Operation Manual for

Grad601 Single Axis Magnetic Field Gradiometer System

Bartington®
Instruments

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1. About this Manual

This document describes the installation, function, testing, operation and maintenance of the Grad601 single axis magnetic field gradiometer system.

It should be read in conjunction with the product brochure (DS1800), which can be found on the Grad601 Single Axis Magnetic Field Gradiometer System product page at www.bartington.com.

A training video is also available from the training page.
Software is available for downlaod available for download at www.bartington.com/software.html.

Note that failure to follow the instructions in this manual may invalidate your product's warranty. If in doubt, do not hesitate to contact Bartington Instruments.

1.1. Symbols Glossary

The following symbols used within this manual call your attention to specific types of information:

Caution: Indicates a situation in which bodily injury or damage to your instrument, or both, could result if the caution is ignored.

Identifies items that must be disposed of safely to prevent unnecessary damage to the environment.

Note: A note provides useful supporting information on how to make better use of your purchase.

1.2 Typography and Units

In the following text, references to keys and displayed characters are shown in italic text. The output of the Grad601 represents a differential measurement. As the separation of the sensing elements in each gradient sensor is 1m, all measurements reported in nT also correspond to gradients in units of nT/m.

2. Safe Use

WARNING: These products are not qualified for use in explosive atmospheres or life support systems. Consult Bartington Instruments for advice.

3. General Description

The Grad601 is a single axis, vertical component fluxgate gradiometer comprising a DL601 Data Logger, BC601 Battery Cassette battery cassette, and either one or two Grad-01-1000L cylindrical gradiometer sensors (Figure 1) mounted on a rigid beam. Each sensor contains two fluxgate magnetometers with one metre vertical separation.

Figure 1: Grad-01-1000L identification label.

The Grad601 magnetic gradiometer is supplied in two versions, the dual sensor Grad601-2 (Figure 2) and the single sensor Grad601-1 (Figure 3).

Figure 2 Grad601-2 dual sensor gradiometer arrangement with harness.

Figure 3 Grad601-1 single sensor gradiometer arrangement.

The Grad601-2, with two sensors, records two lines of data during each traverse and reduces the survey time and distance walked to one half that of using a single sensor gradiometer. Both versions can operate in one of two modes:

Mode	Function
Grid	The instrument can be used: • as a survey tool, where data is logged while covering the site in parallel or zigzag paths. Data is saved in Grids of 10x10, 20x20, 30x30 or 40x40m. The magnetic gradient is measured along a series of lines spaced at 0.25, 0.5 or 1m depending on the resolution required. Measurements are taken at intervals of 0.125 to 1m along each traverse. • in scan mode, where the unit is used as a search tool with an audible output for locating and tracing pipes, cables etc. without data logging. See Grid Mode.
NMEA	NMEA Mode is designed for use with GPS hardware and features an NMEA output. The Grid settings are not present and the logger will only run in scan mode, called Run mode in NMEA Mode (see Scan Mode (Grid Mode)). NMEA Mode has been added to data loggers with firmware version 7.1 and above, and is purchasable as an upgrade to previous data logger versions if the data logger is returned to Bartington Instruments. In this mode data is not recorded but can be streamed to another device in NMEA format, and is intended to be combined with a suitable GPS device and logger. In this way the exact location of each reading can be recorded against the data, removing the need to walk in Grids. See NMEA Mode.

4. Battery Cassette and Charger

The gradiometer battery is a sealed Lithium Ion type and is housed in a sealed, separate cassette (Figure 4a) which also contains the charging circuitry.

4.1. Charging the Battery

To charge the battery, connect the mains adapter supplied, or any isolated 9-18V DC supply (at 1.2A minimum), to the 2.1mm input socket (Figure 4b) for 6-8 hours. One charge will operate the system for up to 27 hours with two gradient sensors or 36 hours with one gradient sensor.

Figure 4a: BC601 battery cassette. & charger

Note: The case may become warm during charging. This is perfectly normal.

The red LED on the side of the cassette will be illuminated while the battery is being charged (Figure 4b). At the end of the charging period the charging current will be switched off automatically and the red LED will be extinguished. The data logger may be switched ON when the battery is being charged, but the red LED will then not indicate the end of the charging period. The protective cover provided for the connector should always be used when not charging.

The battery voltage is shown on the data logger display at switch-on and at the end of each survey Grid.

Note: The battery should be recharged at the end of each surveying session.

Note: The battery contains electronic protection against short circuit which, if activated, will reset after a delay of 10 minutes.

4.2. Changing the Battery

The battery or anti-surge fuse can be replaced by the operator. Remove the back cover of the Battery Cassette. Replace the battery or fuse.

Note: When closing the Battery Cassette, ensure that an anti-surge protection fuse of the type specified in the product brochure is in place. The fuse, and its spare, are shown in Figure 4c.

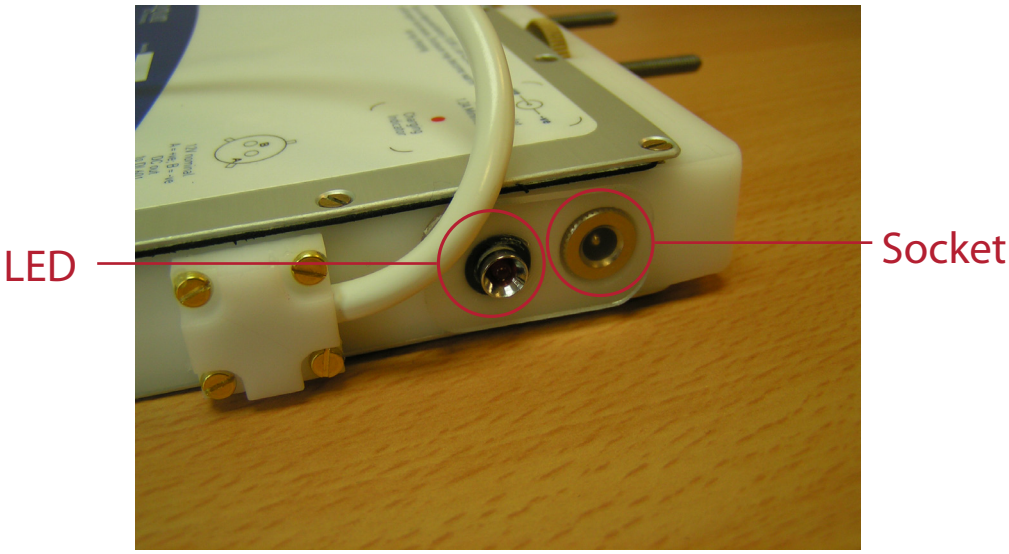

Figure 4b: BC601 battery cassette charging input socket and red LED.

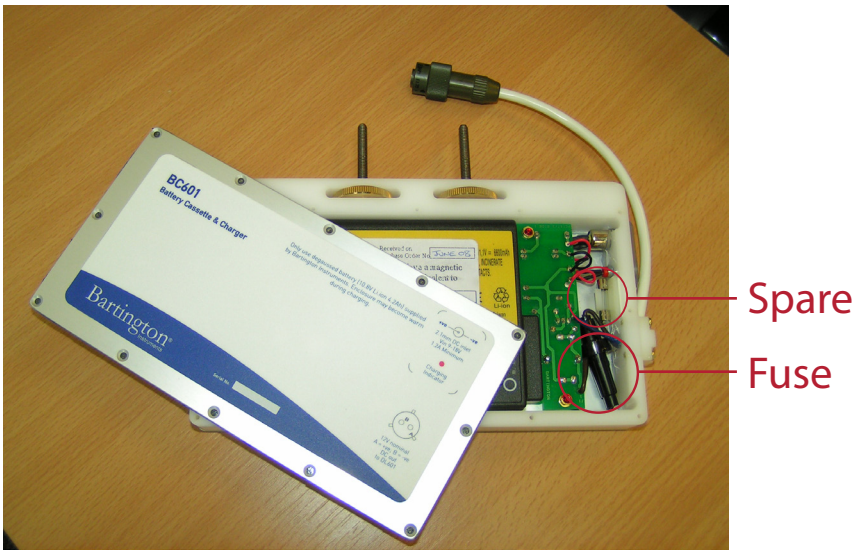

Figure 4c: BC601 battery cassette 5A fuse, and spare.

4.3. Shipping the Battery

Caution: Batteries and equipment containing batteries should only be shipped in accordance with local regulations. Refer to the IATA website (www.iata.org) for regulations regarding air transport.

Caution: If there is any doubt at all as to the integrity of a battery – for example, cracked or dented casing – then it must not be shipped. Remove it from the equipment and dispose of it according to local regulations.

Note: Ensure that any replacement battery is of the same type as described in the product brochure.

5. Assembly

The gradiometer system is supplied with battery and data logger attached to the beam, and one or two separate gradient sensors as appropriate. The data logger, battery cassette and connecting cables will normally be left attached to the beam, which is carried by the operator. For the dual sensor version, the gradient sensors are spaced at a fixed 1m apart at the ends of the beam.

To attach a sensor, loosen the plastic knobs to release the clamp and insert the sensor at the desired working height with the connector at the top (see Figure 5). Rotate the gradiometer(s) so that the heading arrow on the connector junction block label (see Figure 6) of each sensor is pointing away from the operator, in the direction of survey. Re-tighten the plastic knobs, but do not over-tighten.

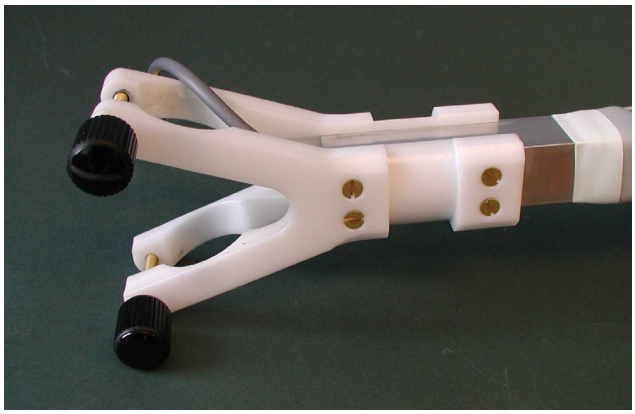

Figure 5: Gradiometer clamp showing Grad-01-1000L cable.

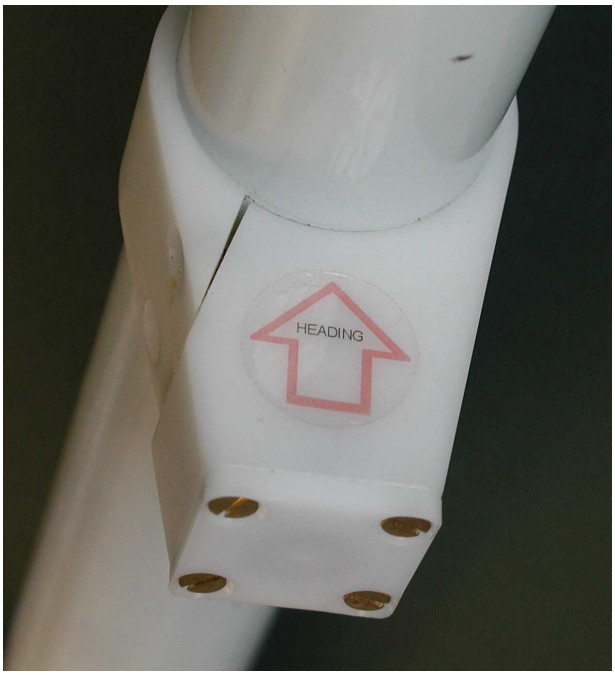

Figure 6: Heading direction label on Grad-01-1000L connector junction block.

Note: Assemble the gradiometer such that the arrows marked on the sensors are carefully aligned to point in the direction in which the operator will walk. This will assist the operator in pointing the arrows in the required direction during the set-up procedure. For a single sensor the arrow should be aligned along the beam. The beam can then be pointed in the appropriate direction during set up. Dual sensors should be mounted with the arrow on each sensor at a right angle to the beam, with each arrow carefully aligned parallel to the other.

Caution: Do not plug or unplug the sensor cables while the data logger is on. Doing so can affect the sensor adjustment, or cause data logger errors.

The data logger unit has a pair of fixing holes on the underside (Figure 7) for securing the unit to the beam. The Grad601-1 single sensor gradiometer has the sensor and data logger mounted in front of the operator and the battery box located at the end of the beam to give a balanced assembly as shown in Figure 3.

Figure 7a: DL601 Data Logger underside.

The Grad601-2 dual sensor gradiometer is carried with the beam across the front of the operator with one sensor on each side as shown in Figure 2. The data logger is located with the controls facing the operator and the battery mounted directly below it, and attached to the data logger through the beam with two knurled captive screws.

To detach the battery from the datalogger, turn the two brass screws at the top of the battery cassette. Ensure to hold the datalogger as it will become loose.

Should the cables need to be removed from the beam, the datalogger side of the cable can be fed through the beam. To remove the right-hand side cable, the green/red push button will need to be unscrewed.

6. Connections

Figure 7b: DL601 Data Logger connections guide

The functions of the sockets on the underside of the data logger are indicated in the label on the front side of the instrument.

Caution: Only connect/disconnect the cable from data logger to sensors with the data logger powered off. Not observing this may cause damage to the data logger.

Note: If only one sensor is used, connect it to socket 1 on the rear of the data logger. If two sensors are used, connect the sensor to the left of the operator to socket 1 and the one to the right to socket 2.

Note: Ensure the battery lead to the data logger is connected.

Note: The 9-way socket on the data logger is fitted with a replaceable gender changer to greatly extend the operating life, and a protective cover which must be fitted at all times except when downloading data.

Note: Protective caps are provided for the sensor connectors and should always be fitted when the connectors are not in use to minimise dirt ingress.

7. Grad601-2 Carrying Harness

The harness supplied with the dual sensor gradiometer is shown in Figure 8. This completely relieves the operator's arms of the weight of the gradiometer system, allowing easy operation of the controls.

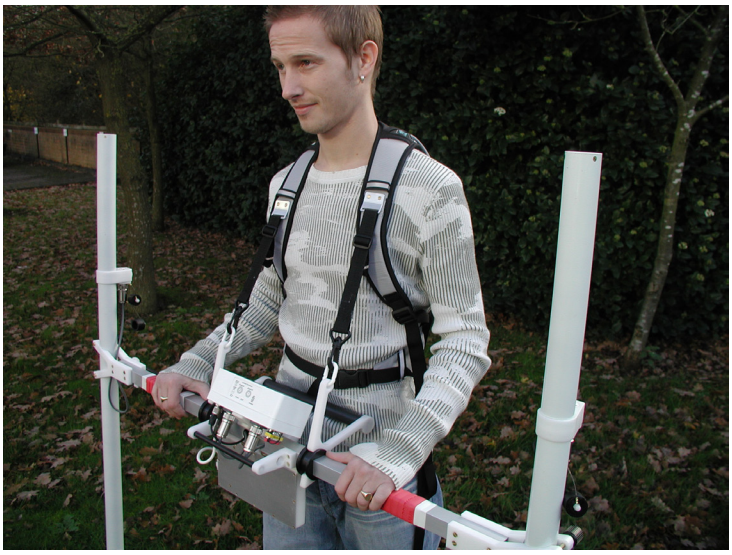

Figure 8: Grad601-2 dual sensor gradiometer carrying harness.

The harness comprises a lightweight, soft, padded shoulder harness, with a bag to contain a balance weight (sand or water), attached to an abdominal spacer by adjustable webbing straps through two replaceable plastic links.

The gradiometer can be quickly attached to and detached from the harness using two simple sprung hooks. This makes it possible to use more than one harness (and operator) with one gradiometer.

The sprung cradles on the abdominal spacer are clipped onto the bearings located on the beam. The webbing straps allow the height of the beam to be adjusted to suit the operator. To remove the gradiometer from the harness, use a thumb on each hand to spring open the cradle. All parts may be separated for repair or replacement and may be cleaned in water.

8. Instrument Stands

The gradiometers each have an integral prop attached to the beam for parking the gradiometer when not in use.

9. Setting Up

The gradiometer must be set up using an automated procedure to help it adjust to the environment in which it is to be operated. The same procedure also removes alignment errors and scaling differences between the sensing elements forming the gradient sensor.
This operation is to be carried out over a magnetically quiet area on or near the site to be surveyed.

Details of the procedure are given in Checking and Adjusting the Sensors. A training video is also available.

> **Note:** After assembly, switch on the Grad601 for a period of at least 15 minutes before carrying out the setting up procedure. During this warm-up period the instrument must be left in the environment in which it will be operating. For example, if it will be used in the sun, let it warm up in the sun rather than in the shade.

> **Note:** The alignment should be checked at intervals over the course of a day by returning to the quiet area and measuring the variation in magnetic gradient when rotating the gradiometer by 180 degrees. The setting up procedure should be repeated as necessary.

> **Note:** This procedure, which takes only a few minutes, must also be repeated whenever the sensors are adjusted for height relative to the beam. It will remove any offset error generated by changes in the position of the battery and other magnetic components relative to the sensor elements.

10. Keypad Operation and Display

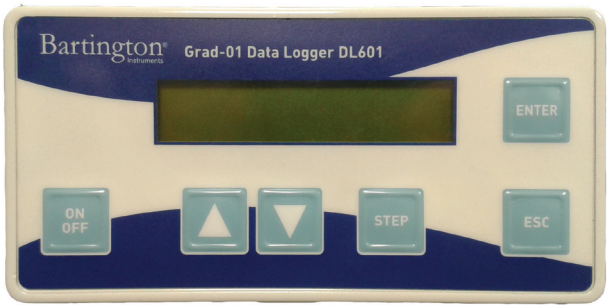

Figure 9: DL601 Data Logger control panel.

The Grad601 Data Logger DL601 (see Figure 9) has 6 keys to set parameters and control the operation. A two-line, 20-character display shows the menus, results etc. The functions of the keys are as follows:

Key	Function
ON/OFF	Controls the power to the unit and sensors. Press to alternately apply and remove power. When the display is blank, the power is OFF. When the display is active, the power is ON. A short delay is incorporated. **Caution:** If power is removed during memory access operations when the screen displays: 'Saving', 'Deleting', or 'Please Wait', then memory corruption can occur and data loss is possible. See Power Loss for more details.
ENTER	Starts the operation of the menu item displayed on the top line against the > cursor. It is also used to progress to the next operation if requested by a displayed message when static information is shown, or to confirm the operator's selection. If in doubt, press *ENTER* to continue and *ESC* to go back.
ESC (Escape)	Exits a procedure and returns to the previous menu or operation.
▲▼ (up/ down arrows)	Scroll through the menus to set the required option to the top cursor line, before starting the operation with the *ENTER* key.
STEP	Step through the available options for each of the operating parameters.

Note: With the exception of the *ON/OFF* key, the required action occurs only when a key is released after being pressed.

Note: External push buttons are provided on the beam for use as optional *ENTER* (green) and *ESC* (red) keys. These are particularly useful in the survey mode and during setting up. They provide control of the data collection, and interruption during surveys and setting up without moving the hand from the beam.

Note: A menu may offer an action which is not valid at that time, for example moving back one line when at the start of the first line. If a non-valid menu selection is made then the data logger will bleep and take no action.

11. Grid Mode

Connect the data logger to the gradient sensors and battery, and then press and hold the *ON/OFF* switch until the display is activated. At switch-on the display will show the title screen with the program version and battery voltage for a few seconds, before switching to the Mode Selection Menu. You can then select either *GRID MODE* or *NMEA MODE*.

Note: To change between Grid and NMEA Modes, the data logger must be restarted by turning off/on.

11.1. Main Menu: Grid Mode

The items in the Grid Mode main menu are as follows:

- Start survey
- Start scan
- Output data
- Delete data
- Set parameters
- Adjust gradiometer
- System reset

The two-line display will show only two items at a time. The first two items in the Grid Mode main menu will be shown as:

>Start survey

Start scan

The > prompt in the top line shows the menu item that will be activated when the *ENTER* key is pressed. The second line shows the next item in the list. Scroll down and up through the list, one line at a time, by pressing the down and up arrow keys. Hence, pressing the down arrow will change the display to:

>Start scan

Output data

After completing each task the program returns to this main menu.

Note: Always return to this menu before pressing the *ON/OFF* switch to turn off the power.

Note: Before selecting *Start survey* or *Start scan*, select *Set parameters* to set the number of sensors being used and all other variables to ensure correct operation.

Note: When using the instrument for the first time, if the *Set parameters* menu shows invalid values or is incomplete, then return to the main menu and select *System reset*. This sets default values into the operating parameters, deletes the memory and resets the memory pointers. The parameters can then be set to the values required by the operator.

11.2. Set Parameters Menu: Grid Mode

From the main menu select *Set parameters* and press *ENTER.* This will give a further menu with default parameters set as shown in the table below. Use the arrow keys to select each item in turn, and then press the *STEP* key to step through the available options for that parameter.

Option	Default	Function
Pace	: 1.8m/s	Select the walking pace of the operator: 0.5 to 2m/s in 0.1m/s increments, or Single shot.
Gridsize	: 30x30	Select the size of Grid: 10x10, 20x20, 30x30 or 40x40m.
Start	: North	Select the starting direction of the Grid: N, NE, E, SE, S, SW, W or NW.
Pattern	: Zig-Zag	Select the traverse pattern to be followed: Parallel or Zigzag.
Lines/m	: 1	Select the required number of data lines per metre: 1, 2 or 4. **Note:** For a dual sensor system the spacing is fixed at 1 metre so the operator will walk (traverse) at 2m intervals to record data at 1 line/m. For 2 or 4 lines/m a special traverse pattern is required with a 2m repeat. See Survey Mode (Grid Mode) and Survey Operation (Grid Mode) for details.
Samples/m	: 4	Select the number of samples per metre along each line: 1, 2, 4 or 8. **Note:** A density of up to 8 samples/m is available for 10x10, 20x20 and 30x30m Grids. A density of up to 4 samples/m is available for Grids of 40x40m.
Range	: 100nT	Select the full scale range of 100nT (resolution 0.03nT) or 1000nT (resolution 0.1nT).
Audio	: On	Select the audio output for scanning and survey operations: Off or On.
Volume	: High	Select volume: High or Low.

Threshold	: 1 nT	Select the deviation in nT at which the alarm is required to operate during a scan operation: increments in units, tens and hundreds and thousands of nT. When the field deviates by the level selected, the ALARM message will be shown in the display for the appropriate sensor, and the audio output rate will start to increase. The audio tone varies from the value set to about ten times this value.
Sensors	: 2	Select the number of sensors to be used: 1 or 2.
Reject	: 50 Hz	Select the local mains frequency of 50 or 60Hz to minimise pick-up.
Save	n/a	Save the parameter settings shown in the display.

When all parameters have been set to the required option, select *Save* as an item and press *ENTER*, or simply press *ENTER* at any point. The display will indicate that the parameters have been saved before reverting to the main menu.

Note: Once set, parameters are saved for use during subsequent operations. Selecting *Delete data* from the main menu will clear the memory.

Note: To leave the *Set parameters* menu without saving the changes, simply press *ESC* at any time. The display will indicate that the parameters have been reset to the previous settings.

Note: The parameter settings can be reviewed at any time and are saved in memory, until changed by the operator. However, if *System reset* is selected from the menu then the settings will revert to the initial default values and will need to be reselected.

12. NMEA Mode

The items in the NMEA Mode main menu are as follows:

- Run
- Set parameters
- Adjust gradiometer
- System reset

The Run option now replaces the *Start survey* and *Start scan* options because there is no distinction between the two in this mode. The *Output data* and *Delete data* items have been removed because no data is stored on the data logger.

The sampling frequency can be changed in the parameters menu, as in NMEA Mode this is not based upon Grid size or walking speed.

The ranges and resolution provided in NMEA Mode are the same as in Grid Mode: see Gradiometer Range and Resolution.

It is still necessary to undergo the setup procedure in a suitably quiet area before use to remove offset, scaling, and directional errors. To scan the area to assess its suitability, set the gradiometer to *Run*. See Checking and Adjusting the Sensors for more details.

> **Note:** When using MLGrad601 (Geomar Software) to collect the NMEA data, press the *Run* button on the data logger before logging is begun in the software.

12.1. Set Parameters Menu: NMEA Mode

Before use in NMEA Mode the data logger needs to be set up with the correct survey and data output parameters. Select these based on your survey requirements, as well as the specification of your GPS and/or data logging device.

The following options can be set via the *Set parameters* menu in NMEA Mode.

Option	Default	Function
Sensors	: 2	Select the number of sensors connected: 1 or 2.
Range	: 100nT	Select the full scale range of the sensors: 100nT or 1000nT.
Sample at	: 1Hz	The measuring frequency of the sensors: 0-10Hz in 1Hz increments.
Baud rate	: 9600	The data transmission rate per second through the RS232: 9600 bits per second.
Audio	: On	Select whether or not the instrument sounds an audible alarm: Off or On.
Threshold	: 1nT	The measurement threshold at which the alarm sounds in nT: increments in units, tens and hundreds and thousands of nT. When the field deviates by the level selected, the *ALARM* message will be shown in the display for the appropriate sensor, and the audio output rate will start to increase. The audio tone varies from the value set to about ten times this value.
Volume	: High	The volume of the audible alarm: High or Low.
Reject	: 50Hz	Select to remove 50 or 60Hz mains interference.
Save		Save the parameter settings shown in the display.

12.2. Capturing Data in NMEA Mode

Whilst in NMEA Mode, the DL601 Data Logger can be connected to any external data logger that is capable of receiving NMEA messages. An NMEA GPS device can then be plugged into the same logger and the data can be correlated. Any Windows-based system can be used as an external logger, including the Archer and Allegro field PCs, or any laptop/tablet PC.

See Downloading Survey Data to a PC for recommended software to use with the NMEA data logger.

13. Gradiometer Range and Resolution

The Grad-01-1000L sensor has two linear operating ranges:

Range	Details
±100nT	Values are recorded with a resolution of 0.01nT, but the actual resolution achieved will be limited to about 0.03nT due to the internal noise of the instrument.
±1000nT	Values are recorded with a resolution of 0.1nT. The values will be clipped at the full scale values with no over-range.

In Survey Mode (i.e. after selecting *Start survey* in Grid Mode), the result is displayed with a resolution of 1nT regardless of the range selected, but the result is saved to memory with the resolution appropriate for the range selected.

Each measured value is the average of many samples. In Survey Mode the sampling time is adjusted to produce an average value over the sampling distance at the pace selected. The measurement time is further modified to integrate the signal over a discrete number of mains cycles. This enhances the high 50/60Hz rejection of the sensors.

Note: The background noise can be further reduced by integration, walking more slowly, or by using fewer samples per metre.

Note: Integrating the readings over the measurement interval reduces the noise level, but also effectively limits the bandwidth. If the sampling interval is set at e.g. 4 samples/m, the minimum spatial resolution will be 0.25m and any anomaly smaller than this will be diluted by the averaging process. The sampling interval should therefore be set to allow the smallest anomaly expected to be recognised, with 4 samples/m being a good compromise.

Note: Under optimum ground conditions the best survey results are obtained with the lower sensor around 20cm above the surface. This produces the highest sensitivity to buried features whilst minimising surface noise. The height of the gradient sensors can easily be adjusted to avoid vegetation.

Note: Each time the height settings are adjusted, the system must be set up again using the *Adjust Gradiometer* menu item before use. See Checking and Adjusting the Sensors.

14. Operator Magnetic Hygiene

Note: The Grad601 gradiometer is a very sensitive instrument, and any magnetic objects placed near the sensors will affect the measurements. The operator must ensure that there are no magnetic items on their person or in their clothing.

Common objects causing errors include glasses, watches, keys, belt buckles, zips, magnetic parts of shoes etc. If the gradiometer is carried close to the ground, the operator's shoes are particularly important.

To check the operator for magnetic items:

1. Set the gradiometer to the 100nT range with the appropriate setting for the number of sensors and run in Scan Mode (see Scan Mode (Grid Mode)).
2. Hold the gradiometer stationary and check the readings when the operator approaches the sensor. The operator should check all parts against the end of a sensor until a change of less than 0.1nT is seen.

Caution: Please ensure that the equipment does not get exposed to strong magnetic field. The battery has magnetic component, but is degaussed in order to reduce it's signature. Exposure to strong field can magnetise the battery, and thus affecting the quality of data.

15. Checking and Adjusting the Sensors

15.1. Introduction

To avoid large variations when rotating the gradiometer, it is necessary to match the gain, offset and exact alignment of the two sensing elements in each Grad-01-1000L sensor. The sensors are extremely stable but over time, and with changes in temperature, it is inevitable that some change will occur in the sensor matching. A setting up procedure is provided to apply corrections to restore the precise matching required.

The procedure requires the operator to point the arrows marked on the sensors in the appropriate direction, press either the *ENTER* key or the green push button, and hold the instrument still until the instrument bleeps and issues the next instruction. This routine, which

automatically applies corrections, must be carried out in a previously selected low magnetic gradient area.

Note: The setting-up procedure takes only a few minutes. It should be carried out after the instrument has been assembled and left switched on for about 15 minutes. The rotational errors should be checked occasionally, at the original set-up position, and the setting up procedure repeated as necessary.

Note: Setting up a single sensor unit is carried out with the operator holding the unit in the normal way. Setting up a dual sensor unit may be carried out with or without the harness.

15.2. Selecting a Site for Error Measurement and Adjustment

Note: Before attempting to set up the instrument or make any measurements, ensure the operator is completely free of magnetic materials: see Operator Magnetic Hygiene.

To check the sensor errors and apply corrections, the sensor must be positioned in a low magnetic gradient environment.

1. Select a site away from roads, drains and any possible magnetic objects. The instrument set-up will only be as good as the area used for the set-up, so select the area with care.

2. Switch on the power using the *ON/OFF* switch, select the appropriate settings from the *Set parameters* menu, and then leave the sensor to warm up for a few minutes.

3. Select *Start scan* and scan the operating area whilst holding the instrument vertically straight and keeping the sensors pointing in a constant direction. Search for an area where the reading on the display does not vary by more than about 0.5nT when moving about 1m in any direction. The two sensors may not have the same value before completing the set-up process so it is important to concentrate only on the variations at this stage.

4. When a convenient spot has been found, ensure that the reading from either sensor does not change by more than about 2nT when raising the sensors vertically from about 30 to 60cm above the surface.

5. Mark this reference area for future use.

Note: When operating with two or more gradiometers, both units can be checked independently over the same reference point as necessary.

15.3. Error Measurement

1. To measure and correct the errors in the sensors, it is necessary to know the directions of magnetic north/south and east/west with reasonable accuracy. Use a compass to determine

easily identified features in the landscape on the north/south and east/west directions from the magnetically clean area selected above.

Note: Be sure to remove the compass from the area afterwards or it will interfere with the setup procedure.

2. Operate the instrument in Scan Mode (see Scan Mode (Grid Mode)) in the 100nT range, in the direction of the arrow marked on the connector junction block of each Grad-01-1000L sensor (see Figure 6). Keeping the sensors over the magnetically clean reference point, measure the errors as follows:

Error	Cause	Maximum value
North/South	Misalignment of the sensors in the direction of the heading direction arrow.	When the arrow points north/ south.
East/West	Misalignment of the sensors at right angles to the direction of the arrow.	When the arrow points east/west.
Vertical	Imbalance between the top (reference) sensor and the lower (measuring) sensor.	When the gradiometer is inverted.
Offset	A fixed zero offset error regardless of the orientation of the gradiometer.	n/a

Note: For optimum results, the difference in the gradiometer readings should vary by no more than about ±0.2nT for any of the above tests, and the offset error should also be less than 0.2nT. If any error exceeds this value, adjust the gradiometer to reduce the variation as indicated below.

15.4. Adjustment

Note: The following is written assuming a dual sensor gradiometer system is used. The procedure is the same for a single system, but read 'sensor' and 'arrow' instead of 'sensors' and 'arrows'.

Note: This procedure must be carried out with the gradiometer over the low gradient site selected earlier. The operator must rotate the complete gradiometer assembly to align the sensors as required by the program, but must keep the assembly static, and the sensor tubes as vertical as possible, while the instrument carries out the necessary adjustments.

Note: If only one sensor is used, keep the sensor over the same point while the assembly is rotated. If two sensors are used, the routine sets both sensors at the same time, and

the operator should keep the centre of the assembly over a fixed point. This is most easily achieved using the harness.

Note: When the display requests that the sensors be moved to the opposite direction, rotate the gradiometer through 180 degrees for the best result. Find N, S, E and W to within a few degrees using a compass, which should then be removed to a safe distance.

Note: At each stage in the sequence of operations, the instrument will bleep and the display will prompt the operator when a change in the position of the gradiometer is required. After setting the required direction, the operator should press the green button – equivalent to the *ENTER* key – and wait for the adjustment to be made.

Note: If set-up is difficult due to a noisy magnetic environment, hold the entire system as high up as is comfortable to perform the setup procedure and protect against interference from the ground.

15.4.1. Procedure

1. From the main menu, select *Adjust Gradiometer*. The initial display will prompt the operator to *Point arrows North and Then Press Enter/PB*.
2. Align the assembly so the sensor arrows point north and the sensors are vertical, then press the green push button. When the button is pressed, the instrument will take readings from the sensors. It will then bleep and prompt the operator with the message *Point arrows South and Then Press Enter/PB*.
3. Rotate the gradiometer to point the arrows south. Press the green button when stable. The gradiometer will then take a series of measurements and make corrections to the sensors in turn.
4. Point the sensor arrows east and west as prompted by the display.
5. When prompted to invert the sensor, face west and rotate the beam so that the tops of the sensors are now pointing vertically downward, and press the green button.
6. When prompted, restore the sensors to the normal position with the arrows pointing west. At this point, both the vertical error and offset are adjusted.
7. Point the sensor arrows east, south and north again as prompted while further corrections are made.
8. If all is well, the display will show *Set up finished* and prompt the operator to press the *ENTER* key or push button.

15.4.2. Adjustment

The above set-up procedure is carried out with the full-scale range set to 100nT by the program. The results are displayed with a resolution of 0.01nT. If at any stage the program detects that

the controls are too far out of adjustment, the controls will be re-set automatically and the procedure will be re-started, with the full-scale range set to 1000nT and the fields displayed with a resolution of 1nT.

After completing the procedure with the range set to 1000nT, the instrument should be within the normal starting range for the set-up procedure. The program will set the range back to 100nT and re-start the procedure from the beginning.

If the program resets the controls and sets the range to 1000nT for a coarse adjustment, the operator will see a *Please Wait* message in the upper line of the display and a series of dots appearing in the lower line of the display. During this short time, no measurements are made and the orientation of the gradiometer is unimportant. The operator will be aware that the fields are displayed to a resolution of 1nT during the coarse setting. The coarse adjustment will end with the operator facing north, and the new fine adjustment sequence will begin with the operator facing north again.

A coarse adjustment may be required after attempting to set up the instrument in a high gradient area. If the coarse adjustment is called a second time, a fault is indicated and the set-up routine will end with the message *Coarse Error Sensor* followed by the sensor number, 1 or 2.

> **Note:** If the set-up is attempted in a relatively high gradient or when some magnetic interference is present, possibly from a poor set-up area or an operator wearing magnetic material, the fine control may still reach the end of its adjustment. The set-up will continue and the result may be acceptable but a warning message, *Fine control limit*, together with the relevant sensor number will be displayed at the end.

> **Note:** Always check the set-up by selecting the *Scan* mode (see Scan Mode (Grid Mode)) and noting the field readings as the gradiometer is rotated so that the arrows on the sensors point north, south, east and west over the set-up area. The results should all be close to zero, within a range of ±1nT. However, the result will depend on the gradients within the setting up area.

Each gradiometer holds the adjustment settings in internal non-volatile memory. Adjustments made during the above operations will be maintained until the next set-up operation.

16. Scan Mode (Grid Mode) / Run Mode (NMEA Mode)

In the Scan or Run mode, the gradiometer readings are continuously displayed but not saved to memory. The operation is determined from the values shown in the *Set parameters* menu.

If the *Audio* option has been set to *On*, the audio output will vary with changes in magnetic gradient. The audio *Volume* can be set to high or low.

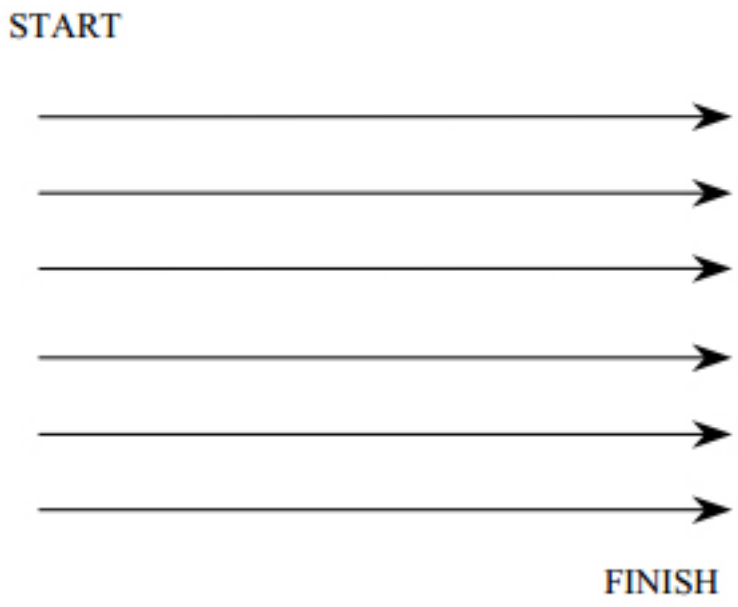

Figure 10: Parallel traverse pattern.

The *Threshold* function selects the field gradient at which the frequency of the audio output will increase. The audio tone increases from the alarm point to about ten times this value with increasing gradient levels.

In Scan Mode, the screen is refreshed at a rate of 5Hz.

In Run Mode, the rate of data transfer can be changed in the 'Set Parameters' menu.

The mode is terminated using the *ESC* key.

17. Survey Mode (Grid Mode)

17.1. Survey Parameters

The data logger is programmed to record surveys based on a series of areas, termed Grids. Each Grid will cover an area of 10x10, 20x20, 30x30 or 40x40m. Each Grid is numbered sequentially, starting at Grid 1, and is surveyed using a pattern of traverses, starting at Traverse 1. In the display 'Traverse' is abbreviated to 'Trav'.

> **Note:** Carefully record the relative position of each Grid, and the order in which Grids are measured, and ensure that the starting direction is set in the parameters for future reference.

The number of lines of data recorded will be determined by the size of the Grid and the line spacing selected as *lines/m*. For the Grad601-1 single sensor gradiometer, one line of data will be recorded for each traverse. For the Grad601-2 dual sensor gradiometer, two lines of data will be recorded for each traverse. The traverse number is displayed during the survey.

Values of the magnetic gradient will be recorded at a series of positions along each traverse. The number of samples per metre, selected in the *Set parameters* menu, determines the number of positions and is set by the operator at 1, 2, 4 or 8 samples per metre. The readings will start at Position 1.

Traverses are walked in either parallel pattern (Figure 10), where each traverse starts at the same side of the Grid, or zigzag pattern (Figure 11), where traverses start at alternate sides of the Grid. A zigzag pattern is normally used to minimise the distance walked.

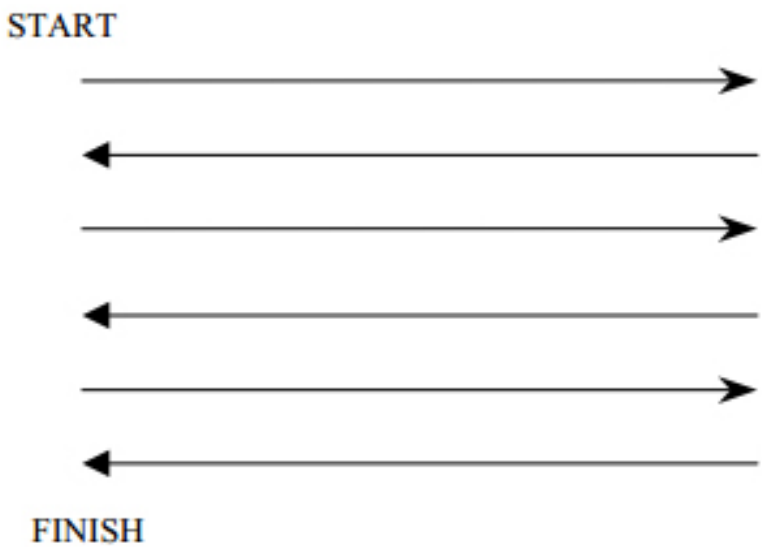

Figure 11: Zigzag traverse pattern.

17.2. Single and Multiple Sensors

The sensors of the Grad601-2 dual sensor gradiometer are arranged to the left and right of the operator with a fixed separation of 1m. The operator therefore walks between two data lines recorded during each traverse. The *Trav* (traverse) number will correspond to two lines of data recorded simultaneously.

When using a single sensor gradiometer, the *Trav* (traverse) number shown in the display will correspond to the data line number.

The number of data lines per metre required is set in the *Set parameters* menu. Therefore, if data is required at a density of one line per metre with a dual sensor gradiometer, then the operator

will select 1 line/m but will traverse the Grid at 2m intervals. Thus, for a 10x10m Grid, only five traverses will be walked but ten lines of data will appear in the results at the appropriate positions after downloading.

Results from each sensor are logged at each position. The sensor to the left of the operator is referred to as sensor 1 and the one to the right as sensor 2. Either parallel or zigzag traverse patterns can be used. Provided the parameters have been set correctly, the software will automatically allocate the correct spatial position to the data when downloading the data to a PC.

17.2.1. Setting Parameters

Before starting a survey, all details must be entered using the *Set parameters* menu to enable the data to be interpreted correctly. The number of sensors is entered to allow the data subsequently to be arranged correctly in the Grid. A spacing of 1m is assumed between sensors when using two sensors. Different sized Grids may be recorded during a survey but may cause complications in the plotting software.

Data is collected at the distance intervals set by the operator assuming a fixed walking pace. The pace can be set as one of the survey parameters between 0.5 and 2m/s. The operator should find a comfortable walking pace but a good starting pace would be between 1.2 to 1.6m/s. Lines are often laid out to mark each traverse, with pace markers placed at 1m intervals along them. If *Audio* is set to *On*, the logger will emit an audible bleep once per metre to allow the operator to match their walking pace with the data recording rate.

The parameters of the current Grid cannot be changed once a Grid has been started, but an incomplete Grid may be deleted and restarted at any time. Grids are saved to memory in numerical order.

When downloaded using the software provided, the data for each Grid will form a separate file with a header containing the details of the parameters with which the Grid was measured.

17.2.2. Survey Conventions

To maintain compatibility with existing practices, it is assumed that each Grid will be surveyed starting in a clockwise direction from one corner (Figure 12). The display of the first line of data can be imagined as a line being printed horizontally from left to right at the top of the page (Figure 13). The next line is measured parallel to the first and one line space away.

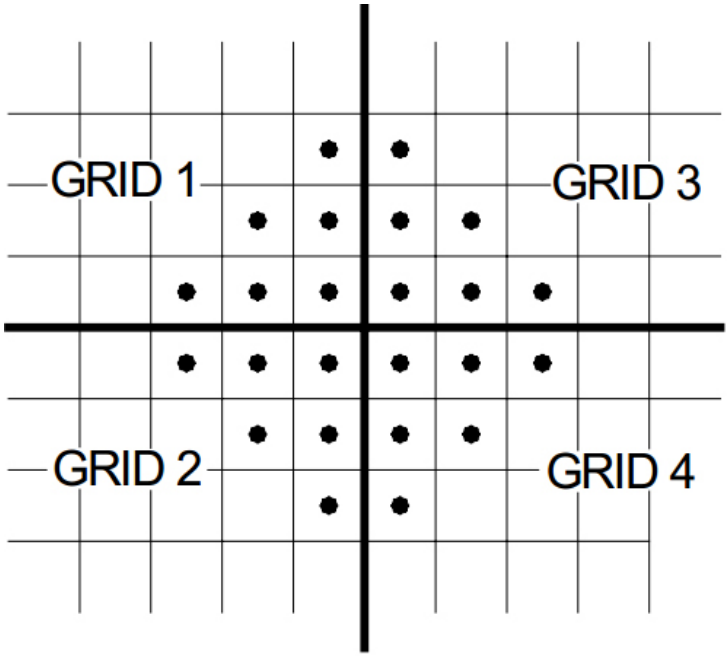

Figure 14: Measurement points on a series of Grids.

Grids may be surveyed using parallel traverses (Figure 10) or zigzag (Figure 11). The *Set parameters* option allows the initial starting direction to be saved as part of the header information.

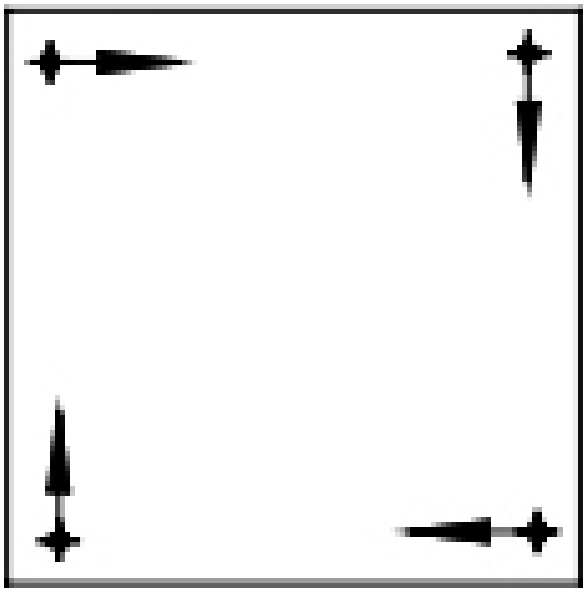

Figure 12: Possible starting points for first traverse.

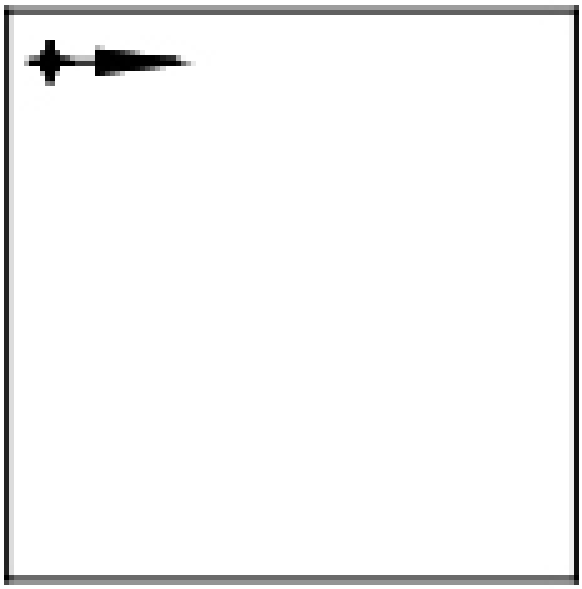

Figure 13: First traverse direction when plotted.

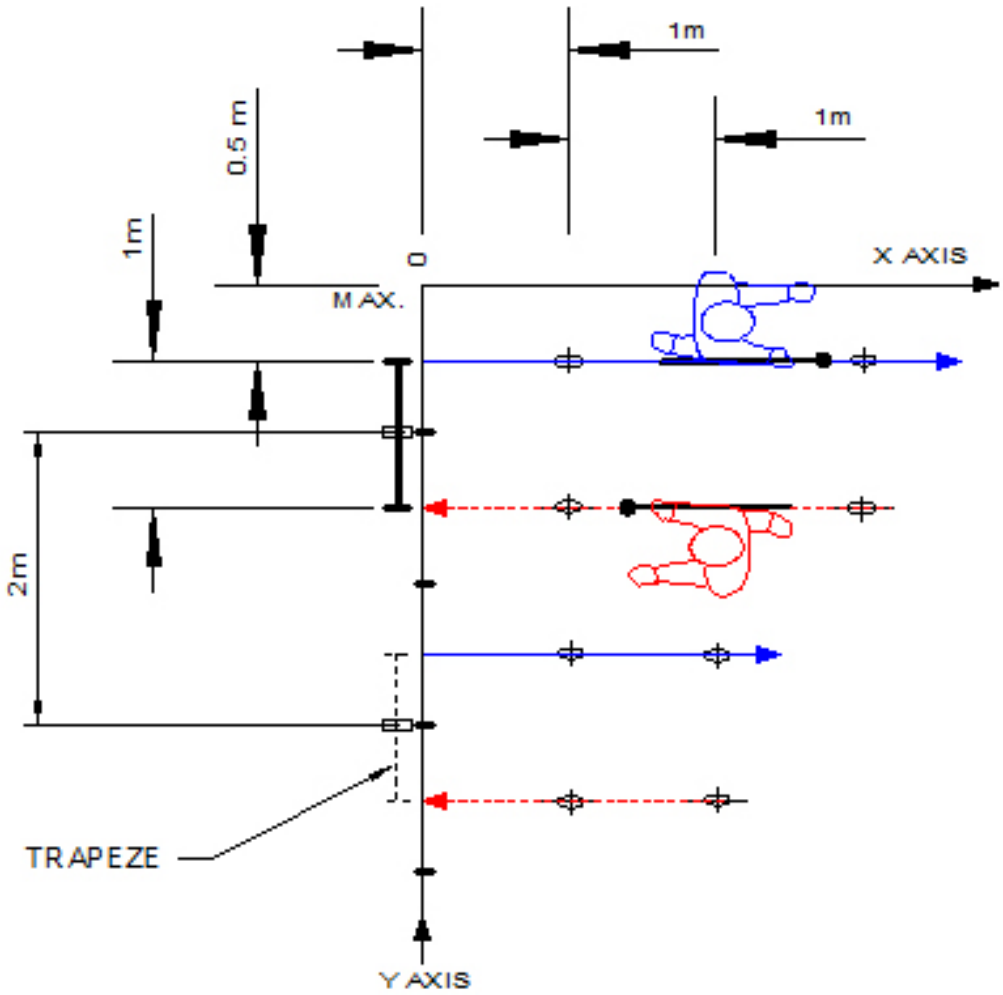

Figure 15: Single sensor operation with trapeze (1m traverses).

17.2.3. Lines and Positions

To interface the data of one Grid with others to form a larger area map, the lines are spaced symmetrically in one direction and the values are measured at positions spaced symmetrically along the lines. The first line should therefore be measured at a distance of one half line space from the edge of the Grid. The first measurement will be centred on a point one half of the reading interval from the start line.

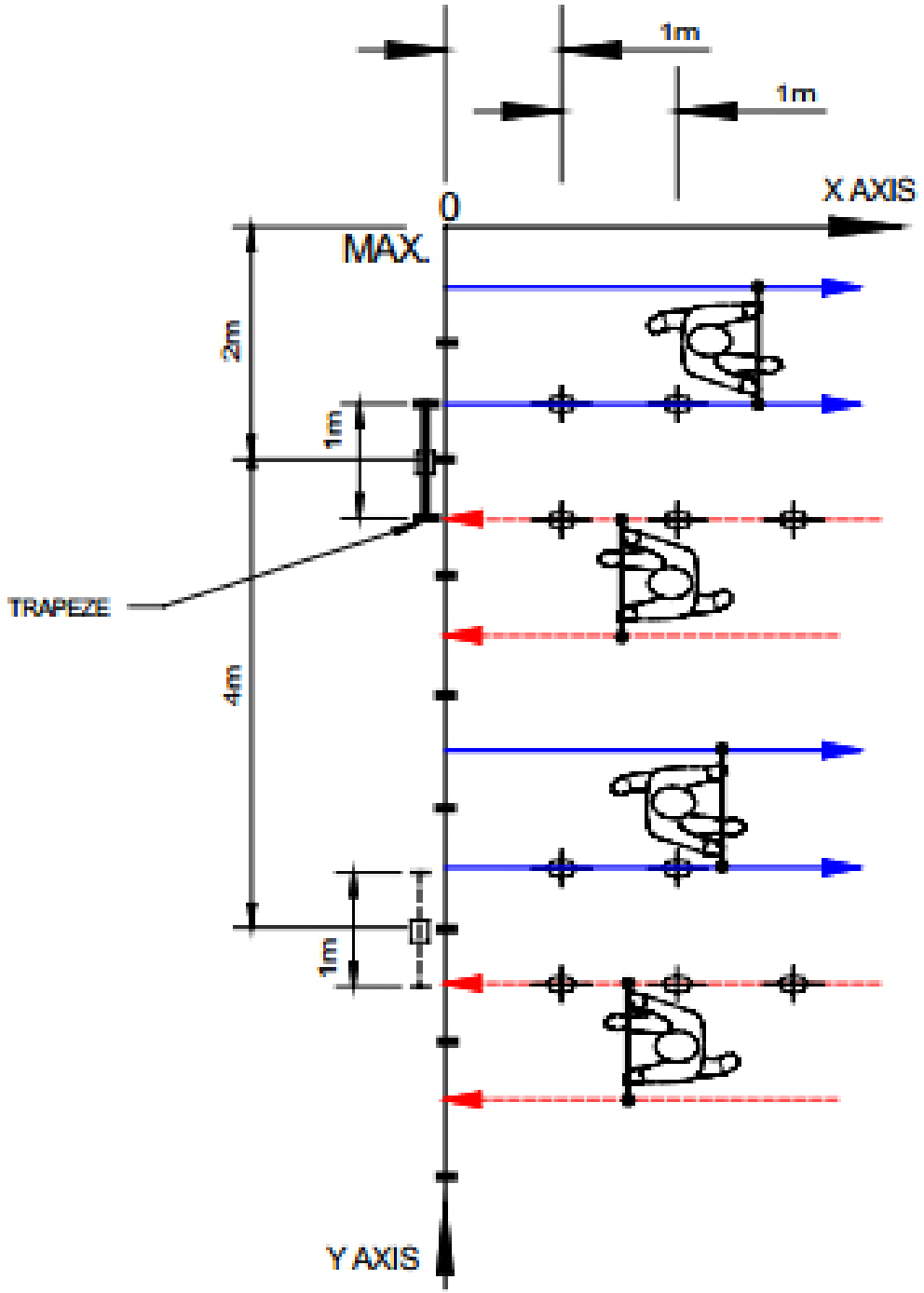

Figure 16: Dual sensor operation with trapeze (1m traverses).

If we consider a 30mx30m Grid with a line spacing of 1m, then the first line is positioned 0.5m from the top edge of the Grid and the remaining lines are then spaced at 1m intervals down the Grid. The last line is 29.5m from the top of the Grid. Similarly, if measurements are taken along the line at intervals of 0.5m then the first measurement will be taken at 0.25m from the start of the line and the last at 0.25m from the end of the line. The results from each Grid will then interface seamlessly with adjacent Grids without the need for a reference edge (Figure 14).

Note: Determine the four corners of the Grid using standard survey practice, and mark them out with non-magnetic flags. The traverse starting and finishing lines can be marked

with suitable ropes. It is also convenient to lay a rope along each traverse with 1m rope markers on it to allow the operator to keep pace with the data logging.

17.3. Surveying at 1 line/m

A line spacing of 1m (*lines/m* set to 1 in *Survey Parameters*) is normally used and is sufficient to locate most archaeological features. A "trapeze" comprising two ropes spaced 1m apart, with marks at 1m intervals along the ropes, will allow the operator to keep pace with the time bleeps.

For a single sensor, the operator should walk with the sensor over one trapeze line and return with it over the other, as in Figure 15.

For a dual sensor, the right hand sensor is held over the trapeze lines as in Figure 16.

Note: Mark the centre of the trapeze and the ropes along the start and end of the traverses appropriately to allow the trapeze to be positioned correctly. If the centre of the trapeze is marked then, for a single sensor gradiometer, mark the start and end traverse ropes at intervals of 2m, with the first mark 1m from the edge of the Grid. For a dual sensor gradiometer the intervals should be 4m with the first mark 2m from the edge of the Grid.

17.4. Surveying at 2 or 4 lines/m

The DL601 Data Logger software Version 5.7, and later, allows data to be collected with a line spacing of 1, 2 or 4 lines/m for both single and dual sensor gradiometers. The line spacing is therefore 1, 0.5 or 0.25m.

Using a Grad601-1 single sensor gradiometer, the situation is straightforward with the first line being recorded at half the line space from the edge of the Grid and subsequent lines separated by one line space. The pattern may be parallel or zigzag as selected in the *Set parameters* menu, and the marking of ropes at the ends of traverse is straightforward. If using a 1m wide trapeze as described above, the width of the trapeze should correspond to the line space selected when using a Grad601-1 single sensor gradiometer.

When using the Grad601-2 dual sensor gradiometer for collecting data at 2 or 4 lines/m, the situation is more complex due to the overlap of the data from the two gradient sensors. The operator must follow the traverse pattern described below so that the downloading software can re-arrange the data into the correct positions in the Grid.

Note: As the surveys can be made in parallel or zigzag, the following description uses the centre of the beam, or the position of the operator relative to the edge of the Grid, as the reference point for measurements regardless of direction.

Note: Surveying a Grid at 2 or 4 lines/m requires proportionally more memory than a Grid surveyed at 1 line/m, and the number of Grids which can be saved will be reduced accordingly.

17.4.1. Surveying at 2 lines/m

When using the Grad601-2 dual sensor gradiometer for surveying at 2 lines/m with a parallel or zigzag traverse pattern, the operator must follow exactly the appropriate pattern shown in Figures 17 and 18.

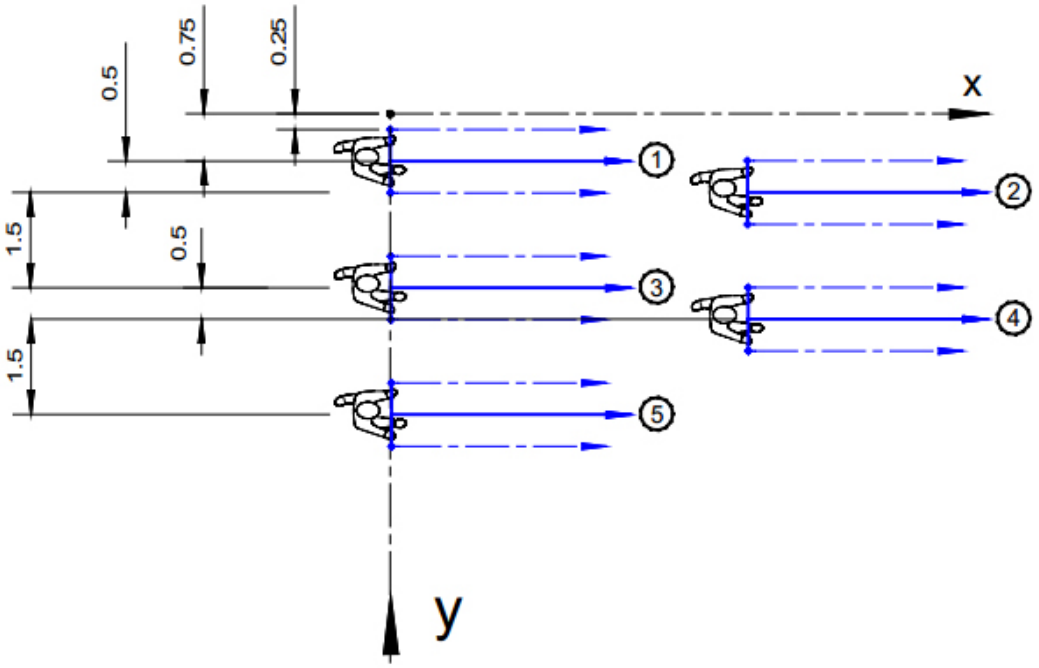

Figure 17: Dual sensor parallel survey at 2 lines/m (dimensions in metres)

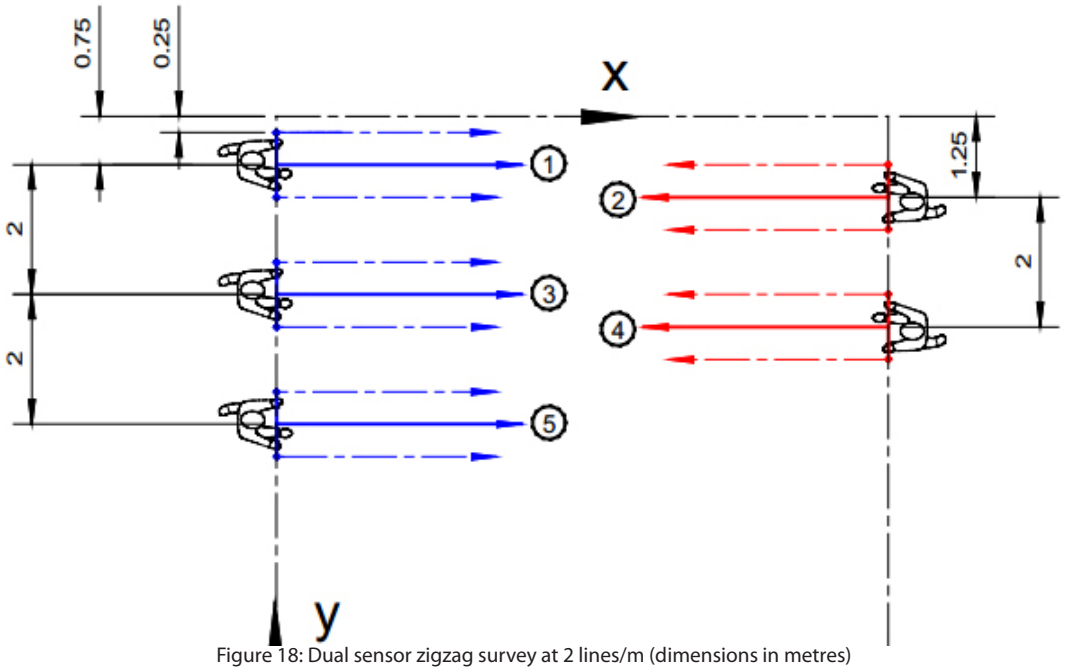

Figure 18: Dual sensor zigzag survey at 2 lines/m (dimensions in metres)

Traverse no.	Positioning of sensor and beam centre
1	Left-hand sensor at 0.25m and therefore centre of the beam at 0.75m from edge of the Grid.
2	Centre of beam 1.25m from edge of the Grid.
3	Centre of beam 2.75m from edge of the Grid.
4	Centre of beam at 3.25m from edge of the Grid

This alternating pattern of 1.5m and 0.5m increments is repeated for the complete Grid.

17.4.2. Surveying at 4 lines/m

When using the Grad601-2 dual sensor gradiometer for surveying at 4 lines/m with a parallel or zigzag traverse pattern, the operator must follow exactly the appropriate pattern shown in Figures 19 and 20.

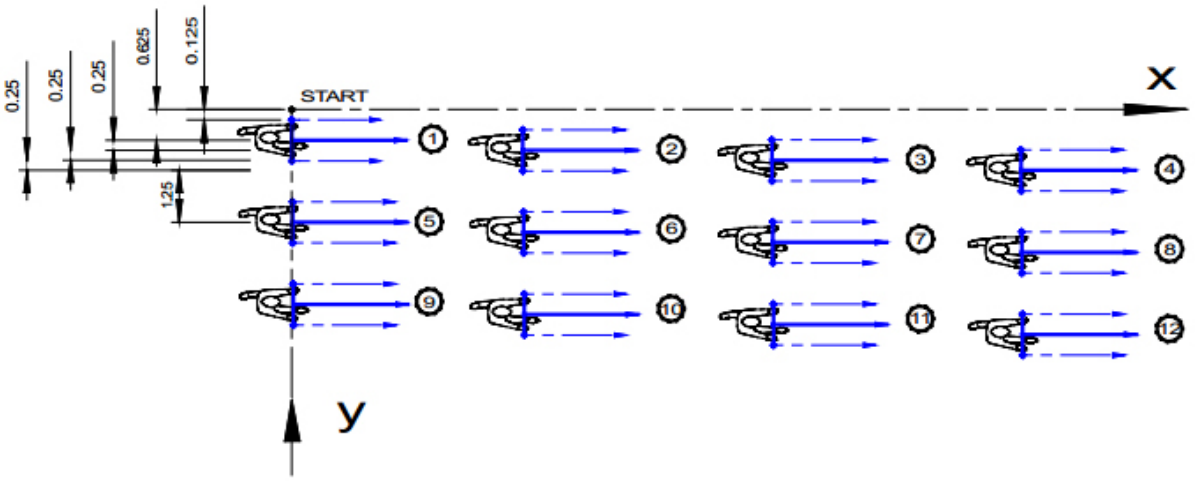

Figure 19: Dual sensor parallel survey at 4 lines/m (dimensions in metres)

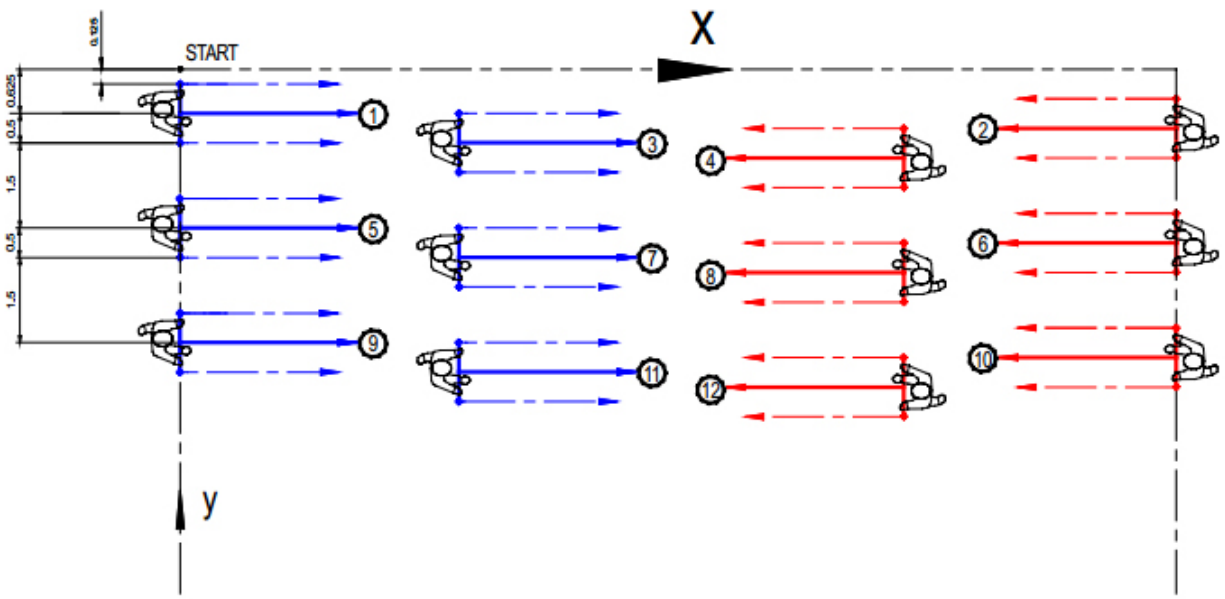

Figure 20: Dual sensor zigzag survey at 4 lines/m (dimensions in metres)

Traverse no.	Positioning of sensor and beam centre
1	Left-hand sensor at 0.125m and therefore centre of beam at 0.625m from the edge of the Grid.
2	Centre of beam 0.875m from edge of the Grid.
3	Centre of beam 1.125m from edge of the Grid.
4	Centre of beam at 1.375m from edge of the Grid.
5	Made with an increment of 1.25m, so centre of beam at 1.625m from edge of the Grid.

The next three increments are 0.25m. This pattern of increments of 1.25m, 0.25m, 0.25m, 0.25m is repeated for the remainder of the Grid.

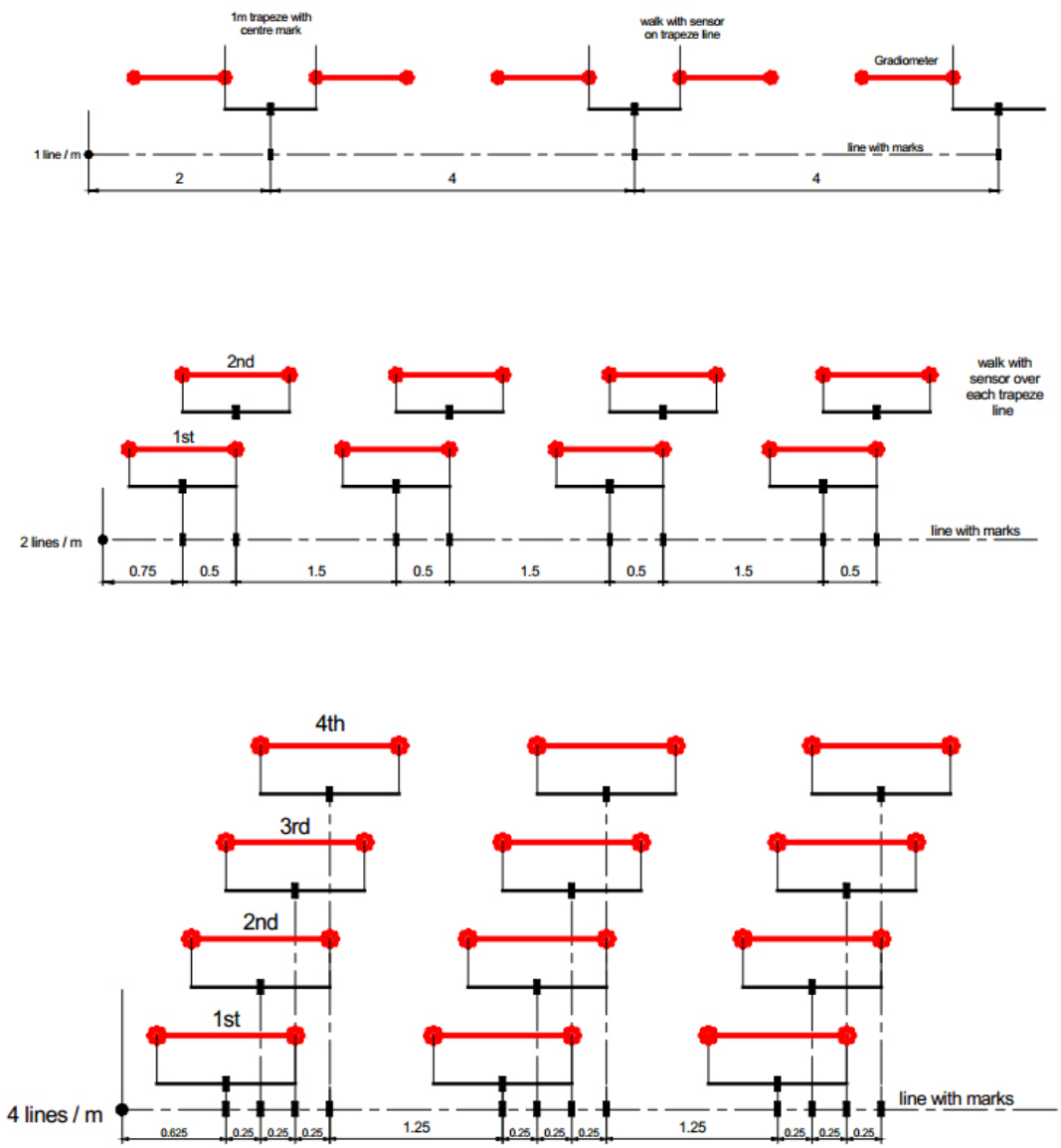

Figure 21: Dual sensor tape markings for 1, 2 & 4 lines/m

Note: For a Grad601-2 dual sensor gradiometer, use a trapeze with 1m between the two ropes. Mark the ropes defining the start and end of each traverse such that placing the centre marks of the trapeze over the marks on the edge ropes guides the operator along the traverse with one sensor over each of the trapeze lines.

Figure 21 shows the rope marking, trapeze position and sensor position for obtaining data at 1, 2 or 4 lines/m with a dual sensor gradiometer.

Use this diagram to prepare different ropes for each case.

Note: Walking between ropes as shown requires two operators to move the ropes, but avoids the possibility of the operator tripping as they carry the sensors along a line on the ground.

Note: With practice, the trapeze guide may be abandoned and the operation simplified by using canes to walk to at each end of the traverse as described later.

18. Survey Operation (Grid Mode)

When *Start survey* is selected from the menu, the data logger indicates the Grid number and waits for the operator to confirm this by pressing the *ENTER* key.

The display will then show that the instrument is ready to start the first traverse.

Note: To ensure good alignment of the data, the operator should:

- stand away from the line marking the start of the traverse
- press and hold the external green push button or *Enter* key
- start walking, reaching the normal pace before crossing the start line
- release the green button or *Enter* key exactly as the sensors reach the start line.

If *Audio on* has been selected, the data logger will bleep as the operator releases the key, and then at 1m intervals along the traverse. The operator should regulate the pace so that the bleeps coincide with the sensor passing the metre markers. A double bleep will sound as the operator reaches the end of the traverse.

Note: It is important to pass the start and end of the traverse at the normal walking pace if staggering of the data is to be avoided.

Note: Precision in releasing the green push button or *Enter* key is very important. For example, with a pace of 1.8m/s and 4 readings per metre, a delay of only 140ms will cause an apparent shift in the data by 0.25m. When this is repeated in the other direction for zigzag traverses, a total stagger of 0.5m will be seen.

During a traverse the data logger will display the current gradiometer readings and the Grid, traverse and position numbers.

The data logger prompts the operator to start each new traverse. When the last line is completed, the operator will be prompted to save the Grid or go back one line. If the *Save* option is selected then a summary will be displayed showing the mean, minimum and maximum values together with the battery voltage. The summary values always reflect the measurements of sensor 1. The *ENTER* key clears the display and returns to the main menu.

> **Note:** During traverses, maintain the sensors in a vertical position to minimise rotational errors. If the instrument is tilted in the traverse direction then the data will be biased in that direction, and a significant stagger may appear between traverses when a zigzag pattern is used.

18.1. Interrupting a Survey

Dummy values outside the normal range are used to fill the data pattern over inaccessible areas. When operating in a zigzag pattern, an obstruction may prevent the end of the current traverse and the start of the next traverse being completed.

Pressing the *ESC* key at any time during a traverse will halt the data collection process. A menu will appear offering the following choices:

Menu option	Function if selected
Finish and mirror	The remainder of the current traverse is filled with the dummy value (32702) and an equal number of dummy values are inserted at the start of the next traverse. Data can then be collected normally for the remainder of the traverse. If the selected pattern is parallel rather than zigzag, then the instrument will simply give an audible bleep to indicate an invalid command.
Finish Grid	The remainder of the Grid is filled with dummy values. The operator will then be prompted to save the Grid or return to the start of the last line.
Finish traverse	Inserts dummy values up to the end of the current traverse, and prompts the operator to start the next traverse. This is used to complete a line where an obstruction prevents a line being completed.
Change pace	The current pace is displayed and the operator is prompted to use the arrow keys and *ENTER* to set the pace required.

Back one trav	Pressing *ENTER* once will cause the displayed position number to return to 1, ready to start the traverse again. Further operations of the *ENTER* key will cause the traverse number to be decremented. If the option is selected before starting a line, the traverse number will be decremented each time *ENTER* is pressed. When the required number of traverses have been deleted, pressing *Esc* will return the unit to the Survey Mode ready to continue from the start of the selected traverse. This option allows the survey to be restarted from the beginning of any previous traverse. If Traverse 1 is reached, the unit will bleep and prompt the operator to start the line.
Back one posn	The Position number shown with the menu item is decremented each time *ENTER* is pressed. When the required position has been reached, pressing *Esc* will allow the survey to continue from that position. When Position 1 is reached, the unit will bleep and prompt the operator to start the traverse.
Enter dummy at	Inserts a single dummy value each time *ENTER* key is pressed. The Position number shown will be incremented accordingly. **Note:** Remember that if data is being recorded at 0.25m intervals then four dummy values are required for each metre of traverse. If a dummy is entered at the last position of a traverse, the unit will bleep and prompt the start of the next traverse.
Delete this Grid	The *ENTER* key will cause the current Grid to be deleted after confirmation and the display will return to the main menu.
Esc/PB to continue	The display will always show the next position to be measured and prompt the operator to press *ENTER* to start. If possible the operator should follow the same procedure as at the start of the traverse, as the recording will continue at the same pace when the *ENTER* key is released.

Note: It is possible to carry out surveys with irregular boundaries or obstructions by using dummy values in a Grid, and using different sized Grids. Dummy values can be transposed to any other value when downloading to a PC.

18.1.1. Data Logging and Control

Data is collected at a fixed rate and is automatically saved to the flash memory at the end of each traverse. If a survey is interrupted by loss of power, the data logger should continue from the start of the interrupted traverse when power is restored. See Power Loss for more details.

Note: Power should not be deliberately removed during a survey.

Note: After restarting, if the survey parameters are changed before continuing with the interrupted Grid then the data may be saved in the wrong format and false results may be seen.

Note: If a download is attempted with a Grid still incomplete then the last Grid will download continuously. If the number of downloaded bytes exceeds 260 000 then the download should be interrupted manually. Only complete Grids can be downloaded.

Data values are stored as two-byte signed integers to minimise both the memory requirements and the time taken to download data. The decimal points are added in the appropriate place by the download software using the range information in the Grid header. The 256kByte memory is sufficient to hold the data for 36 Grids of 30x30m with a line separation of 1m and 4 readings per metre. This corresponds to 36 Grids, each with 3,600 data points. If smaller Grids are used or measurements are made at less frequent intervals then the capacity of the memory will increase proportionally up to the limit of 99 Grids. Dummy values take up the same memory space as real values, and finishing a Grid with dummies utilises the same memory space as a normal Grid.

To place the data into a larger matrix after downloading, the operator must record the relative position of each recorded Grid separately.

18.1.2. Single Shot Operation

If *Single Shot* is selected as *Pace* in the *Set parameters* menu (between 2 and 0.5m/s) then the survey operates as normal, except that only one reading will be recorded each time the operator presses and releases *ENTER* or the green button, rather than data being recorded at a fixed rate. The gradiometer can then be moved between individual readings.

19. Downloading Survey Data to a PC

Contents of the memory can be downloaded to a PC and each Grid saved to a file with one of three formats (see File Formats). All data recorded in a zigzag pattern, or with interlacing as for 2 or 4 lines/m using a dual sensor gradiometer, will be re-arranged automatically to appear as it would if recorded in a parallel pattern with the correct line order.

Grad601 Datalog software for this purpose is supplied with the Grad601 gradiometer on CDROM. It is also available for download on the Bartington Instruments website. Other proprietary data processing software, such as TerraSurveyor from DW Consulting, allows direct download from the gradiometer into the program ready for processing.

If using the NMEA data logger, the recommended software for collecting the Grad601 and GPS data is Trackmaker (by Geomar Software, Canada). This is an ideal solution for the processing of the data. If using more than two sensors, for example when using with a cart system, MultiGrad601 (Geomar Software) can be used. Any other software that can interpret NMEA data and combine the magnetic and GPS data will also work.

19.1. Installing the Grad601 Datalog Software

The firmware version used by the unit is displayed at start-up.

Firmware version used	Software version to use
Version 7.4	Version 3.16
Version 6.6	Version 3.16
Version 6.3	Version 3.13

Place the CDROM in the CDROM reader. The program installation should start automatically. If it does not, use My Computer or File Manager to locate the program setup.exe on the CDROM drive and double click on it to start. Follow the instructions given.

> **Note:** If a previous version of the software is installed then the software program will uninstall it. The PC should then be restarted to install the new version.

19.2. Running the Program

1. Connect the DL601 Data Logger to an RS-232 communications port on the PC using the 9-way cable provided. Alternatively, use the USB to serial converter provided along with appropriate installation software.

2. Switch on the data logger; it does not need to be connected to any sensors.

3. On the PC, start the program *Grad601 Datalog*.

4. Select the com port corresponding to the port on the PC to which the gradiometer is connected. If the USB to RS-232 converter is used, go to My Computer/Control Panel/ System/Hardware/Device Manager/Ports(Com & LPT) to determine the number of the port allocated by the computer.

5. In the Dummy Data window, set the number required to represent dummy data.

   6. **Note:** The default value in the incoming data stream is 32702.

7. From the main menu of the data logger, select *Output data* and press *ENTER*. The message *Waiting for PC* will appear.

8. On the PC select *START*. After a few seconds the data download will begin.

The PC screen will indicate the number of the Grid being transferred and the total number of bytes received. Each value consists of two bytes, and the total number of bytes will be somewhat larger than twice the total number of readings.

The data logger display will also show the number of the Grid being sent.

When all data has been sent, a checksum is sent to validate the data. If the checksums do not match then an error has occurred and the operator will be prompted to repeat the download operation or proceed with the data as received.

If the data is received without error, the screen will change to the Save screen to allow the data to be saved as individual Grid files.

19.3. The Save Screen

The screen will show both the total number of Grids and the next Grid to be saved. The header information for the first Grid, giving the survey parameters, will also be shown. The options given are:

Save Screen Option	Subsequent steps
Save current Grid	A separate *SAVE AS* window will appear and allow the operator to select a folder and file name. When the data has been saved, the information for the next Grid will be presented and the process can be repeated.
Save all grids	A 'Choose a Filename Prefix' window will appear. Select a folder and then enter a name to be used for all the files. The data will then be saved with filenames comprising the chosen prefix and the Grid number: for example, if the prefix *mygrid* is selected, the Grids will be saved in files called mygrid1.dat, mygrid2.dat etc.
Skip current Grid	The next grid is skipped unsaved.
Abandon all data	All data are left unsaved.

Before selecting *SAVE*, the format, number of files and data delimiter must be set as required. The data for each Grid can be saved as two files, one for the header information and the other for data, or as a composite with the header and data in one file. The files can be formatted as a spreadsheet with tab or comma delimiters, as a Z stream with <CR><LF> delimiters, or as XYZ files with tab or comma delimiters (see File Formats).

All data is in ASCII format. X and Y represent the position in the Grid and Z represents the amplitude of the gradient recorded at that point.

Select either one or two files, the data delimiter as a tab or comma, and the file format required.

> **Note:** Use the tab delimiter in countries where a comma is used for the decimal separator. The single file with spreadsheet format and tab delimiter is recommended for initial use. This gives an ASCII file that can subsequently be transferred directly into Excel or various mapping programs.

Other data processing programs may require the Z string or XYZ file format, with a separate header file. When all parameters are correct, select *SAVE* or *SAVE ALL*.

If the *SKIP* or *SAVE* operations are used followed by the *SAVE ALL* operation, the correct Grid number will be allocated to filenames of the remaining Grids.

At the end of the saving process the screen reverts to the initial download screen. Press *EXIT* to close the program.

> **Note:** Check and back up saved data after downloading, before deleting the data in the data logger. After downloading and saving, the data cannot be re-formatted by the downloading program. However, the download process can be repeated with data being saved in different formats whilst the data remains in the data logger.

19.4. File Formats

The provision of three file formats allows the operator to select a type compatible with export to the preferred data processing software. All results are shown in nT/m. One or two decimal places will be shown depending on the range used during the survey.

19.4.1. Spreadsheet Format

If the data has been downloaded in spreadsheet format as one file and opened as tab or comma delimited data in Excel, the header and first section of data will appear as shown (right).

Time = 18:19:39
Date = 08/05/2008
Grid Number = 3
Number of Sensors = 2
Grid Size = 30 x 30
Method of collection = ZigZag
Starting Direction = North
Data Range = 100 nT
Line Spacing = 1.00 m
Sampling = 4 samples / m
Sensor Spacing = 1.0 m
Mean = 0.0
Max = 3.6
Min = -3.7

-0.62	-0.31	-0.33	0.91	1.51	0.92	0.01	0.43	1.52
-0.56	-0.33	-0.54	-0.21	0.04	1	1.58	0.85	1.12
-1.32	-1.22	-0.84	-0.21	0.1	-0.24	-0.31	-0.16	0.13
-1.13	-1.41	-1.33	-0.96	-0.67	0.12	-0.41	-0.75	-0.35
-0.77	-0.83	-1	-1.11	-0.9	-1.33	-1.44	-0.75	-0.37
-2.11	-1.3	-0.18	0.41	-0.43	-0.45	-0.18	-0.16	-0.2
-1.98	-1.64	-1.15	-1.37	-1.1	-0.95	-0.97	-0.99	-0.62
-1.52	-1.82	-1.1	-0.12	-0.22	-0.36	-1.04	-0.72	-0.45
0.11	0.01	-0.22	-0.8	-0.84	-0.83	-0.12	0.21	-0.2
-0.78	-0.5	-0.14	-0.66	-1.23	-1.59	-1.5	-1.22	-0.61

The time and date is recorded from the computer clock when the file is saved. The remainder of the header information corresponds to the parameter settings when the data was recorded during the survey. The mean, max and min values correspond to the data from sensor 1. If the two-file format had been selected during downloading, the header and data would appear in separate files, the data file being given the .dat extension and the header file the .hdr extension.

The data will have been re-arranged by the downloading software to remove the effects of zigzag data collection and the dual sensor arrangement, so that it represents the results as would be seen if the data had been collected by a single sensor working in a parallel traverse mode. The data is therefore organised into a Grid, which represents the plan of the site, with the top left position being the start of the data collection and the top row corresponding to the first traverse.

19.4.2. Z String Format

```
Time = 18:19:39
Date = 08/05/2008
Grid Number = 3
Number of Sensors = 2
Grid Size = 30 x 30
Method of collection = ZigZag
Starting Direction = North
Data Range = 100 nT
Line Spacing = 1.00 m
Sampling = 4 samples / m
Sensor Spacing = 1.0 m
Mean = 0.0
Max = 3.6
Min = -3.7
-0.62
-0.31
-0.33
0.91
1.51
0.92
0.01
0.43
1.52
```

In the single-file Z string format the start of the same data will appear as shown (left).

The data represents a continuous stream of gradiometer readings, re-formatted as though they had been collected using a single sensor working in parallel traverses. Each reading is followed by a <CR><LF> delimiter. If the two-file format had been selected, the header and data would appear in separate files with different filename extensions.

Note: If Geoplot by Geoscan Research is being used to view and process the data then it should be downloaded in Z string format.

19.4.3. XYZ Format

In XYZ format using a single file, the data will appear as shown (right).

```
Time = 18:19:39
Date = 08/05/2008
Grid Number = 3
Number of Sensors = 2
Grid Size = 30 x 30
Method of collection = ZigZag
Starting Direction = North
Data Range = 100 nT
Line Spacing = 1.00 m
Sampling = 4 samples / m
Sensor Spacing = 1.0 m
Mean = 0.0
Max = 3.6
Min = -3.7
0.125    0.5    1.32
0.375    0.5    1.22
0.625    0.5    1.1
0.875    0.5    0.95
1.125    0.5    0.96
1.375    0.5    0.89
1.675    0.5    0.87
1.875    0.5    0.84
2.125    0.5    0.47
```

The data is arranged in comma delimited columns.

Column no.	Column represents	Note
1	Position in the X direction in metres. The X direction corresponds to the direction of the traverse lines.	The minimum value of X corresponds to the start of the first traverse with the values shown in metres.

2	Position in the Y direction in metres. The Y direction represents the spacing between traverses.	So that the plotted values correspond with the spreadsheet view, the first traverse represents the maximum value of Y and the last traverse corresponds to the minimum value of Y. Assuming the first traverse starts at the top left of the Grid then *X=min, Y=min* therefore represents the bottom left of the Grid; *X=min, Y=max* represents the top left; and *X=max, Y=max* represents the top right.
3	Z, the gradient measured in nT at that point	n/a

20. Serial Output

The DL601 Data Logger outputs the data from memory via a three-line RS-232 interface (TX, RX and Gnd). When *Output data* is selected from the main menu, the data logger will turn on the RS-232 interface and wait until the character S is received from the PC before starting transmission. The gradiometer will then transmit 32 signed integers as 64 bytes and wait for the next character S from the PC.

The baud rate is set to 9600 baud with 8 data bits, no parity, 1 stop bit and no handshaking. The last transmission may be less than 64 bytes.

20.1. Data Format

The data represents a number of Grids. The data file for each Grid comprises a header, the gradiometer readings and summary information. An End of Transmission integer and a final checksum follows the data for the final Grid. All data is saved in the gradiometer and subsequently output in binary (signed integer) format, 2 bytes per integer, MSB first. All data is translated into ASCII characters in the PC after receipt.

The gradiometer has ranges of ±100nT and ±1000nT denoted by values of 1 and 10 respectively in the header information. Data is transmitted as signed integers in the range ±10,000, representing values of ±100.00nT for the ±100nT range and ±1,000.0nT for the ±1000nT range. The download software inserts the decimal point at the appropriate place. Integers above 32000 are used for markers in the data stream.

20.2. Markers

The following specific integers are reserved for markers.

Integer	Marker
32700	Start of Header
32701	End of Header
32702	Dummy data
32703	End of Data
32704	End of File
32705	End of Transmission (this will be followed by a two-byte checksum)

20.3. Transmission Format

Each Grid has a 10-integer header containing the conditions under which the data was collected. The gradiometer readings are transmitted in the order in which they were recorded. Therefore:

- for a dual sensor gradiometer system, the data for the left hand and right hand sensors will appear alternately
- if the Grid was covered using zigzag traverses then the data will represent this traverse pattern.

The downloading program uses the header information to re-organise the data as if it was collected with a single system using parallel traverses. The Datalog software allows the header and data to be saved together or as two separate files.

20.3.1. Header

The format of each header is as follows:

Integer Number	Value	Meaning
1	32700	Start of header
2	1,2,3 etc	Grid number
3	1 or 2	Number of sensors
4	10, 20, 30, 40	Grid size 10x10, 20x20, 30x30 or 40x40m
5	0 or 1	Zigzag or parallel
6	1 or 10	Range
7	1,2 or 4	lines/m (number of data lines /m)
8	1,2,4 or 8	Samples per metre along traverse line
9	10	Sensor spacing 1m
10	0 to 7	Starting direction: N, NE, E, SE, S, SW, W, NW
11	32701	End of Header

20.3.2. Gradiometer Data

The header is followed by the data as recorded in zigzag or parallel form. If a dual sensor gradiometer is used then the first integer represents the left-hand sensor reading and the second integer represents the right-hand sensor reading. The data is structured as:

Data	Value or meaning
One or two zero values	One for a single sensor, two if two sensors were used.
The gradiometer data	For a 30x 30 Grid with 4 samples/m, 2 sensors and traverse interval of 2m there will be 3600 signed integers in the range ±10000. Values of 32702 in the data are dummy values, which can be changed by the operator as required.
One or two zero values	One for a single sensor, two if two sensors were used.
End of Data integer	32703
Three signed integers	The summary data of mean gradient, maximum gradient and minimum gradient. For a dual sensor gradiometer system, the values are those recorded for the left-hand sensor.
One zero value	
End of File integer	32704
Other similar files will follow for further Grids	
End of Transmission integer	32705
Two-byte integer	A simple checksum formed by exclusive-or of the current integer with the previous checksum.

21. Troubleshooting

21.1. Adjusting the Gradiometer

Instructions for correctly setting up the Grad601 Gradiometer can be found in Checking and Adjusting the Sensors. See also Care and Maintenance for information regarding environmental impacts on the equipment.

Some of the more common errors and fixes can be found below:

Ensure the user is magnetically clean: Check that the user has no magnetic objects in their pockets, clothing or shoes, and that they have no magnetic implants (e.g. surgical implants - in doubt check with your physician). The Grad601 can be used in Scan mode to check a person before use.

Ensure a magnetically quiet area is used: An area chosen to perform the adjustment should be examined using Scan mode first. A good set-up area has less than 0.5nT variation in magnetic gradient over a 1.5m x 1.5m area. Ensure you face in one direction for this test as directional errors will not yet have been removed. If readings are very high then the ground in the area may have magnetic content and another location should be used.

Coarse/fine ranges: The adjustment cycle varies depending on whether you have selected the 100nT or 1000nT range. If the process restarts at any point, it is because the set-up is being repeated in an alternate range. It is important to know how the equipment works so it is not misinterpreted as faulty behaviour.

> **100nT Range:** A set-up will be attempted in the 100nT range. If this fails then it will repeat the process in the 1000nT range. If successful in the 1000nT range, one further set-up will be attempted again in the 100nT range.
>
> **1000nT Range:** A set-up will be attempted in the 1000nT range. If this is successful then a set-up will be attempted in the 100nT range.

High gradient readings: If the equipment is showing abnormally high values and the surrounding area is known to be magnetically quiet then there are several 'fixes' that can be attempted to bring it back to a normal level. The gradiometer should initially be set to the 1000nT range for these to work.

> **High Balance:** Lift the gradiometer as high as you can above the ground, or stand on a non-magnetic object, when carrying out the set-up process. This will lessen the impact of any ground signals and bring the level of magnetic field registered by the two sensors in each gradiometer closer together.
>
> **Horizontal Balance:** This has a similar effect to the above test. Hold the gradiometer horizontal for the duration of the set-up process in order to bring the values back into a normal range.

Once these tests have been carried out, the Grad601 should then be set up once more in the normal fashion, and will be more likely to be successful.

If these suggestions do not prove helpful, please contact Bartington Instruments at support@bartington.com for further assistance.

21.2. Datalogger

The program for the Grad601 is held in one non-volatile flash memory. Details of the operating parameters, memory locations and data are held in separate sectors in the same memory chip.

In the unlikely event that the data concerning the operating parameters becomes corrupt the system reset option can be used, allowing the processor to restart.

Note: This will also cause the data memory to be cleared and the parameters set in the *Set parameters* menu to be changed to the initial default values.

Report the occurrence of any error messages to support@bartington.com.

21.2.1. Power Loss

Caution: If power loss occurs while the memory is being accessed then a few issues may occur. Care should be taken not to power off the logger while the screen is displaying one of the following messages: 'Saving...', 'Deleting...', or 'Please Wait...'. If this occurs then the memory may become corrupted and data loss is possible.

In order to prevent loss of power, always ensure your battery is charged well before undertaking a survey. It also is advisable to check the battery voltage at the end of each grid. It should be charged if the voltage falls below 10V.

In most cases data can be recovered following a memory corruption.

The datalogger memory is split into sectors, so if one sector is corrupted then data from previous sectors can still be recovered. Attempt to download the data using the Grad601 download software in the usual way. Any recoverable grids will download as normal; however, a memory corruption can sometimes cause the final grid to download in a continuous cycle.

Note: If the number of downloaded bytes exceeds 260 000 then the download should be interrupted manually. After interrupting the download, choosing 'Proceed to Save' will allow the complete grids to be saved.

In order to continue using the equipment following a memory corruption, the **System Reset** option should be selected from the main menu. No further grids should be recorded until a System Reset has been performed.

Caution: Ensure that you have attempted data retrieval before choosing the System Reset option as it will also wipe the memory in the process.

Caution: A System Reset should always be carried out following a memory corruption.

21.2.2. Consequences of Power Loss

Power loss during 'Saving...' : This message appears at the end of each traverse, the end of a grid, and after changing options in the Parameters menu. Losing power at this stage may cause the latest grid to be lost; however, any previous grids can be recovered by downloading as normal.

Power loss during 'Deleting...' : This message is shown after choosing *Delete data* or *System reset* from the main menu. Power loss in this case can cause loss of data; however, this does not usually cause a problem as deletion is likely to be the aim of the user. This most often causes a grid '0' to download seemingly without end.

Power loss during 'Please Wait...' after 'Back one Traverse' is selected: Power loss while carrying out this function can lead to different symptoms, which could include the loss of a sector. Grids from previous sectors will still be recoverable.

Power loss during 'Please Wait...' after 'Delete Grid' operation: Losing power during the delete grid operation can cause the entire sector containing the grid to be lost and download may continue cyclically if left uninterrupted. Grids in other sectors can be recovered.

22. Care and Maintenance

When service is required, contact the Bartington Instruments helpdesk: sales@bartington.com.

Regular maintenance and care by customers may prevent any issues arising and ensure that the equipment can operate for longer without the need to be returned.

Check regularly that:

- top and bottom of the sensor are fixed properly with no loose screws.
- the seals on the sensor connector blocks are in good condition. If there are any gaps or there is noticeable cracking then a small amount of silicon sealant can be applied to prevent water ingress.

  Note: The system is lightly rain-proof, however it is important not to let any water sit on top of the data logger for extended periods.

  Note: If the instrument is wet, allow it to dry before putting it away in its case. If necessary, leave it out of the box overnight in a warm and dry environment.

  Note: Ensure that the connectors are kept clean. If the cable falls on the ground, and dirt enters the connector, then it should be cleaned thoroughly. This can be done with a compressed air canister of the type used on keyboards. Make sure the connectors are clean and dry before plugging back in.

  Note: Avoid leaving the end of the sensor in a puddle when the equipment is placed on the ground.

  Note: Do not drop the equipment on the ground. Avoid large impacts to the sensors.

23. End of Life Disposal

This product (electrical and electronic equipment) should not be placed in municipal waste. Check local regulations for disposal of electronic products.

23.1. Waste Electrical and Electronic Equipment (WEEE) Regulations

The Grad601 complies with RoHS (Reduction of Hazardous Substances) legislation current at the time of printing.

Appendix: Practical Aspects of Surveying

This section describes practical aspects of setting up and using the Grad601 single and dual sensor gradiometers for archaeological prospecting, and for detailed mapping of archaeological features.

> **Note:** Some points, which have been covered in the earlier text, are repeated where it may be appropriate.
>
> **Note:** For the more technical aspects of surveying, see Survey Mode (Grid Mode) and Survey Operation (Grid Mode).

A.1. Conventions

For compatibility with existing plotting software and current practice, certain conventions apply.

- The site to be surveyed will be divided into areas (Grids) of 10x10, 20x20, 30x30 or 40x40m over which data is collected for subsequent assembly into a matrix.
- The gradiometer is carried along a series of traverses across each Grid. The first traverse may start at any corner of the Grid, but the operator must set off in a clockwise direction as shown in Figure 12. This enables the data to be plotted with the correct orientation, using only the starting direction from the list of parameters saved as a header file.
- Plotting software will normally show a single Grid with the first traverse starting from the top left corner as shown in Figure 13.
- Traverses may be done with a parallel or zigzag pattern as shown in Figure 10 and Figure 11, respectively.
- If a 10x10m Grid is constructed from 1m squares, and measurements are to be made at 1m intervals along 1m traverse intervals, then make measurements at the centre of each Grid square as shown in Figure 14. This allows the data from adjacent Grids to be seamlessly joined, and no convention is required about which edges are used for reference.
- The same principle applies when the sampling interval is less than 1m. For a sampling interval of 0.25m, the first reading will be taken at 0.125m from the start of each traverse and the last at 0.125m before the end of each traverse.

A.2. Planning the Survey

- It is important to remember the position of each Grid, and any reference points, to be able to assemble the individual Grids later into a matrix showing the complete site. Keep careful notes when planning the site survey.

- It is helpful if the site is divided into rows of regular Grids. Grids of 30x30m are normal, but difficult areas may be surveyed using 10x10m or 20x20m Grids, and 40x40m Grids can be used where larger areas are involved.
- The Grids will be recorded in the order in which they are measured and given numbers starting at Grid 1. Different Grid sizes may be recorded in any order by changing the Grid size parameter in the data logger.
- The starting point for the survey depends on the shape of the area to be covered. If the area has a major axis in a north/south direction then the first Grid can conveniently be the most northerly, with the first traverse starting in the north west corner and walking east.
- Traversing is normally done with a zigzag pattern to minimise the walking distance. The traverses may be carried out in either parallel or zigzag fashion but it is important to set the pattern parameter correctly in the data logger. The downloading software provided will always re-organise any zigzag data to parallel format before saving it to a file.
- The second traverse is made one interval to the south of the first. Traverses along east/west lines then continue from the north to the south end of the Grid. The adjacent Grid to the south of the completed Grid can then be surveyed and the pattern repeated until a complete column of Grids has been measured. The survey can then move to the next column of Grids.
- Provided each Grid starts with a clockwise traverse, surveys may be run in any direction but it will be most convenient and most easily recorded if successive Grids progress in one direction, i.e. west to east, north to south or vice versa.
- When surveying sloped ground, parallel survey should be used, allowing to keep walking pace consistant. Sloping ground should always be surveyed in the direction of the slope. Surveying across the slope will lead to a piano key effect on the data as one sensor would be closer to the ground than the other.

A.3. Gridding Data

- The Grad601 gradiometer provides gridded data by sampling at regular intervals and emitting an audible bleep corresponding to each metre of traverse.
- A line with one-metre marks can be laid on the ground along the traverse, enabling the operator to maintain synchronism with the data sampling by ensuring that the instrument passes over a mark in time with the bleep.
- A suitable pace can be set as a survey parameter in the data logger, and modified during the course of a survey to suit the operator. A pace of about 1.6m/s is suggested as a starting point.

A.4. Grids, Lines and Positions

- Each Grid is normally surveyed with a line interval of 1m, and a sample interval of 0.25m along the line of the traverse. This is a good compromise between the sampling rate and walking distance, and provides good resolution of archaeological features. The Grad601 may be set for line intervals of 0.25m, 0.5m or 1m and sampling intervals of 0.125m, 0.25m, 0.5m or 1m.
- The Grad601 saves Grids in numerical order starting with Grid 1. The memory has sufficient capacity to store the equivalent of 36 Grids of 30x30m with 1m line spacing and 4 readings per metre.
- For the Grad601-1 single sensor gradiometer, the traverse lines correspond to the data lines. For the Grad601-2 dual sensor gradiometer, the number of traverses will be half the number of data lines. The data logger allocates numbers to the traverse lines starting with 1.
- The positions at which samples are taken along each traverse line are also numbered, starting at position 1. The current position is displayed during the survey.

A.5. Survey Methods

The survey method will depend on the purpose of the survey. For archaeological prospecting prior to land development, the operation may need to be carried out quickly and with the minimum number of personnel. Detailed surveys of archaeological sites may require more precise measurements and additional personnel may be available.

> **Note:** The following suggestions assume data is required at 1m traverse intervals over a 30x30m Grid with a zigzag pattern, and are recommended for most purposes as a starting point. For line spacing of 0.5m or 0.25m, refer to Figures 17 to 21 to prepare the survey equipment.

A.6. Equipment Required

> **Note:** All equipment used must be non-magnetic. Mark about 12 bamboo canes of about 1m in length with fluorescent markers so they are easily seen from a distance.

Assuming a survey of a 30x30m Grid at 1 line/m, prepare a trapeze with two rigid bars just over 1m wide joined by two 30m ropes spaced exactly 1m apart. Mark the trapeze ropes at 1m intervals with the first mark at 1m from the end bar. Mark the supports at the centre between the two ropes.

To mark the start and finish of the traverses, prepare two 30m ropes with loops at the ends to fit over canes when pushed into the ground 30m apart. Mark these ropes with fluorescent sleeves or tape to show the start and end of each traverse.

For a single sensor gradiometer, the first mark should be at 1m from the end and subsequent marks at 2m intervals. This corresponds to the arrangement in Figure 12. For a dual sensor gradiometer, the first mark should be at 2m, and subsequent marks at intervals of 4m as in Figure 13. These are to be used at the edges of the Grid to show the traverse limits and align the trapeze when the centres of the ends of the trapeze are placed on the marks on the start and finish ropes.

A.7. Setting Out the Area

Before setting out the area, switch on the gradiometer to allow the maximum warm up time before setting up the instrument.

Set out the site using standard survey techniques such as a total station at some national Grid reference point. Establish the positions of the corners of the Grids and mark with the bamboo canes. Select the first Grid to be surveyed and loop the edge lines over the canes at opposite sides of the Grid to mark the start and finish of the traverses.

A.8. Setting up the Gradiometer

- See also Checking and Adjusting the Sensors.

  Note: Ensure that the instrument has been switched on for at least 15 minutes prior to setting up.

  Note: Before setting up, always check the operator for magnetic materials. Run the instrument in Scan Mode fixed in one position and check that the readings do not change when the operator moves close to the upper and lower sensors. (See also Operator Magnetic Hygiene.)

  Note: As rotational and tilt errors are likely to be present prior to setting up, it is essential to hold the sensor in one orientation whilst searching the ground for a low gradient area over which to set up.

A.9. Logging Data

- See also Survey Operation (Grid Mode).

At the edge of the Grid where the survey will start, stretch the trapeze across the Grid with the centre marks of the trapeze bars over the first marks of the ropes, as in Figure 15 for a single sensor gradiometer or Figure 16 for a dual sensor unit.

The trapeze lines then mark the position of the first two traverses, 0.5 and 1.5m from one end of the Grid. Remember that the first traverse will start in a clockwise direction. When using a single sensor gradiometer, the operator will carry the sensor over the first traverse line and back along

the second traverse line. A dual sensor gradiometer will be carried with one sensor at 0.5m and the other at 1.5m for the first traverse.

When the first two traverses have been recorded, the trapeze is moved to the next mark on the edge lines and the next two traverses are recorded. This process is repeated until the Grid has been completed. Using a dual sensor gradiometer with a trapeze, as described above, the last traverse for a 10 or 30m Grid will be completed with the centre of the trapeze in line with the edge of the Grid.

The edge lines are then moved to the adjacent Grid, and the next Grid is surveyed in the same manner. In this way a complete row of Grids can be covered quickly.

A.10. Other Methods

The equipment described above is suitable for single or dual sensor operation.

For the highest spatial accuracy, the operator should walk relatively slowly and ensure the sensor is held upright at all times. The movement should be smooth and well synchronised with the bleeps from the data logger. With experience, and where the spatial accuracy is less critical, it is possible to walk at a constant pace without the aid of the 1m marks on the trapeze lines and the trapeze may then be abandoned. The operator may then mark only the end of the traverse lines with canes, count the bleeps during each traverse, and aim to reach the end of the traverse at the last double bleep. This procedure minimises the number of operators required.

If required, Bartington Instruments also sells a cart to mount the sensors upon during GPS surveys. The cart is non-magnetic and specially designed to minimise any shock and vibration that may occur to the sensor during a survey.

Notes

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