A MONOPOLAR ELECTROSTATIC PROBE FOR GEOPHYSICAL ELECTRIC FIELD MEASUREMENTS

B. Üstündağ[1] Ö. Kalenderli[2]

[1] *Computer Engineering Department, Electrical & Electronics Faculty*
Istanbul Technical University, 34469, Maslak, Istanbul, Turkey
[2] *Electrical Engineering Department, Electrical & Electronics Faculty*
Istanbul Technical University, 34469, Maslak, Istanbul, Turkey

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ABSTRACT

Anisotropic minerals, mainly the SiO_2 are highly common in nature and they have the property of piezoelectricity. It is known that electric potential variation over a standard cubic rock sample is directly proportional to the stress change (dδ/dt) under time varying mechanical load. This feature also allows determination of structural changes under constant load by means of electrical methods. It is assumed that earthquake precursory physical structure changes have effects on the electric field displacement of the surface. A forecast system that includes measurement of change in electrostatic displacement close to the Earth's surface regarding to change in fault stress requires a sort of monopolar electric field probe that accepts upper crust as a part of electrode system.

1. INTRODUCTION

There are several research activities on prediction of approximate time and the epicenters of probable earthquakes. Some of these researches depend on evaluation of physical changes on Earth's surface [1 - 4]. As a new alternative to such physical measurement methods, change of electric field is measured by using monopolar probes in a common project of Electrical & Electronics Faculty and Faculty of Mines at Istanbul Technical University.

Design of an electrostatic measurement device, that is the main part of earthquake forecast project, is explained in this study.

Anisotropic minerals, mainly the quartz, are highly common in nature and they have the property of piezoelectric effect [5]. Piezoelectricity and change of dielectric properties inside the mechanical structures take important role in remote diagnostic methods those use electrostatic measurement techniques [6].

In a typical compression type material strength test system shown in figure1.a, hydraulic cylinder applies pressure over the rock sample and the change of stress is measured via load cell.

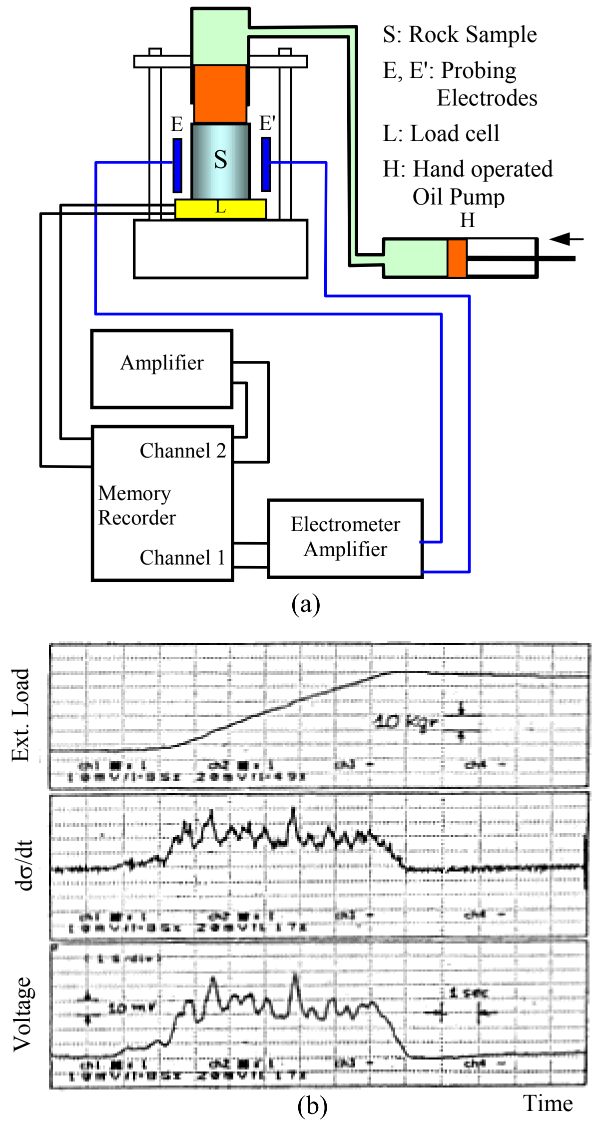


Figure 1. a) Mechanical compression experiment and measurement system. b) Change of load, stress variation and electrical potential between the electrodes with respect to time.

Differentially measured electric field over the sample is directly proportional to the stress change (dσ/dt) under time varying mechanical load as shown in figure 1.b [7].

A monopolar probe system that is used for precision measurement of change of electric fields assumed to be related to earthquake precursory electromechanical changes is described in section 2.

2. MONOPOLAR ELECTRIC FIELD MEASUREMENT

In the proposed method, one part of the sensor mechanism is the Earth that is coupled to the monopolar electrode through air. Maximum electric field strength occurs at the surface of any sphere that is loaded by a voltage source (figure 2) [8]. The electric field decreases inverse square proportional to the distance from the surface of the source. This is also valid for the Earth as a globe since the upper atmosphere consists negative ions. A high sensitive monopolar electric field probe has been developed which is to be installed close to the surface of the earth for this reason.

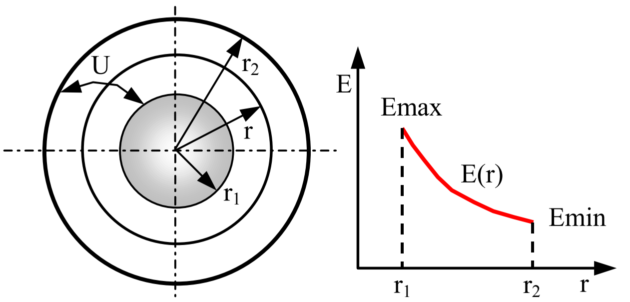


Figure 2. Electric field variation with respect to distance ($r - r_1$) outside a charged sphere

We assume that change in charge induction at the probe should be related to the change in regional resultant stress as an electric potential source. Although there also exist atmospherically electric field changes as noise, which can be filtered since the frequency range is much higher than what is assumed to be proportional to the change in regional stress. On the other hand superposition of the attenuated electric field changes from further regions should be considered. These two facts require vectoral measurement using a group of stations and adaptive filtering for the removal of the atmospheric noises.

The system consists of a spherical capacity as electric charge collector, reverse connected MOSFET circuit as monopolar charge/bipolar voltage converter, indicator device for amplification, analog to digital conversion, signal processing, data acquisition and a personal computer for pattern analysis (figure 3). Monopolar electric charge is collected on the conductor surface of the sphere with the diameter of 40 mm. Collected charge is conducted via a high voltage cable to the reverse connected MOSFET's (Metal Oxide Field Effect Transistor) gate with a high valued resistor, which are placed in a dielectric pot. The cover of the pot has a hole for high voltage cable at the center [9]. The MOSFET is especially worked in high gain region, which is different from regular applications and components' physical sizes, and positions are arranged so that the leakage would be minimum as the measurement accuracy is in 10^{-14} Coulomb level.

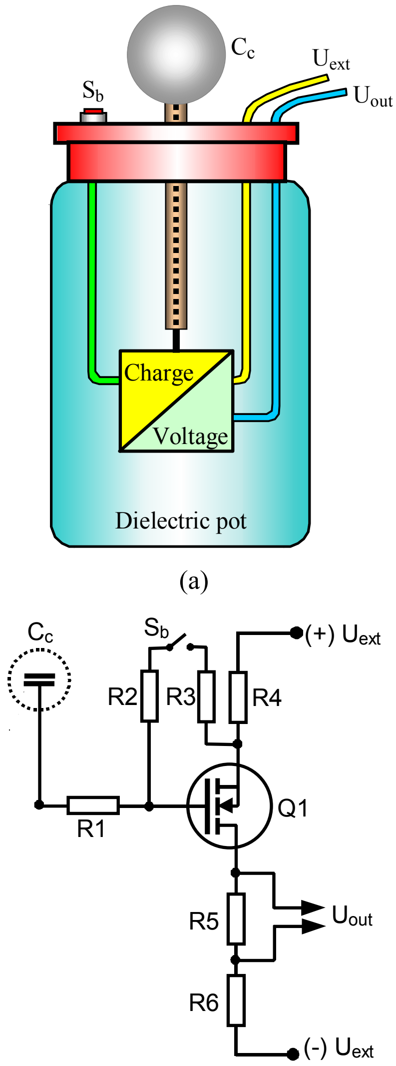


Figure 3. a) Monopolar electric charge measurement probe. b) Electric charge / Bipolar voltage converter

Collected charge amount from the air is calculated with respect to Gauss Law,

$$Q = \oint_S \vec{D} \cdot d\vec{s} \qquad (1)$$

Since the relation between the electric field strength and electrical displacement is,

$$D = \varepsilon E \qquad (2)$$

the amount of charge collected by the probe's sphere is,

$$Q = 4\pi r^2 \varepsilon E \tag{3}$$

where r is the radius of the sphere on the probe (figure 4).

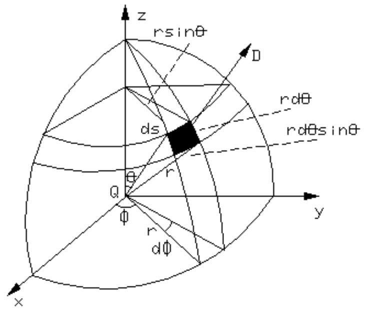


Figure 4. Displacement vector over a charged sphere

Drain current of a MOSFET (Metal Oxide Field Effect Transistor) is a function of gate-source voltage V_{GS} which is determined by the gate charge driven by the electrode Cc [10]. In this case the output voltage related to Q is,

$$V_{out} = R_5.I_D = R_5.f(V_{GS}) = R_5.f(Q) \tag{4}$$

where R_5 is the measurement resistance and the function f(Q) is determined by the transistor parameters given in the data sheets. Dynamic behavior of the charge/bipolar voltage converter is in the form of

$$V_{out}(t) = k_1\,[dE(t)/dt] + k_2 \tag{5}$$

where $k_1 = 0.05$ and $k_2 = 0.186$. Transfer function of the monopolar probe can be written as,

$$T(s) = k_1\, s + k_2 \tag{6}$$

which means that steady state accuracy is 0.186 [counts/(V/m)]. It is clear that accuracy can easily be raised by enlarging the electrode (sphere) surface. Laboratory tests shown in figure 5 verifies the calculated transfer function T(s) with respect to the relation between the applied electric field pattern and the output data pattern.

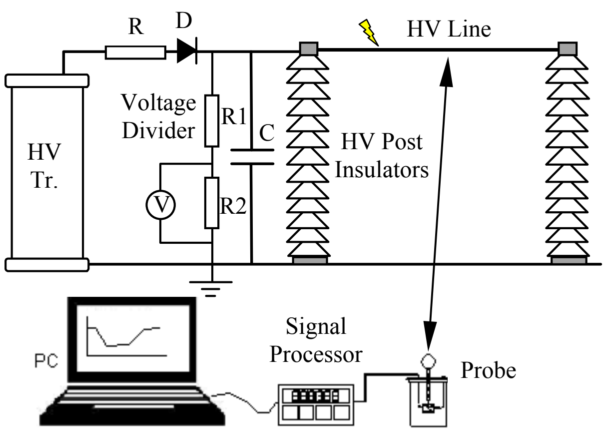


Figure 5. Electric field source and position of monopolar electric field probe for experimental determination of device parameters.

A test system shown in figure 5 is used in order to determine parameters in transfer function of the measurement device. This system is constructed inside the Faraday caged ITU-High Voltage Laboratory. Variable high voltage (HV) source is applied though HV line.

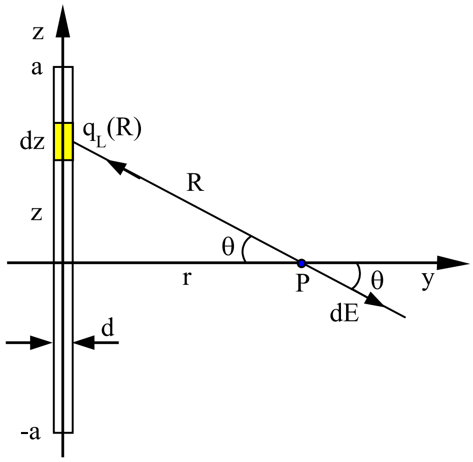
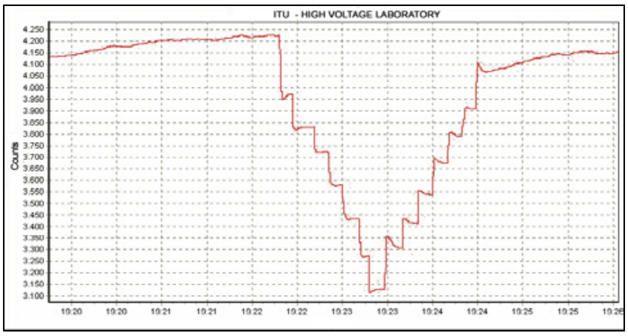


Figure 6. Charge distribution and electric field around the line that is used as a source

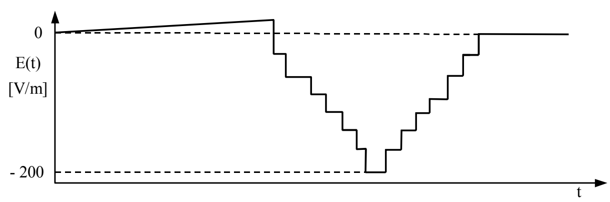
Resultant electric field of the rod shown in figure 6 at the distance r can be expressed as [8],

$$\left|\vec{E}\right| = E_r = \frac{\rho_L}{4\pi\varepsilon_0}\int_{-a}^{+a}\frac{dz}{(r^2+x^2)^{3/2}}$$

$$= \frac{\rho_L}{2\pi\varepsilon_0\sqrt{\left(\frac{r}{a}\right)^2+1}} \tag{7}$$



(a)



(b)

Figure 7. a) Change of electric field strength during the experiment. b) Response of the monopolar measurement system with respect to change in electric field in (a) [output in counts]

Applied electric field change is calculated with respect to equation (7). Charge density ρ_L, depending on the applied voltage, is homogenous and the measurement distance r was 6 m in the experiment. The calculated electric field pattern applied from HV line during the experiment is shown in figure 7.b.

Two of the many similar anomaly patterns that can easily be distinguished from the regular daily behavior are shown in figure 5 and figure 6, respectively. Earthquakes happened at the minimum transition in both cases like many other records. The difference of the second example from the first one is the step up pattern coinciding the earthquake.

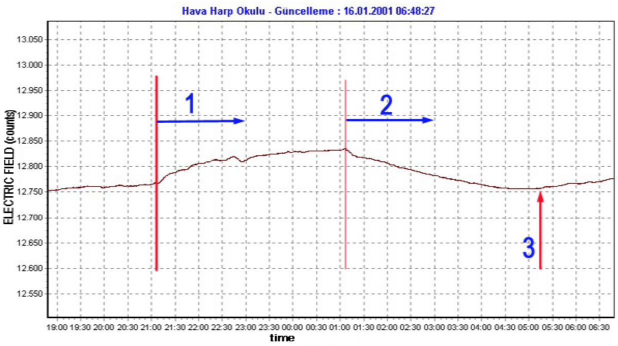


Figure 5. Change of electric field before an earthquake (red arrow) with magnitude 4.2 in 16th January 2001, Kartal-İstanbul

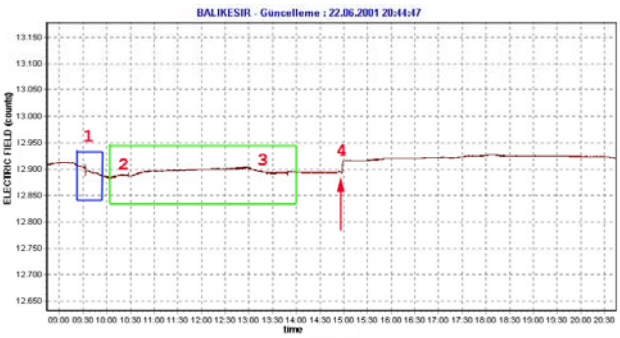


Figure 6. Change of electric field before an earthquake (red arrow) with magnitude 5.1 in 22nd June 2001, Balıkesir.

3. VECTORAL MEASUREMENT SYSTEM

Finding the direction and the magnitude of the electric field source has an important role in geophysical measurement since it is theoretically possible to determine exact location of the source of an observed pattern when triangular intersection method is used. Because of this reason, amount and location of the stations has to be organized such that any anomaly pattern taken into consideration must have an effect on at least three of them.

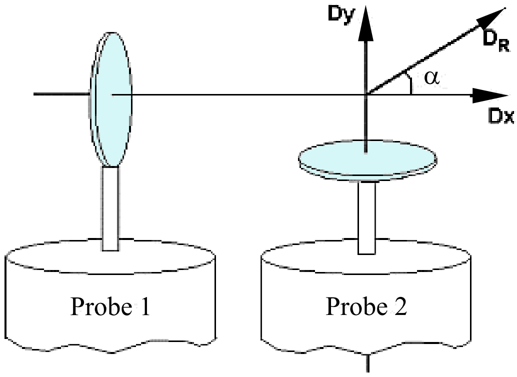


Figure 7. Two dimensional field measurement using plate type electrodes

Magnitude and the angle of the resultant electric field or respecting displacement can be calculated using the following equations in a two dimensional measurement system,

$$\alpha = \tan^{-1}\left(\frac{Dy}{Dx}\right) \tag{8}$$

$$D_R = \sqrt{Dx^2 + Dy^2} \tag{9}$$

Triangular intersection method in coordinate calculation requires three one-dimensional monopolar probes. D_R for 3D measurement can be expressed as a function of Dx, Dy and Dz similar to that in (9). On the other hand, unfortunately it has to be noticed that mechanical structure of the fault lines is not homogenous and induced charge at a point has several different type of mechanisms.

4. CONCLUSIONS

It has been shown that proposed probe system is able to measure change of electrical charges with the sensitivity in level of femto Coulombs. This charge is linked through the electrical displacement over the spherical electrode.

When there exist geometrical model of the electric field source vector that is proportionally related to displacement, it is possible to calculate the electrical potential at the supply by using the transfer function of the measurement system. On the other hand, direction of the electric field can be determined using three-plate type electrodes instead of a single spherical electrode. Contrary to caged laboratory conditions, several electric field sources impose on a single measurement device at the geophysical measurements. Because of this reason, pattern and model based investigations are required in order to construct relationships to geophysical events.

5. REFERENCES

1. M. Ikeya, Earthquake precursors due to seismic electromagnetic signals (SEMS), Applied Physics, pp. 109-127, 1999
2. R. J. Geller, VAN: A Critical Evaluation, A critical Review of VAN, Sir J. Lighthill, World Scientific, 1996.
3. P. Varastos, M. Lazaridou, K. Eftaxias, G. Antonopoulos, J. Markis, J. Kopanas, Short Term Earthquake Prediction in Greece by Seismic Electric Signals, A critical review of VAN, Sir J. Lighthill World Scientific, 1996.
4. M. Ikeya, C. Yamanaka, T. Mattsuda, H. Sasaoka, H. Ochiai, Q. Huang, N. Ohtani, T. Komuranani, M. Ohta, Y. Ohna, T. Nagakawa, Electromagnetic pulses generated by compression of granitic rocks and animal behavior, International Union of Geological Sciences, Vol. 23, No. 4, December 2000.
5. W. G. Cady, Piezoelectricity, McGraw-Hill, N.Y. 1946.
6. O. C. Clint, Electrical potential changes and acoustic emissions generated by fracture and fluid flow during experimental triaxial rock deformation, Ph.D. Thesis, University of London, November 1999.
7. V. Hadjicontis, C. Mavromatou, Laboratory investigation of the electric signals preceding to earthquakes, A critical review of VAN, Sir J. Lighthill, World Scientific Publ. Co., Singapore, 1996.
8. M. Özkaya, High Voltage Technique, Vol. 1, ITU Electrical Engineering Faculty Press, Istanbul, 1996.
9. L. Canyaran, B. Üstündağ, Earthquake Forecast System, Turkish Patent Institute, Application No: 1999/02911, November 1999.
10. B. Üstündağ, S. Özerdem, Earthquake prediction using a new monopolar electric field probe, European Seismological Congress (ESC2002), IASPEI/IUGG, Genoa, September, 2002.