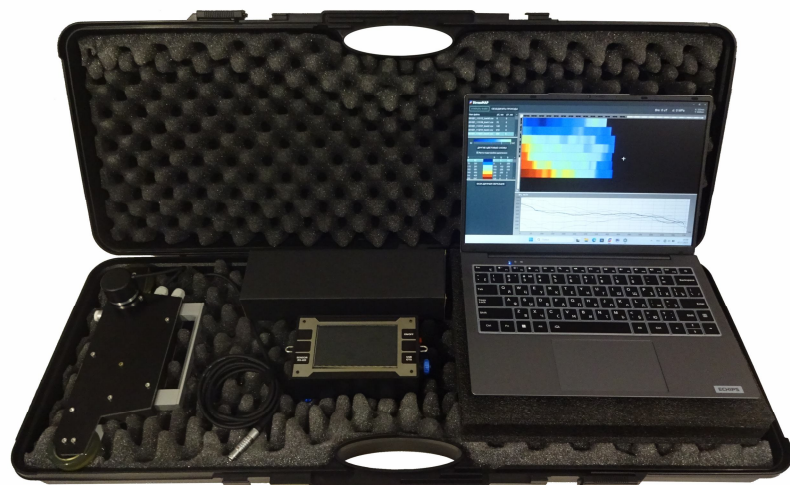




«IN-04» MULTICHANNEL METAL STRESS SCANNER

USER MANUAL

Ufa – Russia – 2024

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This user manual introduces to «IN-04» multichannel metal stress scanner organization and operation and establish the rules of operation, maintenance, storing and transportation that ensure scanner to be ready to use at every time.

1. PRIMARY APPLICATION PURPOSE AND OPERATIONAL CONDITIONS

1.1. «IN-04» multichannel stress scanner designed to perform continuous inspection and monitoring of mechanical stress of steel goods and structures made from structural steel on distribution of residual magnetic field strength (induction) on the surface of object.

1.2. Multichannel stress scanner can be used at the open-air environment, industrial conditions, also in laboratory.

1.3. Any sources of industrial electromagnetic interference should be moved out from scanner for at least 10 m distance.

1.4. According to the Russian standard GOST 14254-2015 scanner components have following protection degrees against the solids, liquids, and the dust penetration:

- magnetic measurement unit – IP68;
- data acquisition unit – IP53.

1.5. Measurements indication:

- real-time graphic sweep of measured distribution of residual magnetic field strength (induction), as well as calculated mechanical stress of metal represented on screen as color map or individual graph on every channel in relation to time or distance;

- displaying and recording numerical results of measurement in units of residual magnetic field strength (induction, uT), and mechanical stress of metal (MPa) on the acquisition unit built-in flash data storage.

1.6. Indicator is color liquid crystal display with integrated capacitive touch screen.

1.7. According to the Russian standard GOST 15150-69 on the operation conditions multichannel stress scanner relates to the UHL 3.1 design and providing stable work under following environment conditions:

- environment temperature from -20°C to $+70^{\circ}\text{C}$,
- relative air humidity up to 98% at $+25^{\circ}\text{C}$,
- atmospheric pressure from 84 kPa to 106,7 kPa.

2. TECHNICAL SPECIFICATIONS

2.1. Residual magnetic field induction measurement range, uT: from 0 to 100000

2.2. Mechanical stress of metal measurement range, MPa: from 0 to σ_B (strength limit of metal)

2.3. Tolerance of metal stress measurement error, MPa:
 $0.5 + 0.05\sigma_i$ (2.1)
 where σ_i – readings of scanner.

2.4. Maximum speed of scan, m/min: - 40

2.5. Measurement frequency range, both single and multichannel samples per second: 0.001 – 500

2.6. Number of scanner units maintained by acquisition unit at one time 1 – 12 (expandable up to 254)

2.7. Data acquisition unit dimensions (length $\times$ width $\times$ height, mm): 151 $\times$ 90 $\times$ 58

2.8. Magnetic measurement (scanner) unit dimensions (length $\times$ width $\times$ height, mm): 245 $\times$ 140 $\times$ 72

2.9. Data acquisition unit weight, g: 540

2.10. Magnetic measurement (scanner) unit weight in portable design, g: 1500 $\pm$ 200

2.11. Maximum length of sensor cable, m (depended on customer's requirements): 1000

2.12. Measurement synchronization sources:
 – built-in timer / odometer (encoder)

2.13. Coordinates measurement units:
 – built-in GPS/GLONASS receiver
 – odometer on the base of incremental encoder

2.14. Power supply source of scanner: 11.4V 3S2P replaceable lithium accumulator battery.

2.15. Maximum supply current from fully charged accumulator battery, mA: 800

2.16. Minimum time interval of continuous work of scanner from fully-charged accumulator battery, hours: 8

2.17. Multichannel metal stress canner launch time interval, in seconds, not more: 30

2.18. Minimum time interval of multichannel metal stress scanner continuous working, hours, at least: 8

2.19. Maximum time required to charge the accumulator battery, hours, not more: 3

2.20. Capacity of built-in data storage: 8GB

2.21. Minimum total duration of data could be recorded on built-in memory, hours: 300

2.22. Personal computer communication: USB MSC

2.23. Type of built-in metal samples database CSV

2.24. Typical GPS/GLONASS positioning error, m:
 – built-in receiver ± 10
 – RTK (special order) ± 0.02

2.25. Average time of repair: 5

2.26. Full service time, years: 10

2.27. Service warranty, years: 2

3. SCANNER OVERVIEW

«IN-04» multichannel metal stress scanner consists of data acquisition unit and system of magnetic measurement (scanning) units connected by flexible electric cable or wireless network radio channel.

3.1. Main components (units) of scanner

3.1.1. Basic configuration of multichannel metal stress scanner includes portable data acquisition unit, single-channel handheld magnetic measurement (scanning) unit, setup of replaceable and rechargeable accumulator batteries (2 pcs.), network charger, setup of connection cables and storing and transportation box (Figure 3.1).



Fig.3.1. «IN-04» multichannel metal stress scanner

3.1.2. Magnetic measurement (scanning) unit is a device on two consecutive wheels, one after another, with metal magnetizing device and residual magnetic field strength (induction) measurement device inside.

Rotation of one of wheels is transmitted to distance counting device (odometer, based on incremental rotary encoder), signals of which are transmitted to the acquisition unit together with the readings of the residual magnetic field strength (induction) measurement device.

To perform scanning of stressed state of the object surface you have to move the magnetic measurement unit straight ahead, as shown in Figure 3.2.

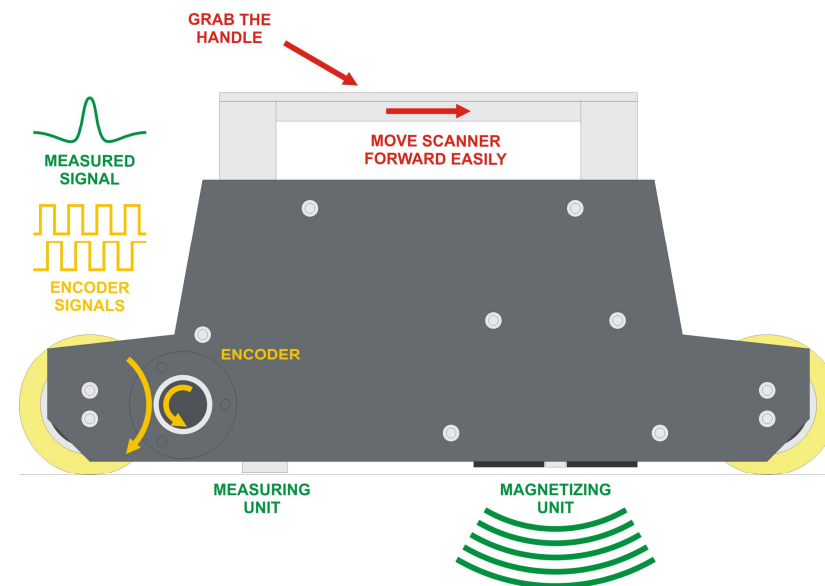


Fig.3.2. Manual scanning of metal stressed state by magnetic measurement unit of «IN-04» scanner



Fig.3.3. Portable data acquisition unit of «IN-04» multichannel metal stress scanner

3.1.3. Data acquisition unit of «IN-04» multichannel metal stress scanner (Figure 3.3) is a portable device with color display and touch screen on the front panel, and battery compartment on the back side.

On left side of the data acquisition unit there is a circular connector for connecting system of magnetic measurement units, on the right there is a power switch, built-in GPS antenna, and USB connector for connecting data acquisition unit to personal computer.

3.2. Graphic user interface (GUI)

3.2.1. A color liquid crystal display with touch screen, «Spector» Scientific and Technical Center logo, as well as designators of connectors placed on the front panel of the data acquisition unit (Figure 3.4).

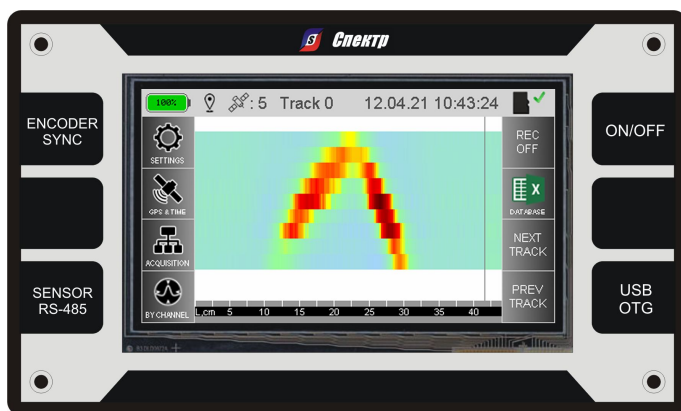


Fig.3.4. Front panel of «IN-04» multichannel portable metal stress scanner data acquisition unit

3.2.2. Color LCD with touch screen is the main device for displaying and entering information, supplying the operator of metal stress scanner with an intuitive graphical interface, which consists of a status bar on the top of screen, workspace with graphic images of measured signals, a screen ruler, a

group of buttons to manage recording of measured signals and a database of steel samples to the right of the sweep, and group of menu buttons to the left of the sweep (Figure 3.5).

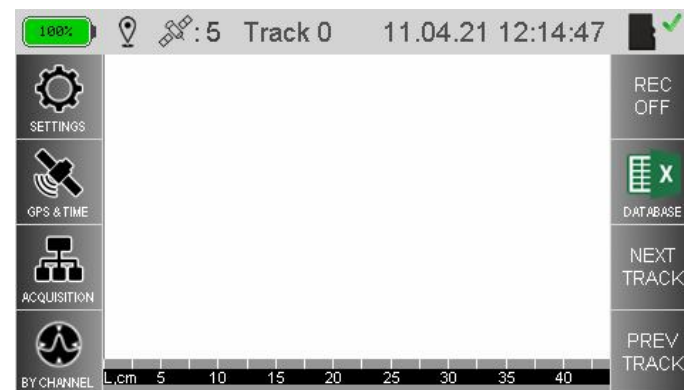


Fig.3.5. User interface of «IN-04» multichannel metal stress scanner data acquisition unit

A color LCD with a touch screen is the main device for displaying and entering information, providing the operator of the multichannel magnetic field measurement system with an intuitive user interface that consists of a status bar on the top of the screen, a graphic sweep of measured signals, automatic screen ruler on bottom of the screen, recording process management buttons on the right and menu buttons to the left of signal sweep area (figure 3.5).

3.2.3. The main indicators of the visual interface are located on the status bar (from left to right):

- the battery charge level indicator;
- GPS location accuracy indicator;
- the number of satellites used to find GPS location;
- number of the currently scanned profile (track);
- current date and time indicator;
- built-in memory card status indicator.

3.2.3.1. Battery level indicator shows the approximate percentage of the remaining battery charge as a percentage.

When the battery charge drops to a level is enough for just a few minutes of operation time of «IN-04» multichannel stress scanner, the battery indicator lights up in red.

When the battery charge drops to a critical level, the battery will be automatically disconnected from the power supply system of the multichannel scanner.

3.2.3.2. GPS location accuracy indicator has 5 states:

 – unknown location, searching for a suitable satellite configuration is performing now;

 – satellites found and location is fixed;

 – the location is fixed in differential mode;

 – the location is floating (RTK mode);

 – the location is fixed with RTK precision.

3.2.3.3. Number of satellites used to calculate the current location in GPS/GLONASS coordinate system.

3.2.3.4. Number of currently scanned profile (track).

If scanning performed for several passes, each pass should be numbered as in order they follows. Detailed explanation of multi-pass scanning order existed in Section 4.4 of this User Manual.

3.2.3.5. The current date and time indicator shows each time the current date and time from the real-time clock integrated circuit the data acquisition unit built-in.

3.2.3.6. The built-in memory card indicator has two states: the memory card is working normally (the indicator is green) and the memory card is missing or malfunction occurred (the indicator is red).

3.2.4. The graphic sweep area (figure 3.7) is used for the continuous output of the measured signals to the screen in color map or convenient graph look.

In horizontal direction of the signal sweep, the distance covered is counted (when synchronizing measurements from

the odometer), or the time is counted (when synchronizing from the timer).

In the vertical direction of the signal sweep the magnetic measurement units are counted from 1 to 12.

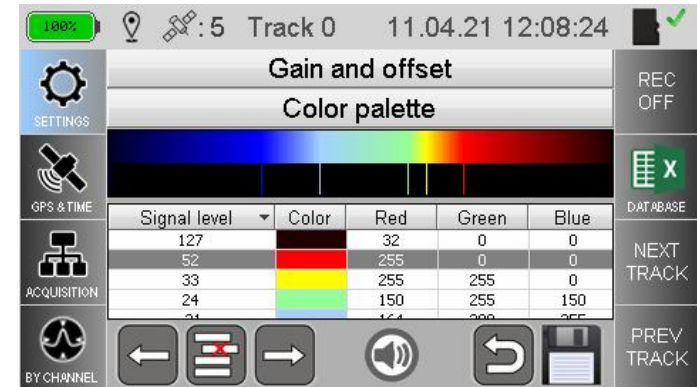


Fig.3.6. Color palette configuration panel

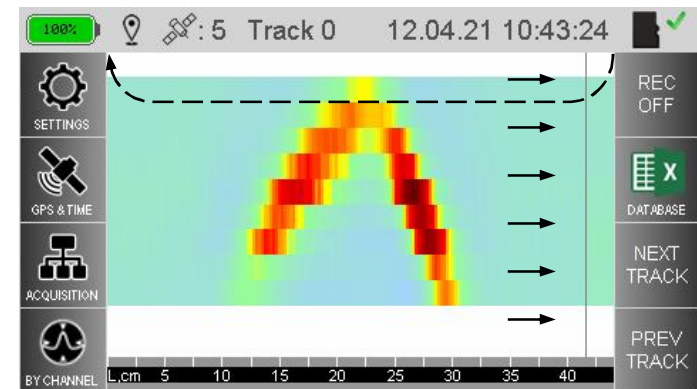


Fig.3.7. Diagram of measured signals sweep drawing

If group of number of magnetic measurement units used in scanning, then measured signals are transformed to color bands and compose on the screen color image of stressed state on the surface of inspected object, according to preliminarily set up color palette configuration (figure 3.6).

Algorithm of transformation of measured signals to color image described in detail in Section 4.2 of this User Manual.

By clicking on any point in the signal sweep, the measurement process is started or stopped.

3.2.5. The cursor, like a thin vertical line on the signal graph sweep area, is designed to update the data on the color map and graphs by measured signals of magnetic measurement units connected to acquisition unit.

When scanning in timer synchronization mode, the cursor continuously moves along the signal sweep from left to right and updates the measured data in real time (figure 3.7).

When the right edge of the signal sweep area is reached, the cursor automatically moves to the start and continues the motion from left to right again, as shown by the dashed line in the figure 3.7.

While magnetic measurement unit is resting, the built-in odometer does not rotating, so cursor stays quiescent on the screen as long as magnetic measurement unit does not continue its motion and does not drive rotation of odometer.

3.2.6. Time and distance measurement screen ruler right on bottom of the signal graph sweep is designed to visually assess the current location, spatial orientation, shape and length of the stressed state anomalies detected.

Length of ruler is always equal to the width of sweep, however its scaling can be varied in dependence on settings of odometer and timer (see Section 6.7 of this User Manual).

3.2.7. The group of buttons to the left of the sweep allows access to the «SETTINGS», «GPS & TIME», «ACQUISITION» panels, and also includes the display mode of the measured signals «BY CHANNEL».

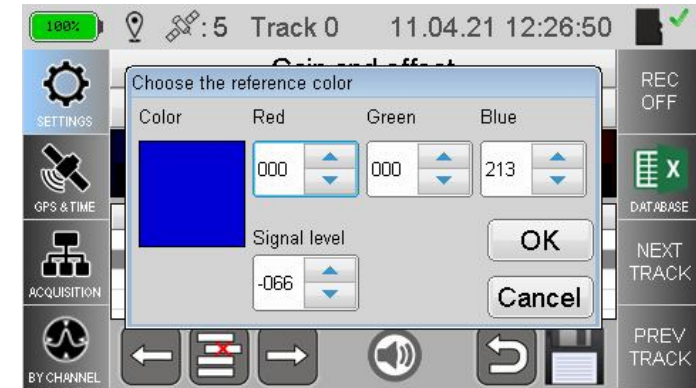


Fig.3.8. Color palette reference color set up window

3.2.7.1. The main settings panel is divided into 2 pages: «Color palette» (figure 3.6) and «Gain and offset» (figure 3.9).

The color palette is a one-dimensional function that establishes the correspondence between the magnitude of the measured signal and the color code. The «Color palette» page contains the following elements:

- interactive color band for editing the reference colors set of the palette (figure 3.8);
- table of the reference colors, containing the attributes of all the reference colors: the signal level of the fluxgate sensor and the three basic color components in most popular and clear to understand RGB color mode;
- group of the buttons including the buttons for navigating on the reference color table «←» and «→», also special button to delete the reference color from palette «☒»;
- button to enable or disable the sound when button would pressed and touch screen would touched «🔊»;
- group of buttons for returning to the factory settings «↶», and the button for saving the current settings in the non-volatile memory of the magnetic field measurement system data acquisition unit «💾».



Fig.3.9. Amplification factors and zero offset adjustment panel for gradiometer (top) and 3-axial topology (bottom) magnetic field sensor units

Track bars on the «Gain and offset» page (figure 3.9) are used to set amplification degree and compensate the signals measured.

Amplification factors of measured signals are adjusted by common signal gain track bar for all channels at one time.

Automatic zero adjustment option subtracts non informative constant component from measured signals, passing only component consisted of informative changes of signal. It give us possibility to set up high values of amplification factors and helps to see more details on images of measured signals of multichannel metal stress scanner on the screen of acquisition unit.

Automatic zero adjustment option calculates and updates value of constant component of measured signal on every channel every time user starts measurement process.

3.2.7.2. The «GPS & TIME» panel of measurement points position, and date, and time setting up, consists of 3 pages: «GPS & TIME» page (figure 3.10), and two pages named «Sensor position configuration» (figure 3.11).

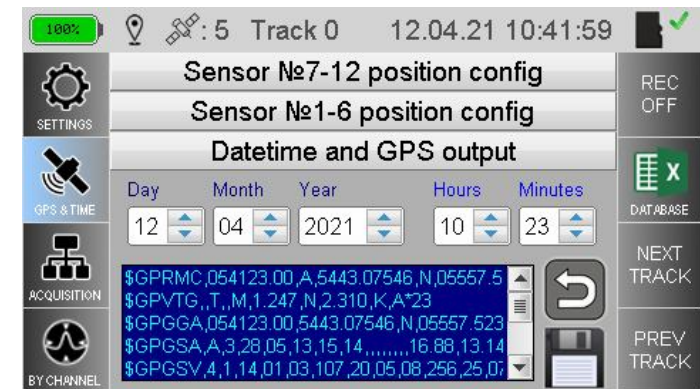


Fig.3.10. Date and time setup page and acquisition unit built-in GPS receiver information window

GPS and datetime settings page has 5 numeric fields to input date and time, and special window to display navigation data of built-in GPS receiver in NMEA 0183 format.

To set actual date and time up, use «up» and «down» regulators of the appropriate numeric fields, then save it in non-volatile memory of built-in integrated circuit of real time clock pressing «» button.

The antenna of the GPS receiver integrated in the data acquisition unit is located on the left side inside the housing.

The buttons for returning to the factory settings «», and for saving the current settings in the non-volatile memory of the acquisition unit «» are also placed in settings panel.

On the other two pages for configuring magnetic measurement units position, there are 12 pairs of numeric fields for entering the coordinates of the magnetic measurement units relative to the built-in GPS receiver.

When performing a survey, the GPS coordinates and the coordinates of magnetic measurement units relative to the built-in GPS receiver are used to calculate the absolute coordinates of measurement points on the surface inspected.

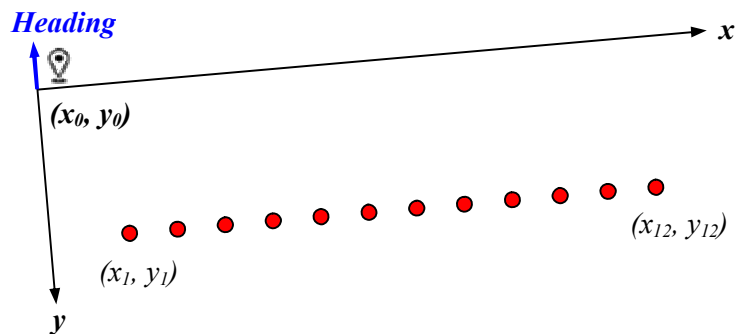


Fig.3.11. Explaining the magnetic measurement (scanning) unit positions configuration page

The procedure how software of «IN-04» multichannel metal stress scanner calculates the absolute coordinates of measurement points in GPS and GLONASS systems is given in Section 4.3 of this User Manual.

3.2.7.3. Survey mode and synchronization parameters are configured on the «Synchronization» page of the «ACQUISITION» panel (figure 3.12).

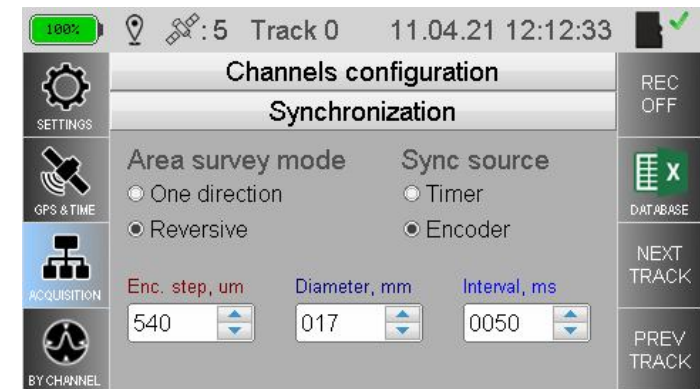


Fig.3.12. Survey mode and synchronization settings panel

The multichannel metal stress scanner has two independent sources of clock signals to synchronize the measurements, switched by the «Synchronization» selector:

- if «Odometer» option selected, then measurements being synchronized on pulses of built-in incremental encoder, the diameter and step of which can be adjusted in existed numeric fields «Diameter» and «Encoder step»;
- if «Timer» option selected, then measurements being synchronized on signals of the built-in timer, the response interval of which is set using the «Interval» numeric field.

To save survey and synchronization parameters in the non-volatile memory of the scanner data acquisition unit the button «» should be pressed; to return to the factory settings the button «» should be pressed.

3.2.7.4. Enabling and disabling the recording of signals to file by channel performed on the «Channels configuration» page of the «ACQUISITION» panel (figure 3.13).



Fig.3.13. Panel for enabling and disabling recording of measured signals of multichannel scanner to file by channel

To enable recording of measured signal on some channel, enable the appropriate checkbox on the «Channels configuration» page; to disable recording disable the appropriate checkbox. To save configuration of recording channels in the non-volatile memory of the scanner data acquisition unit the button «» should be pressed; to return to the factory settings the button «» should be pressed.

3.2.7.5. Signal graph sweep mode «BY CHANNEL» (figure 3.14) allows studying the measured signals of each magnetic measurement unit separately.

Switching the measurement channels is carried out using «< PREV» and «NEXT >» buttons, while the number of current channel is displayed in bottom side of the window. Measurement channels are numbered from 0 to 11 (can be extended up to 255 if need), while the measured signals from the first fluxgate sensor are processed in the zero measurement channels, the second in the first, etc.

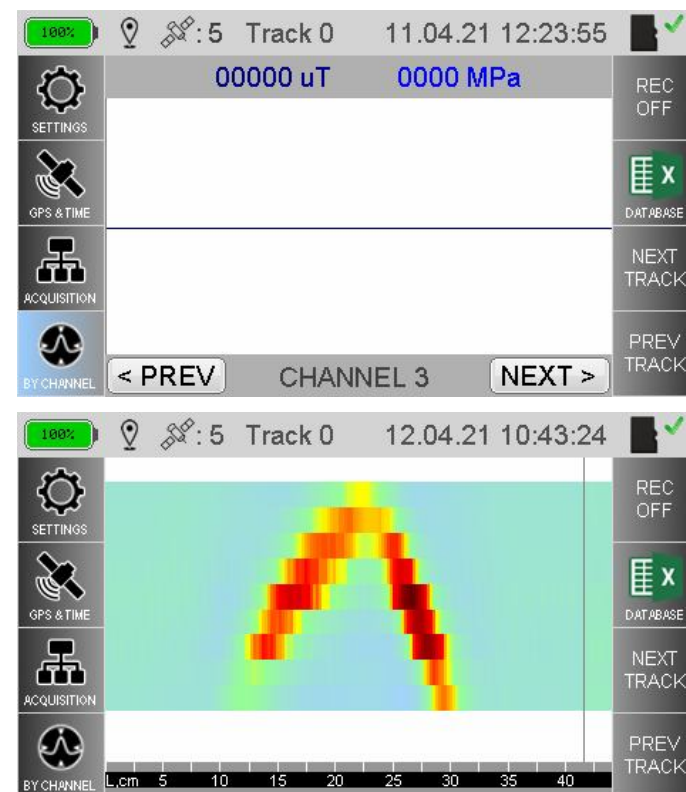


Fig.3.14. Sweep of the multichannel stress scanner signal by channel (top) and normal color map sweep mode (bottom)

3.2.7.6. Built-in metal samples database window with calibrations of «IN-04» multichannel metal stress scanner (figure 3.15) opens then «DATABASE» button pressed. Metal samples required to calibrate dependence of measured by multichannel scanner magnetic parameter – residual magnetic field strength (induction) – on mechanical stress of metal.

As soon as different steels have significantly different magnetic properties, so dependence of residual magnetic field strength (induction) on mechanical stress of metal can be appeared in different materials with different intensity.

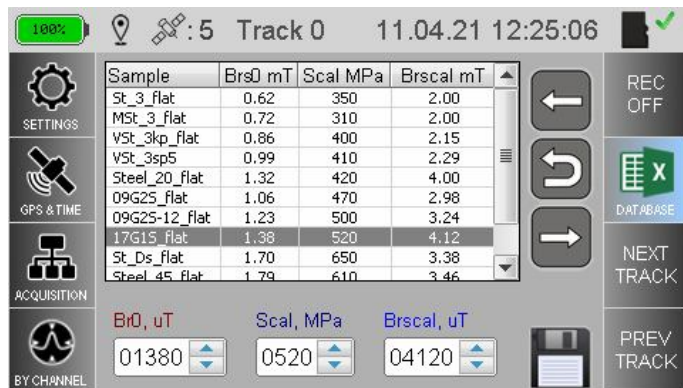


Fig.3.15. Built-in metal samples database window with calibrations of «IN-04» multichannel metal stress scanner

Value of mechanical stress of metal displaying on screen of the scanner (figure 3.14) calculated on three magnetic and mechanical parameters of metal, as well as measured value of surface residual magnetic field strength (induction) of metal, so scanner should be preliminarily calibrated on appropriate steel sample, with same shape and magnetic properties as inspected object.

3.2.8 The group of buttons to the right of the sweep is designed to manage the multichannel metal stress scanner during the measurement and recording measured data.

«RECORD» button enables and disables the recording of the current results of residual magnetic field strength (induction) of metal measurement and results of the total equivalent mechanical stress of metal calculation to the file.

Pressing «NEXT TRACK» button increase the counter of current survey profile (track) by one.

Pressing «PREV TRACK» button decrease the counter of current survey profile (track) by one.

If multichannel metal stress scanner would be powered off then turned on again, the counter of measurement profile (track) will be reset to 0.

3.2.9. When «PRINT SCR» button is pressed (in latest versions of firmware – date and time indicator should be pressed), the image is captured on the screen and saved to a file, and the date and time at the time of saving are automatically selected as the file name.

The screenshots already saved, as well as measurement results in the form of text files, can be transferred to a personal computer via USB port for further analysis using Surfer software.

To transfer the saved measurement results to a personal computer, the multichannel metal stress scanner has the USB Mass Storage Class standard driver. This means that when this mode is turned on, it begins to work as a standard disk device, which can be connected to a personal computer via USB port and used as a convenient USB flash disk.

«USB MSC» mode is automatically activated when a forced stop of the measurement process is performed by clicking anywhere on the graphic sweep.

When the measurement process is resumed, «USB MSC» mode is automatically turned off, while the multichannel scanner continues to operate normally.

4. SYSTEM ORGANIZATION AND OPERATION

The principle of the operation of «IN-04» multichannel metal stress scanner is based on measuring the residual magnetic field strength (induction) on the surface of inspected object, and its dependence on mechanical stress of metal.

A block diagram explaining the multichannel metal stress scanner operation principle is shown in the figure 4.1.

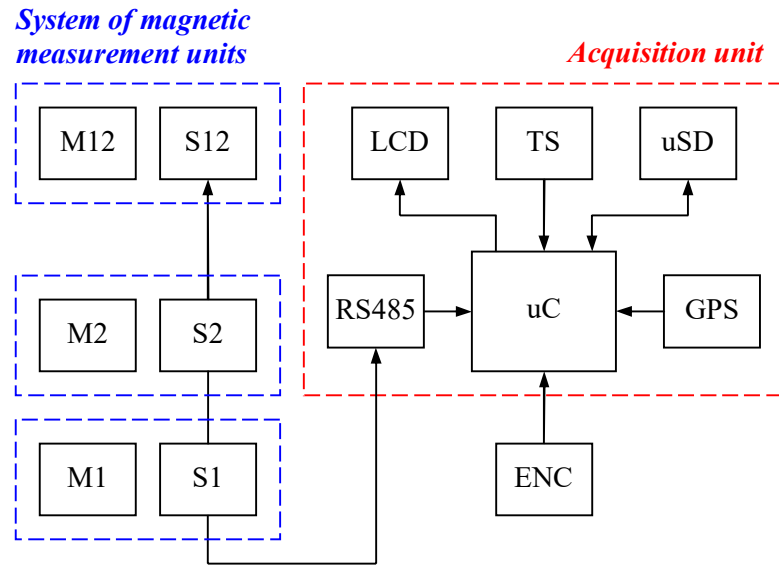


Fig.4.1. Block diagram of the «IN-04» multichannel metal stress scanner

ENC – odometer, M1-M12 – individual magnetizing units, S1-S12 – residual magnetic field value measurement units with integrated microprocessor, uC – microprocessor controller, LCD – liquid crystal display with integrated touch screen TS, uSD – memory card to save the measurement results, GPS – built-in receiver.

Magnetic measurement (scanning) unit consists of magnetizing units M1-M12 and measurement units S1-S12

based on Hall-effect magnetic field sensor and microprocessor controller. The magnetizing unit makes magnetization of inspected object during scanning its surface, the measurement unit measures residual magnetic field strength (induction) on the surface of inspected object, which is, in essence, response of metal to action of magnetizing unit.

Magnetic measurement units connected to the acquisition unit of multichannel metal stress scanner by cable, this way forming RS-485 industrial standard network. Microprocessor controller uC of the data acquisition unit polls data from the magnetic measurement units in cycle, asking them on individual address inside of local network

Topographic referencing of the magnetic field measurement results is carried out according to the odometer ENC counts, or GPS coordinates.

The measurements displayed on the color LCD, can be recorded on the built-in uSD memory card and passed to the personal computer through USB port. The multichannel scanner is configured and driven through the TS touch screen.

4.1. Physical backgrounds of nondestructive stress inspection technique on residual magnetic field of metal

Common physical principle of the non-destructive evaluation of metal stressed state based on dependence of so called structure-sensitive parameters of metal on mechanical stress value.

Residual magnetization of metal J_r is one of such parameters, possessing at the same time highest sensitivity to mechanical stresses and susceptibility to their changes.

Magnetization J appears in steel sample then magnetic field H applied on it. At magnetic fields of very strong values H_s the magnetization of sample can reach its own limit J_s , this state called as technical saturation (figure 4.2). After switching off the applied magnetic field, the sample remains in magnetized state, quantified by residual magnetization J_r .

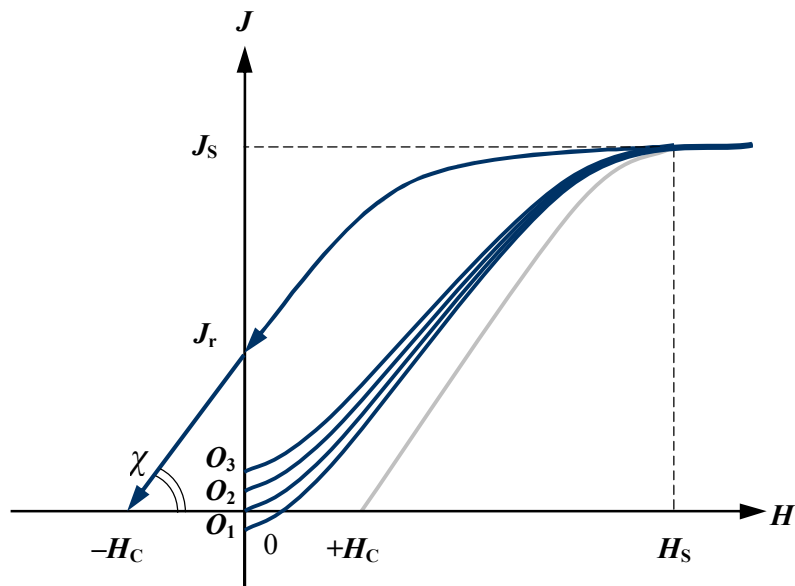


Fig.4.2. Change of magnetization of steel sample J exposed to the action of applied constant magnetic field H

O_{1-3} – weak spontaneous magnetization of sample occurred under action of natural magnetic field of the Earth;

H_s – magnetic field strength enough to magnetize the sample up to technical saturation state, quantitative measure of which is saturated magnetization J_s ;

J_r – residual magnetization of sample after switching off the affecting it applied magnetic field;

H_c – coercive force of metal;

There is known linear dependence of metal residual magnetization J_r on mechanical stress σ existed:

$$J_r(\sigma) = J_{r0} + \frac{\lambda_s J_{r0}}{\mu_0 J_s^2 N} \sigma. \quad (\text{Eq.4.1})$$

In common case mechanical stress σ mean basic single axis stress, equivalent by value and by action to the complex of stresses of all types, existed in sample at the moment.

Direct measurement of residual magnetization in practice technically impossible, however, residual magnetization is multiplicative part of residual magnetic field strength, the direct measurement of which is not a big practical challenge:

$$H_r(\sigma) = J_r(\sigma) \cdot TF(x, y, z), \quad (\text{Eq.4.2})$$

where $TF(x, y, z)$ – is topography factor, describing geometry, shape and dimensions of steel object inspected. In most of cases we can suppose geometry, shape and dimensions of steel object inspected constant, so we can consider topography factor $TF(x, y, z)$ as just a constant coefficient, connecting residual magnetization J_r and residual magnetic field strength (induction) H_r measured on the surface of metal by «IN-04» multichannel stress scanner.

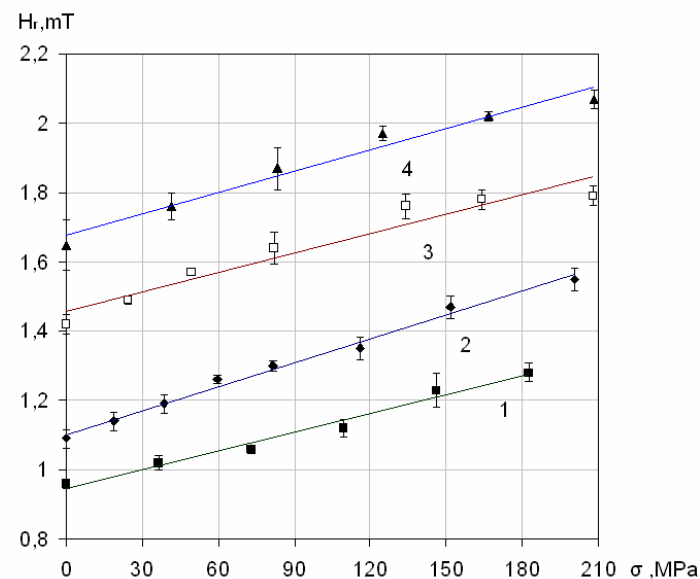


Fig.4.3. Dependence of residual magnetic field strength on mechanical stress of samples made from different steels
1 – St3, 2 – VSt3sp, 3 – 09G2S, 4 – 17GS

Assuming considered conditions the dependence of residual magnetization on mechanical stress of metal (equation 4.1) can be formulated also in terms of residual magnetic field strength (induction) measured on the surface of metal:

$$H_r(\sigma) = H_{r0} + \frac{\lambda_s H_{r0}}{\mu_0 J_s^2 N} \sigma. \quad (\text{Eq.4.3})$$

Steel parts and structures of different shapes and made from different grades of steel obviously have different dependences of residual magnetic field strength on mechanical stress of metal (figure 4.3), that is reason why quantitative measurements of stresses require preliminary calibration of scanner on steel samples (see Section 7 of this User Manual).

4.2. Presenting the results of stressed state scanning on the color map in real time

Each of magnetic measurement unit has an integrated microprocessor that converts measured signals of Hall-effect magnetic field sensors to the residual magnetic field strength (induction) measurement units (uT), then send them to the data acquisition unit as sequence of digital codes.

The measurement results can be recorded on the built-in memory card and displayed on the color display in digital and graphic modes, e.g. color map sweep.

To build a graph and color map sweep, excessive constant signal component compensation should be performed and optimal scaling the measured signals should be performed with respect to dynamic range of the color palette (figure 4.4), then conversion into color code according to the color palette configuration performed finally.

In the horizontal direction of the signal sweep, the distance traveled is counted (when synchronizing measurements from the odometer), or the time is counted (when synchronizing from the timer). In the vertical direction of the signal sweep the magnetic measurement units are

counted from 1 to 12: the top scan line corresponds to the readouts of the first magnetic measurement unit, the second from the top to the second, etc.

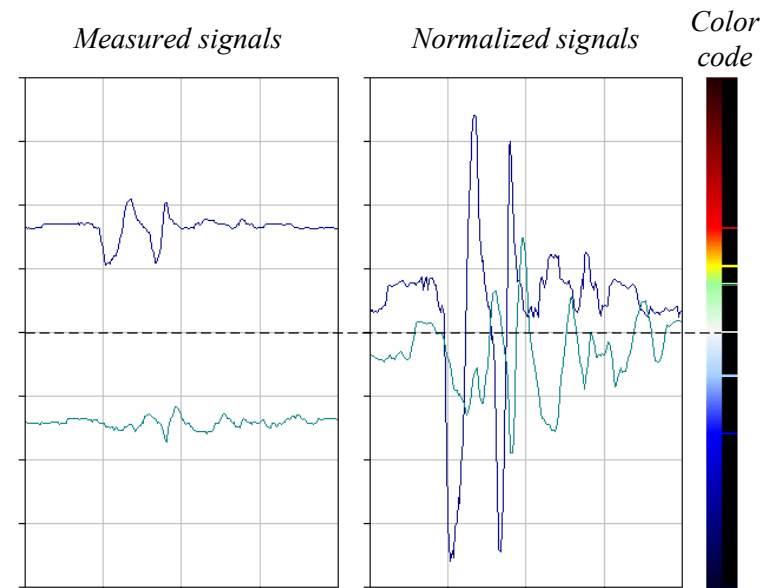


Fig.4.4. Normalization of measured signals and conversion their numerical values to the color palette codes

As an example illustration, the figure 4.5 shows the normalized signals of 12 magnetic measurement units, measured during survey scanning of metal surface with stressed state anomaly, and the color map sweep image of a magnetic field anomaly synthesized from them (figure 4.6).

4.3. Calculating the absolute coordinates of measurement points in GPS/GLONASS system

In common case the magnetic measurement unit configuration of «IN-04» multichannel metal stress scanner can be assembled to any shape on Customer's requirements. For example, in automated surveys on the surfaces of the big

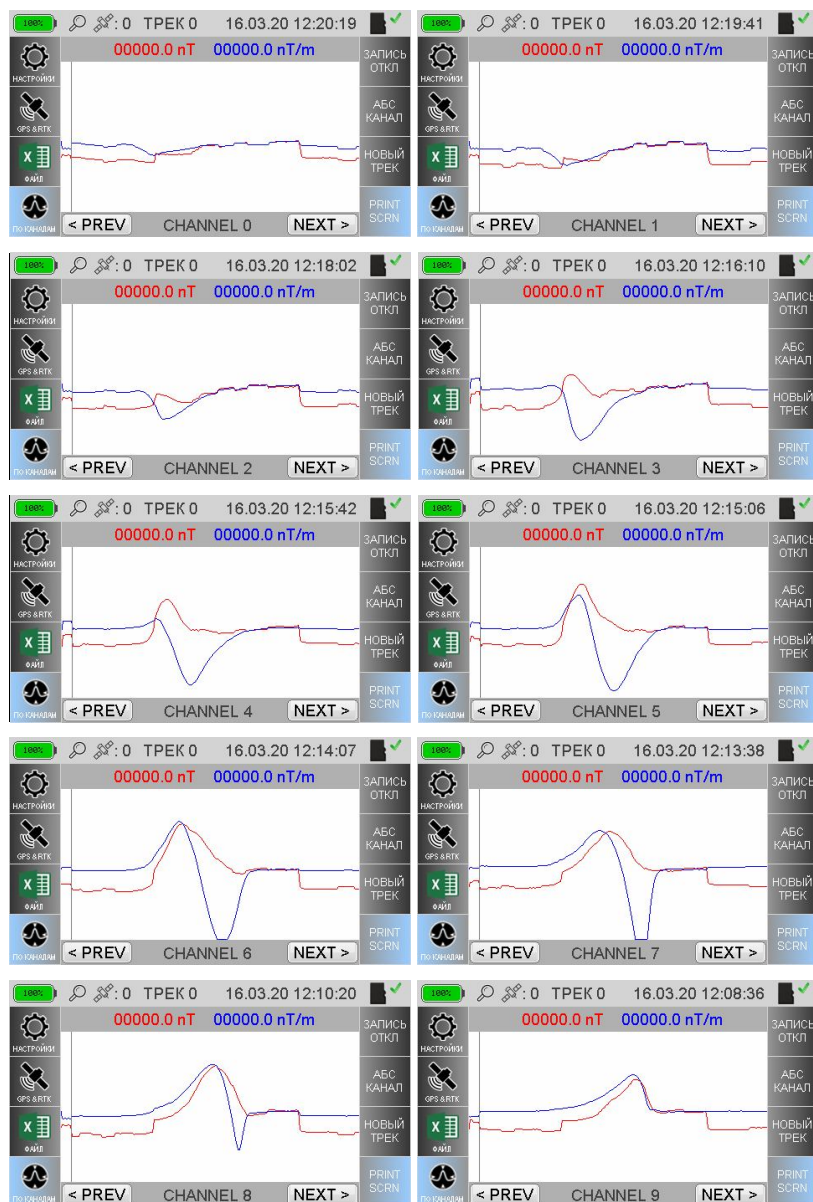


Fig.4.5. Measured signals of 12-channel metal stress scanner on stressed state anomaly detected

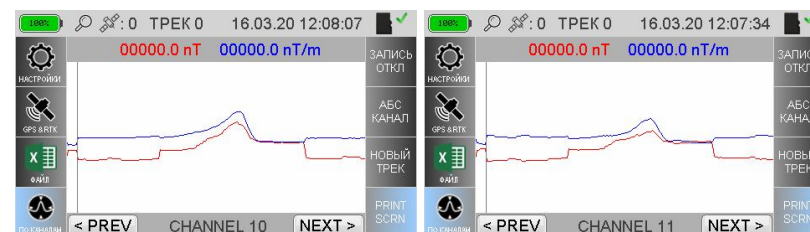


Fig.4.5. (continue) Measured signals of 12-channel metal stress scanner on stressed state anomaly detected

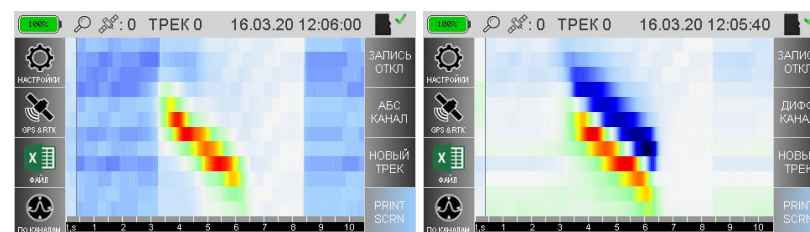


Fig.4.6. Color map image of stressed state anomaly on synthesized on measured signals shown on figure 4.4

flat objects and structures, the magnetic measurement units can be placed in chess order or in simple row across the direction of scanning, as shown on figure 4.7.

If automated mapping and monitoring of stressed state of steel pipelines, ropes need, then measurement units have to be placed around the object cross section in coil shape order.

In most of practical cases of stressed state inspection the single the handheld design of magnetic measurement unit is usually enough (figure 4.8).

The coordinates of magnetic measurement units in the absolute system (GPS/GLONASS) are determined by vector sum of the coordinates of the magnetic measurement units relative to the navigation receiver antenna (x_N, y_N) and the absolute coordinates of the antenna of the navigation receiver (x_0, y_0), while the scanning direction (*Heading*) also considered in given point in time.

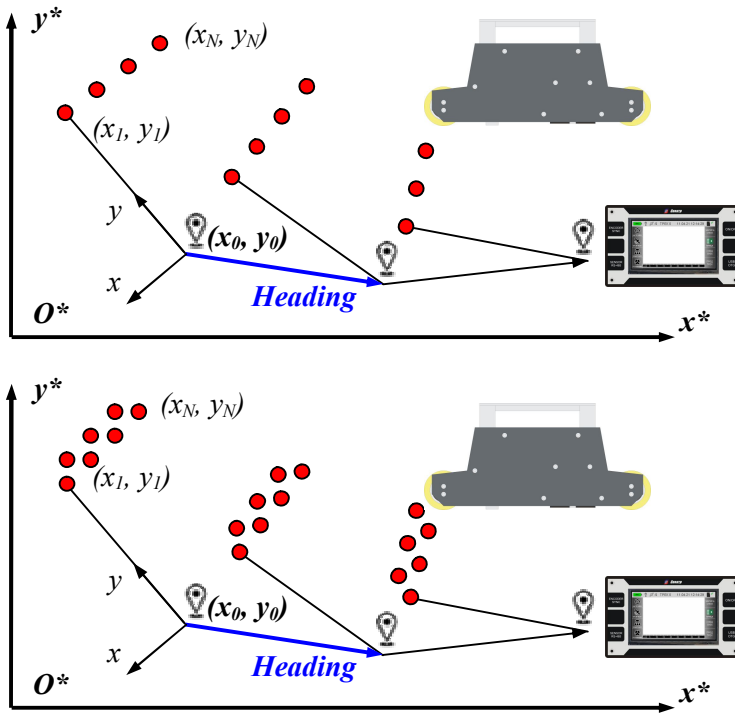


Fig.4.7. Multichannel stress scanner configurations for automated survey of the big flat objects and structures

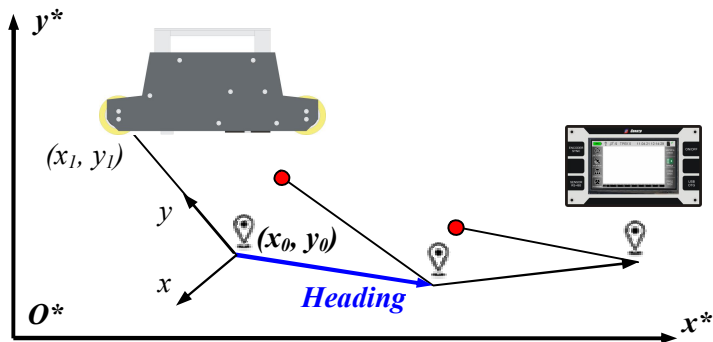


Fig.4.8. Single-channel configuration of stress scanner for manual inspection of stressed state of the metal

The relative coordinate system the configuration of magnetic measurement units determined is considered rectangular (Cartesian), while the absolute coordinates of any point on the world map are determined in a spherical (elliptical) coordinate system (figure 4.9).

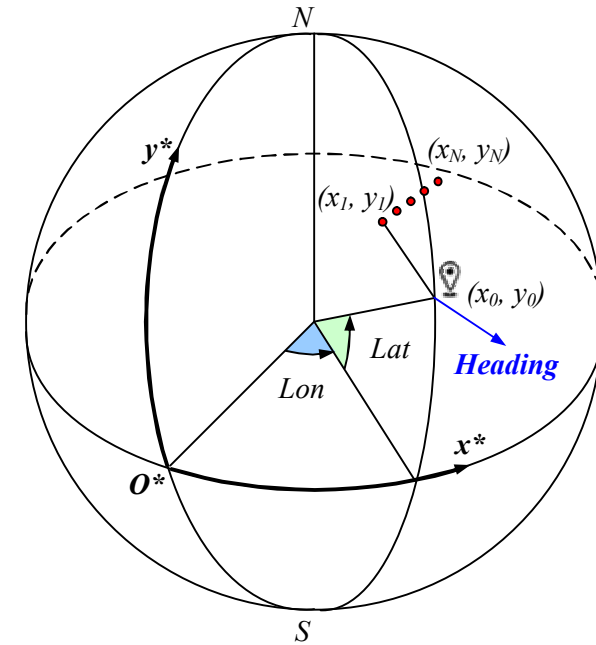


Fig.4.9. Calculating the measurement points on the Earth surface when metal stressed state survey is performed

The coordinates of the magnetic measurement units relative to the antenna of the navigation receiver (x_N, y_N) are entered into the memory of multichannel metal stress scanner through the appropriate configuration panel (figure 3.10).

The absolute coordinates of the navigation receiver antenna (x_0, y_0) are determined automatically, and the direction of movement at each moment of time is calculated from the coordinates of the start and end points.

The listed data is sufficient to calculate the absolute coordinates of each transducer. At middle latitudes:

$$Lat_N = Lat - \frac{180}{\pi} \arcsin \frac{y_N^*}{R_E};$$

$$Lon_N = Lon + \frac{180}{\pi} \arcsin \frac{x_N^*}{R_E} \arccos \frac{Lat}{180};$$

where (x_N^*, y_N^*) – are coordinates of the magnetic measurement units relative to the built-in GPS receiver antenna of the data acquisition unit in the local Cartesian system, $R_E = 6372795$ m – the average radius of the Earth.

$$x_N^* = \sqrt{x_N^2 + y_N^2} \cdot \cos \left(\arctan \frac{x_N}{y_N} + heading \right);$$

$$y_N^* = -\sqrt{x_N^2 + y_N^2} \cdot \sin \left(\arctan \frac{x_N}{y_N} + heading \right).$$

The coordinates of the magnetic measurement units in the absolute coordinate system (Lat_N, Lon_N) are calculated automatically by «IN-04» multichannel metal stress scanner, so the measurement results can be presented on personal computer as color stress maps.

4.4. Calculating the coordinates of measurement points related to built-in odometer counts

The software of the «IN-04» multichannel metal stress scanner data acquisition unit provides two ways to perform area survey scanning during synchronization of measurements from odometer signals: one-directional and reversive scanning.

A one-directional and reversive motion patterns of plane scanning for 5 passes using a linear configuration of 4 magnetic measurement units are presented in the figure 4.10.

For both one-directional and reversive scanning at each measurement point, the odometer readings are added to the relative coordinates Y of the configuration of the magnetic

measurement units, which are entered into the data acquisition unit settings via the user interface (figure 4.11) before the survey being started.

4.4.1. Performing the survey in one-directional mode, the count of traveled distance for each pass starts from zero, so finishing every pass you have to return to the beginning of survey, shifting to the right of the scan bandwidth.

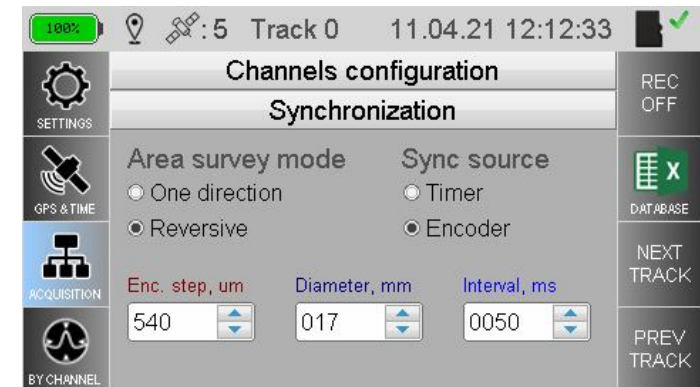
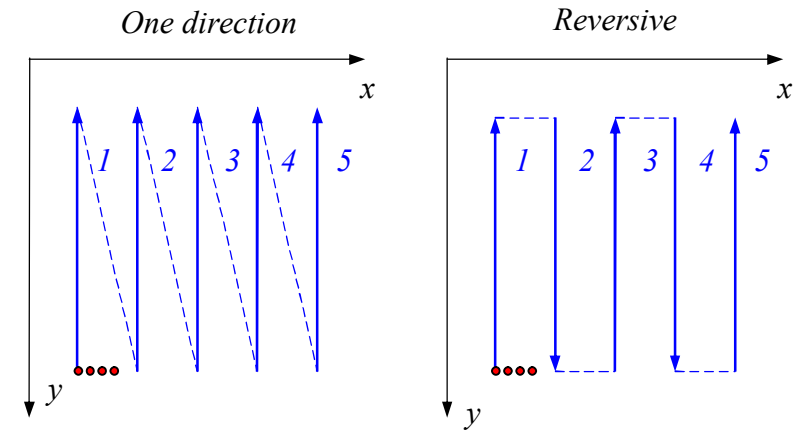


Fig.4.10. One-directional and reversive survey patterns and measurements synchronization parameters page of the «Triton» multichannel magnetic field measurement system

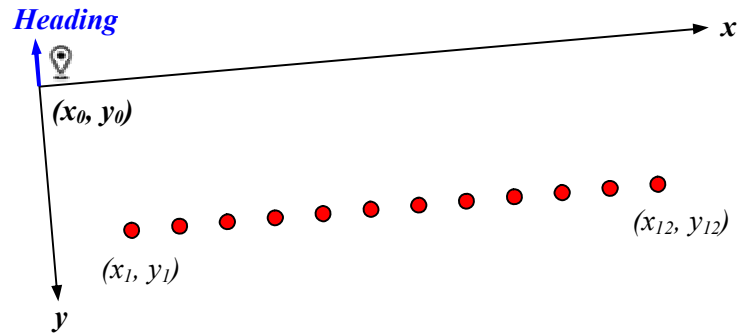


Fig.4.11. Magnetic measurement unit positions of the multichannel metal stress scanner configuration page

After completing the passage, the measurements should be stopped and a new track should be started, while, according to the one-directional scan pattern, the odometer counter is automatically reset to 0.

4.4.2. In reverse scanning mode the distance covered for each pass starts from the last value of the previous pass. After completion of the passage there is no need to return to the beginning of the area surveying; to start the next pass, to stop the measurements is enough, then turn the scanning device in the opposite direction and start a new track.

In reverse scanning, the odometer counting direction and the configuration of the magnetic measurement units are inverted for odd passes.

When area survey scanning is performed with reference of measurement points to coordinates in the GPS/GLONASS system, the settings for area survey parameters (figure 4.10) does not matter, because the direction of movement in this mode is automatically determined by the GPS/GLONASS coordinates of the track points.

5. SAFETY INSTRUCTIONS

5.1. For the operation, maintenance and repair of the «IN-04» multichannel metal stress scanner, persons are allowed only after studying the Sections 2-6 of this operating manual, as well as having been instructed in industrial and fire safety when working with electricity.

5.2. Any manipulations associated with physical contact with the battery, including replacing it, cleaning it from contamination, repairing and setting up the multichannel magnetic field measurement system, are permissible provided that the power switch is in the «OFF» position.

5.3. When working with «IN-04» multichannel metal stress scanner, it is necessary to comply with the requirements of the «Technical operation of consumer electrical facilities Rules PTE-84» and the «The operation of consumers electrical facilities safety Rules of PTB-84 ».

6. PREPARING TO WORK

Preparing of the «IN-04» multichannel metal stress scanner to the work includes a visual inspection, assembly and switching the power on, as well as software settings adjustment.

6.1. Visual inspection, assembling, powering on

6.1.1. Connect the accumulator battery to the power connector inside of the battery compartment on the back of the data acquisition unit. Insert the accumulator battery into the compartment and snap the battery cover into place, tight by hand four handle screws, fastening the cover on the acquisition unit closing the battery compartment. All time while manipulations with accumulator battery performed, the power switch must kept be in the «OFF» position.

6.1.2. Perform a visual inspection of system of the magnetic measurement units. If necessary, clean them from magnetic and non-magnetic particles and mud using a synthetic brush or rags.

6.1.3. Connect the system of magnetic measurement units to the data acquisition unit of multichannel metal stress scanner using a set of connecting cables provided.

6.1.4. Turn on the power of the scanner by setting the power switch of the power supply of the data acquisition unit to the «ON» position, marked with a dot.

6.1.5. Each time you turn it on, a short double sound alarm occurred, and then reading the settings from non-volatile memory and loading of the graphic user interface (GUI).

6.1.6. If the battery level indicator shows less than 20% and colored by red color, replace the battery immediately.

6.2. Setting up the sensor configuration and saving it on the nonvolatile memory of scanner

6.2.1. Open the sensor positions configuration page of the multichannel metal stress scanner (figure 4.11).

6.2.2. Enter the coordinates of the magnetic measurement units relative to the antenna of the built-in navigation receiver antenna in units of centimeters in the appropriate fields. These data will be used to determine the absolute coordinates of the measurement points in the GPS/GLONASS system according to the method described in 4.3 of this User Manual.

The satellite antenna of the receiver integrated in the data acquisition unit is located in the lower right corner of housing of the data acquisition unit.

When calculating the coordinates of the measurement points from the odometer readings, the relative displacements of the measurement points along the direction of scanning are automatically reset to zero.

6.2.3. To save the configuration of magnetic measurement unit positions into non-volatile memory of the multichannel metal stress scanner the save button «» is only need to be pressed.

6.3. Setting up the measurement channels to record measured signals on built-in data storage of scanner

6.3.1. Open the recording channels configuration page of the multichannel metal stress scanner (figure 3.13).

6.3.2. Check the boxes for those measuring channels whose signals are need to be recorded on the memory card, and then transferred to a personal computer. Uncheck the channels whose signals should not be recorded on the built-in flash data storage (memory card).

6.3.3. To save the configuration of recording of the measuring channels selected into non-volatile memory of the multichannel metal stress scanner the save button «» just need to be pressed.

6.4. Configuring the color palette and real-time color sweep parameters

The quality of color map sweep of the magnetic measurement unit signals on the screen of scanner is depended directly on the color palette configuration, which is a one-dimensional function establishing the correspondence between the measured signal value and the color code (figure 4.4).

The color palette configuration performed by setting the reference points on the color palette band within the measurement range of fluxgate magnetic field sensor signals, and synthesizing reference colors at the specified points by adjusting the intensity of three basic color components:

6.4.1. Open the color palette panel (figure 3.6).

6.4.2. Specify the position of the reference color in the interactive color palette band, and the dialog box to adjust the reference color basic components will appear (figure 3.8).

6.4.3. Specify the reference color in the dialog box appeared and click «OK» button, and then color palette will be automatically recalculated in accordance with last changes in the set of reference colors.

6.4.4. If removing the reference color from the palette is required, specify it in the table of reference colors and click the button «» to delete the reference color from palette.

6.4.5. If returning to the initial (default) color palette configuration is required, press the «» button.

6.4.6. To save the color palette configuration into non-volatile memory of the multichannel metal stress scanner the save button «» just need to be pressed.

6.5. Adjusting the gain of measured signals

The measured signals constant offset escaping and then amplification is the essence of signal normalization and is used to construct a graph and color map sweep, as shown in Section 4.2 of this User Manual.

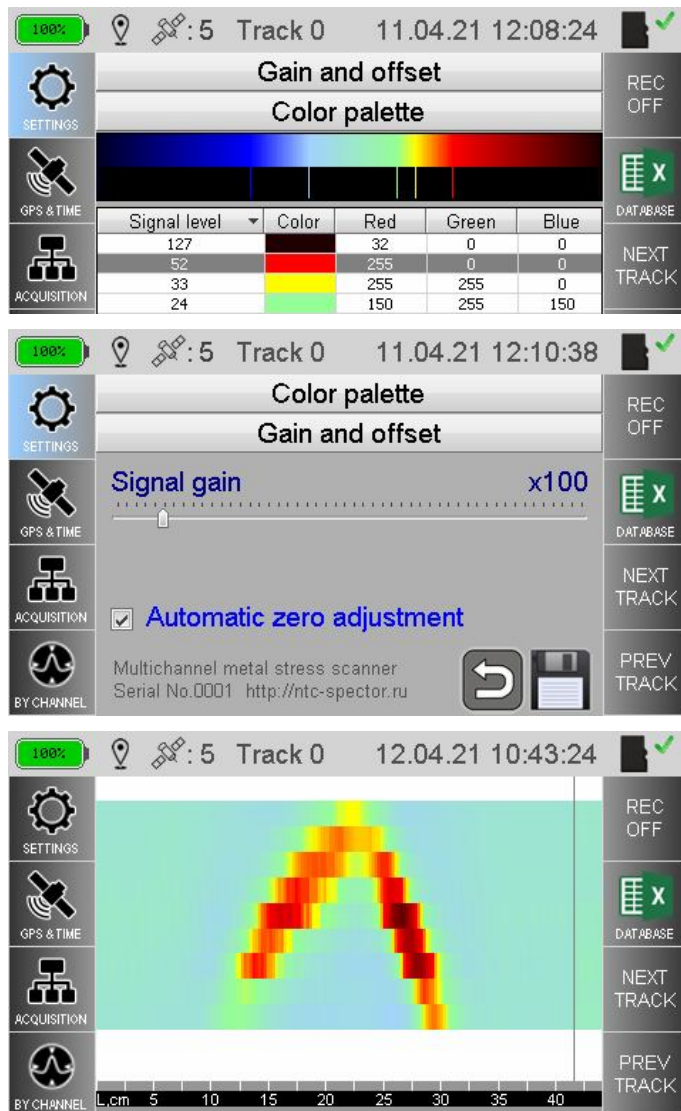


Fig.6.1. Optimal configuration of default color palette and amplification factors of measured signals

Changing the values of the amplification factor and the zero offset magnitude does not affect on values of measured signals being recorded on the built-in flash data storage (memory card).

6.5.1. Open the amplification factors and zero offset adjustment page (figure 3.9).

6.5.2. Adjust the gain of measured signals using the «Gain» control common for all magnetic measurement units.

The gain can be considered to be optimal for information quality and visual convenience of a graph and color map sweep, if the largest range of the measured signals after amplification is approximately equal to the range of the color palette scale, but at the same time does not go beyond its limits (figure 6.1).

6.5.3. To save the values of the amplification factors and the zero offset magnitude just set up into non-volatile memory of the multichannel metal stress scanner the save button «» just need to be pressed.

6.6. Setting up the system date and time

The multichannel metal stress scanner «IN-04» has built-in integrated circuit of real time clock and calendar to fix the date and time at the moment of saving of measured data or print screen on the built-in flash data storage.

To set up actual date and time of system clock please follow next basic steps:

6.6.1. Open the date and time setup page (figure 6.2);

6.6.2. Set up actual values of date and time using «UP» and «DOWN» buttons of the appropriate controls;

6.6.3. Save the date and time just set on the non-volatile memory of real time clock integrated circuit by pressing the save button «».

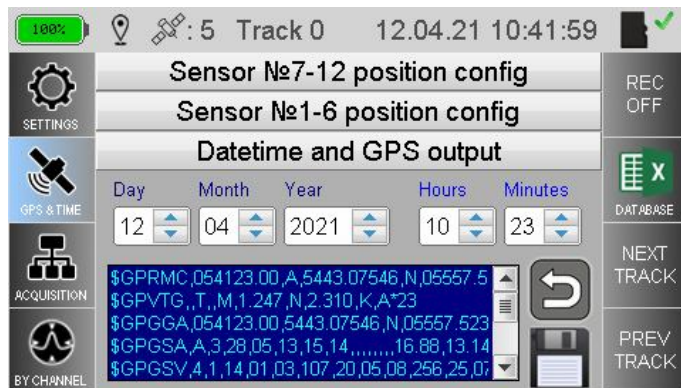


Fig.6.2. System date and time setup page of «IN-04» multichannel metal stress scanner

6.7. Setting up the synchronization parameters of measurements by time and by distance covered

Multichannel metal stress scanner «IN-04» has two built-in independent sources of clocking signals to synchronize the measurements: odometer and timer.

Main source of measurements synchronization signal used for scanning is odometer.

Timer synchronization can be more useful in static monitoring of stressed state of the different objects.

To choose the source of measurements synchronization signal and set up its parameters please follow next basic steps:

6.7.1. Open synchronization page (figure 3.12);

6.7.2. Choose the measurements synchronization source (odometer or timer) using «Sync source» radio button control group;

6.7.3. If odometer was chosen as the synchronization source, then next important step before start measurements is to enter its diameter in numerical field named «Diameter, mm» using up-down buttons, and then to adjust its step in numerical field named «Encoder step, um» (figure 6.3);

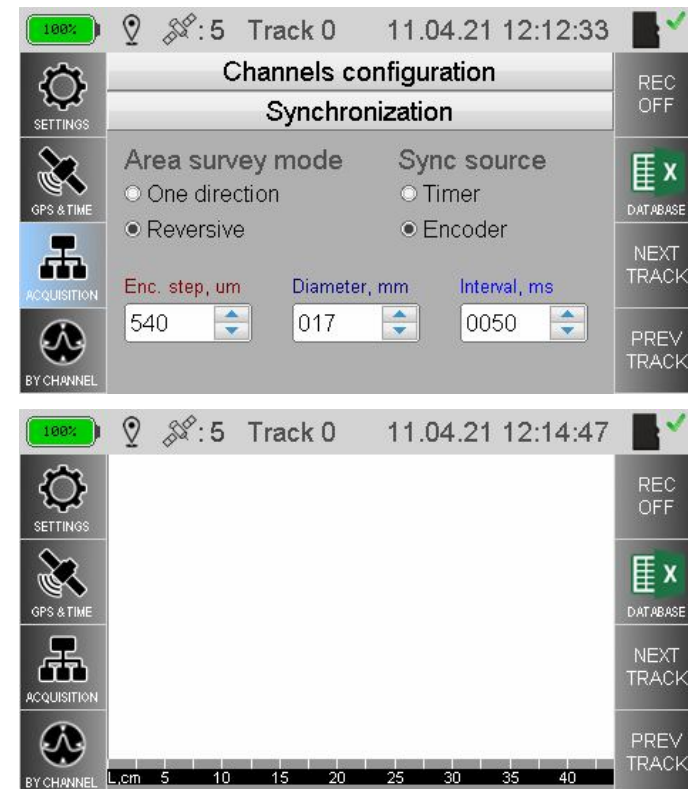


Fig.6.3. Screen ruler scaling in units of distance covered by scanner if odometer synchronization mode enabled

6.7.4. If timer was chosen as the synchronization source, then next important step before start measurements is to set up required interval of measurements in numerical field named «Interval, ms» using up-down buttons (figure 6.4);

6.7.5. Save the synchronization parameters just set on the non-volatile memory of the scanner by pressing the save button «» on the «Channels configuration» page.

6.7.6. Now «IN-04» multichannel metal stress scanner is ready to work! Let's consider calibration principle and procedure, as well as measurement order, in next Sections.

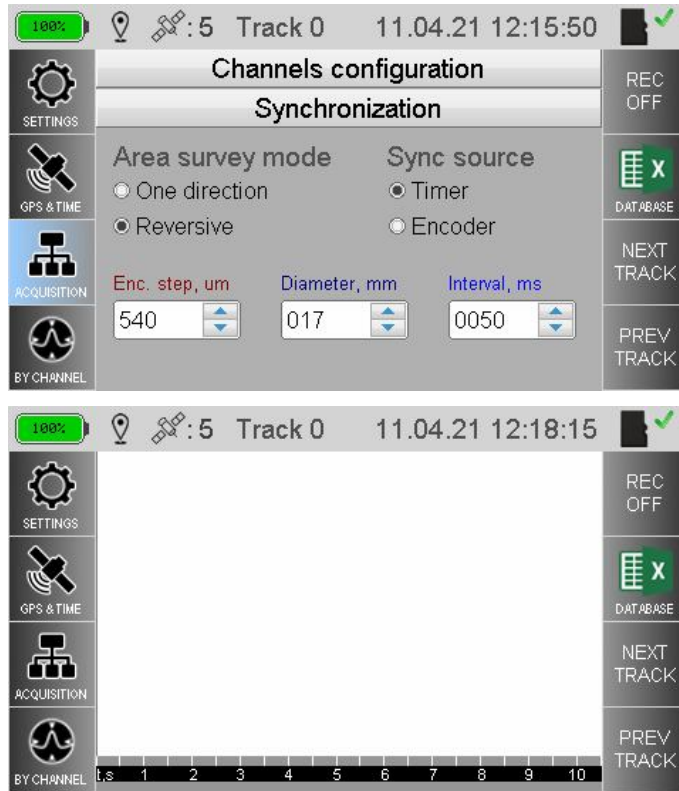


Fig.6.4. Screen ruler scaling in units of time elapsed if built-in timer synchronization mode enabled

7. CALIBRATING SCANNER AND WORKING WITH BUILT-IN METAL SAMPLES DATABASE

The procedure of calibration of «IN-04» multichannel metal stress scanner is usually performed by approximation of empirical dependence of the residual magnetic field measured on mechanical stress of metal by known linear equation.

Calibration of magnetic measurement channels of scanner is always performed at the manufacture during production. There is no need to calibrate them again for all time of service time of scanner.

As shown in Section 4.1 of this User Manual, steel goods and structures of different shapes and made from different grades of steel, can be significantly differed on magnetic and mechanical properties; therefore, dependence of residual magnetic field on mechanical stress of metal (4.3) for them is different too.

As soon as common law of dependence of the residual magnetic field on mechanical stress for different metals is linear one (equation 4.3), therefore linear approximation require just two points, one – is at zero value of stress of the metal ($\sigma = 0, B_{rs} = B_{rs0}$), and another point – is at some known not zero value of stress ($\sigma = \sigma_{cal}, B_{rs} = B_{rsal}$).

Mentioned parameters connected to parameters of equation 4.3 for homogeneous isotropic materials as following:

$B_{rs0} = \mu_0 H_r(\sigma = 0)$ – induction of residual magnetic field of the metal B_{rs} , measured on the surface of steel object, when no stress existed in considered point of the object ($\sigma = 0$);

$B_{rsal} = \mu_0 H_r(\sigma = \sigma_{cal})$ – induction of residual magnetic field of the metal B_{rs} , measured on the surface of steel object, when known not zero stress existed in considered point of the object ($\sigma = \sigma_{cal}$) exposed to known applied load.

σ_{cal} – total equivalent mechanical stress of metal produced in considered point of the object under action of known load applied to make conditions for second calibration point measurement.

Equation 4.3 can be formulated in terms of induction of residual magnetic field of metal, measured on the surface of inspected steel object:

$$B_{rs}(\sigma) = B_{rs0} + \frac{\lambda_S B_{rs0}}{\mu_0 J_S^2 N} \sigma. \quad (7.1)$$

Structure sensitive magnetic parameters, which are hard to be measured on the practice, can be put in common constant of the material, simplified the look of equation:

$$B_{rs}(\sigma) = B_{rs0} + k\sigma. \quad (7.2)$$

Value of k constant calculated by metal stress scanner automatically on parameters B_{rs0} , B_{rs0} , σ_{cal} , preliminarily measured in calibration procedure using steel samples, and entered into the built-in database (figure 7.7):

$$k = (B_{rs0} - B_{rs0})/\sigma_{cal}. \quad (7.3)$$

Let's consider the scanner calibration procedure and how to save calibrations on the built-in metals database.

7.1. Prepare the steel sample appropriate to the material is made from and shape to the object or series of steel goods to be inspected.

7.2. Take the measurement of residual magnetic field induction on the surface of steel sample B_{rs0} by metal stress scanner when no stress existed in considered point (unloaded state). Enter value measured into B_{rs0} numerical field on the built-in metals database window (figure 7.1).

7.3. Load the sample in such a way as to make known stressed state of metal with exactly determined total equivalent stress σ_{cal} in the point of measurement of residual magnetic field induction. Enter σ_{cal} value in appropriate numerical field on the built-in metals database window (figure 7.1).

7.4. Take the measurement of residual magnetic field induction on the same point of the surface of steel sample B_{rs0}

by metal stress scanner at currently determined stressed (loaded) state. Enter value measured into B_{rs0} numerical field on the built-in metal samples database window (figure 7.1).

Sample	Brs0 mT	Scal MPa	Brscal mT
St_3_flat	0.62	350	2.00
MSt_3_flat	0.72	310	2.00
VSt_3kp_flat	0.86	400	2.15
VSt_3sp5	0.99	410	2.29
Steel_20_flat	1.32	420	4.00
09G25_flat	1.06	470	2.98
09G25-12_flat	1.23	500	3.24
17G15_flat	1.38	520	4.12
St_Ds_flat	1.70	650	3.38
Steel_45_flat	1.79	610	3.46

Fig.7.1. Built-in metal samples database window with calibrations of «IN-04» multichannel metal stress scanner

7.5. Calibration procedure is finished. To save calibration parameters just set on the built-in non-volatile memory of the scanner press the save button «».

7.6. To enter the calibrations into the database the scanner have to be connected to the personal computer using USB cable supplied with scanner. Open «Stress_DB.csv» file then create and fill new entry by one of the following ways:

7.6.1. Way 1 – using «StressMAP» software. Open the «Stress_DB.csv» database file in database manager window of the StressMAP software application; enter the name and parameters of the steel sample, add it into the database pressing «Add item» button, then save changes performed in the database pressing «Save DB» button.

7.6.2. Way 2 – using MS Excel or standard text editor. Open the «Stress_DB.csv» database file in MS Excel or standard text editor, add new row then fill the name of sample and calibration parameters, then save the file.

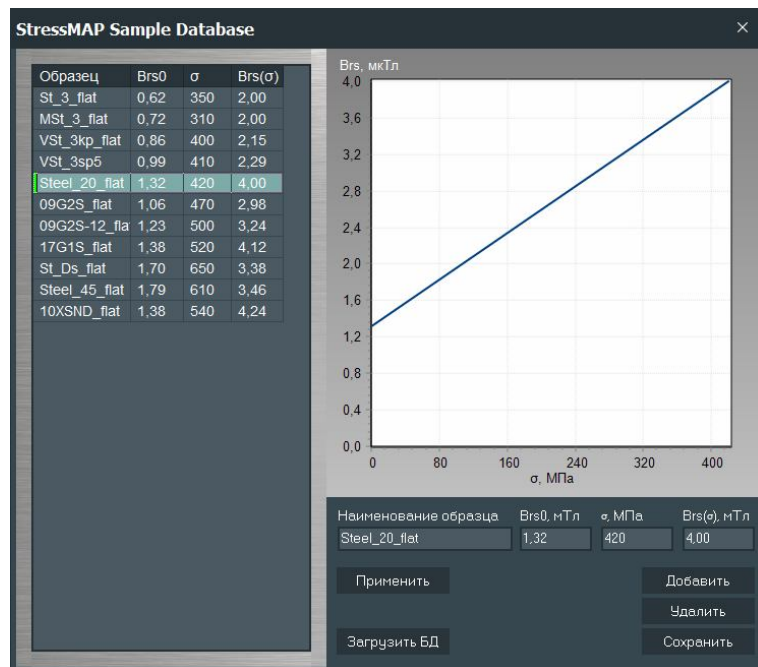


Fig.7.2. «StressMAP» software application database of metal samples with calibrations of «IN-04» multichannel metal stress scanner

7.7. Close the metal samples database file and disconnect USB cable from personal computer, then from the scanner. Restart the scanner switching its power OFF then ON.

7.8. To use calibrations of IN-04 multichannel metal stress scanner from built-in metal samples database open the metal samples database window of scanner again pressing the «DATABASE» button.

7.9. Choose the sample from database using arrowed buttons, and apply its parameters pressing the apply button «». Save active configuration of calibration parameters on the built-in non-volatile memory of the scanner pressing the save button «» if need.

7.10. Taking the calibration procedure for each type of steel goods and structures it is important to find the optimal way of loading the appropriate samples: it should be as simple enough as easily reproduced in the field conditions, in other hand the accuracy of load regulation and metal stressed state calculation make direct influence in accuracy of the calibration and further measurements.

Let's consider one example of the metal stress scanner calibration procedure for nondestructive assessment of the stressed state of the steel pipeline.

7.10.1. Prepare the calibration sample: take the steel pipe section equal on material and sizes to the pipes used in construction of the pipeline to be inspected, muffle the pipe by appropriate hemispheric caps from both free ends. On the side surface, weld the pressure input choke, then connect the pumping station to the pressure input choke through the pressure gauge.

7.10.2. Perform a preliminary pressure test of the assembled structure. Make sure it is safe for nondestructive measurements on the side surface of the steel pipe. Do not proceed with further actions until the required level of safety at the facility is ensured.

7.10.3. Perform the scanning of residual magnetic field induction B_{rs0} on 12-24 profiles on the side surface along the axis of pipe in not stressed state (without pressure).

Generally a lot of hidden defects can be presented in the steel pipe, where concentration of mechanical stress of metal occurs if pressure applied inside of the pipe.

Survey of the all surface of pipe is required to find the probable stress concentration zones of metal and avoid the biases (systematic errors) of the calibration.

7.10.4. Copy the results of stressed state scanning to the personal computer; fill them out on color map or 3D surface using «StressMAP» or «Surfer» software (figure 7.3) and to investigate it for probably existed stress concentration zones.

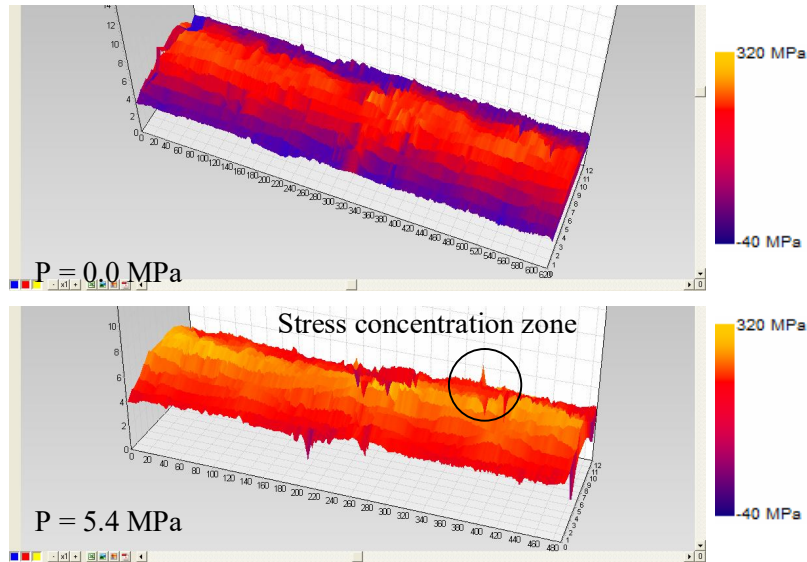


Fig.7.3. Change of stressed state of the steel pipe with change of inner pressure from 0 to 5.4 MPa

As the B_{rs0} parameter value take the average of measured B_{rs} on the overall surface of pipe, and then enter it into B_{rs0} numerical field on metal samples database window.

7.10.5. Pump the pressure inside of pipe up to safety value P_{cal} , and uniform hoop stress will appear in the wall of pipe, value of which is calculated from pressure and pipe parameters on the known expression $\sigma_{cal} = P_{cal} OD/2t$, where OD – is outer diameter of the pipe, t – thickness of wall of the pipe. Put the calculated value σ_{cal} into appropriate numerical field on metal samples database window (figure 7.1).

7.10.6. Perform the scanning of residual magnetic field induction B_{rscal} on 12-24 profiles on the side surface along the axis of pipe in not stressed state (without pressure).

7.10.7. Copy the results of stressed state scanning to the personal computer; fill them out on color map or 3D surface using «IN-01m Connect» or «Surfer» software application

(figure 7.3) and to investigate it for the presence of probable stress concentration zones of metal.

As the B_{rscal} parameter value take the average of measured B_{rs} on the overall surface of pipe, and then enter it into B_{rscal} numerical field on metal samples database window shown on the figure 7.1.

On figure 7.3 shown that if the inner pressure applied to the pipe, the intensive stress concentration zone found, which is not observed when no pressure was applied. As was found subsequently, this point indicates to dangerous defect located inside of the longitudinal weld, ultimately led to the fracture of the pipe along the weld when inner pressure was increased.

Therefore the metal stress scanner allows detecting the stress concentration on the defects of welded seams, while dangerous defects are most clearly detected by the magnetic technique of stressed state inspection if inner pressure applied to the pipe.

7.10.8. Calibration is completed. To save calibration parameters just set up on the non-volatile memory of the multichannel metal stress scanner press save button «».

8. TAKING THE MEASUREMENTS

Before taking measurements, the battery level should be checked on the indicator in the upper left corner of the screen. If necessary, replace or charge the battery.

Wait until the current date and time appears on the screen, while the number of visible satellites must be at least 3, and the navigation status with «Location fixed» .

After performing the stressed state survey, the results of measurements can be transferred to a personal computer for reporting according to requirements of regulatory documents.

8.1. Scanning the stressed state of big object and mapping in GPS/GLONASS coordinates system

8.1.1. If the manual scanning of the stressed state using one handheld magnetic measurement unit performed, then «BY CHANNEL» sweep mode should be activated and the appropriate measurement channel should be selected the magnetic measurement unit is connected to.

8.1.2. If the measurements need to be performed in the survey mode, then, select the default color map mode of sweep switching «BY CHANNEL» mode off.

8.1.3. Launch and configure the measurement channels and survey parameters according to Section 6 of this manual, then start the measurement process pressing by finger anywhere on the sweep.

8.1.4. Take the measurements on the inspected region and stop by pressing anywhere on the sweep again.

8.1.5. If, as a result of the measurements, no significant signals from the expected anomalies of metal stressed state observed, and the background color of the color map is uniform and corresponds approximately to the middle of the color palette scale, then the gain factor should be increased along the corresponding measurement channel.

If an approximately uniform or non-uniform color background is observed on the screen, which corresponds

mainly to the upper or lower limits of the color palette, then gain factor should be reduced, and automatic zero adjustment option should be activated as described in the Section 6.5 of this User Manual.

8.1.6. Repeat the measurements on the inspected region and explore the measured graphs on the screen for anomalies of the stressed state of metal.

8.1.7. If necessary, the images of stressed state anomalies detected can be printed out from the screen to the file, or numerical values of the measured signals of the multichannel metal stress scanner can be recorded to the built-in non-volatile flash data storage (memory card) according with Section 8.5 of this User Manual.

When area scanning performed with reference to the built-in GPS/GLONASS system, the signals recording can be performed continuously, but this is not recommended, because the file size resulting may be turn out too large, which can subsequently lead to inconvenience when processing it on the computer. Therefore, it is recommended to record the signals during area survey by profiles: one profile – is a one file.

Moreover, the shapes of scan profiles and the order of their passage does not matter, because the absolute coordinates of each measurement point are calculated at each step automatically, considering the direction of movement at a given time in accordance with Section 4.3 of this User Manual.

8.2. Scanning the stressed state of steel object using odometer in one-directional survey mode

Recording of the data measured into a file during area surveying is usually performed according to profiles (tracks): one profile – is a one file. In addition, each track corresponds to one series of measurements performed along the region, from its beginning to the end.

8.2.1. Select a one-directional area scanning mode and configure its parameters according to Section 4.4 of this User Manual. The track counter will be automatically reset to 0.

8.2.2. Close the settings window; enable recording of the data measured to a file by pressing the «RECORD» button.

8.2.3. Start the measurements by clicking on the sweep.

8.2.4. Scan the first profile according to one-directional pattern on the figure 4.10 and record the signals measured; then stop the measurements by pressing anywhere on the sweep.

8.2.5. Disable the recording of the data measured into the file by pressing the «RECORD» button again.

8.2.6. Return to the starting point of the next track (profile) according to the one-directional motion pattern on the figure 4.10 and press «NEW TRACK» button.

8.2.7. Continue to follow Sections 8.2.3 – 8.2.6 until the entire area under survey has been covered.

8.3. Scanning the stressed state of steel object using odometer in reversive survey mode

The difference between the reversive area surveying pattern and the one-directional one is that in order to start the next measurement profile, it is not necessary to return to the beginning of the area under survey.

8.3.1. Select a reversive area scanning mode and configure its parameters according to Section 4.4 of this User Manual. The track counter will be automatically reset to 0.

8.3.2. Close the settings window; enable recording of the data measured to a file by pressing the «RECORD» button.

8.3.3. Start the measurements by clicking on the sweep.

8.3.4. Scan the first profile according to reversive motion pattern in figure 4.10 and record the signals measured; then stop the measurements pressing anywhere on the sweep.

8.3.5. Disable the recording of the data measured into the file by pressing the «RECORD» button again.

8.3.6. Return to the starting point of the next track (profile) according to the reversive motion pattern on the figure 4.10 and press «NEW TRACK» button.

8.3.7. Continue to follow Sections 8.3.3 – 8.3.6 until the entire area under survey has been covered.

8.4. Stressed state of steel ropes scanning and monitoring in real time

8.4.1. Install the magnetic measurement unit on a fixed solid base, connect it to the scanner data acquisition unit and configure its parameters in accordance with Section 6 of this User Manual.

8.4.2. Pass the end of the wire rope to be inspected through the odometer wheel in such a way that when the cable is moved, its length is counted.

8.4.3. Switch on the «BY CHANNELS» mode, select the number of the channel through which the magnetic measurement unit with the rope is connected.

8.4.4. Start the measurement process by clicking anywhere on the graphical sweep.

8.4.5. Scan the steel rope by passing it through the magnetic measurement unit along its entire length. After scanning, stop the measurement process by pressing again anywhere on the graphical sweep.

8.4.6. If on the graphs obtained as a result of the measurements, there are no significant changes from the assumed anomalies of the stress state of the metal, then the gain should be increased;

If the graphs partially or completely go beyond the upper or lower border of the screen, then you should reduce the gain and enable the automatic zero adjustment option for measured signals.

8.4.7. Repeat the scanning of the wire rope and examine the displayed signals on the screen of scanner for metal stressed state anomalies.

8.5. Recording the measured signals and making print screens on the acquisition unit built-in data storage

The «IN-04» multichannel metal stress scanner has a high-capacity flash memory card preinstalled to store large volumes of measured data in «IN-01m Connect» and «Surfer» software formats, also instant printed screens.

Before recording, it is necessary to configure a number of parameters and activate channels for recording.

8.5.1. Open the panel for enabling and disabling recording of measured signals by channels (figure 3.13) and enable the checkboxes for the channels whose signals should be written to the file. Press the button  to save the configuration to the nonvolatile memory of the scanner.

8.5.2. Open the configuration panel of the magnetic measuring units for survey (figure 3.11) and enter the coordinates of the magnetic measuring units relative to the antenna of the built-in GPS receiver of the scanner. Press the button  to save the configuration to the nonvolatile memory of the scanner.

8.5.3. Set up the synchronization parameters as shown in part 6.4 of this User Manual, save them in the nonvolatile memory of the scanner by pressing the button .

8.5.4. To record signals during measurements, press the «RECORD» button. The status of the button will change from «RECORDING OFF» to «RECORDING ON», and in the folder «__DATA__» a text file will be created under the name «DDMMYYYY-hhmmss.csv», where DD/MM/YYYY is the current date (day, month and year), hh:mm:ss – is time (hour, minute, second) at the begin of recording moment.

The measurement results of the «IN-04» multichannel metal stress scanner signals by the configuration of the recording of the measurement channels (figure 3.13), the coordinates in the GPS/GLONASS system determined, as well as the odometer counts will be recorded in the file created until

the recording will not be stopped by pressing the «RECORD» button again.

8.5.5. To take a snapshot of the screen and save it on a flash memory installed inside of the data acquisition unit in the form of a raster image, press the current datetime indicator. An image file will be created under the name «DDMMYYYY-hhmmss.bmp» in the root directory, where DD/MM/YYYY is the current date (day, month and year), hh:mm:ss – is the time (hour, minute, second) at the time of taking the print screen.

8.5.6. The universal location of the current datetime indicator on the side of the touch screen allows taking screenshots of any interface elements, including not only sweep, but also settings panels and dialog boxes. Therefore, it is reasonable that all the printed screens presented in this User Manual are made using the «PRINT SCRIN» button.

8.6. Transferring the recorded data and printed screens to the personal computer and arranging them into color maps using Surfer software

Records of the measured signals, as well as printed screens of the stressed state anomalies detected, can be used in documenting the results of the stressed state inspection. For this purpose, the measured data should be transferred to the personal computer.

8.6.1. Stop the measurements by clicking anywhere on the sweep. The data acquisition unit of the multichannel metal stress scanner will turn into a standard flash disk device, which can be connected to a personal computer via USB and used as a convenient USB flash disk.

8.6.2. Connect the data acquisition unit to the personal computer using the USB connection cable supplied together with the multichannel metal stress scanner.

Important! Before connecting the data acquisition unit to the personal computer it must be both powered on.

8.6.3. Wait until the operating system of the personal computer recognize the type and class of the device connected, while a new disk device called «Multichannel Metal Stress Scanner» appears on the taskbar and in the file explorer.

8.6.4. Open the disk device in the file explorer and copy the necessary data from it in the usual way. In case if inspection was performed by covering surface by a number of passes («one pass – is one record file», see steps 8.2 – 8.3 of current User Manual), and measurements was recorded at a number of data files, which are must be merged together, then special folder must be created and required data files must be copied into the folder, separately from each other.

8.6.5. If certain of recorded files on the disk are not more necessary, then they could be removed, or disk be completely cleared, or some useful information could be copied and stored on it as files, e.g. samples of standard inspection forms, printed screens and real photo of detected stressed state anomalies, regulatory documents, etc.

8.6.6. After finishing file transfer process, perform safe disconnect of the «Multichannel Metal Stress Scanner» data storage device from PC.

8.6.7. Launch on your PC the «StressMAP.exe» software application (figure 8.1). At left side of main window located setup tools panel, at right side located data output fields to represent opened data on screen as color map of inspected surface (top right) and basic line chart, every line is separately recorded file (bottom right).

8.6.8. Press the «OPEN FILE» button, open the folder with results of inspection you want to open, and then choose any file into the folder (figure 8.2). List of files in top left corner of window will be filled (one pass – is one record file) and all records will be appeared on chart and on color map according to current color scale (figure 8.3). Color scale minimum and maximum is automatically attached to measured data range.

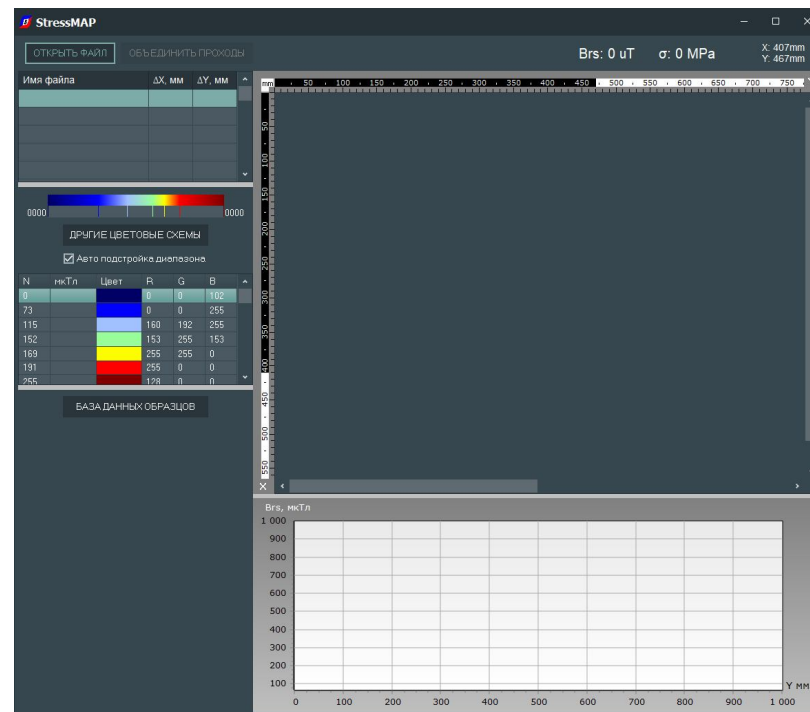


Fig.8.1. Main window of «StressMAP» software application

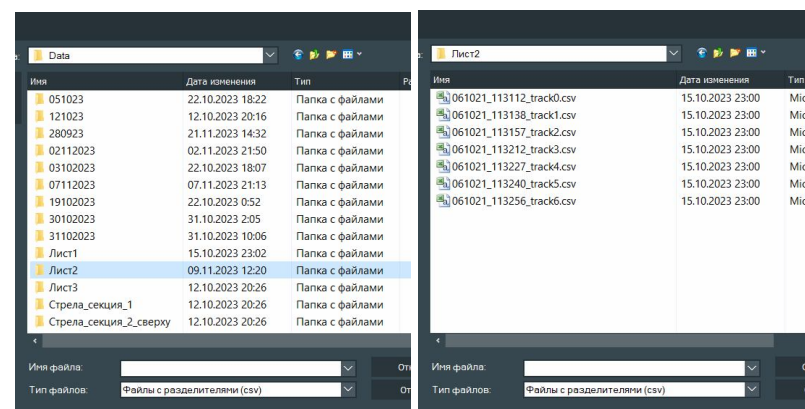


Fig.8.2. Open measured data records

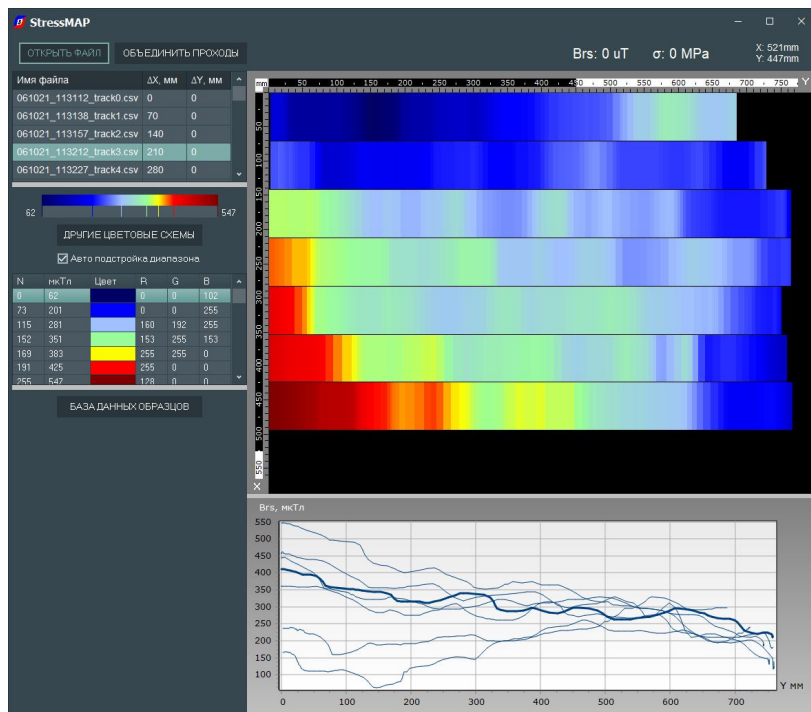


Fig.8.3. Opened data in «StressMAP» software application

If filename at top left field chosen, then correspond line is highlighted on chart at bottom right part of window.

If mouse pointer moved across color map field, the application automatically shows the coordinates of pointer in millimeters on scales and at top right corner as well as numerical value of residual magnetic field strength in specified point of surface in microtesla, and calculated actual value of the total stress in MPa.

To get correct calculation of stress on measured values of residual magnetic field strength first of all need to perform right calibration procedure on sample according to part 7 of current User Manual. To open existed sample database (figure 8.4) press the «OPEN SAMPLE DATABASE» button.

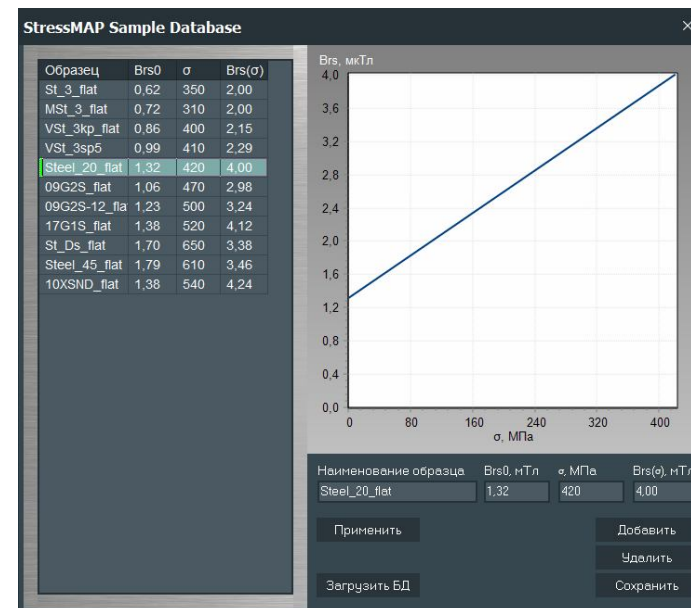


Fig.8.4. Database of metal samples window

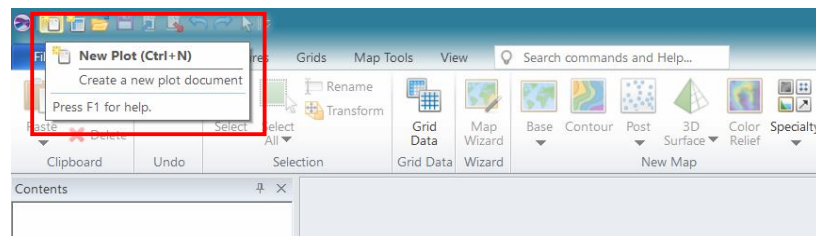
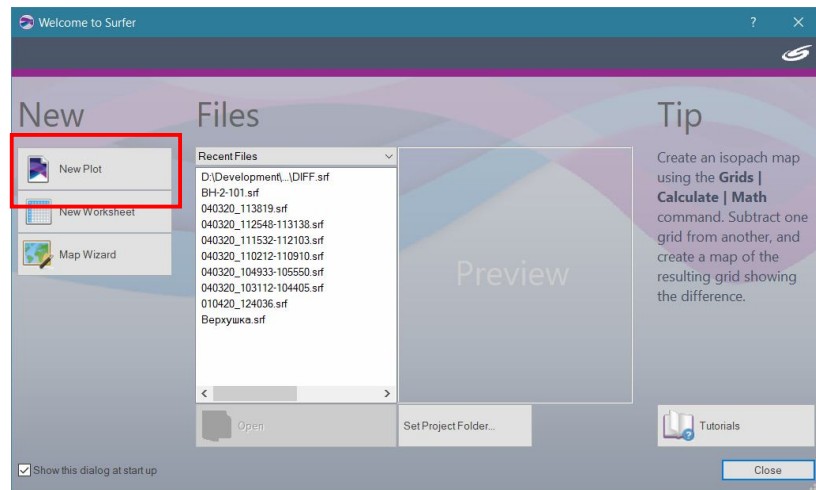
8.6.9. Press the «MERGE TRACKS» button to convert all entries in this folder to Surfer software format. The application will open all the files in an open folder one by one, automatically calculate the coordinates of the measurement points and combine the results, saves the output into 2x text files, according to 2x data display modes, and then displays it out as contour plot and 3d surface (see steps 8.6.24 – 8.6.25):

ENC_Hrs_data.txt – residual magnetic field strength *Hrs* measured on the surface of metal;

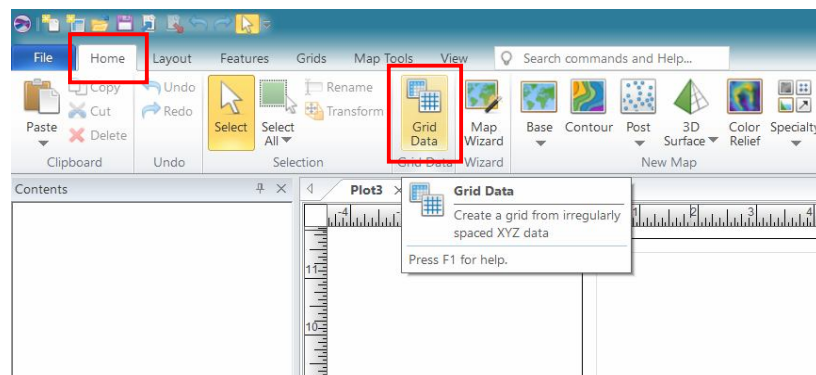
ENC_Sigma_data.txt – calculated distribution of actual total stress value σ on the surface of metal;

The above output files can be displayed and analyzed in the Golden Software Surfer application as contour plots and 3D surfaces manually as shown below.

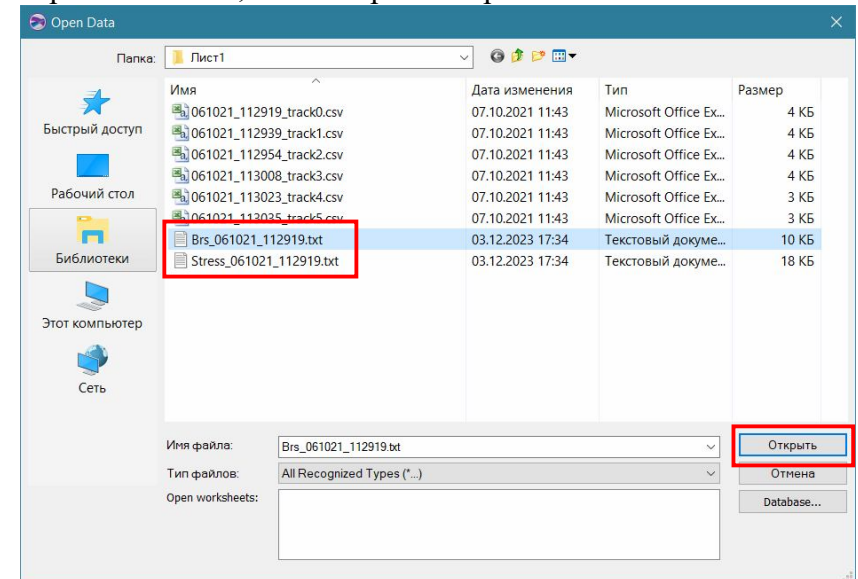
8.6.10. Launch the Surfer software application, and then choose «New Plot» in start window or control panel:



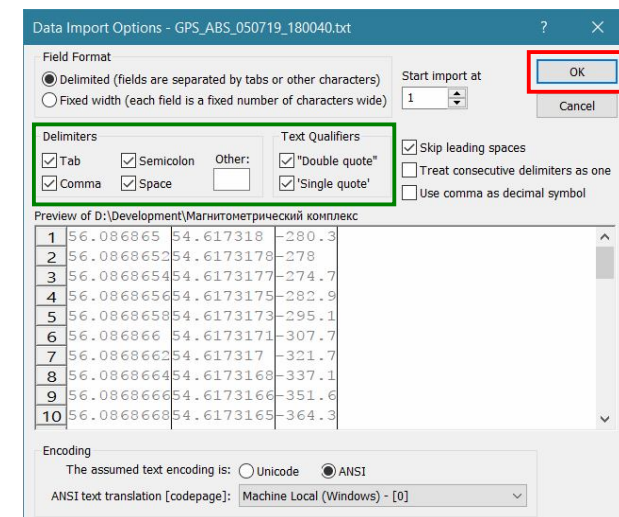
8.6.11. Choose «Home» – «Grid Data» command:



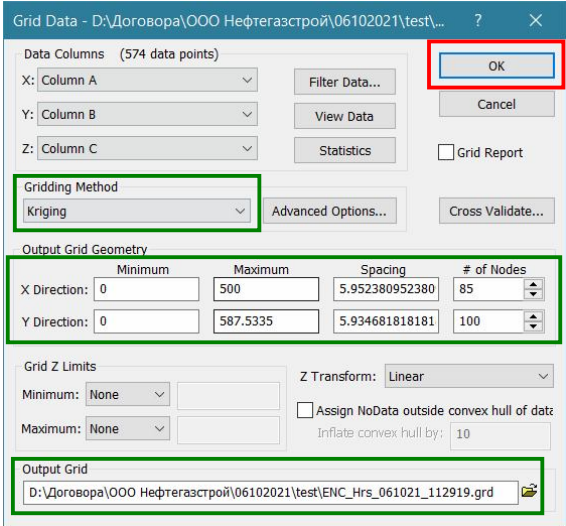
8.6.12. Choose the data file **ENC_Hrs_data.txt** in file explorer window, and then press «Open»:



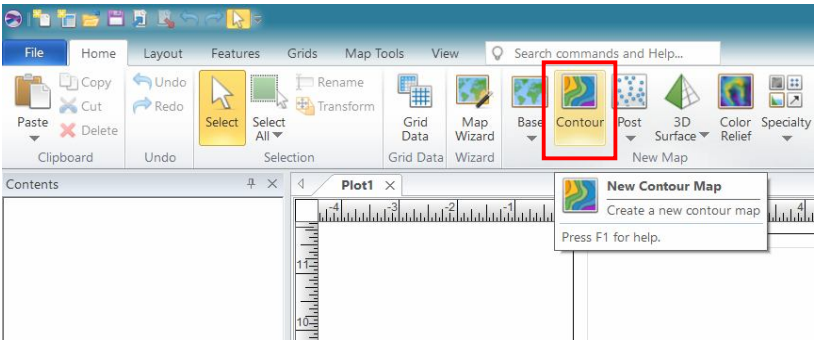
8.6.13. Import data window does not require any actions or adjustments, just press «OK»:



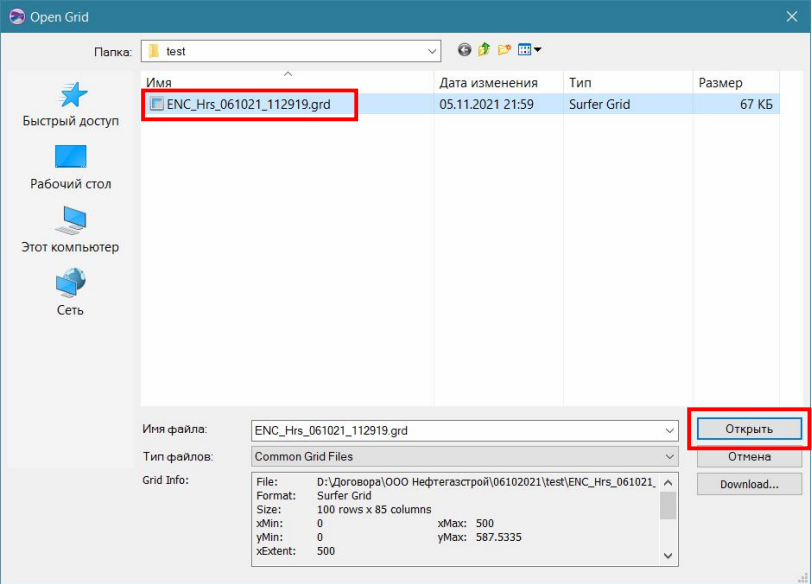
There is possibility of improve the resolution of the resulting map of the magnetic field gradient/components, by increasing the number of Nodes or choosing optimal Gridding Method, if need (however, not necessary).



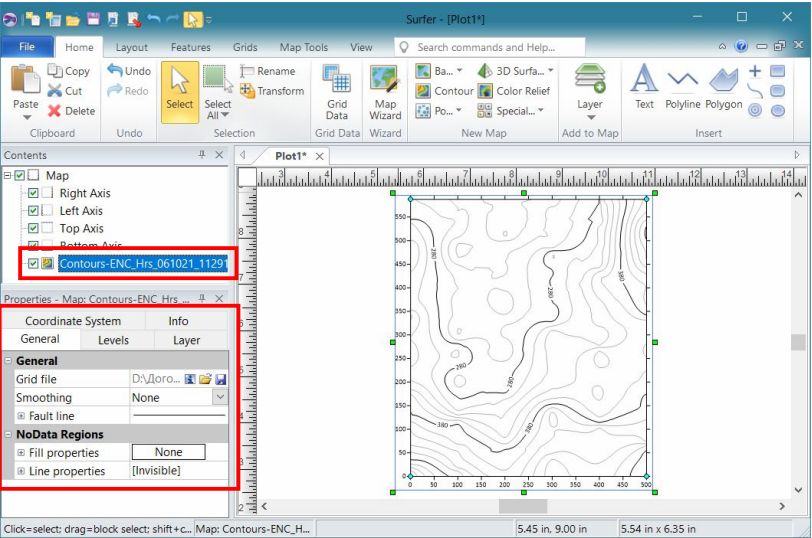
8.6.14. The grid file **ENC_Hrs_data.grd**, then appeared on specified path, which is already Surfer map. Choose «Home» – «Contour» command in order to open it:



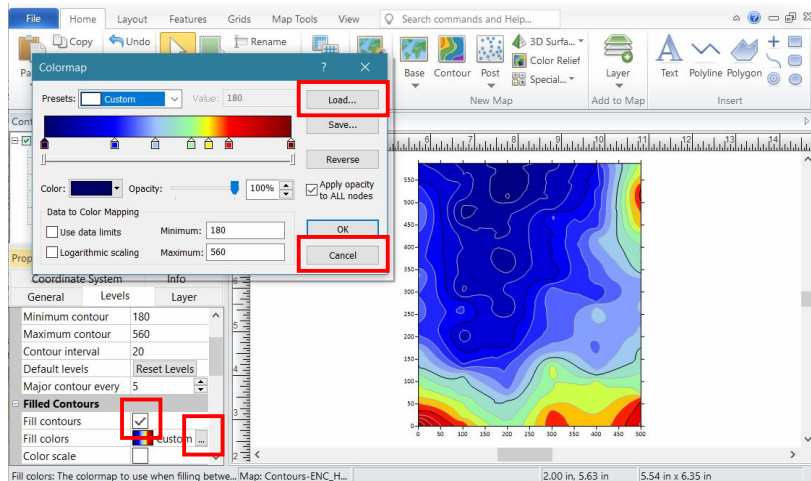
8.6.15. Choose the grid file **ENC_Hrs_data.grd** in file explorer window, and then press «Open»:



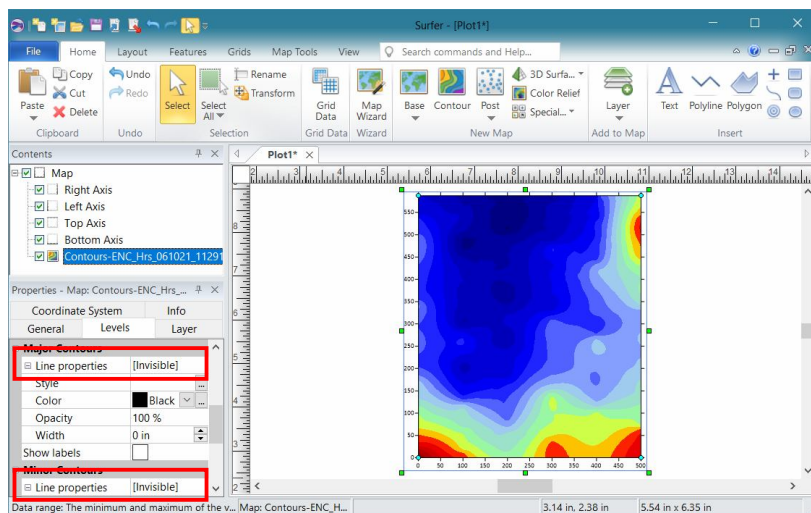
8.6.16. Go to the contour map settings by click on the appropriate item in «Contents» window:



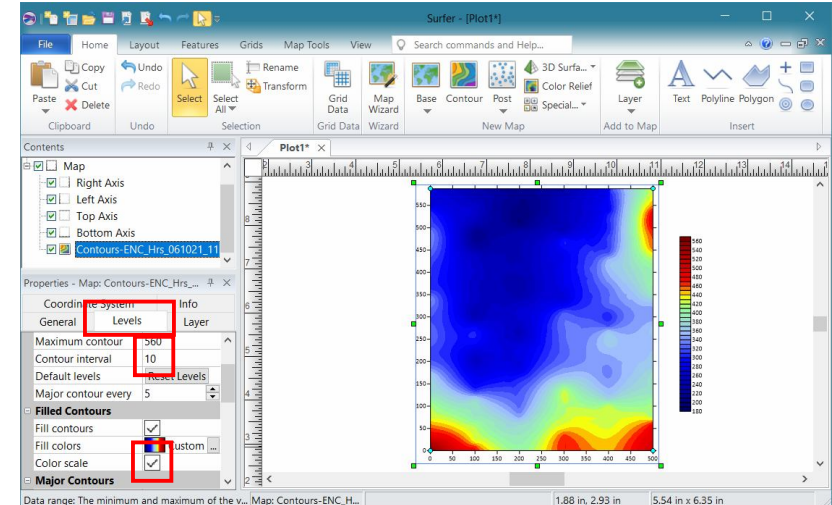
8.6.17. Set up the color palette parameters in «Levels» page: enable «Fill Contours», and then open «Fill Colors» window, choose the custom palette file or one default schemes:



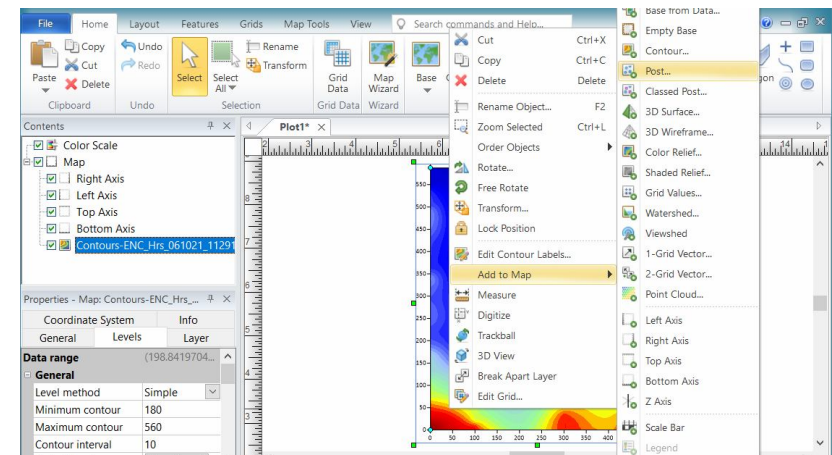
8.6.18. Contour curves can be hidden if need, by setting the «Style» property of the «Major/Minor Contours» objects to «Invisible» state:



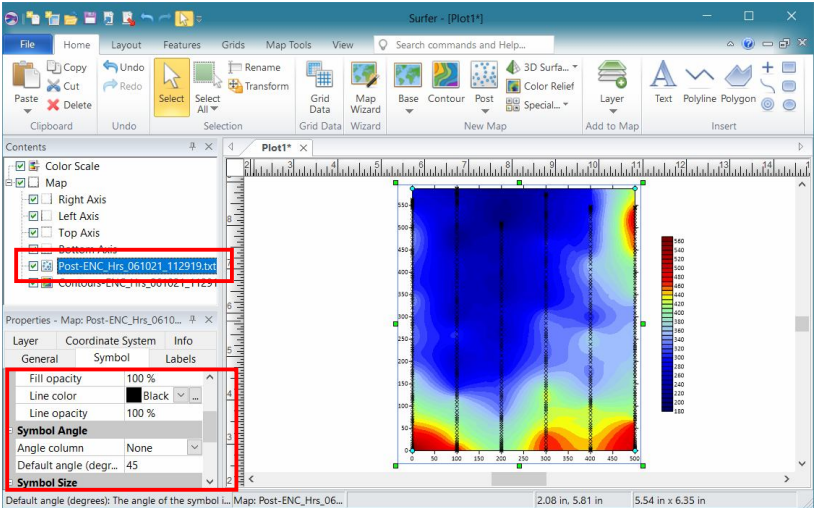
8.6.19. Also legend (page «Levels» – «Color Scale» property) and background filling (page «General» – «NoData Regions» property) can be added on the map if need:



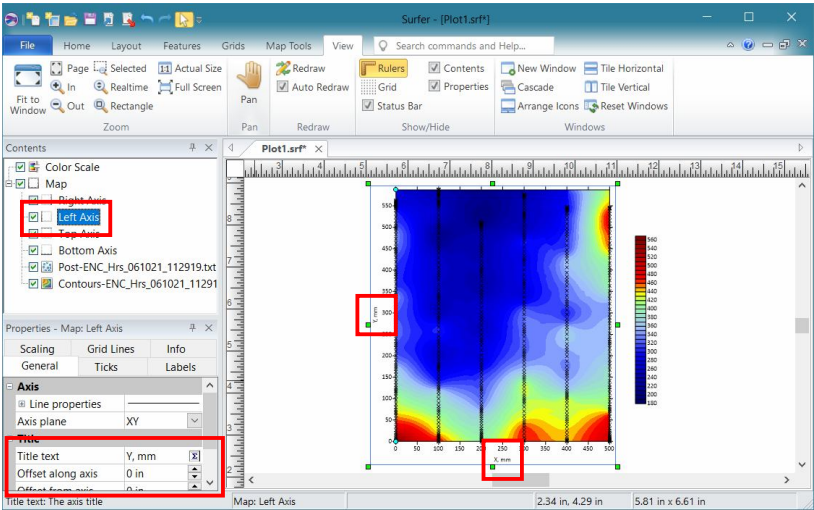
8.6.20. Tracks and measurement points can be added to the map like top layer by right click on the diagram and choose «Add to Map» – «Post...», and then follow instructions of the master. No parameter changes and additional actions required.



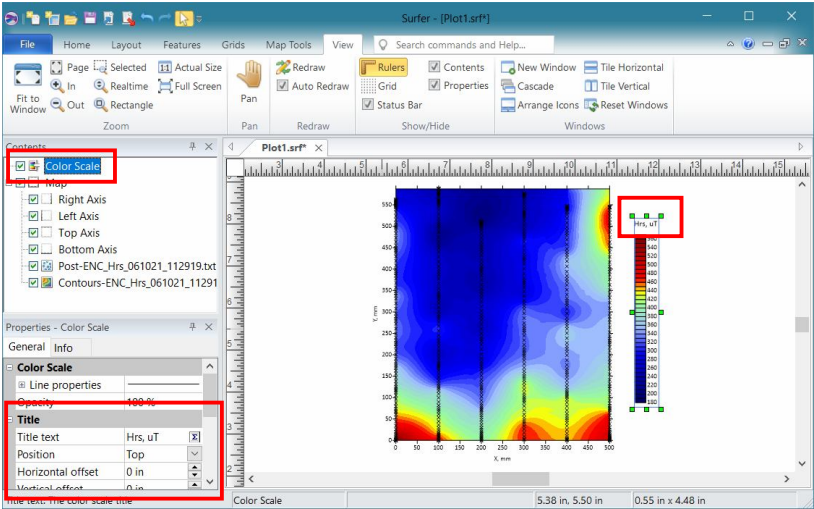
8.6.21. Adjust the optimal size of point symbol, type, color, frequency, transparency, and other properties of the Post object just created:



8.6.22. Adjust designators of diagram axes in «Title» property of every «Axis» object required:

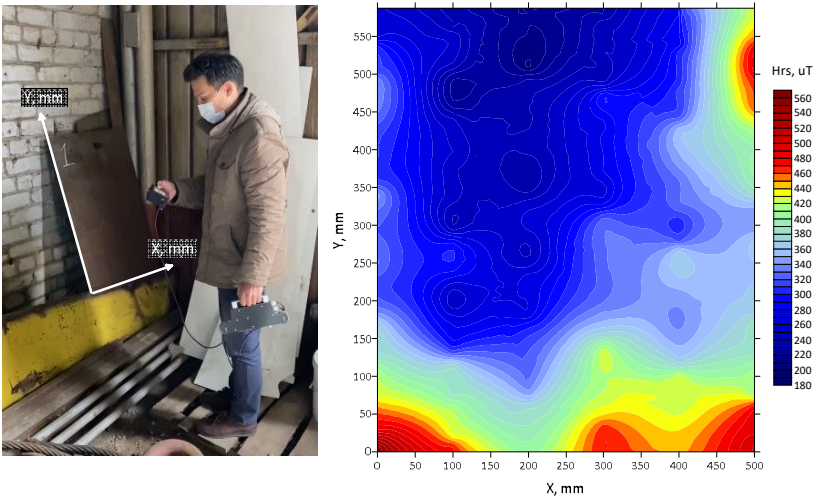


8.6.23. Adjust designator of diagram legend in «Title» property of «Color Scale» object:

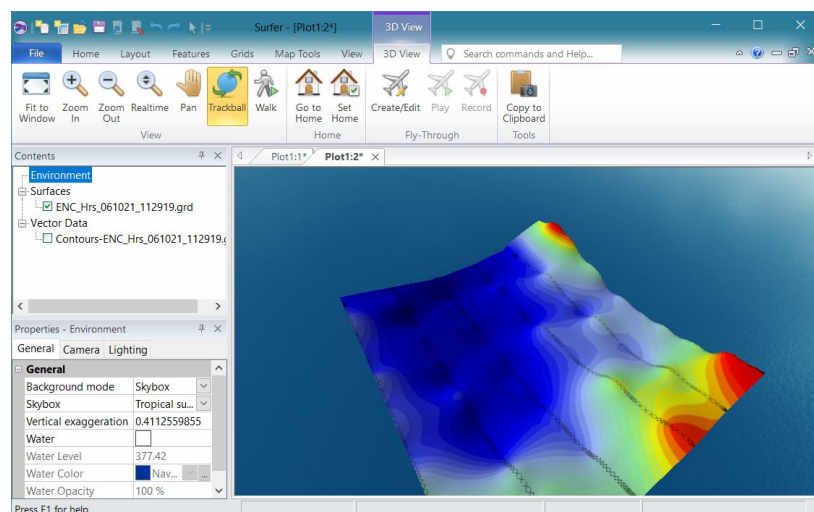
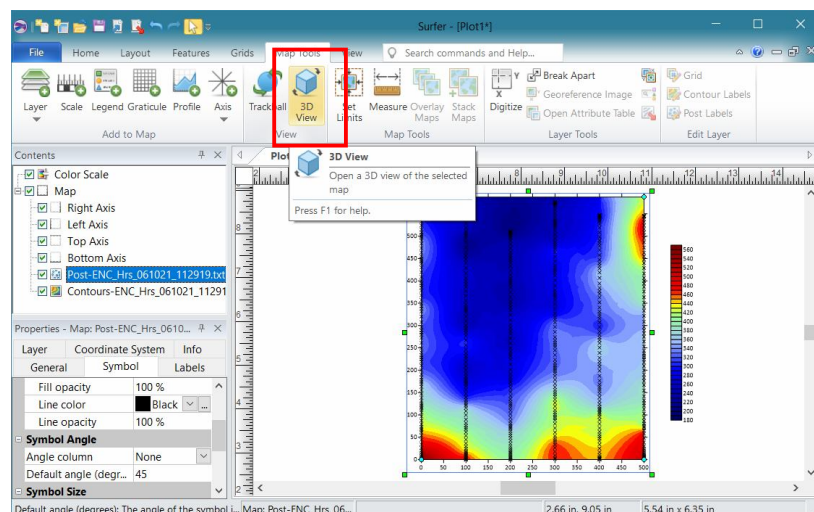


8.6.24. Save the Surfer magnetic field gradient map file just created applying the «File» – «Save/Save As» command.

Comparison of obtained surface stress map with photography of inspected object:



8.6.25. In order to see the data as 3D surface, choose the «3D View» mode on the «Map Tools» control panel:



8.6.26. In latest release of StressMAP software all above described routines 8.6.10 – 8.6.25 for representing measured data on contour plot and 3D surface are executed automatically by pressing the MERGE ALL button.

8.7 Replacing and recharging accumulator battery

As the accumulator battery charge level goes low, the readouts of the charge level linear indicator in the status bar also decrease, and when the minimum acceptable threshold level is reached, the power supply of the magnetic field measurement system will be automatically turned off.

It is necessary to replace the discharged battery in time with a new one, and charge the discharged one.

8.7.1. Turn the power switch of the data acquisition unit to the «OFF» position.

8.7.2. Open the battery compartment and remove the discharged battery out, disconnect it from the power connector, charge it using the charger supplied together with the «IN-04» multichannel metal stress scanner.

8.7.3. Connect new battery to the power connector inside the battery compartment on the back of the data acquisition unit. Insert the battery into the compartment and snap the battery cover into place.

At the same time, the indicator of the charger will light up in red, which means that the microprocessor built into the charger has successfully tested the battery and started the process of charging it.

After the battery charging process has been successfully completed, the charger indicator light will turn green again.

8.7.4. Set the power switch of the data acquisition unit to the «ON» position, marked with a dot. The «IN-04» multichannel metal stress scanner is ready for work.

8.7.5. When accidental mechanical damage of the battery occurred, or its failure, it is necessary to contact the manufacturer of the «IN-04» multichannel metal stress scanner for its disposal and replacement.

9. MAINTENANCE

8.1. Maintenance of the «IN-04» multichannel metal stress scanner is only performed by technical personnel from the departments of the instrumentation workshop or similar.

8.2. Maintenance of the «IN-04» multichannel metal stress scanner consists of routine inspection, preventive maintenance and routine maintenance.

8.3. The frequency of scheduled inspections is established depending on the production conditions, but at least once a month. During a routine inspection, the all mountings, the state of the controls and paintwork, the integrity of the data acquisition unit housing and magnetic measurement units are checked.

8.4. Scheduled preventive maintenance of the «IN-04» multichannel metal stress scanner is performed after the warranty period has expired and at least once a year.

Repairing includes a visual inspection of the «IN-04» multichannel metal stress scanner, inspection of the internal state of mounted items, checking the reliability of electric contacts and joints, removing dust and dirt.

All types of work are performed, the need for which was identified during a routine inspection of the «IN-04» multichannel metal stress scanner. In case of failure of the electronic components of the «IN-04» multichannel metal stress scanner circuits, they must be replaced.

8.5. Current maintenance is performed during the operation of the «IN-04» multichannel metal stress scanner. This eliminates the malfunctions observed during the routine inspection by replacing or restoring individual parts of the multichannel metal stress scanner (replacing electronic components, restoring broken electrical connections, etc.).

10. TROUBLESHOOTING

Possible troubles of «IN-04» multichannel metal stress scanner and ways for to fix them are given in table 1.

Table 1.

Possible trouble	Most like reason	Way to fix
There is no information on the screen when turning on the power	The battery is low.	Replace or recharge the battery.
Saving to a memory card does not work, the memory card indicator in the status bar lights up in red	1. The file system structure is broken. 2. Missing or defective memory card in holder.	Remove the memory card and format it on the computer. Replace the memory card.
When connected to computer via USB, the data acquisition unit is not recognized	1. The process of measurement is does not stopped. 2. The file system structure is broken. 3. A break inside the USB cable occurred.	Stop the measurements clicking anywhere on the sweep. Remove the memory card and format it on the computer. Repair or replace the USB cable.

Odometer measurement synchronization does not work	1. The odometer used is broken. 2. Process of measurements is stopped.	Replace the odometer. Start the measurements clicking anywhere on the sweep.
Recording on one or several channels does not work	Recording on one or several channels is disabled	Enable missing channels in the «FILE» window
Indications on one or several channels are not displayed, or disappeared after the some time	1. Scanning speed too high when synchronizing measurements on odometer signals. 2. A break inside the sensor cable. 3. One or more magnetic field sensor unit is broken.	Decrease the scan speed or increase odometer pitch. Find the cable break point and repair it. Replace broken magnetic field sensor unit.

11. STORING AND TRANSPORTATION

10.1. Transportation of the «IN-04» multichannel metal stress scanner should strictly provided that the power switch of the on the data acquisition unit is in the «OFF» position.

At this time the accumulator battery may be contained inside the battery compartment, or outside from it.

10.2. It is allowed to transport a packaged multichannel metal stress scanner in closed railway carts or containers, in the cars, as well as inside of the heated compartments of aircraft.

10.3. The packed «IN-04» multichannel metal stress scanner must be fixed in vehicles, and when using open vehicles, in case of short-term transportation, they should be protected from atmospheric precipitation and water.

10.4. Placement and fastening of the packed «IN-04» multichannel metal stress scanner in vehicles should ensure their stable position, exclude the possibility of collision with other objects, as well as on the walls of the vehicle.

10.5. Transportation Conditions:

– surrounding temperature, °C: from –20 to +70

– relative air humidity at +35°C temperature, %:..... 95

10.6. Multichannel metal stress scanner in transport packaging withstands mechanical loads with up to 15 m/s^2 acceleration at the frequency from 10 to 120 heats per minute, or 7500 hits at the same acceleration.

10.7. The packed multichannel metal stress scanner should be stored with the power switch on the data acquisition unit turned off, on racks in a dry room with no presence of acid, alkali and other aggressive substances in the air.

At this time, the battery may be inside the battery compartment, or separately from it.

10.8. Storage conditions regarding the impact of environment factors must comply with the requirements of Appendix "L" of the GOST 15150-69.

10.9. Placing the «IN-04» multichannel metal stress scanner in the storage should ensure its free movement and access to it.

10.10. When storing the «IN-04» multichannel metal stress scanner for more than 6 months, it should be freed from transport packaging and kept in consumer packaging in accordance with the conditions above described.