



Certified Quality
Management System

MAGNETO-OPTICAL HYSTERESIGRAPH MOHYSTER REGULA 7708

Operating Manual



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1

INTENDED USE

This operating manual (hereinafter referred to as the Manual) describes the design, operating principle and service instructions for the hardware and software system of magneto-optical hysteresigraph MOHyster Regula 7708 (hereinafter referred to as the device, MOHyster and the MO hysteresigraph).

MOHyster is designed for instrumental examination of magnetic printing and magnetic security features of documents by means of determination of multiple magnetic characteristics of these objects, such as:

1) function of 2D spatial distribution of the stray magnetic field on the object surface $\mathbf{B}(\mathbf{x}, \mathbf{y})$, which can be represented as:

1.1 topogram (spatial distribution function) of the magnetic induction normal component $\mathbf{B}(\mathbf{x}, \mathbf{y})$ in the form of an accumulated (measuring) magneto-optical image (Fig. 1-1), where the brightness of the points represents the value of \mathbf{B} for each of the image points;

1.2 histogram (probability density function) of the magnetic induction normal component \mathbf{B} in the form of a graph (Fig. 1-2) which shows the number of points of the magneto-optical image in the columns. These points have the corresponding value of the stray magnetic field normal component \mathbf{B} [T];

1.3 modulus of the magnetic flux normal component Φ [Wb] through the magneto-optical sensor area (Fig. 1-2), calculated based on the estimation data of magnetic induction $\mathbf{B}(\mathbf{x}, \mathbf{y})$;

2) static magnetic hysteresis characteristics of different types: by magnetic flux Φ - \mathbf{H} (Fig. 1-4), by magnetic induction \mathbf{B} - \mathbf{H} , and by magnetization \mathbf{M} - \mathbf{H} ;

3) function of 3D spatial distribution of the stray magnetic field over the object surface $\mathbf{B}(\mathbf{x}, \mathbf{y}, \mathbf{z})$, which can be represented as:

3.1 tomogram (layer structure) of the stray magnetic field, consisting of a set of 2D functions $\mathbf{B}(\mathbf{x}, \mathbf{y})$, measured at different distances \mathbf{z} from the object surface;

3.2 graphs of magnetic induction maximum functions $\mathbf{B}_m(\mathbf{x}, \mathbf{y}, \mathbf{z})$ or magnetic flux $\Phi(\mathbf{z})$;

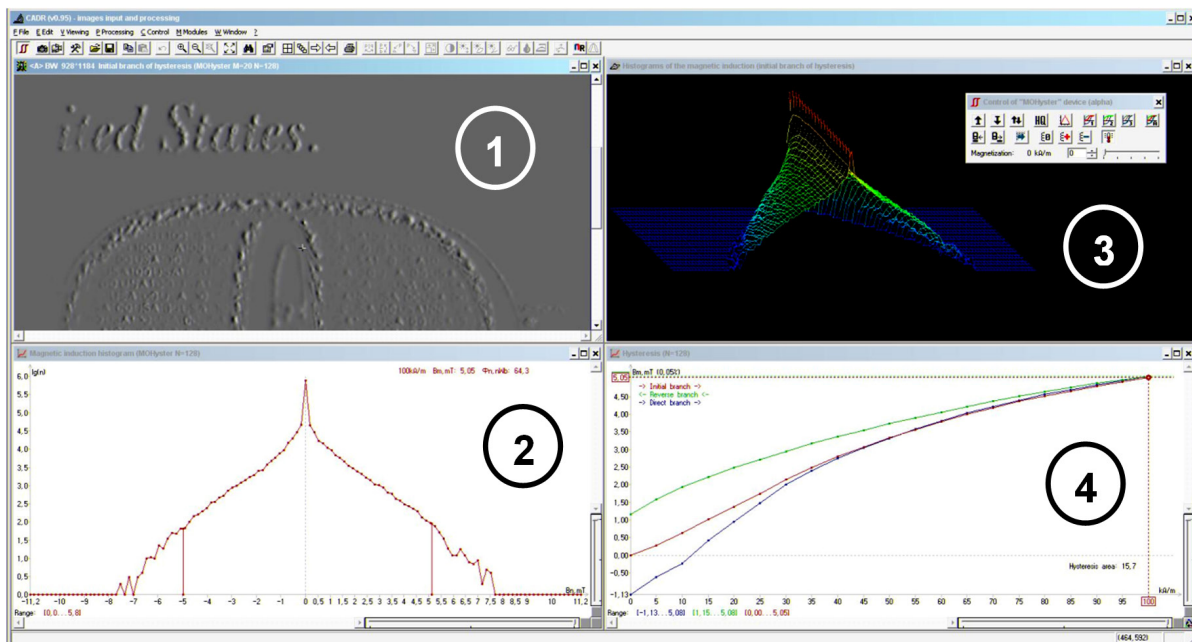
3.3 volume integral of the magnetic induction $\int \mathbf{B}(\mathbf{x}, \mathbf{y}, \mathbf{z})$ [T*m³].

The device comes with specialized software designed to perform the following:

- operation mode selection, configuration and control;
- document authenticity verification/identification by comparative examination of magnetic characteristics using reference specimens;
- secondary mathematical processing of magneto-optical images with the purpose of their analysis, comparison, geometry estimation and intelligibility/visibility enhancement;
- documentation of findings and adding data with magnetic parameters of document security features to the databases of security documents.

To illustrate the technical capabilities of the device, below is a screenshot (Fig. 1) of the main window of specialized software CADR (with the MOHyster module), showing the results of the examination of a magnetic security feature of a banknote. A \$100 banknote of the 2006 series was used as an example. **1** – display area of the accumulated magneto-optical images; **2** – display area of the magnetic induction \mathbf{B}_n histograms and the magnetic flux Φ_n calculated values; **3** – display area of the 3D magnetic history of measurements of the current hysteresis curve; **4** – display area of the magnetic hysteresis characteristics.

Figure 1



2 APPLICATION AREAS

Possible application areas of the MO hysteresigraph:

- applied scientific research in the field of developing new and improving existing magnetic security features of documents;
- judicial forensics: authenticity verification of securities and banknotes; classification of methods of counterfeiting of magnetic protection of securities and banknotes. Classification and identification research of magnetic printing;
- production of securities, banknotes, forms: quality control of magnetic security features; research of magnetic printing technologies and materials;
- banking: authenticity verification of securities and banknotes;
- border and customs authenticity verification of secured documents and banknotes.

General view of MOHyster (Fig. 2–3):

- (A) – case;
- (B) – object table;
- (C) – magneto-optical visualization and magnetic measurement device;
- (H) – pressing unit;
- (D) – magnetic units of the controlled object magnetization device;
- (E) – light target for object positioning;
- (F) – preliminary object magnetization/demagnetization device;
- (G) – control and indication elements;
- (I) – connectors;
- (1) – spring arms;
- (2) – power button;
- (3) – power indicator;
- (4) – digital display;

control buttons:

- (5) – move the object table to the object setting/removal position;
- (6) – move the object table to the magneto-optical visualization position;
- (7) – manual object position adjustment;
- (8) – magnetization intensity setting;

LED indicators:

- (9) – green – operation in progress;
- (10) – red – self-test error;

connectors:

- (11) – power supply unit connector;
- (12) – computer connector (USB);
- (13) – adjustable feet.

MOHyster consists of the following main parts (Fig. 2): case (A) with a flat work surface along which the object table (B) moves forward and backward. Spring arms (1) are used for fixing the object on the object table. In the middle of the protruding upper part of the case, there are magneto-optical visualization and magnetic measurement devices (C), which are magneto-optical sensor and inductors (sources of controlled compensation magnetic field). Below the magneto-optical visualization device there is a pressing unit (H) for uniform pressing of the object to the surface of the magneto-optical sensor and its removal. On the sides of the magneto-optical visualization device there are symmetrical magnetic units of the controlled object magnetization device (D). In the middle of the flat work surface of the case there is a light target for object positioning (E) and a preliminary object magnetization/demagnetization device (F).

On the front panel of the device base there are control and indication elements (G): power button (2), power indicator (3), digital display (4) and mode control buttons. Control buttons: "move the object table to the object setting/removal position" (5), "move the object table to the magneto-optical visualization position" (6), "manual object position adjustment" (7) and "magnetization intensity setting" (8). On the same panel there are LED indicators: green – "operation in progress" (9) and red – "self-test error" (10).

On the back panel of the device base (Fig. 3) there are connectors (I): a connector for power supply unit (11) and a USB connector for connecting to a computer (12). On the bottom surface of the base there are four adjustable feet (13) with plastic pads for protection of the surface on which the device is installed.

Figure 2

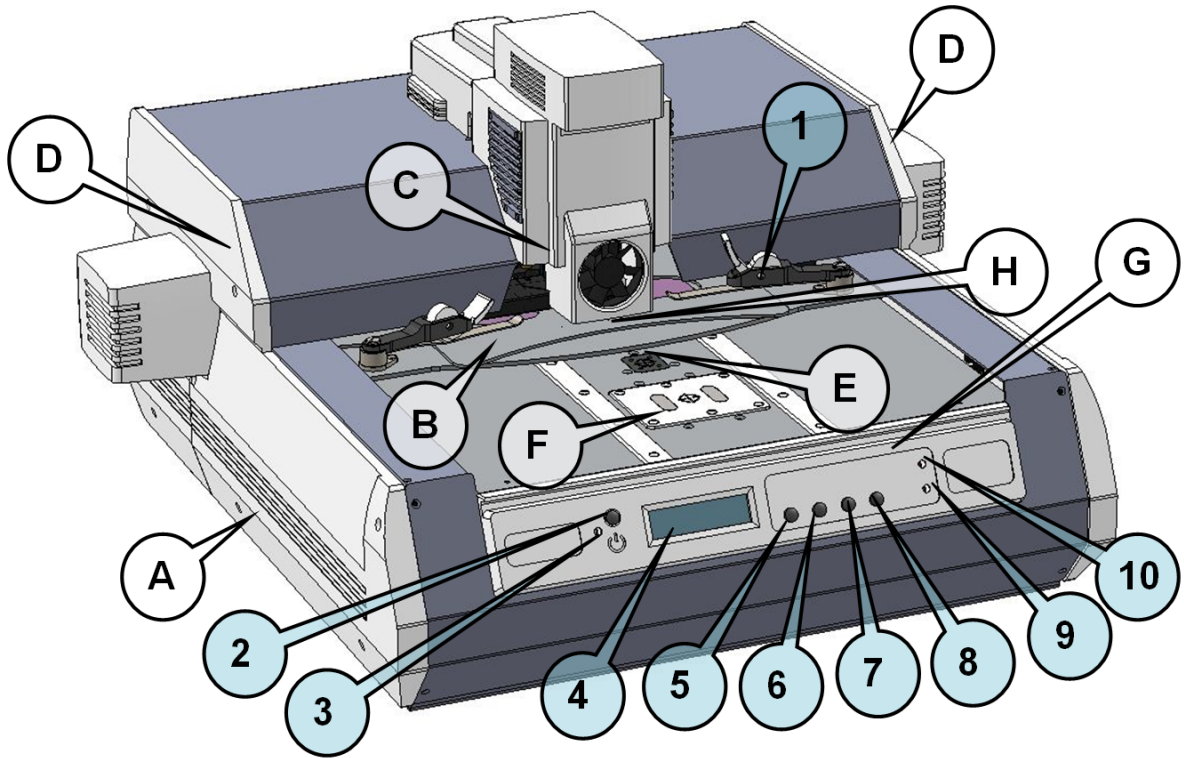
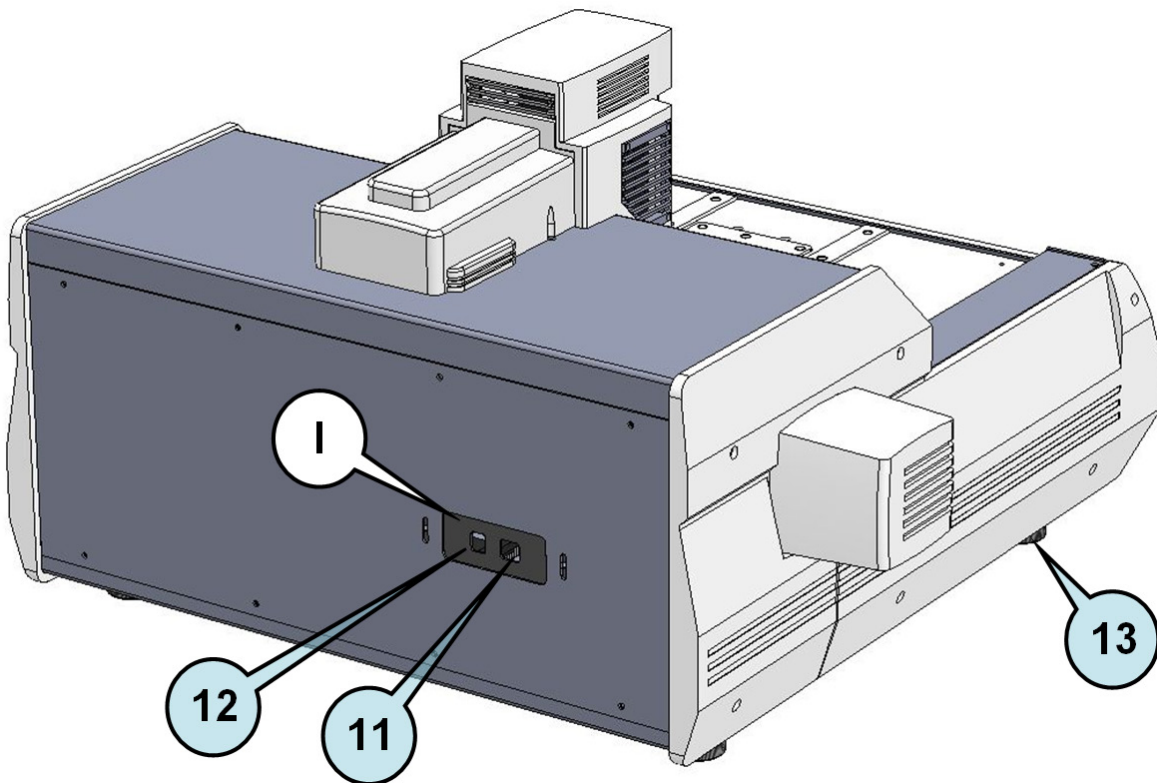


Figure 3



The MO hysteresigraph visualizes stray magnetic fields of magnetic security features made with magnetic inks, threads, fibers and other magnetic materials using a magneto-optical sensor (a sensitive element of the magneto-optical visualization and magnetic measurement device **(C)**) based on the magneto-optical Faraday effect. Digitized magneto-optical images are transferred to a computer for processing and saving in any bitmap format.

When performing magnetic measurements, the magneto-optical sensor, which detects both the object's stray magnetic field and the compensation magnetic field generated by the inductor, determines the state of balance of these fields in each point of the visualization area. Thus, the combined digital processing of a set of magneto-optical images (128 magneto-optical frames with a size of 928×1184) obtained under calibrated compensation magnetic field (64 levels from 0 to +11.2mT and 64 levels from 0 to -11.2mT), allows producing an accumulated magneto-optical image, where the brightness of each point corresponds to the value of B_n .

The stray magnetic field of an object is determined by the following:

1) remanent magnetization, which can be set (from 0 to the maximum) by preliminary demagnetization or magnetization (+120 kA/m or -120 kA/m) in the preliminary magnetization/demagnetization device **(F)**;

2) excitation magnetic field intensity, which is controlled by the controlled magnetization device **(D)** in the range of 0 to 100 kA/m with a sampling rate of 5 kA/m.

The object to be analyzed is fixed on the object table **(B)**, which can move between the said magnetization devices. Depending on the selected magnetic measurement conditions, the object can be premagnetized in a specified direction or demagnetized using the preliminary magnetization/demagnetization device **(F)**. The intensity of the applied magnetic field, acting at the time of the measurement, can also be selected by setting the required value for the controlled magnetization device **(D)**.

MOHyster has an internal microprocessor which is controlled by specialized PC software through the USB. Most of time-consuming measurement cycles (such as obtaining hysteresis characteristics) are automatic.

4

SCOPE OF DELIVERY

The device comes standard with the following:

- Magneto-optical hysteresigraph MOHyster Regula 7708
- Power supply unit
- Personal computer (optional)
- Specialized software CADR (memory card with the MOHyster module)
- Driver for the MO hysteresigraph
- USB cable
- Accessory for transportation
- External magnetization unit HiCo (optional)
- Operating Manual
- Cover
- Spare fluoroplastic covers of the pressure unit (SPTA)
- Spacer kit, 30–1200 μm
- Test object set
- Configuration files (TO_1.gif; TO_2.moh; TO_3.moh)

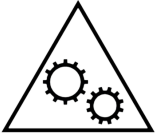
PC and power supply unit specifications are provided in Section 9. Instructions for the accessory for transportation are provided in Section 10.

5 OPERATION

ATTENTION!

This equipment is not suitable for use in locations where children are likely to be present.

WARNING!



Keep body parts away from moving parts. DO NOT put your hands or fingers near the moving parts (the moving portal). Make sure machinery, equipment and power tools are completely off before you try replacing, cleaning or repairing parts.

5.1 Setting-up

The place for installing the MO hysteresigraph must be selected based on magnetic measurements, outside the ranges of any electromagnetic sources, such as power and welding transformers, power cables, contactors or high-power electrical machinery.

The device should be positioned so that the power plug and the power connector on the device body are easily accessible.

Before turning the device on for the first time:

- check for any visible defects or damage. If there are any defects or damage, please contact the supplier;
- dismantle and remove the transportation kit. Unscrew the nuts **(6)** and remove the jumpers **(4)** and thrust plates **(2)** (Fig. 46–48). Keep the parts of the transportation kit for the entire service life of the device.

Place the device on a flat level surface of an office or laboratory desk. Adjust the feet **(13)** (Fig. 3) until the device is stable on the surface.

WARNING: HEAVY OBJECT!

The device is very heavy. To reduce the risk of lifting related injuries, death, or damage to your device, we recommend that a minimum of two people lift the device. It is important to use proper lifting posture when lifting and/or moving the device.

Warning! *Remove all objects and documents from the desk. In particular, ensure that there are no small objects of ferromagnetic materials (paper clips, screwdrivers, screws, nuts, washers, scissors, rulers, etc.), since they can be attracted by powerful magnets of the device or trapped inside the device by its moving parts. If a ferromagnetic object gets inside the device, the magnetization system may be damaged or disadjusted.*

Connect the power supply unit to the connector **(11)** (Fig. 3).

Connect the USB cable supplied with the device to the connector **(12)** (Fig. 3). Connect the other end of the cable to the appropriate USB port of your PC.

Plug the power supply cable in a 110–220 V outlet. The power indicator **(3)** (Fig. 2) on the front panel should light up, indicating that there is a 24 V DC input.

Press the power button **(2)** (Fig. 2). The device will perform a self-test procedure, during which you can see a series of movements of the object table **(B)**, controlled object magnetization device **(D)** units, magneto-optical visualization and magnetic measurement device **(C)** and pressing unit **(H)**. The self-test procedure takes a few seconds. Then the device stops, and if the self-test was successful, the digital display **(4)** shows "ready"; if the self-test was failed, the display shows the error code ("XXX_error").

If there are systematic self-test errors, please contact the supplier.

5.2 Software installation

MOHyster is supplied with the following software:

- 1) Specialized software CADR (with the MOHyster module) for device control, data processing, analysis and storage;
- 2) Device driver.

Software installation procedure:

Insert the external media (CD or flash memory card) with the MOHyster software into your computer. The software can also be downloaded from www.lad.org.ua. Create a working directory and copy the software into it.

Turn on the device as described in s. 5.1 and wait for the self-test to complete.

The operating system will detect a new USB device and launch the Device Driver Installation Wizard automatically. During the installation, specify the path to the device driver.

When the installation is complete, open the Device Manager and check that there is a device named "Magneto-Optical Hysteresigraph" in the "ForensicDevices" section. Ensure that the device is installed correctly (without "?" or "!" marks in the Device Manager).

After the driver is installed, the CADR software is ready to use. The CADR.EXE file can be launched either directly from the working directory or from a shortcut in any place convenient for you.

Since all the described below operations with the device use the CADR software, the program must be running during the entire session. It is also necessary to open the "MOHyster control" toolbar to connect the device to the software (see s. 5.4).

CAUTION!

A strong electrostatic discharge applied to the device body may cause its malfunction. In this case, it is recommended to turn the device off and on again and restart the CADR program.

5.3 Object setting and positioning

After the device is turned on with the power button **(3)** (Fig. 2) and the self-test is completed, the object table moves to the specific position ("object setting/removal position" (Fig. 4). When in this position, the central rectangular positioning window **(1)** of the object table **(2)** is located above the light target, which is four bright red-orange light spots that indicate the angular vertices of the rectangular contour of the magneto-optical visualization area.

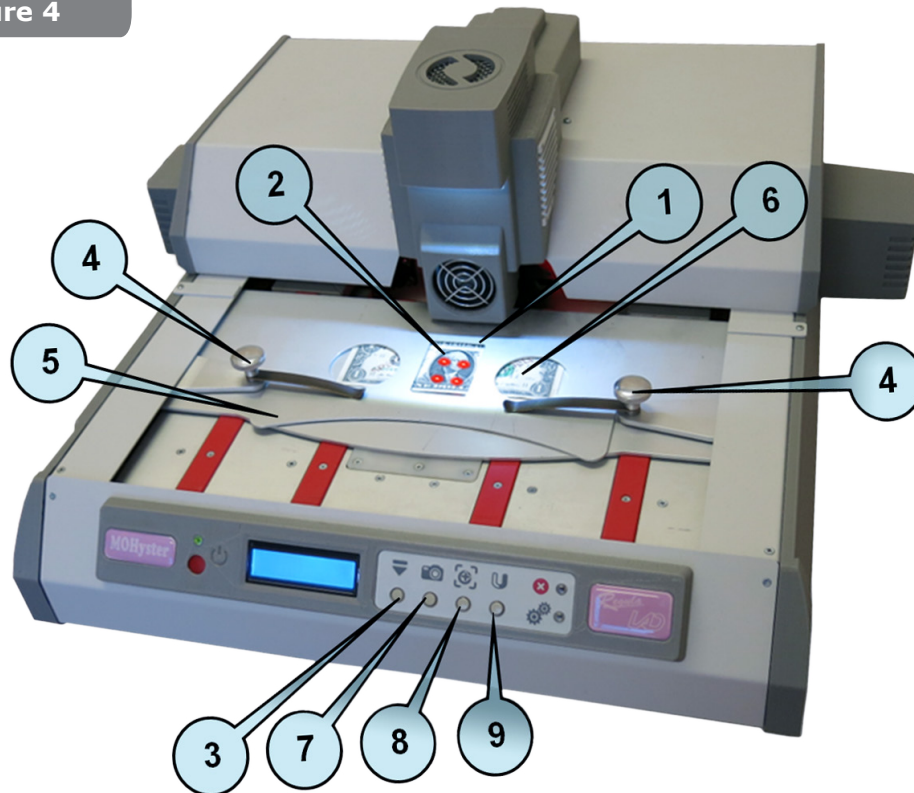
If the object table is in a different position (which is possible during operation), move it to the object setting/removal position by pressing the button **(3)** on the front panel.

Then release the spring arms **(4)**, slightly lift the top **(5)** of the object table (approx. 1–2 mm up) by hand and place the document in the formed slot. Holding the object table top **(5)**, slide the document inside the table with your fingers (through the windows **(6)**) and position the object so that the visualization area is within the positioning light target **(2)**. Lower the object table top **(5)** and leave the spring arm stops **(4)** in the free position, since the positioning of the object is not yet complete.

Press the button **(7)** on the front panel to move the object table to the magneto-optical visualization area. A window displaying the magneto-optical image of the object in real time will automatically open the CADR software.

If the magneto-optical image lacks contrast, the magnetization of the object may be insufficient. In this case, press the button **(9)** on the front panel of the device. The controlled magnetization system will generate a magnetizing field of 50 kA/m. Pressing the button **(9)** again will set the magnetizing field intensity to 0 kA/m. This can be useful for

Figure 4



an initial rough estimation of the type of magnetic material of the object (if the material is magnetically soft and does not leave remanent magnetization, the magneto-optical image of the object will disappear). To adjust the position of the object, set the magnetizing field intensity to 50 kA/m by pressing the button **(9)** (the intensity value is indicated on the digital display **(4)**) (Fig. 2)).

If the object needs to be slightly moved or rotated relative to the magneto-optical visualization area, activate the object position adjustment mode by pressing the button **(8)**. The pressing unit will be operating in the cyclic mode: for a certain period of the time cycle the object is pressed to the surface of the magneto-optical sensor (object cannot be moved), then the object is released from the surface of the magneto-optical sensor (object can be moved).

Move the object with your fingers through the windows **(6)** while holding the object table top **(5)** up. Note that in order to reduce distortion and noise during the positioning an object, the visible magneto-optical image area (1024×1280 pixels in the measurement mode) will be reduced to 928×1184 pixels by cutting off the image edges.

When the positioning of the object is complete, fix the position by pressing the spring arm stops **(4)**.

All the object setting and positioning operations described above can be performed using the CADR software tools (see s. 5.4).

5.4 Description of the "MOHyster control" functional toolbar of the CADR software

The "MOHyster control" function toolbar (Fig. 6) is used for controlling MO hysteresi-graph MOHyster and estimating magnetic characteristics of objects.

Launch the CADR software by double-clicking a shortcut or by double clicking the CADR.EXE file in the installation directory.

In the opened program window (Fig. 5), click the (A) "MOHyster control" button, which is located in the upper left corner of the toolbar.

Figure 5

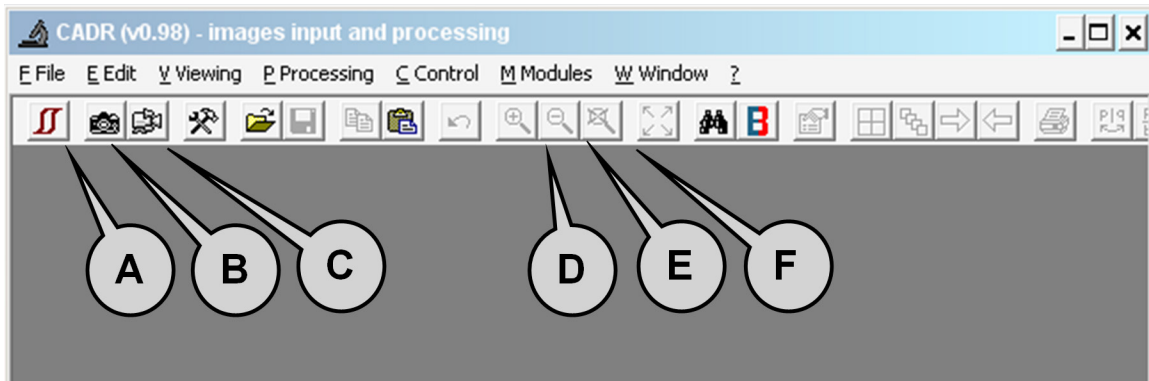
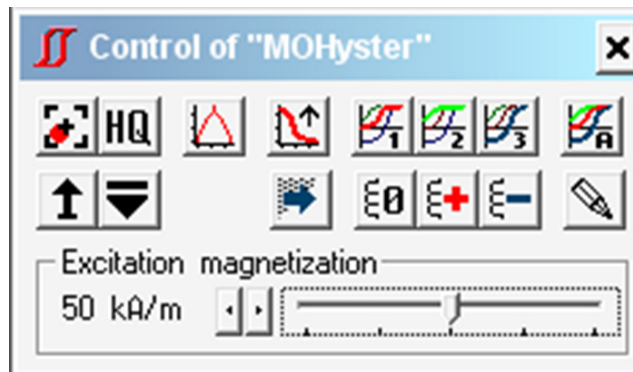



Figure 6





The "MOHyster control" functional toolbar will be displayed (Fig. 6).




On the "MOHyster control" toolbar there are function buttons for controlling the device. Some functions allow parameter setting. To open the settings menu, **right-click** one of the following buttons:


 – enable pressing unit cyclic mode: for a certain period of the time cycle the object is pressed to the surface of the magneto-optical sensor (object cannot be moved), then the object is released from the surface of the magneto-optical sensor (object can be moved). This operation is used to adjust the position of the object. The following parameters can be configured;


HQ – output a single frame of the magneto-optical image of the document in high quality mode (1024×1280 pixels). Multiple initial magneto-optical images obtained with various magnetic field parameters of the inductor are used to create this accumulated high-quality frame. The following parameters can be configured;


 – perform magnetic measurements (determining the spatial distribution function value of the stray magnetic field on the object surface), with the output in the form of: a topogram (accumulated magneto-optical image of 928×1184 pixels), magnetic induction histogram and the magnetic flux modulus value. Parameters can be configured. For a detailed description, see s. 5.5;


 – construct a magnetic field tomogram by performing magnetic measurements at various distances from the object surface. Parameters can be configured. For a detailed description, see s. 5.7;




,  and  – construct individual hysteresis curves: 1 – initial magnetization branch; 2 – magnetic return branch; 3 – magnetization reversal branch. Parameters can be configured. For a detailed description, see s. 5.6;


 – construct full hysteresis characteristic, consisting of the 3 above hysteresis curves. Parameters can be configured. For a detailed description, see s. 5.6;

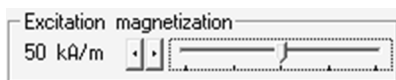
 – lift the magneto-optical sensor one time. This operation is used for service purposes, such as drive adjustment;

 – move the object table to the object setting/removal position;

 – capture background magneto-optical images. These are reference magneto-optical images obtained with specified magnetic parameters without an object. Such images are used by automatic magneto-optical data processing algorithms to reduce distortion and noise. The following parameters can be configured;







,  and  – demagnetize or magnetize the object by a magnetic field with an intensity of +120 kA/m (the magnetization direction corresponds to the magnetic field direction of the controlled object magnetization device), or -120 kA/m (the magnetization direction is opposite to the magnetic field direction of the controlled object magnetization device);

 – enable/disable the "Draft" mode for fast measurements, with a reduced number of measurement iterations and generation of missing data by approximation. The following parameters can be configured;



– panel for adjusting the magnetic field intensity of the controlled object magnetization device. The range of magnetic field intensity adjustment is 0 to 100 kA/m, with a sampling rate of 5 kA/m. The intensity is controlled by setting movable magnet units in the specified fixed position. On this figure the magnetizing field intensity is set to 50 kA/m.

Setting and positioning operations can be performed using the CADR software tools described above by pressing the corresponding menu buttons (Fig. 5–6).

The button  is used to move the object table to the object setting/removal position; Image capture commands (buttons **(B)** and **(C)**, Fig. 5) are used for viewing the object:  – one-time capture (photo) or  – continuous capture (video). When pressed, a window with the magneto-optical image of 1024×1280 pixels will open in the main window of the CADR software (Fig. 7). Depending on the size of the monitor, the image may need to be scaled. This can be done with the following buttons on the toolbar: zoom in , zoom out , undo zoom  and the buttons **(D)**, **(E)**, **(F)** (Fig. 5). The magneto-optical image in Fig. 7 is displayed zoomed-in.

For better contrast of the viewed object, it is recommended to set the magnetizing field intensity to 50 kA/m.


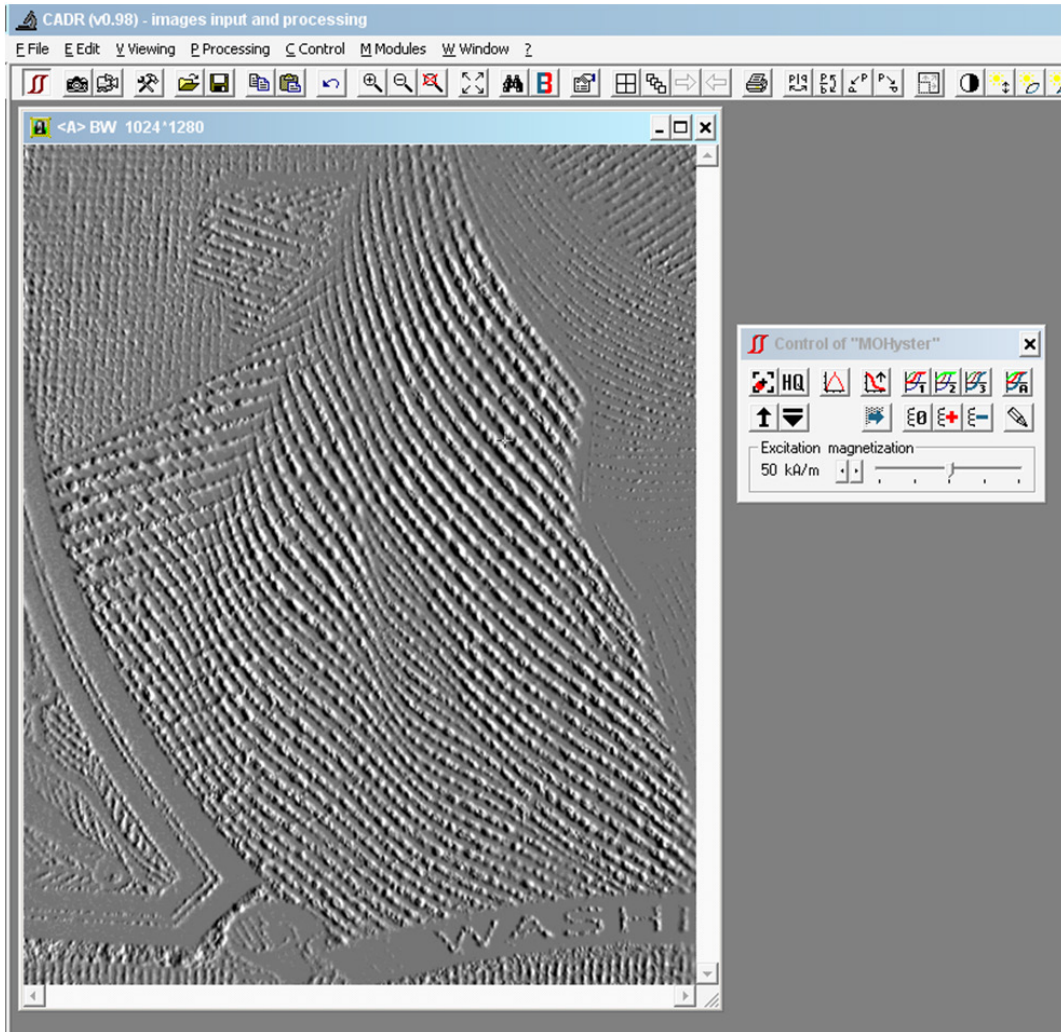

If the object needs to be slightly moved or rotated relative to the magneto-optical visualization area, use the button  to enable the position adjustment mode. When pressed, the pressing unit will operate in the pulsed mode: the object can be moved relative to the image area of the magneto-optical sensor during the release phase.


Figure 7



5.5 Performance of magnetic measurements

The "Magnetic measurements" function of the CADR software  (Fig. 6) sets the hysteresigraph control algorithm, which allows determining the values of the 2D spatial distribution function value of the stray magnetic field on the object surface and output the results in the form of a topogram $\mathbf{B}(\mathbf{x}, \mathbf{y})$ (accumulated magneto-optical image with a size of 928×1184 pixels), magnetic induction histogram \mathbf{B}_n [mT] and the calculated value of the magnetic flux modulus Φ [nWb].



The magnetic induction \mathbf{B} in each point of the magneto-optical visualization area is estimated by a compensation scheme using calibrated compensating magnetic field source (inductor). When performing magnetic measurements, the magneto-optical sensor, which detects both the object's stray magnetic field and the compensation magnetic field generated by the inductor, determines the state of balance of these fields in each point of the visualization area. Thus, the combined digital processing of a set of magneto-optical images (128 magneto-optical frames with a size of 928×1184 pixels) obtained under calibrated compensation magnetic field (64 levels from 0 to +11.2 mT and 64 levels from 0 to -11.2 mT), allows producing an accumulated magneto-optical image, where the brightness of each point corresponds to the estimated value of $\mathbf{B}(\mathbf{x}, \mathbf{y})$.

The process of measurement can be speed up by enabling the "Draft" mode using the button . In this mode, only 32 magneto-optical measurement frames obtained by application of 16 levels of calibrated compensation magnetic field will be used, and the missing data will be generated by approximation.

The initial data for constructing a histogram of the normal component of magnetic induction \mathbf{B} generated by the "Magnetic measurements" function are the experimentally estimated values of $\mathbf{B}_n(\mathbf{x}, \mathbf{y})$ corresponding to the brightness distribution of the accumulated magneto-optical image. Stray magnetic field induction is estimated in the range from the magneto-optical sensor detection threshold (≈ 0.05 mT) to the maximum inductor compensation field (± 11.2 mT) with a sampling rate of 0.175 mT.

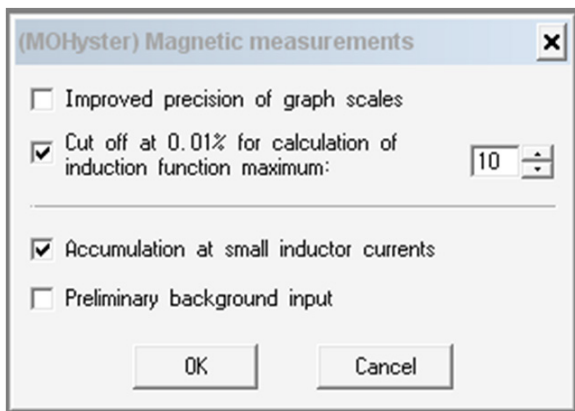
Magnetic flux Φ is calculated in the CADR software by the histogram \mathbf{B} and the known area of the visualized image.

5.5.1 Parameters of the "Magnetic measurements" function

To access the "Magnetic measurements" function parameters, first open the "MOHyster control" toolbar by clicking the button  - **(A)** (Fig. 5). On the "MOHyster control" toolbar, right-click the button . When clicked, the "Magnetic measurements" function parameters window will open (Fig. 8) with the recommended settings indicated.

If the "Precise graph scales" checkbox is selected, the resolution of the point quantity scale of the histogram $\mathbf{lg}(\mathbf{N})$ is increased to two decimal places, and the magnetic induction scale \mathbf{B} [mT] has the smallest scale spacing possible at the current graph window size.

Figure 8



If the "0.01% cutoff for calculating the induction function maximum" checkbox is selected and the threshold value is selected, two vertical segments indicating the values of \mathbf{B} for the positive and negative magnetic induction distribution maxima are displayed in the histogram field of the magnetic induction \mathbf{B} . This parameter is important for the construction of the hysteresis characteristics $\mathbf{B-H}$ and $\mathbf{M-H}$ (see s. 5.6).

All of the above parameters of the "Magnetic measurements" function do not affect the measurement conditions, but only change the format or interpretation of the displayed data, therefore they can

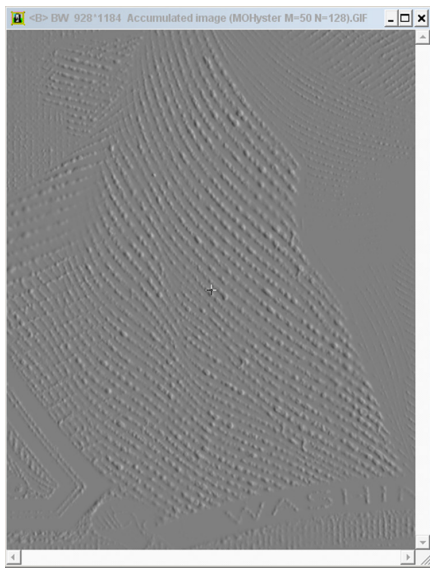
be changed at any time, and they will be applied to all displayed measurement results (both existing and new).

If the "Accumulation at low inductor currents" checkbox is selected, the measurement algorithm changes, increasing the number of magneto-optical frames and accumulating them at low inductor currents. This reduces magneto-optical sensor noises, but increases the duration of the measurement process.


If the "Preliminary background image capture" checkbox is selected, the background magneto-optical image will be automatically captured before the measurement begins. If this checkbox is not selected before performing magnetic measurements, there are two scenarios: the program will use the previously captured background image if it is relevant, or ask for a new background image if it is not irrelevant.

5.5.2 Using the "Magnetic measurements" function

Figure 9



To estimate the magnetic parameters of a specified area, it is necessary to set and position the object first in accordance with the recommendations described in ss.5.3–5.4.

Start the "Magnetic measurements" function To do this, **left-click** the "Magnetic measurements" button  (Fig. 6). The progress of the operation will be displayed on the digital display **(4)** on the front panel of the device (Fig. 2).

Two new windows – "Accumulated Image" (Fig. 9) and "Magnetic Induction Histogram" (Fig. 10) will open in the CADR software window.

The "Accumulated Image" window (Fig. 9) displays the iterative process of processing and accumulating magneto-optical images obtained by calibrated compensation magnetic field. When the process is complete, a magneto-optical image with a size of 928×1184 pixels* is created and displayed directly in this window.

The brightness of the image points corresponds to the estimated value of $\mathbf{B}(\mathbf{x}, \mathbf{y})$. This is the spatial distribution topogram of magnetic induction $\mathbf{B}(\mathbf{x}, \mathbf{y})$, which can be further processed and analyzed (see ss. 6.2.3).

The "Magnetic Induction Histogram" window (Fig. 10) displays the histogram of the magnetic induction \mathbf{B} , constructed based on the accumulated data displayed in the "Accumulated Image" window. Histogram \mathbf{B} is a graphical representation of the probability density function for the matrix of values $\mathbf{B}(\mathbf{x}, \mathbf{y})$. The horizontal axis shows the values of magnetic induction in the measurement range of ± 11.2 mT (0 is the central value) with a sampling rate of 0.175 mT. The vertical axis shows the number of points \mathbf{N} (in the logarithmic scale $\lg(\mathbf{N})$) of the accumulated magneto-optical image with the corresponding magnetic induction. This window also shows the value of the magnetic flux modulus Φ [nWb], which is calculated by integration of the function $\mathbf{B}(\mathbf{x}, \mathbf{y})$ over the area.

Fig. 10 shows the following: **(1)** – image points scale; **(2)** – magnetic induction scale; **(3)** – histogram \mathbf{B} of the analyzed object, **(4)** – values of the magnetizing field \mathbf{H}_{exc} , kA/m, **(5)** – values of the magnetic flux Φ , nWb.

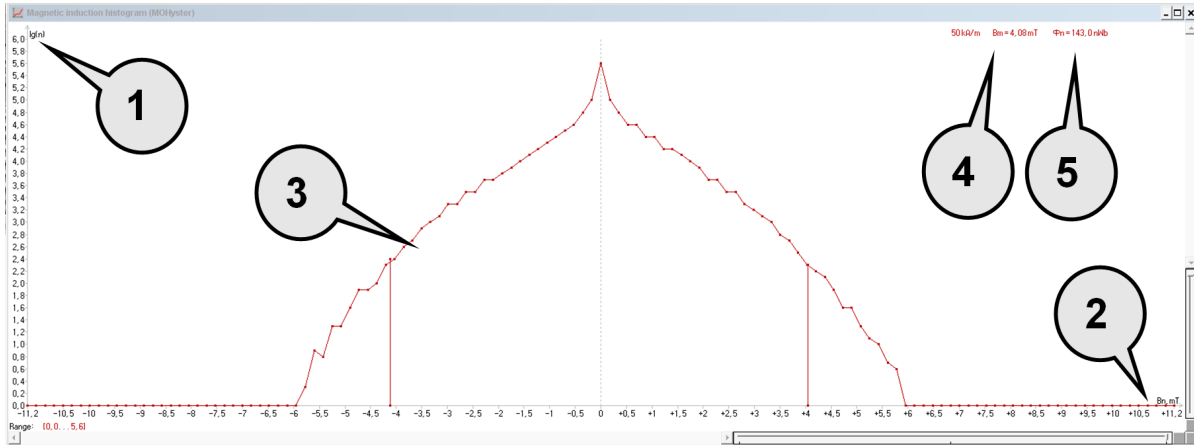
When the "Magnetic measurements" function is performed again, a new "Accumulated Image" window will open, and a new graph of histogram \mathbf{B} will be constructed in the current "Magnetic Induction Histogram" window. Up to three histograms \mathbf{B} can be constructed in a single window.

If there are two or more graphs in the same window, the distance \mathbf{d} between the histograms is calculated. The distance \mathbf{d} between histograms is defined as the sum of the weighted modules of column differences for the compared histograms \mathbf{B} . Similarity criterion: the lower the value of \mathbf{d} , the more similar the histograms are and the higher the probability that the two compared documents were printed using the same ink and technology.


* – to reduce distortion and noise, the visible magneto-optical image area (1024×1280 pixels in the measurement mode, Fig. 7) will be reduced to 928×1184 pixels (Fig. 9) by cutting off the image edges (peripheral points are not seen).

The value of distance **d**, which characterizes the maximum deviation for genuine specimens, may be different for each type of document or banknote. This value should be established by trial in the process of experimental data accumulation.

Figure 10




ATTENTION!


To save the results of magnetic measurements, make the "Accumulated Image" window active (Fig. 9), click the "Save"  button on the CADR toolbar, select the file format in the opened menu (**GIF format is recommended**, BMP and PCX formats are allowed, **JPG format is not recommended** due to the distortion of measurement data), and specify the file name and path for saving. If you close CADR, all unsaved data will be lost.

ATTENTION!

Measurement of the magnetic parameters of objects can be performed under various magnetization conditions, which is important for the classification of magnetically hard and magnetically soft materials. The examples shown in Fig. 7–9 were made with a magnetizing field of 50 kA/m, which corresponds to the unified value used in various magneto-optical measuring devices, such as Regula 4197M MagMouse and Regula 7701M MagReader as well as magnetic measurement specimens from the Currency database.

To change the magnetizing field intensity, use the "Excitation magnetization" slider on the "MOHyster control" toolbar (Fig. 6).

To prevent the effect of the remanent magnetization of the object on the magnetic measurement results when measuring in applied magnetization field with the magnetizing field intensity $H_{exc} \neq 0$ kA/m, it is recommended to demagnetize the object using the button  on the "MOHyster control" toolbar (Fig. 6) before beginning the measurements.

To achieve the maximum possible remanent magnetization of the object when measuring by remanent magnetization with the magnetizing field intensity $H_{exc} = 0$ kA/m, it is recommended to magnetize the object using the button  on the "MOHyster control" toolbar (Fig. 6) before beginning the measurements. In this case, as a result of measurements, the specimen printed with a magnetically hard material will have

a value of the remanent magnetic flux $\Phi > 0$ nWb, and the specimen printed with a magnetically soft material will have value $\Phi_n \approx 0$ nWb (specifically, measurement noise level of $\approx 0-0.2$ nWb).

5.5.3 Magnetic induction topogram processing and analysis

Let's consider the most general approaches to the processing of magnetic measurement results through the example of comparative examinations of two specimens of a 1 USD banknote: genuine and counterfeit (printed on a laser printer).

The compared banknotes were set and positioned in accordance with ss. 5.3–5.4, with examination areas in approximately the same position. Measurements were performed in accordance with ss. 5.5.2. The measurement results were saved in four GIF files: two files are the measurements in applied magnetization field $H_{exc} = 50$ kA/m for the genuine and counterfeit banknotes; the other two files are the measurements by the remanent magnetization, with zero magnetization field $H_{exc} = 0$ kA/m for the genuine and counterfeit banknotes.

The topogram of the accumulated magneto-optical image allows examining the spatial distribution function of the magnetic induction normal component $B(x, y)$ of the object.


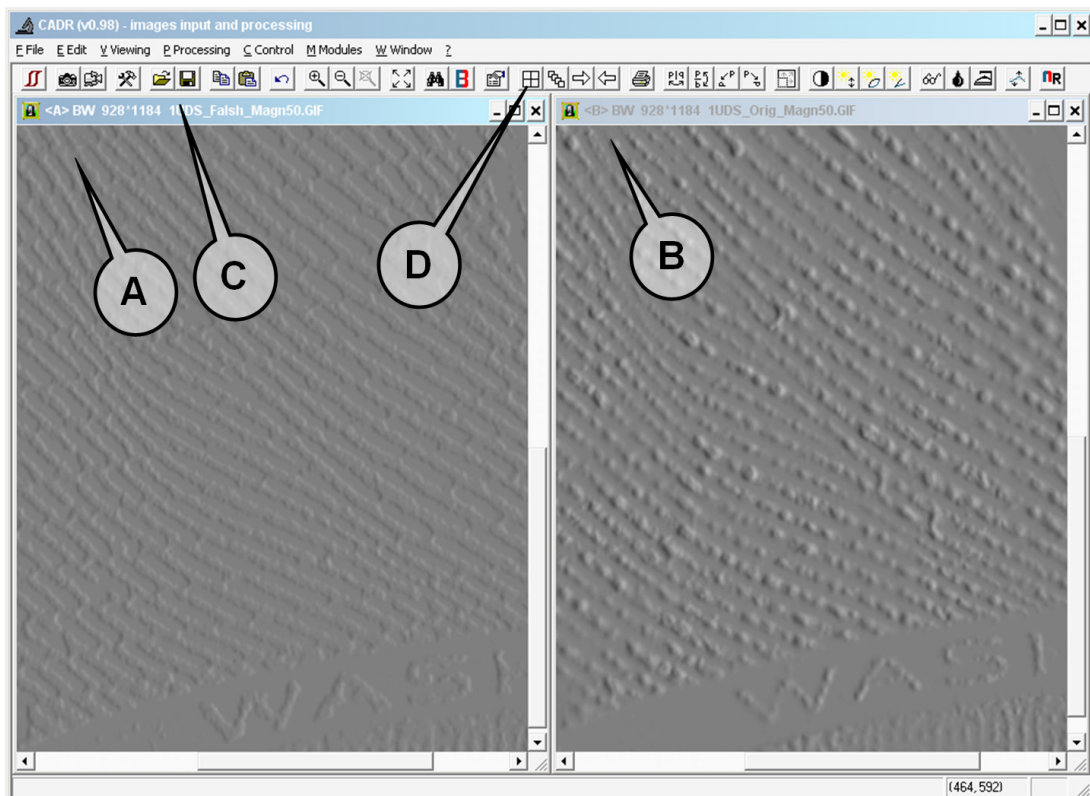

Analysis of the results of the measurements in applied magnetization field $H_{exc} = 50$ kA/m (Fig. 11). To load a saved file (including the results of magnetic measurements), click the "Open"  button on the toolbar **(C)** of the CADR software, select the file name in the menu and specify the path to its location. The file will be opened in the current image window of CADR (window **(A)** shown in Fig. 11 there is an accumulated magneto-optical image of the counterfeit banknote obtained in applied magnetization field $H_{exc} = 50$ kA/m). If the "Open" command is selected while holding down the Shift key, the file will be opened in a new window (in window **(B)** shown in Fig. 11 there is an accumulated magneto-optical image of the genuine banknote).

Figure 11



Magneto-optical images in windows **(A)** and **(B)** have a scale of 1:1 (without zoom), so only a part (approx. 1/4) of each image is visible. For ease of comparing images in windows, arrange them horizontally, by pressing the "Tile"  button on the CADR toolbar **(D)**.

If you visually compare magneto-optical images in windows **(A)** and **(B)**, some differences can be observed in the print stroke width and contrast. However, now we are interested not in the brightness but in the magnetic characteristics of the image points, i.e. in the spatial distribution topogram of magnetic induction **$B(x, y)$** .


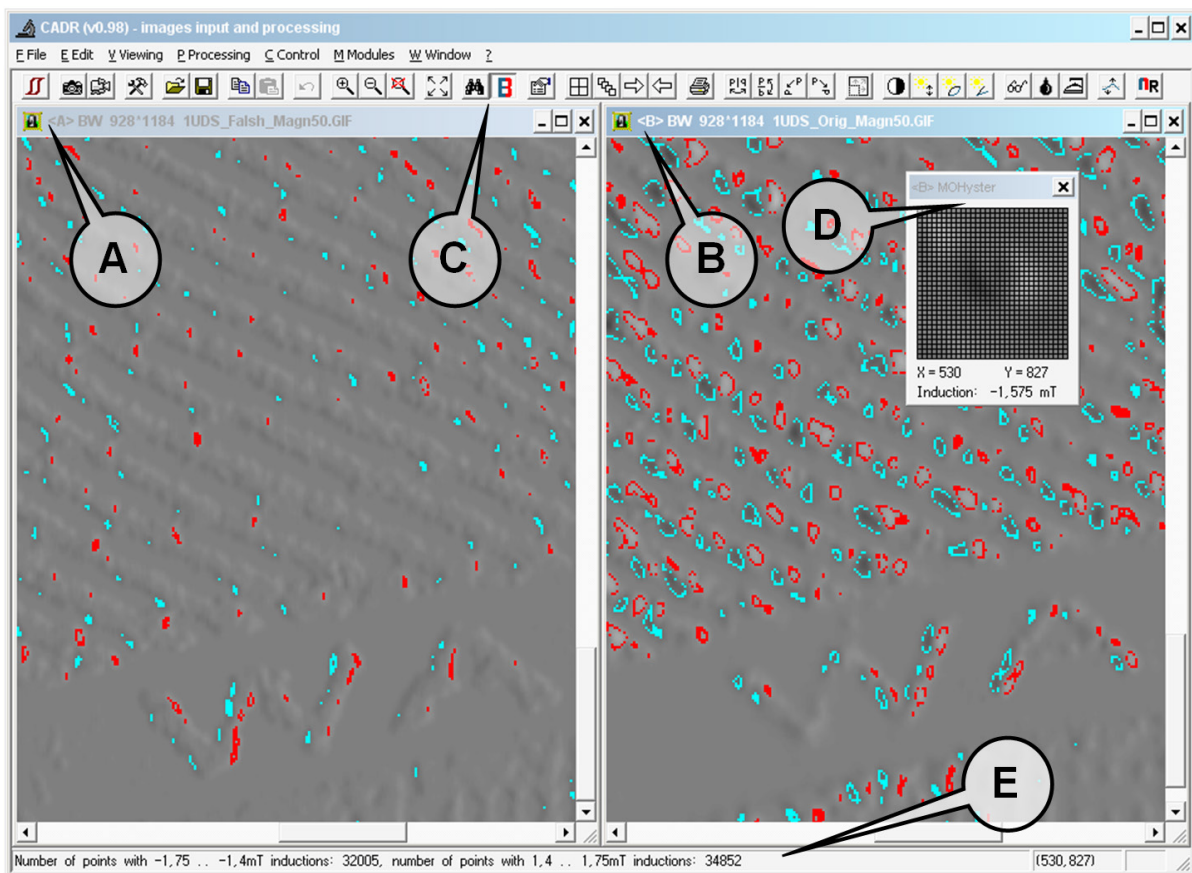


Various tools can be used to examine the topogram of magnetic induction **$B(x, y)$** . For example, you can use the "Magnetic Induction at Point"  button on the CADR toolbar **(C)** (Fig. 12). When pressed, the navigation panel **(D)** is shown, where the magnified magneto-optical image area around the point is displayed, with coordinates **x, y** and magnetic induction value of this point displayed in the details. You can select the current point by clicking on any point of the magneto-optical image or on the graphical window area of the navigation toolbar **(D)**. If you select the current point while holding down the Shift key, all points of the same (or nearby – based on the settings) level of magnetic induction will be highlighted in color on the accumulated magneto-optical image. In addition, the number of points in the selected range **B** of the accumulated magneto-optical image will be displayed in the status bar **(E)**.

Figure 12

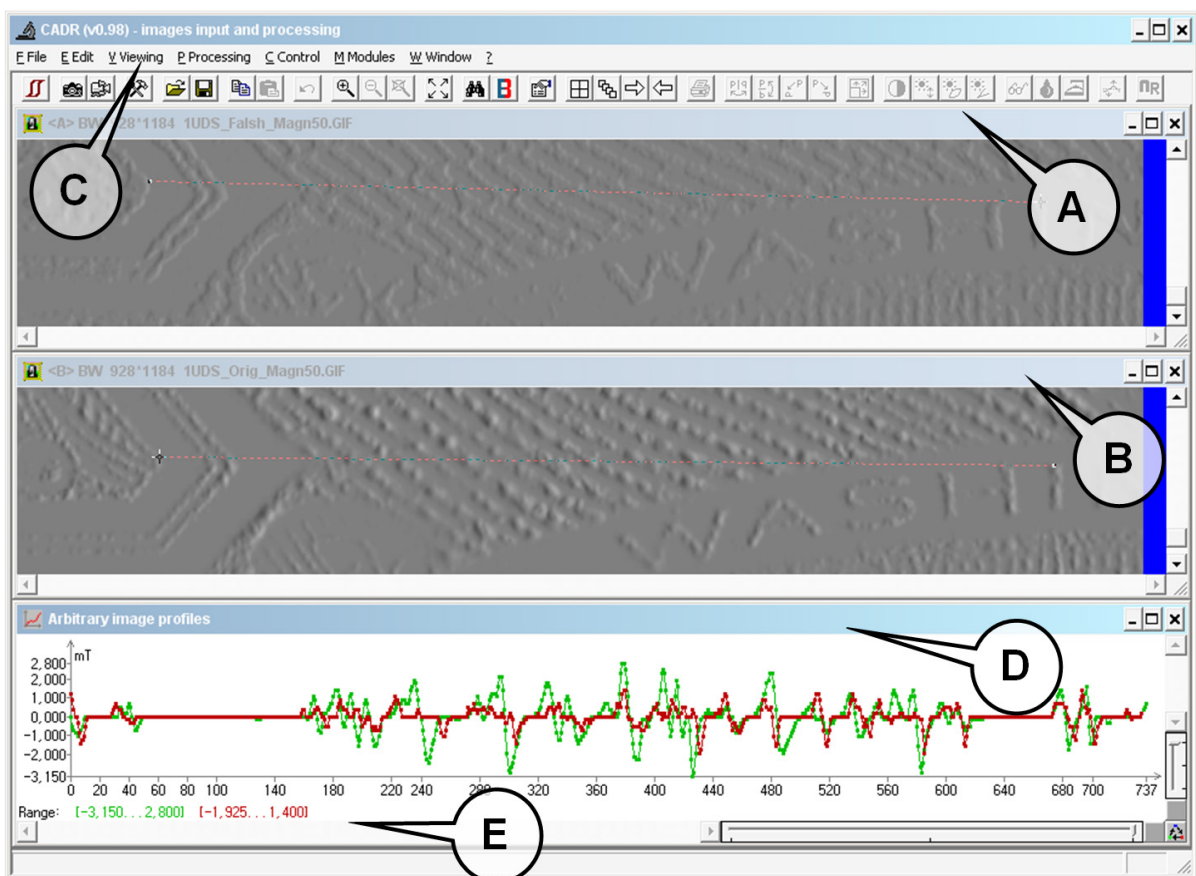



Points of the accumulated magneto-optical image with the set level of magnetic induction **B** can also be selected using other tools, for example, by selecting the "Magnetic Induction at Point" function on the parameter settings panel. To do this, **right-click** the button .

A common magnetic induction value of ± 1.575 mT (red for $+1.575$ mT and blue for -1.575 mT) is set for the compared accumulated magneto-optical images (Fig. 12). The set magnetic induction value of ± 1.575 mT is not fixed and can be set by the user to achieve the best visualization and interpretability of the obtained comparison results. The comparison of the color contours (lines of equal magnetic induction) shows that the genuine banknote (**B**) has larger (high energy) contours of lines with equal magnetic induction, and they adjoin each other in the middle of magnetic ink strokes. Such magnetic induction topogram is typical of magnetic print strokes with a highly triangular or trapezoidal cross-section (a distinctive feature of gravure printing, such as intaglio). At the same time, the counterfeit banknote (**A**) has scarcer and smaller (low energy) contours of lines with equal magnetic induction, concentrated along the edges of magnetic ink strokes. Such magnetic induction topogram is typical of magnetic print strokes with a flattened rectangular cross-section (a distinctive feature of letterpress and printer printing). Since small print details such as the cross-sectional profile of magnetic ink were examined in Fig. 12, the compared accumulated magneto-optical images were examined under magnification (button  on the CADR toolbar).

Another tool which can be used for examination of topograms of accumulated magneto-optical images is graphs of induction in the specified sections (Fig. 13).

Figure 13



The initial data of the example shown in Fig. 13 are identical to those in Fig. 11, except for the windows arrangement. For ease of comparison of the images, arrange the windows vertically by pressing the "Tile"  button on the CADR toolbar **(D)** while holding down the Shift key.

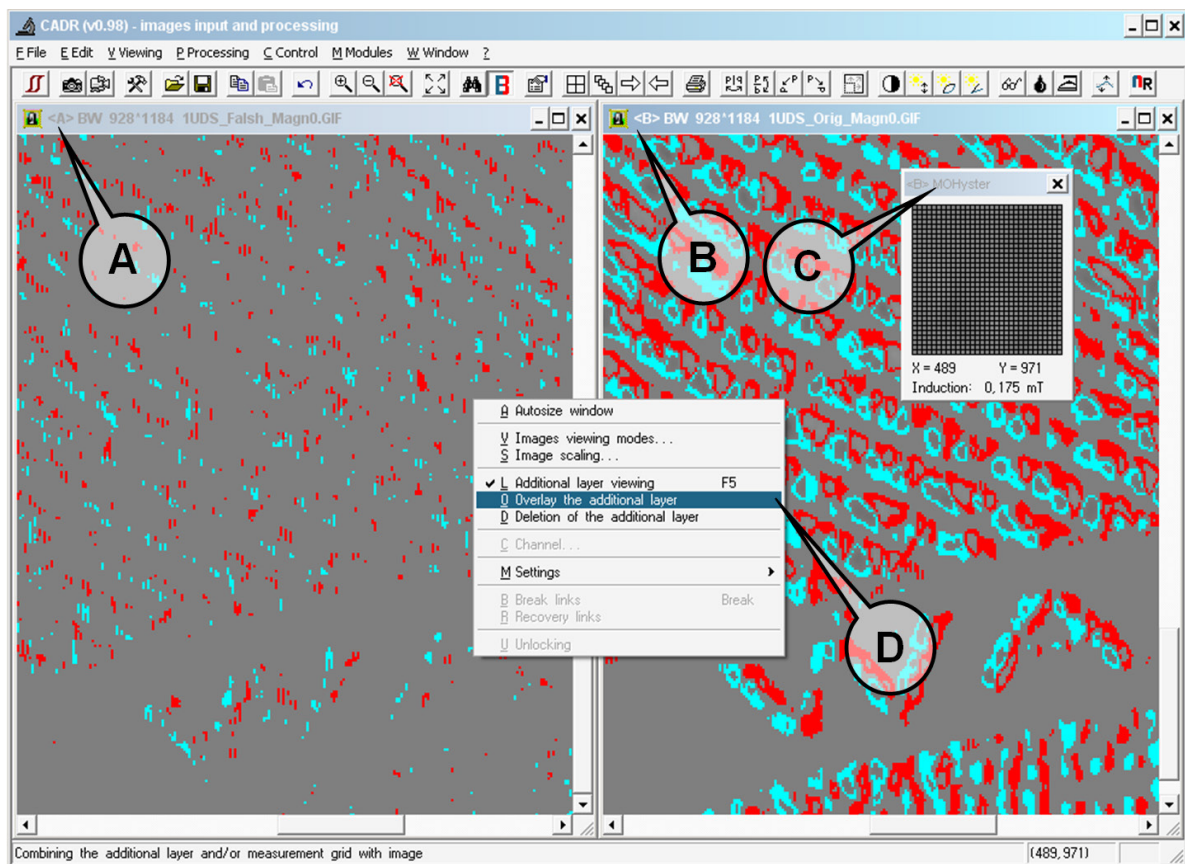
To construct a graph of induction in the specified section of the accumulated magneto-optical frame, make the window with this image active by a single click, then select a graph function, such as "Arbitrary image section" from the menu [View **(C)**, Fig. 13] -> [Graphs] -> [Arbitrary image section].

In the new window "Arbitrary image section" **(D)** (Fig. 13) there is a graph of magnetic induction function in the specified section. To set the start and end points of the secant segment, find it in the active window (a thin blinking line with dots on the edges). Point the mouse cursor on any of these dots (a "+" sign should appear), then press and hold down the **left mouse button** and drag to the desired position of the magneto-optical image. Repeat for the other end. Perform the same in the second image window.

In Fig. 13, the green graph corresponds to the genuine specimen from window **(B)**, and the red graph corresponds to the counterfeit specimen from window **(A)**. From the analysis of the graphs it can be seen that the genuine specimen has a high magnetic induction at all extreme points of the selected section (by 30–50%, for more details see the magnetic induction measurement range values in the graph legend **(E)**). This indicates a more relief section and/or a greater magnetic permeability, and/or a higher concentration of magnetic ink particles.

Analysis of the results of measurements by the remanent magnetization $H_{exc} = 0$ kA/m is performed by the previously described algorithm (Fig. 11–12), but the measurement data obtained under remanent magnetization (Fig. 14) are used.

Figure 14



In fig. 14, a common magnetic induction value of ± 0.175 mT was set in window (C) to construct surface contours of for the compared accumulated magneto-optical images (genuine specimen (B) and counterfeit specimen (A)). A comparison of the color contours (lines of equal magnetic induction) shows that the genuine banknote (B) has larger (high energy) contours of lines with equal magnetic induction, and they adjoin each other in the middle of magnetic ink strokes. This confirms the previous findings (Fig. 12) on the gravure printing method of the specimen (B). The counterfeit banknote (A) has scarcer and smaller (low energy) contours of lines with equal magnetic induction, concentrated along the edges of magnetic ink strokes. This confirms the previous findings (Fig. 12) on the letterpress or printer printing method of the specimen (A). Also, the ratio of the area of the topograms or the number of points in the set range of induction values indicates that the remanent induction of the specimen (A) is very small, and probably it was printed with magnetically soft material.

Examination of section graphs for the specimens shown in Fig. 14 is unreasonable, since the extremely low contrast of the accumulated magneto-optical image (A) does not allow to anchoring cursors to the image details.

All the considered results of magnetic measurement processing (Fig. 11–14) can be saved and used for reporting. Note that the procedures for saving graphic data differ for topograms and graphs.



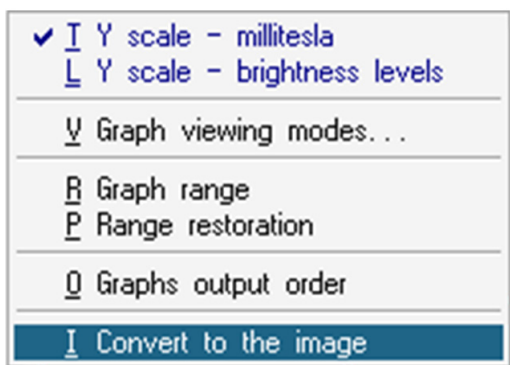



Color topograms as shown in Fig. 12 and Fig. 14 are displayed on an additional image layer which is **not saved** when saving the file using the "Save"  button on the CADR toolbar. To combine the additional color layer and the magneto-optical image, select the "Merge the additional layer" command in the context menu (Fig. 14 (D)). To access this menu, right-click the color topogram window while holding down the Shift key. In the opened menu select the "Merge the additional layer" item (Fig. 14 (D)). The combined image including the color layer and the monochrome magneto-optical image will be opened in a new window. The contents of this new window is a simple graphic object (without measuring properties) and can be saved as an image file using the "Save"  button.

Figure 15



Graphs (such as shown in Fig. 13) which are to be used as figures (in MS Office, etc.) must be first converted to a graphical format before saving. To do this, point the mouse cursor on the graph field and right-click. In the opened graph control menu (Fig. 15) select "Convert to image". A new window with this graph will open, where it can be saved as an image file using the "Save"  button. If the graph is to be used only in the CADR software, you can save it in the GR2 format, which stores all the properties of the graph.

Sometimes magneto-optical images need to be processed for better visualization. However, processing of accumulated magneto-optical images is disabled in the CADR software to prevent distortion of the measurement data. It can be enabled as follows: make the corresponding magneto-optical image window active, copy the image to the clipboard using the button , then paste the image from the clipboard to a new window using the button  while holding down the Shift key. The image in the new window allows graphic processing: filtering, level adjustment, effects, etc. (see the CADR software description), but the measuring properties will be lost after processing.

5.5.4 Magnetic induction histogram processing and analysis

The histogram of the accumulated magneto-optical image allows examining the probability density function of the magnetic induction normal component \mathbf{B} of the object.

Analysis of the results of the measurements in applied magnetization field $\mathbf{H}_{\text{exc}} = 50 \text{ kA/m}$ (Fig. 16). The initial data (contents of windows **(A)** and **(B)**) are fully identical to those previously described with Fig. 11 (these are magneto-optical images obtained under applied magnetic field $\mathbf{H}_{\text{exc}} = 50 \text{ kA/m}$), but the processing procedure is different.

5.5.4.1 Using the "Magnetic remeasurements" function with multiple frames


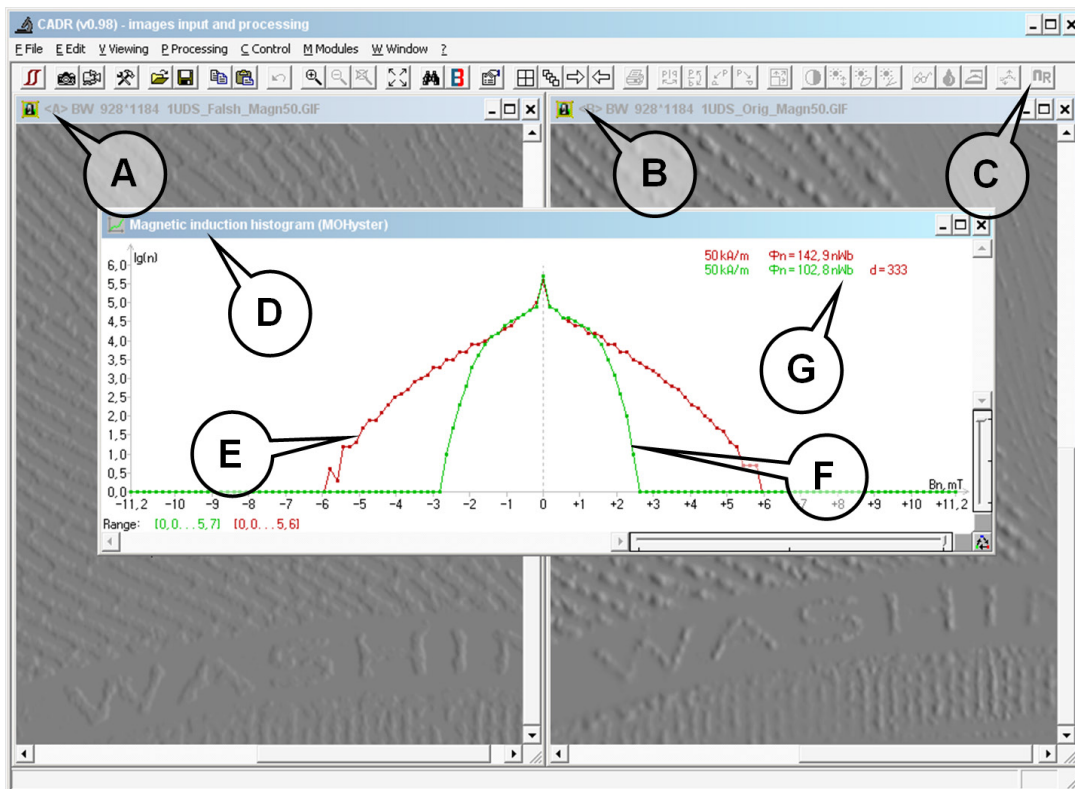

To construct a magnetic induction histogram from the previously saved magneto-optical image file, it is necessary to decode it, extract the data, rank them and present in graphical form. These operations can be performed by selecting the "Magnetic remeasurements" item in the menu: [Modules] -> [MOHyster/Regula 7708] -> [Magnetic remeasurements] or by pressing the button  on the CADR toolbar (Fig. 16 **(C)**).

Figure 16



As a result of this function, the "Magnetic Induction Histogram" window (Fig. 16 **(D)**) opens, where a histogram of the current accumulated magneto-optical image is constructed. In this way the histogram **B** of the genuine object shown in window **(B)** was constructed (red graph - **(E)**). The histogram of the counterfeit object (green graph - **(F)**) was also constructed by selecting the window **(A)** and clicking the button .

5.5.4.2 Using the "Magnetic flux" and "Histogram distance" parameters

The results (Fig. 16) of the calculation of the magnetic fluxes Φ and the distance d between the histograms are displayed in the legend area (**G**). The values of the magnetic fluxes Φ differ by less than 2 times: 142.9 nWb for the genuine object (**B**) and 102.8 nWb for the counterfeit object (**A**). Such a difference in magnetic fluxes is not enough for a categorical statement on the nonidentity of the objects, since the magnetic flux value can reach double the dispersion between a pair of genuine objects (for example, a new and a very worn banknotes). The obtained value of the distance between the histograms is $d = 333$, which significantly exceeds the distance threshold established for this type of objects (a threshold value of $d = 160$ was obtained from a training dataset of several dozen genuine specimens). Thus, according to the criterion for exceeding the allowable distance value, it was found that the object (**A**) does not have group identity with the object (**B**).

5.5.4.3 Using the "Magnetic induction maximum" parameter


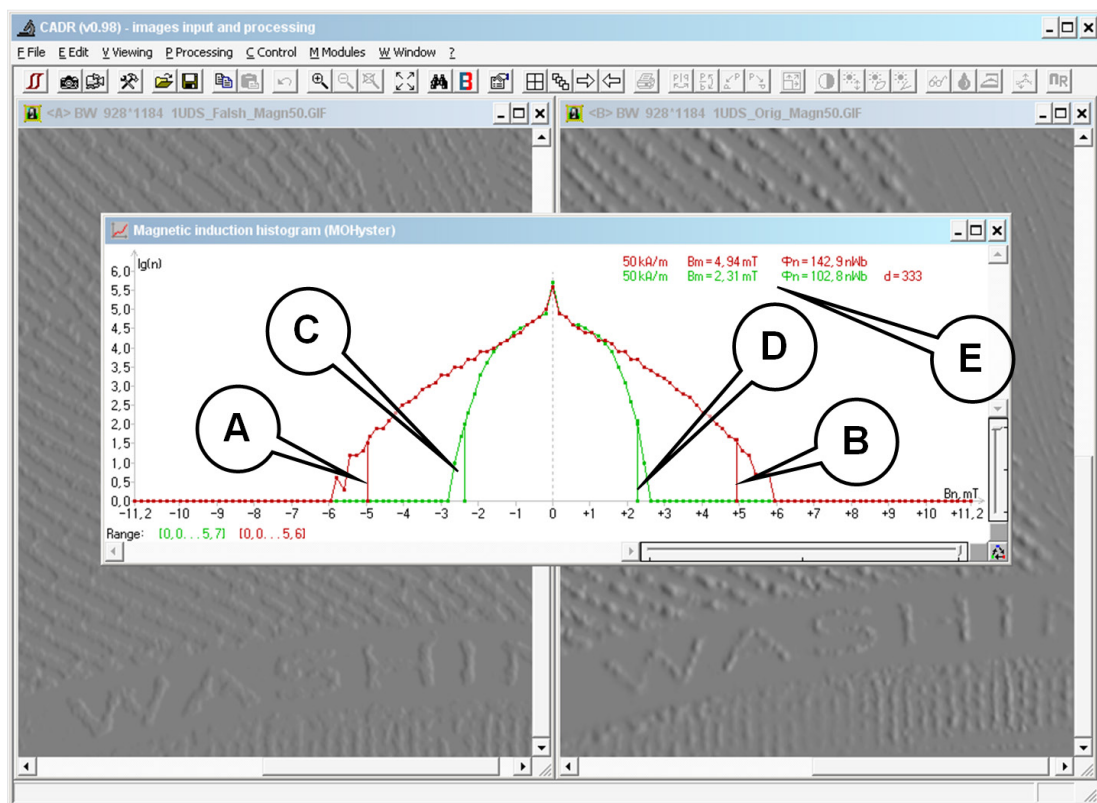
The number of the analyzed parameters of histograms (Fig. 16) can be expanded by considering the range/width of the histogram (Fig. 17), i.e., the value of the magnetic induction maximum in the distribution of B_{max} (B_m). To do this, open the "MOHyster control" toolbar (Fig. 6) and **right-click** the button  to enter the magnetic measurements configuration menu (Fig. 8).

Figure 17



If the "0.01 % cutoff for calculating the induction function maximum" checkbox is selected and the threshold value is set (a threshold value of $1 \times 0.01 \% = 0.01 \%$ is selected in the example in Fig. 17), two vertical segments indicating the values of B_m for the positive and negative magnetic induction distribution maxima (**A-D**) are displayed in each magnetic induction **B** histogram field. The magnetic induction distribution edge cutoff is used to exclude the potential effect of extraneous magnetic particles (such as magnetic dust). The threshold value is usually set in the range of 0.1–0.01 %.

In this case, the average value of the parameter B_m will be also displayed on the histogram legend (E).

The results of calculating the maxima of magnetic induction in the distributions of B_m (E) differ by more than 2 times: 4.94 mT for the genuine object (B) and 2.31 mT for the counterfeit object (A). Thus, summarizing the results (Fig. 16–17): objects (A) and (B) have no group identity by two criteria (the threshold is exceeded for parameters B_m and d). Since the threshold of the parameter Φ was not exceeded, authenticity control devices based on magnetic flux estimation (for example, currency detectors using magnetic reading heads) may not detect a counterfeit banknote of this type.

Analysis of the measurement results by the remanent magnetization $H_{exc} = 0$ kA/m (Fig. 18). The initial data (contents of windows (A) and (B)) are fully identical to the previous description to Fig. 12 (these are accumulated magneto-optical images obtained under remanent magnetization).

The data processing procedure is identical to that for the example in Fig. 17.


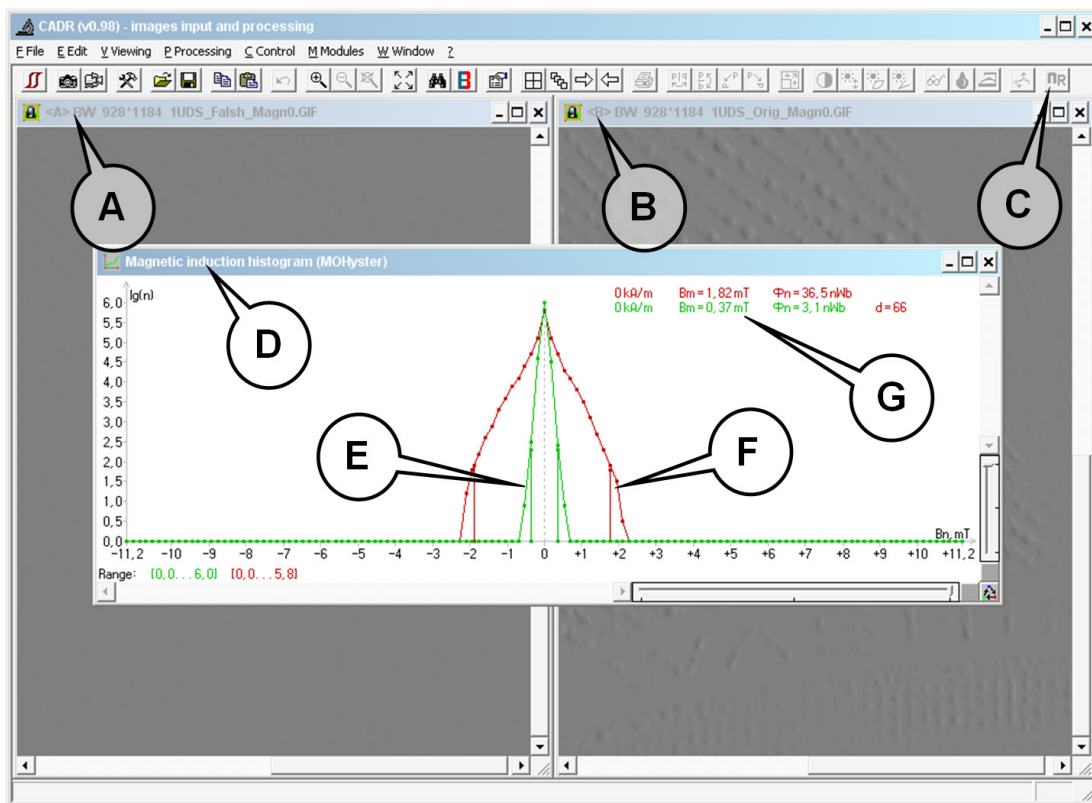
In Fig. 18 there are accumulated magneto-optical images of the genuine object (B) and the counterfeit object (A) opened in the corresponding windows. When magnetic remeasurements are performed using the button  (C), the "Magnetic Induction Histogram" window (D) opens, where the histogram B of the genuine object (B) (red graph (F)) and the histogram B of the counterfeit object (A) (green graph (E)) are constructed.

Figure 18



The results of calculating the magnetic fluxes Φ , the maxima of the magnetic induction B_m and the distances d between the histograms are displayed in the legend area (G) (Fig. 18). The values of the magnetic fluxes Φ differ by greater than 2 times: 31.5 nWb for the genuine object (B) and 3.1 nWb for the counterfeit object (A). The values of the maxima of magnetic induction B_m differ by more than 2 times: 1.82 mT

for the genuine object (**B**) and 0.37 mT for the counterfeit object (**A**). The obtained value of the distance between the histograms is $d = 66$, which exceeds the distance threshold established for this type of objects (a threshold value of $d = 40$ was obtained from a training dataset of several dozen genuine specimens). In conclusion, summarizing the analysis results (Fig. 18), it should be noted that objects (**A**) and (**B**) have no group identity by three criteria: the threshold is exceeded for parameters Φ , B_m and d .

The analysis of the magnetic induction histograms (Fig. 18) also confirms the previous assumption (see the description to Fig. 14) that the remanent magnetization of the specimen (**A**) is very small ($B_m = 0.37$ mT), and probably it was printed with magnetically soft material. The classification of magnetic material specimens by softness/hardness is described in s. 5.6.

5.5.4.4 Estimating the magnetic parameters of a part of the frame

The accumulated magneto-optical image allows constructing histograms of magnetic induction **B** not only for the entire visualized frame, but also for its individual part (fragment). This approach is recommended if the magnetic print area is small relative to the frame area (for example, when examining a banknote number or a security thread with the magnetic print area less than 10 % of the magneto-optical frame area). Frame fragment analysis is also necessary when there are several magnetic objects of different types in the accumulated magneto-optical frame. For example, the **MultiCode security thread** containing high-coercivity (**HiCo**), low-coercivity (**LoCo**), and combined bits.

To select a fragment, create a rectangular (blinking) selection frame by moving the mouse cursor while holding down the Alt key in the window with the image containing the modified frame (see Fig. 19).

This frame selects the area of the visualized frame where magnetic parameters will be estimated. The size and position of the frame can be changed by moving its corners with mouse. A precise movement and adjustment of the selection frame corner coordinates can be done using the "Fragment" function (Fig. 20) in the main menu of the CADR software: [Edit] -> [Fragment].

Figure 19

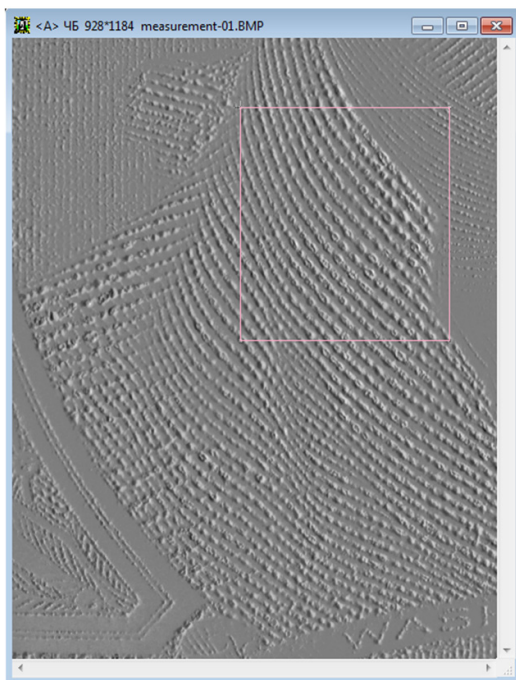
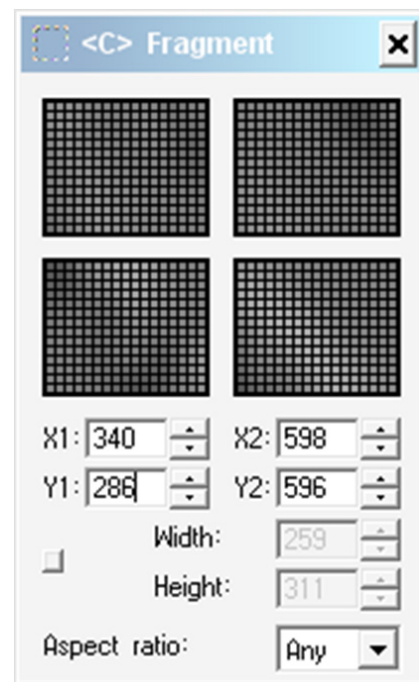



Figure 20



In the Fragment window there are four graphic boxes displaying the area around each of the four corners of the selection frame. You can precisely move each of the corners by clicking on these boxes.

"X1, Y1" and "X2, Y2" – coordinates of the upper left and lower right corners of the selection frame, respectively. "Width" and "Height" – width and height of the selection frame in pixels. "Aspect ratio" – can be "Any", "1:1", "4:3" or "3:4".

After the position and size of the selection frame required for the examination is selected, use the "Magnetic remeasurements" function as described above (from the menu [Modules] -> [MOHyster/Regula 7708] -> [Magnetic remeasurements]) or button  on the toolbar. A window will appear, displaying the histogram of the normal component of magnetic induction **B** for the selected fragment of the visualized frame and the calculated value of the magnetic flux modulus Φ in this area.


The fragment can be selected in a different order. First, select the "Magnetic measurements" (s. 5.5.2) or "Magnetic remeasurements" (s. 5.5.4.1) function, then in the accumulated magneto-optical image window create a selection frame by moving the mouse cursor while holding down the Alt key (see Fig. 19). The readings in the magnetic measurement results window will dynamically change based on the size and position of the selection frame. It is possible to simultaneously select fragments of multiple accumulated magneto-optical frames opened in different windows for simultaneous comparison of their histograms of magnetic induction **B** as described in ss. 5.5.4.1.

ATTENTION!

The magnetic induction histogram **B** and the calculated value of the magnetic flux modulus Φ for the selected fragment is normalized to the total frame area, i.e., it is multiplied by the ratio of the fragment area to the frame area (as if the entire frame was filled with a repeating image of the selected fragment). Therefore, for example, the value of the magnetic flux Φ for a selected fragment can be much greater relative to Φ of the full frame (if a fragment with a strong magnetic field is selected) or much weaker (if a noise fragment is selected).

5.5.4.5 Numerical representation of histograms

Data of histograms of the normal component of magnetic induction B_n can be represented not only in graphical but also in numerical (tabular) form.

To do this, make the window "Magnetic Induction Histogram" active by a single click. Then press the key combination Ctrl+C, or the button  on the CADR toolbar, or select the following item in the menu: [Edit] -> [Copy]. As a result, the numerical data which are hidden in the "Magnetic Induction Histogram" window will be copied to the clipboard.

Then open a spreadsheet or text file (MS Excel, Word, Windows Notepad, etc.). Paste the contents of the clipboard into this file. The contents are spreadsheet columns. The number of columns can be from 2 to 4, depending on the number of histograms constructed in the "Magnetic Induction Histogram" window.

The first (left) column contains the values of the normal component of magnetic induction **B** in [mT]. The following columns (2 to 4) contain the logarithms (**lg(N)**) of the numbers of frame points corresponding to the values indicated in the first column **B**. These columns (from left to right) correspond to the red (**R**), green (**G**), and blue (**B**) histograms.

Similar methods can be used for exporting any other types of graphs from CADR, such as a graph of an arbitrary section of an image, ss. 5.5.3 (Fig. 13).

5.5.4.6 Approximation of histograms

The magnetic measurements data used to construct histograms **B** can be influenced by factors (distortions and noise) that are not related to the physical state of the magnetic objects being examined. Such factors may distort the results of comparing the examined and the reference documents.

For this reason, the CADR software has the "Approximation" function.

When the "Approximation" function is selected, the data of the histogram **B** are additionally processed, and based on the results an approximating curve is constructed with the following properties:

- 1) the approximating curve has the shape of a square parabola;
- 2) when it is constructed from a point array, those points that originate from the background noise (i.e. random points that appear in a frame without any magnetic image) are deleted;
- 3)* when constructing the approximating curve, corrections are made to make the shape and position of the curve independent of the number of magnetic image points in the processed frame. That is, the shape and position of the curve does not depend on how densely the frame is filled with magnetic image lines;

These corrections allow comparing the characteristics of the magnetic material of documents by different contents of the compared frames.

- 4)* when constructing the approximating curve, corrections are made to offset the possible displacement of the magnetization of the examined image in the direction of the pole **S** or **N**.

When the "Approximation" function is enabled, the distance **d** between the histograms **B** is recalculated taking into account all the corrections used in the construction of the approximating curve.

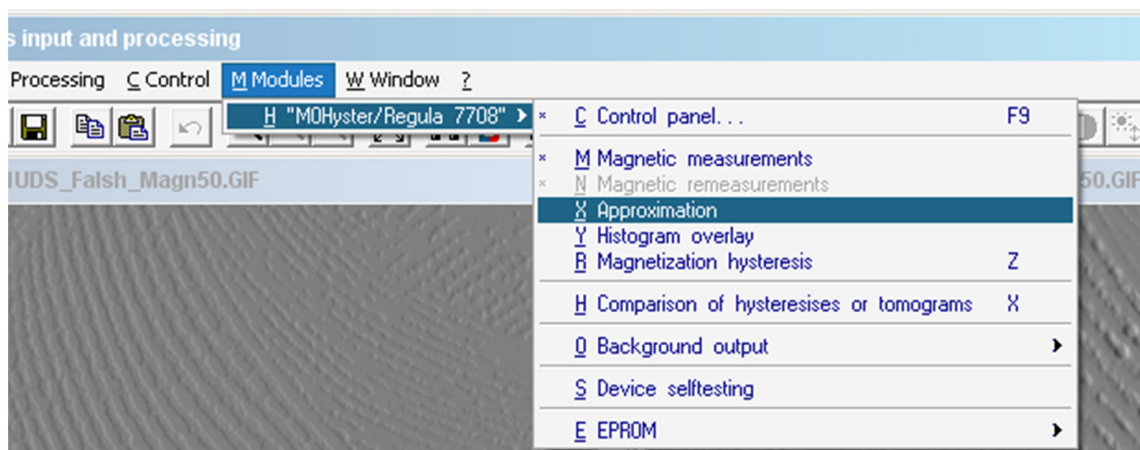
The results of the approximation can reduce the effect of distorting factors, such as the background noise, the difference in the contents and density of the compared frames as well as initial magnetization displacement of the magnetic image.

To enable the "Approximation" function, first make active the corresponding "Magnetic Induction Histogram" window with the results that need to be approximated. To do this, **left click** the histogram window.

Then select the "Approximation" function in the menu [Modules] -> [MOHyster/Regula 7708] -> [Approximation] (see Fig. 21).

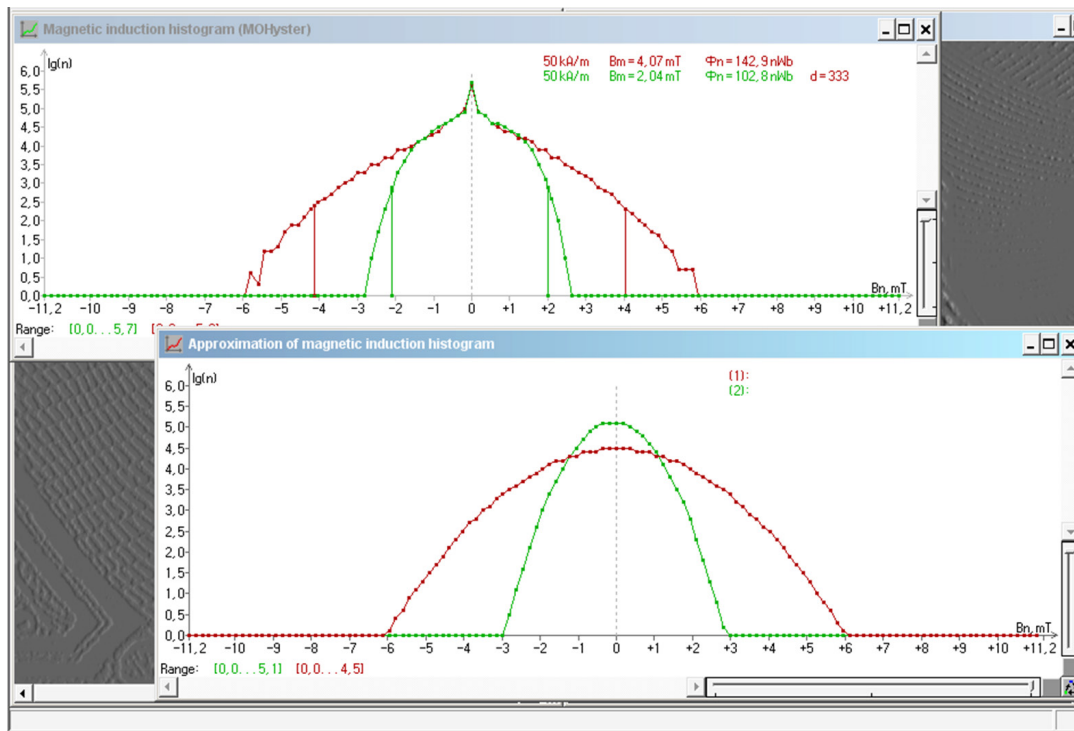
Fig. 22 shows the initial (the top window) and approximated (the bottom window) histograms **B**.

Figure 21



* – to enable the "Approximation" function with corrections 3) and 4), hold down the Shift key and select this function from the menu.

Figure 22



5.6 Construction of magnetic hysteresis characteristics

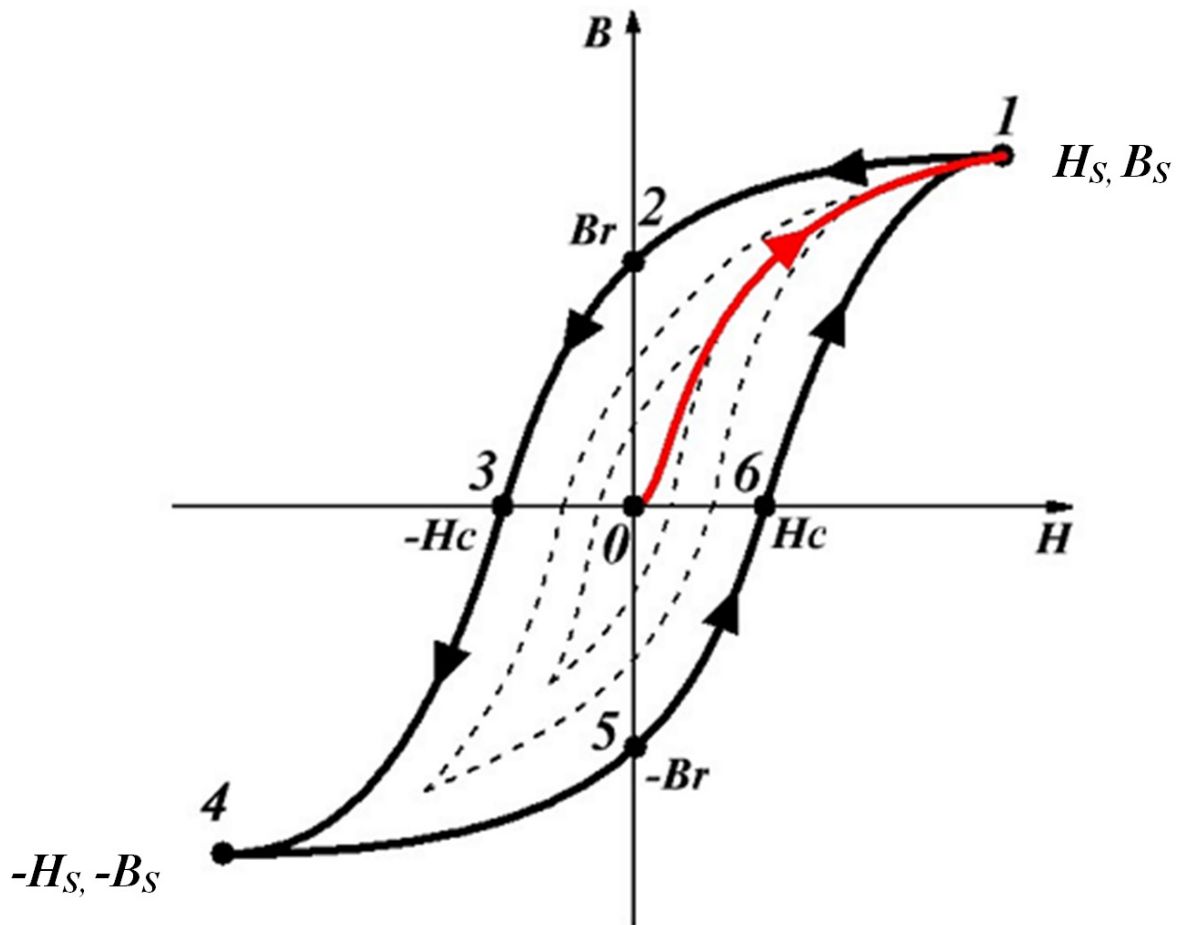
5.6.1 Brief explanation of the magnetic hysteresis phenomenon

Magnetic hysteresis is the phenomenon of the dependence of the magnetization vector and magnetic induction vector in a substance not only on the intensity of the applied external magnetic field, but also on the magnetic history of this object. Mathematically, it is described by a non-linear and ambiguous function (see Fig. 23). Magnetic hysteresis is usually characteristic of ferromagnetic materials (Fe, Co, Ni and alloys based on them), which are used, in particular, in the magnetic security features of banknotes made with magnetically hard materials.

The magnetization process (Fig. 23) begins when the object is completely demagnetized (point **0**): all the domains are magnetized randomly (in different directions), which corresponds to the minimum magnetization. With a monotonic increase in the intensity of the magnetizing field \mathbf{H} , the magnetic induction of the object \mathbf{B} also increases, however, this functional relationship is non-linear: the red curve **0-1** is called the initial magnetization curve. Point **1** (with coordinates \mathbf{H}_s , \mathbf{B}_s) corresponds to the magnetic saturation of the object: all the domains are magnetized in the same direction, which provides for the maximum positive magnetization. A further increase in the intensity of the magnetizing field $\mathbf{H} > \mathbf{H}_s$ is unreasonable, since after reaching the magnetic saturation of the object ($\mathbf{H} = \mathbf{H}_s$), magnetic hysteresis is not observed (all characteristic lines coincide and their behavior is described by a linear function).

If the intensity of the magnetizing field is monotonously reduced from the value $\mathbf{H} = \mathbf{H}_s$ to the value $\mathbf{H} = \mathbf{0}$ in state **1**, then curve **1-2** does not coincide with curve **0-1**, demonstrating the hysteretic nature of the magnetization process. This phenomenon is based on the previous magnetization of the object in point **1**. Point **2** of the hysteresis curve characterizes the magnitude of the remanent magnetic induction \mathbf{B}_r .

Figure 23



If the intensity of the negative magnetizing field is monotonously increased from the value $\mathbf{H} = \mathbf{0}$ to the value $\mathbf{H} = -\mathbf{H}_c$ in state **2**, then the hysteresis curve will come to point **3**, where the magnetic induction of the object turns to zero ($\mathbf{B} = \mathbf{0}$), i.e. a full demagnetization of the object by the opposing field will take place. The value $-\mathbf{H}_c$ of the intensity of the magnetizing field, causing a full demagnetization of the object by the opposing field, is called the coercive force. **For the classification of magnetic materials, it is the value of the coercive force \mathbf{H}_c that is used as a threshold distributor between magnetically soft, semihard and hard materials/objects.** Real magnetically soft materials have a narrow hysteresis loop ($\mathbf{H}_c < 0.8 \text{ kA/m}$), and an ideal magnetically soft characteristic can be represented by one line with all hysteresis branches overlapping each other. Real magnetically hard materials have a wide hysteresis loop ($\mathbf{H}_c > 12 \text{ kA/m}$), and an ideal magnetically hard characteristic can be represented by a rectangle or parallelogram. In addition, magnetically hard materials are often divided into subgroups: low-coercive LoCo ($\mathbf{H}_c \approx 24 \text{ kA/m}$) and high-coercive HiCo ($\mathbf{H}_c \approx 320 \text{ kA/m}$).

If the intensity of the negative magnetizing field is monotonously increased from the value $\mathbf{H} = -\mathbf{H}_c$ to the value $\mathbf{H} = -\mathbf{H}_s$ in state **3**, then the hysteresis curve will come to point **4**, where the magnetic induction of the object will take the maximum negative value $-\mathbf{B}_s$, which corresponds to the magnetic saturation of the object: all the domains are magnetized in the same direction, which provides for the maximum negative magnetization.

A further monotonous change in the magnetizing field intensity from the value $\mathbf{H} = -\mathbf{H}_s$ to the value $\mathbf{H} = +\mathbf{H}_s$ will lead to the construction of the next branch of the hysteresis characteristic passing through points **4-5-6-1** and completing the cycle of full magnetization reversal of the object. Thus, the major hysteresis loop (solid black curve) includes all




of the listed characteristic points **1-2-3-4-5-6**. It is obvious that the greater the absolute value of H_s , B_s , B_r , and H_c , the larger the area of the hysteresis loop will be, and accordingly, the greater will be the energy required for magnetization reversal of the object. Therefore, **as an indicator of the energy loss due to hysteresis**, the loop area integral is used, which is calculated by the following formula: $W = \int B dH$.

All the listed parameters (H_s , B_s , B_r , H_c and W) of the magnetic hysteresis function are important magnetic characteristics for the examination, classification, and diagnostics of the object.

If a demagnetized object is magnetized by a weaker field $H < |H_s|$, the hysteresis characteristic will not be major (magnetic saturation will not be achieved) and the magnetization reversal process will be described by partial hysteresis loops (black dot curves in Fig. 23), which are similar to the major loop in their shape, but have a smaller area. Since the MO hysteresigraph can change the magnetization field intensity in the range of $0 \leq H \leq 100$ kA/m, for objects with a lower or equal value of the saturation intensity $H_s \leq 100$ kA/m, major hysteresis loops will be constructed, and for objects with a larger value of saturation intensity $H_s > 100$ kA/m, minor hysteresis loops will be constructed.

Fig. 23 shows a hysteretic characteristic of type **B-H**, expressing the dependence of the magnetic induction **B** of the object on the intensity **H** of the applied magnetic field. Similar characteristics can be obtained for the magnetic flux Φ -**H** and the remanent magnetization **M-H**. Obviously, this will change the set of parameters (characteristic points of the hysteresis function) and their values.

5.6.2 Parameters of the "Hysteresis" function

To access the "Hysteresis" function parameters, first open the "MagReader/Regula 7701 Complex" window by clicking the button **(A)** (Fig. 5). In the opened "MOHyster control" toolbar (Fig. 6), **right-click** the button , , or . When clicked, the "Magnetic measurements" function parameters window will open (Fig. 24) with the recommended settings indicated.

As it was mentioned in ss. 5.6.1, the magnetic hysteresis characteristic of an object can be represented by several types of functions:

- **B-H**: expresses the dependence of the magnetic induction **B** of the object on the intensity **H** of the applied magnetic field;
- **Φ -H**: expresses the dependence of the magnetic flux Φ of the object on the intensity **H** of the applied magnetic field;
- **M-H**: expresses the dependence of the magnetization **M** of the object on the intensity **H** of the applied magnetic field.

To construct a magnetic hysteresis characteristic of type **B-H**, select the "Induction function maximum in mT" checkbox located in the "Vertical hysteresis scale" area (Fig. 24).

To construct a magnetic hysteresis characteristic of type **Φ -H**, select the "Magnetic flux in nWb" checkbox located in the "Vertical hysteresis scale" area (Fig. 25). Setting the cutoff threshold for the maximum magnetic induction **B** will be enabled (the same threshold will be set in the "Magnetic measurements" menu (Fig. 8)). Note that changing the cutoff threshold for the maximum magnetic induction **B** in the "Magnetic measurements" menu (Fig. 8) will also lead to the same change of the threshold in the "Hysteresis" menu (Fig. 25).

Hysteresis characteristics of types **B-H** and **Φ -H** are constructed by the same magnetization algorithm, therefore they can be changed (recalculated) at any time (including relative to the previously saved measurement data). For all these characteristics, the measured value is the magnetic induction in the effective field H_{exc} of magnetization $B = f(x, y, H_{exc})$, which, in the case of characteristic **Φ -H**, is converted by the CADR software into the function of magnetic flux Φ by the data of the histogram **B** and the known area of the visualized field.

Figure 24

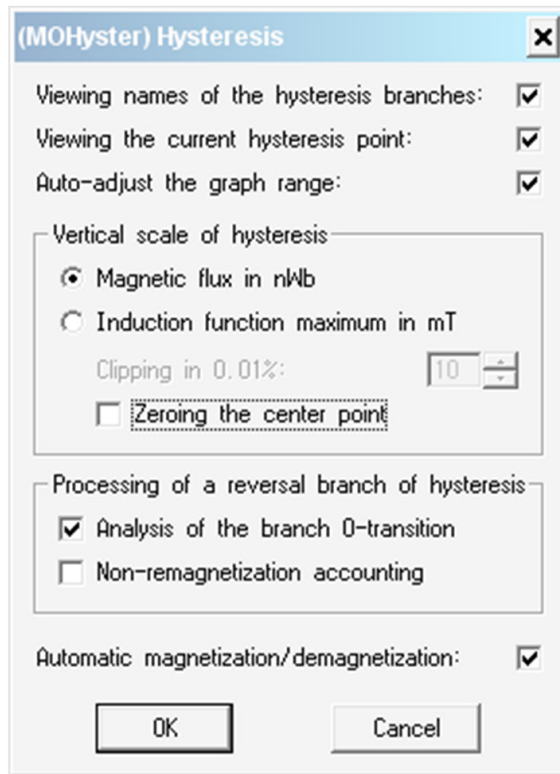
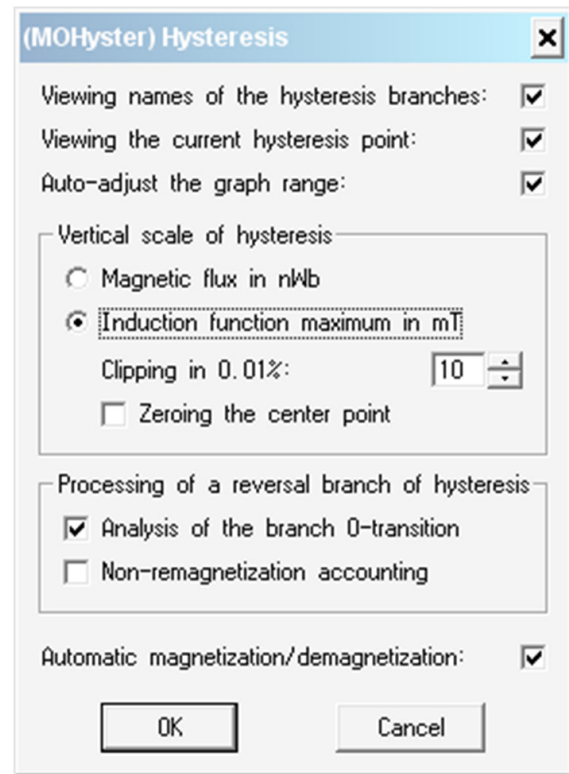


Figure 25











The hysteresis characteristic **M-H** is constructed by a separate command (see ss. 5.6.5), but even in this case, the initial data for calculating the **M-H** type characteristic is the measured **B-H** type hysteresis characteristic.

For the parameters of the "Hysteresis" function, which were not described above, it is recommended to set the checkboxes in accordance with Fig. 24.


5.6.3 Using the "Hysteresis" function


To estimate the magnetic parameters of a specified area, it is necessary to set and position the object first in accordance with the recommendations described in ss. 5.3–5.4 and select the hysteresis characteristic type as described in ss. 5.6.2.



On the "MOHyster control" toolbar (Fig. 6) there are a number of function buttons for partial or full construction of the hysteresis characteristic. Buttons ,  and  are used for construction of individual hysteresis curves: **1** – initial magnetization branch; **2** – magnetic return branch; **3** – magnetization reversal branch. Button  is used for construction of a full hysteresis characteristic, which consists of the three hysteresis curves listed above.

"Hysteresis" functions of CADR (buttons , ,  and ) are used for setting the hysteresis graph control algorithm, which allows determining the values of the magnetic hysteresis function of a specified type (**B-H**, **Φ-H** and calculate **M-H**). All hysteresis curves are constructed by automatic execution of a series of 21 magnetic measurement cycles (each individual magnetic measurement is identical to the cycle previously described in ss. 5.5.2). However, the values of the previous magnetization field H_{PREV} and the values of the effective magnetization field H_{EXC} differ for each of the hysteresis curves. Thus, each of the hysteresis curves is constructed based on 21 measuring points, corresponding to

the coordinate of the current magnetization field H_{EXC} (in the range of 0–100 kA/m with a sampling rate of 5 kA/m).

Let's consider using the "Hysteresis" function in practice. The test object is a genuine 1 USD banknote (Fig. 11 (B)). The Φ - H type function of magnetic hysteresis in the applied magnetization field was selected for construction (the hysteresis settings were set as shown in Fig. 24). Full hysteresis characteristic is selected by the function button  on the "MOHyster control" toolbar (Fig. 6).

After pressing the function button , the automatic process of building the specified magnetic hysteresis characteristic of the object begins. The duration of the process is approx. 10–30 minutes. During the constructing the hysteresis characteristic, 4 new windows are opened in the CADR software (Fig. 26). The contents of these windows change iteratively as the process progress.

To save the results of the "Hysteresis" function, make the hysteresis function window active by clicking there. The title of the active window is highlighted in color (the hysteresis window (D) is active in Fig. 26). Then click the "Save"  button on the CADR toolbar and set the parameters and details of the saved file. A special file format with the extension .moh was developed for storing CADR hysteresis data. When a saved hysteresis file is opened (using the "Open"  button on the CADR toolbar), all measurement data and windows are fully restored (as shown in Fig. 26).


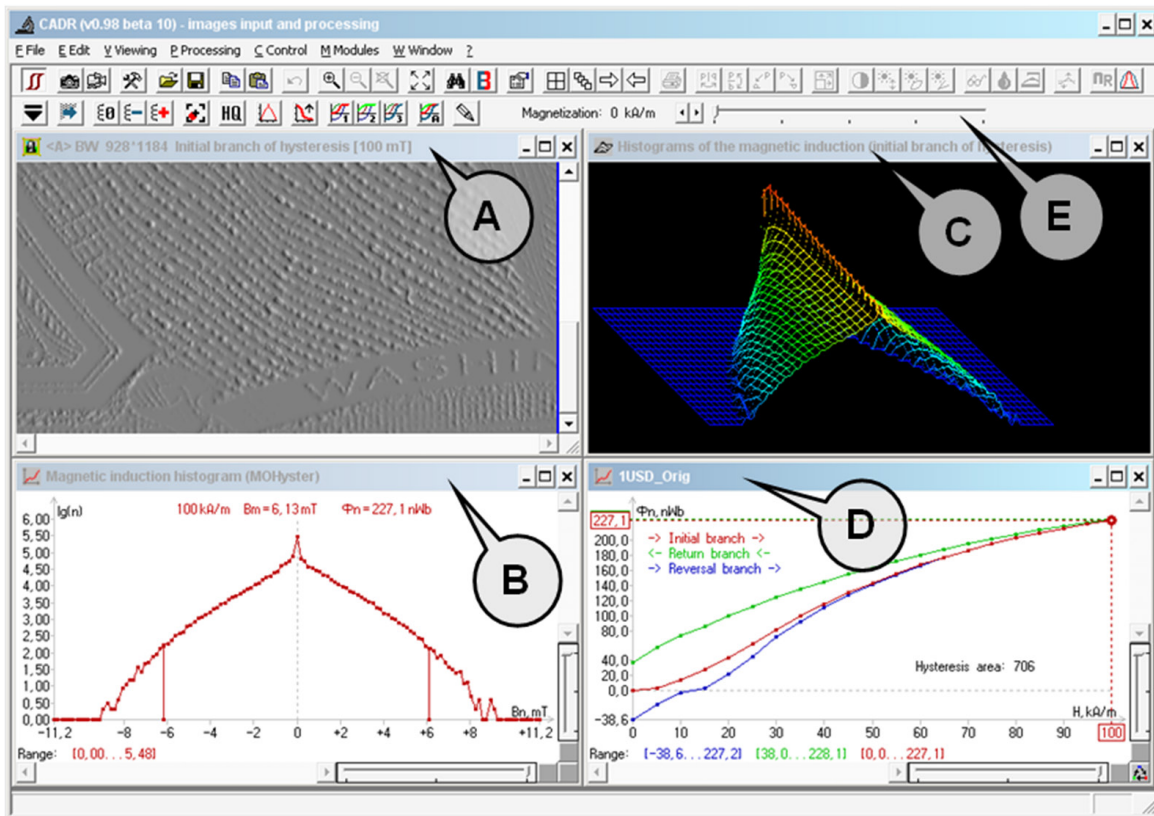
This example (Fig. 26 (E)) also shows an appearance and arrangement of tools on the "MOHyster control" toolbar, different from that described previously (Fig. 6). By **right-clicking** the button , you can change the shape and position of this toolbar.

Figure 26



5.6.4 "Hysteresis" function windows elements and navigation

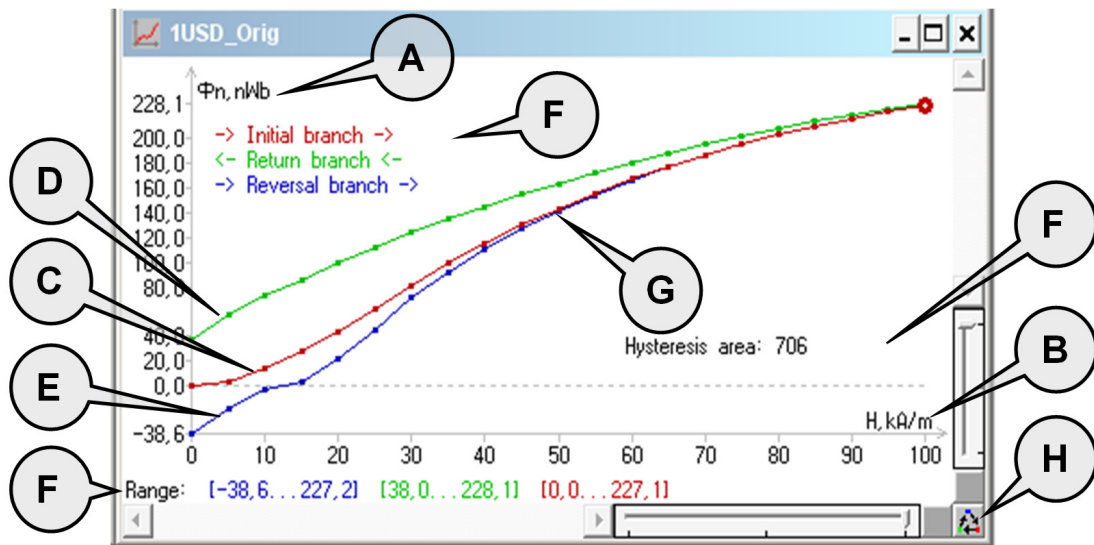
The windows of the "Hysteresis" function (Fig. 26) with fixed image areas contain the following: **(A)** – display area of measuring magneto-optical images; **(B)** – display area of the histograms of magnetic induction **B** and the calculated values of magnetic flux Φ ; **(C)** – display area of the 3D "magnetic history" of measurements (histograms of magnetic induction) of the current hysteresis curve; **(D)** – display area of the magnetic hysteresis characteristics.

To switch between the windows, make the required window active by clicking there. The title of the active window is highlighted in color (the hysteresis window **(D)** is active in Fig. 26).

A more detailed description of the elements and navigation in the hysteresis window is shown in Fig. 27. Graphs of the hysteresis characteristic Φ -**H** express the functional dependence of the magnetic flux Φ on the intensity of the applied magnetization field **H**, therefore they have the following coordinate axes: **(A)** – magnetic flux Φ [nWb] and **(B)** – intensity of the applied magnetic field **H** [kA/m].

Since the full hysteresis characteristic option was selected for this example, the characteristic is expressed by three curves: **(C)** – initial magnetization branch (red), **(D)** – magnetic return branch (green), **(E)** – magnetization reversal branch (blue). The active magnetization curve is selected using the button **(H)**. The hysteresis legend **(F)** shows the following: names and color of hysteresis branches, parameter ranges, hysteresis function area.

Figure 27



The hysteresis characteristic shown in Fig. 27 differs from the canonical form (Fig. 23), since it expresses the function only in the first and fourth quadrants, however, taking into account the central symmetry of this function, missing points can be constructed analytically (reducing the measurement cycle time twice).

You can enable the cursor **(G)** for the selection of the current point of the current hysteresis branch. In Fig. 27, a point on the initial magnetization curve (red color) with the coordinate **H** = 50 kA/m is selected, which corresponds to a magnetic flux Φ = 143.0 nWb (displayed in a rectangular frame on the vertical axis). This point was not chosen randomly: this choice allows us to compare the previously obtained result of a single measurement (Fig. 17) and a point estimation of the hysteresis function (Fig. 27) for the same object under similar magnetization conditions. Here we can observe a good

reproducibility of the magnetic flux estimation results: $\Phi = 142.9$ nWb for the single measurement (Fig. 17) and $\Phi = 143.0$ nW for the point estimation of the hysteresis function (Fig. 27).

When the current point of the current hysteresis branch (Fig. 27) is selected in the hysteresis window (D), the data in the windows (A-C) change. As a result, the initial displayed image (Fig. 26) will change as shown in Fig. 28: the accumulated magneto-optical image obtained under the conditions of magnetic measurements in the selected hysteresis point (the initial magnetization curve, magnetization field 50 kA/m) is displayed in window (A), the magnetic induction histogram corresponding to window (A) is calculated in window (B), and the set of data of 3D "magnetic history" of measurements (magnetic induction histograms) is not changed in window (C), since the current hysteresis curve did not change.

5.6.5 Selecting the hysteresis characteristic type (B-H, Φ -H or M-H)

As it was mentioned in ss. 5.6.2, a hysteresis characteristic of type **B-H** can be converted into a characteristic of type Φ -H (and vice versa) or **M-H** by recalculation of the measurement data. To change the type of hysteresis characteristic, **right-click** the hysteresis window (Fig. 28 (D)). In the pop-up function menu (Fig. 29) select the "Change hysteresis type" option. This operation can also be performed by pressing the F10 key on the keyboard or by selecting the "Induction function maximum in mT" checkbox (Fig. 24). The initial window (Fig. 27) will take an appearance similar to Fig. 29, where the vertical axis correspond not to the magnetic flux Φ [nWb], but to the magnetic induction maximum B_m [mT]. In the value display area for the magnetic induction maximum B_m , the threshold value for the determination of B_m (see ss. 5.5.4.2) is shown in square brackets (Fig. 28 (A)): 0.01 % in this example. When the threshold value for the determination of B_m changes, the values of the hysteresis characteristic **B-H** also change.

Figure 28

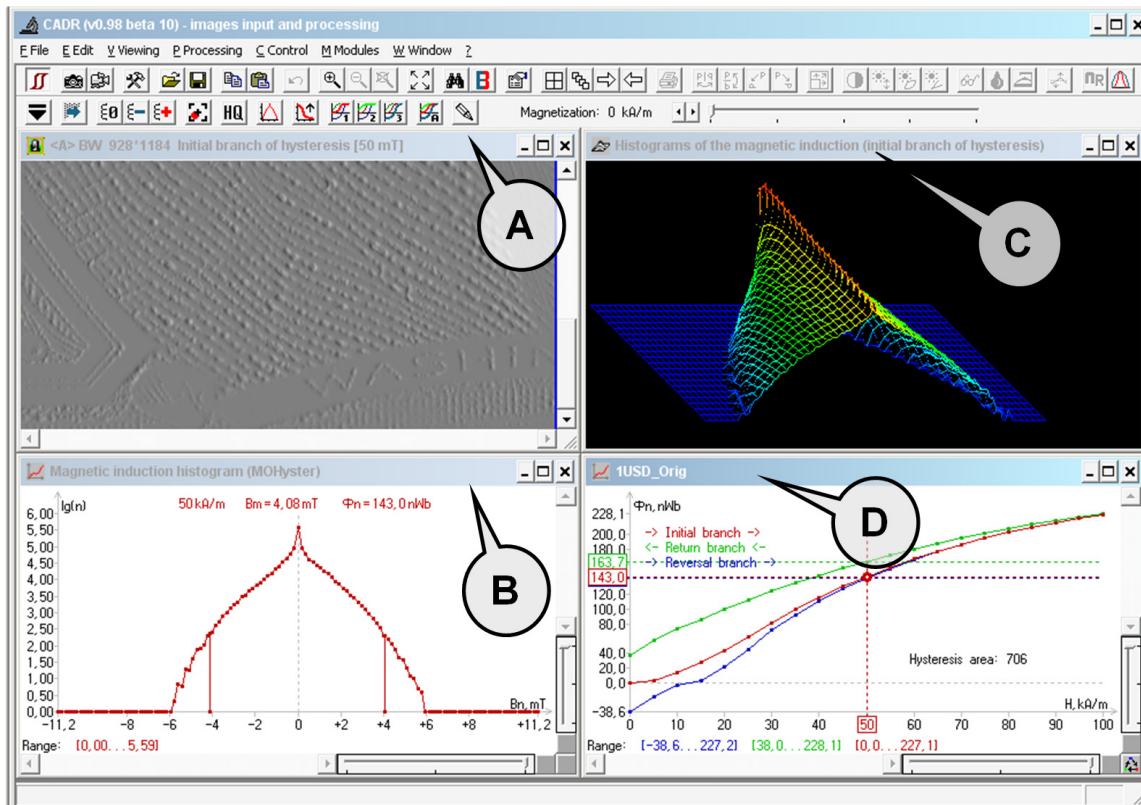


Figure 29

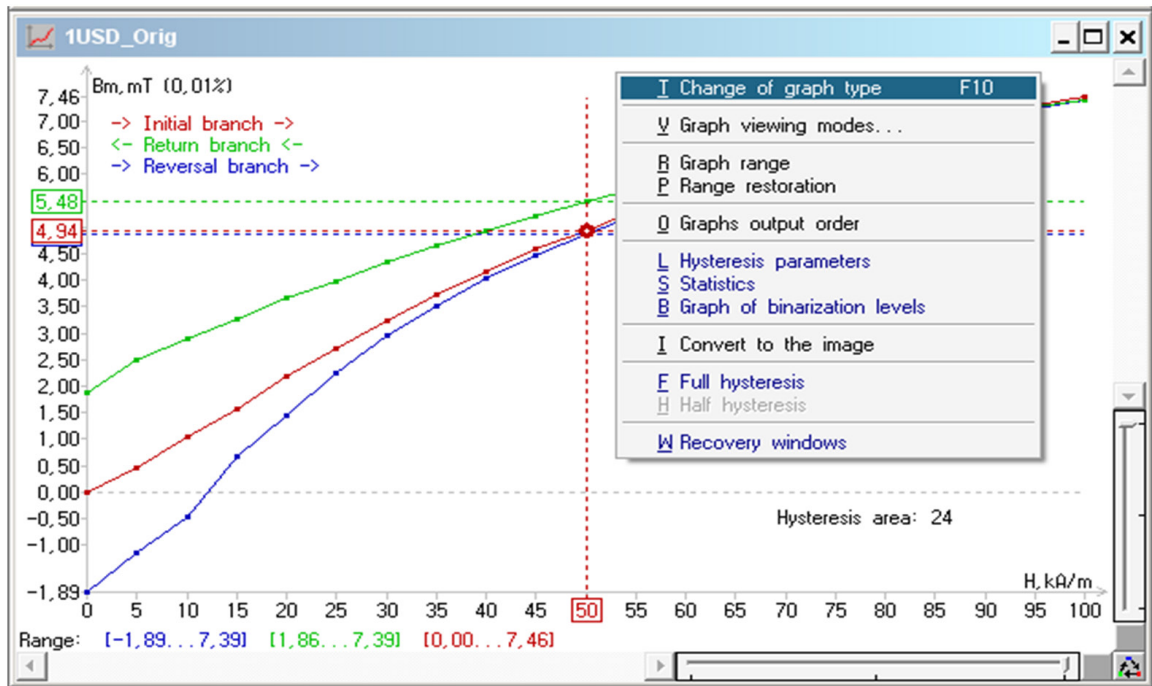


Fig. 29 shows full repeatability of the results of estimating the maxima of magnetic induction: $B = 4.94$ mT for the single measurement (Fig. 17) and $B = 4.94$ mT for the point estimation of the hysteresis function (Fig. 27). This is because both measurements of the same object were performed under the same magnetization conditions using the same threshold value B_m .

Construction of a hysteresis characteristic of type **M-H** (Fig. 30) is slightly different from the above in both the sequence of operations and the calculation algorithms. The initial data for calculating the characteristic of type **M-H** is a hysteresis characteristic of type **B-H**, and it must be fully constructed (the calculations require points of all three branches of characteristic **B-H**).

To construct the hysteresis characteristic of type **M-H** (Fig. 30), make active the window of the required characteristic of the **B-H** (or Φ -H) type, for example, the hysteresis window (Fig. 28 (D)) by clicking it once, then select the **M-H** type graph construction function "Magnetization hysteresis" in the menu [Modules] -> [MOHyster/Regula 7708] -> [Magnetization hysteresis]. A new window "Magnetization hysteresis" displaying the graph of the hysteresis characteristic of type **M-H** (Fig. 30) with the magnetization dimension **M** [kA/m] will be opened in CADR.

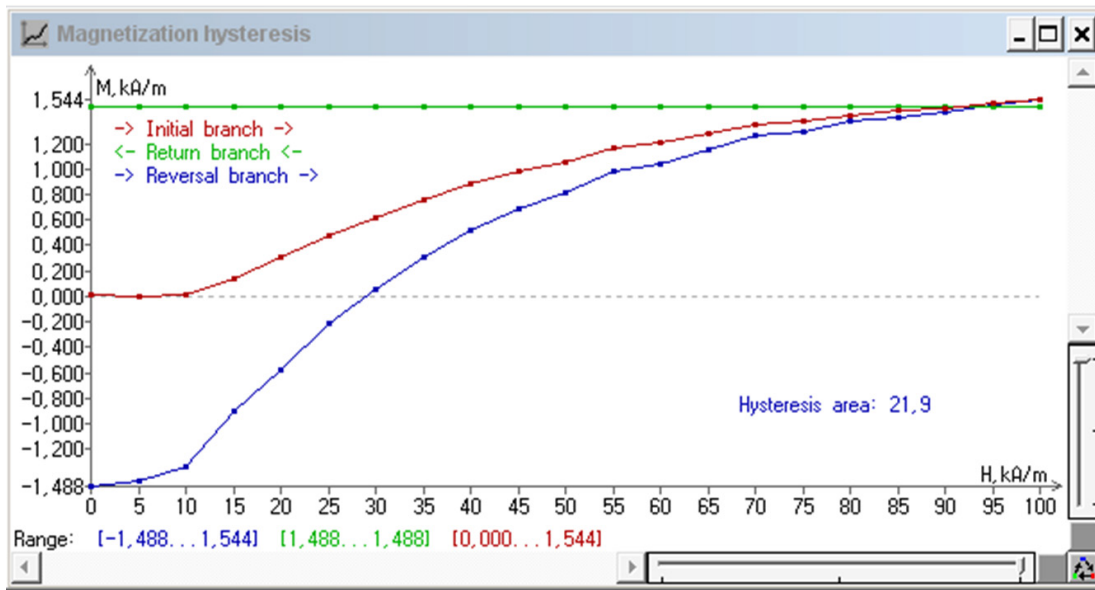
ATTENTION!

If the threshold value for the determination of B_m is changed (see ss.5.5.4.3), the values of the hysteresis characteristic $B-H^m$ will also change, leading to the change in the characteristic of type **M-H**.

5.6.6 Processing and analysis of magnetic hysteresis characteristics

The magnetic hysteresis characteristic allows examining the functional dependences of the magnetic parameters of the object (magnetic induction **B**, magnetic flux Φ and magnetization **M**) on the intensity of the applied magnetic field **H**, taking into account the magnetic history of this object. Thus, comparative examination of magnetic

Figure 30



print specimen involves comparison of their hysteresis characteristics of types **B-H**, **Φ-H** and **M-H**. The compared values can be the following: values of parameters (e.g. for type **B-H**: H_s , B_s , B_r , H_c and W) of the magnetic hysteresis functions (s. 5.6.6.1), the differential characteristics of their graphs (s. 5.6.6.2) and classification categories such as magnetic hardness (s. 5.6.6.3).

Examples of processing and analysis of magnetic hysteresis characteristics based on the comparative examination of known objects – a genuine and a counterfeit 1 USD banknote (printed on a laser printer) (Fig. 11 (A)) are described in the following subsection.

5.6.6.1 Display of the main parameters of the magnetic hysteresis functions

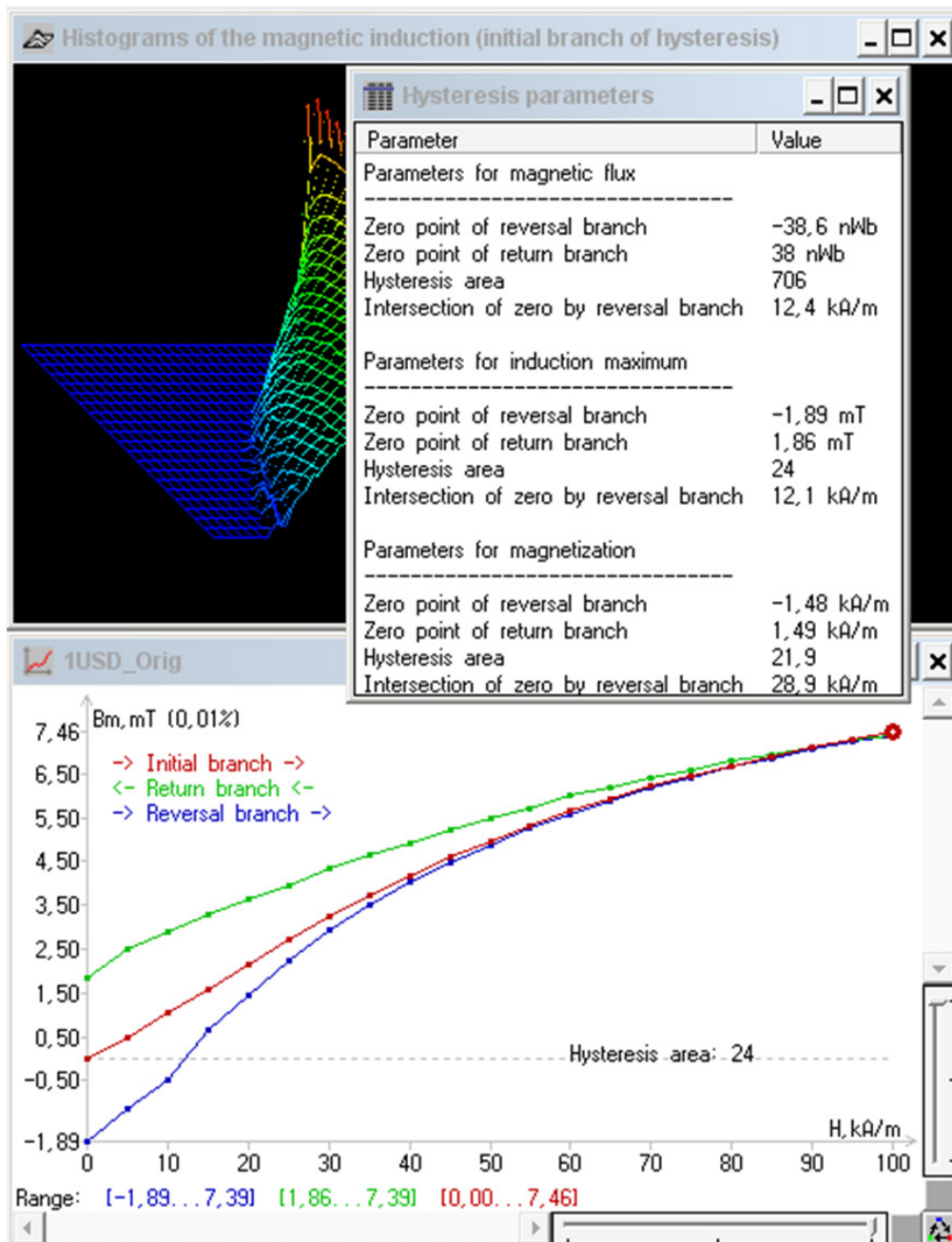
To display the main parameters of the current magnetic hysteresis function, **right-click** the hysteresis window (D) (Fig. 28). In the pop-up function menu (Fig. 29) select the "Hysteresis parameters" option. A new window (Fig. 31) displaying all the basic parameters of the hysteresis characteristics of types **B-H**, **Φ-H** and **M-H** for the selected object displayed in a tabular form will be opened in CADR.

Fig. 31 shows the hysteresis parameters of the genuine 1 USD banknote. The following values were obtained for the characteristic of type **B-H** (Fig. 31): $H_s^B = 80$ kA/m, $B_s = 6.69$ mT, $B_r = 1.86$ to 1.89 mT, $H_c^B = 12.1$ kA/m and $W^B = 24$. The following values were obtained for the characteristic of type **Φ-H**: $H_s^\Phi = 90$ kA/m, $\Phi_s = 227.1$ nWb, $\Phi_r = 38.0$ to 38.6 nWb, $H_c^\Phi = 12.4$ kA/m and $W^\Phi = 706$. The following values were obtained for the characteristic of type **M-H**: $H_s^M = 100$ kA/m, $M_s = M_r = 1.48$ to 1.49 kA/m, $H_c^M = 21.9$ kA/m and $W^M = 28.9$.

The values of the main hysteresis parameters were obtained in the same way for the counterfeit 1 USD banknote (Fig. 32).

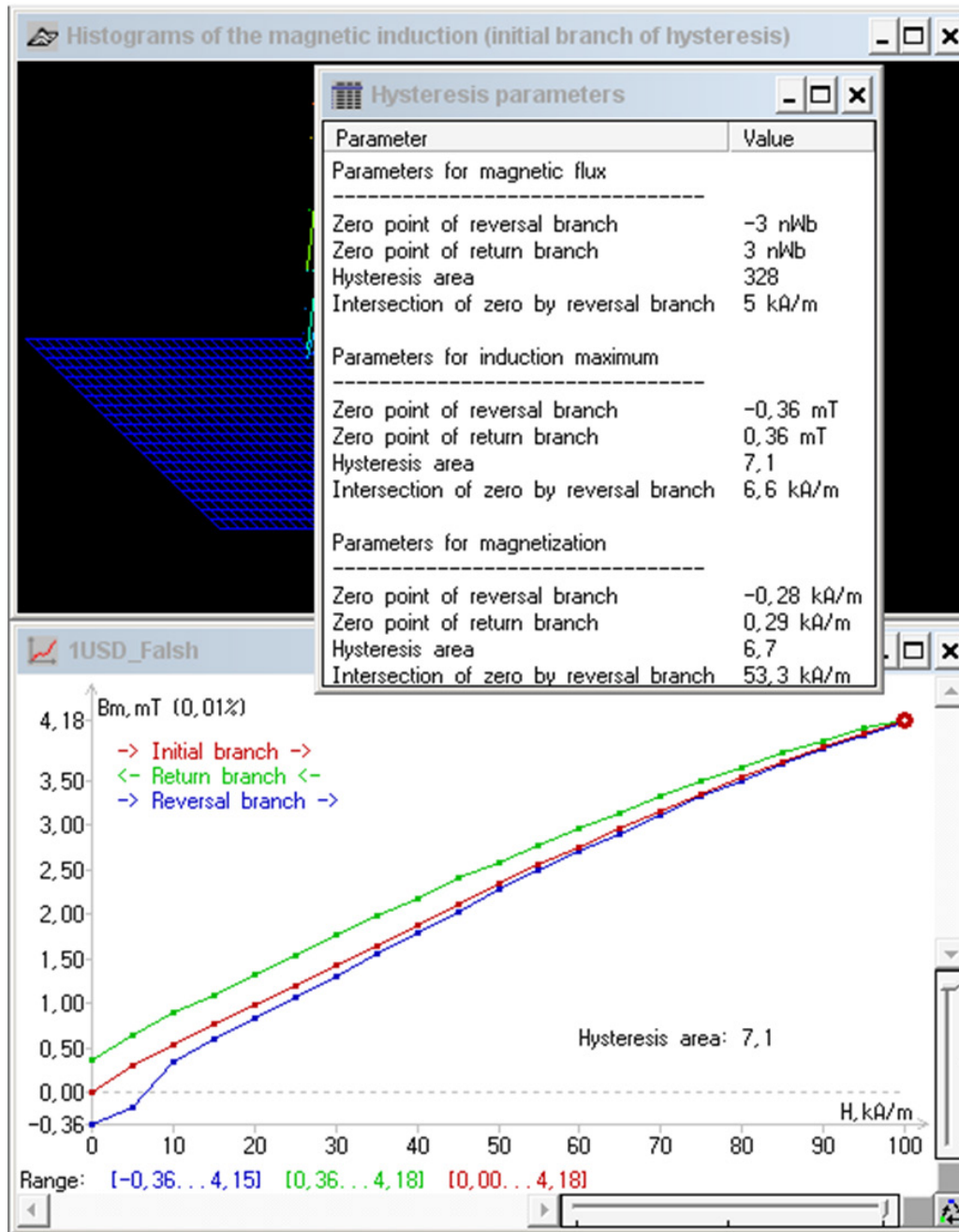
The following values were obtained for the characteristic of type **B-H** (Fig. 32) (parameters that differ by more than 2 times are highlighted in red): $H_s^B \approx 100$ kA/m, $B_s = 4.18$ mT, $B_r = 0.36$ mT, $H_c^B = 6.6$ kA/m and $W^B = 7.1$. The following values were obtained for the characteristic of type **Φ-H**: $H_s^\Phi \approx 100$ kA/m, $\Phi_s = 227.1$ nWb, $\Phi_r = 3.0$ nWb, $H_c^\Phi = 5.0$ kA/m and $W^\Phi = 328$. The following values were obtained for the characteristic of type **M-H**: $H_s^M > 100$ kA/m, $M_s = M_r = 0.28$ to 0.29 kA/m, $H_c^M = 53.3$ kA/m and $W^M = 6.7$.

Figure 31



The definition of the comparison criteria for the hysteresis parameters and setting the threshold values is a methodological task, and is out of scope of this manual. However, in order to complete the analysis of the examples shown in Fig. 31–32), set the "friend-or-foe" threshold to the level of double deviation of the parameter value. The values exceeding this threshold are highlighted in red in the description to Fig. 32.

Figure 32

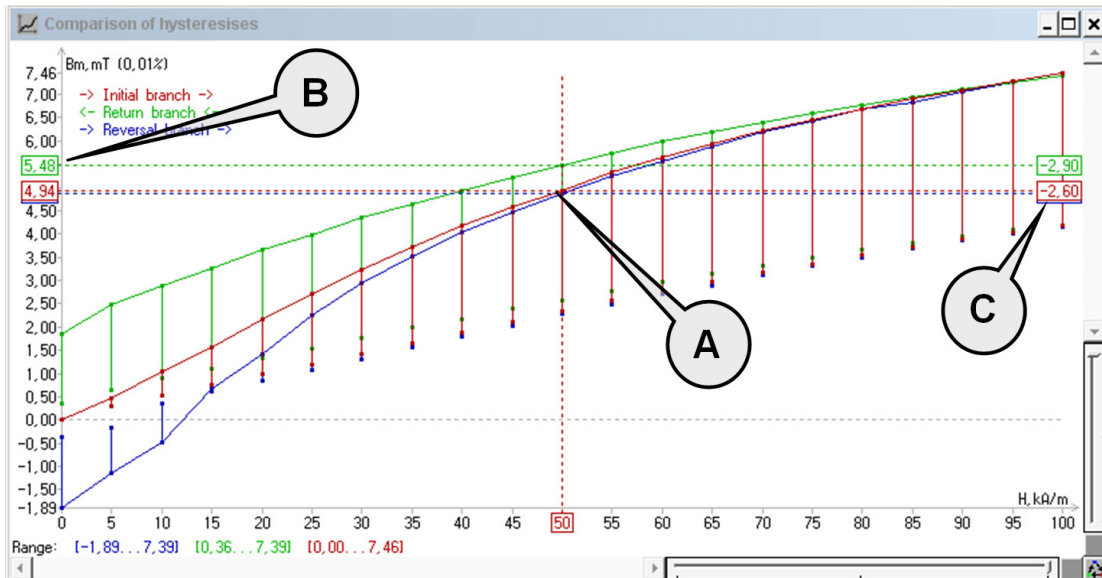


5.6.6.2 Output of differential characteristics of hysteresis graphs

Another method for assessing the similarity of hysteresis characteristics is graphical superposition, where one of the hysteresis is shown with solid lines, and the second is shown with dots in the difference area (Fig. 33). To perform this function, select the windows of the compared hystereses, then enter the menu [Modules] -> [MOHyster/Regula 7708] and select the [Comparison of hystereses or tomograms] item.

A new window "Comparison of hystereses" displaying both compared hysteresis functions will be opened in CADR. Fig. 33 shows the result of comparing hysteresis functions of **B-H** type for the hysteresis loops of a genuine (Fig. 31) and a counterfeit (Fig. 32) 1 USD banknote.

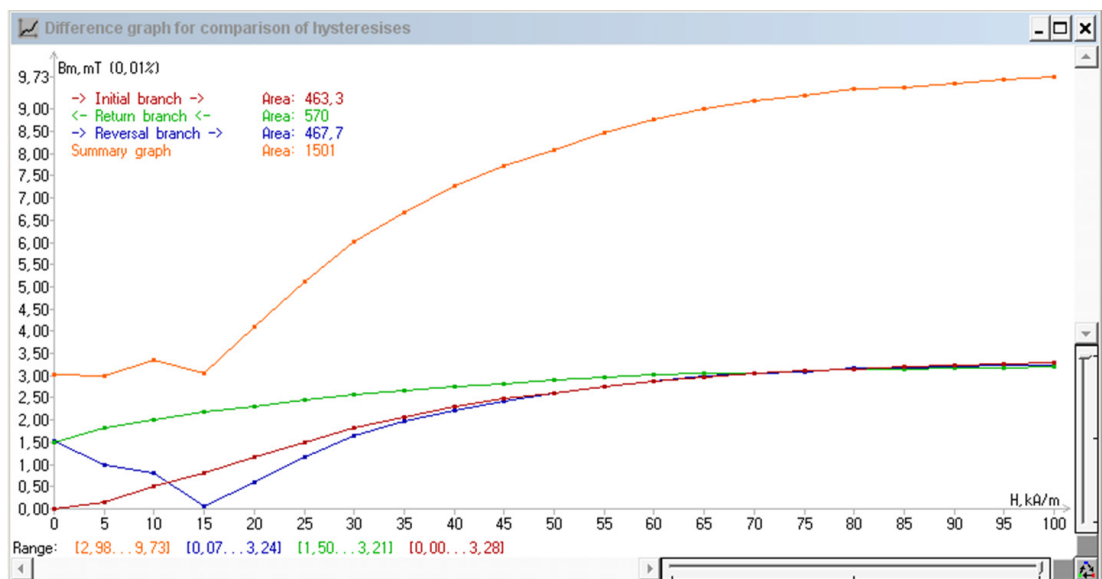
Figure 33



Double-click the graph area (Fig. 33) to enable the cursor **(A)** for displaying the current section parameters: values of the reference hysteresis **(B)** and the difference with the compared hysteresis **(C)**.

In addition to the graphical superposition, a series of difference graphs can be used for the comparison of hystereses (Fig. 34), showing the difference modulus of the compared functions. To access this function, **right-click** the "Comparison of hystereses" window and select the "Difference graph for comparison of hystereses" item in the pop-up menu.

Figure 34



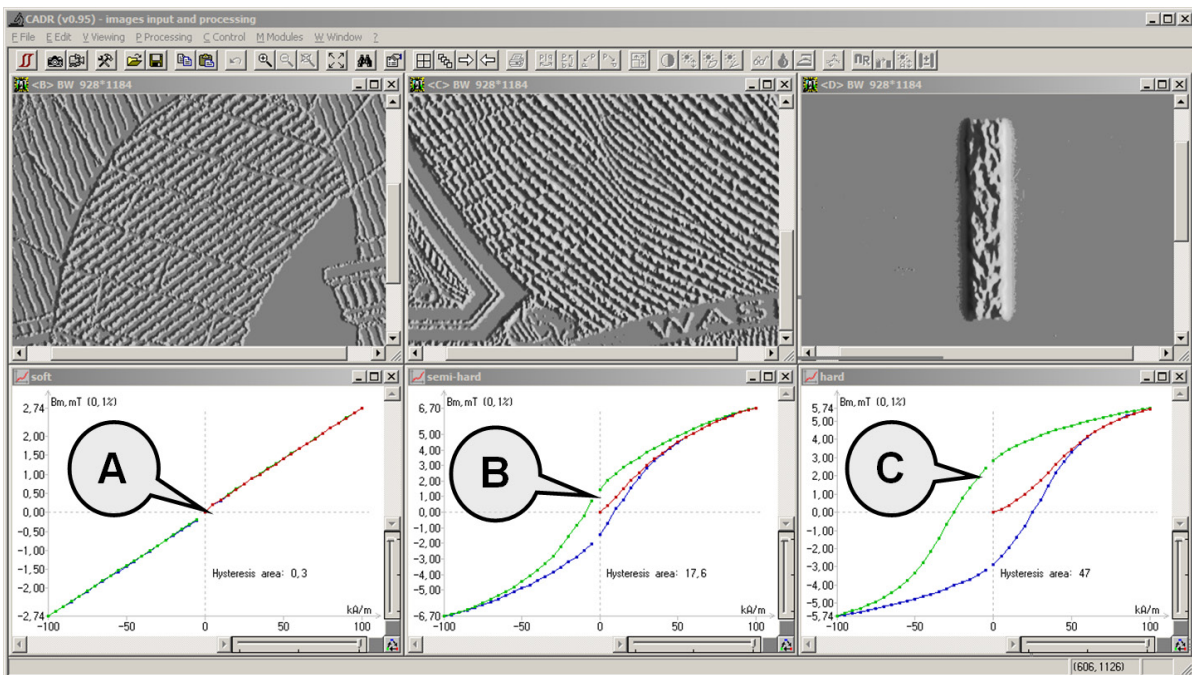
5.6.6.3 Magnetic hardness type classification categories

In ss. 5.6.1 it was mentioned, that when classifying magnetic materials, it is the value of the coercive force H_c that is used as a threshold distributor between magnetically soft, semi-hard and hard materials/objects. It was also noted that the concept of coercive force differs based on the type of magnetic hysteresis characteristic. That is, each of the characteristics **B-H**, Φ -**H** and **M-H** has its own value of the coordinate of intersection with the **x** axis and, accordingly, its own value of the coercive force with a curve type index: H_c^B , H_c^Φ , H_c^M . The values of H_c^B are approximately equal to H_c^Φ (the accuracy depends on the set cutoff threshold B_m and measurement errors), and the value of H_c^B is less than H_c^M (based on the physical properties of ferromagnetic materials). The values of H_c^B and H_c^M are close for magnetically hard materials and, on the contrary, distant for magnetically softer materials. It should be noted that in the previously considered example, the genuine print specimen (Fig. 30, 31) had relatively close values of $H_c^B = 12.1$ kA/m and $H_c^M = 30$ kA/m, and the laser printed specimen (Fig. 32) had significantly different values of the coercive force by magnetic induction and magnetization: $H_c^B = 6.6$ kA/m and $H_c^M = 67$ kA/m.

In technical and regulatory sources there are no uniform interpretation of the approaches to the classification of the types of magnetic hardness of specimen or materials; there are inconsistencies in interpretations related to the type of curve and threshold values of the coercive force. Accordingly, in this manual, the value of the coercive force by the hysteresis of the magnetic induction of H_c^B is conventionally considered reference.

Real **magnetically soft materials (A)** (Fig. 35) have a narrow hysteresis loop ($H_c^B < 0.8$ kA/m), and an ideal magnetically soft characteristic can be represented by one line with all hysteresis branches overlapping each other. Real **magnetically hard materials (C)** have a wide hysteresis loop ($H_c^B > 12$ kA/m), and an ideal magnetically hard characteristic can be represented by a rectangle or parallelogram. Semihard (**B**) magnetic materials/specimen (0.8 kA/m $< H_c^B < 12$ kA/m) take the intermediate position between them. In addition, **magnetically hard materials** are often divided into subgroups: **low-coercive LoCo** ($H_c^B \approx 24$ kA/m) and **high-coercive HiCo** ($H_c^B \approx 320$ kA/m).

Figure 35



The magnetic hysteresis loops in Fig. 35 are displayed in full: they occupy four quadrants (as in Fig. 23), in contrast to the cut two-quadrant loops considered earlier (Fig. 26–33). To display the hysteresis characteristic in a similar way, right-click the hysteresis window. In the pop-up function menu (Fig. 29), select the "Full hysteresis" item.

The following objects were selected as specimens to demonstrate classification categories of magnetic hardness (Fig. 35): intaglio print area of a 5 EUR banknote, intaglio print area of a 1 USD banknote and security thread of a 5 EUR banknote.



5.7 Construction of a magnetic field tomogram

Estimation of stray magnetic fields of an object at a certain distance \mathbf{z} from its surface is necessary for a number of application tasks. Such tasks include: predicting the properties of new magnetic security features, meeting the requirements for sensitivity, spatial resolution and contact conditions for reading devices, comparative assessment of the properties of various printing specimens, calculation of volume integrals from magnetic induction, etc.

From the theory of magnetic recording it is known that the attenuation of the magnetic field as it moves away from the magnetic recording medium depends not only on its magnetic properties and the amplitude of the recording signal, but also on the spatial frequencies recorded on the medium. Low spatial frequencies attenuate much more slowly (i.e., they can be observed at a greater distance \mathbf{z} from the medium surface) compared with high frequencies. As for magnetic print specimens, this means that larger details of magnetic print elements (wide print strokes, protective security threads and thick fibers) will have a larger thickness of the stray magnetic field layer than small details of magnetic print elements (thin-line intaglio printing, fine line printing).

To quantitative assessment of the magnetic field tomogram $\mathbf{B}(\mathbf{x}, \mathbf{y}, \mathbf{z})$, the MOHyster complex performs a series of sequential measurements of scattering magnetic fields of the object in the (\mathbf{x}, \mathbf{y}) plane by the algorithm described in s.5.5 (where the magnetic induction topogram $\mathbf{B}(\mathbf{x}, \mathbf{y})$ on the surface of the object $\mathbf{z} = \mathbf{0}$ was constructed), however, each of these measurements is performed at different values of the distance $\mathbf{z} > \mathbf{0}$ from the surface of the object. In this way, "slices" or layers of magnetic field that attenuate as the distance from the object surface increases are assessed. Since the attenuation of magnetic field is characterized by an inverse exponential function, it is reasonable to use a nonlinear increment step of the \mathbf{z} coordinate for its estimation: the implemented measurement algorithm uses a series of distances $\mathbf{z} = 0; 30; 60; 90; 120; 150; 300; 600; 1200 \mu\text{m}$.

5.7.1 Parameters of the "Magnetic tomography" function

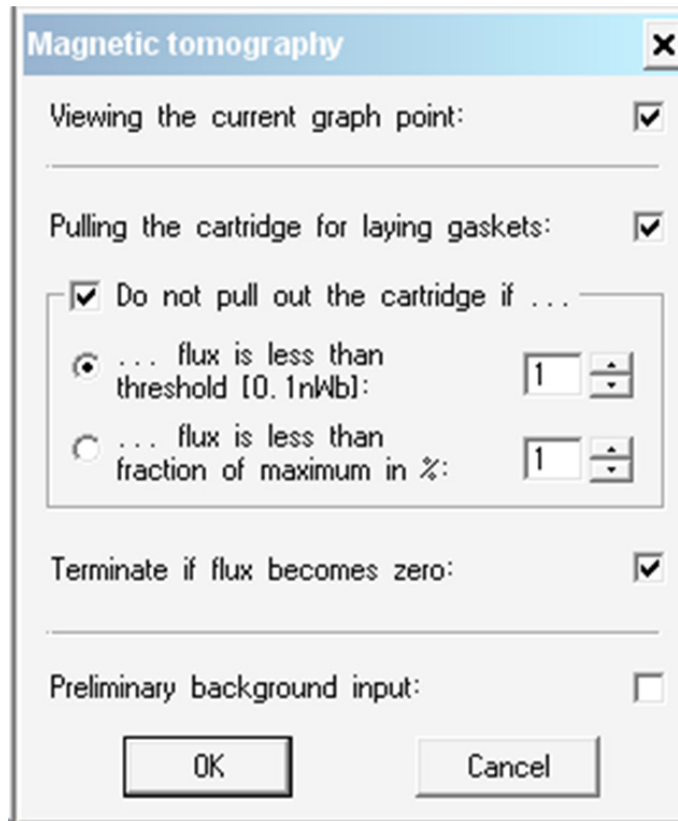
To access the parameters of the "Magnetic tomography" function, first open the "MOHyster control" toolbar by clicking the button  - **(A)** (Fig. 5). On the "MOHyster control" toolbar, **right-click** the button . When clicked, the "Magnetic tomography" function parameters window will open (Fig. 36) with the recommended settings indicated.

If the "Display the current graph point" checkbox is selected, the current point of the graph $\mathbf{B}_m(\mathbf{z})$ or $\Phi(\mathbf{z})$ is round contoured.


If the "Do not extend the cartridge if..." checkbox is selected, the cartridge (object table) will not be extended for installing spacers upon reaching the set threshold value of the measured parameter (absolute or relative value of the magnetic flux).

If the "Preliminary background image capture" checkbox is selected, the necessary background images will be updated. Otherwise, previous background images will be used (which will reduce the accuracy of measurements).


Figure 36





5.7.2 Using the "Magnetic tomography" function

The "Magnetic tomography"  function of the CADR software (Fig. 6) is used for setting the hysteresigraph control algorithm, which allows determining the values of 3D spatial distribution of the stray magnetic field over the object surface $\mathbf{B}(\mathbf{x}, \mathbf{y}, \mathbf{z})$ and present the results in the form of: a tomogram (layered structure) of the stray magnetic field, consisting of a set of 2D functions $\mathbf{B}(\mathbf{x}, \mathbf{y})$, measured at different values of the distance \mathbf{z} from the object surface; graphs of magnetic induction maximum functions $\mathbf{B}_m(\mathbf{x}, \mathbf{y}, \mathbf{z})$ or magnetic flux $\Phi(\mathbf{z})$; volume integral of the magnetic induction $\int \mathbf{B}(\mathbf{x}, \mathbf{y}, \mathbf{z}) [T^*M^3]$.

To estimate the magnetic parameters of a specified area, it is necessary to set and position the object first in accordance with the recommendations described in ss.5.3–5.4.

Run the "Magnetic tomography" function by **left-clicking** the button  (Fig. 6). The digital display **(4)** (Fig. 2) shows the progress of the operation.

Let's consider an example of using the "Magnetic tomography" function in practice. The test object is a genuine 1USD banknote (Fig. 11 **(B)**). Magnetic tomogram parameters are set as shown in Fig. 36. The magnetization value is set on the "MOHyster control" toolbar (Fig. 6).

The magnetic tomogram was constructed in the applied magnetic field with an intensity of $\mathbf{H} = 100$ kA/m after preliminary demagnetization using the button  on the "MOHyster control" toolbar (Fig. 6). To speed up the measurements, the "Draft" mode was activated using the button  (Fig. 6).


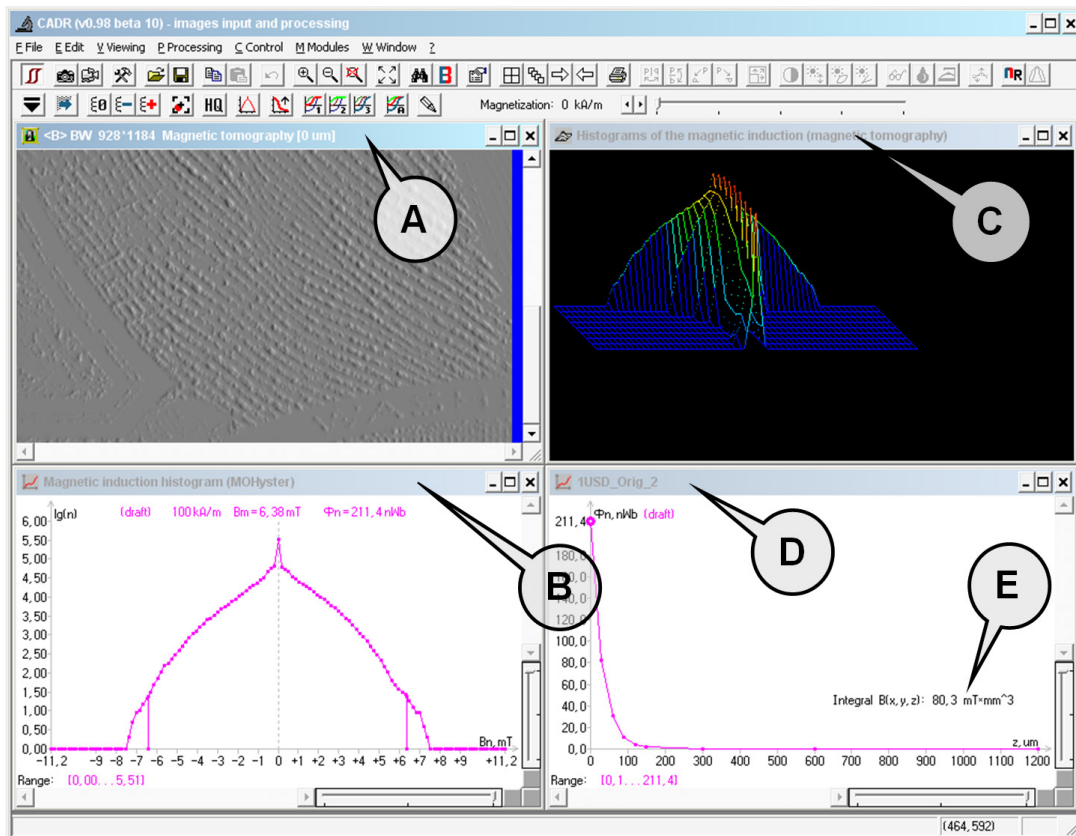
After pressing the function button , the automated process of constructing the specified magnetic hysteresis characteristic of the object begins. It requires the assistance of the operator to change the spacers. This process completes in a few minutes of operation of the MOHyster complex (approx. 3 to 5 minutes). During the constructing the magnetic tomogram, 4 new windows are opened in the CADR software (Fig. 37). The contents of these windows change iteratively as the process progress.

Figure 37



When the first magnetic measurement with the magneto-optical sensor in contact with the object surface (distance $z = 0$) is completed, the object table with the document is extended to the position for setting the object (1 USD banknote), and a pop-up menu asking the operator to install a $30 \mu\text{m}$ spacer strip is displayed in CADR.

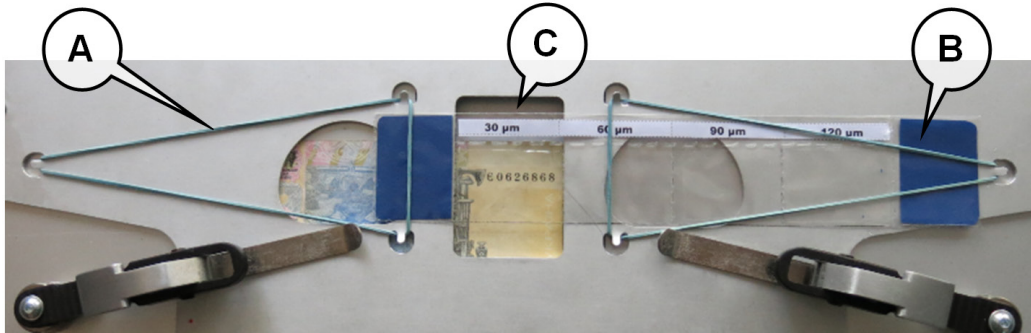
The operator must install rubber bands **(A)** on the hooks the object table, place a set of spacers **(B)** and slide the spacer marked " $30 \mu\text{m}$ " **(C)** into the area of the object table window (Fig. 38). Then confirm the completion of these actions in the pop-up menu. The measurement process will automatically continue: the object table will be slid back into the measurement area, and the measurement of the magnetic field at a distance of $z = 30 \mu\text{m}$ from the surface of the object will be performed. Measurements of the magnetic field will also be made for the remaining points of the characteristic corresponding to a series of distance values $z = 60; 90; 120; 150; 300; 600; 1200 \mu\text{m}$.

The windows of the "Magnetic tomography" function (Fig. 37) with fixed image areas (similar to the arrangement of hysteresis windows) contain the following: **(A)** – display area of the accumulated magneto-optical images; **(B)** – display area of the histograms of magnetic induction **B** and the calculated values of the magnetic flux Φ ; **(C)** – display area of the 3D magnetic history of measurements (histograms of magnetic induction) of the current hysteresis curve; **(D)** – display area of the graphs of magnetic induction

maximum function $\mathbf{B}_m(\mathbf{x}, \mathbf{y}, \mathbf{z})$ or magnetic flux $\Phi(\mathbf{z})$ and (\mathbf{E}) of the volume integral of the magnetic induction $\int \mathbf{B}(\mathbf{x}, \mathbf{y}, \mathbf{z}) [T \cdot m^3]$.

The window navigation and measurement data saving procedure are the same as for the hysteresis function described previously in ss. 5.6.3–5.6.4.

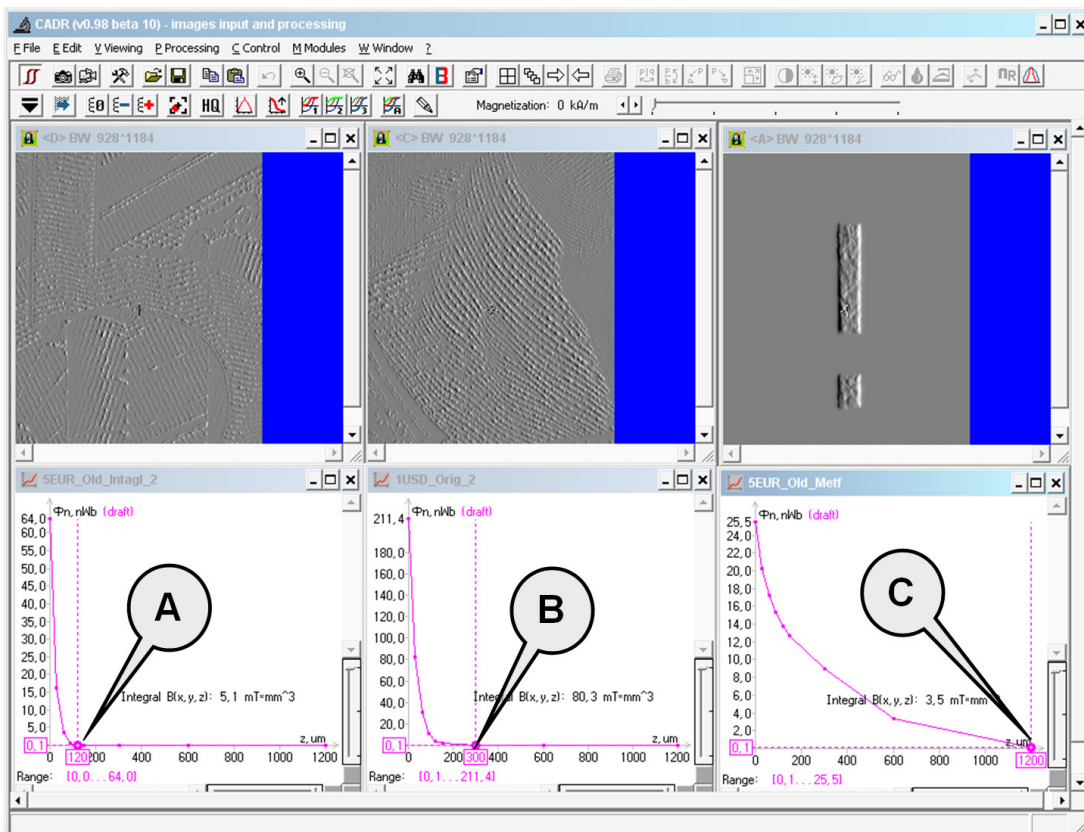
Figure 38





5.7.3 Processing and analysis of magnetic tomograms

Let's consider examples of processing and analysis of magnetic tomograms (Fig. 39) based on comparative examination of the following objects (Fig. 35): intaglio print area of a 5 EUR banknote, intaglio print area of a 1 USD banknote and security thread of a 5 EUR banknote.

Figure 39

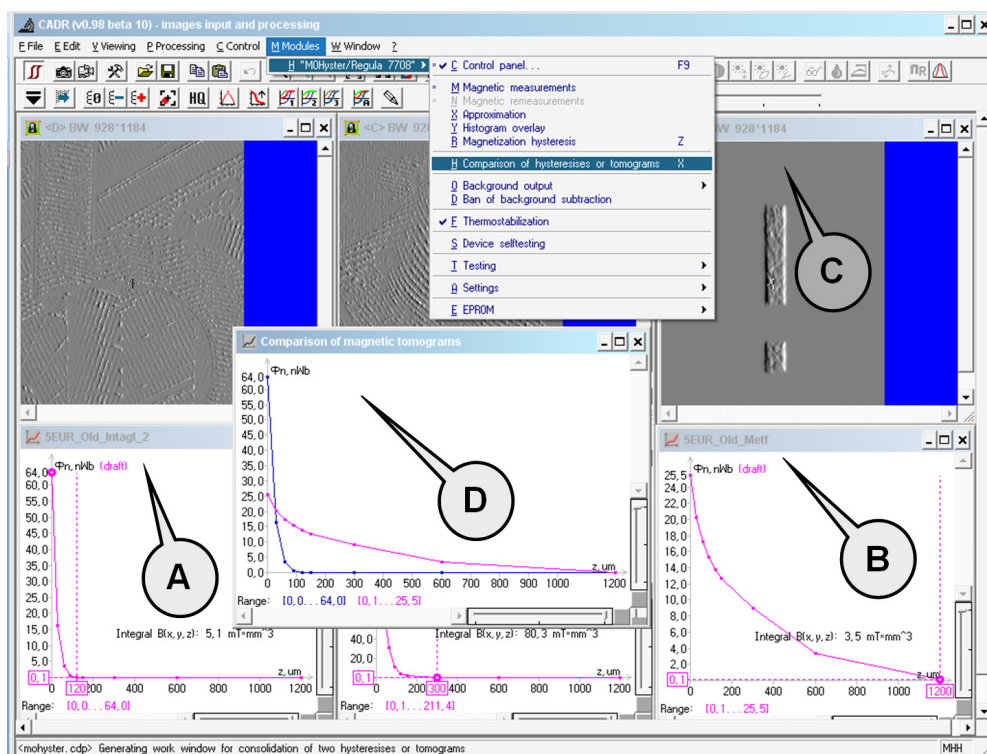


The magnetic tomograms were constructed in the applied magnetic field with an intensity of $H = 100$ kA/m after preliminary demagnetization using the button  on the "MOHyster control" toolbar (Fig. 6). The magnetic tomogram settings were configured as shown in Fig. 36, the magnetization value was set on the "MOHyster control" toolbar. To speed up the measurements, the "Draft" mode was activated using the button  (Fig. 6).

All 3 compared functions of the magnetic flux $\Phi(z)$ follow a common rule: the attenuation of magnetic field is characterized by an inverse exponential function. However, the attenuation level is different: the magnetic flux in the intaglio print area of the 5 EUR banknote (**A**) is decreased to 0.1 nWb at a distance $z = 150$ μm from the surface of the object; the magnetic flux in the intaglio print area of the 1 USD banknote (**B**) is decreased to 0.1 nWb at a distance $z = 300$ μm from the surface of the object; the magnetic flux in the security thread area of the 5 EUR banknote (**C**) is decreased to 0.1 nWb at a distance $z = 1200$ μm from the surface of the object. This pattern of attenuation is explained by the above-mentioned dependence of the attenuation function on the spatial frequencies (sizes) of the magnetic security features. The magnetic field above the intaglio print area of the 5 EUR banknote (**A**) attenuates faster, since the magnetic stroke width in this area ranges from 50 to 120 μm . The magnetic field above the intaglio print area of the 1 EUR banknote (**B**) attenuates slower, since the magnetic stroke width in this area ranges from 80 to 180 μm . The magnetic field above the security thread area of the 5 EUR banknote (**C**) attenuates even more slower, since the magnetic stroke width in this area is 1200 μm .

To compare other characteristics (see Fig. 40), it is necessary to compare the graphs scaled uniformly along the axis of the magnetic flux $\Phi(z)$. To do this, make the windows of the compared graphs active in turn. In this example, the window (**A**) was activated first, then the window (**B**), and then the [Comparison of hystereses or tomograms] function was selected in the program menu (**C**) [Modules] -> [MOHyster/Regula 7708]. As a result, a new window "Comparison of magnetic tomograms" (**D**) is opened, displaying the compared graphs on a single scale.

Figure 40



As can be seen in Fig. 39–40, the magnetic flux on the surface ($\mathbf{z} = \mathbf{0}$) differs noticeably for the compared objects. The intaglio print area of the 1 USD banknote (**B**) has the highest magnetic flux $\Phi(\mathbf{z} = \mathbf{0}) = 211.4$ nWb. Besides the high density and high relief of the print, this area also shows a high magnetic permeability of the magnetic material used ($\mathbf{B}_m(\mathbf{x}, \mathbf{y}, \mathbf{z} = \mathbf{0}) = 5.28$ mT). The intaglio area of the 5 EUR (**A**) banknote has a noticeably lower magnetic flux $\Phi(\mathbf{z} = \mathbf{0}) = 64$ nWb. This is due to a slightly lower print density and a low magnetic permeability of the magnetic material used ($\mathbf{B}_m(\mathbf{x}, \mathbf{y}, \mathbf{z} = \mathbf{0}) = 2.46$ mT). The security thread area of the 5 EUR banknote (**C**) has the lowest surface magnetic flux $\Phi(\mathbf{z} = \mathbf{0}) = 25.5$ nWb. This is due to the very low print density (the area of the security thread is less than 5% of the magneto-optical frame area), which does not allow producing a large magnetic flux despite the high magnetic permeability of the magnetic material used ($\mathbf{B}_m(\mathbf{x}, \mathbf{y}, \mathbf{z} = \mathbf{0}) = 5.76$ mT).

Thus, the following values of the magnetic induction volume integrals of $\int \mathbf{B}(\mathbf{x}, \mathbf{y}, \mathbf{z})$ for the compared objects were obtained: $\int \mathbf{B}(\mathbf{x}, \mathbf{y}, \mathbf{z}) = 80.3$ mT*mm³ for the intaglio print area of the 1USD banknote (**B**); $\int \mathbf{B}(\mathbf{x}, \mathbf{y}, \mathbf{z}) = 5.1$ mT*mm³ for the intaglio area of the 5 EUR banknote (**A**) and $\int \mathbf{B}(\mathbf{x}, \mathbf{y}, \mathbf{z}) = 3.5$ mT*mm³ for the security thread area of the 5 EUR banknote (**C**).

6 TEST OBJECTS AND COMPLEX PERFORMANCE MONITORING

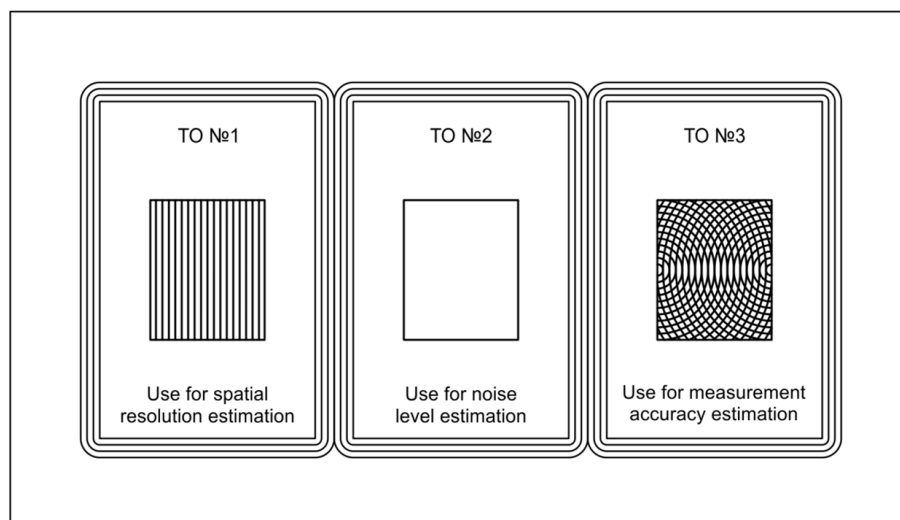
Most of the performance monitoring, self-tuning and calibration functions the MOHyster complex are automated. Therefore, it is enough for the user to follow the requirements of this operating manual and the diagnostic messages of the CADR software. In case of a self-test error or failure of the complex, the CADR software will report the error code in the "XXX_error" format. If there are systematic self-test errors, please contact the supplier.

However, the automatic performance monitoring does not provide for the estimation of some important parameters that have an effect on the quality of magneto-optical visualization and accuracy of magneto-optical measurements. A special set of test objects for checking these parameters is included in the MOHyster package.

6.1 Test objects

The test object set is a sample of magnetic print (printed on a laser printer) with the specified parameters. It is shown in Fig. 41.

Figure 41



ATTENTION!

Fig. 41 shows only the appearance, not the test object set itself. The test object set is located in the MOHyster complex SPTA kit in a plastic bag.

The test object set (Fig. 41) has 3 print areas, each of which corresponds to a certain type of test object. It is used for testing a number of basic technical characteristics of the device:

Test object No.1 is used for estimating the spatial resolution which depends on the focus of the optical input system, the quality of lighting, polarization and pressing systems. It has vertical straight lines printed with magnetic ink: stroke width is 0.005" (127 μm), stroke spacing is 0.005" (127 μm).

Test object No.2 is used for estimating the measurement noise level which depends on the quality of the magnetization system, damage and contamination of the magneto-optical sensor and the cleanliness of the pressing unit. It has a blank area without any magnetic print.


Test object No.3 is used for estimating the measurement accuracy which depends on the quality of the entire complex of magneto-optical visualization, magnetization, magnetic compensation and pressing systems. It has intersecting arcs printed with magnetic ink: stroke width is 0.005" (127 μm), stroke spacing is 0.005" (127 μm).

The complex shall be checked using the test object set as needed, but at least once a year.

6.2

Estimating the spatial resolution using test object No. 1

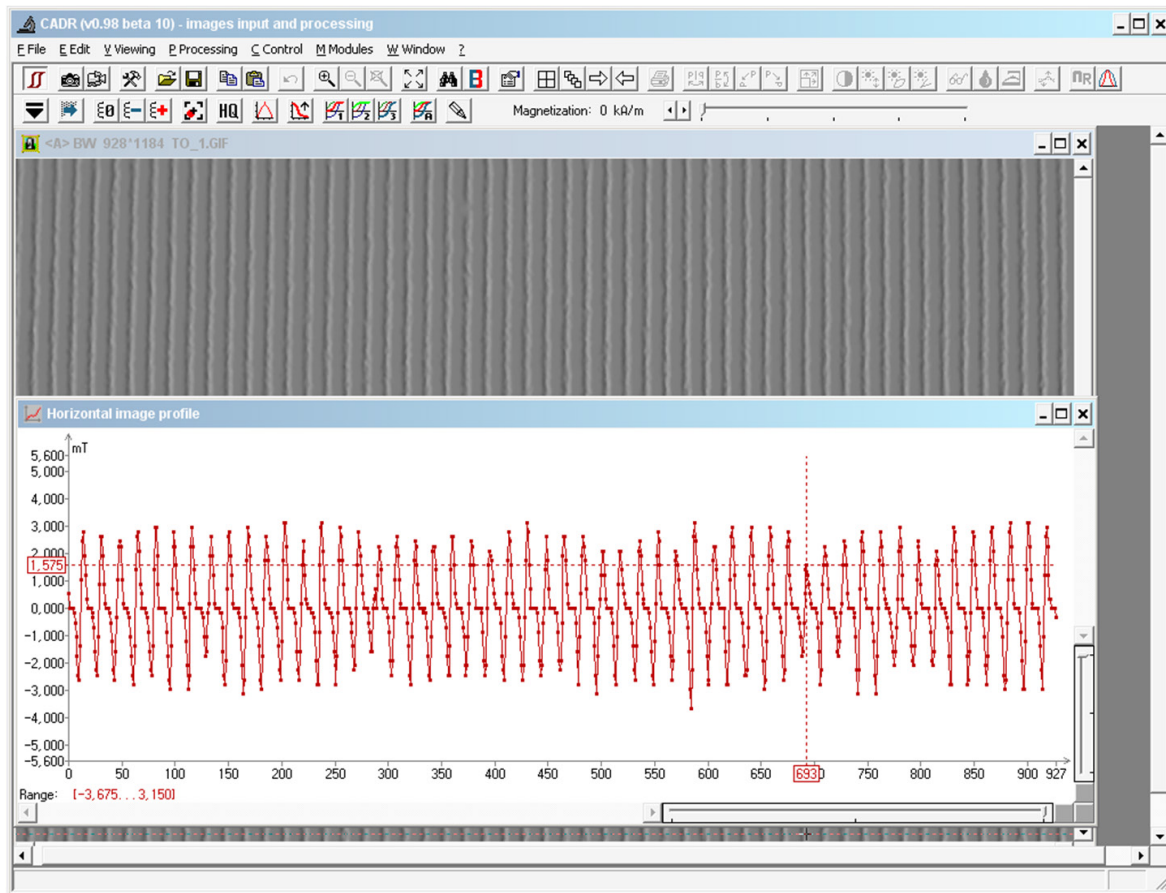
To estimate the spatial resolution, first set and position test object No. 1 in accordance with the recommendations of ss. 5.3–5.4. Check the vertical position of the test object strokes and the alignment of the control area with the image area (the contour frame must be out of the image area).

Perform a magnetic measurement  (see ss.5.5.2) in the applied magnetic field $H = 100 \text{ kA/m}$. The "Draft" mode must be disabled. Construct an induction graph in the horizontal section of the accumulated magneto-optical image. To do this, make the window with this image active by clicking it once, then select the "Horizontal image section" item in the menu [View (C) (Fig. 13)] -> [Graphs]. An example of the test result is shown in Fig. 42.

Analyze the accumulated magneto-optical image (see Fig. 42). The observed vertical strokes must be stable (without any gaps along the entire length), with the sharpness and contrast almost equal throughout the entire image area. For a quantitative assessment, analyze the horizontal section graph of the accumulated magneto-optical image: the amplitude of the observed signal must not decrease below 1.2 mT for 10 or more pulses in a series.


To compare the results with the configured values, open the file TO_1.gif, which is provided with the system. Compare the obtained histogram of magnetic induction (Fig. 42) with the histogram in the file TO_1.gif (see ss.5.5.4). The permissible difference in the magnetic flux is not more than 10% of the reference TO_1.gif. The permissible histogram distance: $d < 30$.

Figure 42



6.3 Estimating the measurement noise using test object No. 2

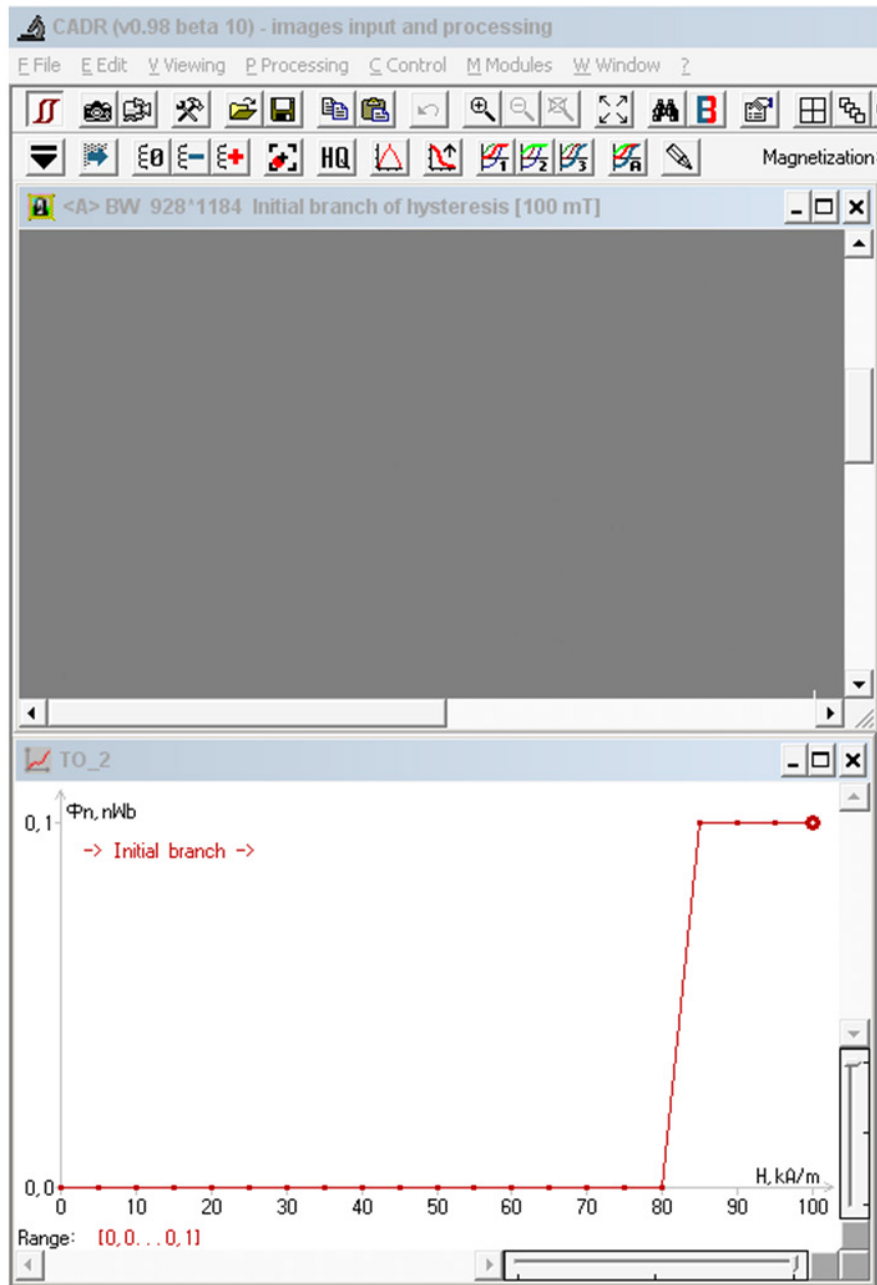
To estimate the spatial resolution, first set and position test object No. 2 in accordance with the recommendations of ss. 5.3–5.4. Check the alignment of the control area with the image area (the contour frame must be out of the image area).

Construct the initial branch of the hysteresis characteristic of type Φ -H  (see ss. 5.6.3). The "Draft" mode must be disabled. An example of the test result is shown in Fig. 43.

Analyze the measurement results (Fig. 43). The value of the noise magnetic flux must not exceed 1.0 nWb for any of the points in the measurement range (in the example in Fig. 43, the maximum value of the noise magnetic flux is 0.1 nWb).

To compare the results with the configured values, open the file TO_2.gif, which is included in the package. Compare the obtained hysteresis characteristic (Fig. 43) with the identical characteristic in the file TO_2.moh (see ss. 5.6.6). The permissible difference in the magnetic flux for any point in the measurement range is not more than 50% of the reference TO_2.moh.

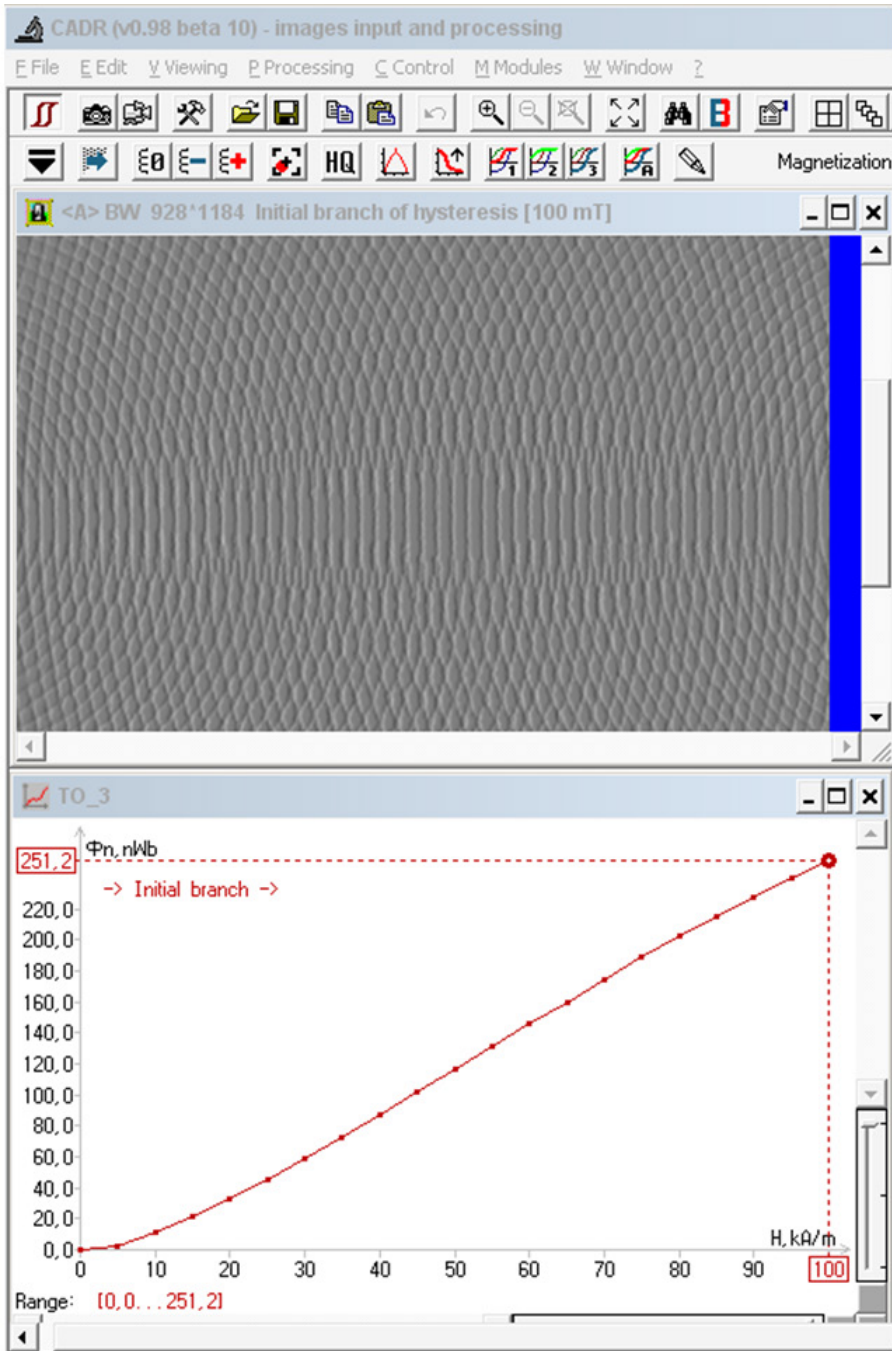
Figure 43



6.4 Estimating the measurement accuracy using test object No. 3

To estimate the spatial resolution, first set and position test object No. 3 in accordance with the recommendations of ss. 5.3–5.4. Check the alignment of the control area with the image area (the contour frame must be out of the image area).

Figure 44



Construct the initial branch of the hysteresis characteristic of type Φ - H (see ss. 5.6.3). The "Draft" mode must be disabled. An example of the test result is shown in Fig. 44.

Analyze the measurement results (see Fig. 44). The hysteresis curve must be smooth, without any kinks or discontinuities through the entire measurement range.

To compare the results with the configured values, open the file TO_3.gif, which is included in the package. Compare the obtained hysteresis characteristic (Fig. 44) with the identical characteristic in the file TO_3.moh (see ss.5.6.6). The permissible difference in the magnetic flux for any point in the measurement range is not more than 10% of the reference TO_3.moh.

7

SHUTTING DOWN

Close the CADR software. The object table of the hysteresigraph will switch move to the object setting/removal position.

If the complex will not be used for more than an hour (pause), turn off the power switch of the device. All indicators on the front panel turn off.

If the device will not be used for a long time (more than 8 hours), disconnect the power supply plug from the power outlet. Cover the device with a textile cover.

8

ROUTINE MAINTENANCE

Keep the surface of the object table and pressing unit clean. Wipe it regularly from contaminations and dust, especially if the unit has not been used for a long time.

IMPORTANT!

Dust particles can cause early wear of the magneto-optical head sensor.

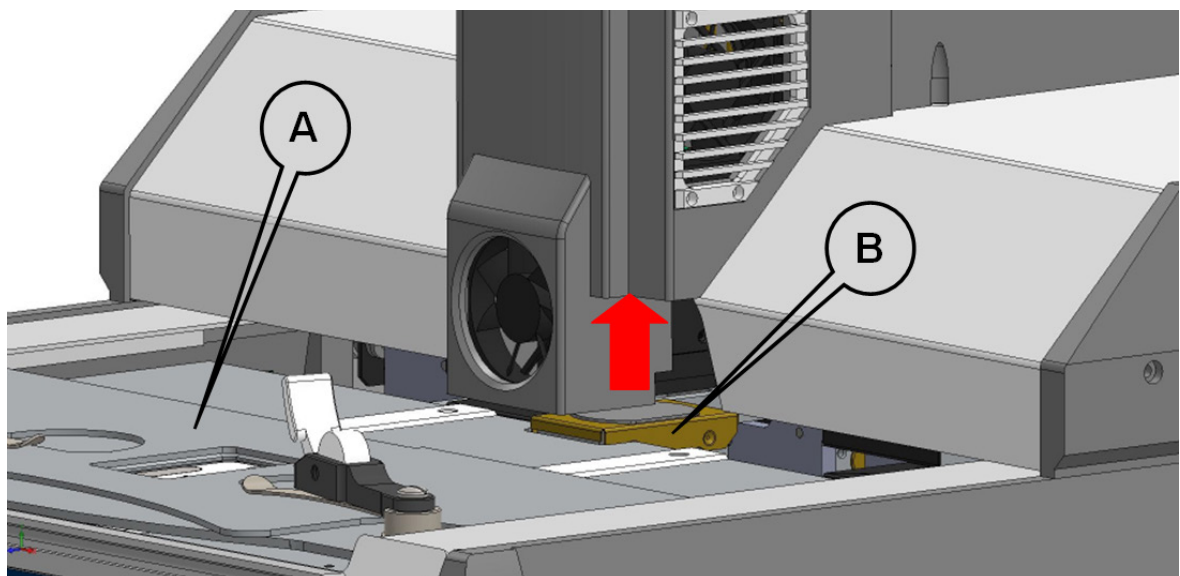
To remove dust and other contaminations, use products designed specifically for cleaning plastic surfaces of office equipment (wet tissues, special liquids, etc.). After using cleaning liquids or tissues, wait for the surface of the object table to dry completely before scanning a document.

Do not use cotton wool or similar fibrous materials or synthetic fabrics for cleaning the object table surface. Cotton fabric or paper towel is recommended.

The only element of MOHyster that can be replaced by the user is the fluoroplastic cover of the pressure unit (included in the package). The fluoroplastic cover should be replaced in case of damage (rupture) or nonremovable surface contamination with magnetic particles.

To replace the fluoroplastic cover of the pressure unit, turn on MOHyster using the button **(3)** (Fig. 2) without starting the CADR software, then wait for the self-test to complete and turn off the device. Manually pull the object table **(A)** (Fig. 45) towards you until it stops.

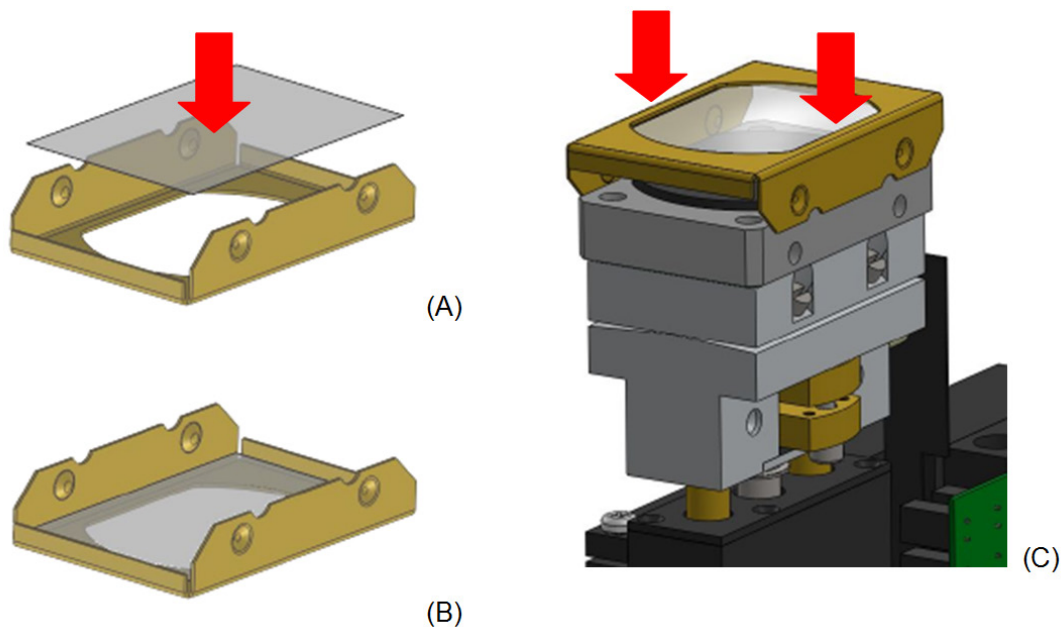
Figure 45



Remove the holding frame **(B)** (Fig. 45) with the damaged fluoroplastic cover by pulling it up.

Remove the damaged fluoroplastic cover from the holding frame. Install a new fluoroplastic cover (included in the SPTA kit) inside the holding frame **(A-B)** (Fig. 46). Place back the holding frame and lock it by pressing until it clicks **(C)** (Fig. 46).

Figure 46



9 SPECIFICATIONS

Table 1

Parameter/characteristic	Value
1. Maximum size of the examined document, mm	160×60×0,2
2. Magneto-optical image area, mm	14.5×18
3. Magneto optical image frame size, pix.	1024×1280
4. Image dot physical size, μm	14
5. Accumulated magneto-optical image size, pix.	928×1184
6. Magnetic induction measurement range, mT	±11.2
7. Magnetic induction sensitivity threshold, mT	0.175
8. Magnetization field adjustment range, kA/m	0...100
9. Magnetization field sampling rate, kA/m	5
10. Limit preliminary magnetization:	
- internal preliminary magnetization unit, kA/m	±120
- external preliminary magnetization unit, kA/m	±350
11. Maximum construction time of full hysteresis characteristic, min	30
12. System requirements:	
- operating system	Windows XP, Windows 7, 8, 10
- communication with a PC	through the USB

Table 1 (continued)

Parameter/characteristic	Value
13. Power	24 V \pm 10%, 2 A from a switched-mode power supply: 100–240 V \sim , 50/60 Hz, 1.5 A max
14. Recommended operating temperature range: – in the magnetic parameter measurement mode, °C – during other operations*, °C	(+25 \pm 1) (+25 \pm 10)
15. Scanner dimensions (W×D×H), mm	560×520×360
16. Weight of the device with the power supply unit, kg	25
17. Operating conditions: – Overvoltage category – Pollution Degree – Altitude above sea level, m – Relative humidity, % – Atmospheric pressure, mm Hg	Indoor use only OVC I 2 2000 45–80 630–800

* – fast magnetic measurements, visualization and processing of results.

ATTENTION!

If the device is used in a manner not specified in this manual, the protection provided by the device may be impaired.

10**TRANSPORTATION AND STORAGE**

Protect MOHyster from shock and vibration.

Transportation and storage of the device shall be carried out in the original packaging using the provided transportation accessories.

WARNING: HEAVY OBJECT!

The device is very heavy. To reduce the risk of lifting related injuries, death, or damage to your device, we recommend that a minimum of two people lift the device. It is important to use proper lifting posture when lifting and/or moving the device.

Before installing the transport accessories, set the movable parts of the hyste-resigraph to the specific position. To do this, turn on the device using the button **(3)** (Fig. 2), without turning on the PC, and wait for the self-test to complete. Then turn off the device and disconnect the power and USB cables.

When placing the device in the package, install the transport accessories from the transport kit, as shown in Fig. 47–49.

Place the device approximately in the middle of the plate of the transport packaging **(1)** (Fig. 47). Make sure that the device case does not sway on the plate. To eliminate swaying, adjust the height of the base feet. Slide the thrust plates **(2)** along the bottom plane of the device so that their recesses are in contact with the device feet. Center the device on the plate to match the fixing holes of the thrust plates **(2)** with the corresponding points on the plate **(1)**.

Secure the thrust plates **(2)** by screwing 6 screws into the corresponding points of the plate **(1)** (Fig. 48).

Figure 47

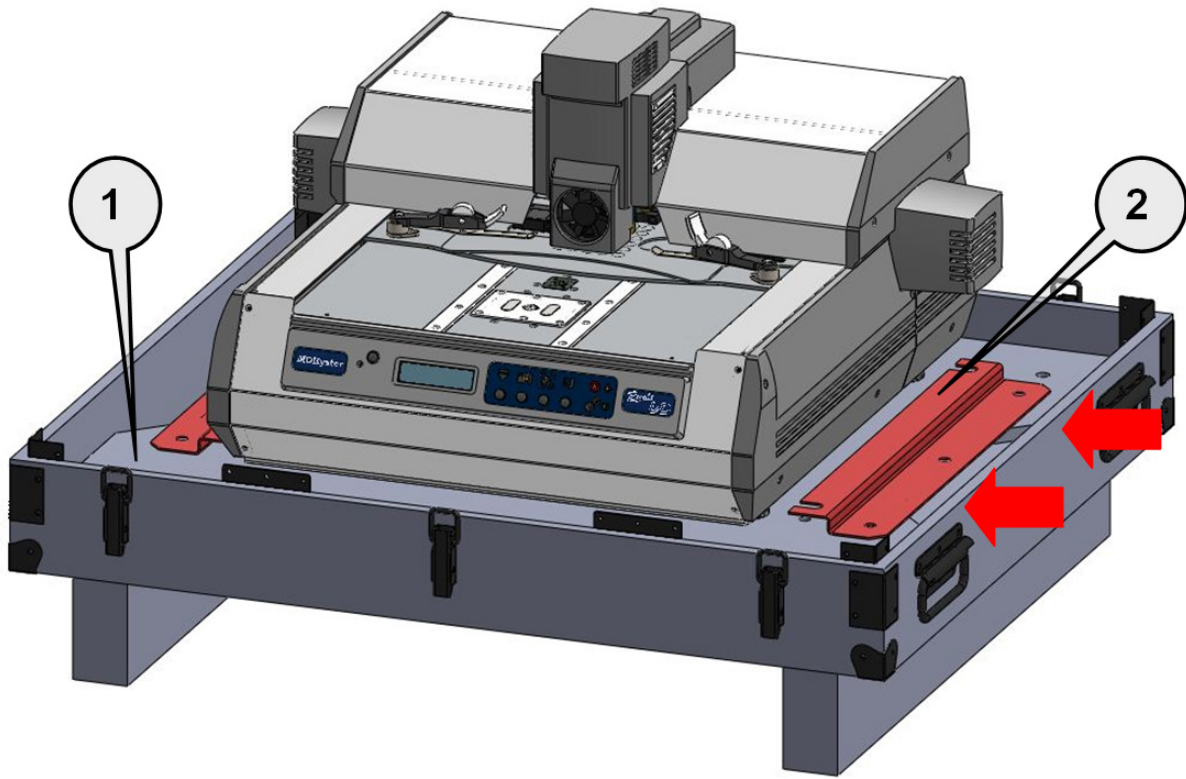


Figure 48

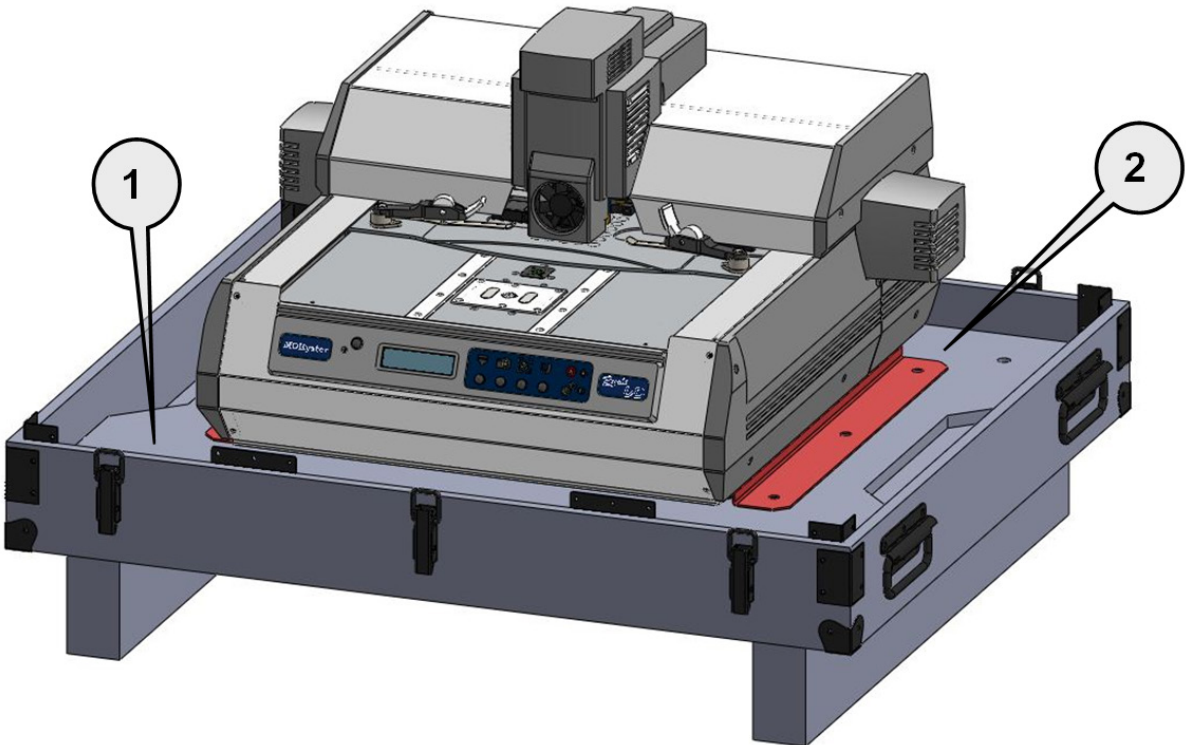


Figure 49

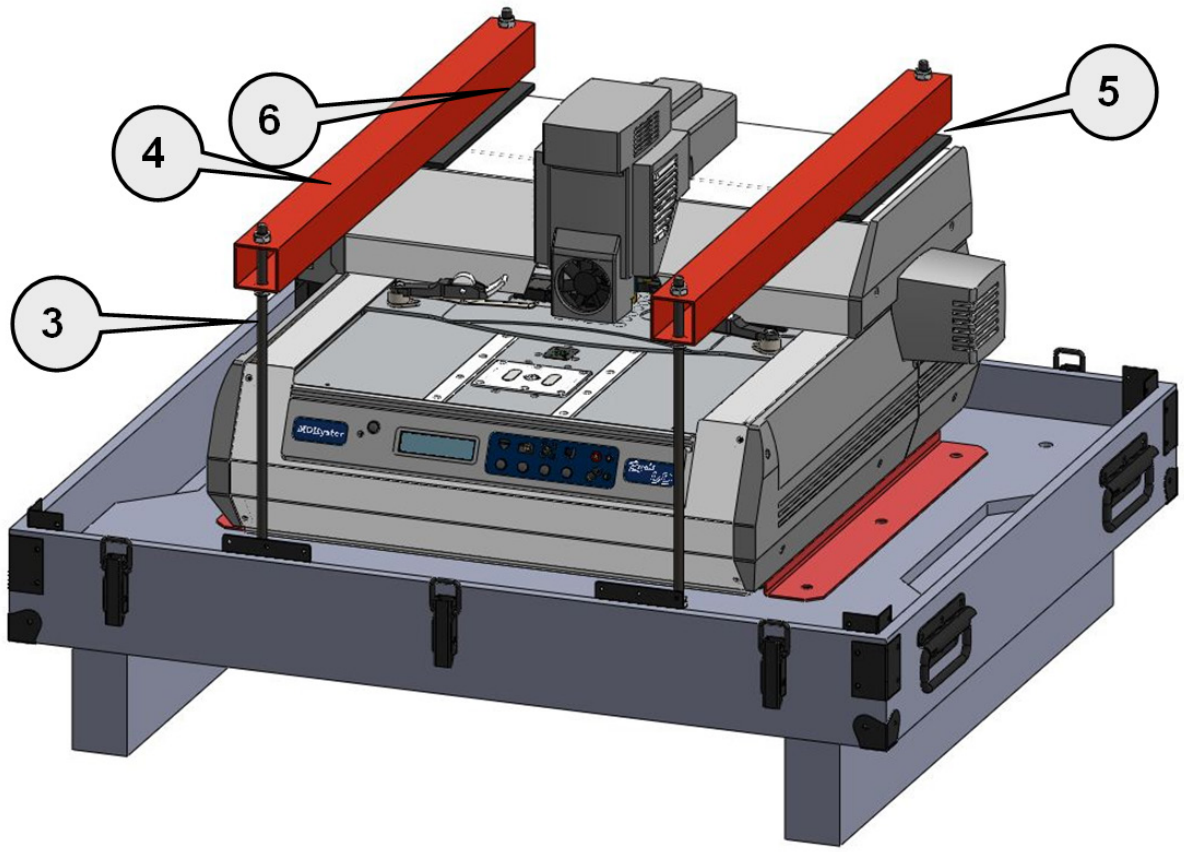
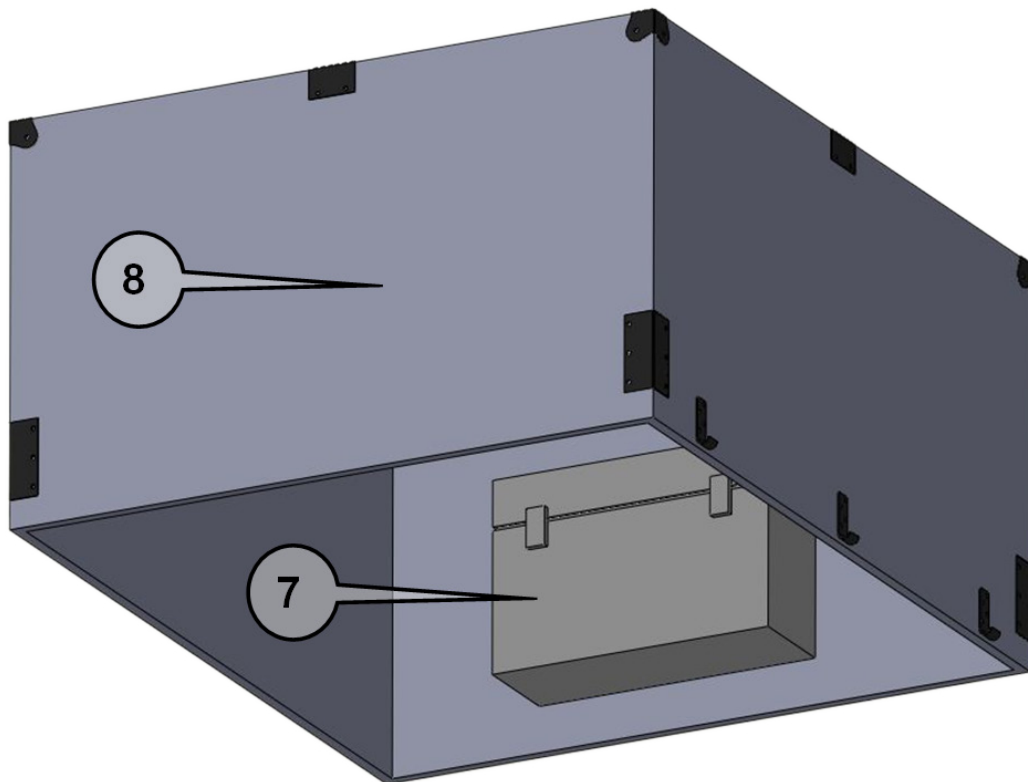


Figure 50



Screw 4 studs **(3)** (if they were previously unscrewed) into the base of the plate (Fig. 49). Place the foam gaskets **(5)** and install the horizontal links of the cradle **(4)**. Secure the cradle with the nuts **(6)**.

During the operation of the device, when transport accessories are not used, it is recommended to store them together in the transport packaging.

For storing the power supply unit, SPTA kit, cables, test objects, etc. for transportation, use the box **(7)** (Fig. 50) located on the inner surface of the transport packaging cover **(8)**.

Climatic conditions of storage and transportation:

- air temperature: (+5...+40) °C
 - relative air humidity: max. 80 % at +15 °C
 - atmospheric pressure: (100 ±4) kPa / (750 ±30) mmHg
- Maximum number of packages for stacking: 5.

11 DISPOSAL

At the end of the service life or in case of nonoperability, the device must be disposed as per the rules established at the user's enterprise and in compliance with the applicable safety regulations.

The disposal of the device may be performed only by trained personnel.



This symbol means the product must not be discarded as household waste, and should be delivered to an appropriate collection facility for recycling. For more information on disposal and recycling of this product, contact your local municipality service, or the shop where you bought this product.

12 MANUFACTURER'S WARRANTY

The warranty period of the MOHyster complex is **12 months** from the date of sale, provided that the Customer observes the rules for operation, storage and transportation stated in this Manual and subject to the integrity of the manufacturer's seals on the device.

The warranty storage period is __ __ months from the date of manufacture.

The average service life is **5 years**.

Use of the device at the end of the service life

The service life of MOHyster specified by the manufacturer is guaranteed subject to the intended use described in this Manual as well as subject to observance of the rules for operation, storage and transportation by the Consumer. The actual service life may exceed the service life specified by the manufacturer, provided that the device is handled carefully and the rules for operation are observed.

At the end of the service life of the device, contact an authorized service center to perform preventive maintenance and determine the serviceability of the device. Services on the preventive maintenance and diagnostics of the device, provided by service centers, are paid.

The manufacturer does not recommend continuing to operate the device at the end of its life without performing preventive maintenance at an authorized service center, since in this case the device may be dangerous to life, health or property of the consumer.

CERTIFICATE OF CONFORMITY

Magneto-optical hysteresigraph MOHyster Regula 7708.

The product with serial number _____ was manufactured and approved for use in accordance with the mandatory requirements of state standards and applicable technical documentation.

Responsible for acceptance:

(position)

(personal signature)

(print full name)

(day, month, year)

Seal

Manufacturer: Regula Baltija Ltd.

Address for mailing claims with regard to the quality of the device:

97, A. Pumpura Street, Daugavpils,

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