Improved resolution and signal-to-noise ratio of magnetic resonance sounding data using a central loop configuration

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SUMMARY

Magnetic resonance sounding (MRS) is an emerging geophysical method used for direct investigation of the subsurface water content. In this study we introduce the MRS central loop geometry, in which the receiver loop is smaller than the transmitter loop and placed in its centre. In addition, we show how this configuration helps to better estimate the subsurface model as compared with the typically used coincident loop configuration. We describe advantages of the MRS central loop geometry in terms of superior behavior of the sensitivity function, increased sensitivity values, reduced noise level, improved resolution matrix and reduced instrument dead time. The results of our field example are in good agreement with complementary geophysical and hydrologic data.

Key words: magnetic resonance sounding, central loop configuration.

INTRODUCTION

Surface NMR, also called magnetic resonance sounding (MRS) for 1D applications, has been successfully used for groundwater investigations (e.g., Behroozmand et al., 2014). MRS data is typically acquired using a coincident loop configuration, i.e. the same wire loop is employed to transmit the energizing pulse and receive the NMR signal. The goal of this study is to introduce a measurement configuration that improves resolution of the estimated model and increases S/N ratio. We show results of central loop MRS data and compare them with results of coincident loop MRS data. We discuss advantages of the central loop configuration as described in the following sections. Finally, we present the results of our field study and compare them with complementary data available in the study area.

CENTRAL VERSUS COINCIDENT LOOP MRS

We assessed different separated loop configurations, the results of which suggest that using central loop geometry provides a better 1D resolution.

Sensitivity kernels

Central-loop MRS kernel possesses a superior behavior over that of coincident loop. Generally, real and imaginary central-loop kernels have higher amplitudes both throughout the pulse moments and over larger depth intervals. In addition, unlike coincident kernels, central-loop kernels contain additional sensitivity to the shallower subsurface.

Noise level

To compare noise levels in receiver loops of the two configurations, we conducted a comprehensive noise-analysis survey during which we simultaneously measured the noise signal in the coincident and central receiver loops at different sites. The results of our study show that the noise amplitude in the central receiver loop is observed to be considerably lower than the noise amplitude in the coincident receiver loop. This advantage, together with higher kernel amplitudes, suggest increased S/N ratio of central loop MRS.

Resolution comparison

We assesse the accuracy of central-loop MRS parameter determination and compare it with that of coincident-loop data. Resolution matrix comparisons of the two configurations suggest significantly improved model parameter estimate throughout the model space when using a central loop configuration.

Reduced measurement dead time

One of the current limitations of the MRS technique, compared with laboratory and borehole NMR, is the relatively long effective dead time (Walsh et al., 2011) which is one of the reasons why surface-NMR relaxation parameters differ from those of e.g. borehole-NMR data (Knight et al., 2012). Existing instruments have measurement dead time of less than or equal to 5 ms for the GMR (Vista Clara Inc.) and 20 ms for the NUMIS (IRIS Instruments) system. Because central loop configuration uses separate instrument channels for transmitting and receiving the NMR signal, the instrument dead time can be reduced to around zero. This is a great advantage of central loop configuration because it makes signals from finer materials obtainable.

FIELD EXAMPLE

To investigate improved resolution of the central-loop versus the coincident-loop MRS data, we acquired MRS data in the Ristrup area, Denmark. MRS data were acquired using both coincident and central loop configurations. The QT inversion results of the two datasets are presented in terms of water contents and relaxation times as a function of depth. The results of central-loop data show an improved model of the subsurface, compared with that of coincident-loop data. The results agree well with direct measure of water level, complementary airborne electromagnetics data, borehole data and hydrologic model of the area.

CONCLUSIONS

We have proposed central loop geometry as a new configuration for improved 1D MRS investigations. This configuration possesses different advantages in terms of superior kernel behaviour, reduced noise level and increased signal amplitude (i.e. increased S/N), improved model parameter estimate and reduced instrument dead time. The results of our field example verify improved parameter estimation obtained by central-loop MRS data, with no extra time and effort in the field.

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REFERENCES

Behroozmand, A.A., Keating, K., Auken, E., 2014. A Review of the Principles and Applications of the NMR Technique for Near-Surface Characterization. Surv Geophys 1–59. doi:10.1007/s10712-014-9304-0

Knight, R., Grunewald, E., Irons, T., Dlubac, K., Song, Y., Bachman, H.N., Grau, B., Walsh, D., Abraham, J.D., Cannia, J., 2012. Field experiment provides ground truth for surface nuclear magnetic resonance measurement. Geophys. Res. Lett. 39, L03304. doi:10.1029/2011GL050167

Walsh, D.O., Grunewald, E., Turner, P., Hinnell, A., Ferre, P., 2011. Practical limitations and applications of short dead time surface NMR. Near Surface Geophysics 9. doi:10.3997/1873-0604.2010073