COMMON PITFALLS MET IN ELECTROMAGNETIC SHORT COIL SPACING SURVEYING

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Presentation discusses of pitfalls met and remedies found with electromagnetic (EM) dipole-dipole transmitter – receiver short coil spacing instruments, mainly operating in HCP and VCP modes and in frequency domain. Such systems are MaxMin and Promis HCP Slingrams, GEM-2 and EMP-400 Profiler instruments, so called conductivity meters EM31, EM38 and EM34 (Geonics) and CMD (GF Instruments) and DUALEM (Dualem) multicoil instruments (HCP, PRP). Some of these are also called as hand-held EM instruments or as ground conductivity meters (GCM). Dipole means small coil diameter in respect to coil separation. HCP is abbreviation for horizontal coil profiling (vertical dipole), VCP vertical and PRP perpendicular coils. Coil separations vary from less than one meter up to hundred meter range.

LEVELLING OFFSET ERRORS

These errors can be static or dynamic. Usually, they are detected as abnormal values and as level changes. If several frequencies are used, one level can behave in non-physical manner or differ from others.

Offset errors are not critical in anomaly detection or for general purpose mappings. But they can lead to erroneous results or poor fitting when numerical inversion is carried out. Erroneous data values can spoil the quality data part. Usually offset errors are more present in real component (Re) than in imaginary (Im) component. It is also known that normal Slingram system calibration by taking it to dry flat ground and zeroing readings may lead to offset errors. One method to try to check dynamic offset is to use a common point or tie line where readings are repeated at succeeding times. Offset errors can have larger influence in hydrology oriented surveys if data leads to misleading water quality estimation.

Later discussed LIN approach based calculation scheme (Geonics, 1980) can be handy in detection of offset errors. In that case measurements at same point are conducted at two heights and additive offset terms are solved. This functions well in homogeneous ground or when surface layer is more conductive than deeper layer(s).

One method to discover offset error is to study Re/Im-component ratio vs. response parameter and check if that follows basic EM relationship. For conductivity meters this requires that electrical conductivity values are first converted back to Im-values and that Re-component values do exist. Because Re-component exhibits more frequently levelling error, one method is to use only Im-components in evaluation and modelling.

NOISE AND MOISTURE

During surveys conducted EM noise from infrastructure, power lines and machinery can be present and deteriorate data quality. Noise can be observed by recording short time series of readings if it is constant. Example is shown in Table 1 below where major 220 kV power line has clear footprint in 4, 8 and 16 kHz readings and higher in Re-component ones.

Table 1. Example, power line noise in hand-held EM instrument surveying control stations.

12 readings at control stations	**Std. deviation, ppm**					
Distance to 220 kV power line	Re 4000	Im 4000	Re 8000	Im 8000	Re 16000	Im 16000
50 m	403.4	219.3	333.7	136.9	124.1	30.6
93 m	28.7	14.7	17.2	9.9	20.0	22.3
240 m	37.5	7.5	26.1	10.7	35.2	27.3

Sometimes noise can spoil data at certain frequencies to unusable quality. Ways to reduce noise is careful line location planning, increasing of stacking in recording and testing of alternative frequencies. Power line noise depends also on the load (current) and some time periods may be better than others. Problem can also be worse in higher resistivity areas because ground response is there smaller.

When using EMP-400 Profiler instrument it has been noted that measurement mode (continuous vs. stationary) has clear significance. Stationary recording (instrument non-moving while recording) results to better data quality although it is somewhat slower than continuous moving. Surveying height with hand-held instruments reduces response in ppm's (about half at 1.0 m compared to 0.1 m) and signal-to-noise ratio gets lower, too.

Moisture condition is important factor in short coil spacing surveying. All moisture on coils, very near laying wet bushes and even tree trunks can cause noise. Due to this fact forest and vegetation covered lines has to measured mainly with 1 m survey height or in very dry conditions. Dry ground is usually a must for survey except in open fields.

TECHNICAL NOTES PUBLISHED BY GEONICS LIMITED

One of basic and much used interpretation aid is Geonics document TN-6 (1980, EM terrain conductivity measurement at low induction numbers (LIN). Basically, theoretical approach is correct (weighted conductance model) but fails in certain important aspects: layer model responses differ from real ones in cases when lower layer is more conductive than surface layer. Second issue is that calculation scheme does not take into account frequency effect. More accurate understanding can be achieved by using exact numeric models. Technical note is widely spread, referred and from prestigious source. Many hand-held instrument and conductivity meter users are non-geophysicists. They do use this simple LIN calculation scheme only which can result to misleading concepts, understanding and data evaluation.

Deviations from LIN based model are shown in Figure 1 for nine models where bottom layer is more conductive than surface layer (Saksa 2016).

Situation was worsened by Geonics TN-30 publication (1996) "Why doesn't Geonics build a multi-frequency EM31 or EM38". After publication some companies like Geophex and GSSI has done that. Multiple frequencies help to achieve shorter coil spacing. It is much easier to measure through bush with 1 - 2 m long coil system than with 4 m long boom. Multi-frequency systems are more demanding regarding zeroing and calibration. Neither do they solve electrical equivalence often present.

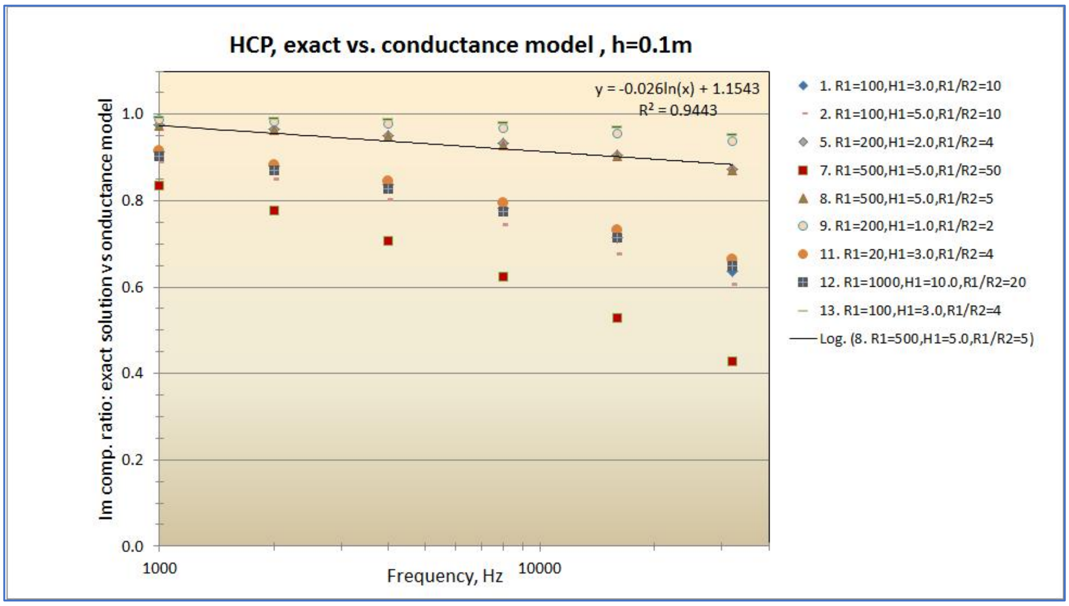

Figure 1. Deviations between conductance vs. exact models in influenced two layer cases (Saksa 2016).

DEPTH OF INVESTIGATION

General statement is that investigation depth is about coil separation or even less than that. In reality for hand-held systems good general rule is that depth penetration is about 1.0 – 1.5 x sqrt(skin-depth). Square root of skin-depth, not skin-depth for short coil spacing systems. This is exemplified by Figure 2 where conductive bottom layer starts at 5 m depth. Depths are apparent depths defined as sqrt(skin-depth), frequencies 0.5 – 32 kHz, HCP and VCP coil spacing 1.22 m, coil heights 0.1 and 1.0 m used in test calculations.

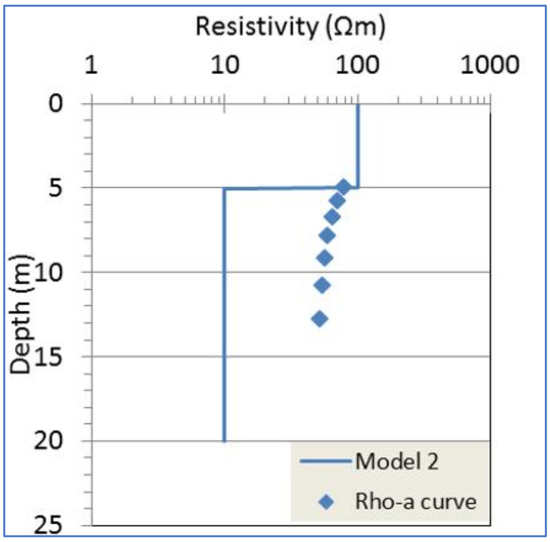

Figure 2. Two layer model response as apparent resistivity values (Saksa 2016).

In modelling studies (Saksa 2016) was concluded that depth penetration was much more than 1 – 2 x coil spacing frequently presented, about sqrt(skin-depth) for HCP and half of that for VCP mode. Frequency effect – if present – originates from deeper ground resistivity variations and from more conductive deeper layers or other objects. Use of exact calculation scheme in data processing is necessary.

When coil spacing increases to tens of meters depth penetration comes closer to coil separation of the system. Theoretical tests for detection limit (>±5% anomaly) indicate that in typical cases depth of investigation with Slingram HCP is (coil-spacing+skin-depth)/2 when skin-depth<coil-spacing otherwise approx. coil-spacing. It seems that Re-component has a bit higher penetration than Im-component when conductive targets were tested.

INTERPRETATION AND MODELLING ISSUES

EM frequency data has clearly two limits in the resistivity world. One is that response limit in higher resistivity range is relatively low, typically around 1000 Ωm. Above that induction does not ignite and create recordable component values. Another consequence is that embedded higher resistivity objects are poorly solved if at all. Second major issue is equivalence so that conductance can be solved for layers and plates but their thickness and electrical conductivity product conjoin. In modelling to prevent ambiguity, it is good to fix layers and adjust or bound resistivities, with the help of electrical DC measurements, GPR layer and depth data, soil types and stratigraphy, groundwater level and quality and so on.

Slingram/Promis HCP instrument can provide multifrequency data, so each point can serve as a sounding station. However, response curve is highly non-linear when B>1 with rapid changes in more conductive end, Figure 3. In inversion – depending on the starting model – it can be difficult to obtain optimal solution. Probably the best approach is interactive modelling point by point. Data levelling errors, bad data or magnetic susceptibility can also interfere seriously quantitative multifrequency Slingram data inversion.

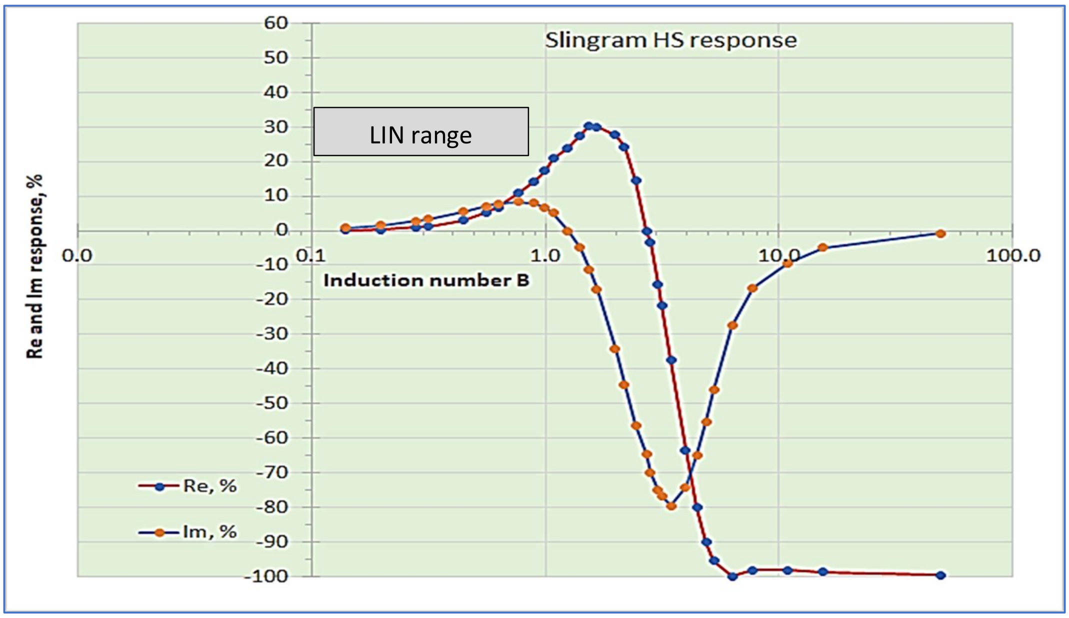

Figure 3. Slingram HCP response curve for half-space earth.

REFERENCES

Geonics Limited, 1980. Electromagnetic terrain conductivity measurement at low induction numbers, Technical Note TN-6, 15 p.

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Saksa, P., 2016. Frequency effects in hand-held electromagnetic short coil spacing data. Poster presentation, EAGE Annual Conference, Wien 2016.