CONSIDERATIONS ON CONTACTLESS ELECTROMAGNETIC MEASUREMENT OF HUMIDITY IN PEDOLOGY

Drd. Fiz. Tudor BURLAN-ROTAR,
Polytechnic University of Bucharest, tudor.burlan@yahoo.com,
Prof. Univ. Dr. Ing. Gabriel Dumitru,
Polytechnic University of Bucharest, gmdumitru@yahoo.com,
Inf. Alina Ioana PRELIPCEANU,
Polytechnic University of Bucharest, prelipceanu.alina@yahoo.com

Abstract: To put into practice the conventional determination of resistivity by the galvanic method, requires a relatively large amount of labor and is, therefore, expensive. At the basis of any interpretation are the lateral or vertical variations of resistivity.

The high cost of resistivity maps execution generally means that fewer measurements are made than desirable, with the result that, either (i) the explored area is not large enough to establish a reasonable background, against which the anomaly areas are to be delineated, or (ii) the anomaly areas are obscure and lack definition.

The application of electromagnetic techniques (EM) for measuring soil resistivity or conductivity has been known for a long time. Conductivity is preferable in inductive techniques, as instrumentation readings are generally directly proportional to conductivity and inversely proportional to resistivity.

The operating principle of this method is: a Tx coil transmitter, supplied with alternating current at an audio frequency, is placed on the ground. An Rx coil receiver is located at a short distance, s, away from the Tx coil. The magnetic field varies in time and the Tx coil induces very small currents in the ground. These currents generate a secondary magnetic field, Hs, which is sensed by the Rx receiver coil, together with primary magnetic field Hp.

The ratio of the secondary field, Hs, to the primary magnetic field, Hp, (Hs/ Hp) is directly proportional to terrain conductivity. Measuring this ratio, it is possible to construct a device which measures the terrain conductivity by contactless, direct-reading electromagnetic technique. (linear meter.)

This latest technique for measuring conductivity by electromagnetic induction, using Very Low Frequency (VLF), is a non-invasive, non-destructive sampling method. The measurements can be done quickly and are not expensive.

The Electromagnetic induction technology was originally developed for the mining industry, and has been used in mineral, oil, and gas exploration, hydrogeology studies, and archaeology. In these applications, differences in conductivity of subsurface layers of rock or soil may indicate stratified layers or voids that could be of interest.

Key-words: electromagnetic, inductive, conductivity, contactles

1. INTRODUCTION.

To put into practice the conventional determination of resistivity by the galvanic method, requires a relatively large amount of labor and is, therefore, expensive. At the basis of any interpretation are the lateral or vertical variations of resistivity.

The high cost of resistivity maps execution generally means that fewer measurements are made than desirable, with the result that, either (i) the explored area is not large enough to establish a reasonable background, against which the anomaly areas are to be delineated, or (ii) the anomaly areas are obscure and lack definition.


2. ELECTROMAGNETIC METHOD FOR MEASURING SOIL RESISTIVITY.

The application of electromagnetic techniques (EM) for measuring soil resistivity or conductivity is known for a long time. Conductivity is preferable in inductive techniques, as instrumentation readings are generally directly proportional to conductivity and inversely proportional to resistivity.

Figure 1 presents the principle of electromagnetic method for measuring soil conductivity.

![Fig. 1 Principle of electromagnetic soil conductivity measurement](image)

The operating principle of this method is: a Tx transmitter coil supplied with alternating current at a frequency audio is placed on the ground. A Rx receiver coil is located at a distance \( s \) from Tx coil.

The magnetic field varies in time and the Tx coil induces very small currents in the ground. These currents generate a secondary magnetic field, \( H_s \), which is sensed by the Rx receiver coil, together, with primary magnetic field \( H_p \).

The current induced in the coil receiver Rx is directly proportional to the conductivity of the soil:

\[
\frac{H_s}{H_p} \approx \frac{i \omega \mu_0 \sigma S^2}{4}
\]  

where:

- \( H_s \) = secondary magnetic field at Rx coil;
- \( H_p \) = primary magnetic field at Rx coil;
- \( \omega = 2 \pi f \) (pulsation);
- \( f \) = frequency;
- \( \mu_0 \) = permeability of vacuum;
- \( \sigma \) = soil conductivity;
- \( S \) = distance between coils;

Since the ratio of the secondary magnetic field and the primary magnetic field is directly proportional to the soil conductivity, can write apparent conductivity indicated by the instrument as defined by the equation:

\[
\sigma_a = \frac{4}{\omega \mu_0 S^2} \left( \frac{H_s}{H_p} \right)
\]
The unit for conductivity is Siemens per meter or, more conveniently, milli Siemens per meter (mS / m).

3. Sounding the layered earth.

3.1 Two layer earth model. In figure 2 is presented the two layer earth model.

![Two layer earth model](image)

Fig. 2: Two layer earth model

The contribution of the upper layer is:

$$\sigma_a = \sigma_1 [1 - R_v(z)]$$  \hspace{1cm} (3)

The contribution of the lower layer is:

$$\sigma_a = \sigma_2 R_v(z)$$  \hspace{1cm} (4)

The instrument reading is the sum of the two quantities:

$$\sigma_a = \sigma_1 [1 - R_v(z)] + \sigma_2 R_v(z)$$  \hspace{1cm} (5)

3.2 Three layer earth model. In the three layer earth model is used the same procedure:

$$\sigma_a = \sigma_1 [1 - R(z_1)] + \sigma_2 [R(z_1) - R(z_2)] + \sigma_3 R(z_2)$$  \hspace{1cm} (6)

In figure 3 is presented the three layer earth model.
4. Survey techniques and interpretation

4.1 Sounding a two layer earth by varying intercoil spacing. This technique can be used to measure the vertical variation of conductivity and is made by expanding the intercoil distance similar to the conventional resistivity sounding techniques in which is expanded the electrode distance.

Tx transmits coil retains its location. For each measurement, distance S from coil to coil is increased by moving the Rx coil. Thus, the maximum depth sounding d is also increased.

In figure 4 is presented the sounding by varying the intercoil distance S. In the illustration is used horizontal dipole.
4.2 Sounding a two layer earth by varying instrument height. The technique presented above cannot be used for stratification analysis when the instrument is made so that the distance between the coils has a fixed value. However, it is possible to measure the vertical variation of conductivity by varying the instrument heights.

In figure 5 is presented the sounding by moving the device vertically. In the illustration is used vertical dipole. It can be seen from figure 5b that at the lifting device on the ground, the area of maximum sensitivity is moved to another layer of soil.

![Diagram of sounding by moving the device vertically](image)

**Fig. 5**: Sounding by moving the device vertically.  
a) the device is at ground level. b) the device is lifted off the ground.

5. Measurement technique

In agriculture, the device is used to measure the salinity and soil moisture. Other agricultural applications currently include mapping, depth estimation topsoil, sand deposition depth after flood damage estimation due to herbicides, etc.

For each of the applications mentioned above, a relationship must be established between the value determined by device and soil characteristic of interest. Once the relationship is established, measurements can be made quickly.

To establish a relationship between the value determined by using the soil and the characteristic of interest for selected points on the ground, are taken simultaneously: soil samples (using a probe) and the apparent conductivity of the soil (through measurement device EM). The data from these points is made EM calibration device. Thus, the final map is drawn deep fertile soil.

Experimental correlations were found in moderate to good conductivity between the apparent conductivity and the results of the classical method, the soil samples, the most accepted and precise method for determining soil salinity.

A mobile data collection unit is mounted on a wooden trailer away from metal objects and away from the vehicle engine interference, which could affect determinations.

In figure 6 is presented the humidity device configuration for \( s = 1 \text{m} \) and maximum sounding deep 1.5 m.
Fig. 6: Configuration for $s = 1m$ and maximum sounding deep 1,5 m.

In figure 7 is presented the diagram of the magnetic field lines.

Fig. 7: The diagram of the magnetic field lines

The coils are air-cored for both: transmitter and receiver. These coils are in fact magnetic antennas.

The mobile unit consists of EM device coupled to an analog to digital converter, a computer and a receiver of differential global positioning system (DGPS).

The unit operates as follows: the analog signal coming from EM is converted into a digital signal and recorded by computer. Together with this information the computer also records your location (where the measurement was performed) received from the DGPS receiver. In the figure 8 is presented the block diagram of the digital system of the pedology mobile unit.
Fig. 8: The block diagram of the digital system of the pedology mobile unit
1) the EM device; 2) analog to digital converter;
3) computer laptop; 4) receiver DGPS

Using this device, data of entire fields can be collected quickly, and then, with appropriate software, you can make maps of soil conductivity. For 1 hectare field data can be collected about one hour.

After drawing the map of the land, for confirmation, it can be compared with aerial photograph (of the same pitch) made in the vegetation season.

In the early 1980s, electromagnetic induction method (EM) has been accepted as a useful method for getting maps of soil salinity. The method provides assessment tools to monitor the salinity.

Information about the depth of topsoil are a valuable tool in choosing appropriate crop management needs.

6. Experimental Results
EM device indicates areas where higher electrical conductivity (soil more fertile) are marked on the map with dark green - green crops. Soil areas with lower conductivity, are marked with color light brown - areas where coverage is less dense crop yellowing occurs due to moisture stress.

Using aerial photography to see plant cover is easy to see differences in productivity potential and how well models of potential productivity are correlated with measurements of soil conductivity using EM device.

The EM behave linearly proportional to the conductivity of the soil when the distance between the coils is less than the depth of penetration. However, in soils with a higher apparent conductivity of 80 mS / m, EM measurements are not linearly proportional to the conductivity of the soil.

7. Conclusions
The device for measuring the conductivity of materials by electromagnetic method (without contact) has a wide range of applications.

Its usefulness in areas such as geology (search for metal ores, oil, salt, etc.), archeology, agriculture (for measuring humidity, salinity) was confirmed in time.

8. References