Defence Science Journal, Vol 50, No. 4, October 2000, pp. 351-359

Analyses of Magnetic Field Induced around a Tank

Zang Kemao, Ma Xiaojun and Xie Yongcheng
Special Vehicle Engineering Institute, Beijing – 100 072

ABSTRACT

A tank is taken to have the shape of a hollow spheroid. Equations for calculating the induced field are derived based on a special coordinate system established around the spheroid. A numerical example to illustrate the magnetic field induced around a tank and its analyses are given.

1. INTRODUCTION

A tank can be magnetised due to the geomagnetic field, and as a consequence, a magnetic field will be induced around it. Mines and artillery shells with magnetic fuses that are directed against the tanks are initiated depending on the magnetic field induced around the tank. A magnetic fuse has advantage of noninterference. In modern tank warfare, it has been shown that the mines and the artillery shells with magnetic fuses constitute a great menace to the tanks[1].

The magnetic field induced around a tank can be separated into a permanent component and an induced magnetic field component. The permanent component exists because the tank is magnetised by the geomagnetic field when it stays in the same direction for a long time. The permanent magnetism is residual and in general it is weaker than the induced magnetic field. In this paper, a method for calculating the magnetic field induced around a tank is presented.

The geomagnetic field varies both in intersect and orientation across the earth's surface. However, for regions where tank travels the geomagnetic field can be considered to be uniform. For the sake of convenience, the geomagnetic field intensity can be resolved into a vertical component and a horizontal component. To simplify the calculation, the tank is taken to be a hollow spheroid shell in which the inner and the outer surfaces have the same focal point and semi-focal distance. Furthermore, it is assumed that the tank is made from a single steel. Since the geomagnetic field is a weak magnetic field, the permeability of the steel can be considered to be a constant.

2. FIELD CALCULATIONS

When the tank is taken to be a hollow spheroid shell, the magnetic field can be calculated using a spheroidal coordinate system. The relationship between the spheroidal coordinate system (u,v,w) and the rectangular (x,y,z) is as follows:

$$x = g\,ch(u)\cdot\cos(v)$$
$$y = g\,sh(u)\cdot\sin(v)\cdot\cos(w)$$
$$z = g\,sh(u)\cdot\sin(v)\cdot\sin(w) \qquad (1)$$

where ch and sh stand for cosine hyperbolic and sine hyperbolic functions, respectively.

A given value of u corresponds to one and only one spheroidal surface. The symbols u_e and u_i correspond to the outer and the inner surfaces,

Revised 12 June 2000

respectively. The values of the major semi-axis or minor semi-axis are:

$$a_e = gch(u_e), \qquad b_e = gsh(u_e)$$
$$a_i = gch(u_i), \qquad b_i = gsh(u_i) \qquad (2)$$

where

$$a_e^2 - b_e^2 = g^2, \qquad a_i^2 - b_i^2 = g^2 \qquad (3)$$

and g is the semi-focal distance, and the eccentricity is given by

$$\varepsilon = \frac{g}{a_e} = \frac{1}{ch(u_e)}, \quad \varepsilon_i = \frac{g}{a_i} = \frac{1}{ch(u_i)} \qquad (4)$$

In a spheroid coordinate system, Laplace's equation is as follows:

$$\nabla^2\varphi = \frac{\partial}{\partial u}\left\{sh(u)\cdot\sin(v)\frac{\partial\varphi}{\partial u}\right\} + \frac{\partial}{\partial v}\left\{sh(u)\cdot\sin(v)\frac{\partial\varphi}{\partial v}\right\} + \frac{sh^2(u)+\sin^2(v)}{sh(u)\cdot\sin(v)}\cdot\frac{\partial^2\phi}{\partial w^2} = 0 \qquad (5)$$

The shell divides the space into three sections (Fig. 1).

The characteristics of these sections are as follows:

Section I. Inside the space of the shell, air (relative permeability is 1, scalar magnetic potential is φ_1).

Section II. In the lamella of the shell, steel products (relative permeability is μ_r, scalar magnetic potential φ_2).

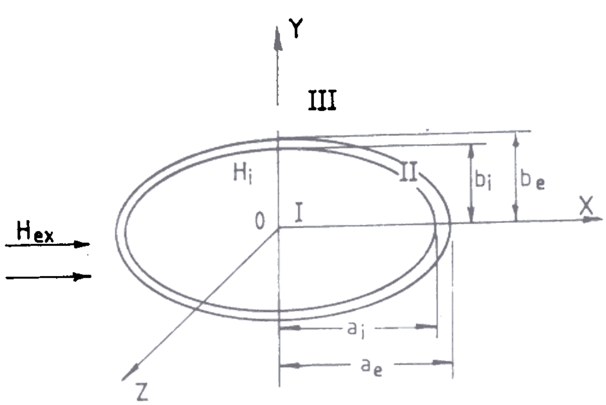

Figure 1. Schematic diagram of hollow spheroid

Section III. Outside section of the shell, air (relative permeability is 1, scalar magnetic potential φ_3).

If the geomagnetic field intensity is H_{ex} and magnetises the shell along the direction of the x-axis, the scalar magnetic potential associated with this field is:

$$\varphi_0 = -H_{ex}x = -H_{ex}\, gch(u)\cdot\cos(v) \qquad (6)$$

Because the direction of H_{ex} coincides with the direction of the major axis, the magnetic field (potential) is independent of the angle w. Therefore, $\partial\varphi/\partial w = 0$ and Eqn (5) reduces to

$$\frac{\partial}{\partial u}\left\{sh(u)\cdot\sin(v)\frac{\partial\varphi}{\partial u}\right\} \frac{\partial}{\partial v}\left\{sh(u)\cdot\sin(v)\frac{\partial\varphi}{\partial v}\right\} = 0 \qquad (7)$$

Separation of variables can be used to solve this equation:

$$\varphi = F(u)\cdot G(v$$

On the outer interface of the shell ($u = u_e$), the continuity of the potential $\varphi_2 = \varphi_3$, yields:

$$F_2(u_e)G_2(v) = F_3(u_e)G_3(v)$$

or

$$G_3(v)/G_2(v) = F_2(u_e)/F_3(u_e \quad = \text{Constant}$$

It readily follows that both $G_3(v)$ and $G_2(v)$ are the same functions of v; φ_2 and φ_3, too. Suppose $\varphi_2 = \varphi_0 + \varphi'_2$, and $\varphi_3 = \varphi_0 + \varphi'_3$, where φ_0 is the potential of the geomagnetic field, and φ'_2 and φ'_3 are the potentials of the induced field that is produced by the magnetised shell. From Eqn (6), it follows that φ_2, φ_3 and φ'_2, φ'_3 are proportional to cos (v). In general

$$\varphi = F(u)\cdot\cos(v$$

Substituting the above equation into Eqn (2) yields:

$$\frac{\partial^2 F}{\partial u^2} + \frac{ch(u)}{sh(u)}\cdot\frac{\partial F}{\partial u} - 2F = 0$$

It is obvious that

$$F_1 = ch(u)$$

is one of the particular solutions. The other one can be calculated *via* integration,

$$F_2 = ch(u)\int \frac{e^{-\int \frac{ch(u)}{sh(u)}du}}{ch^2(u)}du = 1-\frac{ch(u)}{2}ln\frac{ch(u)+1}{ch(u)-1} \quad (8)$$

and then

$$\varphi = (A_3F_1 + A_4F_2)\cos(v)$$

Outside the shell, far from the shell, $u \to \infty$, $F_1 = ch(u) \to \infty$; since the potential produced by magnetised shell $\varphi'_3 \to 0$, $\varphi'_3 = \varphi_0$, φ_3 must not include F_1, and therefore $A_3 = 0$.

Hence

$$\varphi_3 = A_4F_2\cos(v) = \varphi_0 + \varphi'_3$$
$$= -H_{ex}gch(u)\cdot\cos(v) + A'_4\left(\frac{ch(u)}{2}ln\frac{ch(u)+1}{ch(u)-1}-1\right)\cos(v) \quad (9).$$

In the lamella of the shell

$$\varphi_2 = A_3ch(u)\cdot\cos(v) + A_4\left(1-\frac{ch(u)}{2}\,ln\,\frac{ch(u)+1}{ch(u)-1}\right)\cos(v)$$

which can also be expressed as the sum of the geomagnetic field and the induced field.

$$\varphi_2 = -H_{ex}gch(u)\cdot\cos(v) + A'_2ch(u)\cdot\cos(v) + A'_3\left(\frac{ch(u)}{2}ln\frac{ch(u)+1}{ch(u)-1}-1\right)\cos(v) \quad (10)$$

Now, since $\varphi_1 = \varphi_2$ on the interface between sections I and II, one can obtain the following expression:

$$\varphi = F'(u)\cdot\cos(v)$$

where

$$F'(u) = A_1F_1 + A_2F_2$$

Within section I, $u \to 0$, $ch(u) \to 0$, $F_2 \to -\infty$, so $A_2 = 0$

and

$$\varphi_1 = A_1F_1\cos(v)$$
$$= -H_{ex}gch(u)\cdot\cos(v) + A'_1ch(u)\cos(v)$$

In the above, A'_1, A'_2, A'_3 and A'_4 are the undetermined coefficients. They can be determined from the boundary conditions.

On the inner interface

$$\varphi_{1(u=u_i)} = \varphi_{2(u=u_i)}.$$

From Eqns (10) and (11), this condition yields

$$A'_1 = A'_2 + \frac{A'_3}{ch(u_i)sh^2(u_i)}D_1$$

in which

$$D_1 = sh^2(u_i)\cdot\left(\frac{ch(u_i)}{2}ln\frac{ch(u_i)+1}{ch(u_i)-1}-1\right)$$
$$= \frac{1-\varepsilon_i^2}{}\left(\quad 2\varepsilon_i \quad 1-\varepsilon_i \quad\right)$$

On the inner interface, one has:

$$\mu_1\frac{\partial\varphi_1}{\partial n} = \mu_2\frac{\partial\varphi_2}{\partial n}\Big|u = u_i \quad (14)$$

which can be written as

$$\mu_1\frac{\partial\varphi_1}{\partial n} = \mu_2\frac{\partial\varphi_2}{\partial n}\Big|u = u_i$$

Substituting Eqns (10), (11) and $\mu_1 = 1, \mu_2 = \mu_r$ into Eqn (15), one can obtain the following expressions:

$$(\mu_r - 1)H_{ex}g + A'_1 = \mu_rA'_2 + A'_3\mu_rg^3\frac{D_1-1}{a_ib_i^2}$$

A similar analysis applied to the outer interface yields:

$$A'_2 + \frac{A'_3g^3}{a_eb_e^2}D_2 = A'_4\frac{g^3}{\quad}D_2$$

and

$$(\mu_r - 1)H_{ex} g + A_4' g^3 \frac{D_2 -}{a_e b_e^2} = \mu_r A_2' + A_3' \mu_r g^3 \frac{D_2 - 1}{a_e b_e^2} \tag{18}$$

where

$$D_2 = \frac{1-\varepsilon_e^2}{\varepsilon_e^2}\left(\frac{1}{2\varepsilon_e} ln \frac{1+\varepsilon_e}{1-\varepsilon_e} - 1\right) \tag{19}$$

When a_e, b_e, a_i, b_i and H_{ex} are known, in the Eqns (12), (16), (17) and (18), only A_1', A_2', A_3' and A_4' are unknown. These equations may be solved yieding

$$A_1' = X_m (D_1 - kD_2)[X_m(D_1 - kD_2 + k) \\ D_2 + D_1 - \mu_r D_2].H_{ex} g / \mu_r^2 kD_2 + [(D_1 - kD_2) \\ X_m - \mu_r]\cdot[X_m (D_1 - kD_2 + k) D_2 + D_1] \tag{20}$$

and

$$A_4' = \frac{a_e b_e^2 H_{ex} X_m}{P_1 g^2}\left[\quad \mu_r \quad \right] \tag{21}$$

where

$$X_m = \mu_r - \qquad k = \frac{a_i b_i^2}{a_e b_e^2}, \qquad N = 1 - k$$

The magnetic field intensity inside the shell (section I) is given by the expression:

$$H_i = -\frac{\partial \varphi_1}{\partial x} = -\frac{\partial}{\partial x}[-H_{ex} g ch(u)\cdot \cos(v) \\ + A_1' ch(u) \cdot \cos(v)] \\ = H_{ex} - \frac{A_1'}{g}$$

Screen factor

$$P_1 = \frac{H_{ex}}{H_i} \\ = 1 + \frac{X_m}{\mu_r}\{\mu_r D_2 N - (D_1 - kD_2)(1 + X_m D_2)\} \tag{22}$$

From Eqn (9), A_4' is known and it gives rise to the field intensity:

$$\vec{H}_x = H_{xx}\vec{i} + H_{yx}\vec{j} + H_{zx}\vec{k}$$

where

$$H_{xx} = -\frac{\partial \varphi_3'}{\partial x} \qquad H_{yx} = -\frac{\partial \varphi_3'}{\partial y} \qquad H_{zx} = -\frac{\partial \varphi_3'}{\partial z}$$

In Eqn (9), φ_3' is expressed in terms of the spheroidal coordinate system, so the partial derivative of φ_3 wrt x,y,z cannot be calculated directly. However, it is noted that

$$\left.\begin{aligned} \frac{\partial \varphi_3'}{\partial u} &= \frac{\partial x}{\partial u}\cdot\frac{\partial \varphi_3'}{\partial x} + \frac{\partial y}{\partial u}\cdot\frac{\partial \varphi_3'}{\partial y} + \frac{\partial z}{\partial u}\cdot\frac{\partial \varphi_3'}{\partial z} \\ \frac{\partial \varphi_3'}{\partial v} &= \frac{\partial x}{\partial v}\cdot\frac{\partial \varphi_3'}{\partial x} + \frac{\partial y}{\partial v}\cdot\frac{\partial \varphi_3'}{\partial y} + \frac{\partial z}{\partial v}\cdot\frac{\partial \varphi_3'}{\partial z} \\ \frac{\partial \varphi_3'}{\partial w} &= \frac{\partial x}{\partial w}\cdot\frac{\partial \varphi_3'}{\partial x} + \frac{\partial y}{\partial w}\cdot\frac{\partial \varphi_3'}{\partial y} + \frac{\partial z}{\partial w}\cdot\frac{\partial \varphi_3'}{\partial z} \end{aligned}\right\} \tag{25}$$

and from Eqns (1) and (9), one can obtain the partial derivatives of x,y,z,φ_3' wrt u,v,w. Therefore, in Eqn (25) only $\partial\varphi_3'/\partial x$, $\partial\varphi_3'/\partial y$ and $\partial\varphi_3'/\partial z$ are unknown. These equations are actually a linear equation set and can be resolved with Cramer's Theorem. Then solution leads to the following expressions for the induced field components:

$$\left.\begin{aligned} H_{xx} &= -A\left(\frac{1}{2g^3} ln \frac{a_k + g}{a_k - g} - \frac{a_k}{g^2 T}\right) \\ H_{yx} &= A\frac{xy}{a_k b_k^2 T} \\ H_{zx} &= A\frac{xz}{} \end{aligned}\right\} \tag{26}$$

where

$$A = A_4' g^2 = \frac{a_e b_e^2 H_{ex} X_m}{P_1}\left\{N - \frac{X_m}{\mu_r}(D_1 - kD_2)\right\} \tag{27}$$

$$T = \sqrt{(x^2 + y^2 + z^2 + g^2)^2 - 4g^2 x^2} \tag{28}$$

and

$$a_k = \sqrt{(x^2+y^2+z^2+g^2+T)/2}$$

$$b_k = \sqrt{a_k^2 - g^2} \tag{29}$$

If the shell is magnetised along the minor axis, Y (or Z) by the geomagnetic field, a field solution can be obtained using a similar procedure and the resulting field components are:

$$\left.\begin{aligned} H_{xy} &= B\frac{xy}{a_k b_k^2 T}, \qquad H_{xy} = B\frac{a_k yz}{b_k^4 T} \\ H_{yy} &= -\frac{B}{2}\left(\frac{a_k}{g^2 b_k^2} - \frac{1}{2g^3}\ln\frac{a_k+g}{a_k-g} - \frac{2a_k y^2}{b_k^4 T}\right) \end{aligned}\right\} \tag{30}$$

and

$$\left.\begin{aligned} H_{xz} &= C\frac{xz}{a_k b_k^2 T}, \qquad H_{yz} = C\frac{a_k yz}{b_k^4 T} \\ H_{zz} &= -\frac{C}{2}\left(\frac{a_k}{g^2 b_k^2} - \frac{1}{2g^3}\ln\frac{a_k+g}{a_k-g} - \frac{2a_k z^2}{b_k^4 T}\right) \end{aligned}\right\} \tag{31}$$

where

$$B = \frac{a_e b_e^2 H_{ey} X_m}{P_2}\left\{N - (D_3 - kD_4)\frac{X_m}{\mu_r}\right\} \tag{32}$$

and

$$C = \frac{a_e b_e^2 H_{ez} X_m}{P_2}\left\{N - (D_3 - kD_4)\frac{X_m}{\mu_r}\right\} \tag{33}$$

H_{ey} and H_{ez} are the geomagnetic field intensities along Y and Z-axes, respectively. Screen factors are

$$P_2 = 1 + \frac{X_m}{\mu_r}\{\mu_r D_4 N - (D_3 - kD_4)(1 + X_m D_4)\} \tag{34}$$

$$D_3 = \frac{1}{2\varepsilon_i^2}\left(1 - \frac{1-\varepsilon_i^2}{2\varepsilon_i}\ln\frac{1+\varepsilon_i}{1-\varepsilon_i}\right) \tag{35}$$

$$D_4 = \frac{1}{2\varepsilon_e^2}\left(- \frac{1-\varepsilon_e^2}{2\varepsilon_e}\ln\frac{1+\varepsilon_e}{1-\varepsilon_e}\right) \tag{36}$$

Comparing Eqn (32) with Eqn (33), Eqn (13) with Eqn (35), and Eqn (19) with Eqn (36), it yields:

$$C = \frac{H_{ex}}{\cdot\cdot}B, \quad D_3 = \frac{1-D_1}{2} \quad D_4 = \frac{1-D_2}{2} \tag{37}$$

If the geomagnetic field is neither along the major axis of the shell nor the minor axis, it can be resolved into three components, one along the major axis, two along the minor axis as

$$\vec{H} = H_{ex}\vec{i} + H_{ey}\vec{j} + H_{ez}\vec{k}$$

Then the components of the induced field intensity can be obtained. The total induced field intensity is:

$$\begin{aligned} \vec{H} &= H_x\vec{i} + H_y\vec{j} + H_z\vec{k} \\ &= H_{xx} + H_{xy} + H_{xz})\vec{i} + (H_{yx} + H_{yy} + H_{yz})\vec{j} \\ &\quad + (H_{zx} + H_{zy} + H_{zz})\vec{k} \end{aligned} \tag{39}$$

3. EXAMPLE

A tank measures 6 m (long), 2.64 m (wide) and 1.72 m (high) on an average. Its armour steel is 0.08 m thick on both sides and has a relative permeability, $\mu_r = 220$. It is taken to lie from south to north near Beijing in China, where the horizontal and the vertical components of the geomagnetic field intensity are 300 mo_e and 450 mo_e, respectively. The induced field intensity is computed 3.5 m from the centre of the tank (in front on the ground).

The tank is taken as a spheroidal shell. Its equivalent radius of maximum cross-section are:

$r = \sqrt{1/\pi \times 1.72 \times 2.64} = 1.2$ m, then

$a_e = 3.0$ m, $b_e = 1.2$ m

$g = \sqrt{3^2 - 1.2^2} = 2.74$ m

$\varepsilon_e = 2.74/3 = 0.913$

$b_i = 1.2 - 0.08 = 1.12$ m

$a_i = \sqrt{1.122 + 2.742} = 2.96$ m

$\varepsilon_i = 2.74/2.96 = 0.925$

One calculates the following expression

$$D_2 = \frac{1-0.913^2}{0.913^2}\left(\frac{1}{2\times0.913} ln \frac{1+0.913}{1-0.913}\right) = 0.138$$

$$D_1 = 0.127$$

$$P_1 = 1+\frac{219}{220}[220 \times 0.138 \times 0.141 - (0.127-0.859\times0.138)(1+219\times0.138] = 5.035$$

$$k = \frac{2.96\times1.12^2}{3\times1.6^2} = 0.859$$

$$N = 1-0.859 = 0.141$$

$$X_m = 220-1 = 219$$

$$D_4 = \frac{1-0.138}{2} = 0.431$$

$$D_3 = \frac{1-0.127}{2} = 0.4365, \text{ and}$$

$$P_2 = 8.08$$

Because the tank lies from south to north, the coordinate system is taken as shown in Fig. 2.

From Eqns (27) and (33), one calculates the following expression:

$$A = 7541.8\,\mathrm{mo_e}\cdot m^3, \quad C = -3989.5\,\mathrm{mo_e}\cdot m^3$$

Taking the centre of the tank to be the origin, the coordinates of the point to be calculated is (3.5, 0,–1.2), thus

$$T = \sqrt{[3.5^2 + 0 + (-1.2)^2 + 2.74^2]^2 - 4\times2.74^2\times3.5} = 9$$

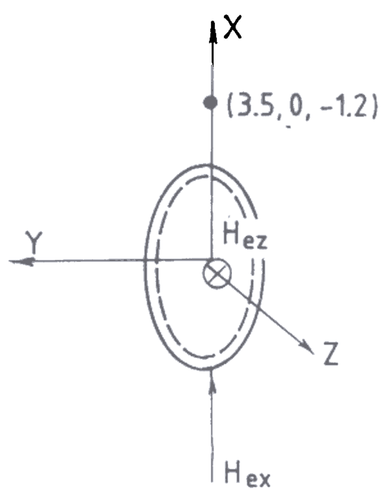

Figure 2. Schematic diagram of tank as situated in coordinate system.

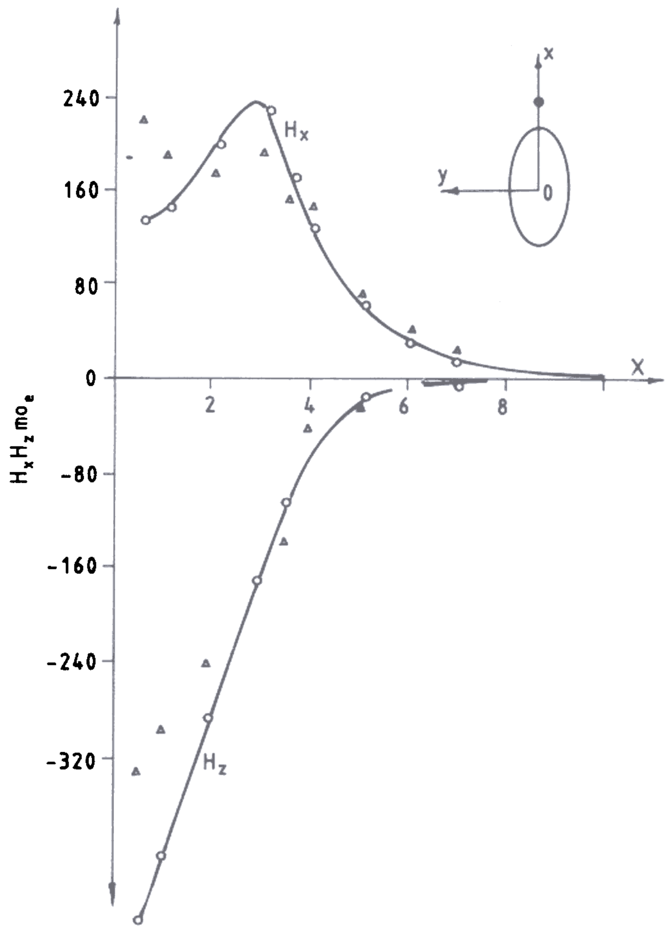

Figure 3. H_x, H_z — x curves at $y = 0$, $z = -1.2$; o — calculated by the derived solution; Δ—measured with a magnetometer.

and

$$a_k = 3.889, \quad b_k = 2.75$$

From Eqns (6), (31) and (39), one obtains H_{xx} = 113.13 mo$_e$, H_{zx} = – 119.58 mo$_e$, H_{zz} = 8.2 mo$_e$, H_{xz} = 63.25 mo$_e$; $\vec{H}_p$ = 176.38 $\vec{i}$ + (–111.38) $\vec{k}$, $|\vec{H}_p|$ = 208.6 mo$_e$.

The induced field intensities at other points can be calculated in a similar manner. In Fig. 3, the field intensities H_x and H_z are plotted as a functin of x for points on the ground in front of the tank (y = 0, z = – 1.2) with the tank facing north. In Fig. 4, a similar plot is shown for points over and in front of the tank facing north (y = 0, z = 1.2). In Figs 5 and 6, plots are shown of H_x, H_y, H_z as a function of y at the left side of the tank facing north (x = 0, z = ±1.2).

Since the spheroidal shell is symmetrical wrt both the major and the minor axes, it is easy to

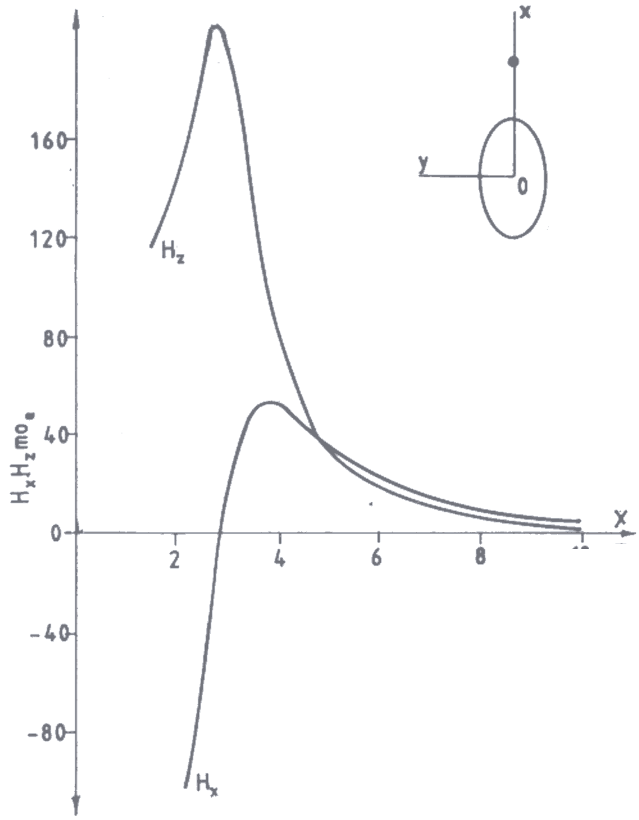

Figure 4. H_x, H_z ·x curves at $y = 0, z = -1.2$

derive the induced field intensity for the right side or back of the tank. For example, the induced intensity on the ground and at the right side of the tank facing north is similar to that on the ground and at the left side of the tank facing south. But it must be noted that the plus or the minus sign of the induced intensity are all relative to the direction of the coordinate axes. Comparing the tank facing south to the tank facing north, the positive direction of X-axis is just opposite, the positive direction of Y-axis, too. If both H_x are different in plus-minus sign, which indicate just that directions of both H_x are the same.

Because the measurements of the spheroidal shell in major and minor axes are different, the points are expressed in the same value of coordinate, their distance from the shell are different. For the purpose of comparing values of induced intensity in front, back or both sides and at the same distance from the shell, Fig. 7 is given. In this figure, the abscissa $d = x$ or y $+ (a_e - b_e)$. Curve 1 is on the ground, in front of the tank facing north;

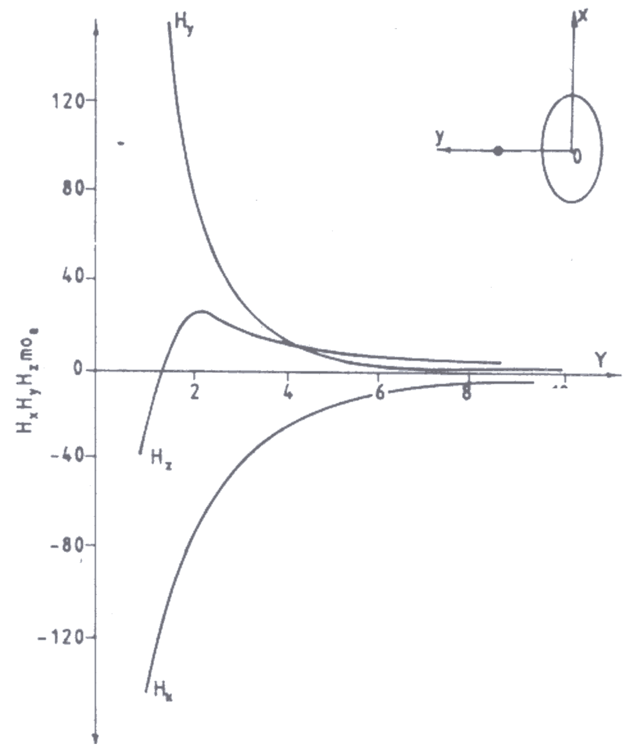

Figure 5. H_x, H_y , H_z y curves at $x = 0, z = -1.2$

or over and in front of the tank facing south. Curve 2 is over and in front of the tank facing north; or on the ground, in front of the tank facing south. Curve 3 is on the ground, at the left side of the tank facing east; or over and at the left side of the tank facing west. Curves 4 is over and at the left side of the tank facing east; or on the ground, at the left side of the tank facing west. Curve 5 is in front or at the back of the tank facing east, or west. Curve 6 is the induced intensity of both sides of the tank facing

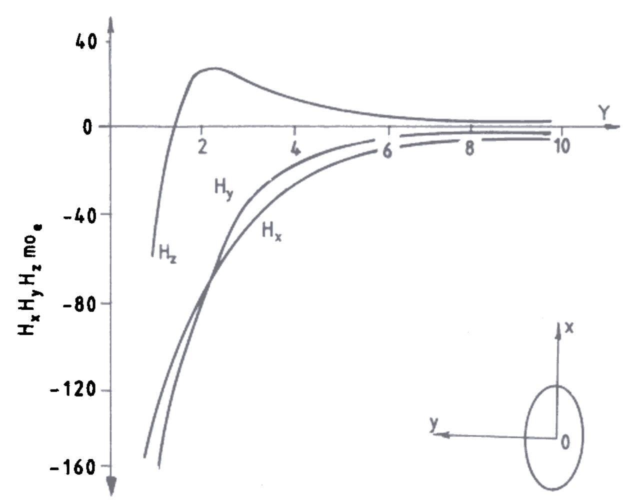

Figure 6. H_x, H_y , H_z ·y curves at $x = 0, z = 1.2$

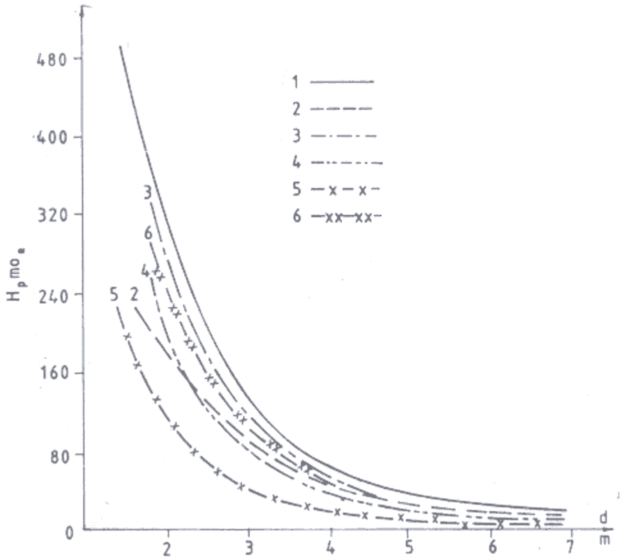

Figure 7. Induced magnetic field intensity H_p versus d, where $d = x$ or $d = y + (a_e - b_e)$.

north or south. Comparing these curves, it is observed that when a tank is facing north or south, the induced field intensity is the strongest on the ground at the north side or at the south side of the tank. When facing west or east, it is the weakest in front or at the back of the tank. It is also observed that the induced intensity in the point which is 1 m from the tank is about 120 mo$_e$ when the tank is facing south or north, and about 40 mo$_e$ when the tank is facing west or east.

4. CONCLUSION

There is no reference material for calculating the magnetic field induced around a tank. In this paper, a tank is taken to be a hollow spheroidal shell and analytic equations are derived for the induced field intensity. For inspecting the accuracy of the derived solution, it was the measurement for the magnetic field induced around a tank that was carried out with a magnetometer, which is the type DCH–1 and made in China. The values of the induced field intensity H_x and H_z measured with the magnetometer at some points and calculated by the derived solution are correspondingly shown in Fig. 3. This figure shows that the derived solution is more accurate for points far away from the tank, but it yields considerable error for points close to he tank. Whether magnetic fuse mine or artillery shell must have a time delay from magnetic fuse being affected by a magnetic field induced around a tank to initiating. Both the tank and the artillery shell are moving bodies, the tank and the mine, or the artillery shell and the tank will be nearer in the above-mentioned time delay. In addition, for increasing armour-penetrating depth, it is desirable that the mine or the artillery shell activates tens of centimeter from the tank. It is thus clear that the value of the induced field intensity at that point which is tens of centimeter from a tank is most significant. Therefore, the method given for calculating induced field intensity has reference value.

REFERENCES

1. Sun Qi. Development plan of land mine in England. *Modern Weapon,* 1984, **12**, 1109-115.

2. Zhang Qiuguang. On field. Geology Publishing House, Beijing, China, 1983. pp. 119-29.

3. Huang Keou. Advanced Engineering Math. China Railway Publishing House, 1982. pp. 165-75.