OPERATION MANUAL

Overhauser magnetometer
MiniMag

Contents

INTRODUCTION

This operation manual (hereinafter referred to as OM) is designed for studying the device, its principle of operation and proper use of the **Overhauser magnetometer MiniMag** (hereinafter — magnetometer / device / product) by the operating personnel.

This OM contains information about the configuration, design, principle of operation, technical characteristics of the magnetometer, operational limitations; instructions for preparing for operation, usage, transportation and storage; safety precautions; disposal instructions and other information regarding the magnetometer necessary for its correct usage in order to maintain the operational reliability and safety of the device.

ATTENTION: REPAIR OF THE MAGNETOMETER IS CARRIED OUT EXCLUSIVELY BY THE MANUFACTURER (GEODEVICE) or by specialized services and professionals who have been trained and have a certificate for the right to carry out repairs, issued by GEODEVICE.

The requirements of this OM are mandatory for all persons involved in the operation, storage, transportation, further disposal and other manipulations with the magnetometer.

This OM should always be in close proximity to the place of operation of the device and be accessible to operating personnel.

The operational reliability and safety of the magnetometer is guaranteed only if all of the following conditions are met at the same time:

- usage of the device for its intended purpose;

- operation of the magnetometer in acceptable environments and conditions in accordance with the OM;

- compliance with the instructions for use, safety measures and all other recommendations and requirements of this OM.

IT IS PROHIBITED TO OPEN / DISASSEMBLE THE MAGNETOMETER, AS WELL AS TO MAKE MODIFICATIONS IN THE DESIGN OF THE DEVICE, DEVELOP IT WITHOUT DUE APPROVAL OBTAINED FROM THE MANUFACTURER.

In case of violation (non-compliance) of the requirements given in this OM, the manufacturer is not responsible for the consequences arising in connection with this (accident, damage to property, injury, etc.)

Manufacturer is constantly improving its equipment and reserves the right to make changes to the design of the magnetometer, change its technical characteristics and completeness. In this regard, there may be insignificant differences between what is described in this OM and the supplied magnetometer, which do not fundamentally affect the conditions of its operation.

The following abbreviations and notations are used in this OM:

SEU — signal excitation unit,

HFG — high-frequency generator,

GPS — Global Positioning System,

DNP — dynamic nuclear polarization,

MU — magnetometer unit,

ETF — Earth's total field,

CU — control unit,

OS — operating system,

PC — personal computer,

SE — sensitive element,

SC — signal conditioner.

1. DESCRIPTION AND PRINCIPLES OF OPERATION

1.1 Description of the product

1.1.1 Designation

Overhauser magnetometer MiniMag is designed for high-precision measurements of the module of the full vector of the geomagnetic field. The sensor used in the design of the magnetometer (the principle of which is based on the Overhauser effect application), does not require maintenance and operates steadily for at least 10 years without deterioration of technical characteristics. MiniMag can be used as a rover hand-held magnetometer, autonomous or remote base station. Increased absolute accuracy and real-time data transfer allow MiniMag to be used in magnetic observatories. Integrated GPS/GLONASS receiver enables automatic coordinate gridding of measurement stations and time synchronization with the base station making convenient the survey implementation as well as data processing.

1.1.2 Technical characteristics, parameters and dimensions

Table 1. Technical characteristics, parameters and dimensions

Parameter	Value
Principle of operation	based on the Overhauser effect application
Range	20 000 ÷ 110 000 nT
Absolute accuracy	0.2 nT
Sensitivity	0.015 nT in cycle 3 s / 0.026 nT/√Hz
Resolution	0.001 nT
Optimal angle between the axis of the sensor and the field vector	90°
The working range of inclination relative to the optimal angle	± 45°
Orientation error	0.5 nT (±45°)
Gradient tolerance	10 000 nT/m
Minimum measurement cycle	0.5 s
Radical stability	10 years at standard conditions
Communication interface with PC	USB
Memory capacity	1 000 000 (in base magnetic station mode), 250 000 (with coordinate referencing)
Power	10 ÷ 16.8 V, Li-ion or Pb battery
Power consumption	3.7 W in 2 s cycle 3.2 W in 3 s cycle 1.4 W in 10 s cycle
Operating temperature range	−40 ÷ +60 °C, readability of the display is provided at temperatures above −20 °C
Weight	3.1 kg (with battery)
Nominal voltage of Li-ion battery	14.6 V
Nominal capacity of the battery	4 A·h
Continuous operation time with a fully charged battery and a 20 °C temperature	15.9 h in 2 s cycle 18.7 h in 3 s cycle 42 h in 10 s cycle

1.1.3 Package contents

The following components are included in the delivery:

- MiniMag magnetometer
- Console
- Set of cables
- Remote start module
- Li-ion battery with power cable
- Charger
- External power supply (for lead battery);
- Backpack harness;
- Rugged shipping / storage container;
- Data storage software
- Calibration certificate issued by authorized organization
- Operation manual

Figure 1 – Overhauser magnetometer MiniMag

Transportation of the Overhauser magnetometer MiniMag is carried out in a sealed, shockproof casing made of bakelite plywood.

1.1.4 Structure and Functioning

1.1.4.1 Principle of operation

For measuring the geomagnetic field in a magnetometer, the phenomenon of protons' free precession of a prepolarized working agent in the ETF is used. In this case, the polarization of nuclei is enhanced by the Overhauser effect (dynamic polarization of nuclei).

The Overhauser effect is a phenomenon that deploys the electron-proton interaction in order to achieve the polarization of protons. To realize this effect, a specially developed compound is used in the magnetometer, which contains a free radical atom (an atom with an unbound electron), which is added to a proton-rich liquid. Unbound electrons in a solution can be easily excited by high-frequency radio frequency radiation, which corresponds to a transition between energy levels. Instead of re-releasing this energy in the form of emitted radiation, unbound electrons transfer it to neighboring protons, which allows to polarize these protons without the need to create a large artificial magnetic field. Therefore, such sensors can generate large-amplitude signals with a high signal-to-noise ratio, with a power consumption of just a few watts. Standard proton sensors cannot generate signals of this magnitude and quality, even when consuming several hundred watts.

1.1.4.2 Measurement cycle

Each measurement cycle essentially consists of two steps:

1. Polarization — proton fluid of the sensitive element (SE) is excited by both constant and high-frequency magnetic fields, thus, orienting the proton spins normally to the magnetic field of the earth (ETF).

2. Measurement — after the exciting field is turned off, it begins free precession of protons in the ETF. Attenuating sine-shape EMF proportional to ETF value is induced in the low-frequency coils of SE:

$$F = \frac{T}{\gamma},$$

where F — precession frequency,

T — total field,

$\gamma = 23{,}487189 \frac{\text{n}T}{Hz}$ — proton gyromagnetic ratio.

1.1.5 Storage & shipping case

Magnetometer is delivered in the special case which protects the device from precipitation and dust.

1.2 Magnetometer description and principles of operation.

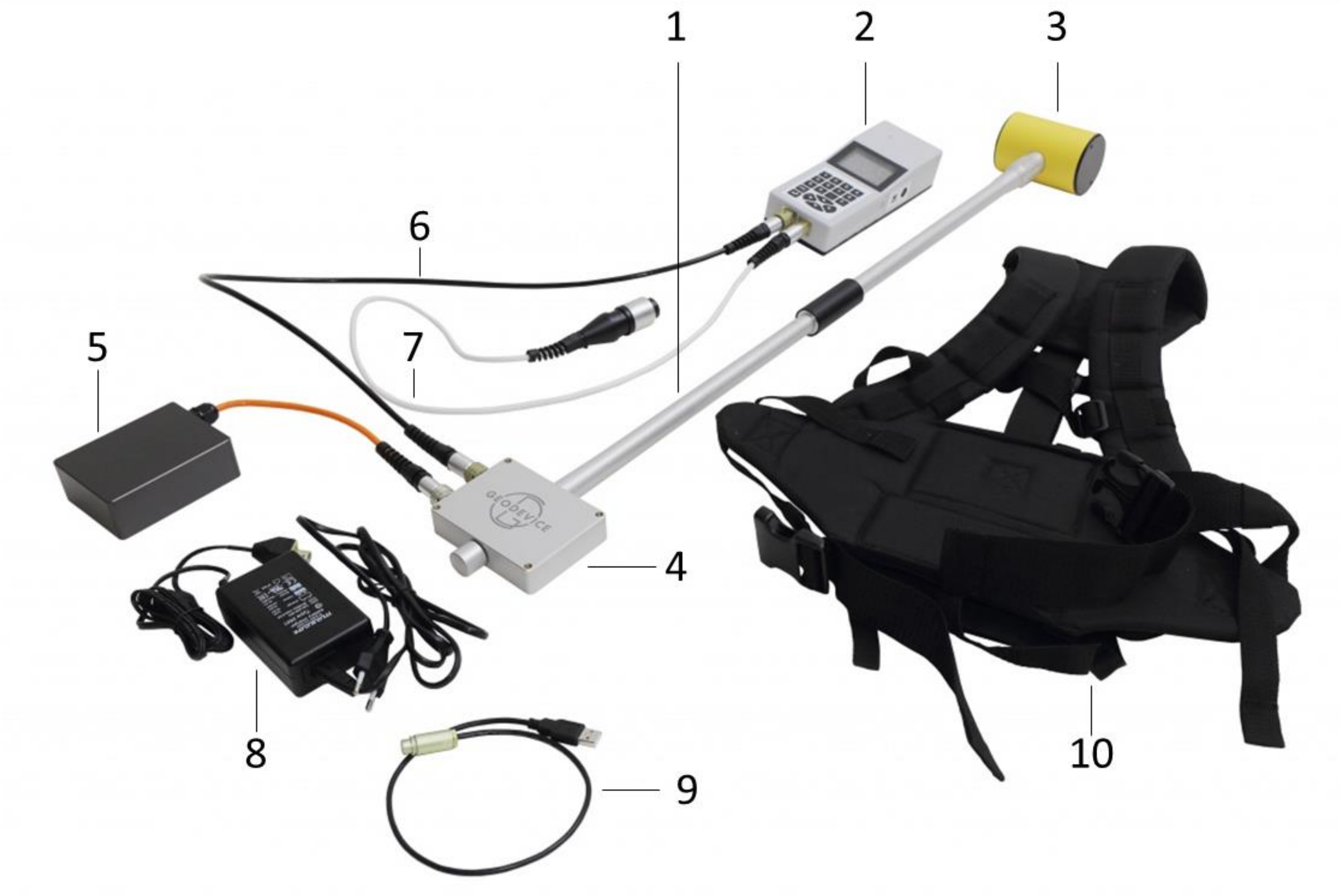


Figure 2 – Overhauser magnetometer MiniMag: package contents

1 – magnetometer unit (MU);

2 – control unit (CU);

3 – sensitive element (SE);

4 – signal excitation unit (SEU);

5 – battery with cable;

6 – CU-to-MU connection cable;

7 – remote start module;

8 – charger;

9 –USB-cable;

10 – backpack harness.

Magnetometer unit

MU is intended for ETF measurement and consist of SE and SEU joined together using the non-magnetic rode.

SE is intended for generating a signal from free precession of protons of working agent placed in the magnetic field measured. SE contains a glass ampoule with a working agent placed in a high-frequency circuit (HF circuit), on top of which low-frequency coils are wound that are designed for recording the precession signal.

SEU is designed to provide a proton precession signal. In terms of construction, SEU is made in the form of a separate unit, which includes HFG and SC

Control unit (CU)

Used to control the magnetometer, perform basic and auxiliary operations, record the results of field measurements in non-volatile memory, followed by the information output of to PC.

Battery with power cable

Intended to power the electronic components of the magnetometer. A Li-Ion rechargeable battery with a voltage of 14.8 V and a capacity of 4 A·h is used as a power source. Also, a 12 V lead-type battery Delta CT 12025 can be used as a source, to connect which a power cable for connecting a lead battery is present in the configuration of the device.

CU-to-MU connection cable

Designed for data transfer between the control panel and MU.

Cable with remote start button

Designed for remote start of magnetometer measurements.

Charger

Designed for charging the battery from AC 220 V, 50 Hz.

USB cable

Designed for connecting CU to PC.

Backpack harness

Designed for carrying the magnetometer during survey.

1.3 Operating controls and operator control chart

1.3.1 Operating controls

The operating controls of the magnetometer are 2 keyboards located in the control panel: the main one, located on the front panel, and two additional ones, located on the side faces of the CU.

In order to control operation, pressing any key is accompanied by a short beep.

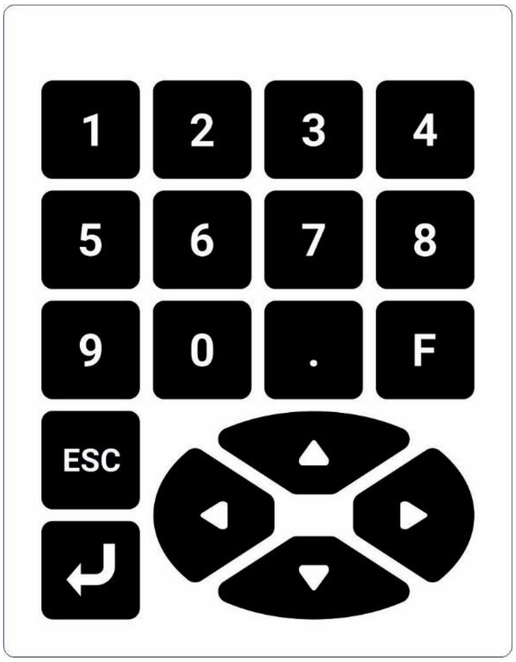


Figure 3 – Main keyboard of CU

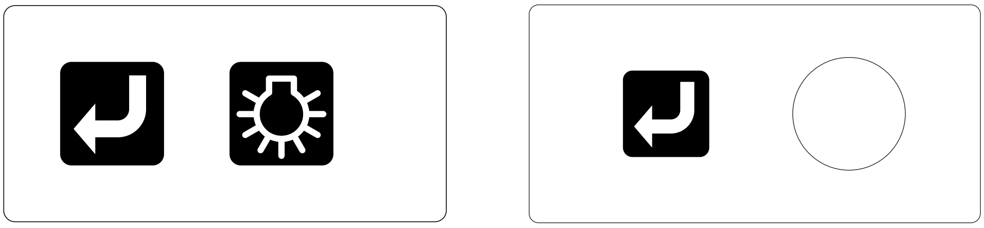
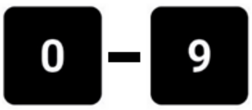


Figure 4 – Additional keyboards of CU

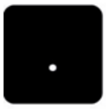


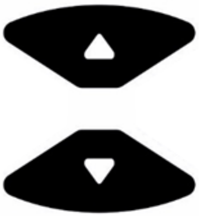
- keyboard keys for digital data;

- key of priority exit to the main menu from any mode, to the initial setup window from the main menu and to the settings menu from any settings mode;

- entering a command and starting the clock after setting the time;

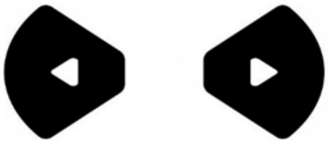

- graphic display mode key;

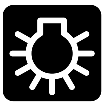

- graph offset key;


- setting the + or – sign, also shifting the frame when viewing memory;

 - return to the previous window;

 - re-measurement in manual measurement mode;


- data shift;


- LCD backlight on.

1.3.2 Operator control chart

The functionality of the magnetometer is realized using a microprocessor control system and by sending due commands. To facilitate the formation of these commands, the magnetometer control circuit was designed according to the dialog principle, in which each subsequent command is selected from the menu or prompt displayed on the screen. A complete list of commands and the operations performed in this process is shown on Figure 5.

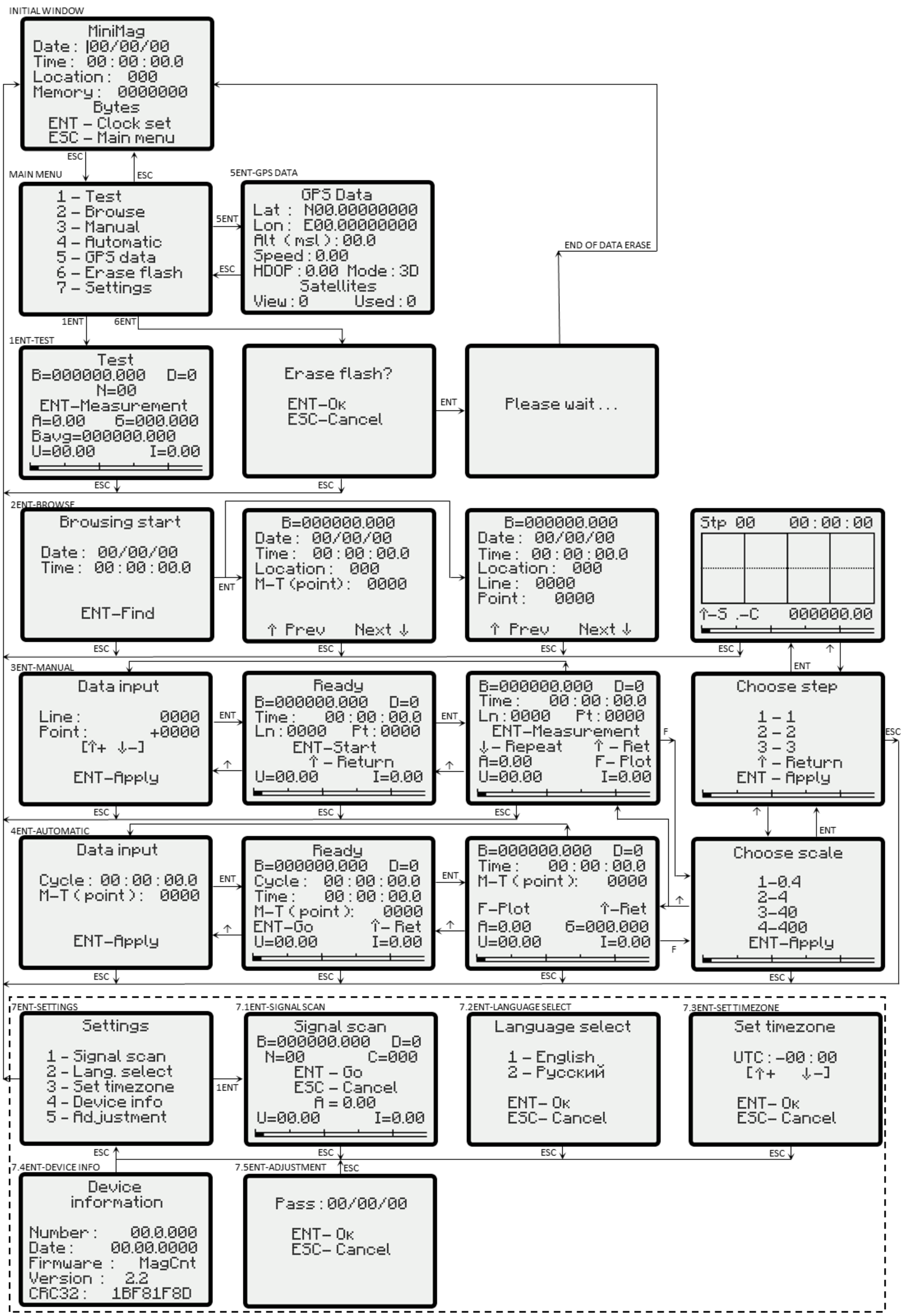


Figure 5 – MiniMag control circuit

2 INTENDED USE

2.1 Operating limitations

MiniMag is designed for operation in the field at ambient temperatures from −20 to +50 °C.

In winter, the magnetometer can be switched on after transportation or storage in an unheated warehouse only after 2 hours at a temperature of +15 °C to +25 °C.

Avoid sudden fluctuations in temperature that can cause forming condensation.

MiniMag is a high-precision instrument and requires careful handling. When working with the device, falls and bumps should be avoided.

2.2 Preparation for use

2.2.1 General safety instructions for use

The magnetometer is powered by a 14.8 V Li-Ion battery, the operation of which must be carried out in accordance with the attached instructions (see APPENDIX) or by a 12 V lead-acid battery of the Delta CT 12025 type, for which a power cable is supplied with the device to connect a lead battery.

In case of using a DC power source, the housing and the negative terminal of the source must be reliably grounded.

2.2.2 The procedure and workflow to prepare the device for use

1. Perform an external inspection of all parts of the device and make sure:

- complete set of the magnetometer corresponds to OM in the volume necessary for work;
- mechanical damages on the magnetometer blocks are absent;
- mechanical damages on the connecting cables and connectors are absent;
- pollution and soaking are absent.

IT IS PROHIBITED TO USE THE MAGNETOMETER IF DAMAGES ARE PRESENT, AS WELL AS WATER OR SIGNIFICANT POLLUTION.

2. If necessary, recharge the battery in accordance with the attached battery operating instructions (see APPENDIX).

3. Fasten the functional blocks of the magnetometer in the backpack harness.

Figure 6 – Magnetometer and battery in the backpack harness

4. Tether the CU-to-MU connection cable to the corresponding connector on magnetometer.

Figure 7 – Connector for a communication cable on the magnetometer case

Figure 8 – CU-to-MU connection cable

5. Connect the battery to the due magnetometer connector.

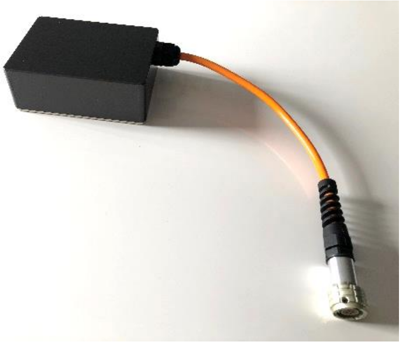


Figure 9 – Battery connector on the magnetometer case

Figure 10 – Battery with power cable

6. Put the backpack harness on the operator and adjust it to his height.

7. Tether the CU-to-MU connection cable to the corresponding CU connector.

Figure 11 – Connector for connecting cable on the CU case

Figure 12 – CU-to-MU connection cable

8. If necessary, connect a cable with a remote start button to the CU.

Figure 13 – Connector for connecting a cable with a remote start button on the CU housing

Figure 14 – Cable with remote start button

9. Wait for synchronization of GNSS coordinates with time on a CU.

When starting for the first time after a long period of inactivity or a significant change in the coordinates of the starting point since the last measurement (more than 200 km), the magnetometer needs to obtain the coordinates and time from GNSS satellites. This procedure can take up to 20 minutes, depending on the reception conditions of the satellite signal. The best result is achieved in an open area without interference for radio waves in the form of trees or buildings. The magnetometer console must be fixed motionless in a horizontal position. Do not change the date before synchronizing GNSS coordinates. For correct synchronization of GNSS coordinates, it is necessary that the date consists of zeros.

Using LED on the front panel, one can determine the current status of the lock-on. When you turn on the power and initialize the CU, the LED flashes red-blue. Further, if the LED blinks with an aquamarine colour — there is no lock-on to GNSS coordinates. If blinking with green colour — reception conditions and lock-on accuracy are optimal. If the LED blinks in red, then the GNSS receiver is malfunctioning. It is worth noting that time synchronization occurs regardless of the lock-on to coordinates and does not affect the LED display in any way.

2.3 USAGE

IMPORTANT Do not start using the magnetometer without reading OM. The actual operation of the magnetometer is allowed only after the implementation of the steps taken to prepare the device for operation, described in this OM.

IMPORTANT The magnetometer operator is prohibited from carrying any objects that include magnetic materials (knives, tools, coins, keys, lighters, etc.) as well as any electronic devices (radio stations, telephones, navigators, headphones, etc.) In addition, the appointment of a magnetometer operator with medical implants made of magnetic materials, pacemakers, as well as earrings, piercings, etc., should be avoided. Clothing elements of the magnetometer operator should also consist of non-magnetic materials: buttons, zippers, eyelets, fasteners, snap hooks, metal strings from mosquito nets and many more items of such a kind may influence the magnetometer readings. Before starting measurements, special attention must be paid to the selection of work clothes and shoes.

IMPORTANT Before starting operation, the magnetometer sensor should be oriented in the right way to ensure the most effective ETF registration. The need for orientation of the sensor depends on the survey area (Figure 15). The optimal position of the sensor is the one when the SE axis is oriented at an angle of 90 ± 5 degrees to the direction of the ETF vector. Its slope of the Earth's can be estimated from the latitude at which the survey is being carrying out (ETF vector in the equator is parallel to the Earth's surface, and at the poles it is subvertical) (see paragraph **7.2**). One can estimate the inclination of the ETF vector using an online web service (e.g. https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#igrfwmm) or a smartphone application with a three-axis compass. It should be noted, that the working area of the MiniMag sensor is ± 45 degrees relative to the optimal angle between the axis of the sensor and the ETF vector (Figure 16).

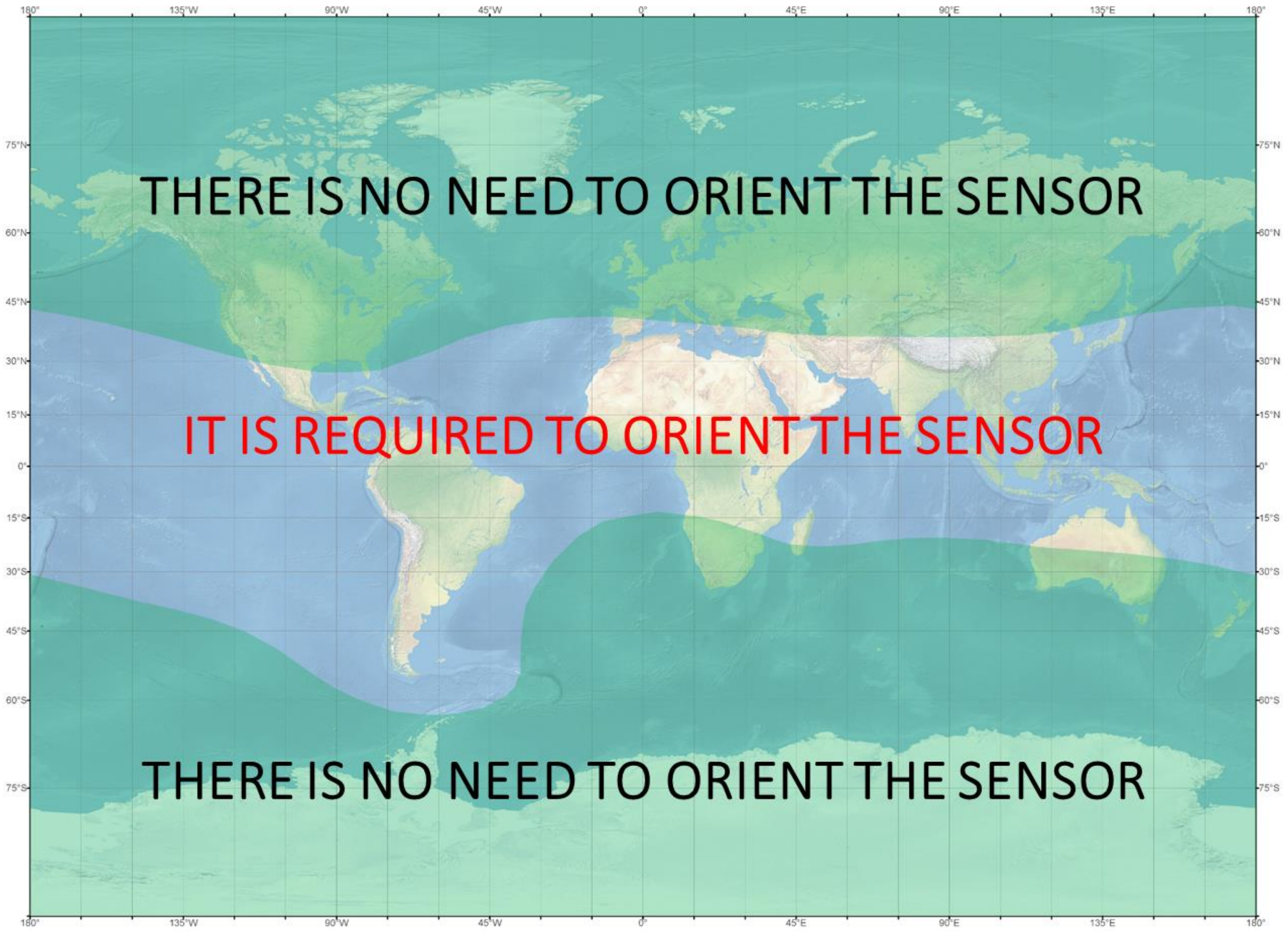


Figure 15 – MiniMag sensor orientation map

Figure 16 – Visualization of the working area of MiniMag sensor.

Inactive *areas of magnetometer are shown in gray*

2.3.1 Initial setup window, viewing GNSS data and entering the main menu

2.3.1.1 Initial setup window

After turning on the power, the initial setup window should appear on the display screen (Figure 17) with an option to set the date, time and number of the work area, as well as indicating the amount of free memory (after clearing the memory, this value should be 4194304 bytes). Information about the amount of free memory is necessary to make a decision on preliminary cleaning of the memory before starting operations or on continuing survey with the remaining memory. Before starting survey, it is recommended to erase previously recorded data (see paragraph 2.**3.4**).

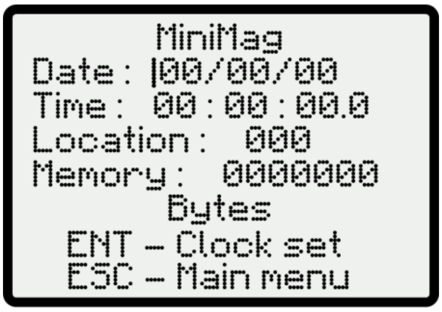


Figure 17 – Initial setup menu

To set the date, current time and number of the work area, the cursor « **|** » is used, and typing could be done using numeric keypad 0 – 9. The cursor moves automatically after entering the value. Keys ◀ and ▶ may be used to move the cursor in one direction or another, regardless of the value of previously set values.

The date data is entered in the format "date / month / year" (DD / MM / YY), and time data – in the format "hours: minutes: seconds" (hh: mm: ss.s). When seconds are set, the clock stops. To start the clock with set time and send the information typed to the memory, press the key ↵.

When used to determine the planimetric coordinates of a satellite navigation system, the installation and synchronization of time should be carried out according to the GNSS receiver data.

By default, the date remains undefined, and the start of the clock will start from the moment when the device is turned on.

If there is a signal from the GNSS satellite system, the time is automatically synchronized in the UTC ± 0 zone. User does not need to enter the time and date manually; for the local time zone, the time will be adjusted when writing data to the computer.

2.3.1.2 Viewing GNSS data

GNSS data can be viewed by moving from the main menu via command 5 ↵. At the same time, a window with GNSS data in WGS-84 system (Figure 18) will appear on the display screen: latitude (Lat), longitude (Lon), absolute height relative to sea level in meters (Alt (msl)), velocity between pickets in km / h, horizontal dilution of precision (HDOP), measurement mode (2D or 3D depending on the number of satellites used), as well as the number of visible and used satellites.

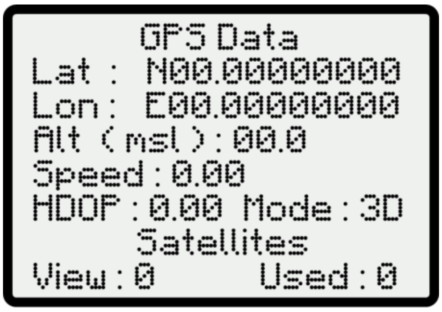


Figure 18 – Window with GNSS data

2.3.1.3 Exit to the main menu

After entering all the data and setting the clock, the exit to the main menu (Figure 19) can be made by pressing the key ESC. Exit to the main menu from any mode can also be made by pressing the key ESC.

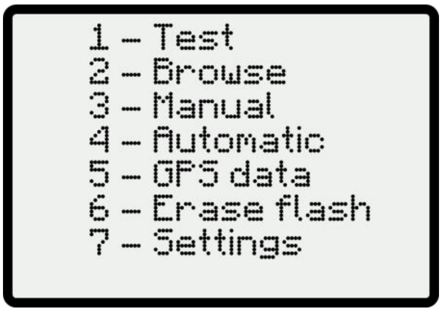


Figure 19 – Main menu

Using the main menu, one can exit to any of the operating modes presented in it by sending a command **N** ↵, where **N** is the number of menu item.

Pressing the key ESC again in the main menu mode returns the device to the initial setup window.

When working in the dark, the screen can be highlighted using the button ☼. The current consumption will increase by about 20 mA. A short single press of the button ☼ turns on the backlight for 10 seconds or turns it off. Continuous (more than 3 seconds) press of the button ☼ turns on the constant display backlight.

2.3.2 Operating modes

2.3.2.1 Test mode

In order to exit to the test mode, a command 1 ↵ should be sent from the main menu. The test measurements window will appear on the display screen (Figure 20).

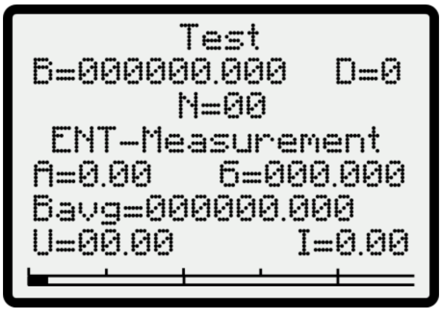


Figure 20 – Test measurements window

On the first status bar of the window (with the SE orientation is optimal) the magnetic field value will be displayed, and on the last bar – the signal strength line. In this mode, a series of N measurements can be automatically performed, while the needed value **N** is entered using the numeric keypad 0–9, and measurements can be started by pressing a button ↵. The magnetometer will automatically perform a given series of measurements with an interval of 2 seconds and display the mean square error **σ** and the arithmetic mean value of the field **Bavg**. Also, for each measurement the signal amplitude **A** is displayed on the screen in volts.

In the test measurements window for monitoring, the voltage of the power source **U** in volts and the consumed current **I** in amperes are also displayed.

Test measurements are not recorded in the magnetometer memory and serve only to evaluate the magnetometer operability.

2.3.2.2 Manual mode

In order to exit to the manual mode, a command 3 ↵ should be sent from the main menu.

In this case, a window will appear on the display screen (Figure 21), offering to indicate the numbers of the current measurement point (profile and picket), as well as the sign of the increment of picket numbers (increase ▲ or decrease ▼).

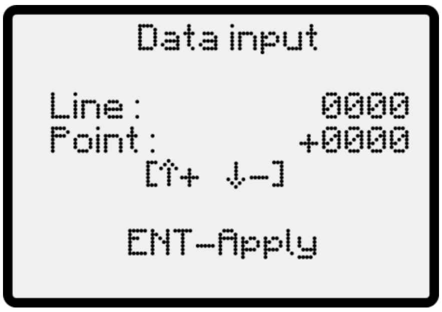


Figure 21 – Data input in manual mode

Then, with the use of cursor | and numeric keypad 0–9, it is necessary to indicate numbers of profile and first station.

After entering input data, the key ↵ should be pressed. At the same time, the Start Menu appears on the display screen (Figure 22), where in the first information line the measured values of the magnetic field will be displayed automatically every 2 seconds (without writing to the memory) accompanied by the reliability parameter **D**. At other lanes current time, specified coordinates of the starting point, as well as parameters under control (supply voltage **U**, consumed current **I** and an indication of the signal level in graphical form) are displayed. If an error in setting the profile or station number is detected, you can quickly return to the previous menu by pressing the button .

Figure 22 – Start menu in manual mode

To perform the measurement, briefly press the button , and the measurement results menu will appear (Figure 23).

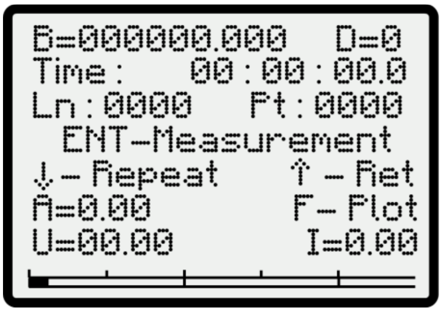


Figure 23 – Measurement results menu in manual mode

From the information presented in this menu, only the main one will be entered into the memory - field, time and coordinates. When measuring at the next station, the station number will update automatically. Repetitive measurement at the station without changing its number is performed by pressing the key . In this case, the coordinates of the point will remain the same in the results menu. Only the field value will be changed. All measurements made at this station will be recorded in memory, the last of which will be considered the most reliable.

After completing the survey, the key is pressed on the specified profile. As a result, a menu will appear on the CU screen for entering initial coordinates of the next profile.

Measurement results can also be presented in graphical form. It requires pressing the key F, after which a menu for choosing a graph's vertical scale will appear on the CU screen (Figure 24).

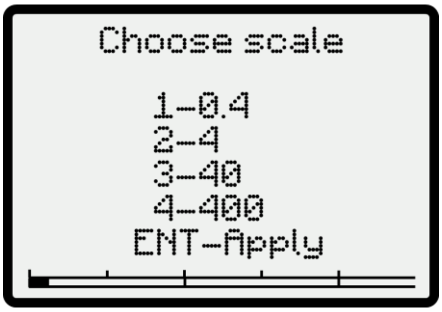


Figure 24 – Menu for choosing a graph's vertical scale

These values correspond to the size of the displayed vertical scale — 40 vertical points (20 points in one grid cell).

After pressing the key ↵ a menu for a graph's horizontal scale call will appear on CU screen (Figure 25).

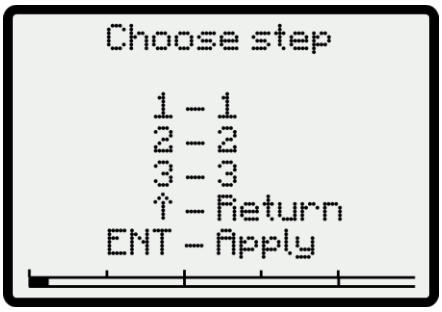


Figure 25 – Menu for a graph's horizontal scale call

120 readings are shown when scaling coefficient 1 is selected; 60 readings — when scaling coefficient is 2, 40 readings – when scaling coefficient is 3.

The vertical grid spacing is 20 points, horizontal — 30. In steps 2 and 3 of a graph's plotting, interpolated field values will be set between points.

After pressing the key ↵, the menu on the CU screen will be shown as in Figure 26.

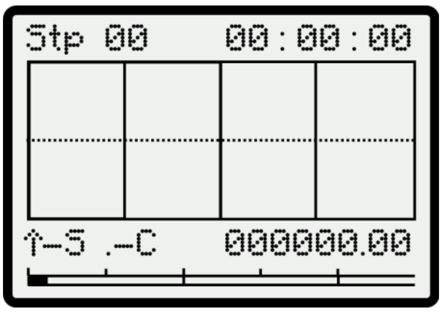


Figure 26 –Measurements graph display window

The selected vertical scale will be indicated in the upper left corner, time of the last measurement — in the upper right corner, and the value of the field obtained at last measurement — in the lower right corner. At the bottom of the menu a signal strength indicator is located. When the graph approaches the edge of the scale, the field level is rescaled automatically. It is also possible to compulsory shift the record to the middle of the scale by pressing the key .

For quick return to the textual representation of information, press the button .

2.3.2.3 Automatic mode

Exit to the automatic mode is performed from the main menu through the command 4 . At the same time, the menu (Figure 27) appears on the display screen asking you to specify the settings for this mode, where **Cycle** indicates the frequency of the magnetometer's automatic start in the "hh: mm: ss.s" format and **M-T point** — the number of the route or setup point for base magnetic station.

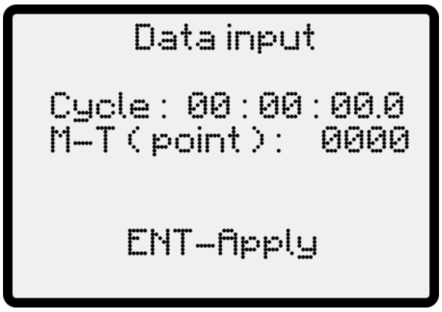


Figure 27 – Data input in automatic mode

After setting the required cycle and route number (or the setup point for base magnetic station), the key is pressed. At the same time, the Start Menu appears on the display screen (Figure 28), where in the first information line the measured values of the magnetic field will be displayed automatically every 2 seconds (without writing to the memory) accompanied by the reliability parameter **D**. At other lanes the value of the set measurement cycle, current time, route number (or number of the base magnetic station setup point), as well as parameters under control (supply voltage **U**, consumed current **I** and an indication of the signal level in graphical form) are displayed. If an error in setting the cycle or route number is detected, you can quickly return to the previous menu by pressing the button .

Figure 28 – Start menu in automatic mode

The magnetometer is launched in automatic mode via the button , and the menu with measurement results will appear (Figure 29).

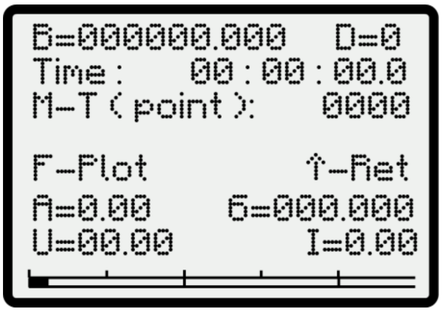


Figure 29 – Measurements results menu in automatic mode

The value **σ** indicates the standard error of the variation field according to the last 15 measurements. In order to proceed to the graphical display of the measurements result, press the  key. Further actions are similar to the recommendations described in manual mode section (see 2.3.2.2) when proceeding to graphics.

When pressing the key , the measurements are interrupted, and the menu goes into condition where you can quickly enter new initial data for automatic mode.

The field value, time and number of the route (base magnetic station setup point) will be recorded in the magnetometer memory. The date, route number (base magnetic station setup point) and the automatic measurement cycle will be indicated in the header of the digital array.

When the memory becomes full, the magnetometer is blocked, and the corresponding message is displayed on the screen (Figure 30).

Figure 30 – Magnetometer memory overflow window

2.3.3 Viewing information

In order to view the information recorded in the magnetometer memory, go to the main menu (Figure 19) and enter the command  . At the same time, a menu appears on the display screen asking you to specify the date and approximate time of the viewed fragment of the data file (Figure 31).

Figure 31 – Menu for entering date and time in viewing mode

Using the keys , and the numeric keypad 0 - 9, the initial data of the frame displayed for viewing are typed, after what the key is pressed. After the search is completed, the measurement result recorded in the magnetometer memory (for a measurement performed in manual (Figure 32) or automatic (Figure 33) mode) corresponding to the specified date and time (or closest to it in time) will be shown on the display screen. To proceed to the call of adjacent frames, as well as when changing direction, use the and keys.

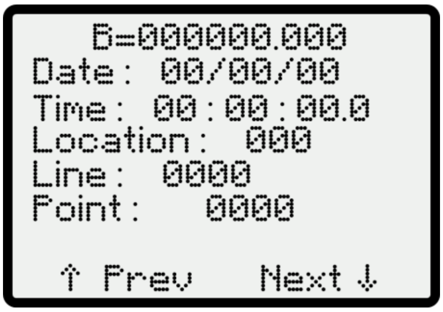


Figure 32 Recorded frame window in manual mode

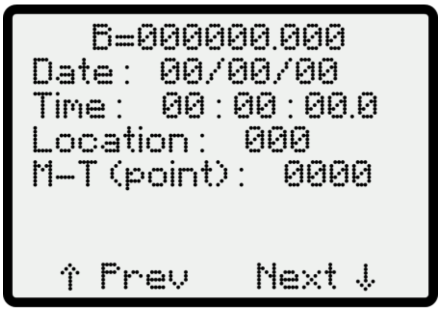


Figure 33 – Recorded frame window in automatic mode

Further, each press on the key of the selected viewing direction will lead to an appearance on the screen the information of the neighbouring frame. By continuously pressing the shift key, the change of information will occur automatically with a frequency of 1 Hz. Thus, you can view any information stored in memory.

When information is called without specifying a date, a frame corresponding to the indicated time with the earliest date will be shown on the display screen.

2.3.4 Erasing information from the magnetometer memory (clearing memory)

To erase the information recorded in the magnetometer memory, proceed to the main menu (Figure 19) and enter the command 6 ↵. Due to the fact that during erasing all the information recorded in the magnetometer memory disappears forever, before performing this operation, it is necessary to submit a confirmation command after the corresponding message appears (Figure 34).

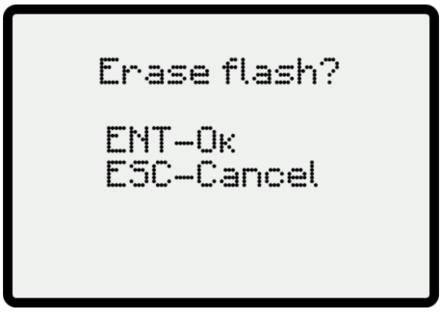


Figure 34 – Memory clear confirmation menu

When you confirm **clearing the magnetometer memory** (by pressing the key ↵), a message (Figure 35) will appear on the screen.

Figure 35 – Magnetometer memory cleaning display window

After the memory cleaning is completed, the display screen will go to the initial setup menu (Figure 17), and if the erase operation is canceled (by pressing the key ESC), the main menu will be displayed on the screen (Figure 19).

2.3.5 Magnetometer settings control

To proceed to the magnetometer settings, go to the main menu (Figure 18) and enter the command 7 ↵. At the same time, a window with a magnetometer settings menu will be shown on the display screen (Figure 36).

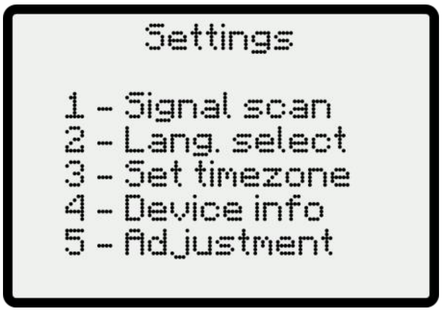


Figure 36 – Menu with magnetometer settings choice

Using this menu, you can exit to any of the operating modes presented in it by sending the **N** ↵ command, where **N** is the number of the menu item.

Exit to the settings menu from any settings mode is achieved by pressing the key ESC.

2.3.5.1 Signal search

This mode is aimed at forced selection of the working subrange of measurements for cases when, due to too large a difference in the magnetic field (more than 10 000 nT) or its gradient, the resonance output of the measured field signal may not be achieved in the operating mode.

To switch to this mode, exit to the main menu (Figure 19), enter the command 7 ↵, and then 1 ↵. In this case, the signal search menu will appear on the screen (Figure 37).

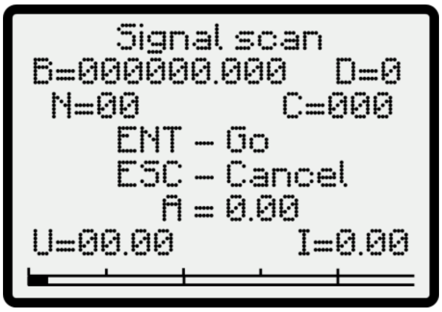


Figure 37 – Signal search menu

After pressing the button ↵ automatically at 1 second intervals, field measurements will be started with searching of all working subranges N, after which a subrange (and the value of the magnetic field) with the maximum signal amplitude and the lowest value of D parameter will be set. The end of setting will be indicated by a beep. Pressing the key ESC provides access to the main menu for continuing operation.

If even after that the D parameter turns out to be unsatisfactory (more than 4) with a noisy sound indication, this means that the MU is placed in a strongly gradient field or it is affected by unacceptable electromagnetic interference. In such a case, it is recommended to change the MU position in space.

2.3.5.2 Language choice

This mode is used to select the language menu on CU.

To switch to this mode, exit to the main menu (Figure 19), enter the command [7] [↵], and then [2] [↵]. At the same time, the language menu will appear on the screen (Figure 38).

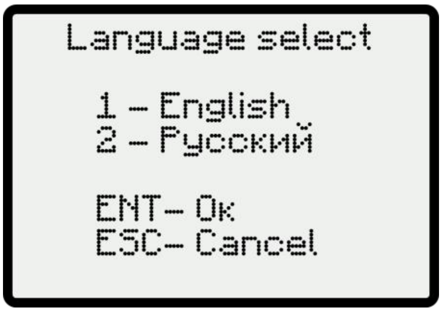


Figure 38 – Language menu

By entering [1] [↵] or [2] [↵] commands, English or Russian language is selected respectively.

2.3.5.3 Time zone

This mode is used to manually adjust the local time zone and display local time on the CU screen, as when there is a signal from the GNSS, the time is synchronized automatically in the UTC +0 zone.

In order to switch to this mode, exit to the main menu (Figure 19), enter the command [7] [↵], and then [3] [↵]. At the same time, the time zone selection menu will appear on the screen (Figure 39):

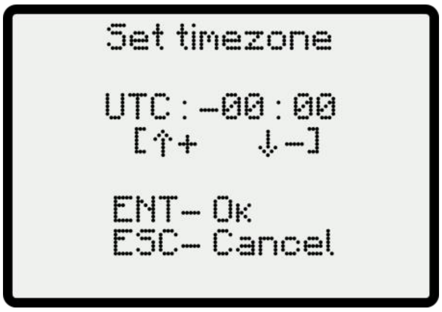


Figure 39 – Time zone set menu

Next, use I cursor and numeric keypad [0]-[9] to enter time zone data. After setting the data, press the [↵] key. In this case you will proceed to the menu with magnetometer settings (Figure 36).

2.3.5.4 Information about device

This menu contains information about the device's serial number, date of its manufacture, as well as the name, version and checksum of the internal software of the magnetometer.

To switch to this mode, go to the main menu (Figure 19), enter the command [7] [↵], and then [4] [↵]. At the same time, a window with information about the device will appear on the screen (Figure 40).

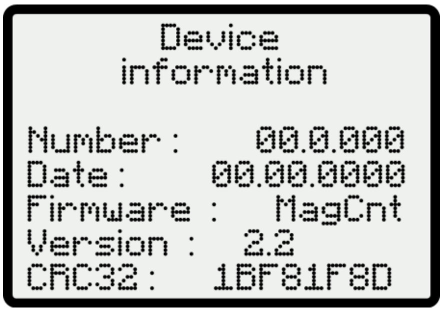


Figure 40 – Window with information about the device

2.3.5.5 Corrections

This mode is necessary for entering corrections when setting the magnetometer at the factory production stage and therefore does not provide for their alteration under operating conditions.

To switch to this mode, exit to the main menu (Figure 19), enter the command [7] [↵] and then [5] [↵]. This will open the password entry menu (Figure 41).

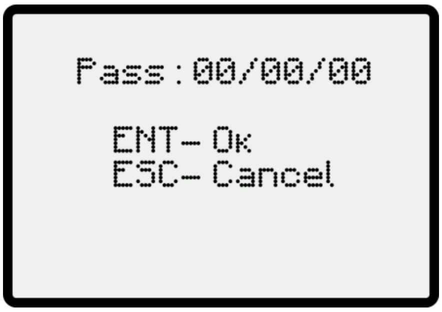


Figure 41 – Password entry menu for setting corrections

2.3.6 Safety measures during device using

When using the device, it is necessary to comply with the requirements of the "Safety rules for geological exploration", approved by the resolution of the Gosgortekhnadzor of Russia No. 40 dated 11.23.93;

IT IS PROHIBITED TO USE THE MAGNETOMETER IMPROPERLY, IN INCONSISTENT CONDITIONS AND / OR ENVIRONMENT.

The magnetometer should be handled with care, should not be subjected to shock or fall from a height as well as to any external influences that could damage the device.

IT IS PROHIBITED TO USE THE MAGNETOMETER IF DAMAGE OR SIGNIFICANT POLLUTION OCCURS

When working in the dark, all sites should have lighting that meets safety requirements.

2.3.7 Procedure for completing operation with the device

At the end of working with the device, take the following steps:

- Finish data acquisition;
- Exit to the main menu on the magnetometer CU;
- Turn off the power.

ATTENTION: It is prohibited to turn off the power during measurements! This can lead to incorrect recording of data in the device memory with subsequent inability to output them to a PC.

2.3.8 Data export from the magnetometer memory to a PC

Magnetometer is capable to upload data via the USB interface. In order to achieve this, take the following steps:

1. Connect the USB cable to the due connector on the CU.

Figure 42 – Connector for USB cable on CU case

Figure 43 – USB cable

2. Turn on the computer and connect the CU to it via USB cable. At the same time, it will be defined as removable media containing the MDL.exe program – Minimag Data loader for downloading data, a driver for Windows 7 (for Windows 10 it is not required) and this OM.

3. Copy the MDL.exe program to PC and run. After the main program window appears (Figure 44), the list will display the connected device or several devices if they are connected simultaneously.

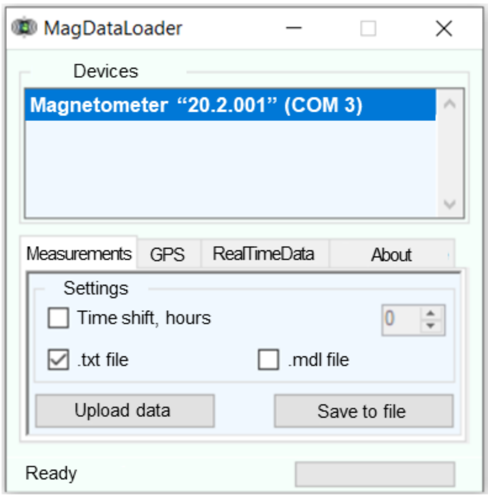


Figure 44 – Main window of MDL program

If the device / devices do not appear, then check the USB connection, and (if using the OS based on Windows 7), install the driver from the "WinDriver" folder by running the install.exe file.

4. Select the needed device from the list. Use the checkmark to select the desired file format (.txt – the standard text document and/or .mdl — the internal format of the Minimag data loader program). If absolutely necessary, use the time offset. This function is used if you want to shift the time relative to a given time zone on the magnetometer CU.

5. Click the “Upload Data” button, then the program will upload the data (Figure 45) and a dialog box will appear in which you should specify the name and location of the saved file.

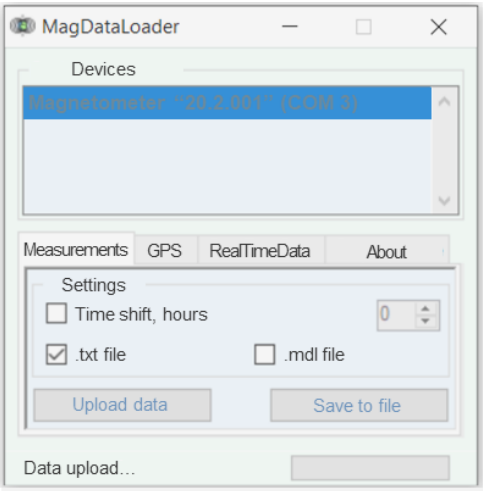


Figure 45 – Data upload

In case of cancellation, the file will not be saved and the program window will take the form as in Figure 46, which displays the volume of received information in kilobytes:

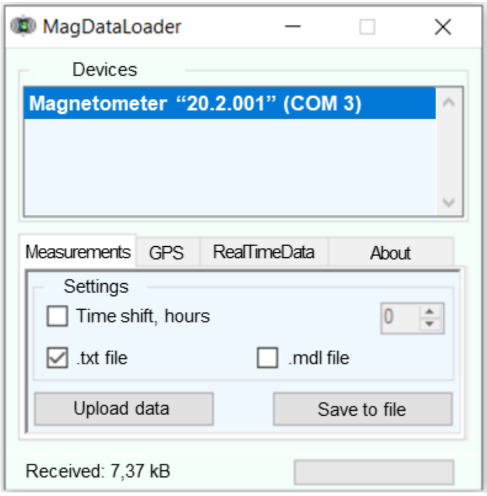


Figure 46 – MagDataLoader dialog box with an indicator of successful data upload

In case of confirmation, the file will be saved and the message “The file was saved” will appear in the lower part of the program window (Figure 47).

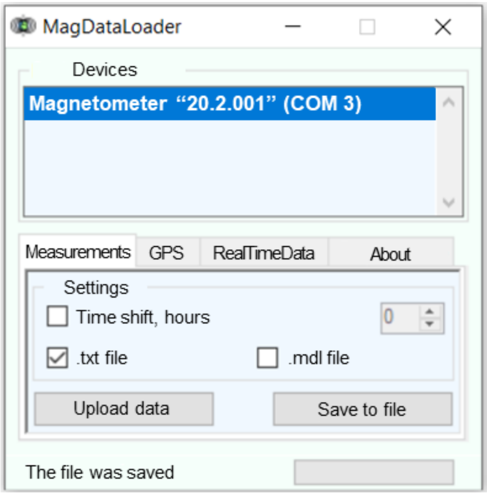


Figure 47 – Successful file saving

The measurements results are saved as a text file that contains headers and several columns separated by tabs. The file header indicates the measurement mode (manual or automatic), the measurements date, numbers of section and measurements profile, as well as the cycle time in case of automatic measurements. The content and number of columns depends on the operating mode of the magnetometer.

When operating in base magnetic station mode (automatic mode), the data is presented in six columns: in the first — the magnetic field value, in the second — the measurement time, in the third and fourth — GNSS measurements coordinates, in the fifth — GNSS reference mode (2D or 3D) and in the sixth — the number of satellites used.

When operating in the field magnetometer mode (manual mode), the data is presented in seven columns: in the first — the magnetic field value, in the second — the field measurement time, in the third and fourth — GNSS measurements coordinates, in the fifth — GNSS reference mode (2D or 3D), in the sixth — the number of satellites used, and in the seventh — the number of station.

If the file type was not selected, the message "File type not selected" will appear in the main program window during the data upload (Figure 48).

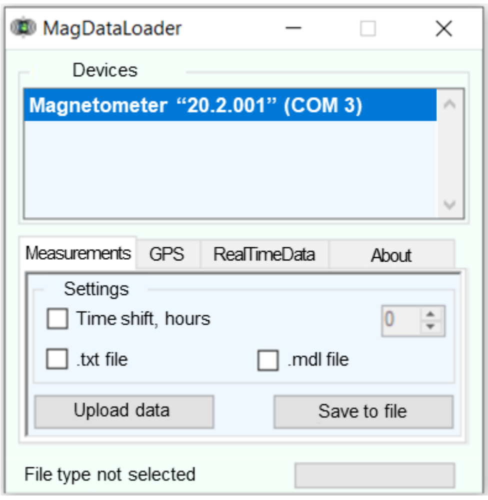


Figure 48 – Error: file type not selected

If the magnetometer does not contain recorded data, the message "No data available" will appear in the main program window during the data upload (Figure 49).

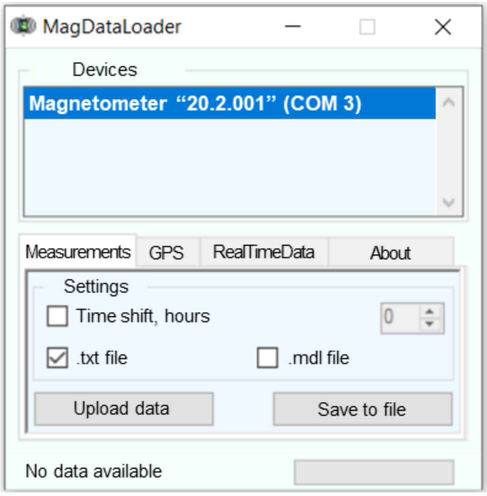


Figure 49 – Error: no data available

In case of an error during data upload, the message "Uploading error" will appear in the main program window (Figure 50).

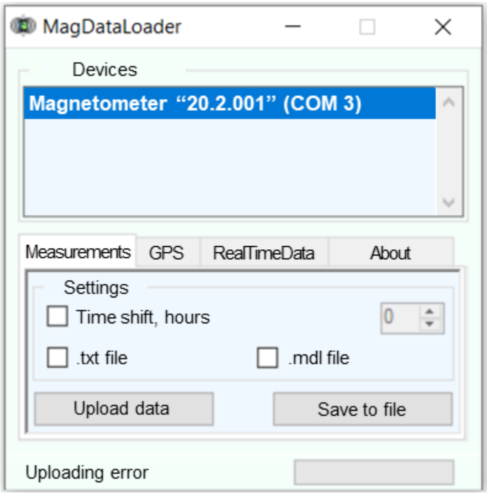


Figure 50 – Uploading data error

It should be noted that the information extracted from the magnetometer is stored in the PC RAM and can be displayed again, for which the "Save to file" button is used. If the data has been previously uploaded and successfully saved, then when disconnecting the magnetometer from PC, clicking on this button will again save the same data in the required format. When you restart the program, the uploaded data is erased from RAM, and in this case clicking on the "Save to file" button will open the previously saved mdl-file.

2.3.9 Real-time data output to PC

The magnetometer is capable to output the obtained data to a PC in real time. In order to achieve this, take the following steps:

1. Follow paragraphs 1, 2 and 3 of paragraph 2.3.8 of this OM.

2. Switching to the GPS tab allows you to display data from a GNSS receiver in real time with a frequency of 1 Hz in case of successful binding to GNSS coordinates (Figure 51). The screen displays the coordinates of the receiver, date and time of measurements, absolute height relative to sea level in meters (Altitude), speed between pickets in km/h (Speed), horizontal dilution of precision (HDOP), measurement mode (2D or 3D depending on the number of visible satellites) (Mode), as well as the number of visible (View sat) and used (Used sat) satellites.

If necessary, a cold restart of the GNSS module can be made by pressing the "Cold reset" button.

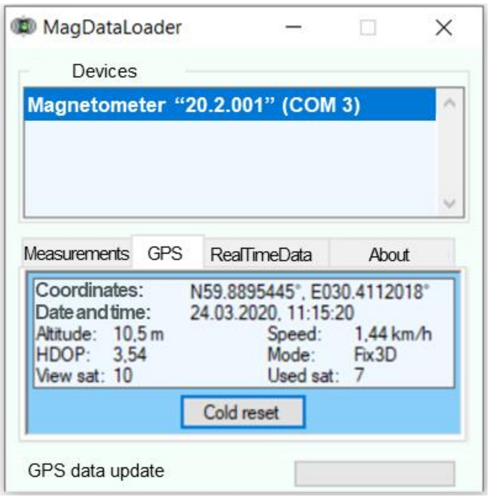


Figure 51 – Successful update of GNSS data

If there is no reference to GNSS coordinates, the screen will take the following form (Figure 52):

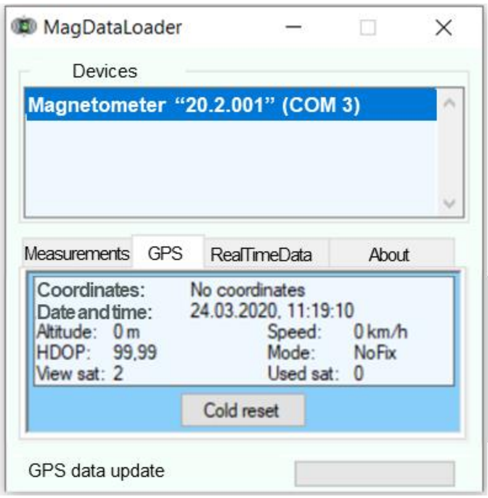


Figure 52 – GNSS data not received

3. Switching to the RealTimeData tab allows you to display real-time data received from the magnetometer (Figure 53). To do this, after opening the program, it is necessary to start measurements on the CU in manual or automatic mode. It should be noted that if you first start measurements on the CU and then run the program on the PC, the date will be displayed incorrectly (zero).

Data is grouped in packets, consisting of the date and time of measurement, measurement mode (2D or 3D depending on the number of visible satellites), the number of satellites used and the value of the measured field in nT. Also, in the lower part of the program window you can see the number of successfully received data packets (“Received”), as well as how many packets were received with an error (“Lost”).

The magnetometer connection and data transmission can be controlled using the LED on the CU screen. It should blink frequently, while its colour depends on the operation of GNSS receiver. If the LED blinks with an aquamarine colour, it means that there is no reference to GNSS coordinates. Blinking green colour — reception conditions and binding accuracy are optimal. If the LED blinks red, the GNSS receiver is malfunctioning.

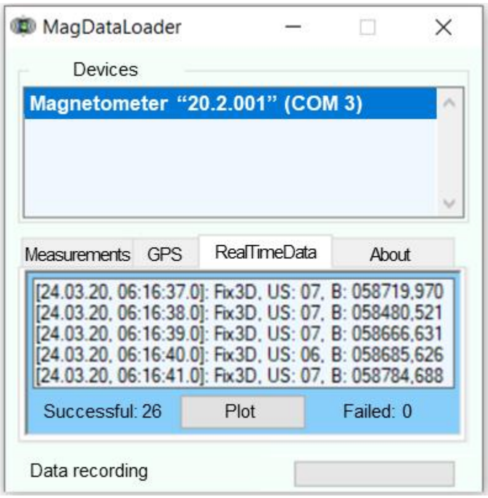


Figure 53 – Real-time data acquisition with normal reception conditions via GNSS coordinates

If there is no reference to GNSS coordinates, the screen will take the following form (Figure 54):

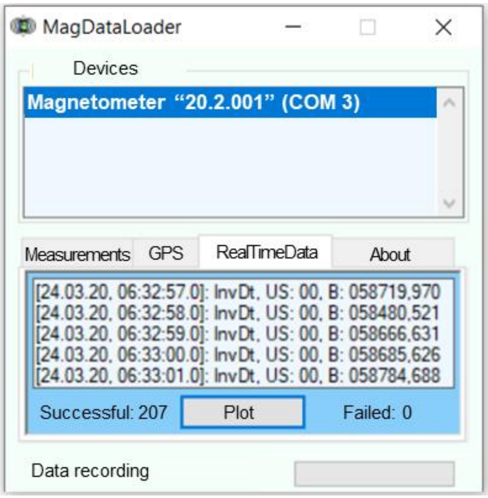


Figure 54 – Real-time data acquisition: no reference with GNSS coordinates

In addition to the test data display, it can be presented in the form of a graph. To do this, click on the "Graph" button on the RealTimeData tab. It should be noted that the construction of the graph starts from the moment you click on the button. On the graph, the value of the measured field in nT is displayed along the vertical axis, and the measurement time is displayed along the horizontal axis (Figure 55).

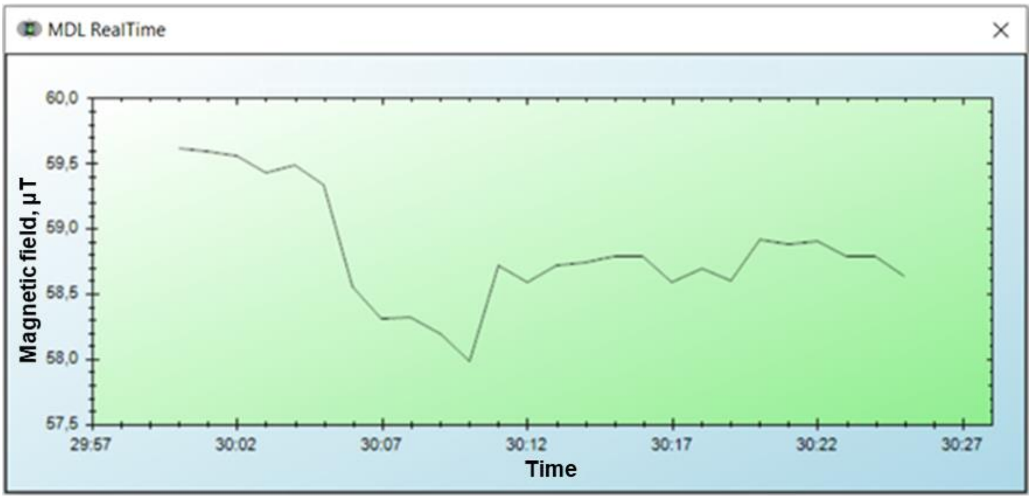


Figure 55 – Real-time graph of the magnetometer data graph

Right-click in the graph window opens a menu with several functions of working with it (Figure 56). The graph can be copied to clipboard and saved as a picture. It is also possible to set up printing options and send the graph to print.

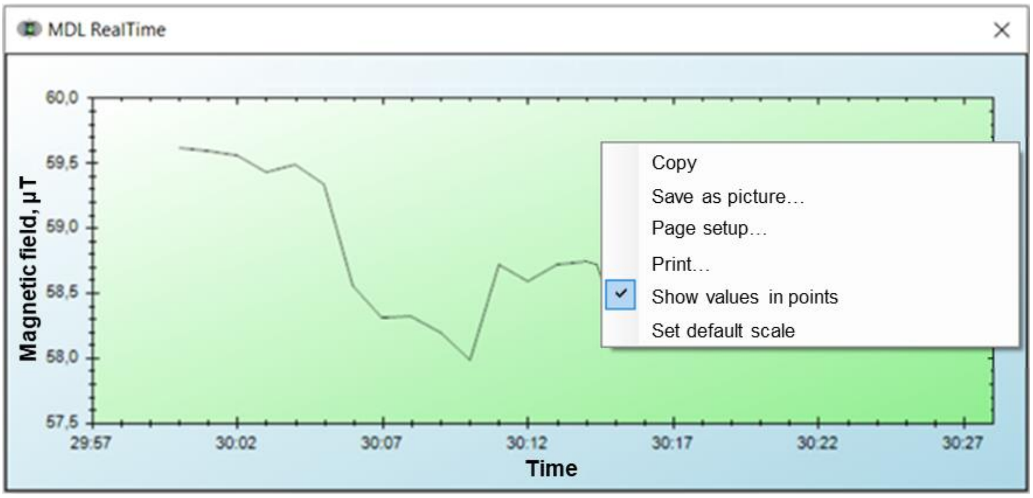


Figure 56 – Options for working with graph

Also in this menu you can select the function “Show values in points”**.** In this case, when you move the mouse cursor over any measured point on the graph, the date, time and value of the measured field will be displayed on the screen (Figure 57).

Another function for the graph is its scaling. To carry out continuous zooming of the graph, hold down the left mouse button and adjust the required size of the zoom window (Figure 58).

In order to set the initial scale of the graph, it is necessary to select the function “Set default scale” in the control menu (Figure 59).

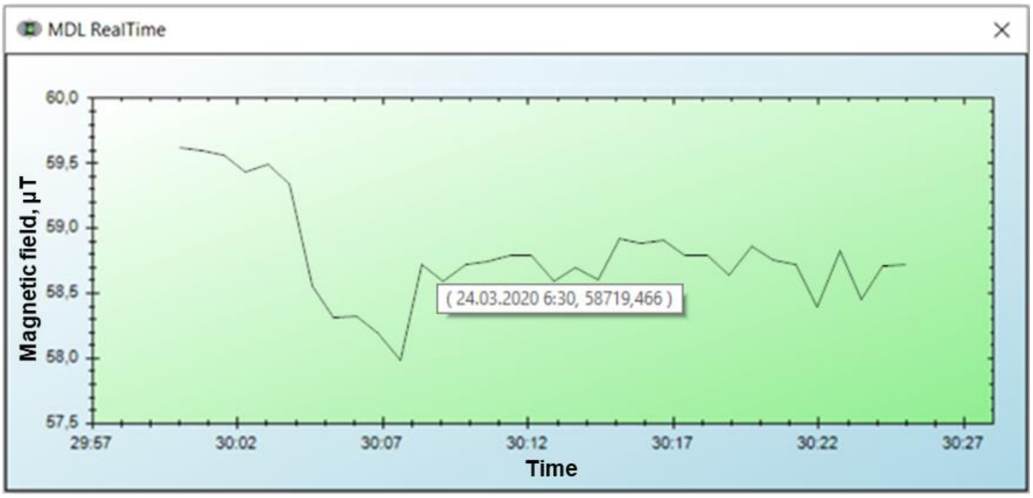


Figure 57 – Visualization of the field value in point

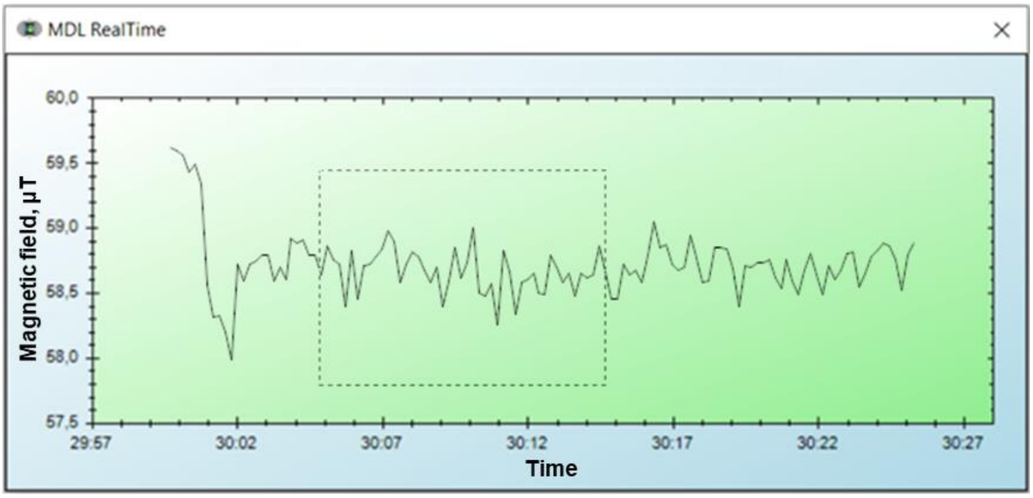


Figure 58 – Graph scaling

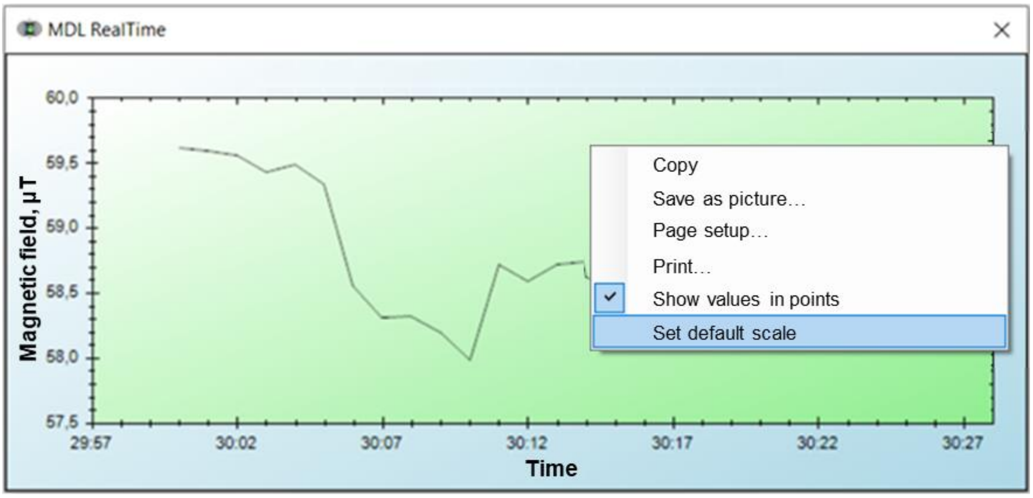


Figure 59 – Setting default scale of the graph

4. Switching to the “About the program” tab displays information on the software used.

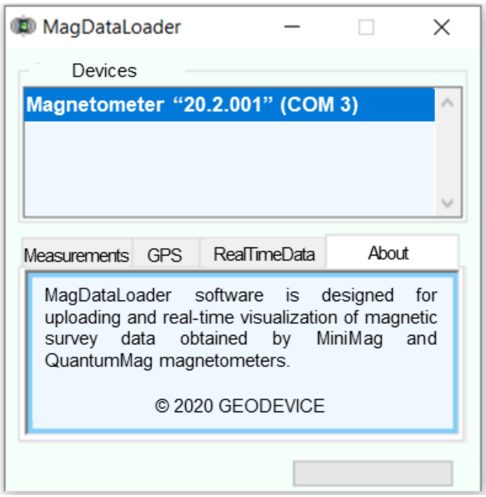


Figure 60 Information about the program

It should be noted that in order to ensure the capability to add the necessary program modules by users themselves, a .dll file with necessary documentation is supplied on the CU media.

2.4 Actions during extreme conditions

Geophysical studies should be suspended when the weather conditions are getting worse: visibility is less than 20 m, wind increasing to a storm (more than 20 m/s), severe icing, extreme and emergency situations.

In case of emergencies that threaten the life and health of people, it is necessary to immediately evacuate to a safe place.

If smoke, cable flashover, a characteristic odor, or other external signs of fire appear, stop working immediately and turn off the power of the device.

2.5 List of possible malfunctions

Table 2. Possible malfunctions and recommendations of troubleshooting

Malfunction	Possible reasons	Troubleshooting
CU display doesn't work	Absence of power supply: 1) Battery is not connected; 2) Power cable is damaged; 3) Battery discharged.	1), 2) Check the cable and connection; 3) Charge the battery. Contact GEODEVICE if the malfunction has not been fixed.
Big measurement error (unstable readings)	1) Big angle between optimal and real positions of the sensor axis; 2) High industrial noise level, big magnetic field gradient; 3Low battery voltage.	1) Orient the sensor in the proper way (see items **2.3**.); 2) Change sensor's position, remove magnetic object; 3) Charge the battery. Contact GEODEVICE if the malfunction has not been fixed.
Keypad is not active, cursor is absent.	Processor error.	Check the battery. If the voltage is between 11 and 16.8 V –it is necessary to re-set the instrument. Contact GEODEVICE if the malfunction has not been fixed.
Error of data upload	Data are broken due to power reset during measurements.	Erase the memory or contact GEODEVICE if the malfunction has not been fixed.
LED "GNSS" is flashing by red	Critical malfunction of the GNSS module	Contact GEODEVICE if the malfunction has not been fixed.

The instrument also displays results of the memory self-test and possible troubleshooting.

Figure 61 – Error— Memory full

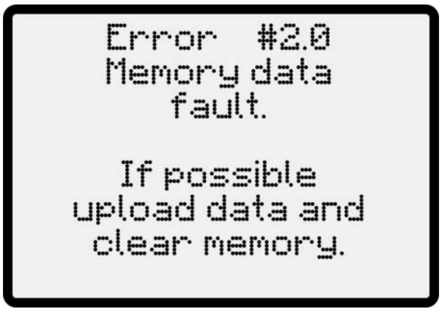


Figure 62 – Error— Memory data fault

Figure 63 – Error— Memory access denied

3 REPAIR

One must contact GEODEVICE LLC or its representatives in case of magnetometer's malfunction or unstable operation.

ATTENTION! REPAIR OF THE MAGNETOMETER IS CARRIED OUT EXCLUSIVELY BY MANUFACTURER GEODEVICE LLC or by professional geophysical service specialists who have been trained and have a certificate for the right to carry out repairs issued by GEODEVICE LLC.

DO NOT UNDERTAKE REPAIRS BY YOURSELF.

Otherwise, the manufacturer does not guarantee the operational reliability and safety of the device. The manufacturer also terminate its Warranty obligations in case of unauthorized repair of the instrument.

4 STORAGE

The equipment should be stored in its standard case in warehouses protected from percipients at an ambient temperature from 5 to 35 °C and relative humidity from 5 to 80 %.

IT IS FORBIDDEN TO STORE THE MAGNETOMETER TOGETHER WITH ACID AND ALKALI VAPORS AND OTHER HARMFUL IMPURITIES THAT CAUSE CORROSION.

5 TRANSPORTATION

The equipment is transported by all means of transport in closed vehicles at an ambient temperature from −40 to 60 °C and relative air humidity from 5 to 95 %.

Before the transportation, the magnetometer with its accessories must be placed into its standard case. The transportation should be carried out according to safety requirements. Shocks and fallings of the magnetometer should be avoided during transportation.

IT IS FORBIDDEN TO USE THE MAGNETOMETER IF THERE ARE SOME VISIBLE DAMAGES CAUSED BY TRANSPORTATION

If the magnetometer has been damaged during the transportation, one must contact GEODEVICE LLC or its representatives to find out the possibility of further use of the instrument.

6 RECYCLING

The buyer (owner) is responsible for the recycling of the inoperative instrument.

DO NOT DISCARD THE MAGNETOMETER AND ACCESSORIES TOGETHER WITH HOUSEHOLD WASTE.

If possible, divide the device into parts depending on the materials (metal, rubber parts, etc.) and decide on the transfer for recycling.

Recycling of the materials to be recycled / transferred for recycling in accordance with the requirements of the Russian Federation legislation in force at the time of recycling.

7 APPENDIX

7.1 General recommendations for magnetic survey fulfillment with Overhauser Magnetometers MiniMag

7.1.1 Installation of a Base station

The Base station (BS) is a permanently installed standard magnetometer intended to record earth's magnetic field (EMF) variations. Its operation mode provides automatic measurements with specified period. Recorded EMF variations are taken into account during the processing of magnetic survey data obtained from rover magnetometers (Rover).

The BS must be installed in a place with small EMF gradient (less than 10 nT/m) away from big magnetic objects and sources of electromagnetic noises. Reconnaissance magnetometry survey should be realized with 5-meter (or less) step at the distance of 20–25 m around the supposed BS position. It is recommended to install the BS 30–50 meters away from roads and not more than several kilometers from the survey area.

The sensor of the BS magnetometer should be normally (90° ±5°) oriented to the EMF vector in order to provide better measurement quality. The sensor must be fixed still to avoid any movements (caused by wind and vibrations). The BS must be protected from sun exposure and percipients by installing of some screens, tents etc.

BS should be started 1.5-2 hours before the survey with rover magnetometers. Batteries of the BS must provide its power supply in standard mode during the period of measurements. It is recommended to install BS control unit and batteries at maximum possible distance from the sensor.

It is not recommended to get closer than 10 meters to the BS station during measurements and make any manipulations with it in order to avoid the disturbances of the data. If these actions are necessary (changing of battery, installation of tent etc.) — one must indicate the time of these manipulations in the BS logbook (paper or electronic).

It is not recommended to make survey and measurements of EMF variations in periods of strong magnetic activity (Kp-index > 3). When the survey is necessary to be done in this period, one need to decrease the sample rate to minimum value and provide the exact time synchronization between BS and Rover.

7.1.2 Magnetic survey with Rover

Every day before the survey and after it is finished, one should make control measurements at specified Control Point. The location of this point should be chosen in the same way as a Base Station.

Measurements at the Control point should be done in the same manner every time before and after the survey day — with the same sensor's orientation and height and by one person.

During the survey, the operator must not have any magnetic objects like: knives; instruments; coins; keys; lighters etc., as well as electronic devices like: walkie-talkies, cell phones, GPS receivers, headphones etc. It is also not recommended to assign as an operator person with medical implants (magnetic), pacemakers, body-piercing etc. Clothing of the operator must not contain magnetic furniture like: buttons, zippers, clasps etc. It is necessary to choose the clothing carefully in order to avoid the influence of all magnetic items to the measurement results.

During survey, the operator must protect the magnetometer from shocks and damages, its cables should be protected from breaking, stretching and jerks. It is recommended to use the backpack-harness from magnetometer delivery set. The harness must be fixed properly and must not hold the operator down in order to provide its safe movement during the survey.

The magnetometer sensor is mounted at the Al rode, which is fixed at the backpack harness. It is recommended to keep the same sensor height during survey and adjust it if the operator is changed.

7.2 Earth's magnetic field inclination and total intensity maps

7.2.1 Main field inclination map

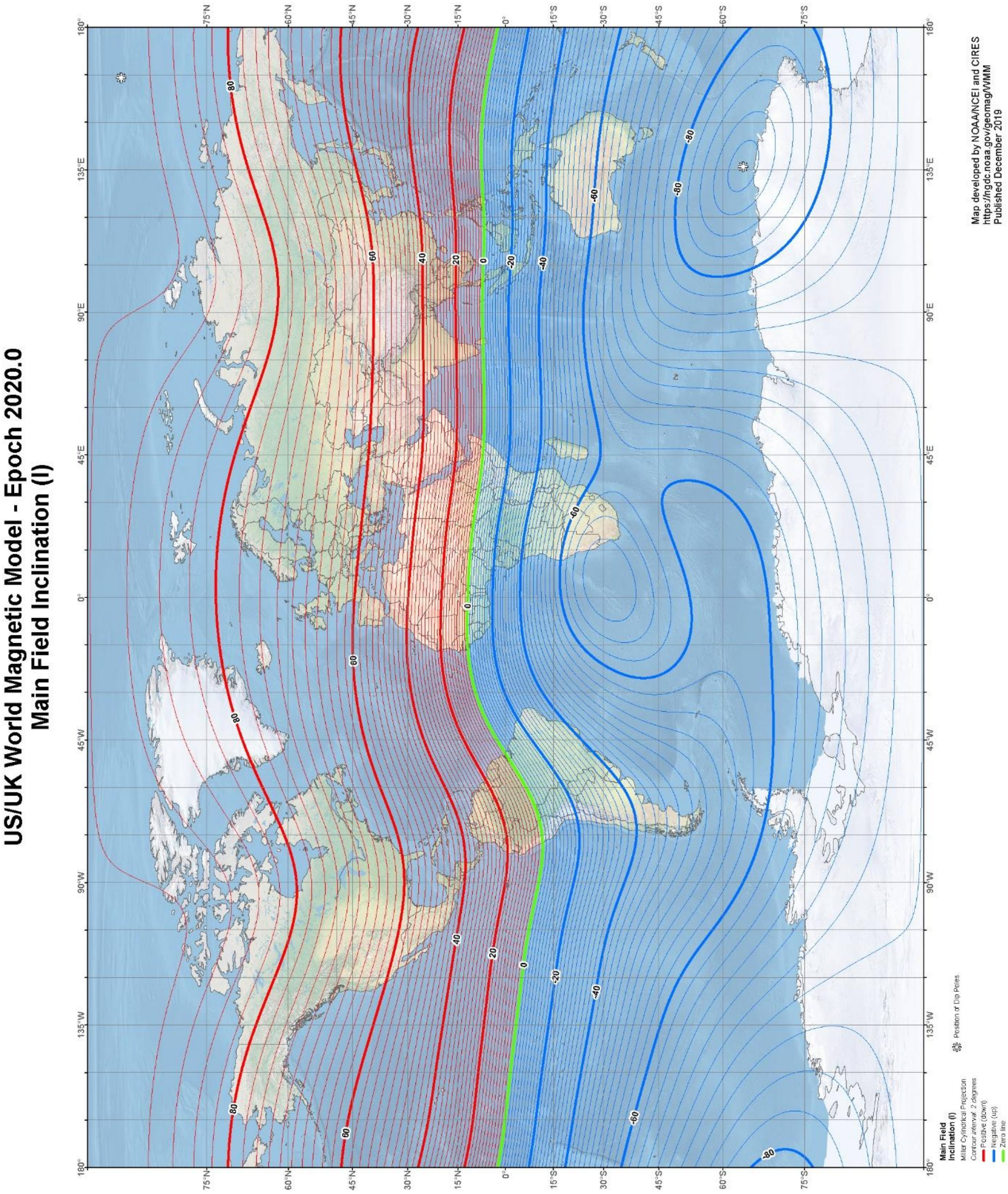


Figure 64 – Main Field Inclination Map. NOAA's National Centers for Environmental Information

7.2.2 Main field total intensity

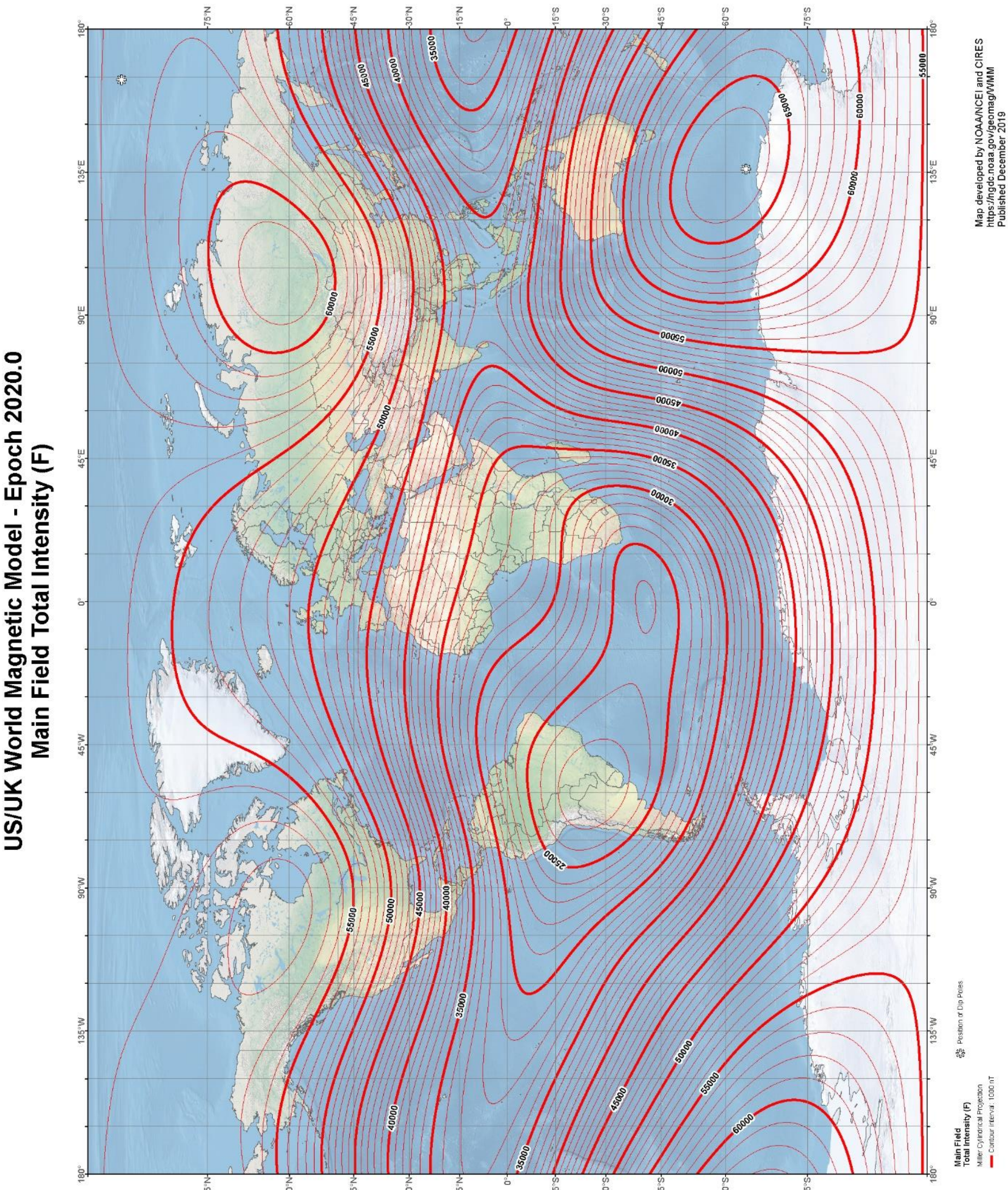


Figure 65 – Main Field Total Intensity Map. NOAA's National Centers for Environmental Information

7.3 Li-ion battery

7.3.1 Battery specifications

MiniMag set includes Li-ion battery (14.8 V, 4 A·h) with connection cable (Fig. 66).

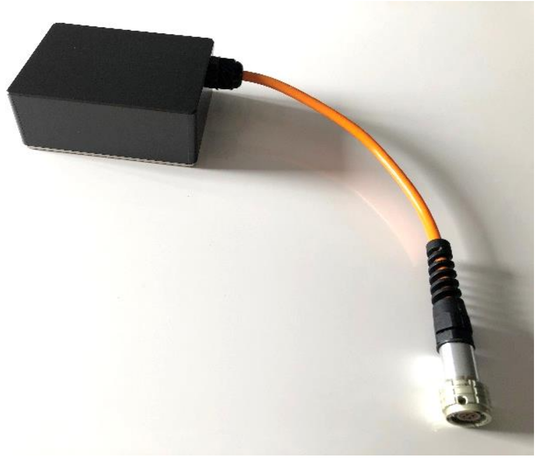


Figure 66 – Li-ion battery with cable

Table 3. Battery specifications

Parameter	Value
Voltage	14,6 V
Capacity	4 A·h
Charge current until the voltage reaches 16.8 V	• In temperature band 0 ÷ +60 C: 4 A • In temperature bands -20 ÷ 0 °C and 60 ÷ +85 °C: 0.8 A • In temperature band −30 ÷ −20 °C: 0.2 A
Discharge mode	Not more than 5 A until the voltage reaches 10 V
Dimensions (L x W x H)	113 × 87 × 42 mm
Weight	650 g
Operation temperatures	−30 ÷ +85 °C — charge −40 ÷ +85 °C — discharge
Storage	In dry warm places at temperatures smaller than 30 °C when the battery is charged on 30±15 % (14.8 V terminal voltage)

7.3.2 Charge

It is recommended to charge the battery at temperatures 0 ÷ +60 °C using the charger from the delivery set (see **7.4**)

Fully charged battery must have terminal voltage16.8 V.

7.3.3 Precautions

The battery must be used according to following requirements:

1. Avoid shocks and falling of the battery.
2. Avoid the sort-cut.
3. Do not use broken and faulty chargers.

4. Do not use inappropriate chargers.
5. Do not disassemble the battery to avoid its damage!
6. In case of damage and contact of battery elements with skin or eyes, wash them by clean water immediately!
7. If there appears some bad smell from battery or it changes its exterior somehow, one must unplug the charger from the power socket and stop use of the battery.
8. Do not leave completely charged or discharged battery for a long time.
9. Protect the battery from sun exposure, water and other liquids.
10. As being stored, avoid the contact of battery connectors with metal objects.
11. Store the battery in dry place inaccessible to children.

7.4 Li-ion battery charger

7.4.1 Charger specifications

MiniMag instrument set includes Li-ion battery and external charging unit (110 – 200 V, 50-60 Hz).

Figure 67 – Charger of Li-ion battery

Table 4. Specifications of the charger

Parameter	Value
Charge type	3-level charge control
Input voltage	90 ÷ 264 V, AC
Power supply frequency	47 ÷ 63 Hz
Pulse converter frequency	40 kHz
Max. output current	2,7 A
Output voltage stability	better than 100 mV peak to peak
Dimensions (L × W × H)	107 × 67 × 36,5 mm
Weight	250 g
Operation temperatures	–20 ÷ +40 °C
Storage temperatures	–25 ÷ +85 °C
Protection	Polarity and short-cut

7.4.2 Charge

One should connect the battery to the charger and then to the power socket (110–220 V, 50–60 Hz).

Charge process consists of three steps (Fig. 68):

Step 1 — charge with constant current

The charger produces the maximum output current DC. LED indicator is orange. This stage provides fast charging until the battery voltage reaches the specified level.

Step 2 — charge with constant voltage

After the battery voltage reaches the required value, the charger turns into the constant voltage mode, when the output current is decreased until its value reached minimum level specified on the charger's box. The LED is still orange. When the battery is charged on 90-95% of its capacity, the output current decreases below the minimum level and the LED turns to yellow indicating the battery is almost charged. The charging process occurs until the Step 3, when the battery is completely charged.

Step 3 – Charging is completed

The battery is completely charged when the LED turns to green.

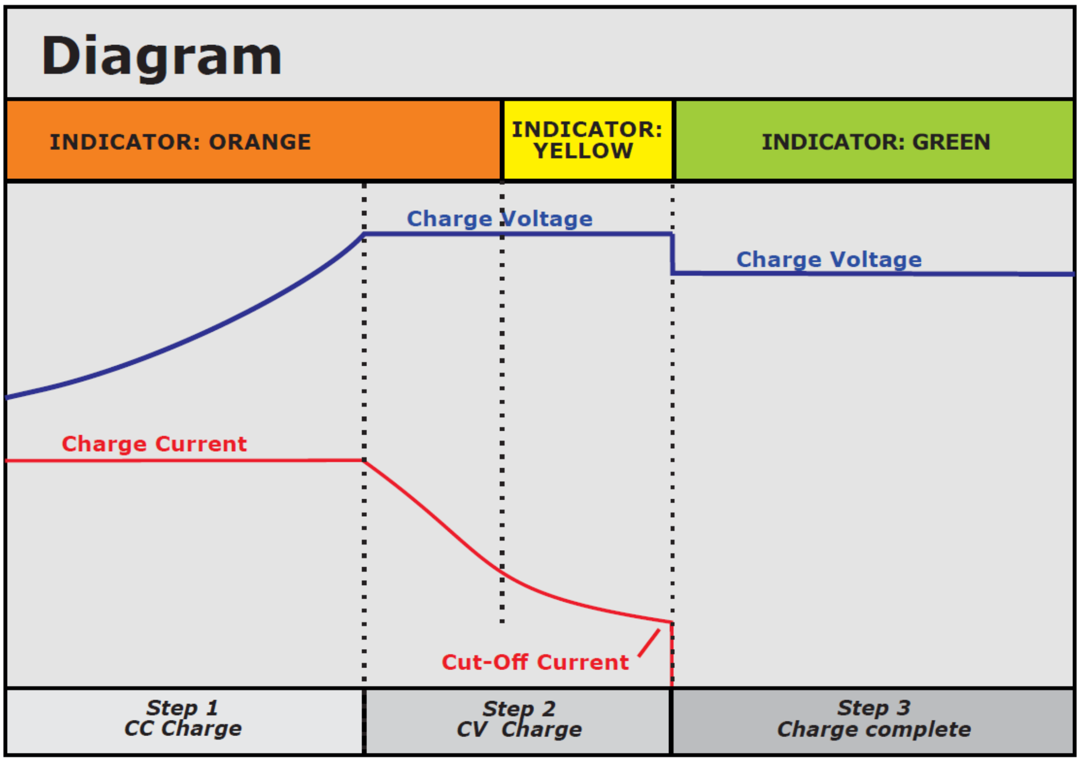


Figure 68 – Charge diagram

7.4.3 Precautions

1. Do not use the charger outside and do not leave it in wet places or in contact with water or precipitation.
2. Unplug the charger from power sockets if you are not going to use it.
3. Do not plug the charger if it seems broken.
4. Do not disassemble the charger.
5. Be sure that charging occurs at temperatures from 0 °C to 60 °C.
6. Both batteries and charger may heat when charging. One must stop charge and unplug the power when the temperature of units is too high and the devices cannot be taken by hand, as well as when there are some smog, melt etc.
7. To avoid overheat; do not place the charger on fabric.
8. Use and store the charger in places inaccessible to children. Incorrect using may cause electric shock or fire.
9. Do not leave plugged-in charger for a long time without control even if the charge is completed.

7.5 Pinout scheme of the magnetometer cables

7.5.1 Cable “Control Unit to Magnetometer Unit”

Shielded connection cable with 7-pin bayonet-type connectors (ONC-BS1-7/12-R12-1V) is used in the CU-MU. The connector’s pinout is shown in the Figure 69.

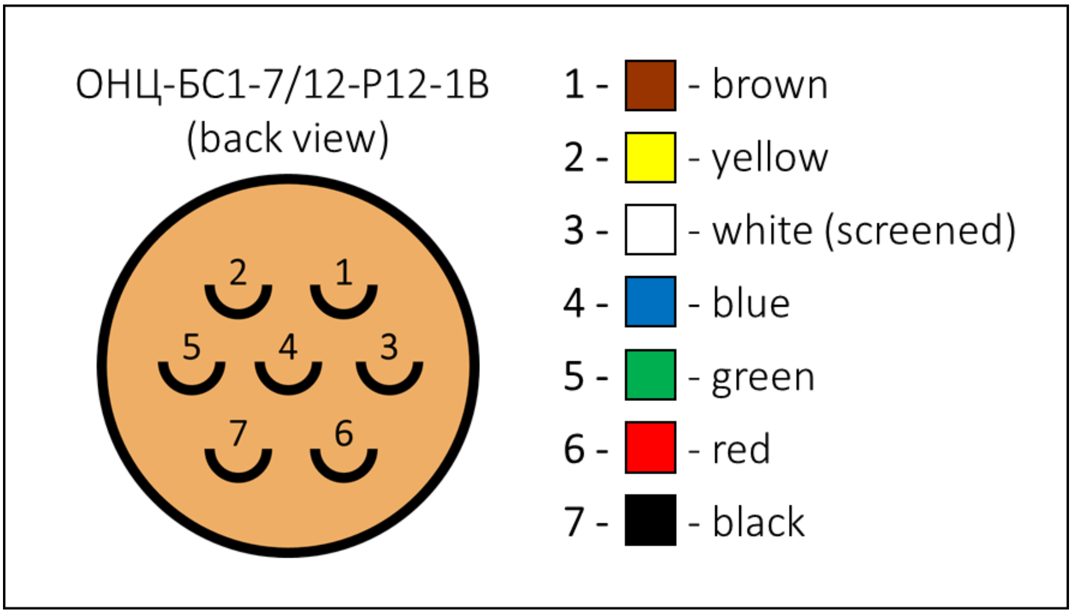


Figure 69 – Pinout of the CU-MU cable

Cable screen is connected to the pin #1 together with the brown wire. The corresponding pin of the CU connector is empty.

7.5.2 USB cable

There are two connectors at the four-core USB cable. From the one side it is 7-pin screw connector (PC7TB) with removed fixator nut. From the other side it is standard USB-socket. The connector’s pinout is shown in the Figure 70.

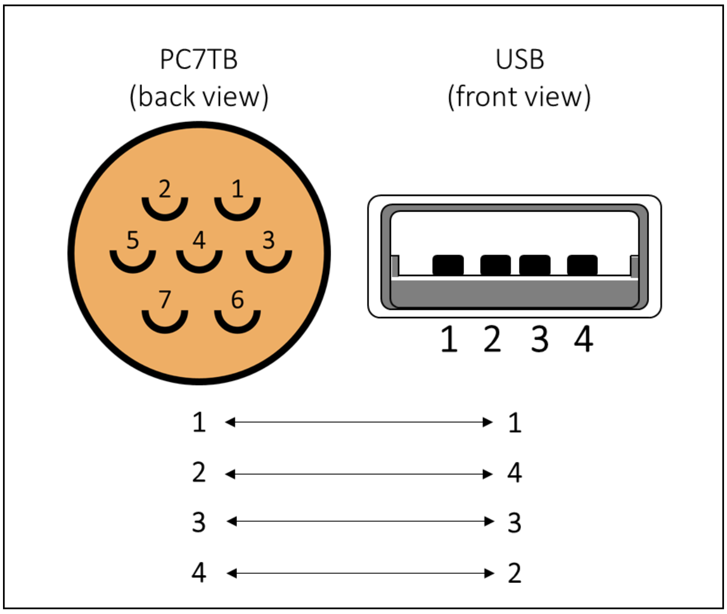


Figure 70 – Pinout of the USB cable

7.5.3 Remote start cable

Two-core cable of the remote start module has 7-pin PC7TB screw connector (Fig 71). Cable cores are connected to pins 6 and 7.

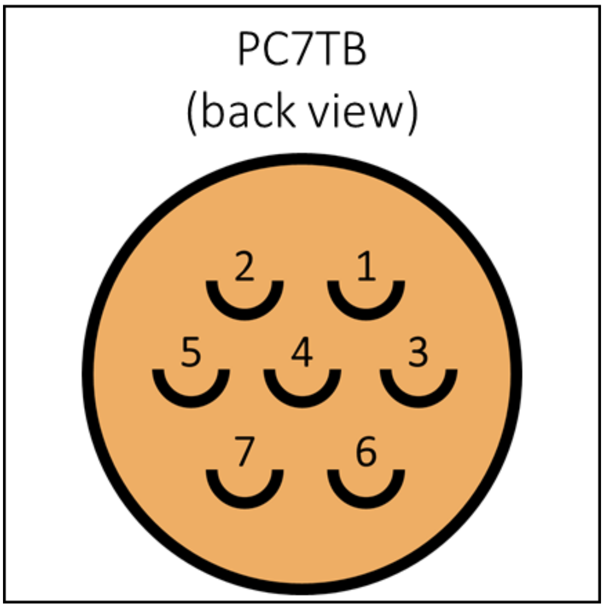


Figure 71 – Screw connector PC7TB (view from behind)

7.5.4 Li-ion battery cable

Two-core cable of the Li-ion battery has 4-pin bayonet-type connector (Fig 72). The connector's pinout is shown in the Figure 72.

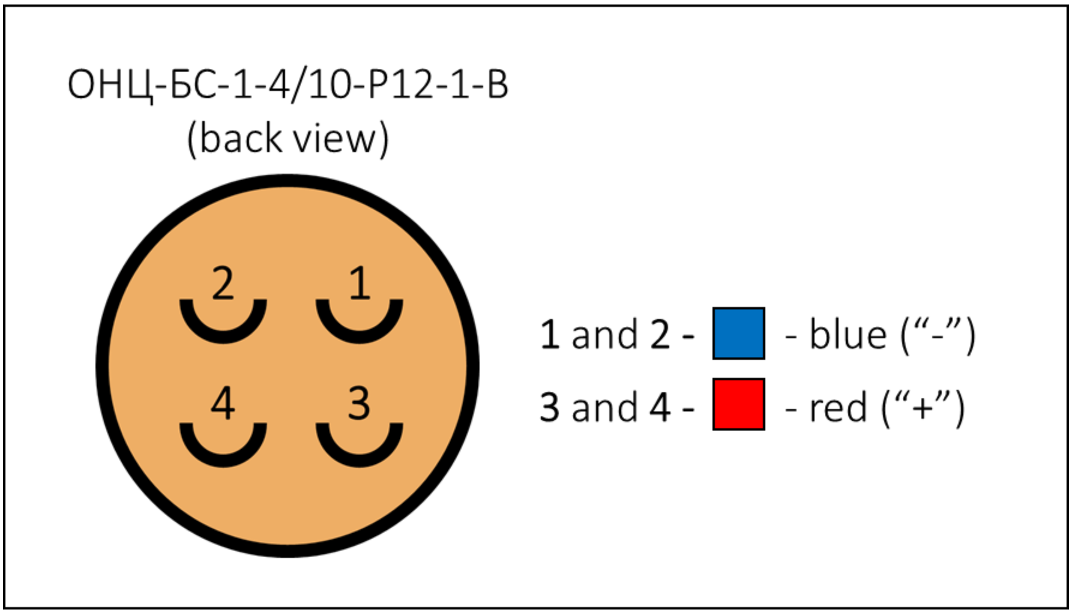


Figure 72 – Pinout of the Li-ion battery cable

Blue wire is connected to the pins 1 and 2; red wire is connected to the pins 3 and 4 of the socket.

7.6 Material Safety Data Sheet for Li-ion battery

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