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UMRS applications of groundwater induced disaster forecasting in tunneling

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SUMMARY

Underground Magnetic Resonance Sounding applications for tunneling disaster forecasting are introduced. Some challenges has to overcome when UMRS is carried out in underground engineering operations, including advance detection theories, detection with small coils in the extreme underground narrow space, adaptive signal processing for suppressing the strong electromagnetic noises, underground whole space forward modeling and inversion, 2D/3D disaster water data processing and inversion, joint detection of UMRS and TEM methods in complex geological environments. Some case studies of UMRS applications are given in this paper. Compared with other forewarning methods for some practical tunneling operations, we found that in UMRS applications, the signal strength of groundwater induced disaster can be directly detected with the practical identification of fractures containing large volumes of water ahead of the tunneling face.

Key words: SMRS, underground engineering, groundwater induced disaster, forewarning, MRS applications.

INTRODUCTION

Surface Magnetic Resonance Sounding (SMRS) has emerged as a new geophysical technique which allows detecting the abound degree of hydrogen nucleus in the subsurface directly on the ground surface. It has been widely used, not only in groundwater exploration and evaluation, but also in groundwater induced disaster forewarning such as the landslides and dam leakage. However, in the underground engineering such as tunneling and mining, the groundwater induced disasters can also caused by the underground engineering operations. The Magnetic Resonance Sounding methods can be applied for the underground engineering to prevent accidents and to ensure higher efficiency, which we call it Underground Magnetic Resonance Sounding (UMRS). This is a new application area of Magnetic Resonance Sounding (MRS) method, however, the signal strength of groundwater induced disaster is too small to be directly detected with the practical identification of fractures containing large volumes of water ahead of the tunneling face. In this paper, the UMRS applications of groundwater induced disaster forecasting in tunneling are studied. To this goal, some challenges has to overcome when UMRS is carried out in underground engineering operations, including advance detection theories, detection with small coils in the extreme underground narrow space, adaptive signal processing for suppressing the strong electromagnetic noises, underground whole space forward modeling and inversion, 2D/3D disaster water data processing and inversion, joint detection of UMRS and TEM methods in complex geological environments. In the usual surface based measurements, with horizontal loop and water layer, the geometry of the problem can be summarized by the value of the inclination of the Earth magnetic field.

METHOD AND RESULTS

Initial amplitude simulation

For UMRS measurements under the geometric conditions associated with underground tunneling, where the loop is non-horizontal, the geometry can be described in an effective inclination that can be expressed in terms of the Earth magnetic inclination and declination, together with two further parameters that characterize the orientation of the tunnel wall.

We examine the consequences of the different geometries on the UMRS signal. Since the loop size is severely restricted in underground extreme conditions, the feasible target depth is also severely limited.

On the theoretical basis of SMRS method, UMRS of whole space is modeled, and the expression of UMRS signal with vertical coil is derived. After numerical calculation and contrast with the international standard simulation model, it is verified to be accurate. By introducing the rotation coefficient matrix, the vertical component of exciting field with arbitrary direction of earth magnetic field and antenna can be easily calculated. The relationship between UMRS signal and antenna declination angle, as well as inclination angle is studied（Figure 1）. The result reveals that when antenna direction is perpendicular to earth magnetic field, UMRS signal is the largest and over minimum by about 30%. Therefore, an effective mean to improve UMRS signal is by changing the direction of antenna. In addition, the forecasting distance of UMRS is closely related to exciting pulse moment and receiving sensitivity. The larger exciting pulse moment and receiving sensitivity are, the longer advanced detection distance is. However, the distance has a limiting value. In the condition of constrained antenna size of 2 m, the receiving sensitivity of 5nV and the forecasting distance of 30 m, variety antenna modes with transmitting and receiving coincident coil or separation coil are proposed. The coincident coil mode needs 100 turns at least, while the separation coil mode needs 10 turn transmitting coils and 160 turn receiving coil. Moreover, by decreasing the thickness resolution of aquifer can further reduce the turns of antenna and pules moment, i.e. 40 turn coincident coil can detect a 5 m thickness aquifer in forecasting of 30 m. In summary, the method of UMRS and the feasible plan of forecasting for disaster water in tunnel proposed in this paper will promote the development of UMRS equipment and provide technical support for early disaster warning.

Sensors consideration

As discussed above, muti-turn coil configuration should be used in underground conditions. Comparing with the surface MRS, this kind of coil has a large value of inductance, which will lead to the difference system noise. Actually, the NMR system is consists of a LC circuit and a preamplifier, both of which determine the system sensitivity.

The 1m diameter coils with different turn numbers, as well as different preamplifiers were strictly investigated both in the shield room (indoor in Fig.2) and a noise-free place (outdoor in Fig.3). An enameled copper wire with a wire diameter of 1 mm was selected to neglect skin depth effects and reduce the thermal noise of the coil (with the large diameter). Four different preamplifiers were choose with distinct current noise and voltage noise, respectively. Preamplifiers with larger current noise, e.g., OP27 and AD797, performed lower system noise at the fewer turns, whereas the system noise increased when the turn number increase. In contrast, AD 745 and OPA 124 exhibit lower sensitivity down to 0.2 fT/Hz1/2 increased to 270 turns. This is an exciting result which is compared to low temperature SQUIDs. It is suggested that preamplifier should be carefully considered in UMRS. It should be matched to the parameters of coil with different diameter.

Noise cancellation and Inversion stagey

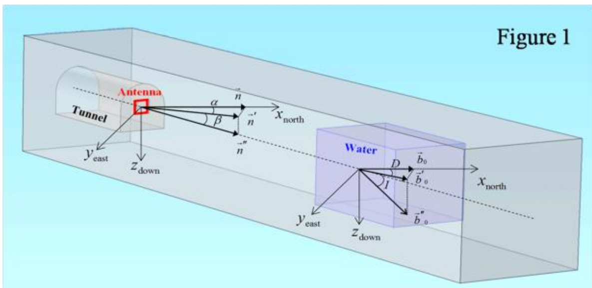
It has been proved that the noise conditions for UMRS is even more severed compare to the SMRS detection. Some of the machine and engineering work can not be stopped for the safety aspects. We therefore developed the integrated broadband and narrowband multi-channel JLMRS instrument. With the narrowband working mode (around 100 Hz), the environmental noise can be reduced in the hard ware level. This will benefit to the system and avoiding the noise saturation of the channels. Also, to suppress the stronger noises in tunneling extreme environments, the fixed reference coils and differencing coil techniques are undergoing studied.

Compared with the surface measurement, SMRS is in the half space and the UMRS is in the hole space. The half space detection kernel function profile for subsurface measurement has to be changed as the full underground space detection kernel function profile for underground measurement and the tunneling space has to be calculated to get the practical measurement results. At present, we considered the 3D structure inversion for the tunnel. Fig.4 shows the simulation results of the 3D inversion using the iterative algorithm of Gauss-Newtown method and linear search. Assuming the coil is 6 m size and 30 turns, the larmor frequency is 2000 Hz, and the I=40°. 30 pulse moment were exponential distributed from 0.01 As to 3 as. The water structure are located ahead of 10-15 meter with the water content of 50%. The initial amplitude curved were shown in Fig.4 a. Fig.b~d showed the x-y,y-z, x-z planes of the aquifer 3D inversion results.

Applications

UMRS has been applied to the practical tunneling groundwater induced disaster prediction in some tunneling operations. Figure 2 is the UMRS application in the Maijishan tunneling operation of BaoLan Railway in China. The initial amplitude of the shallow aquifer has been acquired.

Figures and Tables



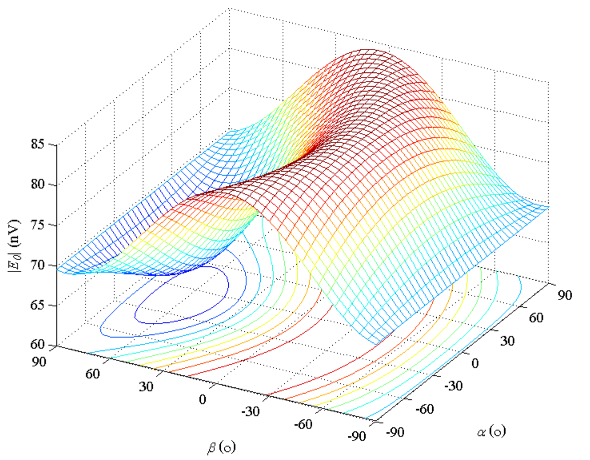


Figure 1. (a) Graphical definition of two angles for characterizing the normal to a tunnel-face antenna, and the geomagnetic inclination and declination. (b)UMRS signal with different antenna directions.

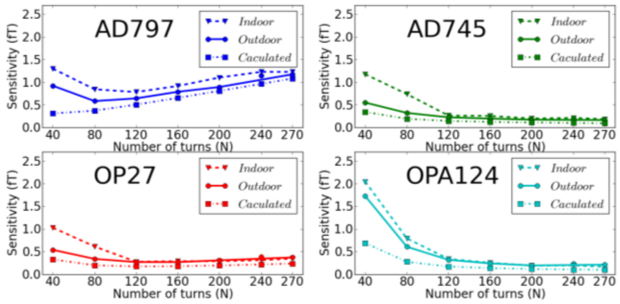


Figure 2. UMRS system noise evaluation using different preamplifiers, theratical results, indoor results and outdoor results were shown.

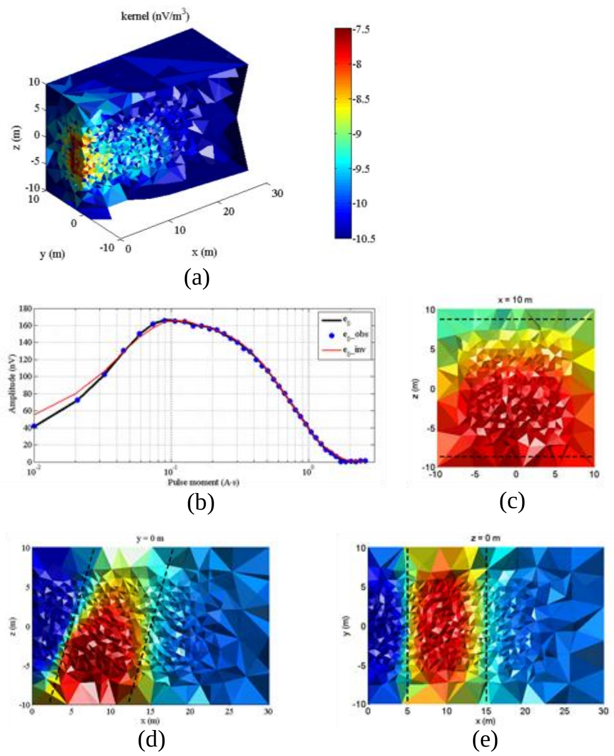


Figure 3. Advanced water detection 3D modeling. (a) Kernel 3D function (b) Initial amplitude curve (c) y-z plane 3D inversion (d) x-z plane 3D inversion (d) x-v plane 3D inversion.

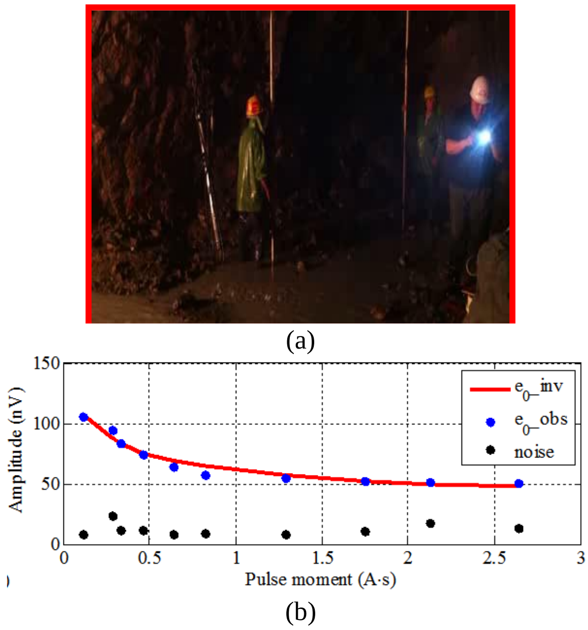


Figure 4. Maijishan tunneling UMRS groundwater induced disaster forewarning detection. (a) Measurement photo; (b) Groundwater content forecasting in the tunneling face.

CONCLUSIONS

Since 2010, the UMRS applications of groundwater induced disaster forecasting in China have been conducted to tunneling operations for railway and metro construction. Compared with other forewarning methods for some practical tunneling operations, we found that in UMRS applications, the signal strength of groundwater induced disaster can be directly detected with the practical identification of fractures containing large volumes of water ahead of the tunneling face.

REFERENCES

Roy, J., and Lubczynski, M., 2003, The magnetic resonance sounding technique and its use for groundwater investigations: Hydrogeology Journal , 11, 455–465.

Greben, J.M., Meyer, R., and Kimmie, Z., 2011, The underground application of Magnetic Resonance Soundings: Journal of Applied Geophysics, 75, 220–226.

Girard, J.F., Legchenko, A., Boucher, M., et al., 2008, Numerical study of the variations of magnetic resonance signals caused by surface slope: Journal of Applied Geophysics, 66, 94-103.

Walsh, D.O., 2008, Multi-channel surface NMR instrumentation and software for 1D/2D groundwater investigations: Journal of Applied Geophysics, 66, 140-150.

Trushkin, D.V., Shushakov, O.A., and Legchenko, A.V., 1994, Application of the integrated NMR-TDEM method in groundwater exploration in Israel: Geophysical Prospecting, 42, 855–862.

Legchenko, A., Descloitres, M., Vincent, C., et al., 2011, Three- dimensional magnetic resonance imaging for groundwater: New Journal of Physics, 13, 1-17.

Jiang, C.D., Lin, J., D, Q.M., et al., 2011, Statistical Stacking and Adaptive Notch Filter to Remove High-level Electromagnetic Noise from MRS Measurements: Near Surface Geophysics, 9, 459-468.

Lubczynski, M.W., and Roy, J., 2005, MRS contribution to hydrogeological system parameterization: Near Surface Geophysics, 3, 131–139.