated bodies (\(\lambda = 10\)) and magnetic susceptibility \(k = 8\) cgs is assumed. Equation (14) is also used in constructing Table 2.
RESULT
The experimental verification of the calculated values in Table 2 is as shown below.

Table 3: Experimental Result of Table 2

<table>
<thead>
<tr>
<th>Object</th>
<th>Distance in metres at which anomaly 1nT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autobus</td>
<td>76.1</td>
</tr>
<tr>
<td>Car</td>
<td>35.9</td>
</tr>
<tr>
<td>Motor cycle</td>
<td>19.1</td>
</tr>
<tr>
<td>Bicycle</td>
<td>6.8</td>
</tr>
<tr>
<td>Spade</td>
<td>5.0</td>
</tr>
<tr>
<td>Hammer</td>
<td>3.6</td>
</tr>
<tr>
<td>Screwdriver</td>
<td>2.2</td>
</tr>
<tr>
<td>Knife</td>
<td>2.1</td>
</tr>
<tr>
<td>Metallic pen</td>
<td>1.2</td>
</tr>
<tr>
<td>Buckle of belt</td>
<td>1.3</td>
</tr>
<tr>
<td>Watch</td>
<td>0.7</td>
</tr>
<tr>
<td>Safety pin</td>
<td>0.6</td>
</tr>
</tbody>
</table>

CONCLUSION
An attempt has been made to calculate the distances in metres of typical magnetic objects at which the anomaly has an amplitude of 1nT. Making all simplifications we tried to rather overestimate the value of disturbed field. In many cases, namely when the permanent magnetization is much bigger than the induced one, or when the body is large in comparison to the distance to the measuring point, the computed value can be smaller. The experimental values are in agreement with the calculated ones except in some cases with little variations of ±0.1m. However, the best way of avoiding the disturbance due to a magnetic body is checking the surrounding of the measurement point with a proton magnetometer.

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