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Susanne Jakob
Dipl.-Ing. Helge Drumm

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T. Chervenkova

Stability of Solution of Inverse Problems for Identification of Moving Charges

INTRODUCTION

Investigation of stability by the solution of inverse problem for identification of moving charges is proposed in this paper.

The cases by solution of inverse problems for identification of moving concentrated charge and moving electrical dipole are considered.

The numerical procedure for investigation of stability is used.

THEORETICAL BACKGROUND

The works [1] and [2] are dedicated to the inverse problem for identification of moving charges. In [1] the case of identification of moving concentrated charge is considered. In [2] the case of identification of moving electrical dipole is considered.

The technique for solving includes following stages.

I. Determination of electric field

The four-dimensional magnetic potential $\vec{\Psi}'_{(\mu)}$ in moving co-ordinate system is obtained first. It is introduced as

$$\vec{\Psi}'_{(\mu)} = \left\{ A'_{\mu\, x}, A'_{\mu\, y} A'_{\mu\, z}, \frac{j}{c}\varphi'_{\varepsilon} \right\}, \qquad (1)$$

where $A'_{\mu x}, A'_{\mu y}, A'_{\mu z}$ are components of the magnetic vector-potential $\vec{A}_{\mu}$ along x- , *y-* , *z-* axes, respectively and φ'_{ε} is a scalar electric potential.

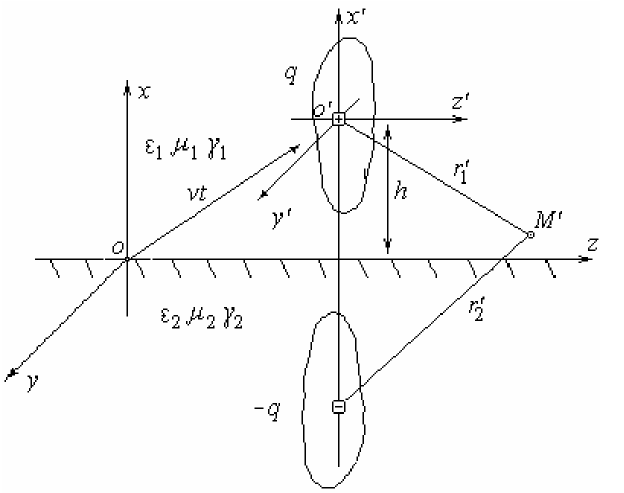
The method of mirror image is used, which has potentiality for application of the basic relations in Minkowski's space, valid for homogeneous medium.

Lorenz's transformations for the coordinates (2) and the electromagnetic potentials (3) are used

$$x' = x \ , \ y' = y \ , \ z' = \alpha(z - v\,t)\,, \ t' = \alpha\left(t - \frac{v}{c^2} z\right) \qquad (2)$$

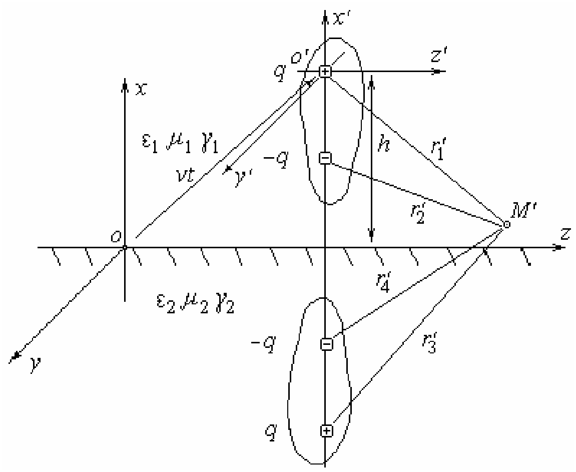
$$A'_{\mu x'} = A_{\mu x} \ , \ A'_{\mu y'} = A_{\mu y} \ , \ A'_{\mu z'} = \alpha\left(A_{\mu z} - \frac{v}{c^2}\varphi_\varepsilon\right), \ \varphi'_\varepsilon = \alpha(\varphi_\varepsilon - vA_{\mu z}) \qquad (3)$$

The coordinates of the equivalent electric charges, presented as concentrated electric charge and as electric dipole can be accepted as coordinates of the exciters of electromagnetic field, presented in Fig.1 and fig.2, respectively. The electric charge and electric dipole are moving in plane, parallel to YOZ - one with velocity $v = const$.



Model of moving concentrated electric charge

Figure 1



Model of moving electric dipole

Figure 2

The upper semi-space (for example the atmosphere) has electromagnetic characteristics $\varepsilon_1 , \mu_1 , \gamma_1$ and the lower semi-space (for example the Earth) is characterized by $\varepsilon_2 , \mu_2 , \gamma_2$. Here the case in which $\varepsilon_1 = \varepsilon_0 , \mu_1 = \mu_0 , \gamma_1 = \gamma_0$ and $\varepsilon_2 = \varepsilon_0\,\varepsilon_r , \mu_2 = \mu_0 , \gamma_2 \approx 0$ is considered.

For example in case for moving electrical dipol we get

$$\vec{\Psi}_\mu = \left\{ \begin{array}{c} \Psi_{\mu 1} = A_{\mu x} = 0 \\ \Psi_{\mu 2} = A_{\mu y} = 0 \\ \Psi_{\mu 3} = A_{\mu z} = \alpha\,\mu_0\,v\dfrac{q}{4\pi}\left[\left(\dfrac{1}{r_1} + \dfrac{\varepsilon_0 - \varepsilon_2}{\varepsilon_0 + \varepsilon_2}\dfrac{1}{r_3}\right) - \left(\dfrac{1}{r_2} + \dfrac{\varepsilon_0 - \varepsilon_2}{\varepsilon_0 + \varepsilon_2}\dfrac{1}{r_4}\right)\right] \\ \Psi_{\mu 4} = \dfrac{j}{c}V_\varepsilon = \dfrac{j}{c}\dfrac{q}{4\pi\,\varepsilon_0}\left[\left(\dfrac{1}{r_1} + \dfrac{\varepsilon_0 - \varepsilon_2}{\varepsilon_0 + \varepsilon_2}\dfrac{1}{r_3}\right) - \left(\dfrac{1}{r_2} + \dfrac{\varepsilon_0 - \varepsilon_2}{\varepsilon_0 + \varepsilon_2}\dfrac{1}{r_4}\right)\right] \end{array} \right\}, \qquad (4)$$

where: $r_1 = \sqrt{[x_1 - (x - v_x t)]^2 + [y_1 - (y - v_y t)]^2 + [z_1 - (z - v_z t)]^2}$;

$r_2 = \sqrt{[x_1 - l - (x - v_x t)]^2 + [y_1 - (y - v_y t)]^2 + [z_1 - (z - v_z t)]^2}$;

$r_3 = \sqrt{[x_3 - (x - v_x t)]^2 + [y_2 - (y - v_y t)]^2 + [z_2 - (z - v_z t)]^2}$;

$r_4 = \sqrt{[x_3 - l - (x - v_x t)]^2 + [y_2 - (y - v_y t)]^2 + [z_2 - (z - v_z t)]^2}$;

$\alpha = \dfrac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}}$ is the relativity factor and c is the free-space light velocity ($c \approx 3 \times 10^8\ m/s$).

The components of the electrical field $\{E_j\} = \{E_x, E_y, E_z\}$ are associated with the Maxwell's tensor $F_{i,k}^{(\mu)}$ [2, 4].

For example in the considered case of identification of moving electrical dipole for componennts of electrical field we get [2]

$$\vec{E} = \left\{ \begin{array}{l} E_x = -\dfrac{q}{4\pi\varepsilon_0}\left[\begin{array}{l} \dfrac{x_1 - (x - v_x t)}{r_1^3} + \dfrac{\varepsilon_0 - \varepsilon_2}{\varepsilon_0 + \varepsilon_2}\dfrac{x_1 - l + (x - v_x t)}{r_3^3} - \\ - \dfrac{x_3 - (x - v_x t)}{r_2^3} + \dfrac{\varepsilon_0 - \varepsilon_2}{\varepsilon_0 + \varepsilon_2}\dfrac{x_3 - l + (x - v_x t)}{r_4^3} \end{array} \right] \\ E_y = -\dfrac{q}{4\pi\varepsilon_0}\left[\begin{array}{l} \dfrac{y_1 - (y - v_y t)}{r_1^3} + \dfrac{\varepsilon_0 - \varepsilon_2}{\varepsilon_0 + \varepsilon_2}\dfrac{y_1 + (y - v_y t)}{r_3^3} - \\ - \dfrac{y_3 - (y - v_y t)}{r_2^3} + \dfrac{\varepsilon_0 - \varepsilon_2}{\varepsilon_0 + \varepsilon_2}\dfrac{y_3 + (y - v_y t)}{r_4^3} \end{array} \right] \\ E_z = -\dfrac{q}{4\pi\varepsilon_0}\left[\begin{array}{l} \dfrac{z_1 - (z - v_z t)}{r_1^3} + \dfrac{\varepsilon_0 - \varepsilon_2}{\varepsilon_0 + \varepsilon_2}\dfrac{z_1 + (z - v_z t)}{r_3^3} - \\ - \dfrac{z_3 - (z - v_z t)}{r_2^3} + \dfrac{\varepsilon_0 - \varepsilon_2}{\varepsilon_2 + \varepsilon_2}\dfrac{z_3 + (z - v_z t)}{r_4^3} \end{array} \right] \end{array} \right\} \tag{5}$$

II. Solution of inverse problem

First the unknown quantities are determined. They are 6 in case of identification of moving electrical dipole, by moving along the z- axis [2].

For finding of solution the measurement values of electrical strength of electrical field E_x, E_y, E_z are substituted in the system of equations (5).

The solution of inverse problem is made with numerical procedure.

INVESTIGATION OF THE STABILITY

As the most inverse problems, the considered one is uncorrected by Hadamard [3]. The solution does not correspond to the necessary and sufficiently conditions of correctness, i.e. the solution to be exist, unique and stable.

The solutions of inverses problem for identification of moving concentrated electric charge and movind electrical dipole are made in [1] and [2]. They are satisfied the necessary condition of correctness.

The condition of unique solution can not be implemented at non-linear character of system of equations. The procedure of regularization in the case of absence of unique solution necessitates is used. It was realized on the basis of the optimization criterion [1, 2]

$$\min_{s} \sum_{k=1}^{p} \left(E_{js}^{(k)} - \hat{E}_{js}^{(k)} \right)^2 \quad ; \quad j = 1,2,3 \quad ; \quad s = 1,2,3,..,n \; ; \tag{6}$$

where: $\{E_j\} = \{E_1, E_2 E_3\} = \{E_x, E_y, E_z\}$; p is the number of unknown quantities; $E_{js}^{(k)}$ are the computed quantities and $\hat{E}_{js}^{(k)}$ are measured quantities.

A solution is chosen, which satisfies the optimization criterion (2).

On account of the availability of non-stable solution the numerical computations are made.

The relative electric permeability ε_{r2} of the lower semi-space is included as variable quantity.

I. Investigation of stability in the case of identification of moving concentrated electrical charge.

The values of the quantities: electrical charge q; coordinates x_1, z_1 of the moving charge, which satisfy the non-linear system, are searched.

The solution of the inverse problem with next input data is searched: coordinates of the observer - $x = 0$, $y = 0$, $z = 0$; velocity of charge toward to earth $v = 30\ m/s$; time for identification $t = 1\ s$; electrical permeability of upper semi-space $\varepsilon = \varepsilon_0$.

By numerical procedure with iteration of the permittivity of the lower semi-space ε_2 we investigate the problem of the stability of the solution for identification of moving charge.

The results for identification of electrical charge are represented in fig.3.

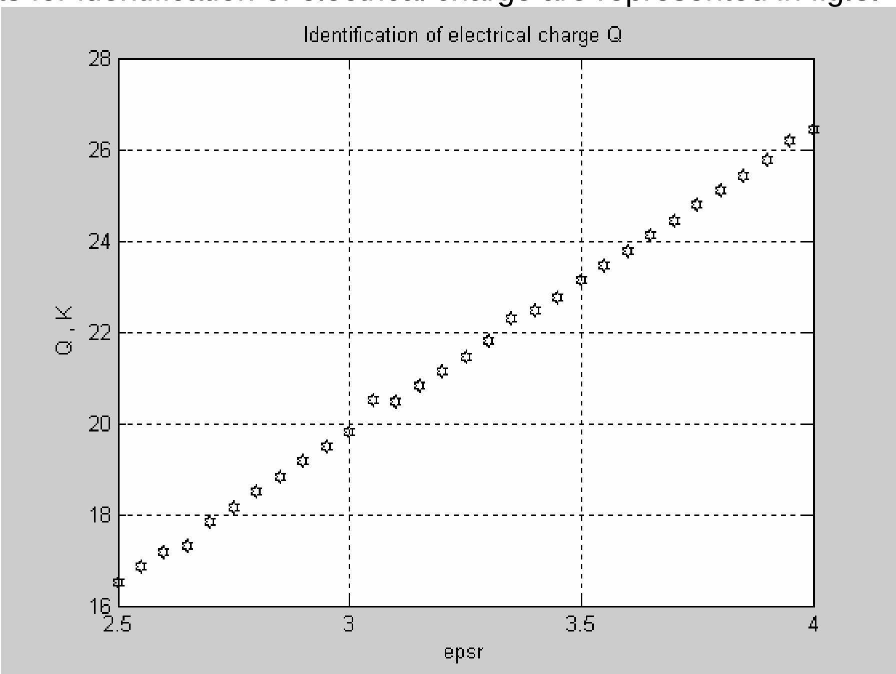


Figure 3

Numerical solution of an inverse problem for identification of moving charge show stability, because small changing of electrical permeability give small changing of searching charge.

II. Investigation of stability in the case of identification of moving electrical dipole

In case of moving of electrical dipole only in one direction, for example on axis *z*, the searched quantities, which satisfy the non-linear system (5), are 6:

- Value of the charge q;
- Distance between the charges in dipole l;
- Coordinate x (for example height over the Earth surface h) and other coordinates y, z;
- Velocity of movement v.

The solution of inverse problem is finding with the next data: the coordinates of observer are $x = 0$, $y = 0$, $z = 0$; time $t = 2\,s$; electrical permitivity of upper semi-space (for example atmosphere) $\varepsilon = \varepsilon_0$; electrical permeability of lower semi-space (for example Earth) - $\varepsilon = \varepsilon_r \varepsilon_0$.

By numerical procedure with iteration of the electrical permitivity of the lower semi-space ε_2 we investigate the problem of the stability of the solution for identification of moving dipole.

The results for identification of charge q of electrical dipole are represented in fig.4.

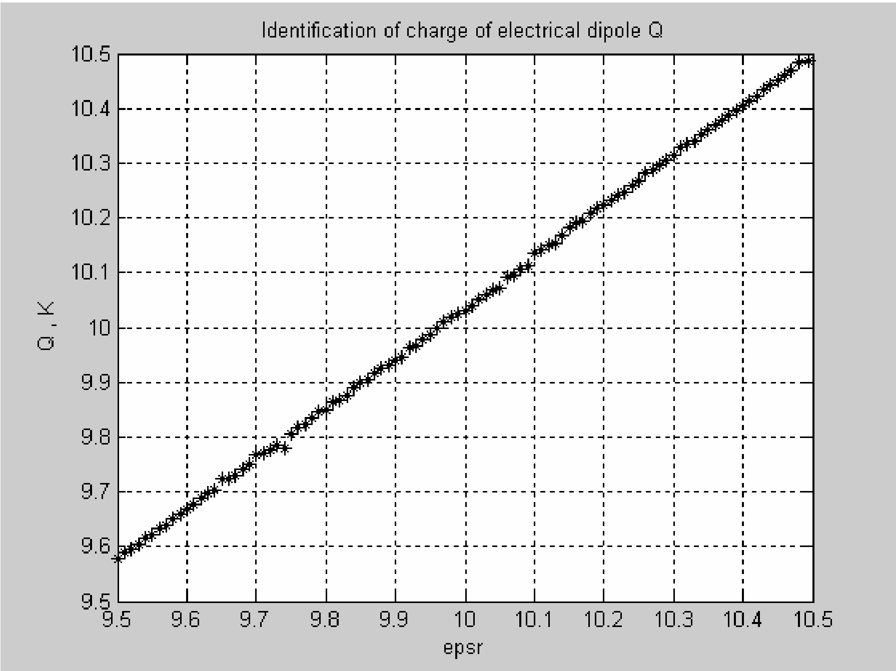


Figure 4

The numerical solution of an inverse problem for identification of moving dipole show stability also.

CONCLUSION

The solutions of inverse problem for identification of moving charge and moving electrical dipole are made numerically with a iteration procedure.

The average electrical permittivity of the lower semi-space ε_2 as a new quantity is included and this additionally give the decision of the stability by solution of inverse problem for identification of moving charges.

Numerical solution of an inverse problem for identification of moving charges show stability, because small changing of electrical permeability give small changing of searching charges of concentrated charge and electrical dipole i.e the third condition of Hadamard is implemented.

With this work the solution of the inverse problem of identification of moving electrical charge and moving electrical dipole is completed.

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Author:

Associate Professor PhD Todorka V. Chervenkova
Technical University of Sofia, Faculty of Engineering and Pedagogy-Sliven
8800, Sliven Bulgaria
Phone:+35944667313/ext.262/
Fax:+35944667505
E-mail: tvchervenkova@yahoo.com