Simulating magnetic field of a ferromagnetic pipe underwater in COMSOL Multiphysics

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Abstract. Nowadays ecological situation in seas and oceans requires permanent supervision and control. Carrying out building activity such as building hydraulic structures, oil- and gas-pipes in areas of past warfare is the reason for the active usage of geophysical methods to search method of the objects underwater. The paper examines the classification of magnetic search methods and theoretical base statements of electromagnetics. The work represents the investigation of an object influence on geomagnetic field in problem-solving environment "COMSOL Multiphysics". The article also contains the results of simulating for variations of different object parameters. This paper is connected with the magnetometric

1. Introduction

Nowadays ecological situation in seas and oceans requires permanent supervision and control. Carrying out building activity such as building hydraulic structures, oil- and gas-pipes in areas of past warfare is the reason for the active usage of geophysical methods to supply safety and environmental security. So, there is the topical problem of developing precise methods and means for search, supervision and investigation of underwater pipelines, cables and other objects [1-6].

As a rule, these objects are made of ferromagnetic materials and as they are in the magnetic field of the Earth they influence it, thus, creating magnetic anomalies. Underwater search means need this information.

There are two types of search magnetic methods: active and passive. Active methods consist of the inductive method that performs the search of metal objects and the radio-locating method that performs the search of both metal and nonmetal objects. Passive method is the magnetometric method that allows to estimate the geomagnetic field distortions induced by ferromagnetic objects and magnetic field sources.

2. Magnitometric method

If current passes not through an object the object location can be determined via magnetic flux density measurement. Magnetic flux density depends on the object size and the distance on it. It is necessary to know the character of magnetic flux density variations to create precise search means.

Modelling such conditions is available with the help of program environment "COMSOL Multiphysics" (COMSOL). Calculations of magnetic fields in COMSOL are based on Maxwell equations [7]:

$$\oint \bar{E}dl = -\int \frac{\partial \bar{B}}{\partial t} dS,$$
$$\oint \bar{D}dS = \int \rho dV,$$
$$\oint \bar{H}dl = \int \left(j + \frac{\partial \bar{D}}{\partial t} \right) dS, \quad (1)$$
$$\oint \bar{B}dS = 0,$$

where $\bar{H}$ – the magnetic field vector, $\bar{B}$ – the magnetic flux density vector, $\bar{D}$ – the bias current vector, ρ – the volume density of exterior charges, j – the current density, S – the surface square, l – the distance.

Except Maxwell equations the system of equations for electromagnetic fields includes the material equation. The material equation in its simple form has the following view (2):

$$B = \mu_0 \mu_r H \,, \quad (2)$$

where B – the material magnetic flux density, T; μ_0 – the vacuum magnetic permeability H/m, μ_r – the medium (material) relative magnetic permeability.

The object magnetic field can be defined by the following more complete relation (3) [8]:

$$B_x = \frac{B_i V}{4\pi x^3} \,, \quad (3)$$

where B_x – the object magnetic flux density, T; B_i - the material internal flux density, T; x – the distance to the object, m.

The material internal flux density B_i is determined by the formula (4) [3]:

$$B_i = (\mu_r - 1) B_E \,, \quad (4)$$

where B_E – the value of the ambient flux density equal to 50 mkT.

3. Modelling

It was a ferromagnetic pipe in water simulated in COMSOL to investigate the theoretical dependence (3) and the object magnetic field dependence on its geometric parameters and the relative magnetic permeability of pipe material. The model consists of the ferromagnetic hollow cylinder (pipe) and the sphere that imitates water space. Modelling process includes the following steps: Geometry building, material assignment, the application of Physics, partitioning into the finite elements, calculations and visualization of the results.

3.1. Geometry building

Geometry building was implemented with the function "Work Plane". Two cylinders of different diameters were created to simulate the pipe. The pipe thickness was assumed equal to 1 % of the external diameter and the length was chosen equal to 10 m. The first meaning of the external pipe diameter D_1 was defined as 1 m. The internal pipe diameter D_2 was assumed equal to 0.98 m, then. Three-dimensional imagine of the observed pipe geometry is shown in figure 1.

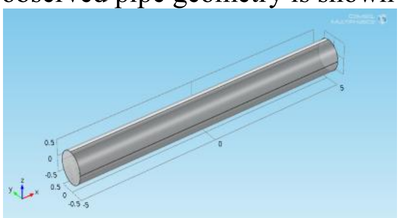

Figure 1. Pipe Geometry.

To calculate the magnetic field induced by the pipe it was necessary to place it into the sphere that simulates water space. The sphere was created around the pipe and had the diameter equal to 10 m. The model of the pipe in sphere water space is presented in figure 2.

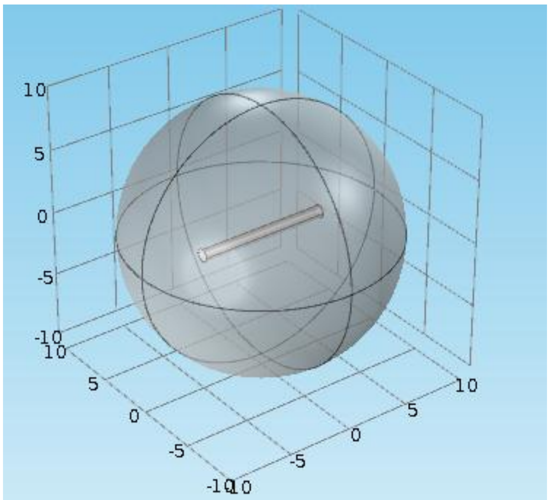

Figure 2. Model Geometry.

3.2. Material assignment
Material assignment in COMSOL is carried out via “Material Browser”. It is convenient for quick system simulating with the real characteristics. The pipe material was defined as “Iron” and the sphere material – as “Water”. User can define the relative magnetic permeability for some materials in the category “Material Contents”. The initial value of magnetic permeability for iron was defined as $\mu_r = 1000$. Relative magnetic permeability for water is equal to 1.

3.3. The Application of Physics
The function “Magnetic Flux Density” in the category “Magnetic Fields, No Currents” allows assigning the value of the background magnetic field and the one of the magnetic field of the object. Background magnetic field corresponds to the geometric field of the Earth and is equal to 50 mkT along the axis z and zero values along the axes x and y. Magnetic field of the pipe is determined through the relative magnetic permeability μ taken from the information about material.

3.4. Partitioning into the finite elements
The model partitioning into the finite elements was carried out after Geometry building, material assignment and the application of Physics. Two types of mesh with different element size were used for partitioning. “Coarser” mesh was chosen with the maximum element size 3.8 m and the minimum element size 0.8 m for the sphere. “Normal” mesh was chosen with the maximum element size 2 m and the minimum element size 0.36 m for the pipe.

3.5. Visualization of the modelling results
Visualization of simulating results after calculations is implemented with the help of the category “Results”. Firstly, it was necessary to create the *zx*-plane for mapping the distribution of magnetic flux density near the pipe. Secondly, we chose the expression for the magnetic flux density absolute magnitude: “mfnc.normB”. Figure 3 demonstrates the distribution of magnetic flux density along *zx*-plane.

The graph of magnetic flux density dependence on the distance to the pipe (along the axis z) was also built in (figure 4). The expression for magnetic flux density variation in per cent in COMSOL has the following view: “((mfnc.Bz+50e-6)/50e-6)*100”.

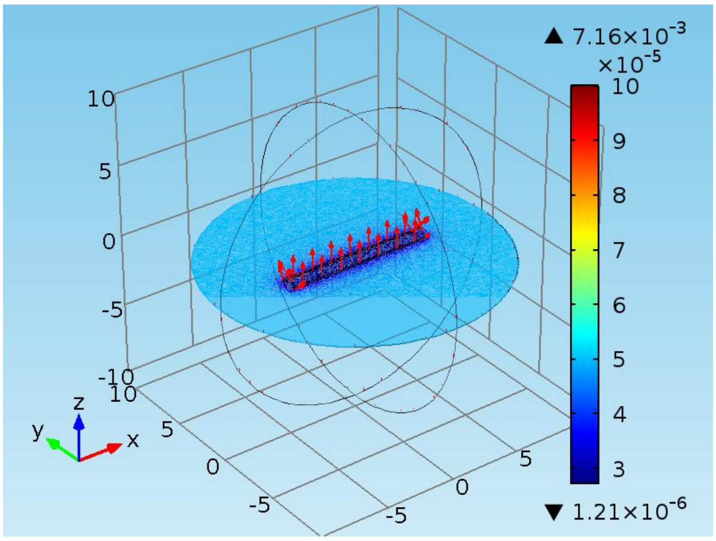

Figure 3. Distribution of magnetic flux density.

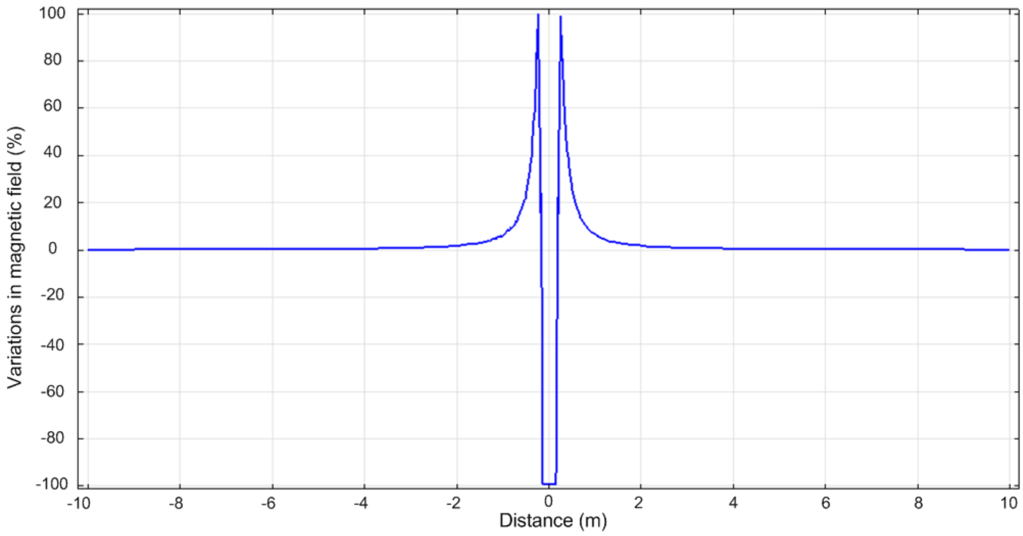

Figure 4. Magnetic flux variation.

The graph in figure 4 demonstrates that the magnetic field near the pipe doubles. While the distance to the pipe increases the magnetic field variation decreases. Thus, the magnetic field variation is equal to zero with the distance of 4 m.

4. Model investigation

Magnetic flux variation was also calculated in the program "Mathcad" with the theoretic formula (3). Magnetic field variation in per cent γ was evaluated by the formula (5), then:

$$\gamma = \frac{\left((B_x + B_E) - B_E\right)}{B_E} \cdot 100\,\% \tag{5}$$

The calculating results are represented graphically in figure 5.

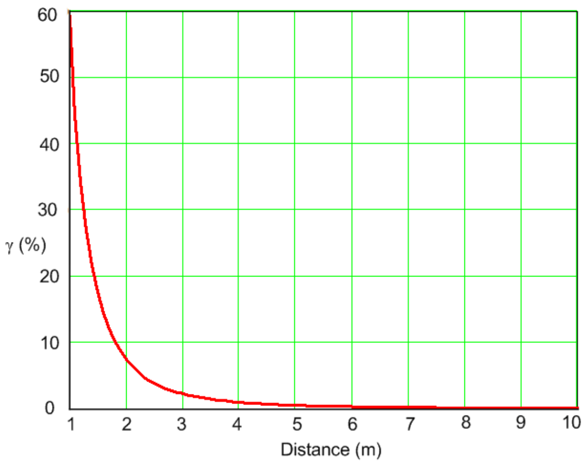

Figure 5. Magnetic flux density variation in “Mathcad”.

It is evident that the theoretical law (figure 5) and the practical law (figure 4) are similar. The table 1 compares the meanings of the laws according to different *z*-coordinates.

Table 1. The theoretical and practical values of magnetic flux density variation.

z-coordinate (m)	The theoretical value of magnetic flux density variation (%)	The modelling value of magnetic flux density variation (%)
1.5	18.5	12
3.0	2.3	2.8
5.0	0.5	0.7

The results obtained by the formula (5) and by the simulating are nearly identical. Thus, it can be said that the computer model of the pipe under water is adequate and can be used to evaluate magnetic field variations.

It is interesting to establish the magnetic field variation dependence on pipe geometric parameters (diameter, length) and the relative magnetic permeability of pipe material.

The pipe length took the values from 1 to 10 m. There were observed the graphs of magnetic flux density variations for each case. All the graphs have similar view as shown in figure 4 and contain not completely different meanings of variation.

The next step was the variation of pipe diameter. Diameter variation range was from 0.5 m to 1.5 m. The graphs observed for the diameters and equal to 0.5 m and to 1.5 m are presented in figure 6 and figure 7.

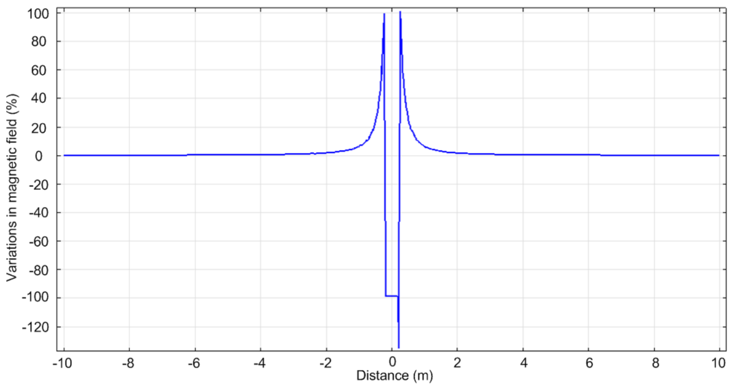

Figure 6. Magnetic flux density for pipe diameter 0.5 m

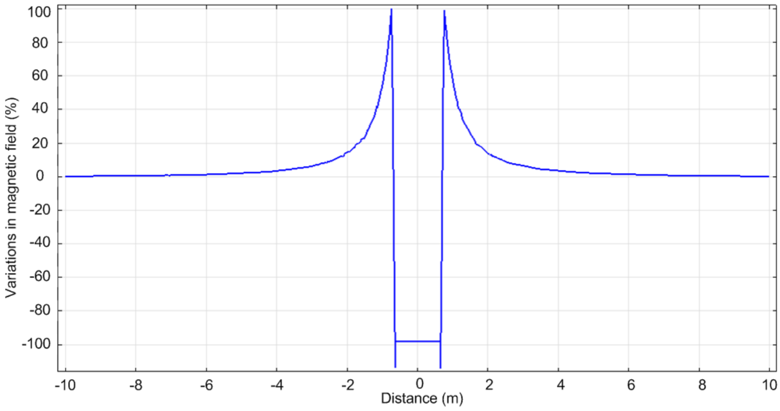

Figure 7. Magnetic flux density for pipe diameter 1.5 m

The comparison of the graphs makes it possible to conclude the following: while the diameter increases the magnetic flux density variation increases, too. For example, the magnetic flux density variation with the distance 1.5 m (x-coordinate is equal to 2 m) for diameter equal to 0.5 m is 1 % or ≈500 nT. Magnetic flux density variation equal to 1 % for diameter 1.5 m corresponds to the distance 5.25 m (x-coordinate is equal to 6 m). Consequently, the distance of magnetic field variation with 1 % increases by a factor of three as the diameter increases in three times. So, direct dependence between diameter and distance is observed.

5. Conclusion

Simulating results make it possible to conclude the following: Earth geomagnetic field variations increase with the object diameter increase because of the influence of the object and they do not depend on the length or relative magnetic permeability of the material for the object. Magnetic field variation near the object directly depends on its diameter.

Acknowledgments

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