Experimental Study of the Guard Electrodes in an ERT System

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Abstract - *The electrode array in an ERT system has a great influence on the system's performance. In this paper, experiments have been carried out to study the effect of guard electrodes for sensing field of an ERT system. Under homogenous medium condition, the comparison between measured data and simulated data obtained by using a two-dimensional(2-D) formula showed that, the electrode array with guard electrodes produces a sensing field with a near parallel distribution. Under heterogeneous condition, the effect of guard electrodes to compress the distribution region of sensing field is tested. Some qualitative analysis of experimental results are given.*

Keywords: Guard Electrode, Sensing Array, ERT

1. INTRODUCTION

The ERT technique is of great application potential in industry process monitoring because of its advantages, such as visualizability, high temporal resolution, low cost, no radiation hazard, etc.. For example, it has been applied to investigate internal flow characteristics of a hydrocyclone operating with solid/liquid mixtures[1], to measure and map laboratory-scale sediment porosity[2], to monitor air core movement in centrifugal cyclonic separators[3]. However, as the sensing field is a three-dimensional(3-D) non-parallel current field, the measured voltages reflect the conductivity distribution in a large region where the exciting current pass through, not merely in the cylinder space surrounded by the electrode array. Some researchers developed 3-D ERT reconstruction algorithms[4][5], which make the ERT technique more attractive. However, the calculation of a 3-D ununiform electric field is queit difficult and complicated. In order to modify the quality of 2-D ERT images, the authors presented a scheme to improve the distribution of the ERT sensing field.

The aims of adding guard electrodes to ERT sensing array are firstly to get a parallel distributed sensing field and secondly to compress the sensing field into a limited region. Parallel field can be exactly simplified as a 2-D filed, and since it does not diverge and it distributes in a limited space, the detecting region, where the conductivity change of medium will effect the measured voltages, can be compressed. Therefore, the physical meaning of ERT images can be explicated.

Authors performed two experiments to study the effects of guard electrode in an ERT system. One is under the homogenous medium condition, the other is under the heterogeneous medium condition. The differences between traditional array, as shown in Fig.1(a), and the electrode array with guard electrodes, as shown in Fig.1(b), are discussed.

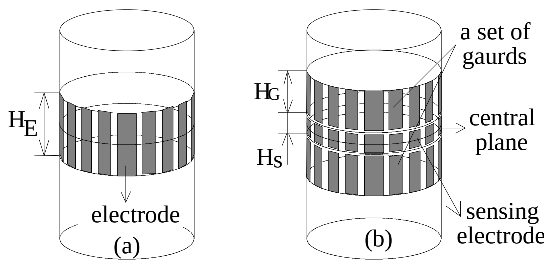

Fig.1 Electrode Arrays of ERT System
(a) Traditional Sensing Array
(b) Sensing Array with Guards

2. DRIVING CIRCUIT OF GUARDS

Sensing array with guard electrodes, as shown in Fig.1(b), has three planes of rectangular electrodes. The electrodes located in the central plane are the sensing ones, used to inject exciting current which produces sensing field and to measure voltages. The electrodes located in upper and lower planes are the guard electrodes. Every two guards in upper and lower planes have the same potential of the sensing electrode in the central plane.

To guarantee this, a measurement circuit is developed, as shown in Fig.2. Where A1 and A2 are operational amplifiers of low input offset voltage, low input offset voltage drift, high input impedance, low input bias current and low input offset current. A3 is a power amplifier of high precision of voltage following.

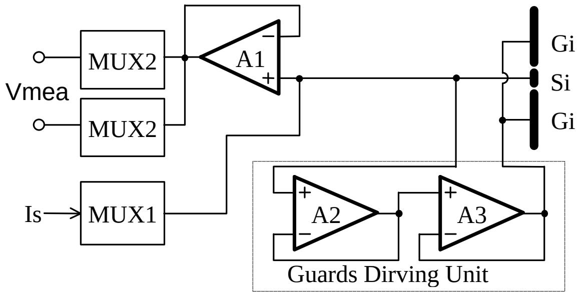

Fig.2 Guards Driving Circuit

Where Si is a sensing electrode and Gi is a set of guards.

3. EXPERIMENTAL RESULTS

Three kinds of electrode arrays have been adopted to study the effect of guards. They are:

A. a single plane of short electrodes, the size of which is 1cm x 1cm;

B. a single plane of long electrodes , the size of which is 1cm x 21cm;

C. an electrode array with guards. The size of the sensing electrodes is 1cm x 1cm and the size of the guards is 1cm x 10cm.

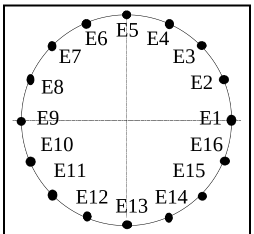

Fig.3 Arrangement of Electrodes

The arrangement of 16 electrodes in a plane is show in Fig.3. The homogenous medium in the vessel is a solution of Na_2SO_4. The experiment conditions are as below:

Exciting Current? 1.7763mA
Vessel Internal Diameter? 139mm
Diameter of glass elliptical ball?ϕ8mm-ϕ6mm
Conductivity of Medium?0.22ms/mm

3.1 Sensing field under homogenous medium condition

In adjacent method, current exciting at electrodes E1 & E2, the measured voltages are listed in Tab.1. Where the rms error between measured voltages and calculated ones is calculated by formula (1).

$$rms = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{V_{mea,i}-V_{cacu,i}}{V_{cacu,i}}\right)^2} \times 100\% \qquad (1)$$

Voltage calculation uses the 2-D field function of (2), and the potential distribution formula of (3).

$$\begin{cases} \frac{\partial f^2}{\partial r^2}+\frac{1}{r}\cdot\frac{\partial f}{\partial r}+\frac{1}{r^2}\cdot\frac{\partial f^2}{\partial \theta^2}=0 & r<R \quad (a) \\ \sigma\cdot\frac{\partial f}{\partial r}=j(\theta) & r=R \quad (b) \end{cases} \qquad (2)$$

$$f(\theta,r)=\frac{2jR}{\sigma\pi}\sum_{n=1}^{+\infty}\left(\frac{r}{R}\right)^n\cdot\frac{1}{n^2}\cdot\sin\frac{n\Delta}{2} \cdot [\cos n(\theta-\theta_1)-\cos n(\theta-\theta_2)] \qquad (3)$$

sensing array	Fig.1(a)				Fig.1(b)	
	H_E=1cm		H_E=21cm		H_S=1cm	
E-Pair	Vmea (mV)	Vcal (mV)	Vmea (mV)	Vcal (mV)	Vmea (mV)	Vcal (mV)
E3-E4	18.768	50.530	3.352	2.406	63.351	50.530
E4-E5	5.184	21.729	1.458	1.035	27.915	21.729
E5-E6	2.241	13.017	0.915	0.620	16.676	13.017
E6-E7	1.294	9.294	0.616	0.443	11.168	9.294
E7-E8	0.914	7.481	0.504	0.356	8.905	7.481
E8-E9	0.742	6.618	0.407	0.315	7.5389	6.618
E9-E10	0.703	6.360	0.402	0.303	7.286	6.360
rms(%)	82.3%		39.0%		22.1%	

Tab.1 Effects of electrode arrays for the sensing field

It can be seen from Tab.1, the array with guards has the least rms error; the array of short electrodes has the largest rms error. The result can be probably explained by Fig.4 as following: the sensing array of short electrodes produces a sensing field which intensively diverges in 3-D space, as shown in Fig.4(a), so its sensing field can not accord with the demands of simplifying a 3-D field to a 2-D field, and have the largest rms error. Increase of the height of electrodes can improve the sensing field distribution in the central region of electrode array, but the diverge still exists at the edge of electrodes, as shown in Fig.4(b). Therefore the long electrode array can reduce the rms error, but its rms error is still higher than the one of the electrode array with guards.

For the electrode array with guards, the electric field produced by a pair of sensing electrodes and two sets of guards is shown in Fig.4(d). Under the focusing effect of guards, the sensing field produced by the sensing electrodes parrallelly distributes in the central region. If the guards are high enough, the 2-D electric field function of (2) can well discrine the sensing field, resulting in the rms error reduction.

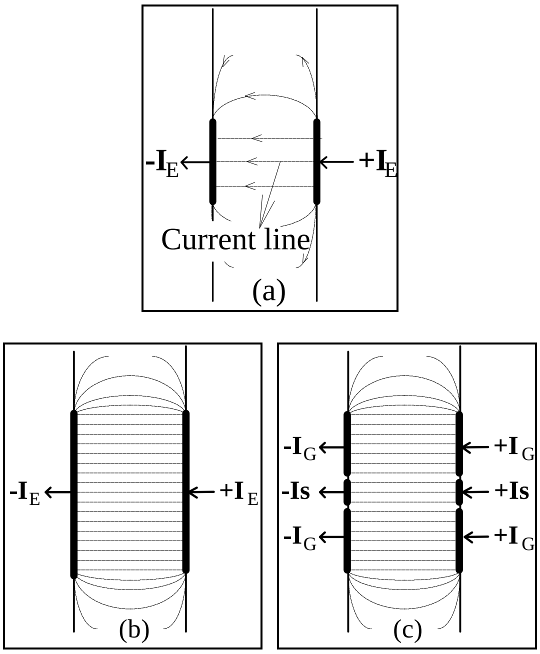

Fig.4 Sensing Field in Homogeneous Field

3.2 Sensing Field under heterogeneous medium condition

In order to check the effect of guards for the sensing region, the following experiment has been carried out. Putting a elliptical glass ball into the medium, as the ball was moving along the Z axial, the changes of measured voltage were observed, as shown in Tab.2.

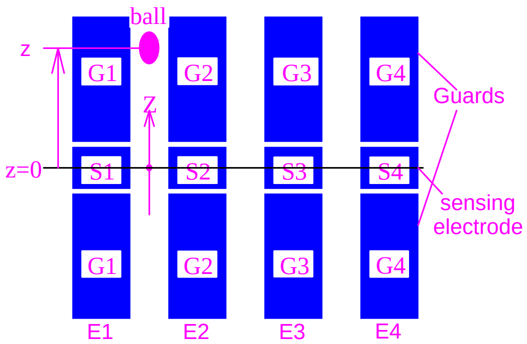

Fig.5 Ball position

Z (mm)	Fig.1(a)		Fig.1(b)
	H_E=1cm	H_E=21cm	H_S=1cm
0	2.431%	0.482%	4.259%
9	1.236%		1.643%
11	0.872%		1.031%
18	0.104%		0.100%
29	0.051%	0.358%	0.098%
34	0.021%	0.338%	0.059%
53	0.003%	0.332%	0.006%
103	0.003%	0.172%	0.007%

Tab.2 Changes of voltage casued by a ball

Here, the current was injected from positions E1 & E2, the voltages were measured between E3 & E4. And changes of voltage are calculated by (4).

$$Change = (V_{ball} - V_o) / V_o \times 100\% \qquad (4)$$

where Vo is the voltage measured without the ball.

It can be seen from the data shown in Tab.2 that, when the glass ball was putted at the position of z=0mm, the change of voltage for the array with guards is the largest, i.e. it is very sensitive to the change of medium; the change of voltage for the single plane of short electrodes is less, i.e. the detecting sensitivity is lower; the change of voltage for the single plane of long electrodes is the least.

When z?18mm, though the ball is still in the region surrounded by electrodes, the changes of voltage for the array with guards is significantly less than that for the single plane of long electrodes. This suggests that the distribution region of sensing field can be compressed by adopting the electrode array with guards.

The results can be explained by Fig.6. In the case of (a), though the ball is positioned at the edge of the electrodes, it is still in the sensing field, and distorts the sensing field. While in the case of (b), the distortion of the electric field caused by the ball is restricted to the guards, and the flowing path of the exciting current injected from sensing electrodes, can hardly be changed.

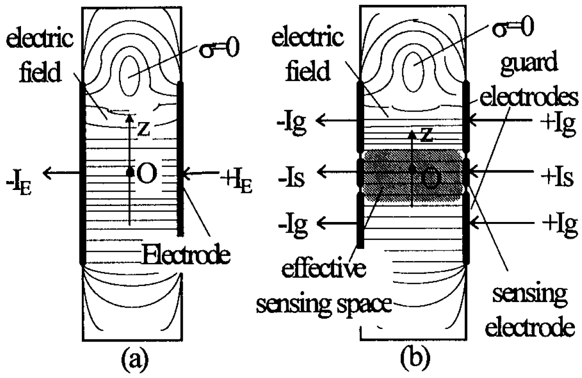

Fig.6 Effect of conductivity change for the sensing field
(a) A pair of long rectangular electrodes
(b) With guard electrodes

In Fig.6(b), as the ball move close to the plane of z=0 and the distorted region of the electric field is close to the sensing field, the change of voltage caused by the ball is increased(compared with voltages without the ball). Contrarily, in Fig.6(a), because the distorted region is in the sensing field all along, the voltage increases slowly and little. And since the ball is too small compared to the size of electrodes, the detecting sensitivity of (a) is less than that of (b).

The distorted region of electric field caused by a ball mainly depends on the size of the ball. Assuming that the radius of the ball is r and the distance between two exciting electrodes is 2d, the distorted region can be described qualitatively as below:

$$|z| \le \frac{1}{2} H_E + \boldsymbol{min\{}3r\boldsymbol{,}3d\boldsymbol{\}} \quad \text{in Fig.6(a)} \qquad (5)$$

$$|z| \le \frac{1}{2} H_S + 3r \quad \text{in Fig.6(b)} \qquad (6)$$

Then, if 3r?3d and H_S>H_E, the detecting region can be compressed by adding guards.

4. SUMMARY

The design scheme of electrode array with guards is meaningful. The guards can improve the parallel quality of the sensing field, so the sensing field can be more precisely described by a 2-D electric field function. Additionally, guard electrodes can also compress the distribution region of the sensing field. Consequently, the physical meaning of the 2-D ERT images will be clarified.

The ERT system with guards is mainly suited for the following three kinds of measurement objects.

1. Homogenous medium. It requests the height of guard electrodes satisfies H_G>3d.
2. Heterogeneous medium, but the diameter 2r of dispersed component, must be smaller than the distance 2d of two exciting electrodes. In this case, the height of guard electrodes should satisfy H_G>3d.
3. Heterogeneous medium, such as bullet flow, if the length of the long gas bubble is longer than 3d, the guard electrodes can also improve the quality of 2-D ERT image.

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