PLEASE, READ

Notice:

- The set you received may differ from the set described in this manual. For more detailed information refer to the specification of your contract.
- Some names mentioned in this manual might be registered trademarks.

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No part of this manual for no purposes may be reproduced or transmitted in any form and by any means, electronic or mechanical, including photocopying and video-recording, without a written permission from the NT-MDT company.

GENERAL SAFETY MEASURES

⚠️ ATTENTION! You have to connect the electronic modules of the equipment through the supply-line filters, for decreasing the influence of possible power line disturbances on the process of measurement.

- When using the device for etching needles, observe safety rules for handling chemical agents;
- Be careful when handling a probe! Observe safety rules for handling piercing objects;
- Observe safety measures for operation with electrical installations. Provide proper grounding before you switch-on the device. Switch-off the device before connecting or disconnecting cables. Connecting or disconnecting cables in working unit may lead to severe damage of the device;
- Do not disassemble any part of the device! Disassembling of the product is permitted only to experts certified by NT-MDT company;
- Do not connect additional devices to the instrument without advice from NT-MDT specialists;
- Protect the device from mechanical shocks and excessive stresses. Note that the scanner’s walls thickness is only 0.5 mm;
- Avoid to expose the device to high temperatures and to spill liquids on it;
- During transport, tight the transporting screw in the lower part of the measurement head’s basis (transporting screw is a part of the delivery set), and keep it inside the protective packaging to avoid damage in the process of transportation.
OPERATIONAL DOCUMENTATION SET

- Instruction Manual;
- Practical Guide.
NanoEducator SPM. Instruction Manual

INTRODUCTION ........................................................................................................................................... 6

1. NANOEDUCATOR SPM WORKING PRINCIPLE AND DESIGN ........................................................................ 8
   1.1. NANOEDUCATOR SPM WORKING PRINCIPLE ................................................................................................ 8
   1.2. NANOEDUCATOR DESIGN ................................................................................................................................ 11
       1.2.1. Force Interaction Probe ............................................................................................................................... 12
       1.2.2. Tunnel Current Probe .................................................................................................................................. 13
       1.2.3. Scanner ......................................................................................................................................................... 14
       1.2.4. Tip-sample Approach Mechanism .................................................................................................................. 15
   1.3. FEEDBACK LOOP OPERATION ....................................................................................................................... 16
   1.4. APPROACHING THE TIP .................................................................................................................................. 16
   1.5. DEVICE TECHNICAL SPECIFICATIONS ........................................................................................................ 17

2. INITIAL SETTINGS OF THE DEVICE .............................................................................................................. 18
   2.1. SWITCHING THE DEVICE ON .......................................................................................................................... 18
   2.2. INSTALLING THE SOFTWARE ......................................................................................................................... 19
       2.2.1. NanoEducator Software Structure ............................................................................................................... 19
       2.2.2. Installing NanoEducator Software ............................................................................................................. 19
   2.3. SAMPLE MOUNTING AND SELECTING AN AREA OF INVESTIGATION ....................................................... 21
   2.4. INSTALLING THE PROBE .............................................................................................................................. 22
   2.5. OPERATING NANOEDUCATOR SPM CONTROL PROGRAM ........................................................................ 23

3. PERFORMING SPM MEASUREMENTS (THE “BEGINNER” LEVEL) .................................................................... 24

4. PERFORMING SPM MEASUREMENTS (THE “ADVANCED” LEVEL) ............................................................... 26
   4.1. CONTROL PANEL ............................................................................................................................................ 26
   4.2. SCANNER TRAINING ...................................................................................................................................... 27
   4.3. OPERATING SCANNING FORCE MICROSCOPE MODE (SFM) ................................................................. 28
       4.3.1. Setting up the Scanning Parameters ............................................................................................................. 38
       4.3.2. Probe Landing .............................................................................................................................................. 34
       4.3.3. Description of SFM Landing Procedure Parameters ..................................................................................... 33
       4.3.4. Probe Rising ................................................................................................................................................. 35
       4.3.5. Phase Shift Image and Force Image .............................................................................................................. 43
       4.3.6. One Line Scanning ..................................................................................................................................... 43
       4.3.7. Spectroscopy ............................................................................................................................................... 44
       4.3.8. Lithography .................................................................................................................................................. 46
   4.4. OPERATING THE SCANNING TUNNEL MICROSCOPE MODE (STM) .................................................... 48
       4.4.1. Fast Landing ................................................................................................................................................. 48
       4.4.2. Interaction Capture ..................................................................................................................................... 48
       4.4.2.1. Probe Landing ......................................................................................................................................... 50
       4.4.2.2. Probe Rising ............................................................................................................................................ 50
       4.4.2.3. Description of STM Landing Procedure Parameters ............................................................................... 51
       4.4.3. Scanning ....................................................................................................................................................... 52
       4.4.3.1. Sample Topography Imaging .................................................................................................................. 52
       4.4.3.2. Setting up the Parameters of Scanning .................................................................................................. 53
       4.4.3.3. Parameter Indication and Data Visualization During Scanning ............................................................. 53
       4.4.3.4. Modifying the Parameters During Scanning ............................................................................................ 54
       4.4.3.5. Saving the Results .................................................................................................................................. 54
       4.4.3.6. Scanning in Current Image Mode ............................................................................................................ 55

5. OPERATIONS WITH THE VIRTUAL INSTRUMENT (“DEMO”) ......................................................................... 57
# Table of Contents

6. WORKING WITH FILES, OBTAINED EARLIER .................................................................................. 58
   6.1. FILES DIRECTORY PREVIEW ................................................................................................... 58
   6.2. GRAPHIC REPRESENTATION OF IMAGES ............................................................................. 59
      6.2.1. Graphic Representation of Images ...................................................................................... 59
      6.2.2. Changing Image Scale ......................................................................................................... 60
      6.2.3. Image Rotation .................................................................................................................... 60
      6.2.4. Changing Image Color Palettes .......................................................................................... 60
      6.2.5. Changing Image Color ........................................................................................................ 61
      6.2.6. Changing the Characteristics of a Light Source .................................................................. 62
   6.3. GRAPHIC REPRESENTATION OF IMAGES ............................................................................. 63
      6.3.1. Image Processing Functions ................................................................................................. 63
      6.3.2. Image Analysis .................................................................................................................... 66
   6.4. CHANGING SCANNING SCALE ALONG OX, OY AXES ........................................................ 68
   6.5. CREATING A REPORT ON THE OPERATION WITH SPM NANOEDUCATOR ....................... 69
      6.5.1. Description of the “Report Generator” toolkit ...................................................................... 69
      6.5.2. Using the “Report Generator” toolkit .................................................................................. 70

APPENDICES ........................................................................................................................................... 73

1. OSCILLOSCOPE PROGRAM OPERATION MANUAL .................................................................. 73
   1.1. PROGRAM START ....................................................................................................................... 73
   1.2. PROGRAM STOP ....................................................................................................................... 74
   1.3. CHANNEL (BEAM) SETUP ....................................................................................................... 74
   1.4. TIME SCALE ........................................................................................................................... 74
   1.5. CURRENT INFORMATION ON SIGNAL ................................................................................... 76
   1.6. DATA SOURCE EDITING ........................................................................................................... 77
   1.7. PROGRAM SETUP ..................................................................................................................... 79
   1.8. COMPACT SIZE ....................................................................................................................... 79

2. TIP ETCHING .................................................................................................................................... 80
   2.1. PREPARATION FOR ETCHING: TIP WORKPIECE MANUFACTURING ...................................... 80
   2.2. THE TIP ETCHING DEVICE DESIGN ....................................................................................... 85
   2.3. TED TECHNICAL SPECIFICATIONS ......................................................................................... 86
   2.4. SOFTWARE INSTALLATION FOR TED ..................................................................................... 86
   2.5. MANUFACTURING A NEW SPM TIP ......................................................................................... 87
   2.6. RESTORING A BLUNT TIP ......................................................................................................... 88

3. VIDEO CAMERA ............................................................................................................................... 90
   3.1. VIDEO CAMERA DESIGN ......................................................................................................... 90
   3.2. SWITCHING ON THE VIDEO CAMERA ................................................................................... 90
   3.3. VIDEO CAMERA SETTING ....................................................................................................... 91

4. ELECTRONIC UNIT .......................................................................................................................... 92
   4.1. GENERAL INFORMATION ON THE ELECTRONIC UNIT ...................................................... 92
   4.2. INTERCONNECTIONS OF THE ELECTRONIC UNIT ............................................................... 93
   4.3. FUNCTIONAL COMPONENTS OF THE ELECTRONIC UNIT .................................................. 94
   4.4. BASIC SAFETY MEASURES ...................................................................................................... 96
   4.5. OPERATING CONDITIONS ....................................................................................................... 96
   4.6. STORAGE AND TRANSPORT INSTRUCTIONS .................................................................... 97
   4.7. CONNECTORS DIAGRAMS SCHEME OF THE ELECTRONIC UNIT ...................................... 97

5. FREQUENTLY ASKED QUESTIONS ................................................................................................. 99
   5.1. SAMPLES ................................................................................................................................. 99
   5.2. TIPS .......................................................................................................................................... 101
   5.3. TIP LANDING .......................................................................................................................... 101
   5.4. OPERATION ............................................................................................................................. 103
   5.5. USB DRIVERS INSTALLATION ............................................................................................... 105
   5.6. GENERAL QUESTIONS ............................................................................................................ 106
Introduction

The achievements of modern science and technology directly relate to the appearance in the arsenal of experimenters of a basically new instrument – Scanning Probe Microscope (SPM), which allows visualization, diagnostics and modification of a sample with spatial resolution at nanometric level. SPM made direct experiments with specific molecules and atoms real and even conventional not only for fundamental research, but for applied nano-technology developments as well, though they seemed fantastic only recently.

Scanning probe microscopy and spectroscopy are based on the interaction between a tip, advanced a small-scale distance $\lambda$ to the object of investigation, where $\lambda$ is the characteristic attenuation length of “tip – object” interaction. In order to obtain the image of the object surface and to spatially distribute its physical and chemical properties, precision systems of mechanical scanning by tip relative sample (or by sample relative tip) are used, where a feedback loop stabilizes the parameters of nano-contact between the tip and the object while scanning. SPM spatial resolution is determined by the specific size of nano-contact between the tip and the sample and can reach the atomic scale. To put it figuratively, where in optical and electronic microscopes a sample is inspected, in SPM it is sensed and tapped. In a way, a stethoscope, using which a doctor felt a patient as early as a century before last, is a prototype of SPM. Indeed, the size of a stethoscope (a tip) and the distance to the object of investigation is much lesser than the wave length of detected acoustic oscillations, which allows scanning stethoscope to determine the position of heart in the chest with spatial resolution much greater than the length of the sound wave.

The nature of interaction between the tip and the object is quite various, which fact originated a variety of SPM types and techniques of measurement. Scanning Tunnel Microscope (STM) detects a tunnel current, flowing between the tip and the sample. Scanning Force Microscope (SFM) detects a local force, active between the tip and the sample, said force resulting from Van der Waals, electrostatic, or magnetic interactions, friction, etc.; the performance of Scanning Near Field Optical Microscope (SNOM) is based on the use of optical photons, existing near a small-scale aperture (whose diameter is smaller than the light wavelength). There are other SPM types, such as capacitance microscopes (detecting local capacity), acoustic microscopes (detecting sound oscillations), electrochemical microscopes (detecting currents of local electrochemical reactions), etc.

SPM techniques allow not only to visualize and diagnose micro and nano-objects of varying nature, but also to manipulate single nano-objects and modify their structure with high spatial resolution. To accomplish this, high density electrical currents, strong electric fields and mechanical pressures are used, which can be easily produced in a “nano-sized” contact.

The first SPM was apparently R. Young’s profiler (Young R. Phys.Today, V.24.P.42. (1971)), which detected auto-emitted current between a scanning metallic tip and the investigated surface. Young’s experimental approach was developed brilliantly in the works of G. Binning and G. Rohrer, which resulted in the appearance of SPM with atomic spatial resolution. Its authors were awarded the Nobel Prize in physics in 1986.
As SPM became one of the basic instruments of nano-technology, which, in turn is one of the driving forces of scientific development in XXI, the necessity of SPM incorporation into educational process becomes quite obvious. **NanoEducator** scanning probe microscope was developed to serve exactly this purpose. Its characteristic features are the following:

- Simplicity of use;
- Absence of complicated settings and adjustments;
- Provision of a video camera for visual control of tip condition;
- Inexpensive and repeatedly restorable tip;
- Friendly interface for Windows 98/2000/XP;
- Connection of electronic unit to PC via USB port;
- Multitasking, which allows using PC simultaneously with working device;
- It is completed with test objects, necessary for educational process.

**NanoEducator SPM** allows the accomplishment of various measuring techniques in tunnel and semi-contact atomic-force microscopy and can be used to pursue not only educational, but scientific goals, being applied in the fields of micro and nano-structural physics and technologies, in science of materials, catalysis, in physics and chemistry of polymers, in tribology and cytology.
1. NanoEducator SPM Working Principle and Design

1.1. NanoEducator SPM Working Principle

NanoEducator SPM working principle is based on the dependence of the value of interaction between the tip (made of a sharp tungsten needle) and the surface of investigated sample on the value of tip-sample distance. The interaction nature can be either a current (the tunnel current) or a force.

By detecting a tunnel current, flowing under a constant applied voltage between the tip and the sample, only conductive objects can be investigated, whereas by detecting the force of tip-surface interaction, either conductive or dielectric samples can be investigated. The more pronounced is the dependence of current or force on the tip-sample distance, the higher is the spatial resolution of SPM, where the nature of said dependence is determined by physical-chemical properties of investigated surface. Spatial resolution is limited by the curvature radius of the tip, as well as by the level of mechanical vibrations and thermal drift of the construction and by the level of electric noises of measuring equipment. The apex of the tungsten needle is sharpened by electrochemical etching and has a curvature radius smaller than 100nm.

The mounting of the needle-tip in NanoEducator SPM is fixed, while the sample can move with respect to the needle in three spatial directions:

- $X$, $Y$ – along the sample surface;
- $Z$ – vertically (perpendicular to $X$-$Y$).

In a working device the sample is moving along $X$-$Y$ (Fig. 1-1) row-wise, in such a way that the needle gradually passes above the assigned total sample area with $\Delta$ increment. This process is named scanning.
While scanning, the tip can pass above surface areas with differing physical properties, which results in modification of value and nature of the tip-sample interaction. Besides, in case of any irregularities on the sample surface, the $\Delta Z$ distance between the tip and the surface will also change during scanning, modifying the value of local interaction correspondingly.

The value of local interaction is kept constant during scanning a system with a feedback loop, which holds the average value of the measured interaction signal (force or current) at a constant level. This is accomplished by moving the sample vertically using the Z axis of the scanner.

Fig. 1-2 shows the contour of the tip movement relative the fixed sample (curve 1) and of the sample relative the fixed tip (curve 2) with tip-sample interaction value kept constant. In the case 2, if the tip is above a depression or an area with weaker interaction, the sample moves upward and vice versa. Generally the value of the tip-surface interaction depends either on the value of the tip-surface clearance or on local surface characteristics, so the sample offset, implemented by the automatic tracking system can occur as a result of simultaneous effects of topography modification and of physicochemical properties of the sample surface. That is why the interpretation of information, obtained during scanning deserves special attention.
NanoEducator SPM registers the sample offset in Z-direction and in X, Y directions. An image is formed on PC monitor, synchronously with the movement of the sample, where the modification of local brightness is proportional to the measured sample movement in Z-direction during scanning. This SPM technique is called the technique of constant interaction (constant force or constant current).

Fig. 1-3. An example of SPM image of erythrocytes topography and its vertical section line profile.
1.2. NanoEducator Design

The structure of the measuring head is shown on Fig. 1-5. A scanner (8) with a sample holder (7) and a step-motor approach mechanism (2) are mounted on the base (1). Approaching the tip (6), fixed on the interaction probe (4) to the sample may also be manually performed using the approach screw (3). Interaction probe is tightened by a probe fixing screw (5). Pre-selection of an investigation area of the sample is accomplished with the help of scanner and sample moving screws (9, 10).
On Fig. 1-6 shows a functional layout of the device.

**NanoEducator** consists of a measuring head, an electronic unit, connecting cables and controlling PC. A video camera is implemented as a separate device, connected to PC via USB. The output signal from the interaction probe is preamplified and fed to the electronic unit. Control signals from the electronic unit are fed to the measuring head. PC controls the electronic unit via PC communication controller.

![Fig. 1-6. NanoEducator functional layout](image)

### 1.2.1. Force Interaction Probe

![Fig. 1-7. Force interaction probe (a), and details of piezotube (b)](image)
The force interaction probe consists of a needle-shaped tip 1 (Fig. 1-7), mounted on a tubular piezo 2, which is fixed to a stable base 3.

One part of the tube is used as a piezo-vibrator (actuator), and the second part as a mechanical oscillations detector (sensor) (see Fig. 1-7 b). The piezo-vibrator is driven by an a.c. voltage signal at the probe resonance frequency.

The oscillation amplitude is maximum at large probe-sample distance. Far from the surface the tip deviates from its equilibrium position by an amount (of fractions of micron) that is the amplitude A of the forced mechanical oscillations produced by one half of the piezo tube (actuator), while on the second half of the piezo-tube (sensor) an a.c. voltage proportional to the tip displacement occurs, due to the piezo strain.

During approach of the tip to the sample surface, the tip-sample interaction starts to increase leading to a left-shift of the frequency response curve with respect to the frequency response measured far from the surface. Since the frequency of the piezo-tube driving signal is kept constant during the approach, the oscillations amplitude decreases from the initial value A to a new value $A_1$ (Fig. 1-8).

![Fig. 1-8. Force interaction detection principle](image)

A measurement of the change in the tip-sample interaction force is obtained by recording a signal proportional to the change of the tip oscillation amplitude $\Delta A = A - A_1$.

### 1.2.2. Tunnel Current Probe

In using NanoEducator as a Scanning Tunnel Microscope (STM) the (grounded) needle of force interaction probe serves as STM tip. When measuring the tunneling current, the piezo-tube plays the role of a rigid passive tip-holder. A bias voltage $U_T$ is applied to the sample with respect to the grounded tip. The converter shown in Fig. 1-9 generates the bias voltage $U_T$ as well as the output voltage $U$, that is proportional to the current tunneling from the conducting tip and the conducting sample.
1.2.3. Scanner

Scanner is a device, which moves the sample in three spatial directions:

X, Y- motion along the sample surface, Z-motion perpendicular to the sample (as guided by the feedback system) (Fig. 1-10).
Three piezo plates are mounted to the sides of cubical scanner body 2. Each piezo plate can move a tappet 3, affixed to it, in one of the three mutually perpendicular directions - X, Y or Z, when an electric field (voltage) is applied. As shown in the figure, all three tappets meet in one point 4. It can be assumed to some extent, that this point moves in three directions X, Y, Z. A stand 5 with a sample holder 6 is fixed to that point. Thus the sample moves in three directions, being driven by three independent voltage sources. Maximal X-Y movement of the sample in NanoEducator is about 70 microns, which sets maximum scanning area.

### 1.2.4. Tip-sample Approach Mechanism

The range of scanner movement in Z direction is about 10 microns, which primarily requires approaching the sample to the tip, keeping said distance in mind. An approach mechanism, depicted on Fig. 1-11 is intended to serve this purpose. When electric pulses are applied to the step motor 1, it starts turning the feeding screw 2 and moves the bar 3 with the tip 4, approaching it to the sample 5, mounted on scanner 6 or moving it away. Increment value is about 2 microns.

![Fig. 1-11. Approach mechanism layout](image-url)
1.3. Feedback Loop Operation

Fig. 1-12 shows a functional layout of the feedback loop, which keeps the average value of tip-sample interaction constant.

When using NanoEducator SPM as scanning force microscope (SFM), the sinusoidal signal generator 1 is switched on permanently. This signal is used to oscillate the interaction probe 2 with the attached tip 3 at its resonance frequency. When the tip interacts with the sample, the output signal A, whose amplitude change is proportional to the force interaction change, is fed to the control unit 4. The feedback loop is designed to enable the user to set a desired value A0 of the interaction using the control computer. The control unit compares the value of the signal A with the value A0, preset by the user (Fig. 1-12). The control unit 4 feeds to the scanner 5 the control voltage that moves the sample up or down in Z direction, in order to keep constant the average oscillation amplitude A. The scanner continues moving the sample in Z direction till the value A of signal reaches the assigned level A0. This results in keeping the average value of interaction constant. If a STM configuration is used, the feedback loop operates in a similar way. The only differences are: the application of a bias voltage between the sample and the tip, the signal from the tunnel current probe is used as input signal for the electronic unit 4, and the generator is switched off.

1.4. Approaching the Tip

Prior to operation, the tip in NanoEducator SPM is positioned rather far from the sample, so there is no tip-sample interaction. But once the feedback loop is on, the electronic unit outputs the voltage, which makes the scanner move the sample up to the maximum height (about 10 mm). To operate the device it is necessary to set the required small tip-sample distance. This procedure is called tip approaching. As the Z increment of the step motor is much greater than the required tip-sample distance, to prevent tip deformation, the approaching procedure is accomplished with the step motor operating simultaneously with movement of scanner in Z direction as described in the following:
1. The feedback loop switches off and the scanner “retracts”, sinking the sample to its lowest position.

2. The step motor moves one increment and stops.

3. The feedback loop switches on and the scanner moves the sample gradually up with simultaneous analysis of tip-sample interaction.

4. In case there is no interaction, the procedure is repeated from 1.

5. If during scanner extension a non-zero interaction signal appears, the feedback loop stops the scanner upward movement and registers the value of interaction at the level set.

The range of the scanner movement in Z direction exceeds the increment of the step motor, therefore the force interaction is always detected during the scanner extension.

### 1.5. Device Technical Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanning area</td>
<td>70×70×10 microns (10 %)</td>
</tr>
<tr>
<td>Nonlinearity of the scanner</td>
<td>5 %</td>
</tr>
<tr>
<td>Minimal step</td>
<td>1Å</td>
</tr>
<tr>
<td>Number of points in the frame</td>
<td>1024x1024</td>
</tr>
<tr>
<td>Range of STM currents</td>
<td>from 100 pA up to 200 nA</td>
</tr>
</tbody>
</table>

**Tip parameters:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of resonant frequency</td>
<td>from 6 kHz up to 14 kHz, typical 8 kHz;</td>
</tr>
<tr>
<td>Quality Factor</td>
<td>20;</td>
</tr>
<tr>
<td>Tip curvature radius</td>
<td>100 nm (up to 10 nm).</td>
</tr>
</tbody>
</table>

**Spatial resolution:**

<table>
<thead>
<tr>
<th>SPM</th>
<th>X-Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFM</td>
<td>~50 nm (depends on tip radius of rounding);</td>
<td>2 nm;</td>
</tr>
<tr>
<td>STM</td>
<td>~50 nm (depends on tip radius of rounding);</td>
<td>2 nm.</td>
</tr>
</tbody>
</table>

**Type of scanning**

- Scanning by sample;

**Sample size**

- Diameter up to 12 mm;
- Thickness up to 5 mm.
2. Initial Settings of the Device

2.1. Switching the Device on

In order to switch NanoEducator SPM on, the following actions must be performed:

1. Connect SPM measuring head and the electronic unit, inserting the two cables into the suitable ports of the two devices. Connect the electronic unit to the first USB port of PC with USB cable.
2. Connect the electronic unit to mains supply (220 V).
3. Connect the video camera, located on the cover of the measuring head to the second USB port of PC.
4. If SPM Measuring head has built-in flash drive\(^1\), it is necessary to connect it to a third USB port of PC (Fig. 2-1).

\[\text{Fig. 2-1. The connector for the connecting of the built-in flash drive of the measuring head to PC}\]

\(^1\) All SPM Measuring heads made since 01.01.2005 are delivered with built-in flash drive
2.2. Installing the Software

2.2.1. NanoEducator Software Structure

The operation of NanoEducator is controlled by a personal computer (PC) and a controller integrated into NanoEducator’s electronic unit (Fig. 1-6. The controller is used to provide SPM measurements in real time. The controller performs the following functions:

− Storage of scripts, written in the processor language;
− Execution of scripts;
− Data exchange with PC via USB protocol;
− Data exchange with analog devices of NanoEducator’s electronic unit.

2.2.2. Installing NanoEducator Software

The following operations are required in order to install NanoEducator software:

1. Installation of USB drivers of the controller.
2. Provision of access to the file system of the controller.
3. Recording of scripts, necessary to implement SPM measurements to the memory of the controller.
4. Installation of NanoEducator program.
5. Installation of video camera drivers.

To install NanoEducator software, insert NanoEducator installation disc in PC CD-ROM unit and switch on the controller. A message will be displayed on the screen, stating that a new device is found. You should cancel the standard procedure of the device driver installation (see autorun menu of Install USB Controller Driver Instruction disc, item 1). During the first installation you should successively (top-down) execute autorun menu items of NanoEducator disc:
1. **USB Controller Driver Installation Instruction.** Read the instruction on the controller driver installation, which appears after this button is pressed and go down to the next menu item. To read the instruction you need Acrobat Reader. If Acrobat Reader is not installed on the computer, execute the **Install Acrobat Reader** item.

2. Install USB Controller Drivers.

   **ATTENTION!** Each controller is different, so the controller driver should be installed anew each time a new controller is connected to the computer. The data, relating to the previously installed controller are stored.

3. **Install NanoEducator.** Pressing this button starts the installation of **NanoEducator** and **Oscilloscope** programs on PC. The installation of **NanoEducator** and **Oscilloscope** is accomplished using **Setup.exe** program, located in **NanoEducator** directory of the installation disc. To provide for the proper operation of the digital **Oscilloscope**, it is necessary to record the parameters of signals it uses to **Windows** register. To do this, press button in the toolbox, once **NanoEducator** program is started, then press the oscilloscope settings button . The **Oscilloscope** program User’s Manual can be found in Attachment on page . **Video Camera Drivers Installation Instruction** opens the instruction on the installation of the camera drivers. Read the instruction and proceed to the next menu item;
4. **Install Video Camera Drivers.** No auxiliary programs should be installed. The installation CD is supplied with the camera. The drivers can also be found on NanoEducator installation disc.

### 2.3. Sample Mounting and Selecting an Area of Investigation

⚠️ **ATTENTION!** The probe with the tip should be removed prior to sample mounting so as not to damage the tip.

A sample is fixed on the magnetic substrate and then is mounted on the magnetic stage.

⚠️ **ATTENTION!** Take care when installing the sample holder, to avoid damaging the device.

To select an investigation area on the sample uses the two screws of X-Y table, located in the lower part of the device (see. Fig. 2-3).

![Screws for horizontal sample movements](image)

Fig. 2-3. Screws for horizontal sample movements
2.4. **Installing the Probe**

ATTENTION! The probe with the tip should be installed after the sample is mounted. It is recommended to perform this operation with the probe holder in upper position. The probe is brought to upper position by turning the manual approach screw clockwise (Fig. 2-4), or by performing “Rising” operation of the “Approach” procedure.

![Fig. 2-4. Manual adjusting of the probe holder Z position](image)

Take the probe (holding it by metallic rims of the base) (Fig. 2-5 a), loosen the probe fixing screw on the cover of the measuring head (marked by the arrow in Fig. 2-5 b), insert the probe in holder socket till it stops and screw up the fixing screw clockwise.

![Fig. 2-5](image)
2.5. Operating NanoEducator SPM Control Program

Launch the control program. The main window appears on the computer screen (Fig. 2-6). To start operating, set the user level first. There are three levels: “Advanced”, “Beginner” and “Demo”. These options provide different levels of user control over the instrument and measurement procedures. The user levels are set using the button User Level available from the toolbar. The option “Advanced” is suitable for advanced users; the option “Beginner” is for the beginners and “Demo” demonstrates operations of an “advanced” user with a virtual system.

Once user’s settings are done, follow to File menu item, selecting Open or New, or using the corresponding buttons on the toolbar. Selecting FileÆNew means to start SPM measurements, whereas selecting FileÆOpen means to start viewing and processing data, obtained earlier. The program allows viewing and processing of data simultaneously with measurements.

![Program Main Window](image)

Fig. 2-6. Program Main Window

After installing the software, all information is presented in English. To change the language of the information system, enable the option Set Language available from the menu Help of the main menu bar, and select another language.
3. Performing SPM Measurements (the “Beginner” Level)

Select the instrument type before the beginning of an experiment:

- **SFM** – Scanning Force Microscope (SFM);
- **STM** – Scanning Tunneling Microscope (STM) (Fig. 3-1).

Experiments are performed in several steps:

1. Resonance search and operation frequency setup.
2. Fast landing.
3. Landing.
4. Scanning.
Each next step is executed by clicking the button **Next**. Click **Previous** to return to the previous step. Click **Run** to enable **Fast landing** (Fig. 3-2) and **Landing**.

![Image](image.jpg)

**Fig. 3-2**

If the **Fast landing** procedure has been done successfully, the message **Fast landing done** appears. Then, the **Landing** procedure is performed to capture the interaction. One of the following messages are generated in the case of errors:

- *'Error!! The Scanner Resonance Frequency is not found. Pass to the level for advanced user(A)!!'* - In this case the user should switch into the “Advanced” mode and perform resonance search.

- *'Error!! Tip too close to a sample. The probe will be automatically risen in a save place. Verify landing option or physical unit state'* - If the picture in the video camera indicates that the probe has hit the sample, it is necessary to withdraw it from the sample. Otherwise switch into the “Advanced” mode and check the device settings.

- *'Attention!!! The step motor has achieved top position! Turn screw counterclockwise by hand!!'* – In this case the probe has reached its maximum top position. To eliminate this error, lower the probe by winding the top cover screw with fingers.

The scanning procedure is performed similarly to that described below, in Chapter 4 on page 26 excepting some modes that are not accessible.
4. Performing SPM Measurements (the “Advanced” Level)

4.1. Control Panel

Once File→New menu item is selected, a working directory selection dialog box appears. The directory is meant for storage of the working measurement files. The working directory selection dialog box also appears when changing the microscope (switching over from SFM to STM or vice versa). It is also possible to change the working directory during measurements, by pressing the button, located in the toolbox of the main window. During measurements all the obtained data are recorded sequentially to ScanData+i.spm files, where the value of the index i is zeroed at the program start, increasing with each new measurement. The standard mask Scandata of a working filename can be modified in the working directory selection dialog box.

Once the dialog box is closed, the device control panel appears on the screen (Fig. 4-1). Select the instrument type before the beginning of an experiment. The SPM configuration selection list is located in the left part of the panel:

- **SFM** – Scanning Force Microscope;
- **STM** – Scanning Tunnel Microscope.

Other buttons control main functions of the device and the measurement process stages.

**The following buttons are accessible prior to operation:**

- **Resonance** – adjusting the resonance and setting the working frequency;
- Preview of parameters, set for a given configuration of the measuring head and of the electronic unit. Preview of planned measurement parameters;
– activation of the video camera, showing the sample-tip positions;
– scanner training;
– digital oscilloscope control program activation.

Control panel buttons:

– tip-sample landing-rising;
– scan button becomes accessible at a later stage of the measurement process.

### 4.2. Scanner Training

Before beginning to work it is recommended to carry out training of the scanner. Training of the scanner must be performed with the tip far from the sample surface. At training the scanner makes cyclic movements with the maximal speed. Time sufficient for training is 10 minutes.

![Fig. 4-2](image)

**NOTE.** It is recommended to make training once a day before the measurements.

To start the scanner training press the button **TRAINING**. In the displayed window (see Fig. 4-2) set the training time in minutes and press the button **RUN**.
4.3. **Operating Scanning Force Microscope Mode (SFM)**

4.3.1. **Measurement Preparation**

SFM measurement preparation includes the accomplishment of two operations:

- Tracing a resonance curve and setting the working frequency of the piezo-probe oscillations;
- Probe-sample fast landing.

The determination of the resonance frequency is obligatory at the start of each measurement. Moreover, there often occur situations during measurement, which require to repeat this operation (for example, when the contact is lost).

Fast landing operation is not necessary for every measurement, it depends on the tip-sample distance. Fast landing operation is desirable if the distance is greater than 0.5–1 mm. The tip-sample distance is controlled either by the camera or by eye.

4.3.1.1. **Adjusting the Resonance and Setting the Working Frequency**

This operation is performed at the start of each measurement. If the operation is not performed, all further stages of measurement process are inaccessible.

![Resonance](image)

command activates the resonance adjustment window (Fig. 4-5).

Performing this operation implies the measurement of the probe oscillations amplitude while sweeping the forced oscillations frequency. To do this, press the RUN button (Fig. 4-4).

**Automatic** mode automatically sets the working frequency to the peak value, after the resonance curve is traced. A plot of the resonance curve is displayed, and both the working frequency and the oscillation amplitude are shown at the bottom. (Fig. 4-4) In case the resonance peak is too small (less than 1V) the parameters of measurement should be modified (choosing the Manual mode), and the frequency setup procedure must be repeated.
Chapter 4. Performing SPM Measurements (the “Advanced” Level)

Fig. 4-3. Resonance adjustment and Operating frequency setup window

Fig. 4-4. The window of Resonance adjustment and Operating frequency setup additional functions
Manual mode is intended for the manual adjustment of the parameters. When this mode is selected, an additional panel (Fig. 4-4) is displayed in Frequency Scanning window, allowing to adjust the following parameters:

- **Generator-set Oscillation Amplitude.** This value should not be greater than 50 mV;
- **AM Gain** (amplitude gain). If (with oscillation amplitude = 50 mV) the probe oscillations amplitude in the resonance peak is still less than 1 V, **AM Gain** increase is recommended.

Press **RUN** button to initiate the resonance adjustment operation.

**Manual** mode allows also the modification of the working frequency by moving the green cursor on the plot, using the mouse. It also allows to reduce the range of the frequency sweep close to the selected frequency. To do this, set **Manual Regime** button to **Fine** position and press **RUN** button.

### 4.3.1.2. Fast Landing

![Fig. 4-5. Device control panel. Fast landing activation](image)

Once the resonance search procedure is performed and an operation frequency is set, the procedure of fast probe-sample landing can be carried out. Pressing the button on the control panel a double drop-down Menu appears. Choosing command activates the probe-sample fast landing operation (Fig. 4-5). If no video image appears in the fast landing control window (Fig. 4-6), it is necessary to activate the camera. To do this, select **Settings** menu item in FAST LANDING window and specify the driver of the system’s camera, if it is not present in the list, select the standard video capture driver Microsoft WDM Image Capture (win32).

In order for the video image in a window to be dynamical, it is necessary to press the button.

The execution of fast landing operation is initiated by pressing the **RUN** button. Video image allows to control the tip-sample distance and properly stop the landing by pressing the **STOP** button. The landing speed is regulated by **Fast Landing Steps Number** setting, accessible in Landing Options window, which contains landing procedure settings. Fast landing can also be accomplished manually using manual landing screw (see Fig. 1-4).
ATTENTION! The probe-sample distance should be controlled during this operation to avoid damaging the probe. If the probe has hit the sample, the landing procedure is halted. A warning message 'Error!! Tip too close to a sample. The probe will be automatically risen in a safe place. Verify landing option or physical unit state'

If the parameter **Fast Landing Steps Number** is \( \leq 5 \), a preliminary capture of the probe-sample interaction can be performed. Once the message ‘**Fast landing done**’ has appeared, perform probe landing.

### 4.3.2. Probe Landing

The procedure of a controlled probe-sample landing is accomplished in order to bring the tip-sample distance into the operating area, so that the interaction signal is captured by the feedback loop. The window, controlling this procedure is activated by pressing the button on the control panel and choosing in appeared double drop-down menu. In SFM operation this button becomes accessible after the operation of resonance frequency adjustment and setup is performed. The Scanning Force Microscopy, **Landing** window (Fig. 4-7) contains elements, controlling probe landing as well as parameter indicators showing the procedure progress.

Indicators of the measured parameters are located in the right part of **LANDING** window.
The user can monitor the following parameter in **LANDING** window:

- The protraction of scanner in Z-direction (**Scanner Protraction**) relative maximum protraction, assumed as a unit. The value of relative protraction of the scanner is shown by the level of color of the left indicator (the different colors have the following meanings: green – the scanner is in the operating area; blue – the scanner is out of the operating area; red – the scanner is too close to the sample surface, which may result in probe deformation). In the latter case the program generates a warning sound. Scanner Protration indicator’s horizontal marks limit the safe operating area. The scanner is assumed to be properly operating if the green color level is between the marks. Operating area limiting values are set in Landing Options window (Z values);

- The amplitude of probe oscillations (**Probe Oscillation Amplitude**) relative to the oscillations amplitude in the absence of force interaction, assumed as a unit. The level of magenta color of the right indicator characterizes the value of the relative oscillations amplitude. **Probe Oscillation Amplitude** indicator’s horizontal mark specifies the limiting level, at which the scanner Z-position is compared with the Zmin and Zmax values: if Zmin<Z<Zmax the landing process is stopped and the feedback is switched-on;

- The number of steps (**Steps**), taken in the direction set.
4.3.2.1. **LANDING Window Control Elements**

1. Setting the probe movement direction (**Probe Moving**). The probe is moved by the step motor:
   - **Landing** – protracting (lowering the tip);
   - **Rising** – retracting (rising the tip).
2. Setting the value of the probe-sample interaction force (**Set Interaction**) in operating mode.
3. Setting the feedback loop gain (**Feed Back Loop Gain**).
4. Activating the **Landing Options** window makes accessible the landing procedure parameters (Fig. 4-7).

4.3.2.2. **Description of SFM Landing Procedure Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Probe Amplitude Level</strong></td>
<td>the level of <strong>Probe Oscillation Amplitude</strong> indicator, at which the scanner operating condition in landing process is analyzed. The level changes in relative units. The amplitude of probe oscillations in the absence of probe-sample force interaction is assumed as a unit. The minimum value is defined by the condition <strong>Probe Amplitude Level &gt; (1 - Amplitude Suppression)</strong> (See item 4.3.2.5 on page 36);</td>
</tr>
<tr>
<td><strong>Z Gate Min, Z Gate Max</strong></td>
<td>scanner protraction operating area limits, measured in relative units. Maximal scanner protraction value is assumed as a unit;</td>
</tr>
<tr>
<td><strong>Scanner Decay</strong></td>
<td>the delay (in ms) determined by the time of transient processes decay in piezo-ceramics;</td>
</tr>
<tr>
<td><strong>Integrator Delay</strong></td>
<td>the time interval (in ms), necessary to fully protract the scanner when the tracking system is activated;</td>
</tr>
<tr>
<td><strong>Frequency Band Rough</strong></td>
<td>a fixed parameter set by the manufacturer;</td>
</tr>
<tr>
<td><strong>Rising Steps Number</strong></td>
<td>the number of steps performed by the step motor for each cycle during the scanner retraction;</td>
</tr>
<tr>
<td><strong>Fast Landing Steps Number</strong></td>
<td>the number of steps performed by the step motor for each cycle during the scanner fast landing operation;</td>
</tr>
<tr>
<td><strong>Landing Amplitude Suppression</strong></td>
<td>the value of probe oscillations amplitude suppression during the scanner landing operation.</td>
</tr>
</tbody>
</table>
4.3.2.3. Probe Landing

To start this procedure, it is necessary to do the following:

1. Make sure that the **Landing** item is selected in the **Probe Moving** element.
2. Verify the correctness of landing parameters.
   - **Feedback Loop Gain** should be set to 3 (Fig. 4-7).
3. Press the **Set Interaction** button and make sure that the approximate value of **Amplitude Suppression** parameter in **Interaction** window is 0.3 (see item 4.3.2.5 “Tip-sample Interaction Value Setup” on page 36).
   - Verify the correctness of parameters, set in **Options** window, **Landing Options** page.
4. Press **RUN** button.

**Scanner Protraction** indicator on the left can determine the presence or absence of the interaction. Full protraction of the scanner (the entire **Scanner Protraction** indicator is blue) and magenta colored **Probe Oscillation Amplitude** indicator (Fig. 4-7) indicate the absence of the interaction. The probe free oscillations amplitude is being assumed as a unit.
If the scanner is not protracted fully before or during landing, or the program displays 'Error!! Tip too close to a sample. The probe will be automatically risen in a safe place. Verify landing option or physical unit state ' message, the procedure should be suspended, followed by one of the following:

a) modifying one of the parameters:
   - Increasing the value of Amplitude Suppression interaction, or
   - Increasing the value of Feed Back Loop Gain, or
   - Increasing the delay interval between landing steps (Integrator Delay parameter on Landing Options page in Options window);

b) increasing the tip-sample distance (operations described in Probe Rising (section 4.3.2.4 on page 35) should be performed to do this);

c) performing the Resonance operation and return to the Landing procedure afterwards.

Steps indicator starts counting the steps passed. Once the interaction is captured, Landing Done message is displayed.

During landing the protraction indicator should be blue colored to the mark, exceeding the upper limit of the specified operating area or be at least within the limits of the specified range. If this is not the case, landing parameters should be modified.

When it is required to perform approachment on the value of one step, click the button One Step RUN. In this event, a one-step movement is done first and, then, an analysis of the interaction criteria is performed.

### 4.3.2.4. Probe Rising

The operation is used to increase the tip-sample distance or to automatically transfer the probe to its uppermost position for replacement. Once the uppermost position of the probe is achieved, ‘Error!! Probe crosses allow boundary. Turn screw counter-clockwise by hand!!’ message is displayed.

To perform the rising operation, it is necessary to do the following:

- Select Rising in Probe Moving;
- Press the RUN button (Fig. 4-9).

Steps indicator starts counting the steps in reverse direction. Press the STOP button to stop the movement. The Rising Steps Number parameter, accessible in Landing Options window defines the rising speed.
When it is required to perform rising on the value of one step, click the button **One Step RUN**. In this event, a one-step movement is done first and, then, an analysis of the interaction criteria is performed.

### 4.3.2.5. Tip-sample Interaction Value Setup

Press the **Set Interaction** button in **Landing** window to display the **Interaction** window (Fig. 4-10).
The force of the interaction is determined by two factors:
- The amplitude of alternating voltage, fed to the piezo-oscillator;
- The degree of suppression of the probe oscillations amplitude in the result of interaction.

The vertical element in the left part of Interaction window shows the amplitude of the generator’s alternating voltage, fed to the piezo-oscillator. This value is set either using Oscillation Amplitude parameter in Manual regime of Frequency Scanning window, or by default. The value should not be modified. Amplitude Suppression vertical element in the right part of the window defines the value of probe oscillations amplitude suppression due to tip-sample interaction. This value increases in stronger interaction and decreases in weaker one. The value of Amplitude Suppression should be greater than the value \( a = (1 - \text{Probe Amplitude Level}) \)

The resulting interaction value is monitored in the Interaction window horizontal element.

### 4.3.3. Scanning

Once the Landing procedure is accomplished and the interaction is captured, scanning becomes accessible (button on the device control panel window).

![SFM scanning results imaging and process control window](image)

Fig. 4-11. SFM scanning results imaging and process control window
Pressing this button (scanning window is shown on Fig. 4-11) the user starts the measurement **NanoEducator SPM** in SFM configuration allows the performance of sample surface scanning in semi-contact mode, to maintain the feedback. The following characteristics are represented in the imaging window:

- Sample surface topography (Semicontact mode);
- The surface topography is obtained by visualizing the Z signal (voltage controlling the scanner along the Z axis);
- Phase shift distribution (Phase Imaging mode);
- Distribution of phase difference between the voltage that oscillates the piezosensor, fed by reference generator, and the voltage output from the piezosensor;
- Probe oscillations amplitude distribution (Semicontact Error mode, Force Image);
- Signal amplitude value distribution, output from the piezosensor (feedback loop mismatch error).

**Sample topography imaging**

**NanoEducator SPM** performs sample topography imaging, using all probe force microscopy techniques mentioned above.

The scanning process and the imaging of the results are controlled by the Scanning window (Fig. 4-11) control elements. The key elements for setting and controlling the scanning are located in the upper part of the Scanning window. The lower part of the window is divided in two fields for the imaging of the results.

### 4.3.3.1. Setting up the Scanning Parameters

The values set for the parameters of **Feed Back Loop Gain** and **Interaction** during **Landing** are preserved when Scanning window opens.

**ATTENTION!** In order to weaken the impact of the tip on the sample and to prevent the tip deformation, it is recommended to decrease Suppression value (Set Interaction button) prior to scanning. This should be done without altering the scanner protraction value (Z), established in the process of interaction capture.

![Fig. 4-12. Panel of Scanning window including the parameters of scanning area](image-url)
The parameters of scan area and the velocity of scanning should be set in scanning mode. These parameters are located in the right part of the Scanning window upper panel (Fig. 4-11, Fig. 4-12).

When the program is run for the first time, these parameters are set by default:

- **Scan Area Xnm*Ynm**: 5000*5000 nm;
- Number of measurement points in X, Y directions: NX=100, NY=100;
- Direct pass scanning velocity (Velocity) = 4000 nm/s;
- Reverse pass scanning velocity 8000 nm/s.

The direct and reverse passes can be performed at different speeds during scanning.

When the lock is ON (when it is marked), the speed of the direct and reverse passed varies proportionally to the initial value. Otherwise their values vary independently on each other.

Scanning path (Path) determines the method of tracing the sampled points. The program allows to select the direction of fast scanning (X or Y). Path=X+ is set by default at the program start.

**Step X,Y** scanning step is calculated as the ratio between the length of the scanning line and the number of sampled point in the line.

**Area** field represents the maximal scan area, accessible for this device.

**A new scan area can be selected using the following methods:**

- Selecting an area in the maximal accessible scan area. The selection is accomplished by moving the mouse with the left button pressed across the Area page. The program allows to scan different areas with constant spatial resolution (i.e. with the fixed value of StepX,Y). To do this, check the fix StepX,Y box. When the right mouse button is pressed within the boundaries of a pre-selected scan area, the area is transported following the mouse movement;

- Selecting an area within the obtained image. Select the required area in the right lower part of Scanning window (Fig. 4-13) using the mouse;

- By scan area length and width values in nm input into the windows Scan Area.
Fine selection of a scan area is achieved by clicking the button. A new imaging window **Zoom Scan Area** with the scan area on a larger scale will appear. This window can be used to select a new scan area similarly to the procedure described for the window **Scan Area**.

Square area selection mode is set by default. Rectangular area can also be selected. To do this, press button. Press button to return to the square area selection.

Press button to modify the position of the scanning start point.

The scanning start point position setup window appears.
To modify the number of sampled points, it is necessary to specify the number of points in the line (NY parameter). Once Apply button is pressed, the number of points in the image (NY parameter) is automatically recalculated according to the shape of scan area.

Specifying a new value in Velocity window modifies the scanning speed.

To scan a smaller area with higher resolution (Fine), press F button on Area page. The length and width of the maximal accessible scan area and the step of scanning are decreased. When this mode is selected, the scanner returns to X=Y=0 and the parameters of scanning become equal to those set by default. Pressing R button cancels smaller area scanning mode.

Once the parameters are modified, it is necessary to press Apply button.

Press RUN or STOP buttons respectively to start or stop the scanning process.

### 4.3.3.2. Parameter Indication and Data Visualization During Scanning

During scanning Current Line bookmark opens in the right upper corner of Scanning window. This field represents the current line of scanning.

Previous Line box displays the following information: Line Number - the number of the last line of scanning passed and Height – the difference between the greatest and the smallest Z values for the corresponding topography profile.

An indicator, representing the current Z condition is located in the left upper part of the window. The lower part of Scanning window is divided in two fields, imaging the scanned surface:

a. Side View;
b. Top View.

The top view pixel color is determined by the height of topography features and by the palette ( ). It also depends on the normalization technique. There are three normalization techniques:

- By the previous line (the buttons and aren’t clicked);
- By the area scanned. After subtracting an approximation plane defined by the area scanned (the button is clicked);
- By the area scanned. After subtracting an approximation plane of the second order defined by the area scanned (the button is clicked).

There is the possibility of viewing the current line image in a separate window on a larger scale. To enable this, click the button available on the bookmark of the current line (Current Line).
There is a function which allows the user to capture and process intermediate results of scanning. To capture the current image without halting scanning, click the button 📺. The scanning process is not interrupted, while the captured data are visualized in the window with the title “ScanDataCapture+i” and are saved to a file with the same name to a temporary folder TMP (where i is the image index in the sequence of captured images). After the completion of experiment, the files “ScanDataCapture+i” are removed automatically (unless they are renamed by the user).

4.3.3.3. Modifying the Parameters During Scanning

The user can modify the following parameters during scanning:

- **Amplitude Suppression**;
- **Velocity**;
- **FM Gain** (amplification of a signal, proportional to the phase shift).

If the contact is lost during scanning (the loss of contact is accompanied by an audio signal. The color of Z direction scanner protraction indicator changes to blue), it is necessary to either increase the value of interaction (Interaction), or to repeat the procedure of landing (Landing). If the Oscillation Amplitude value in the indicator is less than a unit, it is necessary to set up the working frequency (Resonance) again and to repeat the Landing procedure.

To make Resonance procedure accessible, press the Landing button to move the probe away from the sample surface, using the Rising command and perform the Resonance and the Landing procedures.

4.3.3.4. Saving the Results

During measurements all the obtained data are sequentially recorded to ScanData+i.spm files, where the value of i index is zeroed at the program start, increasing with each new measurement. The ScanData+i.spm files are stored to the working directory, which is set prior to the start of measurements. Another working directory can be selected during measurements. To do this, press button, located on the toolbox of the program control panel.

To save the results of scanning, it is necessary to press Save Experiment button in the Scanning Window and select a directory in the displayed dialog box, specifying the file name. The ScanData+i.spm file, which temporary stores the data obtained during measurements, acquires the name specified by the user. By default the file is stored in the working directory. If the measurement results are not saved, the results, stored in ScanData+i.spm temporary files shall be successively re-recorded (if the same working directory is preserved) at the next start of the program. The presence in the working directory of temporary files, containing measurement results is indicated by a warning, appearing when exiting or starting the program. ScanData standard file name can be modified in the working directory selection dialog box. The working directory selection
dialog box is called by pressing button, located in the toolbox of the main control window. The measurement results can also be saved in SPM File Explorer window, by selecting the required files one by one and saving them in the selected directory.

It is possible to export data obtained by means of the instrument NanoEducator in the ASCII format for further use by both the control program Nova and other programs. Scanned images and data on their cross-sections are converted into the ASCII format and are made available for export. To export the data, click the button Export, located on the toolbar of the main window, or select Export \text{\textarrow} ASCII in the menu File of this window.

### 4.3.3.5. Phase Shift Image and Force Image

To obtain Phase Shift Image or Force Image, select the corresponding bookmark in the right lower field of Scanning window prior to scanning and press the START button. The (Z) topography image appears in the left part of the window during measurement. Selecting Top View bookmark results in top view imaging of Z measurement, whereas selecting Side View bookmark results in side view imaging. The results of images measurement (top view) obtained according to the selected measurement technique – Phase Shift or Force Image - are represented in the right part of Scanning window.

FM Gain element, which allows setting the amplification ratio of a signal, proportional to the phase shift, appears in the upper part of Scanning window during Phase Shift measurement.

### 4.3.3.6. One Line Scanning

Selecting the One Line Scanning bookmark makes active the OneLineScanning mode. It performs multiple scanning and measurement of the sample topography along one line. The procedure of setting up the scanning parameters is standard, but NY value is interpreted as the number of repeated passages along one line. In one line scanning it is recommended to select a rectangular area of scanning.

Multiple one line scanning is recommended for:
- Watching and measuring the creep processes in the scanner’s piezo-ceramics;
- Evaluating the thermal drift;
- Scanner “training” to prevent the adverse effects of the creep.

In viewing the results obtained in One Line Scanning mode, the function of distance measurement (button) allows measuring the distance in OX scanning direction, as well as the corresponding time interval (OY direction offset) and the speed, measured as the distance-time dependence.
4.3.3.7. Spectroscopy

Spectroscopy procedure yields the relation between the changes in Oscillation Amplitude of the probe and the probe-sample distance, i.e. so called amplitude-distance curve. Spectroscopy can be performed either in one sample point (which corresponds to the current X,Y position of the probe), or in points, specified on the image of the sample surface, obtained during previous scanning. Spectroscopy allows selecting the value of probe oscillations suppression amplitude (Amplitude Suppression setting), which is optimal for a given measurement. It also allows evaluating the value of the probe oscillations amplitude in the absence of interaction.

The result is represented by a plot, of two curves (Fig. 4-15), in blue and red color, respectively:

![Spectroscopy procedure window](image)

1 (red) – the curve is obtained while the probe is approaching the sample,
2 (blue) – the curve is obtained while the probe is retracted from the sample

Start Point the initial position of the probe, nm. This value should be negative, since the probe rises to Start Point distance from the sample prior to measurement;
Final Point the final position of the probe, nm;
Step the probe travel between sampled points, nm;
Points the number points where the probe oscillations amplitude is measured;
Delay the delay between steps in the probe movement, ms.

The following actions are performed in (X,Y) point of the sample:

1. The tracking system is switched off.
2. The probe rises from the sample to the distance defined by Start Point parameter.
3. The probe approaches the sample by the Step value. The total number of probe steps is set by Points parameter. The relative amplitude of the probe oscillations (Oscillation Amplitude) is measured in each step.
4. Then the relative amplitude of the probe oscillations is measured in the same points during the reverse movement of the probe (when the probe is rising from the sample).

The result is represented by a plot, of two curves (Fig. 4-15), in blue and red color, respectively:

- the first (1) curve is obtained while the probe is approaching the sample;
- the second (2) curve is obtained while the probe is retracted from the sample.

The abscissa axis of the diagram contains values of the probe movement in Z direction. Zero value of the axis corresponds to the position of the probe when the tip is “in quasi-contact” with the sample surface. The position is marked with the green cursor.

Negative values of the plot’s abscissa axis in Spectroscopy window correspond to the changes in the probe-sample distance when the probe rises from the sample, whereas positive values correspond to the changes in the probe-sample distance when the probe get closer to the sample.

Point A corresponds to the onset of the probe-sample interaction as a result of their approachment. Starting from this point, further approachment results in the decrease of the tip oscillations amplitude down to complete attenuation (point B). The area of the curve to the right of point B corresponds to the oscillations of the piezo-probe in full mechanical contact with the sample surface. The position of point B is better determined by the slope of the curve.

The difference \( Z(B) - Z(A) \) measures the tip-sample gap with the interaction captured. The distance \( Z(B) - Z(A) \) over which the oscillation amplitude changes from the maximum value (free oscillation) to the nearly zero value (complete damping at contact) is approximately equal to the amplitude of the tip oscillation.

The Spectroscopy procedure for the point, where the probe is at a given moment is started by pressing the Spectroscopy button in the Set Interaction window.

To obtain spectroscopy measurement data for different points on the sample, it is necessary to perform the following sequence of operations:

1. Perform surface topography imaging scan.
2. Select Spectroscopy bookmark in the right lower field of Scanning window.
3. Using the left mouse button, select the points on the sample topography image, for which spectroscopy measurement is required. Pressing Clear button, located in the image field cancels the selection.
4. Press RUN button in Scanning window to display Spectroscopy window (Fig. 4-15).
5. Set up Spectroscopy procedure parameters (Start Point, Step, Points, Delay).

Once these operations are performed the spectroscopy measurement data for each selected point should appear on separate pages of the multi-page diagram as the measurement progresses.
4.3.4. Lithography

An image is formed on the sample surface in the course of force lithography (embossing), which modifies the force of the probe impact, affecting the sample. Lithography is performed using a prepared image matrix, and a sample with a very smooth and soft surface.

The following preparatory operations should be performed before starting the lithography procedure:
- Probe-sample fast landing;
- Resonance adjustment and working frequency setup;
- Opening the Scanning window.

Before the lithography is accomplished, it is recommended to scan the sample area chosen for the embossing of the lithography drawing, making sure it is smooth enough.

The process of embossing of a drawing on the sample surface is accomplished by scanning a selected surface area and impacting the surface in the preset points with the force, which depends on the brightness of corresponding pixels of the image matrix.

Selecting Lithography bookmark in the right lower field of Scanning window activates the lithography procedure. The control elements of the lithography procedure appear in the left lower field of Scanning window (Fig. 4-16).

![Fig. 4-16. Performing lithography procedure]
To accomplish the lithography procedure it is necessary to do the following:

- Load the matrix of an image, which should be embossed on the sample surface. The image matrix should be prepared in advance and saved in BMP graphic format (black and white drawing is recommended). Pressing Load Image button activates a dialog box for selection and loading;

- Set the value in nm of the maximum possible depth of action (Action) directed to the sample;

- Set the value in microseconds of Action Time. The default Action Time value is 100 microseconds;

- Set the distance in nm between the image points on the sample surface (lithography Step X,Y). By default, this parameter is equal to the scanning step in the previous operation of surface topography imaging. Modifying Step X,Y parameter alters the size of the surface area, subjected to lithography drawing;

- Pressing Projection button results in projection of the image matrix to the scanning area, forming the matrix of action on the surface. The user may then change the location of the lithographed area by moving the frame, which indicates its boundaries within the total scanning area. If a new scanning area does not coincide with the previously set area, Apply button is indexed in red. Press this button to confirm the parameters set;

- Press RUN button in Scanning window. This initiates the lithography process with the progress represented symbolically in the right lower field of Scanning window.

The left field of the window Scanning is used to visualize the surface image obtained during the backward pass of the scanner. Therefore the user can control the interaction with the sample surface in the process of lithography dynamically.

The maximum depth of interaction with the sample (Action) can be increased during the process of lithography by factors of 2 or 4.

For control check of the results of the process, it is recommended to perform surface topography over the same area either on the same scale or on a larger scale (Fig. 4-17).

Fig. 4-17. Laser disc lithographed area topography image
The following parameters are recommended to perform the lithography procedure using a probe with a tip curvature radius not greater than 100nm: the larger is the tip radius the larger should be the Lithography step. Note that the width of the indentation of any pixel also depends on the level of penetration (the tip shape is conical):

- Scanning velocity - 2000 nm/s;
- Action value – from 1000 to 2000 nm (depending on the surface hardness);
- Action duration, Action Time, is 100 μs;
- Lithography step - 100 nm.

4.4. Operating the Scanning Tunnel Microscope Mode (STM)

STM is intended for working with conductive samples.

To accomplish STM measurements it is necessary to choose STM in NanoEducator’s Control panel window (Fig. 4-1).

4.4.1. Fast Landing

STM and SFM fast landing procedures are identical. The instructions for SFM fast landing may be found in chapter 4.3.1.2 on page 30.

4.4.2. Interaction Capture

Press the button on the control panel and choose to perform the landing procedure.

‘Scanning Tunneling Microscope, Landing’ window (Fig. 4-18) contains the following control elements:

- Setting the probe movement direction (Probe Moving). The probe is moved by the step motor;
- (Landing - protracting, Rising – retracting);
- Activating the measurement parameters (Options) window;
- Setting the (SetPoint:Tunnel Current) tunnel current value, maintained by the feedback system once a tunnel contact is achieved;
- Setting the (Bias Voltage) tip-sample bias voltage value;
- Setting the Feed Back Loop Gain value.
The right part of **LANDING STM** window (Fig. 4-18) contains the following indicators:

- An indicator, showing the value of the scanner protraction in Z direction (**Scanner Protraction**) relative maximum protraction, assumed as a unit. The value of relative protraction of the scanner is shown by the level of color of the left indicator (the different colors have the following meanings: green – the scanner is in the operating area; blue – the scanner is out of the operating area; red – the scanner is too close to the sample surface, which may result in probe deformation. In the latter case the program generates a warning sound. **Scanner Protraction** indicator’s horizontal marks define the safe operating area. The scanner is assumed to be properly operating if the green color level is between the marks. Operating area limiting values are set in the parameters window (**Options** button) on **Landing** page;

- **Tunnel Current** indicator, showing the value of tunnel current. **Tunnel Current** indicator’s horizontal mark specifies the value, at which the system will try to keep the tunneling current by acting on the scanner. This tunnel current value is specified in **Level IT** line of **Landing Options** page in **Options** window. **Level IT** value should be less than **Set Point** value before the landing starts;

- The number of steps (**Steps**), taken in the direction set.
4.4.2.1. **Probe Landing**

To start this procedure, it is necessary to do the following:

1. Make sure that the **Landing** item is selected in the **Probe Moving** element.
2. Verify the correctness of landing parameters:
   - **Set Point**: Tunneling Current;
   - **Bias Voltage**.
3. **Feed Back Loop Gain** should be set to 3 (Fig. 4-18).
4. Verify the correctness of parameter values set in **Landing Options** window.
5. Press the **RUN** button. During landing, the **Z** indicator should be blue colored to the mark, exceeding the upper limit of the specified operating area or be at least within the limits of the specified range. If this is not the case or the program displays: 'Error!! Tip too close to a sample. The probe will be automatically risen in a save place. Verify landing option or physical unit state' message. Suspend the procedure by pressing the **STOP** button and modify one of the following parameters:
   - Increase the value of **Feed Back Loop Gain**, or
   - Increase the delay interval between landing steps (**Integrator Delay** parameter on **Landing Options** page in **Options** window).

If these actions do not yield the required result, it is necessary to increase the tip-sample distance (following the procedure, described in **Probe Rising** section. The **Steps** indicator counts the steps passed during landing. Once the tunnel current appears, reaching its preset value, “**Landing Done**” message is displayed.

When it is required to perform approachment on the value of one step, click the button **One Step RUN**. In this event, a one-step movement is done first and, then, an analysis of the interaction criteria is performed.

4.4.2.2. **Probe Rising**

The operation is used to increase the tip-sample distance. To perform the operation, it is necessary to do the following:

- Select Rising in **Probe Moving**;
- Press the **START** button.

The **Steps** indicator starts counting the steps in reverse direction. Press the **STOP** button to stop the movement. The **Rising Steps Number** parameter, accessible in **Options Landing** window defines the rising speed.

When it is required to perform rising on the value of one step, click the button **One Step RUN**. In this event, a one-step movement is done first and, then, an analysis of the interaction criteria is performed.
4.4.2.3. **Description of STM Landing Procedure Parameters**

Once the **Options** button is pressed, a table of landing procedure parameters is displayed (Fig. 4-19):

- **IT Level** – the level of tunnel current, that is used as a threshold to activate the feedback system;
- **Z Gate Min, Z Gate Max** – scanner protraction operating area limits, measured in relative units. Maximal scanner protraction value is assumed as a unit;
- **Scanner Decay** – the delay (in ms), determined by the time of transient processes decay in piezo-ceramics;
- **Integrator Delay** – the time interval (in ms), necessary to fully protract the scanner when the tracking system is activated;
- **Frequency Band Rough** – a fixed parameter, set by the manufacturer;
- **Rising Steps Number** – the number of steps performed by the step motor for each cycle during the scanner retraction;
- **Fast Landing Steps Number** – the number of steps performed by the step motor for each cycle during the scanner fast landing operation;
- **Scale Max IT** – a fixed parameter, set by the manufacturer.

![Fig. 4-19. STM landing parameters window](image)

**NOTE.** If the interaction is captured during SFM measurements, it should probably be preserved in STM configuration. This allows measuring the same sample areas in SFM and STM configurations. If this is the case, the interaction capture should be obtained at the beginning of landing process in STM configuration.
4.4.3. Scanning

Once the Landing procedure is accomplished and the interaction is captured, scanning becomes accessible (button on the device control panel).

Pressing this button the user starts the measurement (Fig. 4-20).

4.4.3.1. Sample Topography Imaging

NanoEducator SPM in STM configuration uses the Direct Current Technique to perform sample topography imaging, allowing also the performance of other STM measurement techniques.

Sample topography imaging is performed using the Scanning window control elements (Fig. 4-20). The main elements for setting and controlling the operating parameters of scanning are located in the upper part of the Scanning window. The lower part of the window is divided in two fields for the imaging of the results obtained.
4.4.3.2. Setting up the Parameters of Scanning

The values set for the parameters of Feed Back Loop Gain, Set Point, and Bias Voltage during Landing are preserved when the Scanning window opens. Before scanning it is recommended to set the values of these parameters, required for the given measurement.

To perform scanning, it is necessary to set the parameters defining the area to be scanned and the scanning speed. These parameters are located in the right part of the Scanning window upper field.

The procedure of setting and modifying the parameters of the scan area and the scanning speed is similar to that of SFM.

Once the parameters are modified, it is necessary to press the Apply button.

Press RUN or STOP buttons respectively to start or stop the scanning process.

4.4.3.3. Parameter Indication and data Visualization During Scanning

During scanning the Current Line bookmark opens in the right upper corner of Scanning window. This field represents the current line of scanning.

The Previous Line box displays the following information: Line Number – the number of the last line of scanning passed and Height – the difference between the greatest and the smallest Z values for the corresponding topography profile.

An indicator, representing the current Z condition is located in the left upper part of the window. The lower part of the Scanning window is divided in two fields, imaging the scanned surface:

a. Side View;

b. Top View.

The top view pixel color is determined by the height of topography features and by the palette (button). It also depends on the normalization technique. There are three normalization techniques:

1. By the previous line (the buttons  and  aren’t clicked).
2. By the area scanned. After subtracting an approximation plane defined by the area scanned (the button  is clicked).
3. By the area scanned. After subtracting an approximation plane of the second order defined by the area scanned (the button  is clicked).

There is the possibility of viewing the current line image in a separate window on a larger scale. To enable this, click the button available on the bookmark of the current line (‘Current Line’).
There is a function which allows the user to capture and process intermediate results of scanning. To capture the current image without halting scanning, click the button ![Capture button](image). The scanning process is not interrupted, while the captured data are visualized in the window with the title `ScanDataCapture+i` and are saved to a file with the same name to a temporary folder TMP (where `i` is the image index in the sequence of captured images). After the completion of experiment, the files `ScanDataCapture+i` are removed automatically (unless they are renamed by the user).

### 4.4.3.4. Modifying the Parameters During Scanning

The user can modify the following parameters during scanning:

1. **Set Point**: Tunnel Current;
2. **Bias Voltage**;
3. **Velocity**.

If the contact is lost during scanning it is necessary to either increase the value of **Set Point** Tunneling Current parameter or to repeat the **Landing** procedure.

### 4.4.3.5. Saving the Results

During measurements, all the data obtained are sequentially written to files with the names `ScanData+i.spm`, where the index `i` is zeroed on the start-up of the program and is, then, incremented with each new measurement. The files `ScanData+i.spm` are stored in a working folder, which is set before measurements. Another working folder can also be used during measurements to store data. To find another working folder, click the button ![Folder button](image) available on the toolbar of the main window.

To save results of the current measurement, click the button **Save Experiment** in the Scanning Window. A dialog box will appear. Indicate a folder and a file name. The file `ScanData+i.spm`, which is only used during measurements for temporary data storage, will be saved under the new name. By default this file is kept in the working folder indicated before measurements. If data are not saved following the procedure above, all measurement results stored in the temporary files `ScanData+i.spm` will be erased (unless the working folder is changed). Information on the presence of temporary files in the working folder is sent to the user in the form of a warning after the program start-up and before its termination. The standard name `ScanData` can be changed by indicating another name in the working folder dialog box. The working folder dialog box appears after clicking the button ![Folder button](image) available on the toolbar of the main window. Results can also be saved using the box **SPM File Explorer** by selecting the files of interest and saving them in the corresponding folders.

It is possible to export data obtained by means of the instrument NanoEducator in the ASCII format for further use by both the control program Nova and other programs. Scanned images and data on their cross-sections are converted into the ASCII format and are made available for export. To export the data, click the button ![Export button](image). Export, located on the toolbar of the main window, or select **Export ➔ ASCII** in the menu **File** of this window.
4.4.3.6. Scanning in Current Image Mode

To scan in Current Image mode, select a corresponding bookmark in the right lower field of Scanning window prior to scanning and press the RUN button. The \((Z)\) topography image appears in the left part of the window during measurement. Selecting the Top View bookmark results in top view imaging of the \(Z\) measurement, whereas selecting the Side View bookmark results in side view imaging. The top view of the tunnel current value distribution, measured during the Current Image scanning is represented in the right part of the Scanning window. In some cases increasing the velocity of scanning allows to perform the Current Image scanning at constant height. This happens if increasing the velocity of scanning results in decreasing the contrast of the topography image, whereas the contrast of the Current Image increases.

STM One Line Scanning

One Line Scanning in STM configuration is performed as in SFM configuration (see “Scanning” section of “Operating a SFM” chapter).

4.4.4. Tunnel Spectroscopy

Spectroscopy procedure yields the relation between the tunnel current and the applied voltage (Volt-Ampere Characteristic, VAC) working with open feedback loop. “Spectroscopy” is performed in points, specified on the image of the sample surface, obtained during a previous scan.

“Spectroscopy” procedure interface allows to control and modify the following parameters:

- Start and Stop bias voltage \((\text{StartV, StopV})\);
- The number of points between \(\text{StartV}\) and \(\text{StopV}\) parameters in the voltage scale. These points are used to measure the value of tunnel current;
- The number of VACs, measured at each point, set on the sample topography image (Graphics);
- The delay in ms between the sampled points in voltage sweeping \((\text{Delay})\).

To obtain spectroscopy measurement data for different points of the sample, it is necessary to perform the following succession of operations:

1. Perform surface topography imaging scan.
2. Select the Spectroscopy bookmark in the right lower field of Scanning window.
3. Using the left mouse button, select the points on the sample topography image for which spectroscopy measurement is required. Pressing the Clear button, located in the image field, cancels the selection.
4. Press the **RUN** button in **Scanning** window to display the **Spectroscopy** window (Fig. 4-21).

5. Set up the Spectroscopy procedure parameters (**StartV**, **StopV**, **Graphics**, **Points**, **Delay**).

6. Press the **RUN** button in the **Spectroscopy** window.

Once these operations are performed the spectroscopy measurement data for each selected point should appear on separate pages of the multi-page diagram as the measurement progresses.

Fig. 4-21. **STM Spectroscopy procedure** window
5. Operations with the virtual instrument ("Demo")

The virtual instrument ("Demo") is a special program that is run on the PS without connecting the electronics and mechanical modules of the instrument NanoEducator. The virtual instrument emulates all basic functions of the instrument NanoEducator during operating in the SFM and STM configurations. The interface of the instrument "Demo" is the same as that of the “advanced” user level. When running the virtual instrument, the user can adjust operating parameters and observe the corresponding variations in the instrument performance.

The instrument “Demo” is used for the following tasks:

1. Familiarization with the interface and the capabilities of the instrument.
2. Training users to operate the instrument at the “advanced” user level.

Before operations with the instrument “Demo”, read about the interface and functions of the instrument NanoEducator for the “advanced” user level (see chapter 4).
6. Working with Files, Obtained Earlier

To work with data obtained earlier, it is necessary to select File → Open menu or the button in NanoEducator program toolbox.

6.1. Files Directory Preview

The topography images for all SPM format (*.spm extension) files, located in the current directory are displayed in the right part of the SPM File Explorer window in tree preview (Fig. 6-1). When the right mouse button is pressed, File Header window is displayed in the file image field. File Header window contains the parameters used to obtain each file. Pressing Delete button on the keyboard deletes the file, selected in the right field of SPM File Explorer.

![Fig. 6-1. SPM NanoEducator’s files directory preview window](image)

To analyze or process a file, double-click the file image using the left mouse button or press <ENTER>.

This done, the windows are displayed, containing the images of data stored in the selected file. When one of these windows is active, new tools are added to NanoEducator’s program main window, allowing to perform the analysis and data processing.
6.2. **Graphic Representation of Images**

6.2.1. **Graphic Representation of Images**

- **3D** – illuminated three-dimensional image;
- **2D** – illuminated two-dimensional image, top view;
- **3D Geo** – three-dimensional image. The points color intensity is determined by their location in Z direction;
- **2D Geo** – two-dimensional halftone image.

Fig. 6-2. NanoEducator program image representation. a) 3D, b) 2D, c) 3D Geo, d) 2D Geo
6.2.2. Changing Image Scale

The image scale can be modified using View→Zoom menu item, or by standard stretching of the image window.

6.2.3. Image Rotation

In 3D and 3DGeo representations an image can be rotated using the left mouse button or keyboard arrows.

6.2.4. Changing Image Color Palettes

In order to change the image color palettes presented as 2D Geo, 3D Geo, press the button (palette icon) on the Tools toolbar, to display the Geo Palette window (Fig. 6-3). The user can select a palette from the list or create a new one. It is necessary to set proportions of each base color (red, green, blue) for various brightness levels to create a new palette. It can be done by changing the form and position of graphs of the corresponding colors in the Geo Palette window with the left mouse button pressed. After the mouse button is released, the active window of the image is redrawn in a new palette.

![Fig. 6-3. Change of image representation palettes](image)

It is necessary to press the Save Current Palette button and to specify a name to save the palette created by the user, after which it will be included in the list of standard palettes. To change the default palette, select the chosen palette from the list in the Geo Palette window and to press the Save Current as Default button.
6.2.5. Changing Image Color

To change the image color presented as 3D, 2D, press the button on the Tools toolbar, to display the Material Options window (Fig. 6-4).

![Material Options window](image)

Fig. 6-4. Changing the image color in 3D, 2D representation

Various materials reflect the light differently. Optical properties of a material are defined by the following constants:
- dispersed color (Ambient);
- diffuse color (Diffuse);
- mirror color (Specular);
- emitted color (Emission);
- degree of mirror reflection (Shininess).

Most frequently taken into account in various models are the diffusion and the mirror component of color. Diffusion reflection gives to the image natural color, mirror reflection determines how much the image resembles a mirror.

The user can choose the color from the Base Color Material list or to create a new one, changing the values of constants with the help of scroll bars.
6.2.6. Changing the Characteristics of a Light Source

In order to change the characteristics of light sources on the images presented as 3D, 2D, press the button on the Tools toolbar, to display the Light Options window (Fig. 6-5).

![Fig. 6-5. Changing the light source parameters](image)

Properties of light sources are defined by their position and characteristics of the environment. These characteristics develop from the background (Ambient) and the diffusion (Diffuse) components.
6.3. **Graphic Representation of Images**

6.3.1. **Image Processing Functions**

All image processing functions can be accessed in various ways:

- from **NanoEducator** window **main menu** items;
- using the pop-up menu, which is activated by pressing the right mouse button (in case there is an open window with an image);
- using **Tools** panel (Fig. 6-6).

![Image Processing Toolbox](image.png)

Fig. 6-6. Image processing toolbox

Working with images, the user can operate the following functions:

- Fragment cutting:

  Select **Cut Fragment** from **Edit** menu or pop-up menu or press the button on Tools panel to select an image fragment. Fragment cutting is performed by moving the cursor over an image with the left mouse button pressed. A fragment, displayed in a separate window, is subject to all image transforming and processing functions. Deselecting **Cut Fragment** or releasing button cancels the performed fragment cuttings;

- Section cutting:
Select **Cut Section** from **Edit** or pop-up menu or press the button on **Tools** panel. Section cutting is performed by moving the cursor over an image with the left mouse button pressed. A section is displayed in a separate window (Fig. 6-7).

Enabling (disabling) of Cut Section analysis is done by selecting (deselecting) the **Analysis** item of **Tools** section of the main program menu (or its duplicate **Analysis** menu item, which pops-up by right mouse button click). Section analysis is allowed by default. To perform section analysis, place marks on the graph. To place a mark, press left mouse button in a graph point or move the mouse cursor along the graph using left-right arrow buttons and setting points by pressing the **Enter** key. To deselect an active mark, press the **Delete** button. Adding and removing the marks on the graph can be done also using the **Labels** menu item, which pops-up by right mouse button click. dx and dy distances between the marks are displayed on the panel of results in the right part of the section diagram (Fig. 6-7). Presence (absence) of the cursor on the graph is controlled by the **Cursor** menu item. Cursor is set by default. If the cursor is present, its current coordinates are displayed on the panel of results (Fig. 6-7).

To save the graph in a file with *.bmp, *.jpg formats, use **Edit**→**Copy to File** main menu item.

![Image section analysis](image_section_analysis.png)

**Fig. 6-7. Image section analysis**

- **Median Filtration 3x3 points** (Median Filtration, or Median button);
- **AverageFiltration 3x3 points** (AverageFiltration, or Av 3x3 button);
- **Delete constant background** (Level Delete, or button);
- **Delete brightness steps** (Steps Delete, or button);
- **Plane delete** (Plane Delete, or button);
- **Second order surface subtraction** (Surface delete, or button);
- **Change contrast** (Contrast, or button):

To facilitate processing of a series of images, it is possible to apply filters to the images following a preprogrammed sequence by means of scripts.
To use this option, click the button **New Script** available from the panel **Image tools** (the window **Script Generator** will appear) and create a new script. To append new commands, click the button **Add Action** and select the required filter from the list. The buttons **delete** and **clear** are used to edit the text of the script. The new script can be tested by clicking the button **Run Script**, and it will be applied to the active image. Once the window **Script Generator** is closed, the button **Run** is made available. Further on this script can be applied to the active window by using the button **Run** available from the panel **Image tools**. Once the panel **Image tools** is closed, the current script is deleted. To append Fourier filters to scripts, it is necessary to tune them first. Tuning of Fourier filters is done using the window **Image Analysis**. The procedure is as follows: open the page **Fourier Spectrum** from the window **Image Analysis** and apply a filter to one of the images of the series. Then save this filter using the button **Save Filter**. The set therefore filter can be used to process a series of images of the same size.

The result of application of functions can be cancelled by activating **UnDo** operation.

**Two methods of image contrast modification are implemented:**

a. Press the button. A brightness scale will be displayed to the right of Toolbox panel (Fig. 6-6). Moving the scale sliders modifies the image brightness level;

b. If Fragment selecting function ( ) is selected with the button pressed the image brightness level changes and becomes equal to the brightness level of the points in the fragment cut.

Change of the image scale on the vertical axis (Z Scale, button): pressing this button calls a window that allows to change the scale of the vertical axis. If the original image is a topography, the scale can be changed from the real one (identical scale along all axes) up to the maximal one, corresponding to the image stretched to the whole window height.

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**Rule:**

In order to measure distances between points on the image select the item **Rule** in section **Tools** of the main menu, or in the pop-up menu, or press the button on the **Tools** panel. The operation is carried out in the active image window by left clicking the mouse button. The measurement result is displayed in the header of the active window.

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**Protractor:**

In order to measure the angles between directions selected on the image it is necessary to select the item **Angle** in section **Tools** of the main menu, or in the pop-up menu, or to press the button on the **Tools** panel. The operation is carried out in the active image window by left clicking the mouse button. In order to perform the measurement it is necessary to draw an angle. The vertex of the angle is determined by the end point of the first drawn line. The measurement result is displayed in the header of the active window.

All functions are applied to the last active image window.
6.3.2. Image Analysis

Fig. 6-8. Image analysis window.
Analyzing the image surface properties

Fig. 6-9. Image analysis window.
Analyzing the image Fourier spectrum
Pressing the Image Analysis toolbox button activates the image analysis window (Fig. 6-8, Fig. 6-9). The image in the window, active when the Image Analysis button is pressed, is analyzed. The image is reproduced in the left part of Image Analysis window. The calculation results are displayed in the right part of the window. The toolbox of the original image is located above it. The toolbox allows performing the following functions:

- Smoothing by way of averaging (Av 3x3 button);
- Median filtration (Median button);
- Plane subtraction (button);
- Background roughness removal (button);
- Measuring distances on the image. This function is performed using the mouse left button with button pressed;
- Measuring the angles between directions on the image. This function is performed using the mouse left button with button pressed.

The Clear button clears the image.

The following operations can be performed in the Image Analysis window:

- The analysis of the image surface properties is performed with the Roughness bookmark in the right panel of the active window. A histogram of the values of image elements is plotted, accompanied by the computation of the values of the average and mean square surface roughness (Fig. 6-8);
- Fourier spectrum. With the Fourier bookmark selected, a two-dimensional spectrum of spatial frequencies of the active image is displayed in the right panel of the Image Analysis window (Fig. 6-9). The toolbox, located above the Fourier spectrum plot allows performing the following measurements:
  - Determination of the values of the spectrum spatial frequencies and computation of correlating repetition periods of elements in the original image (the function is performed using the left mouse button with the Freq button pressed);
  - Determination of angles between the directions for different frequency components of spectrum (the function is performed using the left mouse button with the pressed. The button is located above the Fourier spectrum plot).
Performing the frequency filtering. To obtain a selective filter in the frequency area, it is necessary to preset the Frequency Weights (gain or suppression) for Selected and UnSelected frequency components (Fig. 6-9). During filtering the selected frequency components can be either increased (weight >1), or suppressed completely (weight=0) or partially (weight <1), as well as left unmodified (weight= 1). The unselected frequency components are either suppressed completely (weight=0) or left unmodified (weight= 1). The selection of frequency components is accomplished using the left mouse button. To obtain a filter, one of the two center symmetrical areas of Fourier spectrum should be selected. The Add button should be pressed to include the frequency area, selected in Fourier spectrum in the filter mask with the weight of Selected. The outline of the selected area becomes red. The filter mask may consist of several successively selected areas with different Selected weights. The filtering weight for the frequencies beyond the selected area should be constant, when obtaining a single filter. Once the spectral components for filtering are selected, press the Execute button. The result, obtained after the inverse Fourier transformation is displayed in the left part of the Image Analysis window, on a new Back Fourier Transform page (Fig. 6-10). All newly obtained filters shall apply to the original image.

6.4. Changing Scanning Scale Along OX, OY Axes

In NanoEducator device the scanning scales along OX, OY axes are determined by the sensitivity of the scanner moving along these directions. The Sensitivity is set in terms of nm/V and is the characteristic of the scanner of the device. Piezoceramic elements of the scanner can “age” in time, which influences its sensitivity. Therefore, sensitivity of the scanner is recommended to be monitored periodically. For this purpose it is necessary to measure the topography of a test object - a bidimensional periodic lattice - and to analyze the obtained image. Control and correction of the X, Y sensitivity values can be performed
using Image analysis window on the Calibration page. The sensitivity values are shown in the Sensitivity X, Y windows when switching to this page (Fig. 6-11). These values were used during test object topography measurement. Measurements of distances on the image are conducted using the Ruler tool. Change of sensitivity values is done by entering new values in X and Y fields. Pressing the Preview button the image on Calibration page is reconstructed according to the changes entered. Use the ruler to view the result. New scanner sensitivity values are saved by pressing the Save button. After that all measurements will be performed with the new values of scales along X, Y axes. Press Load Default button on Calibration page of Image Analysis window to restore the values set by the device manufacturer.

Fig. 6-11. Window of scanning scale along OX, OY axes changing

6.5. Creating a Report on the Operation with SPM NanoEducator

6.5.1. Description of the “Report Generator” toolkit

NanoEducator software includes Report Generator module designed for fast, interactive creation of the reports on operation.

NOTE. Report Generator requires Microsoft Office package installed on the computer (Microsoft Word or Microsoft Power Point is the necessary component of the package).

With Report Generator the user can create reports containing both text and graphics, and after that:

− print the report;
− save it as a Microsoft Word or a Microsoft Power Point file;
− open it as a Microsoft Word or a Microsoft Power Point document for further editing.
**Report Generator** allows to save the structure of the generated report as a template and use it later for creating similar reports. This feature might be useful for writing reports on fulfilling laboratory practices.

The advantage of using **Report Generator** for creating reports on operation with **SPM NanoEducator** over conventional word processors is that it compacts information and enables the inclusion of the **NanoEducator** graphics windows in the report using simple 'drag-and-drop'.

### 6.5.2. Using the “Report Generator” toolkit

In order to activate the **Report Generator** window in the main menu of NanoEducator window select **Report → Report Generator**

The upper part of the **Report Generator** window contains the control elements (Fig. 6-12). The body of the report is placed beneath. When using **Report Generator** the report is built of structural elements, called containers (blocks) of information, just like in Meccano. There are two types of containers: for textual and for graphical information.

![Fig. 6-12. Report Generator window](image-url)
The description of the “Report Generator” control elements

The control elements are grouped according to the logic of working with the report:

− **Type.** The selection of the Microsoft Office program to be used for the final conversion of the report into a document, for printing it and saving it as a file;

− **Report.** The selection of the form for the final report presentation: printing a hard copy, saving as a file or opening as a Microsoft Office document;

− **Action** serves for adding new containers of information and also for deleting the active (marked) blocks and pictures from **images containers.** In order to delete several blocks or pictures at a time mark them using the left mouse button while holding the <Shift> key, then select in sequence **Delete Active** **Delete Image**;

− **Personal Data** group is used to enter the information on the author of the report;

− **Font** serves for selecting the font. The chosen font replaces that of the marked text fragment or becomes the current font.

**Report Generator** also provides facilities for:

− Saving the structure of the created document as a template with a user-defined name. The template stores the headers of all the containers in the document and the content of the text containers with the formatting preserved. To create a template from the current report press **Save as Template** button, then in the window that appears enter the name for the template and press **OK**;

− Using the previously saved templates for creating reports of the same type. To do this, press **Load Template** button and in the window that appears choose the template name from the list and press **OK**.

**Editing the report using “Report Generator”**

**Report Generator** produces the report from a set of containers.

Initially, each container is included in the report in a shortcut form of a header panel. In the left side of the panel there is a designation of the container type: (text) for textual information and (images) for graphics. The container header field is displayed in the center of the panel. The right part of the panel is the button by clicking which the container can be expanded (-expanded, or minimized -minimized).

To add text to the report either a new text container shall be added (Add Text Container) or the existing one shall be expanded. The text is entered in the expanded container field. After the input has been complete, the container can be minimized, with the information having been stored in the container.

As graphics, the user can place the images of any NanoEducator program window. For instance, the windows with the scanned images, **Resonance** window, **Image Analysis**, **Spectroscopy** etc. can be copied to the report. To add images, expand the **images** container
and holding the <Alt> button drag the required objects in the container field. This will sequentially embed the images into the report, with the objects comprised of the image thumbnails and the caption input fields, if required, appearing in the container field (Fig. 6-13).

![Image of the Report Generator window](image)

Fig. 6-13

When minimizing the container or exporting the report that includes minimized containers, the information stored in the containers of both types is saved.

**Exporting and printing the report created with “Report Generator”**

In the report created with Report Generator, the headers and the data from all containers are added sequentially.

Using the buttons of the Action Report Generator group the report can be exported to the programs of Microsoft Office package for viewing and further editing. The report can also be printed without preview and can be saved as a file with *.doc or *.ppt extension.
Appendices

1. Oscilloscope Program Operation Manual

Oscilloscope.exe (further on referred to as oscilloscope) is a software emulating a two-channel oscilloscope. It allows selecting the number of data channels displayed, setting up their graphic representation, selecting the data source, performing the preprocessing of signals, etc. The program is developed in Microsoft Windows 98 and can operate in Microsoft Windows ME, Microsoft Windows 2000/XP as well. A Controller of Scanning Probe Microscope (CSPM) is required to operate the oscilloscope. The program parameters are stored in the register. Elements of the program configuration can be transferred to other PCs.

1.1. Program Start

Oscilloscope program is launched by pressing the button on the control panel. The oscilloscope can be launched independently by activating Oscilloscope.exe program from NanoEducator\Oscilloscope directory. If the program is started for the first time or no configuration is found on the PC, the following message is displayed:

![Information dialog box]

This is conditioned by the requirement of at least one data source for the beams to be displayed. The procedure of editing data sources is described in a section below. The program does not display any data after launching, as both beams are switched off. To switch the beams on, select the OptionsÆSetup menu item and set the number of channels in the Number of channels parameter. Allowed settings are the following:

- Both beams are switched off (initial state);
- One beam (left) is switched on;
- Both beams (left and right) are switched on.

Once the beams are switched on, the oscilloscope displays them, allowing to adjust their graphic representation.
1.2. **Program Stop**

Select either the **File → Exit** menu item or press the button with a cross in the right upper corner of the application window to stop the program execution.

1.3. **Channel (beam) Setup**

The following parameters are set up for each beam:
- Vertical axis scale (1 in Fig. 1-2);
- Vertical scale zero position (2 in Fig. 1-2);
- Vertical scale reference point (3 in Fig. 1-2);
- Data source (4 in Fig. 1-2).

The first three parameters are set by acting on the sliding buttons, the fourth by selecting from the list in the pop-down menu. The location of control elements is presented below.

![Fig. 1-2](image)

The amplification of each channel can be increased using vertical scaling. The scale is divisible by two and can be increased not more than 16 times. Half frame is considered to be the original (unitary) size.

The required portion of a signal can be visualized by modifying zero position. This also allows to vertically shift one beam with respect to the other. The range of scroll bars corresponds to the range of modification of a given parameter. The size of a slider...
corresponds to the displayed portion of the signal. Increasing the scale leads to the decrease of the slider and vice versa.

A reference point is required for scaling. If this point is set in the center of the frame, the size of the signal is modified relative the center (growing up and down). If the point is set in the upper part, the increased signal grows down. A reference point is set up using the grid.

Data source contains a set of parameters for signal display. These parameters include plot color, signed or unsigned data, unit of measurement, etc. The description of data source parameters is contained in data source editing section.

### 1.4. Time Scale

The oscilloscope allows modifying the time base. Operating in real time, the oscilloscope supports two time scales: seconds and milliseconds. The time scale can be modified in the range from 1 sec/frame to 10 sec/frame in the first case and from 4 ms/frame to 2 sec/frame in the second case. Time scale modification is accomplished using a slider (1). Use a marker (2) to switch between seconds and milliseconds range.

![Fig. 1-3](image.png)

In addition to operating in real time, the oscilloscope allows to view and store to a file the data, obtained during the last several seconds of operation. This operating mode is called Offline mode and is activated using a marker (3). Offline mode activates the time scroll bar (4) and time markers (5), corresponding to the limits and the center of the frame. If the position of a slider is modified, the time markers also change. The scroll bar range corresponds to the size of data captured (in time), whereas the size of a slider corresponds to the displayed portion of the signal.
1.5. **Current Information on Signal**

Apart from the signal and signal shape, the oscilloscope provides additional information to the user, including the following:

− Color and name of signal;
− Size of the frame grid cell;
− Frame and reference point position.
The name of the beam data source is displayed in the lower corners of the frame (Fig. 1-5). The lettering of the name and the signal plot are similar in color.

![Source Editor](image)

Fig. 1-6

The grid of the oscilloscope’s frame consists of 10 horizontal and 6 vertical cells. Central lines of the grid have additional points, marking the deciles. Each beam is displayed with its own scale.

The markers with signal values, corresponding to the upper and lower limits of the frame are also displayed. The average marker is displayed at the level of the reference point, marking the signal value in it.

### 1.6. Data Source Editing

Select the **Options ➔ Source Editor** menu item to edit data sources. The following functions are implemented in the program for working with data sources:

- Editing the current data source;
- Creating a new data source;
- Deleting the current data source;
- Importing signal sources database in the form of REG file;
- Exporting signal sources database to REG file.
Signal sources database is displayed in the form of a list of signal names and their addresses. Pressing the button (1) or double-clicking on the list item a user can edit a source. Pressing the button (3) or Delete a user can delete a source. Data sources cannot have similar names since their names are the unique names of signals. A user can assign different names to signals with the same address.

**Fig. 1-7**

![Descriptor Editor dialog box](image)

Fig. 1-7 shows the **Descriptor Editor** dialog box for editing and creating data sources, where all necessary options can be specified. The options are the following:

- **Name**: the name of a data source. The line should not contain more than 80 characters. The sources are identified by their names;
- **Address**: the address of a system variable in CSPM controller. The value of this variable is the value of the signal. The address can be specified either in 10\(^{th}\) or in 16\(^{th}\) system of notation;
- **Color**: the color of the signal plot. The color is selected using a standard color selection dialog box. Color components are specified in the form of three numbers;
- **Modifier**: the type of the signal: signed or unsigned;
- **Min**: the minimal value of the signal, expressed by a floating point number;
- **Max**: the maximal value of the signal, expressed by a floating point number;
- **Unit**: the unit of signal measurement: the line should not contain more than 80 characters. This parameter is optional.

**Min** and **Max** parameters for the signed and unsigned values are calculated differently. All data at the oscilloscope input are 2-byte words. Their range is \([0,65535]\) and \([-32768,32767]\) for the unsigned and signed values respectively. **Min** parameter specifies a signal value, corresponding to 0 and –32768 at the oscilloscope input for the unsigned and signed values respectively. **Max** parameter specifies a signal value, corresponding to 65536 and 32768 at the oscilloscope input for the unsigned and signed values respectively.
1.7. **Program Setup**

Select the *Options→Setup* menu item to set up the program.

![Program Setup Image](image)

Fig. 1-8

Global settings include the number of displayed channels (beams). The allowed values are 0, 1, 2. **FPS (Frames Per Second)** setting indicates the oscilloscope frame refresh rate. The rate range is 10 - 25. This setting should be decreased on older PC. The next setting defines the buffer capacity in milliseconds (fixed volume data flow), where the data is stored. This value is related to the volume of data, captured in switching to **Offline mode**. The program stores data, obtained during the time interval, set in this setting.

The program can emulate the closed input mode by emulating the input RC-string. RC-string parameters are set in options.

1.8. **Compact Size**

The user should double-click on the frame of the oscilloscope to switch between its normal and compact size. The compact size program window consists of program menu and the frame with channel names.
2. Tip Etching

2.1. Preparation for Etching: tip Workpiece Manufacturing

Tools and materials:
− Tungsten wire of 0.15 mm diameter;
− Device for tip workpiece manufacturing;
− Scissors.

Procedure on tip workpiece manufacturing:
1. Straighten the wire for the length of approximately 3 centimeters;
2. Insert the wire against the stop into the metal capillary on the part of the measuring flute of the device (Fig. 2-3);

![Fig. 2-3](image)

3. Bend the wire to approximately 180 degrees angle, pressing it with a finger to the metal capillary (Fig. 2-4);

![Fig. 2-4](image)

4. Pull out the wire from the capillary. Insert the wire’s bent end into the measuring flute against the stop (Fig. 2-5);

![Fig. 2-5](image)
5. Block the wire with a finger against the measuring flute (Fig. 2-6);

![Fig. 2-6]

6. Cut off the wire with scissors, resting the cutting plane of scissors upon an end face of the capillary (see Fig. 2-7). It is important to provide the length BC=18.5±0.3mm (see Fig. 2-8);

![Fig. 2-7]

![Fig. 2-8]

7. Insert the wire on the part of B point (see Fig. 2-9) into the aperture located in the center of the device to form ABC angle;

![Fig. 2-9]
8. Drag the wire through the aperture (Fig. 2-10);

9. Insert the wire from the C point against the stop into the capillary marked by a red point;

10. Bend the wire to approximately 90 degrees, pressing it with a finger (Fig. 2-12);
11. Drag the wire from the capillary. BDC angle (see Fig. 2-13) should be within the limits of 90±5 degrees. The width of a backlash should be not less than 1.0±0.5 mm. If the backlash is too narrow, the gauge can work unstable;

![Fig. 2-13](image)

12. Insert the wire into the piezo tube from the part of point B (Fig. 2-14);

![Fig. 2-14](image)

13. Sink in the wire with a tweezers against the stop;

![Fig. 2-15](image)
14. The probe is ready for the subsequent manufacturing of the apex by electrochemical etching.

2.2. **The Tip Etching Device Design**

The tip etching device (TED) is intended for the manufacture and restoration of SPM tips by means of electrochemical etching.
The tip etching device is presented schematically on Fig. 2-17. Operation of the device is based on the process of electrochemical etching of metal, immersed into the alkaline solution. The etching takes place when the electrical current is applied to the solution, involving the transfer of atoms of the metal to the solution. The tips, made of tungsten wire and sharpened in the course of the process described are used in probe microscopes.

The TED, shown on the figure above operates in the following way:

A piece of tungsten wire 1 is mounted in a holder 8, which is moved manually up and down in vertical direction by the screw 3. By turning the screw 3 the wire is placed in the ring 2, down to the required depth. The ring is made of nichrome wire. A drop of 5 percent KOH or NaOH solution is applied to the ring 2 in advance. After that a source 6 of alternating or direct voltage, marked as V, is switched on. This causes the start of the etching process of tungsten wire and the formation of a sharp tip. The operator monitors the process of etching using an optical microscope or the videomicroscope 7.

Illumination is provided with the light-emitting diode light 4. All design elements are fixed on the basis 5. Once the etching is finished, the holder 8 and the tip 1 are moved to the upper position, where the tip is removed.

### 2.3. TED Technical Specifications

- Typical tip apex rounding radius: 0.2 micron;
- Tip workpiece material: tungsten wire of 0.1 mm in diameter;
- Vertical movement range: 25 mm;
- Voltage source: 6-9 V / 0.5 A alternating current;
- Optical microscope magnification: X 20;
- Tip etching time: not more than 2 min.

### 2.4. Software Installation for TED

Install software for a videocamera to work with TED. The distribution kit and the instruction are supplied on a compact disk.

⚠️ NOTE. If after software installation the camera does not work, open the system control panel: Control Panel ➔ System ➔ Device Manager and select in the Device item: Videocamera and Update camera drivers. Windows operational system will update the information.
2.5. *Manufacturing a New SPM Tip*

1. A universal interaction probe with a replaceable apex is required to manufacture a new tip.
2. Using a tweeze carefully remove the old tip from the probe’s piezo-tube and insert a new work piece.
3. Turn the ring 2 away from the holder 8.
4. Insert the probe in the holder 8 (Fig. 2-17).
5. Connect the TED to the adaptor supplied, and connect the adaptor to mains (220V).
6. Make sure the etching mode is disabled (the red light on the switch is off).
7. Connect the video camera output to USB port of a computer according to the NanoEducator Operation Manual.
8. Move the holder 8 with the probe (using the side screw to loose and block the hinge) in order to place the wire workpiece 1 in vertical position.
9. Using the screw 3 move the holder 8 with the probe to the upper position, so the apex of the wire 1 is above the ring 2.
10. Turn the ring 2 to position it under the wire 1.
11. Adjust the position of video camera so that it focuses on the ring 2.
12. Return the ring 2 to the initial position and apply a drop of 5 percent KOH (or NaOH) solution to it from Petri dish as shown on Fig. 2-17. Touch the wire ring to the surface of the liquid, putting the dish down afterwards. A drop of solution should form on the ring. If the drop falls down when moving the ring, touch the wire ring to the surface of the liquid again.

![Diagram](image.png)

**Fig. 2-18. Applying a drop to the ring**

13. Turn the ring under the wire 1 again and immerse the wire into the drop by turning the screw 3.
14. Set a clearance of approximately 2 mm between the drop and the lower surface of the probe. The length of the tip-to-be should be some 5mm.
15. Start the etching process by turning the switch on. The light on the switch turns on and the liquid starts to boil.
16. While watching the etching process through the video camera, turn it off periodically with the switch and watch the thinning of tungsten wire inside the drop.

17. The lower end of the wire falls away after complete etching.

⚠️ **ATTENTION!** Watch the etching process closely to turn the switch off immediately after the lower end of the workpiece 1 falls away.

18. Move the holder 8 with the tip up to a position, where only the apex of the tip is immersed in the liquid.

19. Switch on the etching process momentarily (for not more than 1 second). Switch off the etching.

20. Move the holder with the probe up, using the screw 3.

21. Remove the probe with the finished tip from the holder.

22. Wash the tip in running water, holding it with the apex down. Dry the tip in warm air flows, using a hair dryer.

23. Insert the probe into the SPM measuring head, checking the presence of a resonance peak according to SPM Operation Manual.

24. If the peak’s amplitude is insufficient, repeat the tip drying procedure, as the moisture remaining can electrically shunt the electrodes of the piezo-element.

>Note. It is recommended to perform etching of a tip NOT in the probe which you will use for work, but in a different one, since alkali fumes can form a humid film on the piezoelement and break temporarily its work. After tip etching and drying it can be inserted into the working probe.

### 2.6. Restoring a Blunt Tip

If a tip is blunt, SPM image quality deteriorates.

A tip should be etched to make it sharp again:

1. Insert a probe with a tip into the tip etching device.
2. Apply a drop of alkali to the wire ring, as described above.
3. Turning the screw 3, immerse the tip apex into the drop, observing the process through the video camera.
4. Repeat step 3 several times with the apex of the tip slightly touching the surface of the liquid (the sharpness of the tip depends on this).
5. Switch the etching process on and wait till the apex of the tip moves away from the surface of the liquid.
6. Switch off the etching.
3. Video Camera

The video camera is intended for visual control on the PC monitor over the sample surface and the positioning of the tip with respect to the sample during tip landing.

The video camera is connected to the PC through the USB port and is controlled by a VideoCAM NB driver through the NanoEducator program. The video camera is equipped with an independent source of illumination.

3.1. Video Camera Design

![Video Camera Design Diagram]

Video camera design is shown in Fig. 3-1. The video camera case is installed on the SPM measuring head. Guide pins 1 are provided for a reliable placement on the head. The screw 2 moves the video camera objective 5 in the horizontal plane, the screw 3 – in the vertical plane. The screw 4 serves for focusing by approaching or removing the objective from the object. Screw 7 is used for light vertical movement, screw 8 is used for light rotation.

3.2. Switching on the Video Camera

1. Install the video camera driver on a computer from the compact disc supplied, if it is being connected for the first time.

2. Connect video camera cable to USB port of the PC or to the USB concentrator supplied with the SPM NanoEducator. Thus the light 6 (Fig. 3-1 a) located near to objective 5 should light up.
3.3. **Video Camera Setting**

1. Install the tip and a sample according to the **NanoEducator SPM** Instruction manual (see item 2.3 on page 21 and item 2.4 on page 22).

2. Lower the tip manually so that the distance between the apex of the tip and the sample surface is about $1 \div 2$ mm.

3. Install the video camera on the SPM measuring head so that guide pins were set in apertures on the measuring head case, and the unit support balls were set in the seats (Fig. 3-2). To fix the video camera on the SPM measuring head, lightly push the top of the video camera until click.

4. Loosen the screw 3 for 2÷3 revolutions counter-clockwise.

5. Rotate the screw 2 in both directions until the image of a probe on the screen appears.

6. Focus the image using the screw 4.

7. Rotating the screw 3, adjust the video camera objective to the apex of the tip, periodically adjusting the focus by the screw 4 to obtain a precise image.

8. In case of excess or lack of illumination the lighter (light-emitting diode) can be shifted by screws 7, 8.

9. Periodically arrange the focusing with the screw 4 during tip landing with **NanoEducator SPM**. It is not recommended to perform adjustment of the video camera after interaction capturing in order to prevent tip mechanical vibrations, which can result in deformation of the apex of the tip or damage of a sample.

10. To remove video camera, pull it upwards, so that the support balls would come out of the seats.
4. Electronic Unit

4.1. General Information on the Electronic Unit

The Electronic Unit (Fig. 4-1) is designed to control processes of collecting data with the educating scanning probe microscope of the NanoEducator model. The Electronic Unit (SPM controller) performs the following functions:

- Controls scanning along X and Y directions;
- Generates signals to excite oscillation of the tip-sample system in force/tunneling microscopy modes;
- Processes signals of the measuring head preamplifier in force/tunneling microscopy modes;
- Provides maintaining of the prescribed current/voltage level and generating the signal coding the sample landscape in the course of scanning of the surface.

![Fig. 4-1. Electronic Unit of the NanoEducator SPM](image)

**Designation of the connectors panel of the Electronic Unit**

Overall view of the connectors panel of the Electronic Unit is shown on Fig. 4-2.

![Fig. 4-2. Rear panel of the Electronic Unit](image)
- **POWER** – socket for main supply of 220 V/ 50 Hz;
- ** grounded terminal;**
- **SCANNER** – socket for connection of the measuring head;
- **CHECK** – socket for connection of the device of automatic etching of tips;
- **HEAD** – socket for connection of the measuring head;
- **RS-232 port** – used for maintenance purposes only;
- **USB port** – socket for connection of the Electronic Unit to the computer.

**Specification**

Overall dimension 260×160×360 mm;
Mass 5 kg;
Supply voltage 220 V (+10/-15)%;
Frequency of the supply voltage 50 Hz;
Power consumption less 30 W.

### 4.2. Interconnections of the Electronic Unit

The Electronic Unit is connected to the computer and to the measuring head with cables. The device components are interconnected according to the schematics shown on Fig. 4-3.

![Fig. 4-3. Schematics of interconnection of the NanoEducator SPM](image-url)
ATTENTION! Before you connect or disconnect any unit switch off the electronic unit. Disconnecting or connecting cables while the electronic unit is operating may cause damage to their electronic circuits.

4.3. **Functional Components of the Electronic Unit**

**Computer communications controller**

The communications controller provides transmission of scan controlling signals from the computer to the SPM and reading the scanning information into the computer.

**Feedback loop**

The feedback loop is the base of the tip-sample distance control system.

The feedback loop provides comparison of the reference level of current/voltage ($U_{REF}$) with the measured one ($U_M$). The produced difference signal ($U_{RM}$) is integrated, amplified, and applied to the input of the high-voltage of the Z-scanner. The Z-scanner displaces the sample to/from the tip and thus changes the measured level of $U_M$ so that to minimize the difference $U_{RM}$. In the course of scanning, the signal applied to the Z-scanner is proportional to height of the landscape of the sample under scan.
**Synchronous detector**

In force microscopy modes, the synchronous detector runs under control of the SPM detector to generate voltage of appropriate frequency and amplitude that excites the piezotube defining oscillation of the tip.

Performs amplitude and phase detection of the preamplifier signal from the measuring head with its amplification and low-pass filtration.

**Controller of the stepper motor**

The controller of the stepper motor controls the direction of the two-stage stepper motor motion and switching of the motor stages supply on and off. The controller runs under control of the SPM controller.

**X, Y amplifiers**

In the **ROUGH** mode, amplify the DAC_X and DAC_Y signals of the controller to +250 V. The amplifiers provide control of scanning on X and Y directions.

In the **FINE** mode, amplify power of the DAC_X and DAC_Y signals of the controller.

**Z amplifier**

In the **ROUGH** mode, amplifies the closed-loop signal to +150 V.

In the **FINE** mode, amplifies power of the closed-loop signal.

The card contains a DC/DC converter to generate 250 V voltage from 12 V voltage for high-voltage amplifiers on X, Y, and Z.

**Power supply**

The SPM power supply consists of:

- AC/DC converter LPT-41 (produced by ASTEC company) to supply voltages of +5 V and ±12 V from the main AC voltage of 220 V;
- card of linear converters to supply voltages of ±15 V.
4.4. Basic Safety Measures

**ATTENTION!** You have to connect the electronic modules of the equipment through the supply-line filters, for decreasing the influence of possible power line disturbances on the process of measurement.

- Ground the instrument before operation!
- Do not disassemble any part of the device. Disassembling of the product is permitted only to persons certified by NT-MDT.
- Do not connect additional devices to the instrument without prior advice from an authorized person from NT-MDT.
- This instrument contains precision electro-mechanical parts. Therefore protect it from mechanical shocks.
- Protect the instrument against the influence of extreme temperature and moisture.
- Switch the SPM controller off before connecting/disconnecting its cable connectors. Disconnecting or connecting the cable connectors during operations may cause damage to the electronic circuit and disable the instrument. A warning label is attached to the SPM controller of the instrument (Fig. 4-5).

![Attention!](image)

4.5. Operating Conditions

To provide for the normal operation of the electric Unit, it is recommended to observe the following conditions:

- Environment temperature: 25 ±5°C;
- Temperature drift less than 1°C per hour;
- Relative humidity less than 60%;
- Atmospheric pressure 760 ±30 mm Hg;
- Electric mains with 220 V (+10%/-15%), 50 Hz and grounding;
- The room should be protected from mechanical vibrations and acoustic noises, either internal or external;
- The device should be protected from the direct sun radiation impact.
4.6. **Storage and Transport Instructions**

**Storage Instructions**

The instruments should be stored packaged (the Russian state standard GOST 10354-82 and GOST 3956) in clean and dry premises with low ambient temperature variations:

- Acceptable temperature inside the premises is plus (25 ±5)°C;
- Acceptable humidity inside the premises is less than 60%.

Storage conditions should comply the Russian state standard specification GOST 15150-69. Conservation of devices for storing should comply the Russian state standard specification GOST 9.014-78.

**Transport Instructions**

The instrument should be carefully packaged to avoid damage during transport. Transportation packaging should comply the Russian state standard specifications GOST 10354-82, GOST 3956 and GOST 9142.

4.7. **Connectors Diagrams Scheme of the Electronic Unit**

**Slot SCANNER (25-contact socket)**

<table>
<thead>
<tr>
<th>Contact number</th>
<th>Signal</th>
<th>Signal designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ux_SCAN</td>
<td>Voltage applied to the X-section of the scanner. Ranges from 0 to +250 V.</td>
</tr>
<tr>
<td>3</td>
<td>Uy_SCAN</td>
<td>Voltage applied to the X-section of the scanner. Ranges from 0 to +250 V.</td>
</tr>
<tr>
<td>6</td>
<td>Uz_SCAN</td>
<td>Voltage applied to the Z-section of the scanner. Ranges from 0 to +150 V.</td>
</tr>
<tr>
<td>17</td>
<td>GND_HV</td>
<td>High-voltage grounding</td>
</tr>
<tr>
<td>18</td>
<td>GND_HV</td>
<td>High-voltage grounding</td>
</tr>
<tr>
<td>24</td>
<td>GND_HV</td>
<td>High-voltage grounding</td>
</tr>
<tr>
<td>25</td>
<td>GND_HV</td>
<td>High-voltage grounding</td>
</tr>
</tbody>
</table>
### Slow Head (37-contact socket)

![Diagram of Slow Head (37-contact socket)]

<table>
<thead>
<tr>
<th>Contact number</th>
<th>Signal</th>
<th>Signal designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>It+</td>
<td>Positive tunneling current.</td>
</tr>
<tr>
<td>2</td>
<td>It-</td>
<td>Negative tunneling current.</td>
</tr>
<tr>
<td>3</td>
<td>VERT+</td>
<td>Positive signal of the piezosensor.</td>
</tr>
<tr>
<td>4</td>
<td>VERT-</td>
<td>Negative signal of the piezosensor.</td>
</tr>
<tr>
<td>9</td>
<td>Ut</td>
<td>Tip-sample bias voltage. Ranges in ±5 V. Used in tunneling microscopy modes.</td>
</tr>
<tr>
<td>10</td>
<td>Upz</td>
<td>AC voltage applied from the generator of the synchronous detector to the piezo tube of the probe. Used in force microscopy modes. Ranges from 0 to 50 mV.</td>
</tr>
<tr>
<td>17</td>
<td>+15 B</td>
<td>Positive 15 V voltage from the power supply.</td>
</tr>
<tr>
<td>18</td>
<td>-15 B</td>
<td>Negative 15 V voltage from the power supply.</td>
</tr>
<tr>
<td>19</td>
<td>+5 B</td>
<td>Positive 5 V voltage from the power supply.</td>
</tr>
<tr>
<td>20</td>
<td>+12 B</td>
<td>Positive 12 V voltage from the power supply.</td>
</tr>
<tr>
<td>21</td>
<td>GND A</td>
<td>Grounding of analogous signals.</td>
</tr>
<tr>
<td>23</td>
<td>GND D</td>
<td>Grounding of digital signals.</td>
</tr>
<tr>
<td>25</td>
<td>GND A</td>
<td>Grounding of analogous signals.</td>
</tr>
<tr>
<td>26</td>
<td>SM_W1</td>
<td>Starting the stage 1 of the stepper motor.</td>
</tr>
<tr>
<td>27</td>
<td>GND A</td>
<td>Grounding of analogous signals.</td>
</tr>
<tr>
<td>28</td>
<td>SM_W2</td>
<td>Stopping the stage 1 of the stepper motor.</td>
</tr>
<tr>
<td>29</td>
<td>GND A</td>
<td>Grounding of analogous signals.</td>
</tr>
<tr>
<td>30</td>
<td>SM_W3</td>
<td>Starting the stage 2 of the stepper motor.</td>
</tr>
<tr>
<td>32</td>
<td>SM_W4</td>
<td>Stopping the stage 2 of the stepper motor.</td>
</tr>
<tr>
<td>34</td>
<td>MARGIN</td>
<td>Indicating the full protracting of the Z-scanner.</td>
</tr>
</tbody>
</table>
5. Frequently Asked Questions

5.1. Samples

Q: What is recommended to be used as a laboratory sample for STM measurements?
A: A metal matrix for CD manufacturing is delivered with the device. Besides that, NT-MDT company manufactures gold plated diffraction gratings. It is also possible to use fragments of a compact disc with gold covering as samples for the STM measurements. Generally, gold or platinum films can be used as a laboratory sample.

Q: How to prepare a CD sample?
A: To prepare the sample the following tools are required:
   − CD (it shouldn’t have a plastic protective layer);
   − Scissors;
   − Scalpel;
   − Tweezers.

To prepare the sample perform the following steps:
1. Using the scissor cut a small disk fragment (the fragment should be less than 12 mm in diameter).

NOTE. If the CD fragment has any recording, pits will be imaged in the scan. If the fragment is empty, only tracks will be imaged. So decide previously what you would like to scan: pits or tracks.
2. Catch the protective layer using the scalpel.

3. Take off the protective layer carefully using the tweezers.

⚠️ ATTENTION! The side of disk with removed protective layer is meant for investigation. Be careful, do not touch the surface while removing the protective layer, otherwise you’ll damage your sample.

4. After removing the protective layer the sample is ready for investigation.

5. The side which was under protective layer is meant for scanning.

6. The sample should be mounted on a double-sided scotch tape.

Q: The Instruction Manual says that a compact disc fragment with no information recorded with the protection layer removed can be used for force lithography. At the same time the strips strongly prevent from drawing of an image. Is it possible to use any other samples for lithography?

A: Strips are used as a reference point for estimation of the sizes and quality control of the apex of tip. If the strips are dim on the topography image, the apex quality is poor and the lithography process will fail. If the strips are interfering, it is possible to perform the lithography on the reverse side of any old CD, using a slice cut off with scissors.

Q: Compact disc fragments were provided as the samples for the topography image acquisition and carrying out of lithography processes. But these fragments are different. Specify this difference, please.

A: The delivery set includes fragments of compact discs both with and without information recorded. In order to perform the processes of lithography it is recommended to use only the disks with no information recorded. It is possible to use any disk to acquire the topography image.

Q: Is it possible to use a DVD disk as a sample and how should it be prepared?

A: DVD disks must have two layers. Use scissors to cut a strip and split it by a sharp knife. Pits are located on the top part of the bottom transparent layer. There is a thin sticky film between the layers; it must be removed accurately; after that it is possible to cut the strip in squares and to put them on a double adhesive tape.
5.2. **Tips**

Q: What is the proportion for preparation of a solution (KOH or NaOH) for tip etching – is it 5 % on volume basis or 5% by weight?

A: The solution is prepared by weight. Use 50 grams of alkali for 950 ml of water.

Q: What wire should be used to manufacture replaceable tips?

A: Tungsten wire. Diameter 0.15 mm.

5.3. **Tip Landing**

Q: “Landing done” message appears during tip landing, i.e. the system informs that the tip has entered interaction with a sample. However, after the <OK> button is pressed, it can be seen that the interaction is not taking place, since the scanner lengthening is equal to 1 and the amplitude of tip fluctuations is close to the free fluctuations amplitude.

A: False response happens when the amplitude of tip fluctuations changes drastically during tip landing due to motor vibrations. This happens when the probe or its apex have insufficiently stable position.

<table>
<thead>
<tr>
<th>Possible malfunction</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>False occurrence of Landing done message</td>
<td>1. Replace the force interaction probe</td>
</tr>
<tr>
<td></td>
<td>2. Remove the probe and insert it again, but not against the stop</td>
</tr>
<tr>
<td></td>
<td>3. Repeat item 2 and measure the resonance curve every time. The curves must be the same.</td>
</tr>
<tr>
<td></td>
<td>4. Change the force acting on the probe using the probe fixing screw, until a good peak is achieved on the resonance curve. Repeat tip landing procedure after this.</td>
</tr>
<tr>
<td></td>
<td>5. Remove the tip from the probe and insert it again or replace it with another.</td>
</tr>
</tbody>
</table>

NOTE. It is not recommended to use the probe immediately after it was etched, since it can change the parameters during alkali drying. It is recommended to etch the apex of the tip in one probe and to work with this tip inserted in another dry probe (when using replaceable tips, which are simply inserted into the tubular piezoelectric tube, and not glued)

Q: The tip is not landing on the sample; the manual approach screw does not rotate when starting the landing procedure; resonant frequency search is carried out normally.

A: Address the customer support service.
Q: When starting the tip-sample approach procedure (“Approach” window, “Start” button) the procedure stops after the second step (Step=2), displaying a message: “Error!! Verify landing option or physical unit state”

A:

<table>
<thead>
<tr>
<th>Possible malfunction</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. “Options” menu parameters set incorrectly.</td>
<td>(See Instruction Manual). To increase “Integrator Delay” parameter value and/or increase “Interaction” or “Current” parameters value, and/or increase “Feed Back Loop Gain” parameter value; the “Scanner Protraction” value should increase at this with each approaching step. The color-filled area of “Z” indicator should be higher at this than the bottom “Z Gate min” threshold, set in the “Options” menu.</td>
</tr>
<tr>
<td>2. No voltage supplied to the scanner. An signal of voltage presence on the scanner is a double click at the head, during each tip approaching step. The first click means a step of the motor, the second click is the sound occurring at voltage resetting from a piezoelement in the scanner.</td>
<td>Check electrical continuity at cable connectors connecting the controller to the measuring head. Check whether the sample movements up and down are visible on the screen of the video camera during Fast Landing operation. If both above remedies fail, address the customer support service.</td>
</tr>
</tbody>
</table>

In the force microscope configuration:

<table>
<thead>
<tr>
<th>Possible malfunction</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The “Oscillation Amplitude” synchronous detector input amplitude value is insufficient.</td>
<td>Increase “Am Gain” value in the “Resonance” window so that the “Oscillation Amplitude” peak value in the resonance curve is not less than 2V.</td>
</tr>
<tr>
<td>2. The resonant frequency was searched after the tip touched the sample.</td>
<td>Remove the tip from the sample and repeat the resonant frequency search process.</td>
</tr>
<tr>
<td>3. Unstable behavior of the force interaction probe.</td>
<td>Replace the probe and/or the tip in the probe</td>
</tr>
</tbody>
</table>

In the tunnel microscope configuration:

<table>
<thead>
<tr>
<th>Possible malfunction</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The set current value $I_t$ is less than the measured tunnel current value.</td>
<td>Make sure that the tip does not touch the sample, (“Current” indicator should display the noise current value of about 0.1-0.2 nA). Set the tunnel current value to 0.7 nA and repeat the landing procedure by pressing “Start” button.</td>
</tr>
</tbody>
</table>
5.4. **Operation**

Q: There is no peak on the dependence curve of the tip fluctuations amplitude on the frequency after the probe resonant frequency search (“Start” button in “Resonance” window).

A:

<table>
<thead>
<tr>
<th>Possible malfunction</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Piezosensor is malfunctioning</td>
<td>Replace the piezosensor</td>
</tr>
<tr>
<td>2. Some contact in the cable, connecting the head and the controller, is disrupted.</td>
<td>Switch off the device. Disconnect the “Head” cable and connect it again. Switch the device on again and launch the program.</td>
</tr>
</tbody>
</table>

Q: Why does not the servo-system switch off in the process of lithography?

A: The sample is affected by interaction with the tip due to voltage pulses applied to the Z-scanner, which are added to the feedback voltage from the servo-system. The duration of pulses must be so short that the servo-system would have no time to process them, and the sample would tap the tip, resulting in sample deformation. But if the pulse duration is too small, the scanner will have no time to perform the movement to the tip due to its own time response. Therefore the pulse duration must be chosen appropriately. This duration is specified in recommendations. The full description of the lithography process is presented in the control program help section.

Q: The “Scanner Protraction” value smoothly varies from 0 up to 1 and back. What is the reason of this?

(After the interaction is captured, the “Scanner Protraction” is not fixed on any value but smoothly varies from 0 up to 1 and back (during this the “Probe Oscillation Amplitude” does not change but stays precisely set to a current value). After some time (about five minutes) the “Scanner Protraction” stops on one value, but after switching to the “Scanning” window everything repeats. The scanner “floats” just the same also during scanning. This does not depend on the probe).

A: The problem can arise in the following cases:

- There is a hair on the sample or on the tip – it is necessary to change location of scanning or the tip.
- The sample is too soft and it is impossible to provide support of necessary force.
- The tip is too thin and bends after interaction is.
- The user has set a too large interaction value, the scanner is extended upwards to reduce the tip fluctuations amplitude, but the range of protraction appears insufficient. In this case it is necessary to reduce the “interaction” parameter and to increase the “integrator delay” time, and to repeat the approaching procedure.
- In any of the cases mentioned above the steepness of amplitude dependence on tip-sample gap is insufficient. It is necessary to measure the approach curve (to perform the spectroscopy).

- The tip is poorly fixed in the piezo-tube and when interaction occurs, the resonant frequency changes. In this case it is necessary to measure the resonance curve before interaction, approach the tip to the sample before interaction is captured, retract the tip from the sample and measure the resonance curve again; the resonant frequencies should not differ much. Besides that, it is necessary to control the “Amplitude suppression” value during resonance curve measurement by means of the virtual oscilloscope. The amplitude should be constant after each start of resonance search process and stay the same in time.

- Amplification is too weak – Increase “Feed Back Loop Gain”.

- The sample (or the sample stage) poorly fixed. The sample stage should be screwed on the shaft against the stop.

- The scanner has broken as a result of mechanical strain of the sample stage.

Q: After starting a new measurement and a selecting a working directory the control panel does not appear and the program does not respond.

A: Before the control panel appears on the screen, the scanner is preliminary retracted from the piezosensor; the scanner retracting script is launched for this purpose. In case if the USB controller is malfunctioning, the controller starves, and the program cannot finish execution of a retraction command.

<table>
<thead>
<tr>
<th>Possible malfunction</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>The controller does not work</td>
<td>1. Check whether FAR program displays the controller (CSPM device in the list of devices);</td>
</tr>
<tr>
<td></td>
<td>2. Check USB connection of the controller and of computer;</td>
</tr>
<tr>
<td></td>
<td>3. Reinstall USB drivers of the controller.</td>
</tr>
<tr>
<td></td>
<td>4. Address the customer support service.</td>
</tr>
</tbody>
</table>

Q: The scanner suddenly retracts when working as a force microscope (i.e. Z=0) and “Oscillation Amplitude” signal on the virtual oscilloscope screen becomes unstable and noisy.

A:

<table>
<thead>
<tr>
<th>Possible malfunction</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>The amplitude of probe fluctuations is insufficient</td>
<td>Increase the “Oscillation Amplitude” value. Repeat the resonant frequency search process.</td>
</tr>
</tbody>
</table>
Q: The topography image gets worse during scanning and then vanishes in the force microscope configuration. Z value decreases and becomes equal to zero.

A:

<table>
<thead>
<tr>
<th>Possible malfunction</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Oscillation Amplitude’’ value has decreased due to the change of the probe resonant frequency value - for example, because of the temperature change or a bump of the measuring head of the device</td>
<td>Remove the tip from the sample. Repeat the resonant frequency search in the “Resonance’’ window.</td>
</tr>
</tbody>
</table>

Q: There is no image of an area being scanned in any scanning options; the scanning lines do not repeat. The interaction is captured normally.

A:

<table>
<thead>
<tr>
<th>Possible malfunction</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. There is no sweep voltage on axes X, Y</td>
<td>Choose the X+ scanning direction, set the maximal scanning area. Observe using the video camera, whether the sample is moving along the X direction during scanning. Choose the Y+ scanning direction, set the maximal scanning area. Observe using the video camera, whether the sample is moving along the Y direction during scanning. If the sample does not move, there is no high voltage on the scanner. Address the customer support service.</td>
</tr>
<tr>
<td>2. Cable contact with the head is disrupted</td>
<td>Switch off the device. Disconnect and connect again the cables connecting the controller with the head.</td>
</tr>
</tbody>
</table>

5.5. **USB Drivers Installation**

Q: What problems arise at installation USB drivers of the controller?

A: Sequence of installation of drivers the following:

1. Connect the controller and the computer by USB cable;
2. Include a feed of the controller

Windows should give out the message on detection new USB devices with name Scanning Probe Microscope. If device Scanning Probe Microscope is revealed, continue installation USB drivers, following the instruction. If the message is given, that the new device is not known or has not appeared any message, it means, that either the computer USB port or the controller USB port does not work. In this case for extended diagnostics carry out the following actions:

a) Connect the controller to another USB port of the computer
b) Check up USB connection on the controller,
c) Try to connect the controller to another computer.

If the problem was not resolved, it means that the controller USB port does not work, and it is necessary to address to the customer support service.

5.6. General Questions

Q: What is the Delay parameter meaning during spectroscopic measurements?
A: “Delay” is a delay between the steps during tip-sample approaching (the sample is moving). The delay is connected with the response time of the electronic block (for the synchronous detector the response time is 1 ms), and during tunnel current measurement there is a delay of the current-voltage converter (also about 1 ms). It is possible to observe the Delay parameter effect as follows: in the STM configuration the reference resistor is installed in the probe holder and the current-voltage diagram is recorded. When the Delay value is strongly decreased, the current-voltage diagram start deviating from a straight line due to the measuring electronics delays.