REAL-TIME MONITORING OF GEOLOGICAL CONDITIONS DURING MECHANIZED TUNNELLING BY MEANS OF BEAM4 METHODS

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Geoelectrical Monitoring of TBM-Grounding (CS), Complex Impedance (CI), Induced Polarization (IP), BEAM4 Integral, BEAM4 Scan.

INTRODUCTION

BEAM4 technology is focused on geoelectrical measurement concepts for mechanized tunnelling, applied for patent at first 1998 and optimized continuously since then. In 2007, the fourth generation of layout and system configurations has been inaugurated by QuMon.
Through dynamic electrical profiling using TBM, TBM-grounding CS (Complex Scatter), Complex Impedance and Induced Polarization are monitored in real-time while downtime and boring by BEAM4 Integral or BEAM4 Scan methods.
CS spectra, which are mainly due to the interface conditions TBM-to-rock, are used to indicate the current characteristics of rock mass or sedimentary deposits encountered.
CI and IP values determined serve to predict geological conditions ahead or nearby the tunnel contour. Occurrences of water-bearing zones and other significant volumes of sufficient parameter contrasts compared to the geological background are detected in advance within the prediction ranges, which are a function of the tunnel diameter, BEAM method in use and heterogeneity of geological conditions.
BEAM4 monitoring processes run completely automated through electrode placements on TBM and in tunnel and by electronic interfaces to the TBM guidance system. Operation maintenance is carried out through internet access.

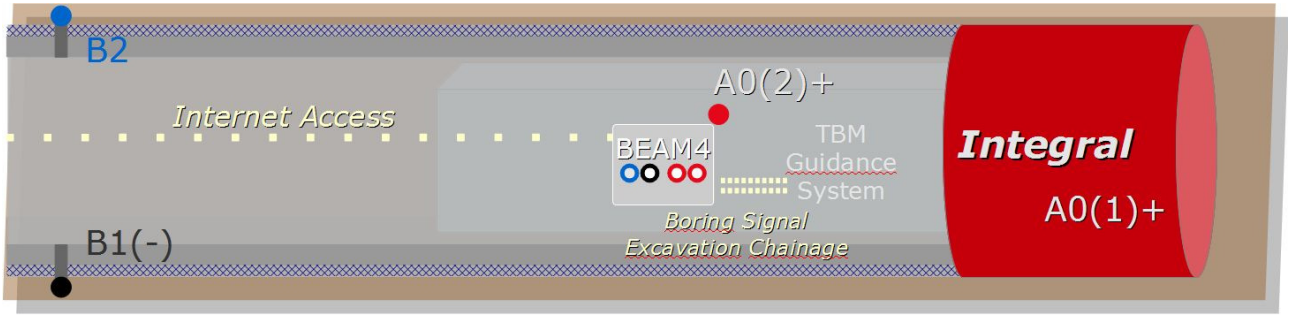
BEAM4 METHODS FOR GEOELECTRICAL AHEAD MONITORING

BEAM4 methods comprise a range of electrical configurations, layouts and interpretation concepts, which enable the use of TBM or parts of it as sensors for the investigation of rock conditions encountered and for geology prediction. In-situ geological conditions and the ahead situation in a distance are permanently mirrored integrative or by selective scans.
BEAM4 operations are steered by control programs implemented in smart system units (s. photo). Raw data recorded and parameters derived are stored against time (UTC), chainage and tool angle in case of Scan method.
Real-time results are displayed by BEAM4 Visual programs through representative graphs or diagrams. Moreover

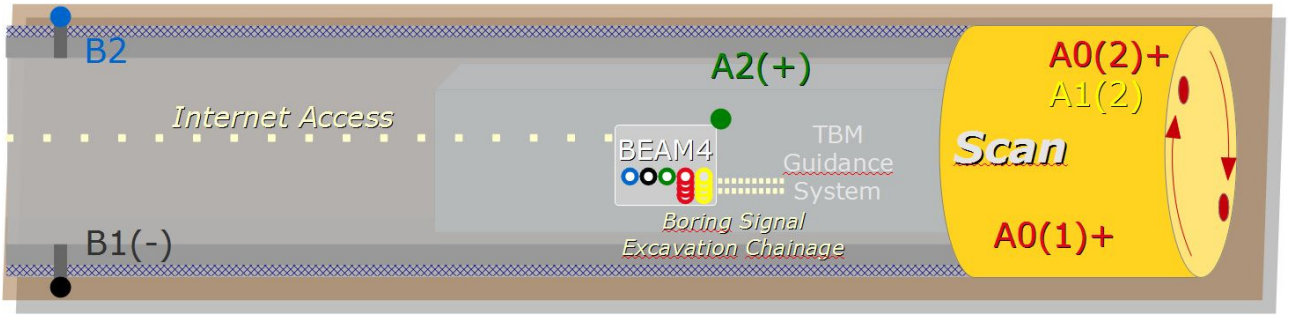
BEAM4 Scan enables to identify stratification and detection of obstacles in or nearby the tunnel contour ahead.

Principles of Electrical Layout and Measurement Concepts for Integral and Scan Method

BEAM4 Integral uses the whole TBM for continuous geoelectrical profiling along the tunnel axis. Two welding points inside the TBM serve as A0(1) for ground current sensing and A0(2) as ground current reference, thus controlling the electrical current flow via TBM against B1, used as counter electrode, with B2 as reference electrode. B1 and B2 are fixed in rock e.g. in back tunnel.

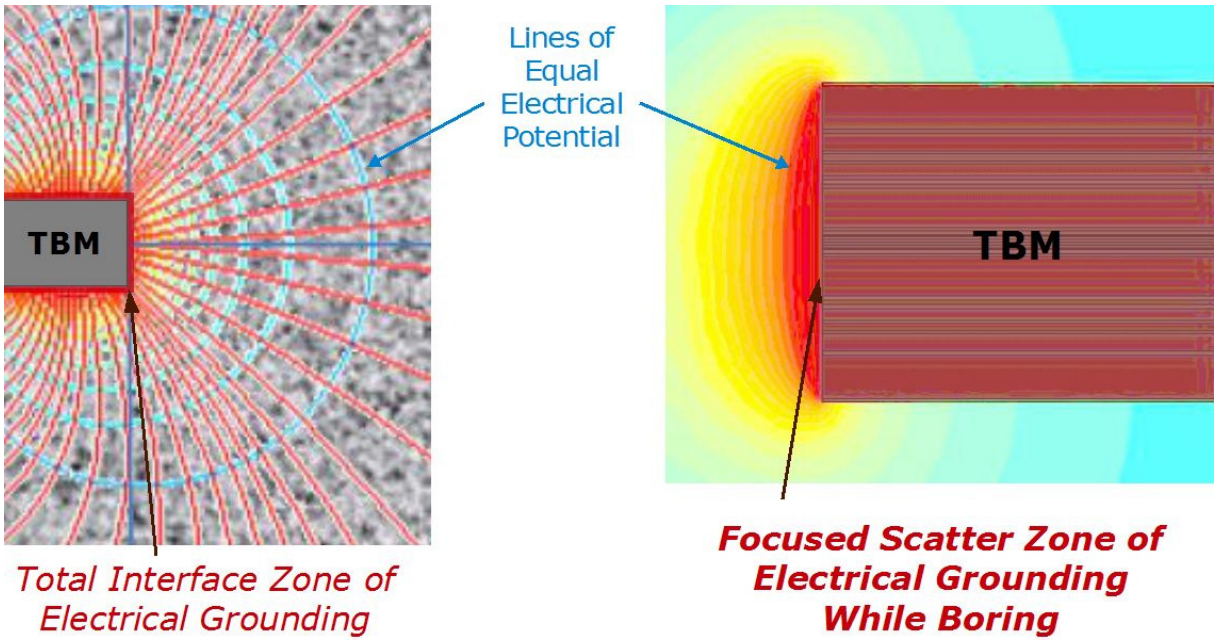


BEAM4 Scan method acquires data in two axes, i.e. parallel and vertical to the tunnel axis, whereby A0(2) is used as current sensor, A1(2) for voltage control and A2 for guard current feed (see below).

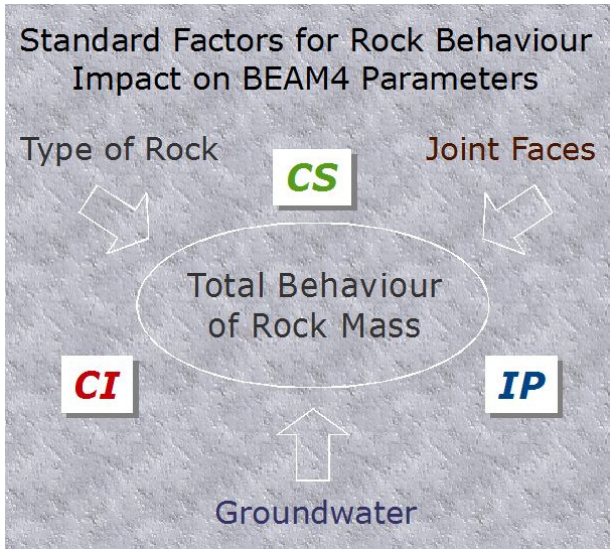


Dynamic Sensing of CS to Characterize the Electrical Interface TBM-to-Rock

The determination of CS spectra points out the fluctuations of TBM-grounding. CS spectra increase due to TBM boring in general, moreover anomalous peaks appear e.g. in case of rock burst.



Electrical Parameters Related to Standard Factors of Rock Behaviour

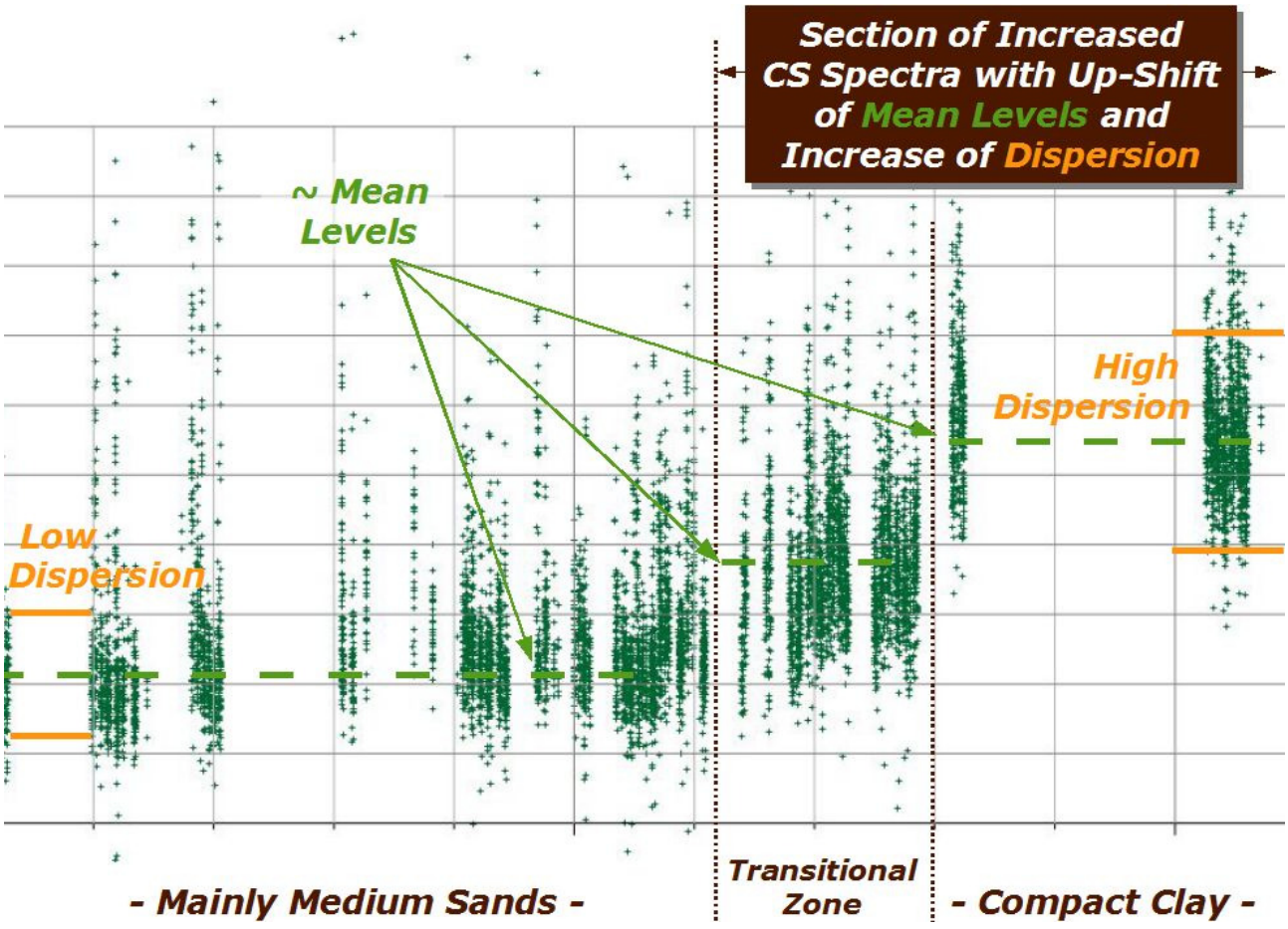


CS spectra shift in levels and show higher dispersion during the period of a stroke. CS while boring is basically correlated to the factors 'type of rock' and 'joint faces' of in-situ rock (s. chart on right). Since e.g. rock burst can cause spontaneous CS peaks, CS monitoring also serves to provide criteria for sorting out non-valid CI and IP values in case. Thus quality of geology prediction is improved, when sequences of CI and IP data are revalued which are affected by anomalous CS peaks.

CS spectra acquired by BEAM4 Scan enable to explore the selective behaviour of native rock in detail. In-situ stratification and different mechanical layer characteristics are prospected by CS spectra accordingly.

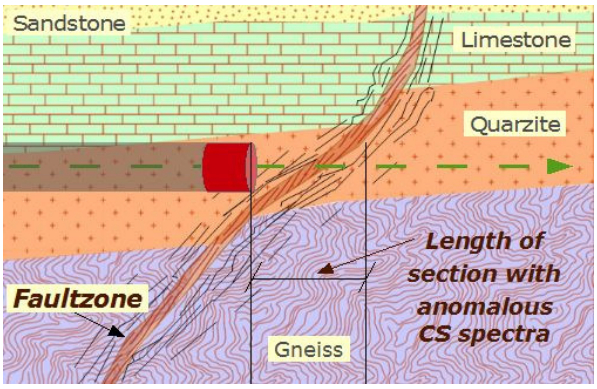
Widths of fault zones and positions of ground changes of geotechnical relevance can be detected by change of CS spectra, in certain cases even for unchanged CI and IP behaviours of rock.

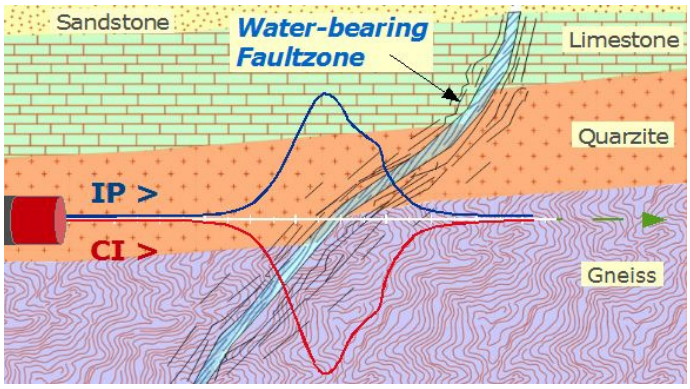
This is advantageous for mechanized tunnelling particularly with shield machines, where no possibility for visual checking of in-situ geology is given (s. example chart below).



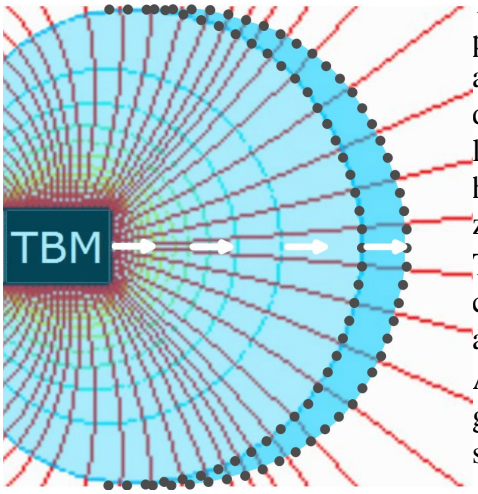
Features of Real-Time Ahead Monitoring of CI and IP while Heading

CI and IP of rock are essentially related to the amount of mineral-conducting constituents and the contents of more or less mineralized water in the pores, fractures and fissures. Membrane and electrode polarization enhance the complex frequency-dependent behaviour of resistivity of rock. Water-bearing fault zones e.g. modify CI and IP levels acquired through TBM increasingly during approach, as shown in principle for a crossing water-bearing zone on right below.





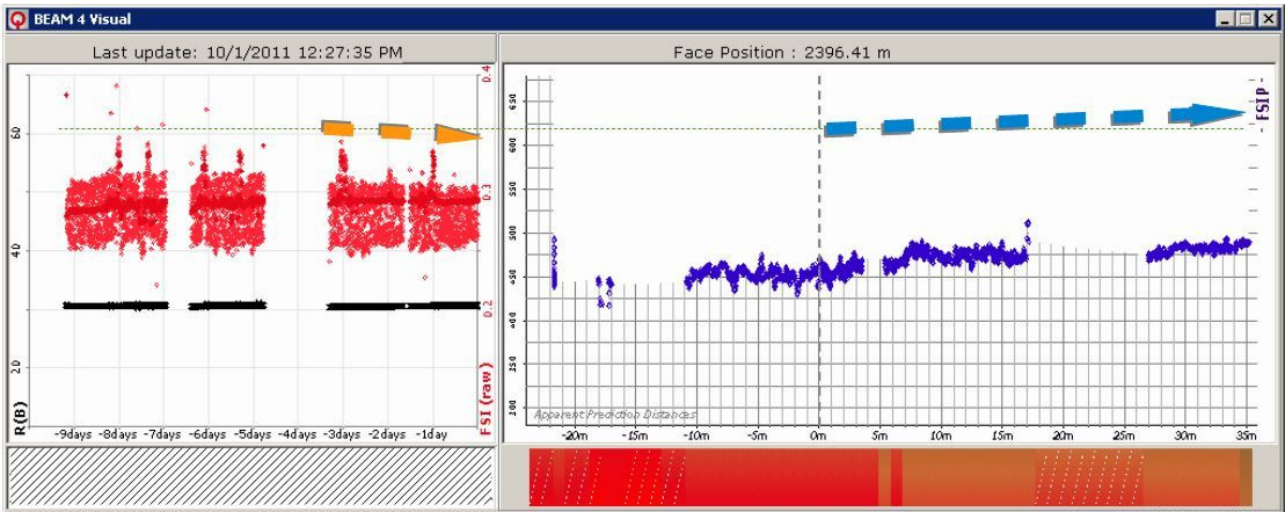
BEAM4 Integral Method – Geoelectrical Profiling along Tunnel Axis for Geology Prediction



The sensitivity range of the TBM used for geoelectrical profiling is related to the tunnel diameter. Due to TBM advance, rotation-symmetric crescent-shaped differential zones develop as shown in 2D-view on left by margins of grey dotted lines for two selective TBM positions ahead, i.e. in case of homogeneous geology. Shapes and distances of 3D-differential zones differ in case of heterogeneous geology.

The interpretation of CI/IP data regarding ahead geology conditions is carried out by comparison with anteceding amplitudes from non-critical TBM heading, taken as reference.

Abrupt changes of geological conditions in front of heading generate exponential incline of CI/IP before encountering, as shown by fault zone example on chart up right.



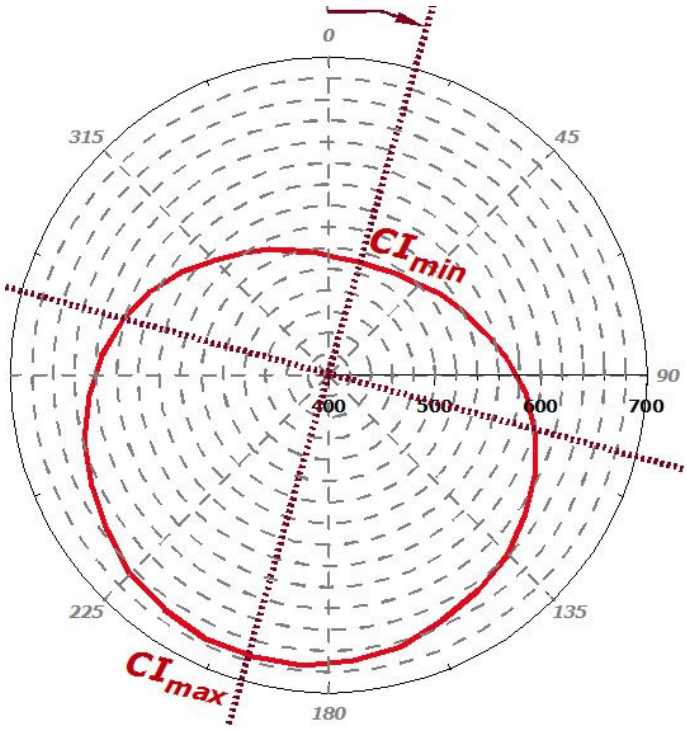
Smooth changes in rock or ground, e.g. due to gradually widening of pore spaces with water-bearing and increasing permeability, appear as linear increase or decrease of CI/IP levels (s. case above: detail of BEAM4 Visual real-time display).

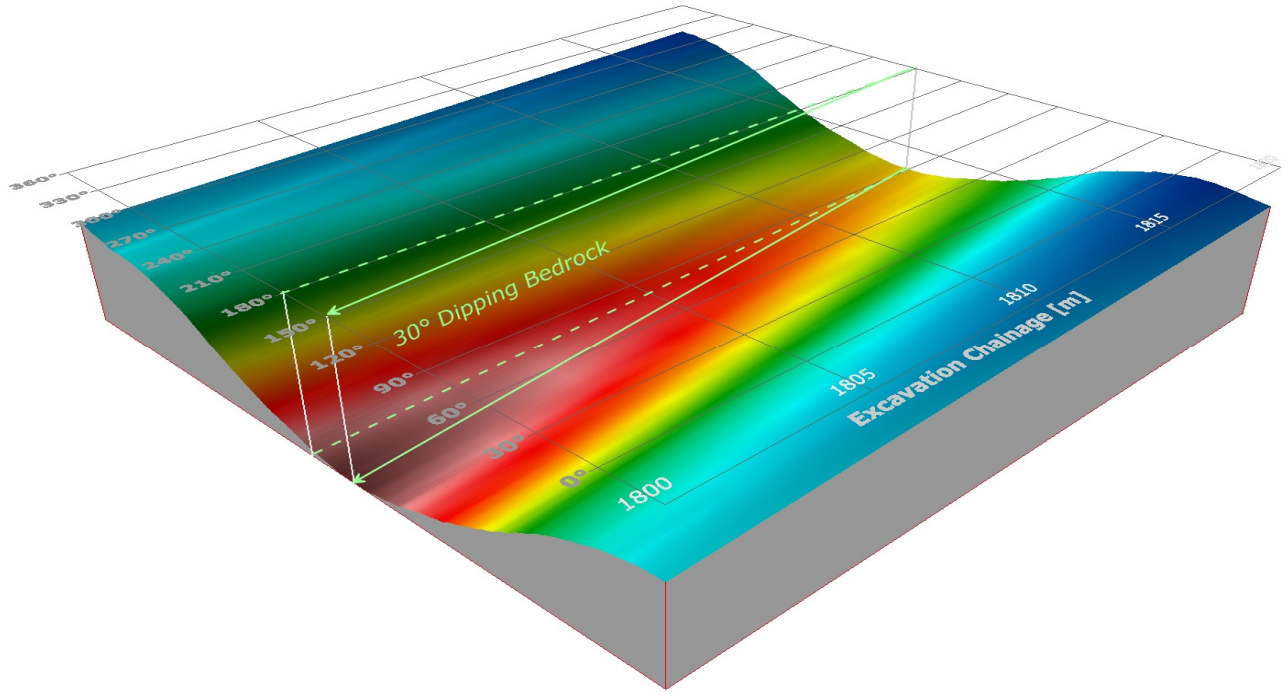
BEAM4 Scan – Geological Prospection with one Focused Electrode or Electrode Group

BEAM4 Scan data are recorded along orbits of electrically isolated single cutting tools or groups, which require special mechanical adaptations within the cutting wheel, wire connections, rotary feedthrough and tool angle decoder. This measures need to be provided by TBM owner or manufacturer before BEAM application can start.

Real-time Scan data are displayed per stroke by polar diagrams, to identify anisotropies of parameter amplitudes. In case of polar anisotropies, linking lines between minima and maxima mark the inclination of stratification (chart on right).

Moreover combined visualization of data strokes enables to develop polar data along the excavation chainage to give an easy overview of dipping strata as shown by example below.

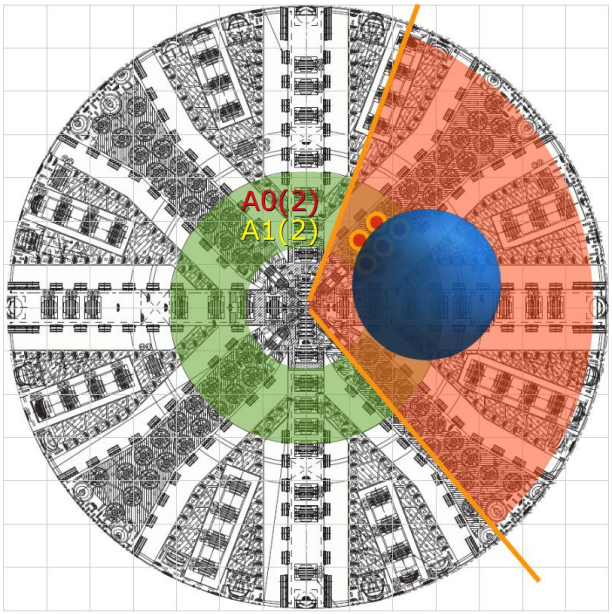


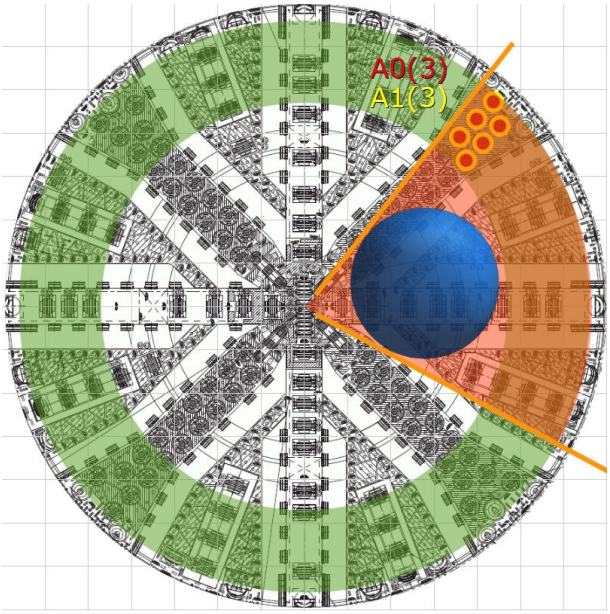


BEAM4 Scan – Geological Prospection with two or more Focused Electrodes or El. Groups

If two or more electrodes or electrode groups are used, obstacles within the tunnel contour like karst cavities or e.g. UXO etc. can be detected by determination of different angle widths of distortion of

parameter amplitudes (s. charts below with two different tool group orbits (green) and areas of amplitude distortion marked in orange).





CONCLUSIONS

BEAM4 methods comprise electrical configurations, layouts and interpretation concepts, which enable the use of TBM or parts of TBM for the investigation of in-situ and ahead rock conditions. BEAM4 operations are steered by smart control units. Graphical displays and draft data interpretation schemes provide criteria for fast on-site decisions through BEAM4 Visual programs. Post-processing and interpretation algorithms as well as visualization techniques enable to print out advanced continuous documentation.

Chainage information and boring signal are needed from project site, internet access is recommended. Rotary feedthroughs, wirings and angular positioning data of electrode tools are required for BEAM4 Scan applications. Installation assistance, taking into operation as well as BEAM4 system provisions and application training are part of QuMon services.

Detection targets need sufficient electrical parameter contrast compared to the geological background and significant sizes in relation to the TBM (Integral) or drivage electrodes (Scan).

Targets in detail:

BEAM4 Integral:

- Water-bearing zones, fault and karstified zones
- Foundation structures or other anomalous volumes of significant sizes and/or electrical contrasts compared to tunnel diameter

In addition for BEAM4 Scan:

- Identification and dipping of strata
- Obstacles, cavities, UXO, smaller foundation structures or other anomalous volumes

REFERENCES

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