# Simulation for a new-style electromagnetic current meter

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**Abstract.** In this paper, a new-style electromagnetic current meter is designed and simulated in order to accurately measure the velocity of the ocean currents. The distribution of the magnetic flux density, the velocity profile and the induced potential differences are simulated using finite element method. A linear relationship between induced potential differences and velocity of ocean currents is established after simulating. The order of magnitude of induced potential differences up to 10-3 V can be achieved.

**Keywords:** magnetic flux density; induced potential difference; Electromagnetic current meter; Ocean current.

## 1. Introduction

Electromagnetic current meters are a sort of instruments which have been used to measure the velocity of the ocean currents. They employ excitation coils or permanent magnets to produce magnetic fields. The seawater will incises the magnetic lines of force and generate an induced electromotive force when it moves in the magnetic fields. Velocity of the ocean currents can be obtained on the basis of the induced potential differences between electrodes [1-2].

Electromagnetic current meters play a significant part in oceanographic researches and marine investigations nowadays. In the past decades, great scientific progresses have been made in electromagnetic current meters. Spherical, discal and annular electromagnetic current meters have been manufactured [1, 3], And different electromagnetic current meters have different characteristics [1]. They have many virtues which are not possessed by other kinds of current meters: long useful life, high sensitivity, simple operational approach etc. The influence of their shapes on ambient flow field has also been taken into account. Their shape has been changed to reduce the influence, whereas the influence can't be eliminated completely by changing their shapes.

In order to accurately measure the velocity of the ocean currents using electromagnetic current meters, two new models are designed and a new method is employed to reduce measurement error in this paper. In this method, we use the unaffected velocity of ocean currents in the distance to calculate velocity profile in the neighborhood of the electromagnetic current meter, and then use the velocity profile to work out induced potential differences for the purpose of seeking relationship between velocity of ocean currents and induced potential differences between two sides of the meter. The result indicates that the induced potential differences between electrodes increase almost linearly with velocity of the ocean currents. And it can be expressed as a type of simple equations. The new-style electromagnetic current meter is portable and durable.

## 2. Basic theory of the electromagnetic current meter and models

### 2.1. Basic theory of electromagnetic current meters

The radical principle of electromagnetic current meters is the law of electromagnetic induction which was discovered by Michael Faraday. A piece of conductor moving in a magnetic field may generate an electromotive force which is perpendicular to the magnetic field and direction of the motion. The direction of electromotive force can be determined by right hand rule. Then there is an induced potential difference between its two ends. The motion of ocean currents in a magnetic field can also produce electromotive forces and induced potential differences because seawater is a kind of liquid conductor.

The distribution of the electric potential $U$ inside the electromagnetic current meter is given by a Poisson type equation [1, 4-7]

$$\nabla^2 U = \nabla \cdot (\vec{v} \times \vec{B}) \quad (1)$$

Where $\vec{B}$ the magnetic flux density is vector and $\vec{v}$ is the fluid velocity vector. If we assume that the conductivity and the magnetic field is uniform, the induced potential difference is described by the following equation [1, 7]

$$U_{AA'} = \int \vec{v} \times \vec{B} \cdot \mathrm{d}\vec{l} \quad (2)$$

Where $U_{AA'}$ and $\vec{l}$ are the induced potential difference and position vector of the conductor respectively. Here $U_{AA'}$ in this equation is independent of the electrical conductivity, viscosity and pressure of the conductor.

Because of the resistance from the meter shape in ocean current, the velocity in the neighborhood of the electromagnetic current meter will changed to some extent. In order to calculate induced potential differences between the two ends of the ocean currents, the velocity profile around the electromagnetic current meter should be given firstly. It can be solved using the unaffected velocity of ocean currents in the distance in fluid mechanics. After neglecting the effect of compression of the seawater, Navier-Stokes equation and the continuity equation are as follows [8]

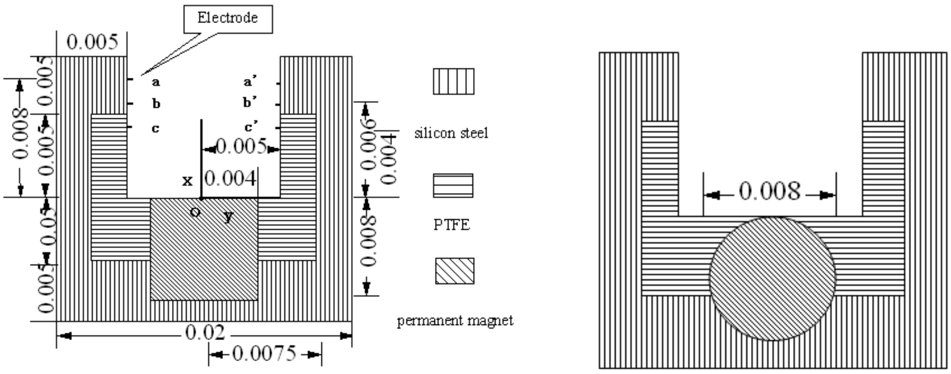
$$\begin{aligned}
&\rho \frac{Dv_x}{Dt} = \rho F_x - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 v_x}{\partial x^2} + \frac{\partial^2 v_x}{\partial y^2} + \frac{\partial^2 v_x}{\partial z^2}\right) \\
&\rho \frac{Dv_y}{Dt} + = \rho F_y - \frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v_y}{\partial x^2} + \frac{\partial^2 v_y}{\partial y^2} + \frac{\partial^2 v_y}{\partial z^2}\right) \\
&\rho \frac{Dv_z}{Dt} = \rho F_z - \frac{\partial p}{\partial z} + \mu\left(\frac{\partial^2 v_z}{\partial x^2} + \frac{\partial^2 v_z}{\partial y^2} + \frac{\partial^2 v_z}{\partial z^2}\right) \\
&\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial x} + \frac{\partial v_z}{\partial x} = 0
\end{aligned} \quad (3)$$

Where $F$, $p$ and $v$ are the mass force, the surface force and the fluid velocity respectively. Here, the coefficient of viscosity $\mu$ and the density $\rho$ of the seawater are all constant (we choose $\mu = 1.26 \times 10^{-3}\,\mathrm{Kg/m \cdot s}$ and $\rho = 1.025 \times 10^{3}\,\mathrm{Kg/m^3}$ for the seawater).

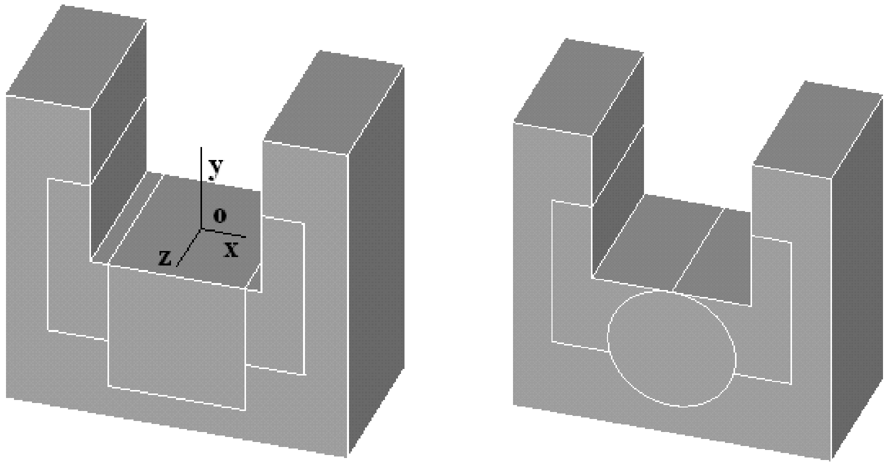
**2.2. Two models of a new-style electromagnetic current meter**

For the sake of computing induced potential differences of an electromagnetic current meter accurately, two geometrical models and their external dimensions are designed which are shown in Fig.1. International unit system (SI) is used in this paper. Fig. 1(a) and Fig. 1(b) are the x-y view of the two geometrical models. We call the two models model-1 and model-2 respectively in the rest of the paper. The two models assume that the electromagnetic current meter is made of silicon, steel sheets, PTFE and Nd-Fe-B permanent magnets. In the two models, silicon steel sheets are put outside and PTFE is cast inside. A cuboid permanent magnet and a cylindrical permanent magnet are used in model-1 and model-2 respectively. The two models have a height of 0.02 m, a width of 0.02 m and a thickness of 0.01 m. Their inner quadrate grooves have a height of 0.01 m, a width of 0.01 m. Their 3D appearances are shown in Fig. 1(c) and Fig. 1(d). The origin of coordinates is located in the geometrical center of groove bottom. The surface of models and interfaces of materials are covered by insulating varnish entirely. Three pairs of electrodes which are shown in Fig. 1(a) are put on the inner surface of the electromagnetic current meter. Here we choose three y coordinates of electrodes: y=0.004 m, y=0.006 m and y=0.008 m. Z coordinates of electrodes are zero.

The necessary parameters we used in the two models are as follows: The grade of the Nd-Fe-B permanent magnets is N35. Their relative permeability is $\mu_r = 1.05$. Their x, y, z component of coercive force are 850000 A/m, 0 and 0 respectively. The relative permeability of PTFE is 1.0. The grade of silicon steel sheets is DW470-50. All calculations were performed using the Elmer finite element software [9], which is an open-source finite element software for multi-physics problems.




(a) x-y view of model-1 (b) x-y view of model-2




(a) 3D appearance of model-1 (b) 3D appearance of model-2

Fig.1. Geometrical models and position of electrodes

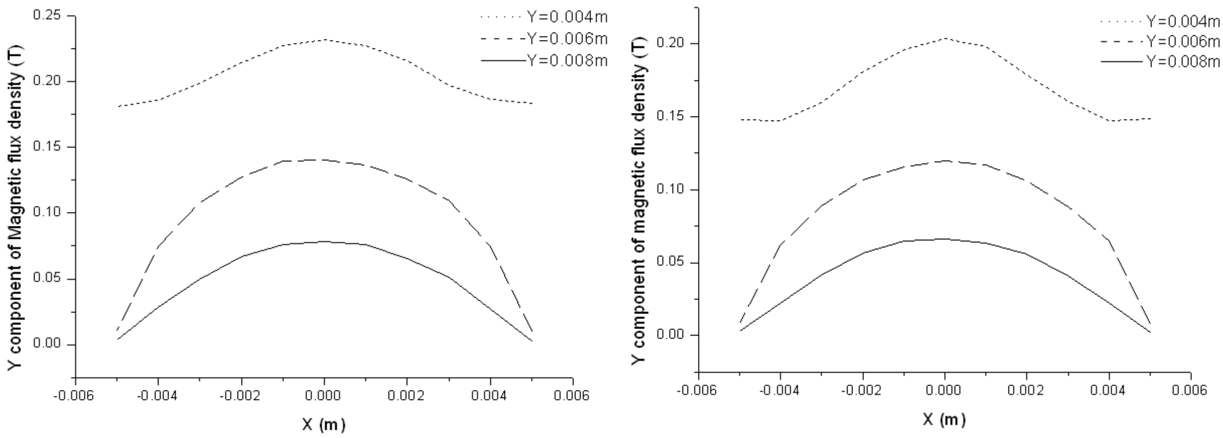
## 3. Simulation results

In this simulation, we assume that the velocity of ocean currents only have z components and choose the velocity of ocean currents in the distance increasing from 0.1m/s to 2m/s on the basis of the velocity scope of ocean currents [10~12]. Obviously, z components of velocity around the quadrate groove and y components of the magnetic flux density should be calculated firstly in order to obtain induced potential differences. In order to reduce error, the boxed dimension of calculation we choose is $1 \times 1 \times 1\text{m}^3$. In this Simulation, we calculated velocity distribution in the neighborhood of the electromagnetic current meter, the distribution of the magnetic flux density and the induced potential differences between electrodes.

### 3.1. Magnetic flux density

Considering the law of electromagnetic induction and the right hand rule, only y components of magnetic field are contributed to the induced potential between electrodes. The result of magnetic field on x-y plane is shown that y-axis is symmetry axis of magnetic flux density on x-y plane. The y components of magnetic flux density in the quadrate groove ranges from 0.001T to 0.5T in model-1 and 0.001T to 0.6T in model-2. And y components of magnetic flux density around the origin of coordinates are larger than that of magnetic flux density in the rabbet of the electromagnetic current meter.

Y components of magnetic flux density of the two models from x=-0.005 m to 0.005 m on the x-y plane is presented in Fig. 2(a) and Fig. 2(b) respectively. Here we choose three y coordinates according to positions of three pairs of electrodes: y=0.004 m, y=0.006 m and y=0.008 m. From the two figures we can see that the y components of magnetic flux density in model-1 are stronger than that of magnetic flux density in model-2.




(a) Magnetic flux density in model-1 (b) Magnetic flux density in model-2

Fig.2. Magnetic flux density B on the x-y plane

### 3.2. Velocity profile in the quadrate groove of the electromagnetic current meter

Obviously, only the z components of velocity for ocean currents are contributed to the induced potential differences. Y components of velocity in the neighborhood of the meter when velocity of the ocean currents ranges from 0.1 m/s to 2 m/s is shown in Fig. 3. Here we also choose three y coordinates: y=0.004 m, y=0.006 m and y=0.008 m. The curves in Fig. 3 display that y components of velocity in quadrate groove is not maximal when x=0. The velocity maximum of seawater in the quadrate groove is larger than the velocity of the ocean currents. The velocity near the inner surface of quadrate groove changes greatly.

### 3.3. Potential differences under different velocity of the ocean currents

Based on the result presented above and the equation (1) and (2), we can figure out the induced potential differences under different velocity of the ocean currents between the three pairs of electrodes. Fig. 4(a) and Fig. 4(b) show the different induced potential differences between different pairs of electrodes as a function of the velocity of the ocean currents in model-1 and in model-2 respectively. The potential differences on electrodes in Fig. 4 depend almost linearly on the velocity of the ocean current. For the same pair of electrodes, the slopes of the potential differences after curve fit in model-1 are larger than those in model-2. In other word, stronger potential differences are generated in model-1. For the same model, the slopes are increase with y coordinates of electrodes and strongest potential differences are generated on electrodes which has y coordinate y=0.004m. It is due to the strongest y components of magnetic field formed there among the three y coordinates of electrodes. Of course, a linear relationship between the potential differences and velocity of the ocean current is favorable to the actual measurement.

Because the curves in Fig. 4 are linear, the functions of every curve could be figure out easily. These curves must pass the origin of coordinate because there is no induced potential difference if velocity of the ocean currents is zero. So the function of every curve could be expressed as a kind of simple equations:

$U(v) = kv$

Where $U$, v and k are the induced potential differences, the velocity of the unaffected ocean currents and slopes of curves. The functions of six curves as shown in Fig. 6 are as follows:

In model-1:

$U(v)$ = 0.52E-3 (y=0.008 m)

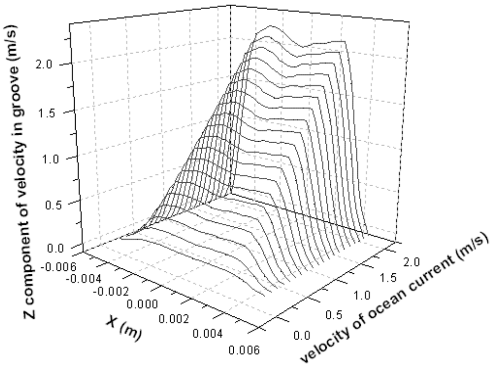
$U(v)$ = 1.02E-3 (y=0.006 m)

$U(v)$ = 1.80E-3 (y=0.004 m)

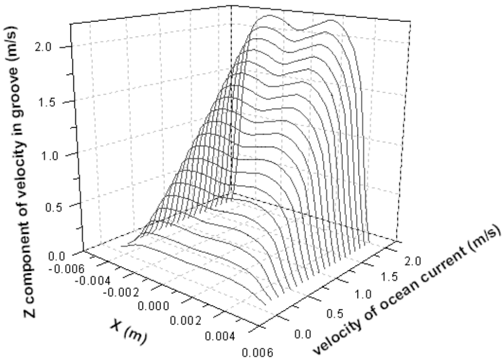
In model-2:

*U* (*v*) = 0.43E-3 V (y=0.008 m)
*U* (*v*) = 0.85E-3 V (y=0.006 m)
*U* (*v*) = 1.50E-3 V (y=0.004 m)

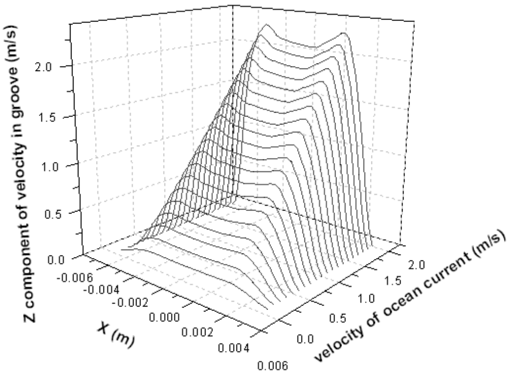
If the electromagnetic current meter is put into seawater, we can obtain the unaffected velocity of the ocean currents from measuring the induced potential differences between electrodes on x-y plane using the relationship above. Obviously, stronger signal will be obtained in model-2. The transform from induced potential differences to velocity of the ocean currents is very convenient because of the linear relationship.




(a) Y=0.004 m

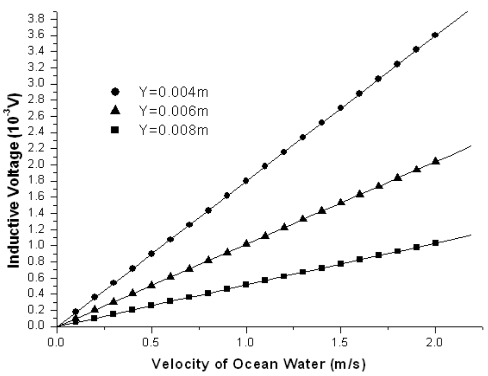



(b) Y=0.006 m

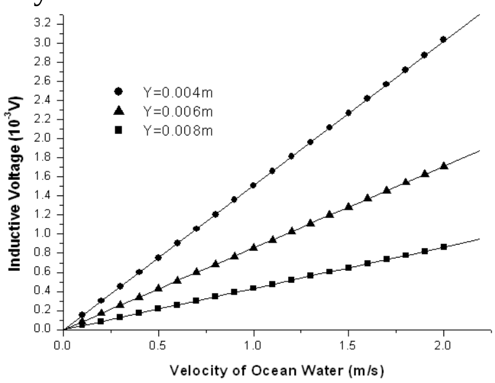



(c) Y= 0.008 m

Fig.3. Relation of y components of velocity in the quadrate groove, velocity of the ocean currents and x coordinates in different y coordinates.




(a) Induced potential differences in model-1




(b) Induced potential differences in model-2

Fig.4. Different induced potential differences between different pairs of electrodes under different velocity of the ocean currents.

## 4. Conclusions and further work

Numerical simulation for a model of new-style electromagnetic current meter which is used to measure the velocity of ocean current has been carried out. The induced potential differences on electrodes under different velocity of the ocean currents have been calculated. A linear relationship between the potential differences and velocity of the ocean current is found. The relationship could be expressed as a kind of simple equations: $U$ (V) = k$v$. Using these functions, we could work out the velocity of ocean currents easily. The model-1 has better sensitivity for the reason that slopes after curve fit in model-1 are larger than slopes in model-2 to the same pair of electrodes.

The presented model above could only measure the velocity of the ocean currents which only has z components. Further work should be performed to investigate the relationship between the induced potential differences and the velocity of ocean currents which possesses x, y and z components. The model will be improved to meet needs of measuring. In further work a series of appropriate parameters of the improved model will be provided for the instruments.

Additionally, there is a distribution of ionic concentration in the meter because sodium chloride exists in the seawater. Deeply research will be made on the distribution of ionic concentration accordingly.

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**References**

[1] H.J. Lin: Ocean Technology: Vol. 24(2005) No. 2, p.13-17.
[2] H.T. Wang: Ocean Technology. Vol. 25(2006) No. 4: p.36-38.
[3] G. Griffiths, P.G. Collar and A.C. Braithwaite: Institute of Oceanographic Sciences, Vol. 1(1978) No. 56, p.1-4.
[4] J.A. Shercliff: The theory of electromagnetic flow measurement. (Cambridge University Press, UK 1962), p.1-10.
[5] M.K. Bevir, Journal of Fluid Mechanics: Vol. 43(1970) No.3, p.577-90.
[6] J.Z. Wang, G.Y. Tian, G.P. Lucas: Flow Measurement and Instrumentation. Vol. 18(2007): No.2, p.99-105.
[7] J.Z. Wang, C.L Gong, G.Y. Tian and G.P. Lucas: Journal of Physics: Conference Series; Vol. 48(2006) No.1, p. 36-40.
[8] J.S. Edward, M.K. Ira, P.S. James: Introduction to fluid mechanics. (Oxford Press, UK 2005), p.: 676-77.
[9] Information on https://www.csc.fi/web/elmer and http://sourceforge.net/projects/elmerfem.
[10] Y.C. Yuan, H.Q. Wang, R.Y. Lou, H. Chen, K.S. Wang: Acta Oceanologica Sinica.; Vol. 27(2005) No.4, p.1-9.
[11] Y.C. Yuan, C.H. Yang, Z.G. Wang: Acta Oceanologica Sinica. Vol. 28(2006) No.3, p. 17-28.
[12] C.H. Yang, Y.C. Yuan, H.Q.Wang: Acta Oceanologica Sinica. Vol. 29(2007) No.3, p. 1-13.