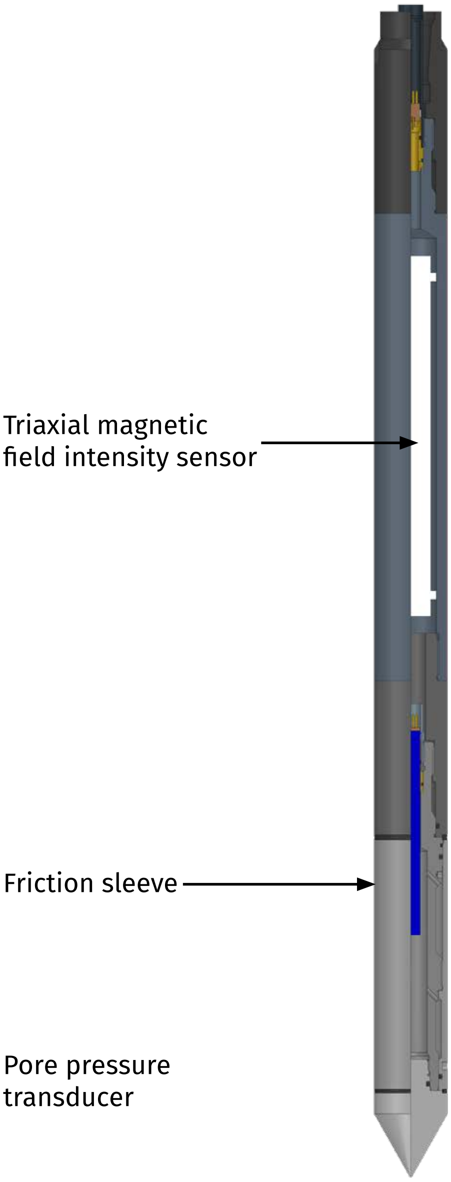
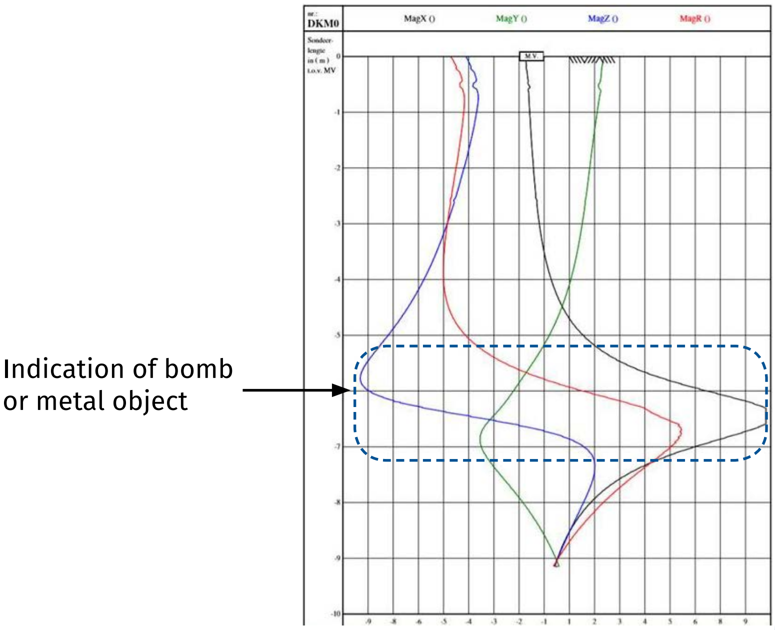
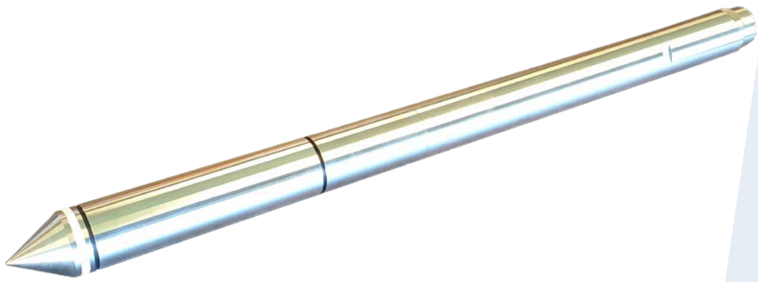
Eijkelkamp GeoPoint
SoilSolutions

# Magnetometer cone

## User manual



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## On these operating instructions

☞ **If the text follows a mark (as shown on the left), this means that an important instruction follows.**

⚠ **If the text follows a mark (as shown on the left), this means that an important warning follows relating to danger to the user or damage to the apparatus.The user is always responsible for its own personal protection.**

*Text* **Italic indicated text indicates that the text concerned appears in writing on the display (or must be typed).**

## 1. Introduction magnetometer cone

A magnetometer is a scientific instrument used to measure the strength and/or direction of the magnetic field. The earth's magnetic field (the magnetosphere) varies from place to place, for various reasons such as inhomogeneity of rocks and the interaction between charged particles from the sun and the magnetosphere. A mass of ferromagnetic material creates though a detectable disturbance in this magnetic field. This magnetic anomaly produces a weak alternating magnetic field that is picked up by the magnetometer, amplified electronically, and fed to the DAC system and subsequently recorded on a computer.

Magnetometers are typically used in ground-based electromagnetic geophysical surveys (such as magnetotellurics and magnetic surveys) to assist with detecting mineralization and corresponding geological structures and the detection of buried or submerged objects.

## 2. Gradient magnetometer method

The magnetic field of the earth is homogeneous with regards to the field strength and the direction of the field strength. If a ferromagnetic object is brought into this homogeneous field, the own field of the object is superposing the local magnetic field of the earth, hence creating a distortion. With increasing distance from the object the field distortion is decreasing.

The extent of the distortion depends on several factors. The most important ones are the size of the object to be detected and its permeability. The larger the object to be detected is the larger will be the detection distance.

If the buried object is magnetized, i.e. it has an own magnetic field, the field lines are reacting according to the polarity of the object. In general, the total disturbance of magnetized objects is larger than the disturbance of objects having no own field. But very rarely the total disturbance might even be smaller depending on the object orientation towards the terrestrial magnetic field.

UXO detectors are differential magnetometers, i.e. multiple sensors are arranged in geometrically true alignment at a certain distance and are connected in a way that they measure the value zero in a homogeneous field. Each sensor passing a ferrous object is differently affected. The indication of the gauge is in nT and deflects depending on the orientation of the object in the ground.

# 3. Magnetometer unit

The magnetometer unit itself can either be equipped with a dummy tip or mounted on top of an electric S15CFI(P) (piezo-)cone made of a high-grade non-magnetic steel. Due its high strength and small diameter (44 mm) the magnetometer cone is capable of penetrating soils up to greater depths with relative ease. The magnetometer cone can, in the configuration with a (piezo-)cone, also collect CPT(U) data, such as cone tip resistance (qc), lateral sleeve friction (fs) and in-situ pore pressure (p) needed to produce soil profiles and pile designs simultaneously in one operation. This saves the costs of running two operations.

The magnetometer cone and (piezo-)cone share the same (non-standard) 16-pins CPT sounding cable for data transmission to the surface. This 16-pins sounding cable goes to the signal conditioning box, where the signals coming from the electric (piezo-)cone go directly to the GeoLogger data acquisition system. The signals coming from the magnetometer sensors are made suitable (conditioned) for recording by the data acquisition system. The GeoExplorer data acquisition software fully supports the magnetometer and produces magnetometer test results graphed against depth in an Excel-format for further processing.

The magnetometer cone allows for tri-axial magnetometer testing for magnetic anomaly modelling. The magnetic field is measured in three orthogonal directions and a resultant is calculated as well. Furthermore, the gradient of the resultant will be calculated, which gives a much better indication of changes in the magnetic field.

As the magnetometer survey begins, the module containing the tri-axial magnetometer and, if mounted, the CPT(U) electric (piezo-)cone is pushed into the ground by means of a CPT penetrometer rig. The magnetometer cone can detect magnetic anomalies up to 2 m away laterally so that each probe position clears a vertical cylinder of land up to 4 m diameter. Please do realise that the sensibility of the magnetometer diminishes with distance.

The magnetometer cone generates data from all three directions and transmits these signals separately to surface so that the anomalies can be fully modelled using geophysical software helping to define the source and character of any anomaly.

# 4. Possibilities and advantages

The magnetometer cone has two major advantages over other systems for magnetic anomaly modelling, i.e.:
- In situ tests are done without pre-drilling or any other preparation
- It generates both geotechnical and magnetic field data simultaneously in one single push

Since the magnetometer senses variations in the subsurface magnetic field materials and relays these variations to a geophysicist in real time, it is an excellent tool to identify metal targets to depths exceeding 20 m in soft sediments. This high-resolution method has proved to be very suitable for:
- Unexploded bomb/ordnance surveys (UXB/UXO)
- Determination of the driving depth of foundation piles
- Determination of the length of sheet piles
- Determination of the position of retaining or tieback anchors
- Determination of the position of power cables

Advanced processing provides the option of producing a detailed 3D model of site hazards.

# 5. UXB/UXO Unexploded Bomb Detection

The magnetometer has proven to be a highly efficient tool for the detection of ferrous UXB/UXO, due to its capability to model magnetic anomalies. Since the magnetometer cone is used primarily for this purpose, we wish to elucidate its capabilities.

Unexploded ordnance surveys are important to reduce and manage the underground risks faced by construction contractors on many bombed sites in areas underlain by relatively soft soil. The typical depth of investigation for an unexploded bomb survey is 6 ... 15 meter.

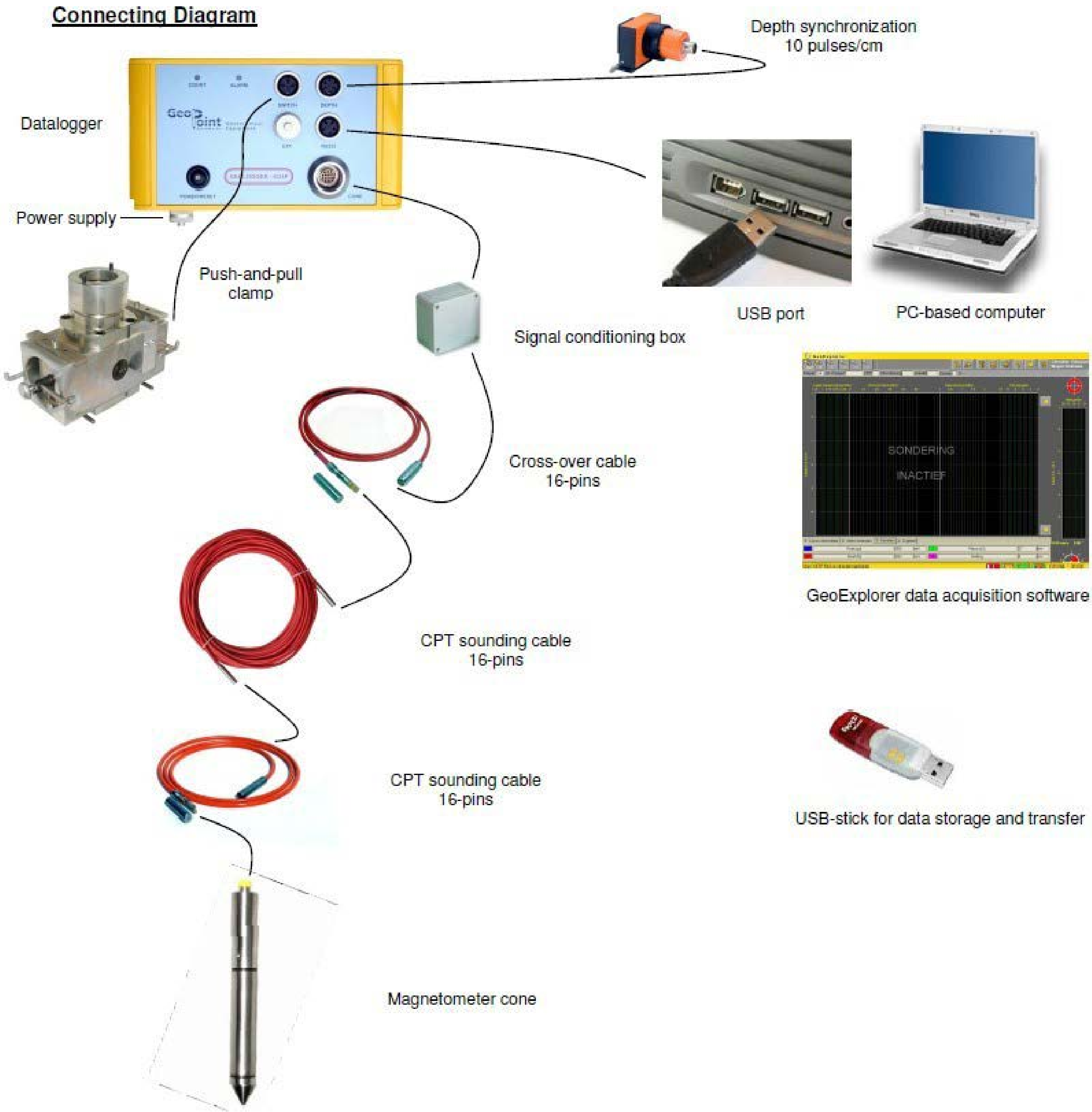
The magnetometer cone rapidly maps in-ground structures with a high-resolution and enables to detect and locate ferrous unexploded ordnance. The fact that the Magnetometer cone can be pushed into the ground using the effective direct-push CPT technology allows for exceptional productivity and associated cost savings, ensuring you to deliver projects on time and on budget.

The magnetometer cone clears the way for piling, excavation and tunnelling by confirming a site is safe from unexploded ordnance. Obstacles can be avoided by using the information to modify pile location plans or to conduct a bomb clearance programme if necessary. It is vital for the redevelopment of locations where ordnance or buried obstructions may pose a special risk -such as sites that were subjected to wartime bombing, and former military ranges.

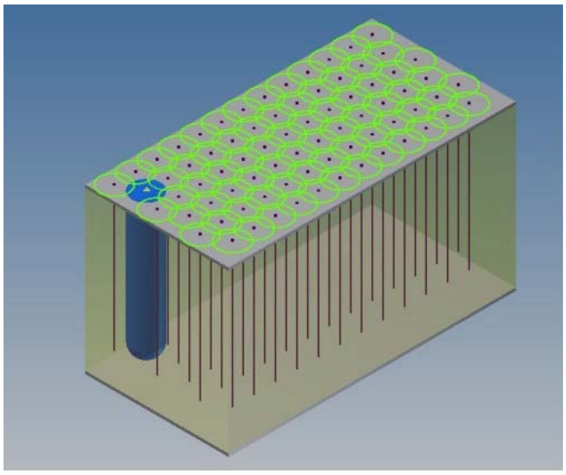
# 6. Technical specifications

| **Item** | **Specification** |
|---|---|
| Measuring range | 100,000 nT or 250,000 nT |
| Sensitivity | 1 nT |
| Accuracy | Better than 0.5% of the full scale (FS) |
| Resolution | Better than 5 nT (10nT for the 250,000 nT version) |
| Resolution in Z-axis direction | 10 mm |
| Noise level | Less than 20 pT |
| XY inclinometer | Measuring range +/-25°(accuracy better than 0.1°) |
| Working temperature | 0 -60°C |
| Length of the magnetometer module | 350 mm (excl. cone or dummy tip) |
| Length in combination with a dummy tip | 500 mm |
| Length in combination with a non-magnetic S15 type (piezo-)cone | 750 mm |
| Diameter | 44 mm |
| Material | Non-magnetic wear resistant steel |
| Orientation marking | “North” marking on the exterior of the housing (Y-axis) |
| Screw thread on top | Standard tapered thread on top for connection to the string of CPT sounding tubes |
| Max. load on the cone (tip + sleeve) | 80 kN |
| Connector on top | Lemo 16-pins |

## Connecting Diagram



## 7. Determination of testing spots



The magnetometer cone measures the changes in the magnetic field in both the X, Y and Z direction. During the penetration procedure a “vertical cylinder” with a certain diameter is scanned. Since the accuracy of the measurement diminishes with the distance from the magnetometer, the operating company has to determine in close deliberation with the project owner what the distance between the testing spots has to be.

The image on the right shows a typical magnetometer testing field in which the rows of testing spots are positioned such, that there is an overlap between the different testing spots assuring perfect scanning. The fluxgate sensor of the magnetometer cone measures in X, Y and Z direction. This makes it possible to determine the position and orientation of an object. Built-in bidirectional inclinometer in line with the XY sensors with for determination of the orientation of the magnetic field.

## 8. Compass orientation


The North Magnetic Pole is the point on the surface of the earth at which the planet’s magnetic field points vertically downwards. This implies, that if a magnetic compass needle is allowed to rotate about a horizontal axis, it will point straight down when it is over the North Magnetic Pole.
The magnetometer cone is provided with an orientation marking, i.e. a “North” marking on the exterior of the housing pointing in the Y-direction. Using an accurate compass makes it possible to do all magnetometer tests with the same orientation. This makes it possible to compare all tests done and to locate objects disturbing the magnetic field.

## 9. Testing speed

**The penetration speed depends strongly on the risk; the risk of hitting or overlooking an unexploded ordnance or hitting an obstacle like a boulder or a hard layer. These risks have to be assessed first.**

When using the magnetometer in combination with an electric CPT cone, the penetration speed is max. 20 mm/sec. In cases where the magnetometer is used as stand-alone unit, the operator can penetrate the soil with other speeds. Maximum penetration speed is limited to 50 mm/sec.

## 10. Accuracy vs. sensitivity

The magnetometer cones features a sensitivity of 1 nT. Absolute measuring values aren’t important; those values represent the natural magnetic field (approx. 62.000 nT) and is considered to be constant. It is the change in these magnetic field values that is important.

That implies that there is an anomaly of some kind present effecting the magnetic field. It is up to the supervisor or operator to determine the magnitude and character of this object and how to deal with this anomaly.

The magnetic field is measured in 3 orientations. The largest and therefore most important component are the values measured in the "z" direction. These values have for this reason most effect on the calculated resultant of the measured values in 3 orientations.

If required the gradient of the resultant can be calculated and displayed as well. The gradient is the 1st derived value of the resultant. When the magnetic field is constant, this gradient will be "zero". As soon as a change in the magnetic field occurs, the gradient will change. This enables the operator to detect changes in the magnetic field more rapidly. The graph of the gradient is yellow (and will not be displayed in a digit format). The display of the gradient can be activated by pressing "*G*" on the keyboard.

The GeoExplorer software also has the possibility to display the average value of the gradient. This average value is much more fluent. The display of the average value of the gradient can be activated by pressing "*B*" on the keyboard. Pressing "*G*" or "*B*" again deactivates the display of the gradient and average gradient graphs.

Considering the fact that the magnetometer values measured in 3 orientations differ considerably one from the other, it is recommendable to have these graphs centred around the "zero" axis. The values in digit format will never be set to "zero" ("*CTRL+HOME*"). It is an on/off toggle functionality. Now it is possible to zoom in into the graphs ("*Alt-↑*"). In case the 3 graphs would not be centred around the "zero" axis, the graphs will be too far apart making zooming in impossible.

The CPT penetrometer rig is a massive metal object having a great influence on the magnetic field just underneath the rig. During the first 4 metres of penetration only the influence of the CPT penetrometer rig is measured. It is for this reason highly recommendable to do a preliminary site scan with a hand carried magnetometer with the CPT penetrometer rig parked at a distance.

The centring of the graphs around the "zero" axis is only to be done when the CPT penetrometer rig has no influence no more on the magnetometer readings and all values are more or less constant. In order to reduce "noise" and to improve the resolution of the graph the factor over the gradient can be increased ("*CTRL-↑*") or decreased ("*CTRL-↓*").

Please do realise that the sensitivity and accuracy of the magnetometer diminishes with distance. During the first stage of magnetometer testing there is also the magnetic effect of the CPT penetrometer pushing rig to be reckoned with. The scale of the graphs is to be adjusted such, that the slightest disturbance of the magnetic field is observed. This implies the highest resolution possible.

The integrated bi-axial inclinometer sensor enables to determine accurately deviation of the vertical axis the actual testing depth.

## 11. Independent supervision

**When a magnetometer is deployed for unexploded ordnance surveys it is strongly recommended or even compulsory by law to have the UXO/UXB surveys supervised by degree-qualified geoscientist / geophysicist with appropriate experience to ensure that the surveys are conducted within the limitations of the equipment. This person ought to have authority to stop the probing if a UXB is detected or suspected.**

The geophysicist should monitor the magnetometer tests; he can view all data sets and soil profile being plotted in real-time on the computer screen whilst the magnetometer cone is being pushed.

**If a suspicious magnetic anomaly comes into view then the test may be stopped and the anomaly is to be identified by excavation if necessary.**

# 12. Data file

The measured values are stored in "*L*" and "*1*" log files are in count units and are to be converted into engineering parameters. The conversion of the count units in mV values is pretty straightforward; 3 count units equal 1 mV. By means of the data stored in the calibration file these mV values can be converted in the relevant engineering parameters.

Every line represents the data recorded over 1 cm depth (= 10 pulses generated by the depth synchronisation encoder).

Every line consists of 12 different elements, i.e.:

- Element 1: represents the cone resistance (in count units)
- Element 2: represents the local sleeve friction (in count units)
- Element 3: represents the pore pressure (in count units)
- Element 4: represents the inclination in the "x" direction (in count units)
- Element 5: represents the inclination in the "y" direction (in count units)
- Element 6: represents the magnetometer read-out in "x" direction (in count units)
- Element 7: represents the magnetometer read-out in "y" direction (in count units)
- Element 8: represents the magnetometer read-out in "z" direction (in count units)
- Element 9: represents the total number of pulses generated by the depth synchronisation encoder since the beginning of the CPT test. 10 pulses equal 1 cm penetration length.
- Element 10: represents the depth (in cm)
- Element 11: represents the time (in seconds) lapsed since the beginning of the CPT test
- Element 12: represents the time (in hundreds of seconds) lapsed since the beginning of the CPT test. So the description |41|95| for element 11 and 12 is to be read as 41,95 seconds elapsed since the beginning of the CPT test.

The actual penetration speed can be recalculated from the CPT data file. Furthermore it is possible to calculate the graph showing the penetration speed over the entire CPT test (removing the time for adding extra tubes and "smoking/talking") from the information stored.

# 13. Interpretation

☞ **It is extremely important to be well aware that the interpretation of magnetometer data is a specialist job and not to be judged lightly.**

For more information on this subject, please consult the following publication:
"Interpretation of borehole magnetometer data for the detection and characterization of unexploded bombs" by Q. Zhang, W. Al-Nuaimy, and Y. Huang.