P051 THREE-COIL EMI MULTI-FREQUENCY SOUNDING DEVICES IN NEAR-SURFACE APPLICATIONS

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Abstract

The paper is devoted to the brief application feasibility study of three-coils multifrequency sounding device, its advantages in comparison to devices that have two-coils. Influence of initial phase determination error into secondary field measurement accuracy was assessed. The estimation results of penetration depth are presented under the following models: conductive layer with non-conductive bottom half-space and conductive layer in resistive half-space. The estimated depths were compared with depth, conventionally calculated using skin-effect approach. Several cases studies are included to prove the usefulness of multi frequency approach.

Introduction

Recently the electromagnetic induction near-surface prospecting is quite well developed and still upcoming topic. The methods are applicable in civil engineering, ecology, archaeology, precious farming etc. Several EM devices are presented in the market. The fixed distance between transmitter and receiver featured the classic EMI devices such as EM31 and EM38 of Geonics. We could also find in the market their Czech analogues CM-031, CM-032, CM-138. The mentioned devices operates at one single frequency (10kHz approx). More recent device that should be taken into consideration is GEM-2 of Geophex – multi-frequency device working at the range 300 Hz – 48 kHz.

Some discussions are presented in professional society about usefulness and applicability of multi-frequency EM devices. Quite wide spread opinion exists that even at up to 1 MHz frequency range it is has no sense to use multi-frequency device with fixed TX-RX distance that is less than skin-layer thickness (McNeill, J.D., 1996), because it will not allow to resolve layered earths. However, we guess that other authors (Won, I.J., 2003), (Huang, H., Won, I.J., 2003) had better argumentation and more reliable results.

Being EMS EMI induction sounding device developers (Manstein, A.K., Manstein, Y.A., **Balkov, E.V.**, 2003), authors consider necessary to express own opinion about multi-frequency device applicability, the device's technical features and vertical resolution ratio of such a system.

Three-coil multi-frequency EMI sensors

Calibration is one of the fundamentals issues due to an EM multi-frequency device development. The following equations describe the receiving signal on the homogenous half-space, where M_r, M_T - momentums of receiver and transmitter, $k^2 = i\omega\mu\sigma$ - wave number:

$$\varepsilon = -i\omega\mu \frac{M_r M_T}{4\pi r^3}\left\{\frac{2}{k^2 r^2}\left[9-\left(9+kr\ +4k^2r^2+k^3r^3\right)e^{-kr}\ \right]\right\},\ \varepsilon = -i\omega\mu \frac{M_r M_T}{4\pi r^3}\left\{1+\frac{k^2r^2}{4}+O(k^3r^3)\right\}.$$

Second equation is the low-frequency approach of the first one. It is more convenient for analysis. It can be seen that theoretically the quadrature electromotive force component has no primary field included and is proportional to the media's conductivity (for low-frequency approach). The main item of in-phase component is driven by primary field.

However, due to hardware imperfection, the measurement phase is set with some error. The error causes some influence of primary field onto measured quadrature component. The influence is assessed with different errors of initial measurement phase. The factual features of EMS device with no compensation coil are taken. The lowest frequency – 2.5 kHz is chosen, because there is the lowest level of secondary field.

Calculation shows that to get less than 5% of alias, the phase accuracy should be 0.001 degree. One single frequency device with two coils can be precisely adjusted to suppress the primary field. Though for the multi-frequency device it is impossible to get such a good phase adjustment for the whole frequency range. It produces the problem of work with the regard for primary field in the measured signal. This problem causes the dramatic loss in measurement accuracy and reduction of dynamic range.

Now let's simulate at the same circumstances the same dimensions 3-coils device with the coil compensating the primary field (**Balkov, E.V.**, Epov, M.I., Manstein, A.K., Manstein, Y.A., 2004). The simulation shows that due to 1000 times compensation even 1 degree phase adjustment accuracy will give 5% limit of primary field influence onto measured signal.

Hence, to create EM multi-frequency induction device it is possible to use primary field cancellation approach such as 3-coils layout, where one coil is transmitter and two-receivers.

a)

b)

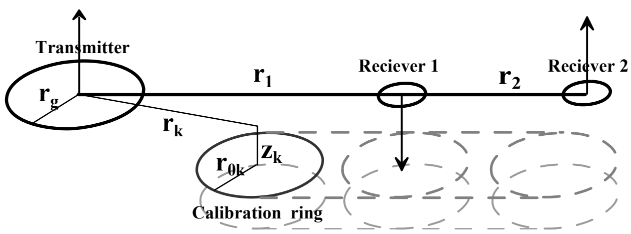


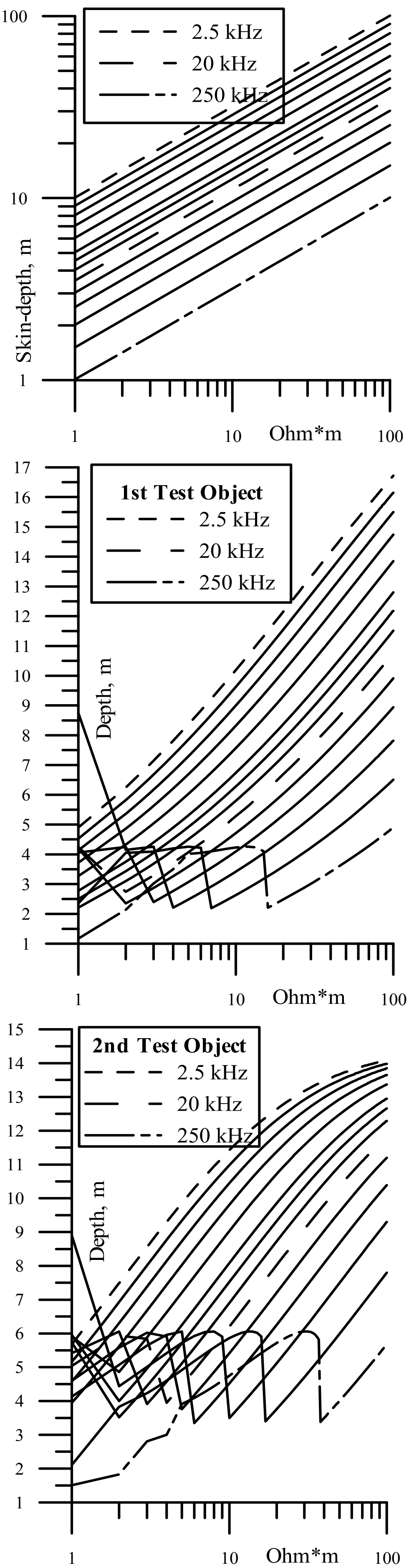
Fig. 1. (a) EMS and operator view. (b) Scheme of EMS device and placement of calibration ring.

Multi-frequency EMI device EMS

EMS device is the three-coil sonde that includes the transmitter and two receivers (Figure 1b). Alternating magnetic field with controllable phase is generating consequently on several frequencies within the range from 2.5 to 200 kHz. Receivers have special geometry to cancel primary field in the air. So EMS registers differential electromotive force induced by secondary sources. The transmitter and remote receiver is separated by about 2.5 meters.

EMS Depth Resolution

Sometimes estimation of field penetration depth and resolution is based on the value of skin-depth. The values of skin-depth can be seen at the upper graph. But theory analysis and practice show that such estimation is not quite correct for the case of field exciting by the horizontal loop placed on the surface of horizontally layered earth. Let estimate the penetration depth of discussed method for the case of EMS device. Consider the horizontally layered Earth model with vertical magnetic dipole as a transmitter on its surface (**Balkov, E.V.**, Epov, M.I., Manstein, A.K., Manstein, Y.A., 2004). Estimation is based on the examination of induced emf sensitivity to the test objects of two types. The first test object is an insulating half-space under conductive layer of the given resistivity. The second one is a conductive layer of fixed thickness in resistive half-space of the given resistivity. The resistivity contrast of the layer and the half-space in the last model is 10:1. Lets assume as a depth of investigation such a value of thickness of the first layer (in other words the depth to the test object) when the EMS signal, induced by the test object model differs from uniform half-space response more than by 5%. Thus for the first test object type we get the depth of the part of medium where the main part of induced currents is concentrated. For the second one we get the depth where the induced currents in conductive layer give sufficient contribution in measured signal. Diagrams at the right show the dependence of the depth of investigation on the frequency and resistivity for the both object types. Its nonmonotonic form at the high wave-number values is caused by the features of layered earth response. It can be seen that the values of skin-depth is greater than the depths obtained for test objects for the same frequencies and resistivities. At the same time the depths obtained for the both tests objects are quite similar. Their values are small and similar to the depths investigated in real applications. Diagram study shows that the depths strongly depend both on frequency and resistivity. It can be said that sounding within the EMS frequency range investigate the different volumes of the media that allows us to study the Earth structure with depth variation.



Of course, it is more correct to examine the influence of test objects onto objective function used by inversion procedure as well as the effect of equivalence. So the next step is to create reliable inversion algorithm. But we think that results described above are another one arguments that real frequency sounding by the portable EMI device is possible. Moreover the results of field works (see below) confirm it

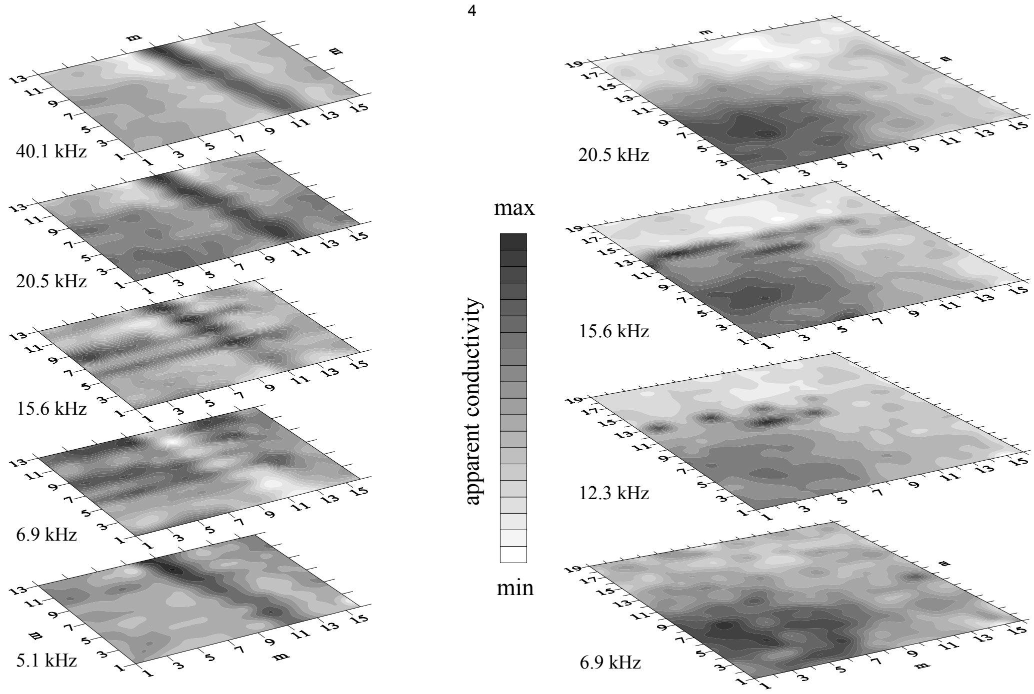


Fig 2. EMS Device Case Studies. (a) Sounding over the metal pipe within frequency range from 5 kHz to 40 kHz. (b) Sounding over the ancient burial mound within frequency range from 7kHz to 20 kHz.

Case Studies

Figure 2a demonstrates five maps of distribution of EMS signal at different sounding frequencies within the range from 5 kHz to 40 kHz over the metal pipe. The 5.1 kHz, 20.5 kHz, 40.1 kHz maps show the pipe alone. Thus, unknown conductive objects lying across the pipe can be seen at the others maps. Figure 2b shows that only burial mound slightly conductive body can be seen at the 6.9 kHz, 20.5 kHz maps. Meanwhile others maps show small highly conductive archaeological targets. The result is proved by excavation.

Conclusion

Even a short theoretical study shows that it makes sense to develop multi-frequency EMI devices. Such a device can give information about resistivity distribution of layered Earth. In addition the field experiments show the applicability of the set of frequencies using to get the sufficient result.

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