MICROTESTMACHINES Co.

Atomic Force Microscope

NT-206

Operating Manual

2004

Atomic force microscope NT-206: Operating manual. – Gomel: Microtestmachines Co., 2004. – 68 p.

Attention! In view of constant improvements of the device and updating of its mechanical and electronic parts some differences may exist between real details and the illustrations, that, however, does not mean deterioration of quality and characteristics of the complex.
Specific versions of the AFM may contain no some optional features depending on supplied complete set.
The AFM control software SurfaceScan described in the manual refers to the build 113 of the software.

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Microtestmachines Co., Ltd.,
Telman St. 44 of. 6, Gomel, 246050, Belarus
Tel./Fax: +375 232 555463
E-mail: microtm@mail.ru

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CONTENTS

1 GENERAL CHARACTERISTICS OF ATOMIC FORCE MICROSCOPE NT-206 5
1.1 AFM NT-206 complete set 5
1.2 Characteristics of atomic force microscope NT-206 7
1.3 Design of the scanning unit 7
1.4 Control electronic unit 11
2 AFM NT-206 CONTROL SOFTWARE 14
2.1 Main panel of scanning control 16
2.2 Panel of indicators 18
2.3 Laser source control panel 19
2.4 Generator settings panel (at operation in dynamic mode) 20
2.5 Feedback setting panel 23
2.6 Panel of spectroscopy settings and control (panel FvsD) 24
2.6.1 Static force spectroscopy 25
2.6.2 Dynamic force spectroscopy 26
2.7 Panel of scan area settings 28
2.8 Control panel of positioning stage stepper motors 30
2.9 AFM image visualization window 32
2.10 Panel of calibration parameters 35
2.11 Acquired data pane 36
2.12 Panel of option settings 36
3 INSTALLATION OF AFM NT-206 38
3.1 Placement of the AFM 38
3.1.1 General requirements for the AFM placement 38
3.1.2 Requirements to the room environment 38
3.1.3 Requirement to an electrical network 39
3.2 Connection of the AFM 39
4 GETTING READY FOR OPERATION WITH ATOMIC FORCE MICROSCOPE NT-206 41
4.1 Turning the AFM on and off 41
4.1.1 Turning the AFM on 41
4.1.2 Turning the AFM off 41
4.2 Probe installation 41
4.3 Tuning the detection system 44
4.4 Sample installation 46
5 OPERATING ATOMIC FORCE MICROSCOPE NT-206 47
5.1 Static mode 47
5.1.1 Initial adjustments 47
5.1.2 Sample approaching 47
5.1.3 Scanning 48
5.1.4 Finishing the work 48

5.2 Dynamic mode ... 49
5.2.1 Initial adjustments ... 49
5.2.2 Tuning the cantilever oscillation parameters ... 49
5.2.3 Sample approaching ... 50
5.2.4 Scanning ... 50
5.2.5 Finishing the work ... 51
5.3 Two-pass mode ... 51
5.4 Multilayer scanning ... 53
5.5 Force spectroscopy ... 55
5.5.1 Static force spectroscopy ... 55
5.5.2 Dynamic force spectroscopy ... 56
6 CALIBRATION OF THE AFM MEASURING SYSTEM ... 58
6.1 Defining basic calibration parameters ... 58
6.2 Nonlinearities of a piezoceramic scanner and their correction ... 60
6.2.1 Simple cubic correction ... 62
6.2.2 Advanced cubic correction ... 64
APPENDIX 1 Schematic diagram of AFM NT-206 control electronics ... 68

1 GENERAL CHARACTERISTICS OF ATOMIC FORCE MICROSCOPE NT-206

Atomic-force microscope (AFM) in a complex with control and image processing software is intended for measurement and analysis of surface micro- and submicrorelief, objects of the micro- and nanometer range with high resolution.

Fields of application of the AFM are physics of solids, thin-film technologies, nanotechnologies; micro- and nanotribology, microelectronics, optics, testing systems of the precision mechanics, magnetic record, vacuum engineering etc.

The AFM can be used in scientific and industrial laboratories.

The image of a surface in the AFM is obtained at scanning a sample in a horizontal plane by a tip with the curvature radius about tens–hundreds of nanometers attached to the cantilever. A control system traces the probe position relative the sample surface in every measurement point and adjusts the tip-to-sample separation at constant level set by the operator. The changes of the probe vertical position in every point make an AFM data matrix which is recorded in a file and then can be used for further processing, visualization and analysis.

The instrument features:

- use of laser-beam system for detecting the probe position and torsion;
- operation in static and dynamic modes, static and dynamic spectroscopy;
- digital scanning control system;
- motorized positioning of the measuring head over sample;
- a video system embedded in the measuring head for observing the probe and scanned area on the sample surface;
- connection with host computer via USB port;
- modular structure of the control electronic unit and software allowing easy upgrade to meet specific research tasks.

1.1 AFM NT-206 complete set

Complete set of atomic force microscope NT-206 includes:

- A scanning unit (Fig. 1.1);
- A control electronic unit (controller) (Fig. 1.1);
- A set of electric cords: 3 cables for connection of scanning unit and control electronic unit, a USB A-to-B cord for connection of control electronic unit and host computer, AC power cords for switching control electronic unit to electrical outlet;
- A CD with software suite: AFM NT-206 control software 'SurfaceScan'; software for AFM-data processing, visualization and analysis 'SurfaceView'; additional CD with drivers for embedded video camera.

Optional:

- A set of probes for operation in static and dynamic modes;
- A set of microfabricated calibration gratings;
- Additional probe holder(s).

Fig. 1.1. General view of atomic force microscope NT-206 in basic configuration: scanning unit (foreground device) with control electronic unit (background device).

Note that the AFM operates under the control of specialized software run on a host computer with **Windows 98SE/Me/2000/NT/XP** operating system. It is strongly recommended to allocate a separate personal computer for the purposes of AFM controlling, data acquisition, storing, processing, visualization and analysis. The recommended PC configuration should be at least: Pentium III/Celeron 1700 MHz, RAM 256 Mb, HDD 40 Gb, USB port, VRAM 32, monitor 17”, operating system Windows 98SE/2000/XP.

Additionally, it is recommended for convenience of setup and work with the AFM to equip it with a long-focus optical microscope with magnification ×50 to ×400 and an oscilloscope with sensitivity 5 mV/pt.

Consumables like probe chips and calibration test gratings are available from their original manufactures (e.g., Mikromasch, NT-MDT and other).

1.2 Characteristics of atomic force microscope NT-206

Operation modes	Static (including contact mode and lateral force microscopy) Dynamic (including non-contact and intermittent /analogous to Tapping Mode®/ mode), Static/Dynamic force spectroscopy.
Multiple mode operation	In dynamic/intermittent mode: simultaneous topography measurement and phase shift imaging. In static mode: simultaneous topography measurement and mapping of local friction forces (torsion) and cantilever deflection variations.
Maximum scanning area	20×20×3 μm
Scanning matrix size	Up to 1024*1024 points and more
Scan rate	10 μm/s in X–Y plane.
Detection system	Laser beam, four-quadrant position sensitive photodetector.
Scanning scheme	The sample is moved in X-Y plane (horizontal) and in Z-direction (vertical) under stationary probe.
Nonlinearity correction	A software nonlinearity correction provided
Cantilever	Commercial AFM cantilever chips 3.4*1.6*0.4 mm
Maximum size of a researched sample	30×30×8 mm (width–depth–height)
Range of measuring head motorized movement	10*10 mm in XY-plane
Field of view of the video system	1*0.75 mm, size of the visualization window 640*480 px.
Working environment	air, 760±40 mm Hg col., 22±4°C, RH <70%
Vibration isolation	Additional vibration isolation is recommended
Scanner DAC word length	16
The high-voltage amplifier output voltage	±200 V
Overall dimensions	*Scanning unit:* 185x185x290 mm; *Control electronic unit:* 470x210x195 mm (w-d-h)
Weight of the units, not more than	*Scanning unit:* 4.7 kg; *control electronic unit:* 7.7 kg
Power supply	220 V, 50 Hz
Consumed capacity	Not more than 300 W

1.3 Design of the scanning unit

The scanning unit (Fig. 1.2) is designed for work in open air and gives convenient access for sample installation and change of scanning probe. The instrument employs measuring scheme with stationary probe over the movable sample. During measurements, precision movements of the sample are provided by a tube piezoscanner on which the sample is placed. Before measurements, one can position probe over sample to target necessary area using motorized positioning stage.

The scanning unit comprises base platform (case) (1) and detachable measuring head (8). All mechanisms are assembled on the case upper plate that serves as a base plate. From lower side (inside the case) on the base plate is mounted a mechanism of the piezoscanner vertical motion. The mechanism provides approach (lifting) and withdrawal (lowering) of the piezoscanner with a sample placed on sample platform established on the tube top (16) relative the probe (Z or vertical motion). Range of the mechanism motion is 20 mm with step down to about 200 nm.

From upper side of the base plate is mounted XY positioning stage used for preparatory motion of the measuring head over the sample (coarse XY positioning) to target necessary area on it. The positioning stage consists of Y stage (2) with its driving stepper motor (3) and X stage (4) with own driving stepper motor (5). The XY positioning stage motion range is 10 mm in both directions with step 2.5 micron.

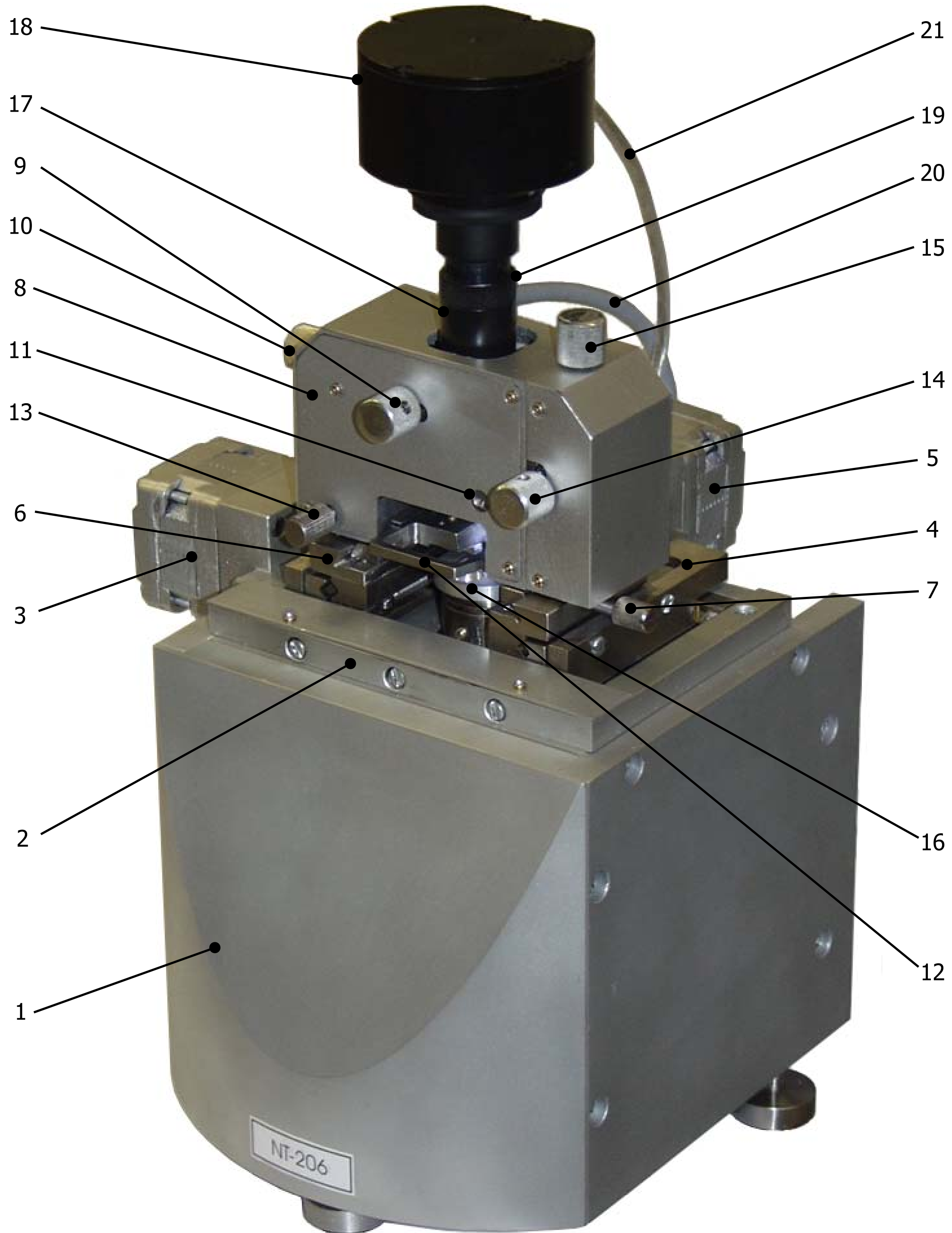


Fig 1.2. Scanning unit of atomic force microscope NT-206. 1 – case (base platform); 2 – Y positioning stage; 3 – driving stepper motor of Y positioning stage; 4 – X positioning stage; 5 – driving stepper motor of X positioning stage; 6 – a dove tail couple for mounting measuring head; 7 – screw for fixing the measuring head in dove tail; 8 – a measuring head; 9 – a knob of laser source adjusting mechanism for X direction; 10 – a knob of laser source adjusting mechanism for Y direction; 11 – a mirror axis; 12 – a probe holder; 13 – a screw for locking a probe holder; 14 – a knob of a photodetector adjusting mechanism for X direction; 15 – a knob of a photodetector adjusting mechanism for Y direction; 16 – sample platform on the piezoscanner top; 17 – a video system tube; 18 – a video camera module; 19 – a turnable ring for fine focusing of the video system; 20 – video system output cable (USB type); 21 – measuring head cable.

From above the X positioning stage, a dove tale (6) is mounted for installation of the measuring head (8). The measuring head (8) is installed by moving it forward from the front in horizontal plane. Screw (7) serves for tight fixing of the measuring head on base platform. To switch the measuring head into the general circuit, plug its cable (20) into socket on the rear side of the case. Additionally it is necessary to plug the USB cable (21) of the video camera (18) into free USB socket on the host computer. To detach the measuring head from the base platform (case), unplug the connectors (from measuring head and from video camera), unscrew the fixing screw (7) and pull the head off the dove tail (6).

Measuring head (8) represents a high-precision system comprising mechanical, optical and electronics equipped with specially designed video camera (18). In the lower part of the measuring head a removable probe holder (12) is installed. Screw (13) is used for locking the probe holder after installation it in the measuring head. Knobs (9) and (10) serve for targeting the laser beam on to the probe at tuning. Note that laser source and video camera optics are integrated in one system and therefore video camera (18) will move with the laser source adjustment. This scheme provides permanent targeting of the video camera on to the area around the laser beam center. Knobs (14) and (15) are used for tuning the photodetector on to the beam reflected from the rear side of the probe cantilever. Axis (11) turns a mirror reflecting the bounced beam on to the photodetector and can be used for additional tuning of the measuring system (it is, however, recommended to keep this axis as it was established by the manufacturer and use this option in extreme cases).

Ring (19) on the video camera tube (17) serves for fine focusing of the video system in the range about 1 mm along vertical axis. The video camera module (18) can be detached from the system by unfixing special screw on the tube and pulling it then up. Note that the video system contains fine optical elements inside and therefore it is strongly recommended to protect the opened ends of the tubes against dust and dirt.

For realization of measurements, a segmented tube piezoscanner moves a sample in horizontal plane (movement in XY-plane) under the probe tip from point to point on a kind of raster pattern (Fig. 1.3). The scanner goes across the first scan line, and back. Then it steps in the perpendicular direction to second scan line, moves across it and back, then to the third line, and so on. AFM collects data in one direction called the fast-scan direction. To drive the scanner in such pattern, the AFM electronics applies appropriate voltage to segments of the tube piezoscanner that causes its bending in a plane parallel to sample surface (Fig. 1.4).

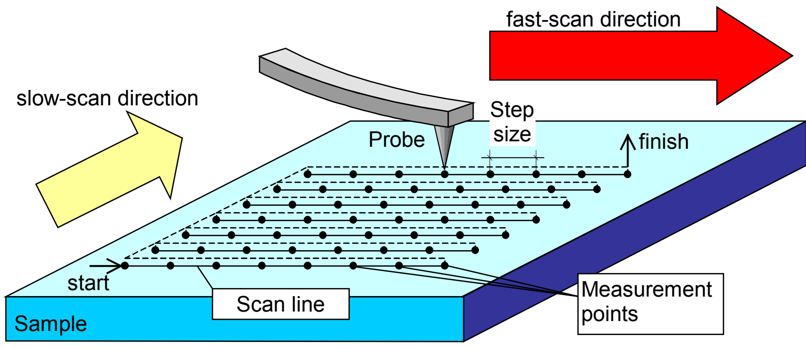


Fig. 1.3. A sample motion under the AFM probe during the data acquisition

In every measurement point, AFM detects the probe position. When the probe tip approaches to a sample surface at a distance about several nanometers, the probe cantilever bends under influence of molecular forces (attractive or repulsing) arising between the tip and the sample surface. For estimating the cantilever deflection, a position sensitive photodetector (PSPD) is used (Fig. 1.4).

Light beam reflected from the cantilever rear side goes to the PSPD. Change of the probe position causes the shift of a reflected light spot on the PSPD and can be easily measured. Electronic system defines change in the probe-to-sample separation and applies corresponding voltage to Z-piezotube to extend or to shorten it to keep the tip-to-surface separation constant. So, the tip moves over a surface at constant distance and repeats its relief.

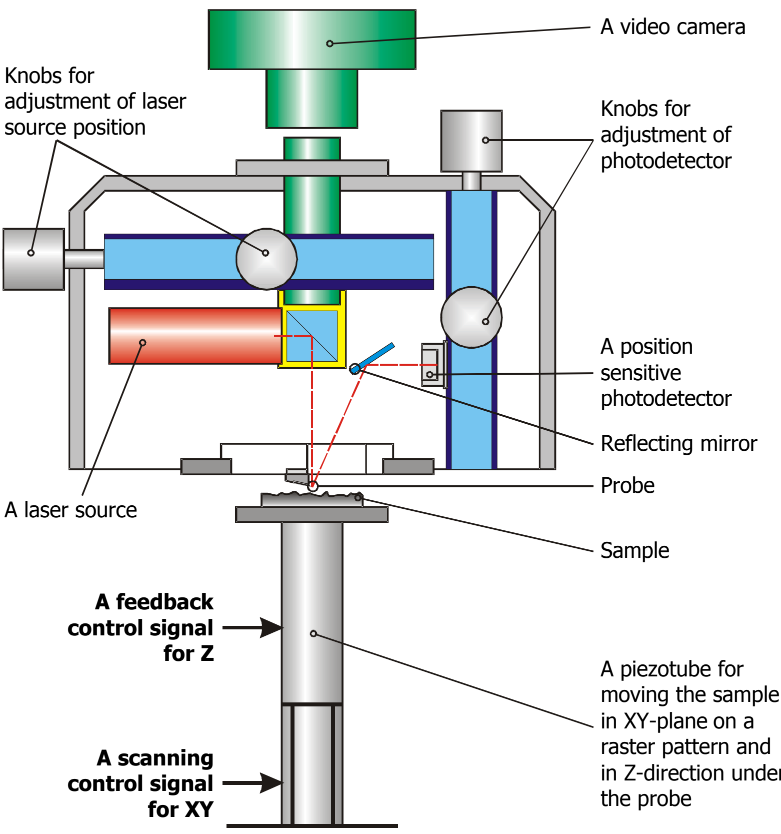


Fig. 1.4. A schematic diagram of the scanning system and probe position detection

The voltage values on Z-piezotube in every measurement point are collected and recorded by the host computer and make the AFM data matrix. From these data the relief height parameters or corresponding micromechanical or other characteristics are derived to build a 3D AFM-image of the surface site.

A four-quadrant PSPD installed in the system allows measuring of both vertical deflection and torsion of the probe cantilever. That enables simultaneous topography measurement and lateral force (local friction force) mapping under contact mode operation. Scheme of this measurement as well as the difference from two-segment PSPD allowing only vertical deflection measurement is shown in Fig. 1.5.

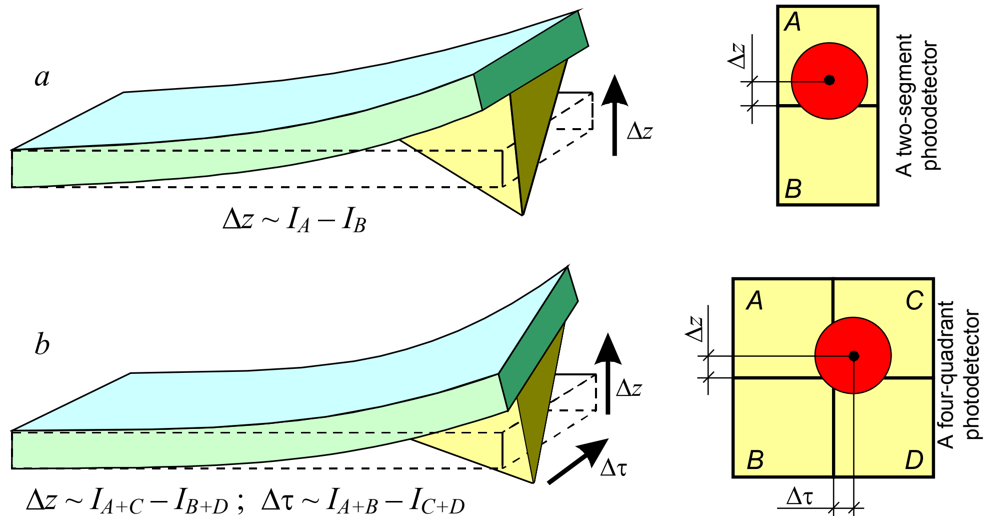


Fig. 1.5. Detection of vertical Δz and lateral Δτ (torsion) deflections of the cantilever by PSPD: **a** – measurement of vertical deflection only by a two-segment PSPD; **b** – a four-quadrant PSD of a Lateral Force microscope for simultaneous measurement of vertical and lateral deflections.

For operation in dynamic mode, the system makes the probe to oscillate with frequency *f* up to 600 kHz. The oscillation frequency is chosen corresponding to own resonant frequency of probe. The probe oscillations are excited by modulated voltage applied to a piezoactuator that is mechanically connected with the probe.

1.4 Control electronic unit

Control electronic unit serves as a link between the host computer and scanning unit. It contains electronic systems driving the atomic force microscope according to instructions from the host PC. It also transmits the acquired data to the control software. The functions of switches and connectors on the electronic unit case are specified in Fig. 1.6.

Control electronic unit consists of six functionally complete systems located on separate boards (Fig. 1.7):

- system of the connection with host computer (2);
- probe oscillation generator (4);
- feedback monitoring system (5);
- system of the tube piezoscanner Z-position control (6);
- system of the tube piezoscanner XY-movement control (7);
- system of the stepper motors control for measuring head positioning and probe approaching/withdrawal (8).

All the boards are installed on common bus (3).

The control electronic unit operates as follows. The commands from the AFM control software are sent from host computer through USB interface (1) to the connection board (2) in the control electronic unit and then transmitted to common bus (3) which joins all control systems of the unit. The common bus consists of 8-bit address bus, 16-bit data bus and 2-bit control bus.

Under dynamic mode, according to the preset parameters of the probe oscillating frequency *f*, phase shift $\Delta\varphi$ and amplitude *A*, generator (4) produces a signal for the piezoactuator (9) and lock-in signal for the feedback monitoring system (5). The hardware provides variation of the oscillation frequency, phase shift and amplitude in the following ranges: f = 10…600 kHz; $\Delta\varphi$ = 0…360 °; A = 0…7.5 V (in absolute units).

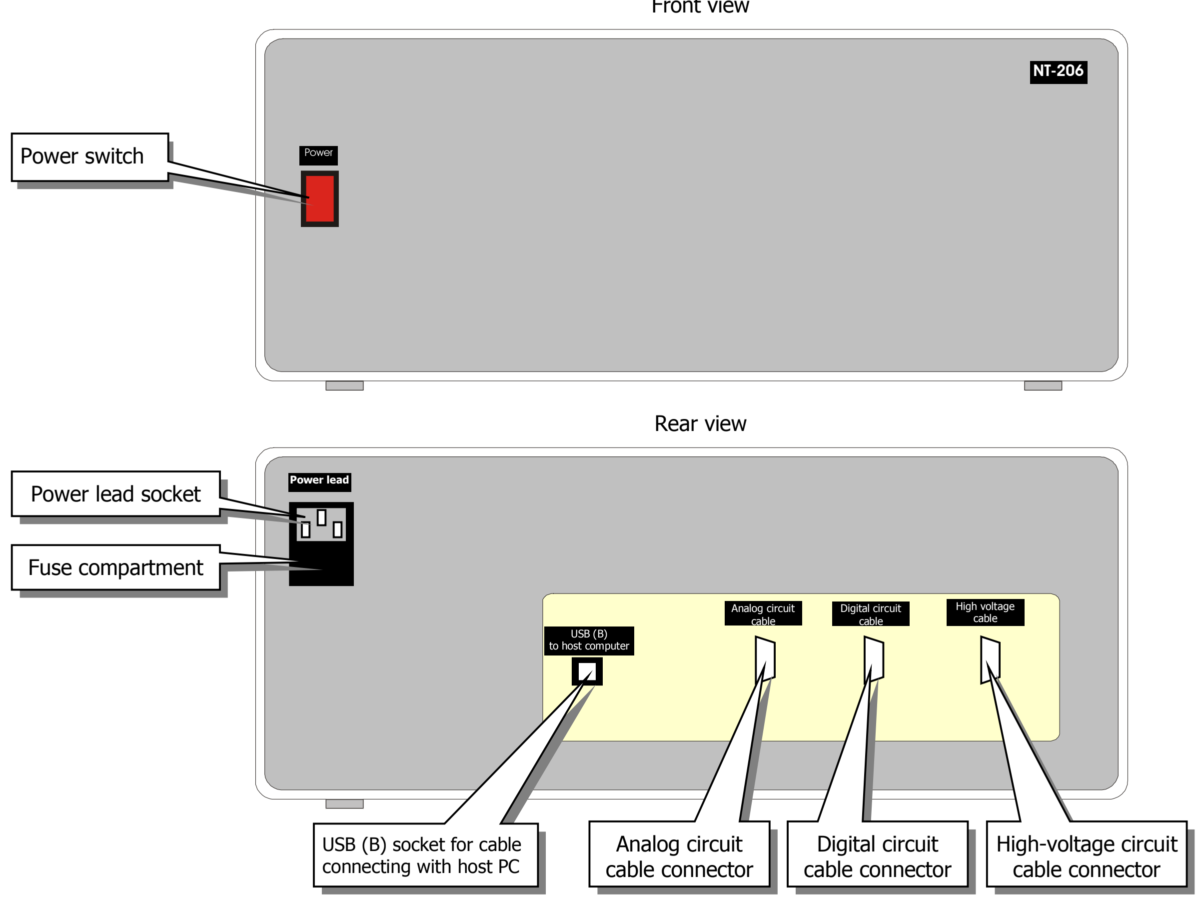


Fig. 1.6. Switches and connectors on case of control electronic unit

Feedback monitoring system (5) analyzes signals from PSPD (10) and using the analog-to-digital converter forms a signal describing the direction and magnitude of the cantilever deviation.

According to these signals and the preset feedback coefficient, system of the tube piezoscanner vertical position control (6) changes voltage applied to Z-electrode of the scanner (11) to keep probe-to-sample separation at the preset level. The AFM control software registers values of a voltage at Z-scanner in each measurement point, collects them in the computer RAM and uses to build an AFM-image of the researched surface.

System of the tube piezoscanner XY-movement control (7) generates signals for electrodes –X, –Y, X, Y of piezoscanner (11) to provide its movement in a raster pattern (Fig. 1.3). The researched surface moves in the same pattern under the stationary probe.

System of the stepper motors control (8) manages the preparatory procedures. Stepper motor (12) enables vertical movement of the tube piezoscanner with sample installed on its top necessary for approaching it to the probe and moving off it. Stepper motors (13) and (14) enables in-plane movements of the measuring head necessary for its coarse positioning over sample to target the area to be scanned.

Circuits of feedback monitoring system (5), system of the tube piezoscanner vertical position control (6) and system of the tube piezoscanner XY-movement control (7) are integrated at one PCB and are built with use of programmable logic controllers. System of the stepper motors control is located inside the scanning unit and is connected with the common bus (3) by cable.

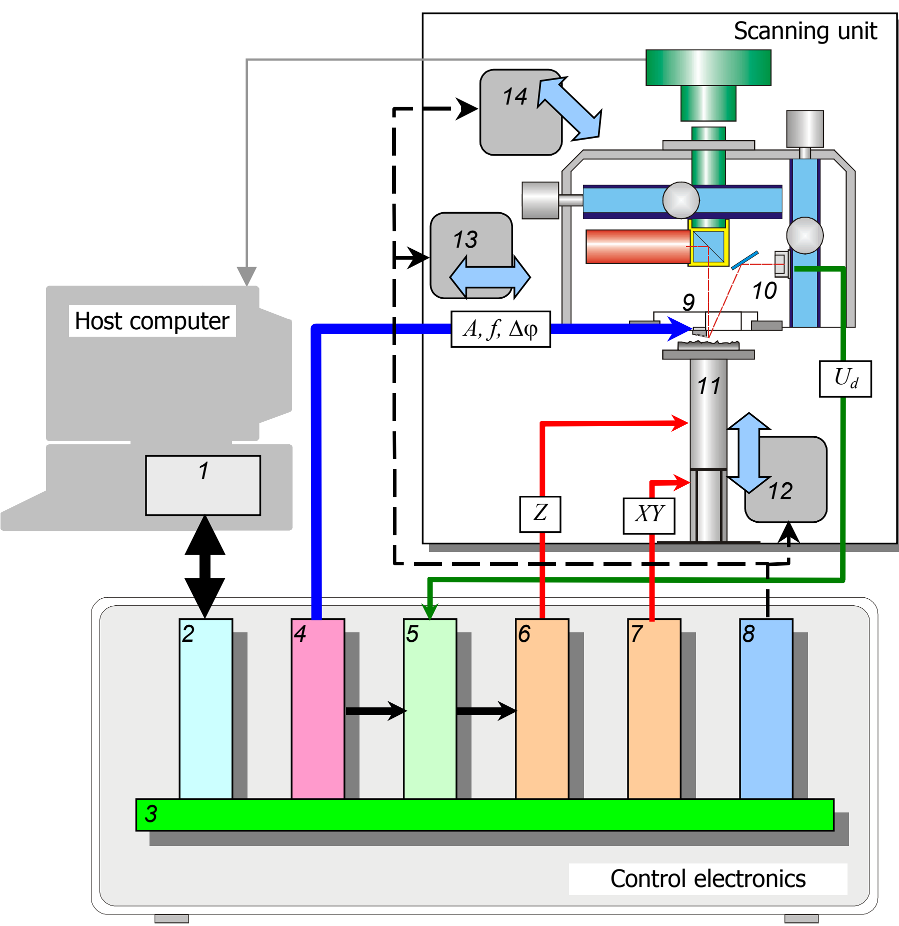


Fig. 1.7. Functional scheme of the control electronic unit: 1 – interface card of the host PC; 2 – system for connection with host computer; 3 – common bus; 4 – probe oscillation generator; 5 – feedback monitoring system; 6 – system of the tube piezoscanner vertical position control; 7 – system of the tube piezoscanner XY-movement control; 8 – system of the stepper motors control; 9 – piezoactuator of probe oscillation system; 10 – position sensitive photodetector for measuring the cantilever deflection and torsion; 11 – a piezoscanner moving the sample in XYZ directions; 12 – steper motor of the probe-to-sample approaching/removing mechanism; 13 – stepper motor of the measuring head Y-positioning stage; 14 – stepper motor of the measuring head X-positioning stage.

More detailed schematic diagram of PCB's and their connections is shown in Appendix 1.

2 AFM NT-206 CONTROL SOFTWARE

Atomic force microscope NT-206 operates under the control of a specialized software delivered in the complete set and executed on the IBM PC-compatible computer. The specialization allows thus the most full use of the instrument features.

The AFM control software enables tuning of the measuring systems and control over measurement process of the solid surface topography with the subsequent saving of the acquired data in a file of a special format. The default extensions of the data file name is **`*.SPM`**. In one file, a set of acquired AFM-data relating to one measurement is stored: topographical image usually is accompanied with additional contrast images collected simultaneously with it.

The AFM control software is a 32 bit program run under **Windows 98SE/Me/NT/2000/XP** operating system and realizes its user interface characteristic features. The AFM control software consists of functionally completed components playing own role during work with the instrument and having own virtual control panels. User interface of the panels is organized by a principle of analog set-up of the device with the help of virtual buttons, switches and regulators (slidebars). Besides, some adjusted parameters are duplicated in the digital form for more exact tuning. The access to the majority of functions of the program interface, all set-up procedures and adjustment in control panels is fulfilled with mouse.

The AFM control software comprises executable file **`SurfaceScan.EXE`**, supporting libraries **`bulk.DLL`** and **`hcl.DLL`** and configuration files **`SurfaceScan.INI`** and **`hcl.INI`**. All these files are to be placed in the same folder. Before the first running of the executable file, install properly library **`bulk.DLL`** to ensure correct operation of the USB interface. For that, right click on the file **`bulkn.inf`** and chose item 'Install' in the context menu. Proper installation is possible only when files **`bulk.DLL`** and **`bulkn.sys`** are in one folder (directory) with file **`bulkn.inf`**.

To run the control software, double click on its shortcut placed on the desktop. The software can be started in other usual ways existing in the operating system, such as double click on a file **`SurfaceScan.EXE`** in Windows Explorer and others.

Check that the USB port in host computer is enabled (in the PC's BIOS) and works properly before plugging the communication USB cable from the AFM control electronic unit into a USB port in the PC and running the AFM control program.

To exit from the AFM control program, common **Windows** ways can be used – by pressing the left mouse button on the button ☒ in a right top corner of the program window or choosing menu item *File > Exit*.

After the start of SurfaceScan, main program window appears at the desktop (Fig. 2.1). By default, the window contains a menu and tool bar; all other control panels and interface elements in the main window appear after choosing corresponding menu items or pressing corresponding button in the tool bar. Visualization windows showing progress and results of the measuring process appear after running corresponding commands available in control panel and menu or tool bar.

Prompt line in the bottom of main window provides description of currently executed functions or buttons under mouse cursor.

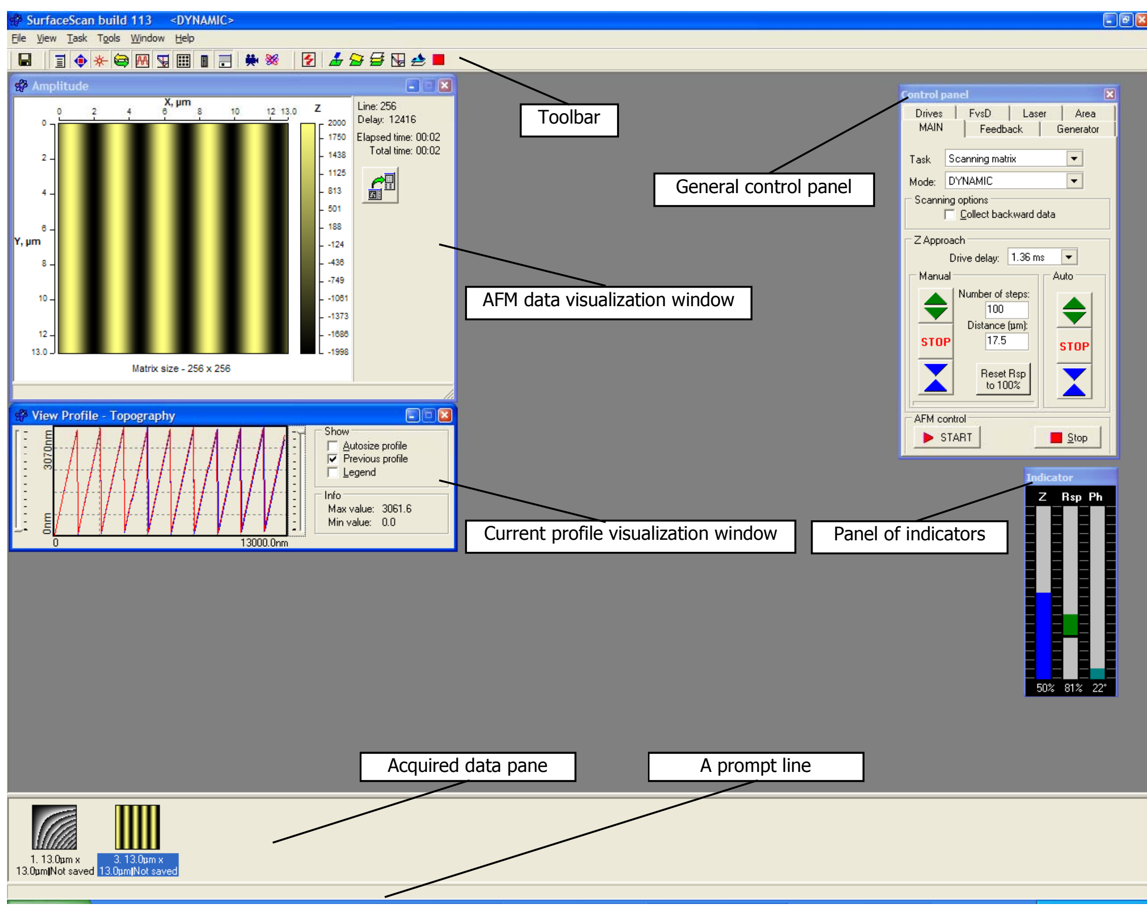


Fig. 2.1. Main window (desktop) of AFM NT-206 control software SurfaceScan.

Commands available in SurfaceScan menu are shown and briefly described in Table 2.1.

Table 2.1. Command in menu of SurfaceScan program.

File	View	Task	Tools	Window	Help
Save Save as Options Exit	Main Drives Laser Feedback Generator FvsD Area Indicatror Container	Reset hardware Calibrate Scanning matrix Two-pass scanning Multilayer scanning Spectroscopy in point Dynamic force spectroscopy	Video Cam Express SurfaceView	Tile Cascade Arrange all Hide Show	About
Common saving operations with acquired data in current window, activation of the SurfaceScan options panel, exit from the program.	Commands to show/hide corresponding control panels.	Commands of the hardware reset (initialization), activation of the panel for entering calibration parameters, run commands for corresponding measuring processes.	Commands for quick launch of accessory applications.	Commands for arrangement and control over the windows in main window.	Information about Surface Scan program and its current version.

Buttons in toolbar below the program menu duplicates all main and frequently used commands from the menu. Functions of the toolbar buttons are described in Fig. 2.2.

Fig. 2.2. Toolbar and functions of its buttons.

All control over the AFM operation is performed through the specialized panels that are called out by pressing corresponding buttons in the toolbar or by choosing corresponding menu items. Below, functions of the control panels are described.

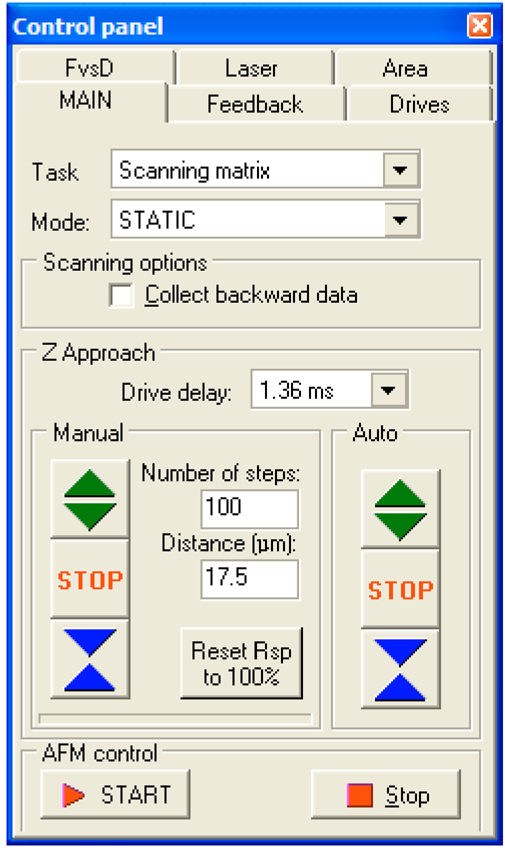
2.1 Main panel of scanning control

This panel is activated by clicking on button in the toolbar or by choosing menu item *View > Main*. ***Main*** panel opens general control panel (floating panel *Scan properties*) and therefore has a priority over all other control panels. That means that ***Main*** panel should be activated for the first turn. All other control panels can be then docked to the general control panel and undocked of it by dragging them with a mouse pointed at panel tab/heading. ***Main*** panel of scanning control with all other docked control panels set for operation in static and dynamic modes is shown in Fig. 2.3.

The panel (Fig. 2.3) allows to the operator control tasks to be fulfilled with the instrument, switch AFM modes and tasks and run vertical approach/withdrawal of sample relative the probe. Besides, it also contains buttons for the scanning process start and termination.

Tasks available for fulfillment in the instrument are:

- *Scanning matrix* – measurement of the set area (area is defined in 'Area' control panel;
- *Two-pass scanning* – a specialized two-pass SPM technique for measuring two images at the same area with different tip-to-sample separation; first image can be a topography and then second a contrast image;
- *Multilayer scanning* – a specialized technique for automated measurement of a series of images at the same area with different set-point values;
- *Spectroscopy in point* – a spectroscopic measurement in predetermined point within the scanned area.



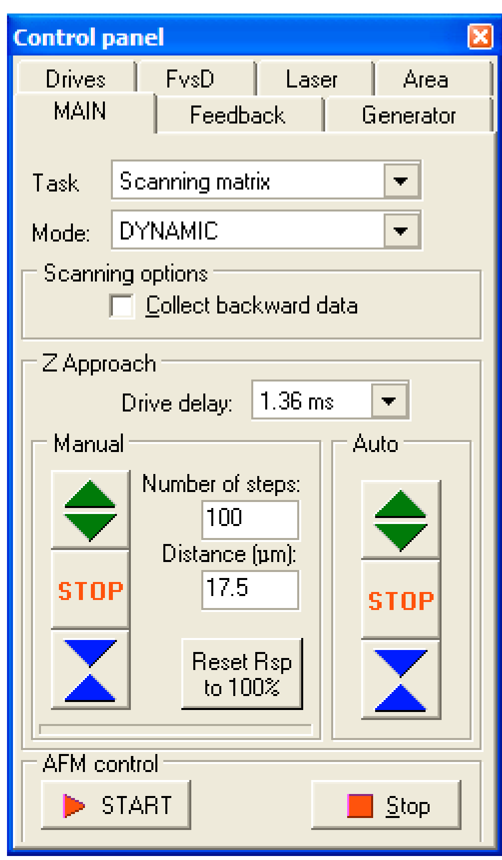


Fig. 2.3. Main panel of scanning control with all other docked control panels set for operation in static (left) and dynamic (right) modes

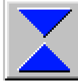
AFM NT-206 supports operation in both *STATIC* and *DYNAMIC* **Modes** for all **Tasks**. However, *Two-pass scanning* for imaging electrostatic foirces must be run under *STATIC* **Mode**.

Depending on the selected **Task**, a field below the **Mode** selector provides turning on of specific parameters:

- at *Scanning matrix* – additional option *Collect backward data* that allows to collect and show data acquired by the system at return motion of the probe relative surface and then to save the obtained data in file together with onward data (collected by default along the fast scan direction);
- at *Two-pass scanning* – an offset or lifting distance before the second pass at the beginning (Start lift, nm) and the end (End lift, nm) of the scan.

Field **Z Approach** allows controlling vertical motion stepper motor in *manual* (in left part) or *automatic* (in right part) modes for approach/withdrawal of the sample relative probe. *Drive delay* parameter allows also to change the speed of the approach/withdrawal motion: greater delay means slower motion. Buttons of the field serves:

to start withdrawal of sample platform off the probe (withdrawal);



to start approach of sample platform to the probe (approach);

to stop motor of vertical motion and, correspondingly, any vertical motion. To stop the motor, key **Esc** on the host computer keyboard can be used as well.

Button Store set-point settings allows to set current reference level to 100 per cent in Reference level indicator (Ref).

In *Auto* mode approach of the sample platform will be performed till the probe starts to 'feel' the surface. After that *Auto* approach button will be disabled. *Auto* withdrawal is always available and is performed till the Stop button pressed or the mechanism reaches the lowest point of its range. If after completing the *Auto* approach it is necessary to move the sample closer to the probe, operator can use *Manual* mode. The system will fulfill the number of steps set in pane *Number of steps*. Distance corresponding to that number of steps is indicated in pane *Distance (micron)*. Each step of the mechanism is about 200 nm.

Be careful! In *manual* mode it is possible to move sample towards the probe without limitations. It means that too big number of steps to perform can lead to the system breakdown!

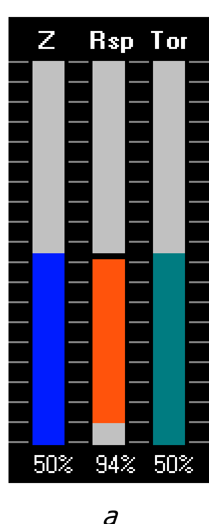
Control over the scanning process is fulfilled by the buttons:

Start of the measurement process;

Stop — Termination of the measurement process.

2.2 Panel of indicators

Panel of ***Indicators*** (Fig. 2.4) is activated by button in the toolbar or menu command *View > Indicator* and shows graphically following parameters of the measuring system:



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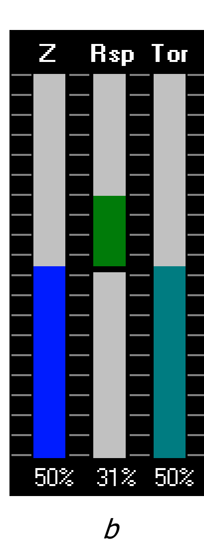
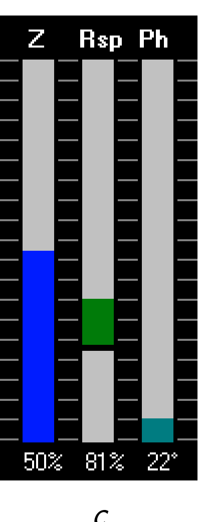
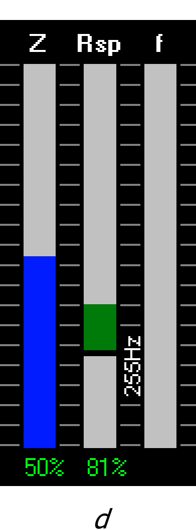


b



c



d

Fig. 2.4. Panel of indicators in Static (a, b) and Dynamic (c, d) modes.

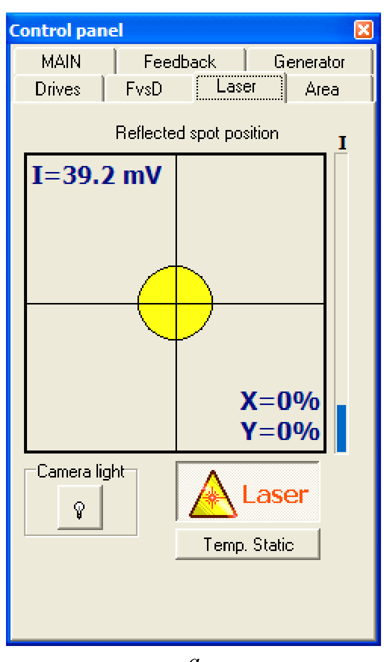
- *Z* – relative Z-extension of the tube piezoscanner. Completely colored indicator (100%) means the piezoscanner is fully extended;
- *Rsp* – current value of set-point ratio (in per cent). In *static mode* it corresponds to relative deflection of the probe cantilever; in *dynamic mode* it describes level of the free oscillation amplitude suppression (in percent) – 100% corresponds to free oscillation amplitude, 0% corresponds to complete suppression of the probe cantilever oscillation;
- *Tor* (in static mode, Fig. 2.4 a and b) – torsion value defined by a balance between left and right parts of the photodetector. Equal state of the cantilever, i.e. without torsion corresponds to 50%;

- *Ph* (in dynamic mode, Fig. 2.4 c) – phase shift of the probe cantilever oscillation (in degree). The shift between the phase of applied signal driving the probe oscillation and outgoing signal measured on the photodetector. The shift is conditioned by mechanical processes occurred at the contact of the probe tip with measured surface and bears additional information on local properties of the surface. This mode of the panel runs when *Feedback mode* in ***Generator*** panel is set to *Auto phase*.
- *f* (in dynamic mode, Fig. 2.4 d) – Current value of the autogenerator frequency. Digital value of the autogenerator frequency is repeated by left side of the bar. This mode of the panel runs when *Feedback mode* in ***Generator*** panel is set to *Auto frequency*.

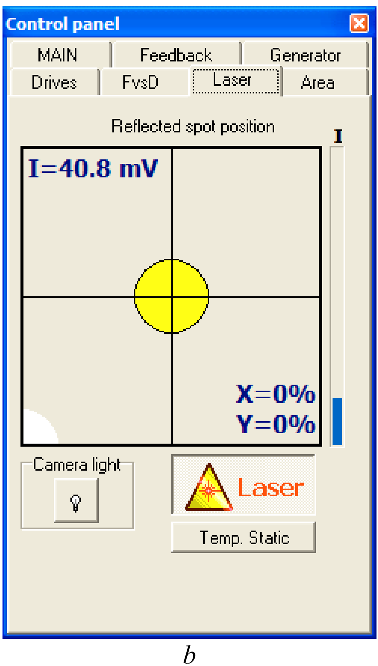
Note that ***Indicators*** panel does not provide for docking it to general control panel as it should be visible (when activated) at any time for watching state of critical parameters of the instrument and its measuring system. The panel has two states – full (when the panel borders and title are visible) and reduced (when the panel borders and title are switched off). To toggle between the states, double click with left mouse button within the panel area. Full state of the panel allows its dragging with mouse.

2.3 Laser source control panel

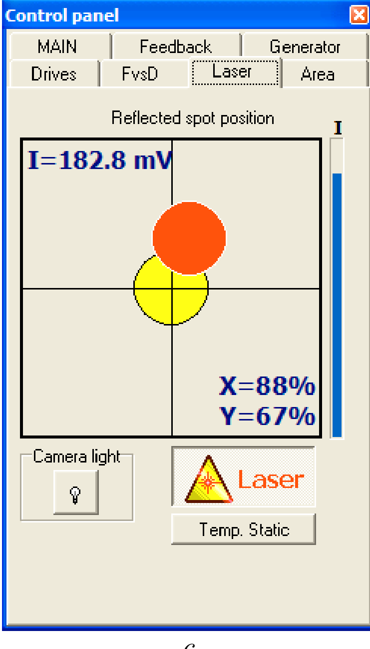
Panel ***Laser*** (Fig. 2.5) is activated by clicking on button [icon] in the toolbar or by choosing menu item *View > Laser*. It contains button for turning the laser source on and off, additional buttons of help functions and a field for graphical display of position of laser beam spot reflected to photodetector from the probe cantilever rear side.



a



b



c

Fig. 2.5. Laser source control panel under different states of detection system: a – the reflected spot is out of the photodetector; b – the reflected spot is on the outer edge of the photodetector; c – the reflected spot is approaching the center of the photodetector (intensity I and its threshold values may vary depending on the specific tuning of detection system)

Button Laser switches the laser source on and off.

Button Camera light turns on and off a service photodiode illuminating the field of view of the embedded video camera. That allows to improve picture shown on the monitor.

Button Temp.Static allows during operation in dynamic mode to switch temporary to static mode for checking and adjustment of photodetector position.

Field *Reflected spot position* graphically interprets signals from the photodetector that helps in correct adjustment of the measuring system for operation. Yellow circle marks the center of the photodetector. Position of the reflected laser spot is rendered by movable circle that changes its color depending on the intensity of the photodetector illumination by this spot. White color of the circle corresponds to lowest illumination intensity of the photodetector; red color corresponds to maximum intensity of the spot light read by the photodetector.

Note, low illumination intensity may be caused by different reasons:

1) 'weak' spot reflected from the cantilever rear side due to improper targeting of laser beam on the cantilever rear side or poor reflecting ability of the cantilever rear side. In this case the circle will move across the graphical field without changing its color (intensity) at checking adjustment of the photodetector position (by rotating knobs 14 and 15, Fig. 1.2);
2) improper adjustment of the photodetector when the reflected spot gets to the photodetector edge (Fig. 2.5b). In this case additional adjustment of the photodetector position (by rotating knobs 14 and 15, Fig. 1.2) will move the circle closer to the field center and the circle color will change from white to red (Fig. 2.5c).

When the spot is out of the photodetector, the movable circle is not shown at all (Fig. 2.5a). The illumination intensity threshold responsible for the circle appearance/ disappearance may be changed by editing value **BottomIntensity** in section **[Laser]** of the SurfaceScan **ini**-file.

Vertical bar *I* from right side of the graphical field shows level of illumination intensity based on readings from the photodetector and may be also used at the photodetector adjustment. Absolute value of the illumination intensity I (in mV) is displayed in upper left corner of the graphical field.

Values X and Y (in %) displayed in lower right corner of the graphical field provide digital information on the reflected spot targeting on the photodetector. This information allows more precise adjustment of the photodetector position: 100% means full centering of the spot on the corresponding axis (X or Y).

Note that adjustment of the photodetector position is to be done under static mode as dynamic mode does not provide correct information on the reflected spot position on the photodetector. Therefore if you need to check and readjust the photodetector position, switch temporary to the static mode that can be conveniently done with button Temp.Static.

2.4 Generator settings panel (at operation in dynamic mode)

Panel **Generator** (Fig. 2.6) is available when Dynamic mode is selected (see §2.1) and can be activated by pressing button in the toolbar or by choosing menu item *View > Generator*.

Field *Feedback mode* allows to select parameter that the control system will support at constant level during the operation (measurement). Two options available in the field set either *Auto phase* or *Auto frequency* to be supported correspondingly at the set constant level at the measurement procedure. Default activated option is Auto phase that is recommended for majority of applications.

Field *Autogenerator settings* contains sliders necessary for tuning the autogenerator parameters. The parameters are *Phase, °*, *Left bound, Hz* and *Right*

bound, Hz that set corresponding parameters to the control system. This option is activated when a self-detecting piezocantilever is installed in the instrument.

Note that fine adjustment of the slider settings is available by pressing up and down arrow keys on the host computer keyboard when necessary slider is active. Additionally, one can set exact value (in decimal form) for the parameter by typing number in corresponding pane above the slider. The pane also repeats in digital form the parameter value adjusted by the slider. This principles are valid for all sliders in the Surface Scan software.

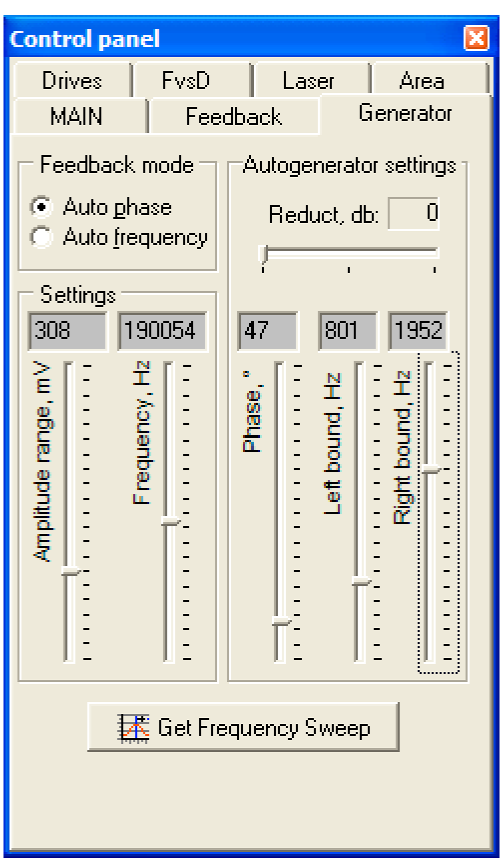


Fig. 2.6. Activated panel of ***Generator*** settings.

Switcher *Reduct, dB* serves for weakening 10 times (20 dB) the piezoactuator driving voltage amplitude in cases when its initial range is too big and it is hard to tune precisely the amplitude. This switch enables the amplitude reduction for all generator operation modes.

Field *Settings* contains the sliders that are in most cases applied for the generator operation tuning. *Amplitude range, mV* adjust amplitude of the piezoactuator excitation voltage and, hence, amplitude of the probe cantilever free oscillation. *Frequency, Hz* slider sets the frequency of the piezoactuator driving voltage signal. The frequency is to be correspond to the probe cantilever resonant frequency. In this case the measuring system gets maximum sensitivity. To detect resonant frequency(-ies) of the probe cantilever, a ***Frequency Sweep*** function can be run.

Button Get Frequency Sweep activates a specialized panel ***Frequency Sweep*** (Fig. 2.7) used for scanning the probe cantilever response on applied mechanical excitation to get Amplitude vs. Frequency plot. The plotted curve is then used to determine the probe cantilever resonant frequency. Button Start runs scanning the frequency range, button Stop serves for termination of the frequency scanning process.

Table in lower left corner of the panel allows to adjust values for beginning and end of the frequency range (panes *Start (Hz)* and *Stop (Hz)* correspondingly), number of points on the acquired plot (*# of points*), step between the points (*Step (Hz)*) that is calculated from the range width and number of points, and calibration coefficient *Kf* that is set by the instrument manufacturer for specific system.

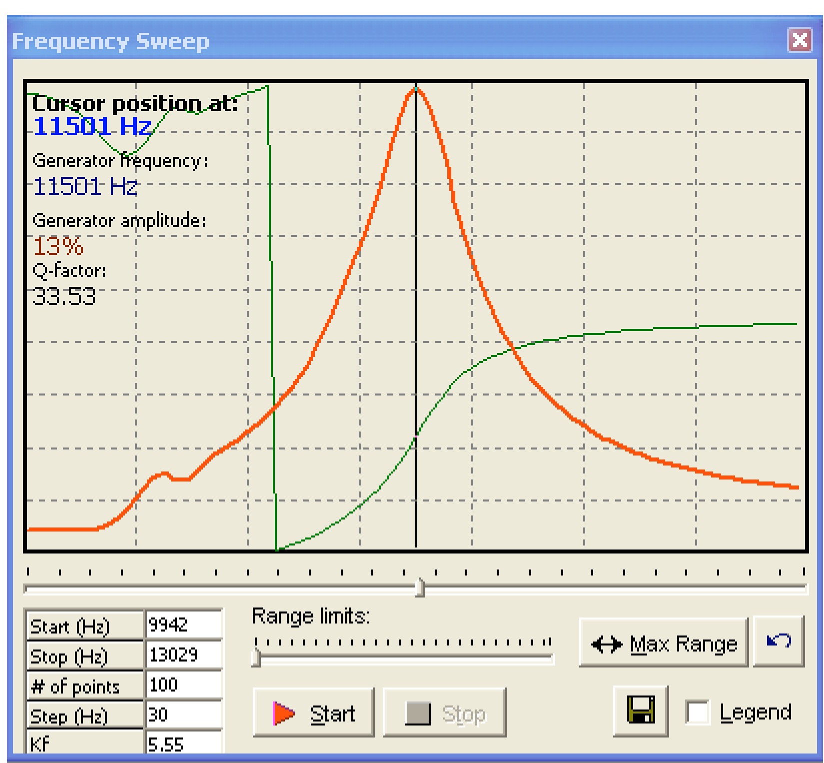


Fig. 2.7. Frequency Sweep panel for tuning the probe cantilever oscillation frequency.

Slider below the plot pane is a cursor for adjusting working frequency. Its position is repeated by the slider *Frequency* in ***Generator*** panel. Note that motion of the slider *Frequency* in ***Generator*** panel does not effect the cursor position in panel ***Frequency Sweep***. Additional information about current frequency value set by cursor in the plot (*Cursor position at:*), generator frequency set in Generator panel (*Generator frequency:*), current value of cantilever driving signal amplitude corresponding to the generator frequency (*Generator amplitude:*) and Quality factor for current generator frequency (*Q-factor*) is displayed in the plot pane.

Q-factor is calculated as

$$Q = f_0/\Delta f.$$

Frequency values f_0 and Δf are determined according scheme in Fig.2.8.

Slider *Range limits* serves for easy setting of the frequency range limits by widening the limits to the left and to the right starting from the cursor position. Button ↔ Max Range sets maximum range for frequency scanning (shifts the start point to zero position and end point to maximum value, i.e. 400 kHz). Undo button returns the previously adjusted frequency scanning range and acquired plot.

Option *Legend* toggles the displaying of a legend for the Frequency Sweep plot. Accordng the legend, red curve corresponds to Amplitude, green curve shows phase behavior.

Button allows to save current plot in a file. The plot can be saved as a picture of BMP format or a set of data in TXT format.

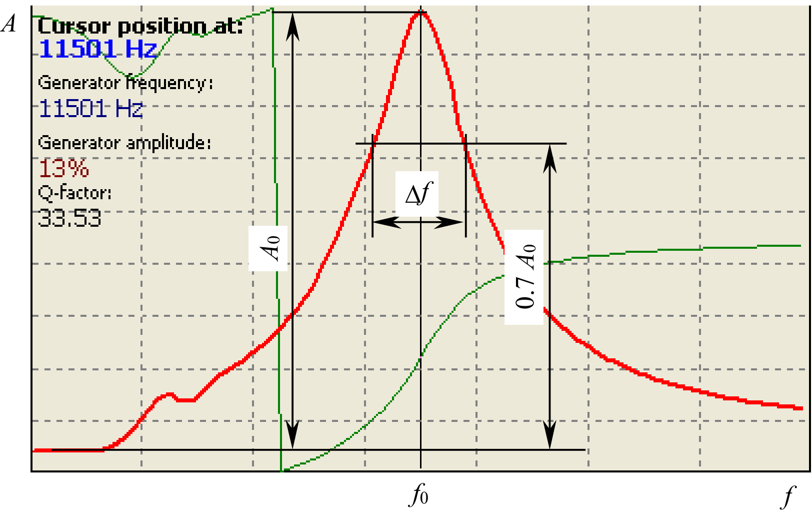
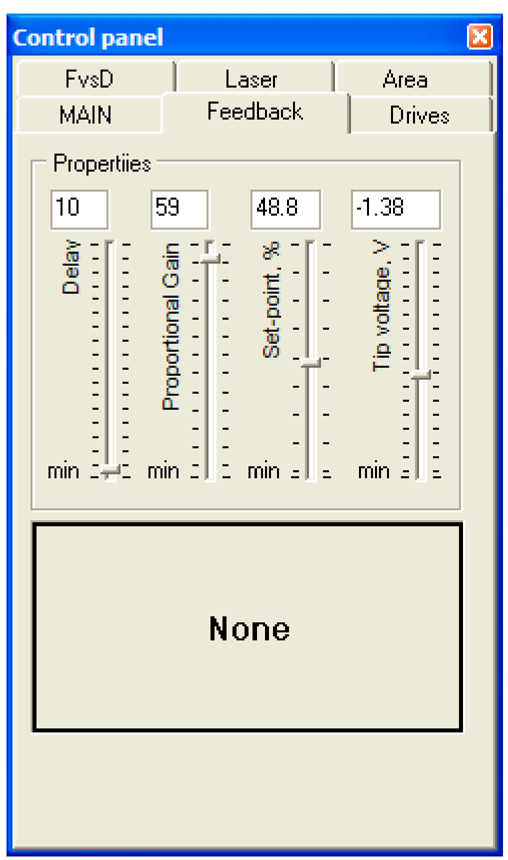


Fig. 2.8. Scheme of determination parameters for calculation of Quality factor.

2.5 Feedback setting panel

Panel ***Feedback*** (Fig. 2.9) provides adjustment of the feedback system settings and can be activated by clicking on button [button icon] in the toolbar or by choosing menu item *View > Feedback*.



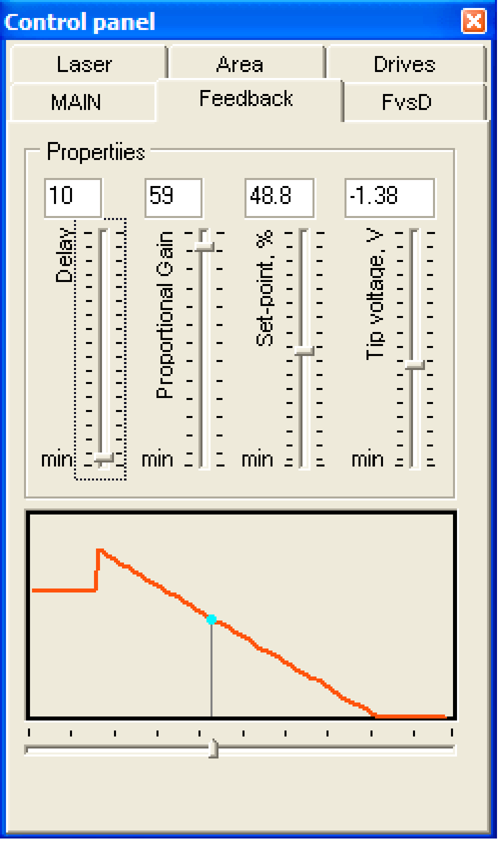


Fig. 2.9. Panel of feedback system settings in initial state (left) and after obtaining Force-vs-Distance curve (right).

Slider *Delay* sets time lapse between processing of two successive control pulses by measuring system. The greater delay value, the slower speed of the feedback response.

Slider *Proportional Gain* regulates discretization (number of iterations used to compensate an error signal) of the feedback system response on changes in output signal. Greater value of proportional gain allows more precise response of the feedback system but simultaneously slows it down.

Both delay and proportional gain parameters allow flexible tuning of the feedback system speed.

Slider *Set-point, %* sets the allowed level of probe cantilever deflection at measurement. This parameter is also called a reference level in the system. Set-point value equaling 1.0 corresponds to free state of the probe cantilever. Note that under static mode set-point describes deflection of the probe cantilever from its position in free state. Under dynamic mode, set-point determines level of free oscillation amplitude suppression for the probe cantilever.

Slider *Tip voltage, V* adjusts the bias voltage applied between tip and sample for performing electrostatic force measurements under two-pass scanning and similar. The tip voltage ranges from –10 V to +10 V with grounded sample (i.e. with sample under zero potential). This function is enabled when the instrument includes additional hardware option for electrostatic force measurements.

Plot pane in lower part of the ***Feedback*** panel is used for displaying Force-vs-Distance curve if it was acquired in panel **FvsD** (see below). By default, a word 'None' is displayed in the area. If the Force-vs-Distance curve is obtained it is displayed in the panel plot pane and below the plot pane a slider is activated to move the cursor adjusting position of set-point parameter. This procedure allows correct adjustment of the set-point for scanning.

2.6 Panel of spectroscopy settings and control (panel FvsD)

Panel ***FvsD*** (Force vs Distance curves) (Fig. 2.10) is used for adjusting parameters of the instrument systems for executing spectroscopy measurements. It can be activated by clicking on button in the toolbar or by choosing menu item *View > FvsD*.

Force vs Distance curve can be measured in two ways depending on set *Controlled parameter* option. When *Set-point* is set as a controlled parameter, the system moves the sample step-by-step towards the probe in such way that set-point changes in the preset range with equal steps between the set-point values. Measured cantilever deflection is plotted as a function of set-point.

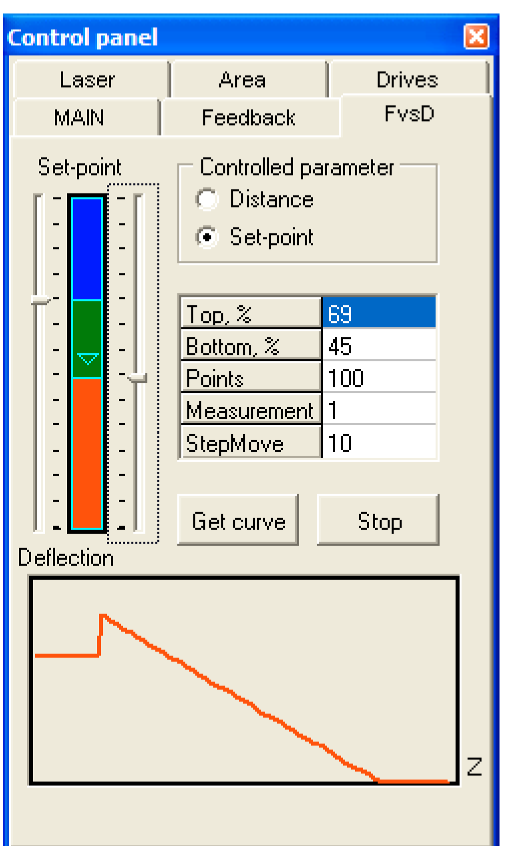
When *Distance* is controlled by the system, the sample moves step-by-step towards the probe within the preset distance between sample surface and the probe with equal steps. Measured cantilever deflection is plotted as a function of probe-to-sample distance. Note that in both cases distance means the separation between sample surface and the fixed end of probe, not the probe tip.

Table of parameters allows to set top boundary of the tube piezoscanner motion range (*Top*), its bottom boundary (*Bottom*), number of points on the measured curve (*Points*), number of measurements in each point (*Measurement*) and discretization steps between the measurement points (*StepMove*). With set-point set as controlled parameter, units for top and bottom boundaries are per cent of free oscillation amplitude (in dynamic mode) or relative values (in static mode). With distance set as controlled parameter, units for top and bottom boundaries are nanometers implying that the shown scale corresponds to full range of piezoscanner extension.

Bar *Z Distance/Set-point* (at left side of the panel) graphically shows the set top and bottom boundaries relative full vertical motion range of the scanner. This

sliders at the bar sides can be used for manual setting the upper (left slider) and lower (right slider) limits of the scanner vertical motion at the spectroscopy measurement.

Button Get curve starts the process of acquiring Force-vs-Distance curve with the set parameters. Measured data are displayed in plot pane in lower part of the panel ***FvsD*** and are repeated in plot pane in lower part of the ***Feedback*** panel as well to provide correct adjustment of set-point parameter for further scanning.



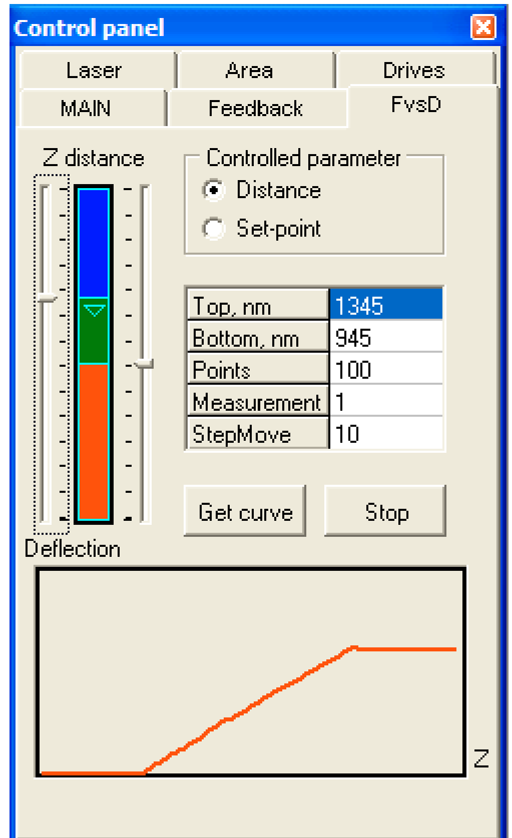


Fig. 2.10. Panel FvsD of settings and control over measurement of Force vs Distance curves with the set-point (left) and probe-to-sample distance (right) as a controlled parameter.

Advanced plotting for the Force vs Distance curves is available when function **Static force spectroscopy** is run. It is also achievable through menu item *Task > Spectroscopy in point*, or by pressing button in toolbar, or by starting task *Spectroscopy in point* under *STATIC* operation mode in ***Main*** panel.

Task *Spectroscopy in point* under *DYNAMIC* operation mode started in ***Main*** panel runs **Dynamic force spectroscopy** described below and plotting graphs of three operation parameters. This function is also available through menu item *Task > Dynamic force spectroscopy* or by pressing button in the toolbar.

2.6.1 Static force spectroscopy

Static force spectroscopy function is run through the menu item *Task > Spectroscopy in point* or by pressing button in the toolbar. From the ***Main*** panel, **Static force spectroscopy** function is available when **Task** is set to *Spectroscopy in point* and **Mode** is set to *STATIC*. When the function is started, visualization window ***View spectroscopy data*** is activated (Fig. 2.11)

To run function **Spectroscopy in point**, the system uses settings adjusted in panel ***FvsD*** for the Force-vs-Distance curve measuring. Activated option *Show selected range* at the window bottom displays lines corresponding to top and

bottom boundaries of the tube piezoscanner motion range set in the panel ***FvsD*** that allows control the boundaries position in convenient way. Point where the Force-vs-Distance curve measurement will be done is defined in panel ***Area*** (in mode **Point**).

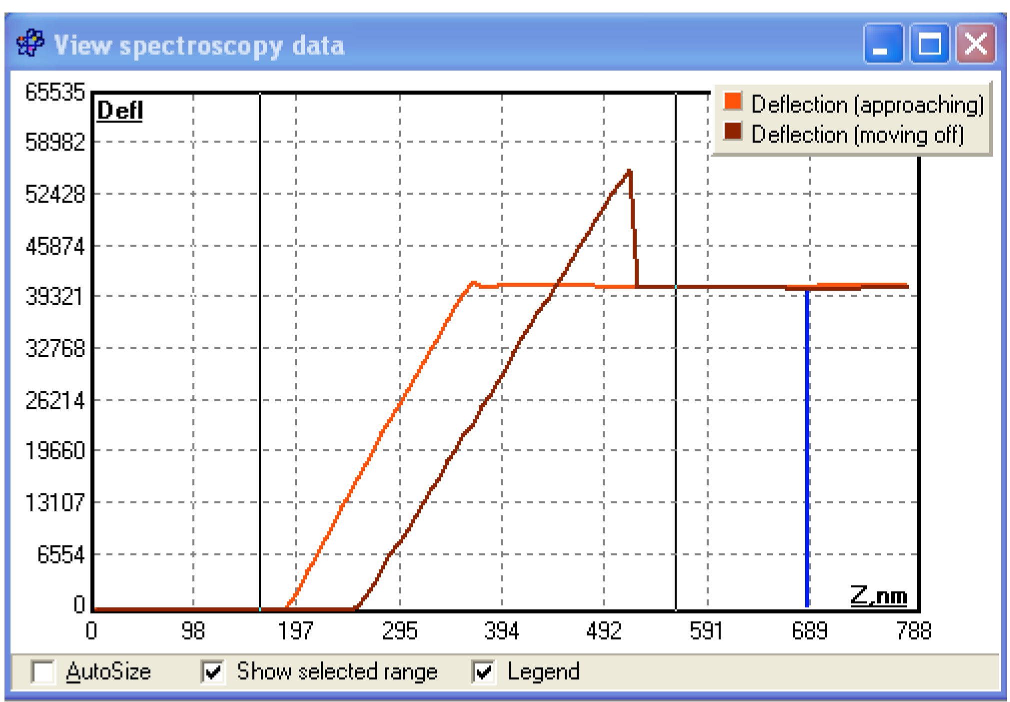


Fig. 2.11. Visualization window for advanced plotting of static force spectroscopy data.

2.6.2 Dynamic force spectroscopy

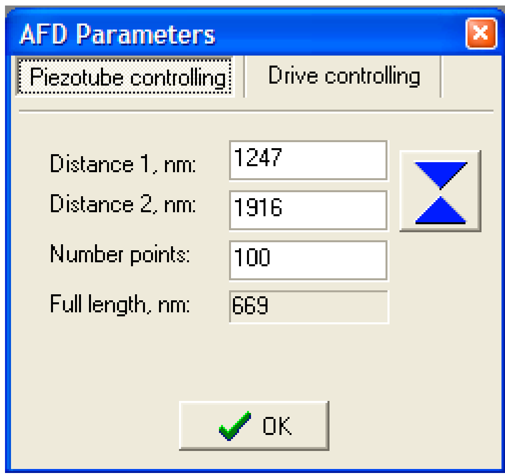
Dynamic force spectroscopy is other one type of spectroscopy measurement available with the instrument. To start it from panel ***Main***, select **Task** *Spectroscopy in point* and **Mode** *DYNAMIC*. The function can be also run by pressing button in the tool bar or by choosing item *Task > Dynamic force spectroscopy*. These commands will activate panel ***AFD parameters*** providing for adjustment of settings necessary for measuring Amplitude-Frequency-Distance characteristic of the probe–sample system (Fig. 2.12). In the instrument, two ways of probe-to-sample distance variation are realized – by moving sample along Z-axis either by piezoscanner or by vertical motion stepper motor. Correspondingly, panel ***AFD parameters*** is shared onto two modes: *Piezotube controlling* and *Drive controlling* (Fig. 2.12).

In the *Piezotube controlling* mode, following settings are available for adjustment:

- Distance 1 – start of the working region;
- Distance 2 – end of the working region;
- Number of points – number of measurement points on the distance axis;
- Full length – information about length of working region.

In the *Drive controlling* mode, following settings are available for adjustment:

- Number of points – number of measurement points on the distance axis;
- Drive step – number of steps performed by the vertical motion stepper motor between measurement points;
- Full length – information about length of working region.



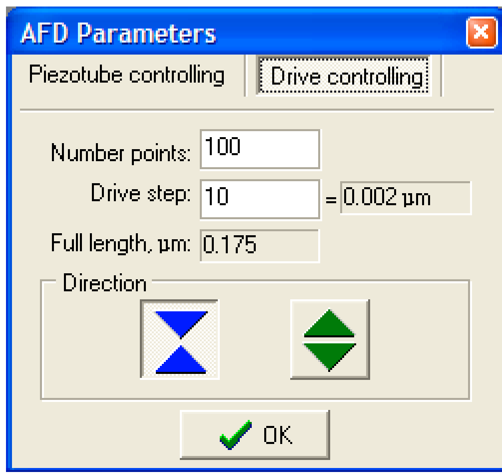
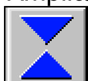
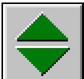


Fig. 2.12. Panel of settings for dynamic force spectroscopy with the distance control by piezoscanner (left) and vertical motion stepper motor (right).

Buttons in the field Direction assign direction for the stepper motor at which the Amplitude-Frequency-Distance characteristic will be measured:

 at approaching only;  at withdrawal only.

After starting the measurement by clicking on button OK, visualization window for AFD function (Fig. 2.13) will appear in which two 2D images show:

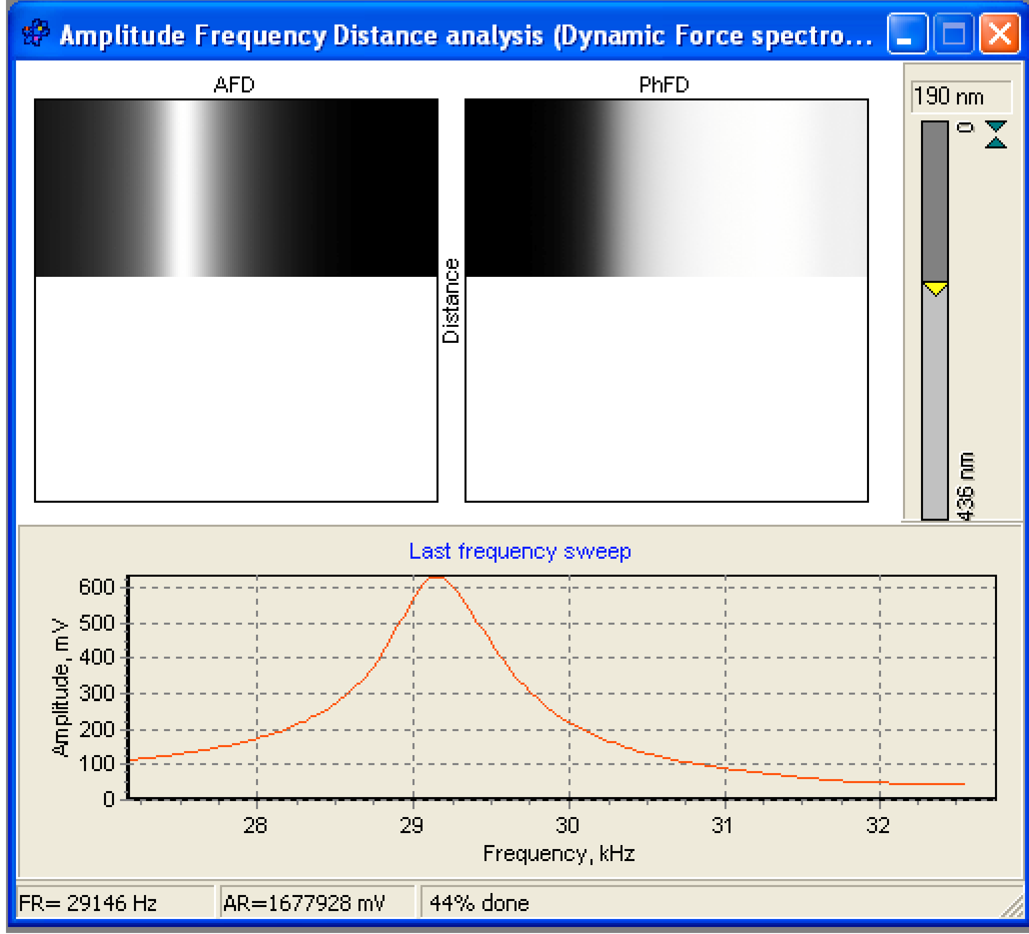


Fig. 2.13. Amplitude-Frequency-Distance analysis visualization window (visualization of dynamic force spectroscopy data).

- left (*AFD*) – Amplitude (Z axis, refer to grayscale) as function of Frequency (X axis / horizontal) and probe-to-sample Distance (Y axis / vertical);
- right (*PhFD*) – Phase shift (Z axis, refer to grayscale) as function of Frequency (X axis / horizontal) and probe-to-sample Distance (Y axis / vertical).

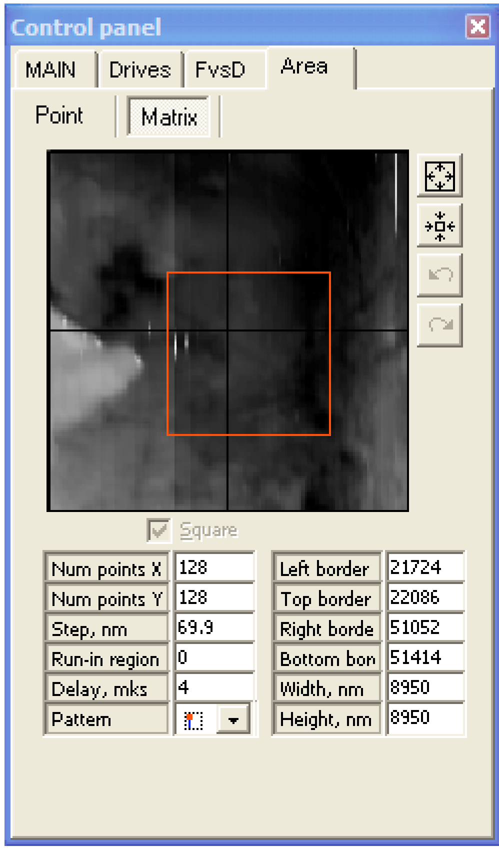
A bar at the right side from the 2D images displays motion of the probe relative sample surface.

Plot area *Last frequency sweep* at lower part of the window displays last Amplitude vs. Frequency curve taken at the measurement.

Status line at the window bottom shows current resonant frequency (*FR*), amplitude at the resonant point (AR) and progress of the function measurement.

2.7 Panel of scan area settings

Panel ***Area*** (Fig. 2.14) provides control over parameters of the scanned area and can be activated by pressing button in the toolbar or by choosing menu item *View > Area*. The panel has two modes: **Point** and **Matrix**. Default mode is **Matrix** responsible for general settings of the tube piezoscanner motion. Mode **Point** provides additional functions of pointing out the desired point where Force-vs-Distance curve (function **Spectroscopy in point**) will be measured. Image pane of the panel is used to load in it preliminary scanned AFM image. To fill the image pane with the AFM image it is necessary to press button (Send this image to area control panel) in the AFM image visualization window.



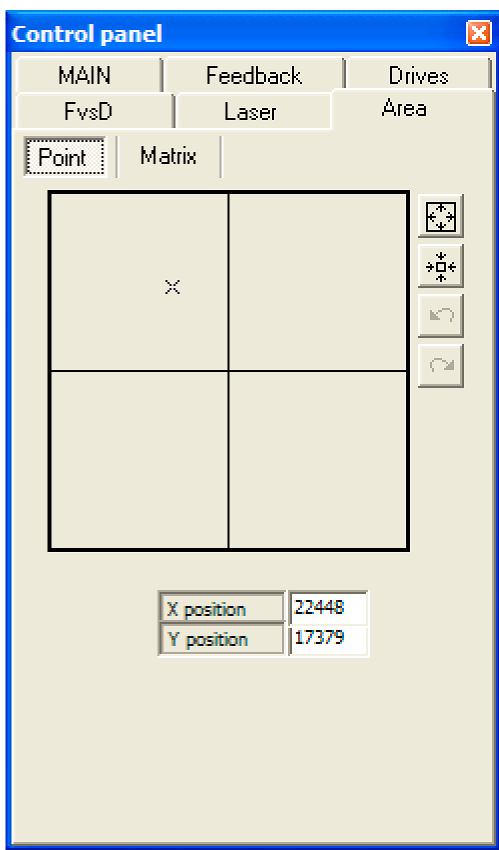


Fig. 2.14. Panel of scan area settings in Matrix (left) and Point (right) modes.

Image pane in the **Matrix** mode is used to mark the field where following scan will be taken. You can use mouse to mark the area of interest or move the area boundaries to necessary position dragging them with mouse. Note that scan area is square. To move the marked area within the image pane, drag it with right mouse button pressed.

Buttons from the right side of the image pane serves for

	quick setting of maximum available scan area (the size defined by installed tube piezoscanner characteristics; refer also to calibration parameters);
	zooming in to the marked area. The marked area (if it is smaller than maximum scan range) will be 'stretched' to fit full plot pane;
	undo function; allows to return the area transformations up to two steps back;
	redo functions canceling undo operations.

In the **Matrix** mode, table of parameters allows to adjust following values:

Num points X	number of points for the AFM measuring matrix in X direction;	Left border	coordinate (in bits) of left border of the scan area relative leftmost side of maximum scan range;
Num points Y	number of points for the AFM measuring matrix in Y direction;	Top border	coordinate (in bits) of top border of the scan area relative topmost side of maximum scan range;
Step, nm	step length between two adjacent measurement points in scan matrix. Step length is calculated from the scan area size and number of points. If you will type in the pane custom number, scan area size will be recalculated based on the set scan matrix dimension in points and the step length;	Right border	coordinate (in bits) of right border of the scan area relative leftmost side of maximum scan range;
Run-in region	option allowing to decrease non-linearity of the piezoscanner at the beginning of scanning process caused by creep. The parameter is set in number of lines. These lines scanned along the fast scan direction are idle lines after moving the piezoscanner into start position that provides time for passing creep region by;	Bottom border	coordinate (in bits) of bottom border of the scan area relative topmost side of maximum scan range;
Delay, mks	delay in microseconds before measurement in current point. It allows to adjust speed of scanning;	Width, nm	width of the marked scan area. Calculated based on calibration parameters;
Pattern	sets fast scan direction and starting point, see explanation below;	Height, nm	height of the marked scan area. Calculated based on calibration parameters.

Option *Pattern* allows to set one of following scanning schemes:

	fast scan direction along X-axis starting from upper left corner;
	fast scan direction along Y-axis starting from upper left corner;
	fast scan direction along X-axis starting from upper right corner;
	fast scan direction along Y-axis starting from upper right corner;
	fast scan direction along X-axis starting from lower right corner;
	fast scan direction along Y-axis starting from lower right corner;
	fast scan direction along X-axis starting from lower left corner;
	fast scan direction along Y-axis starting from lower left corner.

Mode **Point** allows to set coordinates of the point where spectroscopy (or Force-vs-Distance curve) measurement will be then done. The coordinates X position and Y position are set in bits relative top left corner of maximum scan range. You can also simply mark necessary point clicking in the desirable place left button of mouse.

2.8 Control panel of positioning stage stepper motors

Panel ***Drives*** (Fig. 2.15) controls coarse horizontal position of measuring head relative sample by moving positioning stage to necessary point with stepper motors. The panel can be activated by pressing button in the toolbar or by choosing menu item *View > Drives*.

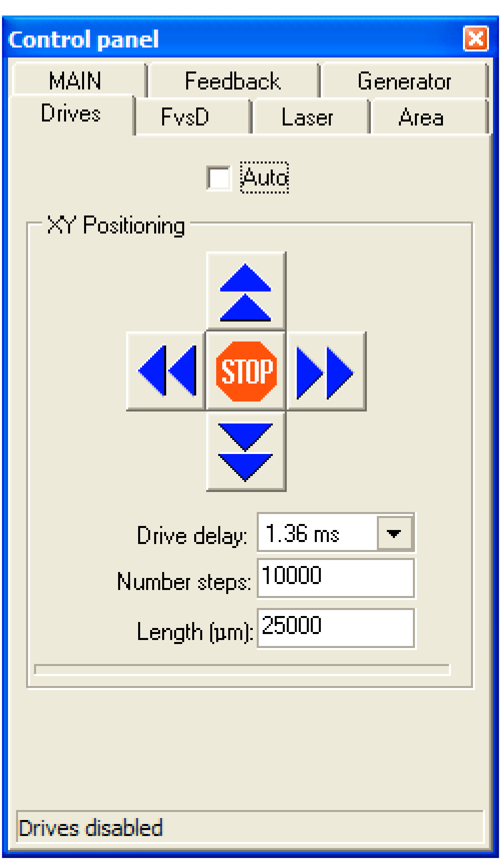
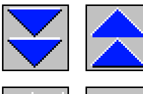
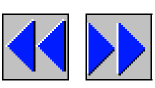


Fig. 2.15. Control panel of positioning stage stepper motors.

The stepper motors of the positioning stage are controlled with following buttons:

 starting motion along X axis;

 starting motion along Y axis;

stopping the started motion of positioning stage.

Visually, arrows of start buttons correspond to directions of positioning stage movement if to look at the instrument from above.

At the same time it is possible to turn on only one motor in one direction. When the system is set for scanning and probe is engaged to the measured surface or scanning is in progress, XY positioning stage control buttons are disabled.

Switch *Auto* toggles manual and automatic operation of the stepping motors. Under automatic mode, the stepping motors will work until operator stop it by pressing ESC key or other on the host PC keyboard (excepting the spacebar and Enter key). In *manual* mode (with unchecked switch *Auto*) the system will perform the preset number of steps in necessary direction. One step of the stepping motor corresponds to the linear motion for 2.5 micron. The number of steps is set in the field *Number of steps*. Corresponding distance is calculated and shown in the field *Length (μm)*. Progress bar below the Length field shows the execution of motion for the set number of steps by the system.

Field *Drive delay* sets the delay time in millisecond before each step of the motor. This parameter can be used to control the speed of the stepping motor rotation and, correspondingly, linear motions of the positioning stage.

CAUTION!
It is urgently recommended to watch the positioning procedure.
Remember! You can stop stepping motors at any time by pressing any key on the host PC keyboard!

Progress bar at lower border of the *XY Positioning* area shows execution progress for currently run command in *manual* mode. Note that the bar depicts number of steps sent to the motor for execution, not mechanical motion of positioning stage.

Status line at the panel bottom shows current state of the stepper motor controlling system.

2.9 AFM image visualization window

AFM image visualization window (Fig. 2.16) is activated at start of the scanning process. It displays in a 2D form the acquired AFM data and service information about the scanning process: the number of currently measured line (*Line:*), delay time (*Delay:*), time used to scan one line (*Time per line:*), time elapsed after the scanning start (*Elapsed time:*), estimated time necessary to scan current image (*Total time:*). Additionally, in the visualization pane one can get information on size of the scan area (numbers on the axes), grayscale for the rendered height map (vertical scale) and the AFM matrix size in points (below the visualization pane). Button (Send this image in area control panel) sends the obtained image to the area control panel to be used in further settings of site to be scanned. (*Number reads:* is a debugging parameter of the software.)

First AFM image visualization window activated at the scanning start is parental window for other optional visualization windows. Simultaneously with the first AFM image visualization window, window of current profile visualization is activated (Fig. 2.16). Curve in its plot pane displays profile of currently scanned line. Sliders from the pane sides adjust bottom (left slider) and top (right slider) boundaries of the vertical display range that allows to show the line at the best scale. *Show* options available in this window are automatic fitting of the vertical scale to the measured data (*Autosize profile*), keeping displaying prevoiusly scanned line (*Previous profile*) and displaying a legend for colors used for drawing the profile lines in the visualization pane (*Legend*). Information on maximum and minimum values of the profile lines measured during current scanning is also available in the window.

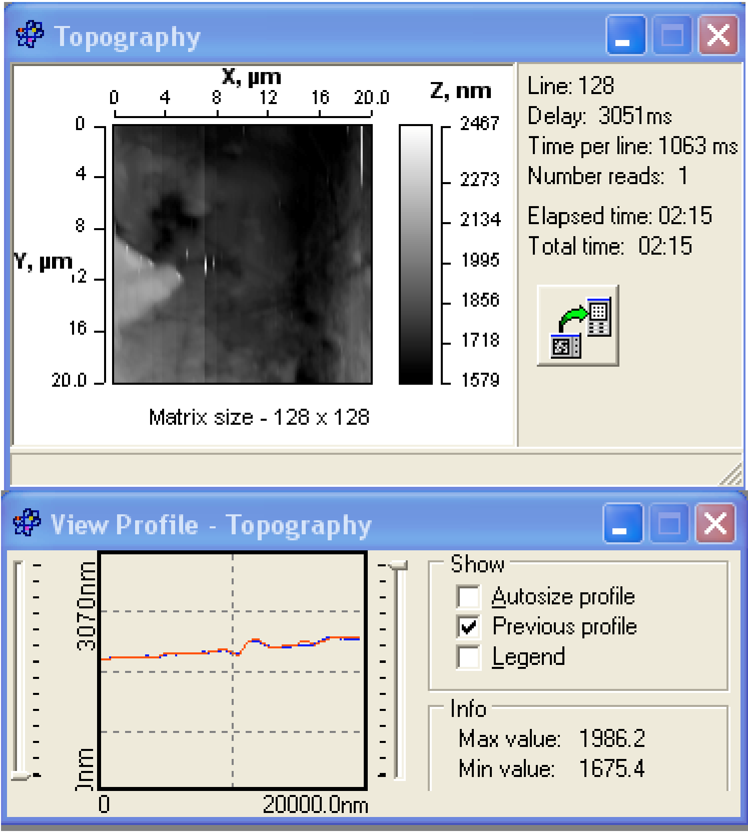


Fig. 2.16. AFM image visualization window (top) and window of current profile visualization (bottom).

By default, visualization windows display 2D image and profile of measured topography. Clicking with right mouse button on the visualization panes, one can call a context menu with options allowing refreshing the displayed image (*Refresh*), opening a child 2D visualization window (*New window*), opening new profile visualization window (*New profile*) and change the displayed data type. Optional data types are *Topography*, cantilever *Deflection* (error signal) and *Torsion* of the cantilever under static mode of operation and *Topography*, cantilever oscillation *Amplitude* (error signal) and cantilever oscillation *Phase* shift. You can open as many child windows as necessary and select for displaying own data type in each of them. However, remember that 2D image displaying consume the host computer system resources and too many opened visualization windows can significantly impede the scanning process.

Data measured at multilayer scanning are visualized in special window ***Multilayer scanning / Tomography*** (Fig. 2.17). It shows the progress in acquiring either one layer or a sequence of all layers one by one. A field from right side of the SPM data visualization area and vertical gray scale bar provides information on the parameters of current multilayer scanning and also provides adjusting of some additional options at the function visualization. Selector **Layer** specifies what layer (from currently acquired set) to show in the visualization pane (note, that initial layer number is 0). Total number of layers is shown after the layer selector. Switch *Show layers alternately* toggles visualization either of one specific layer (assigned by selector **Layer**) or all layers one by one as an automatically changing sequence (in activated state of the switch). When switch *Show layers alternately* is checked, selector of current layer will automatically show number of currently measured layer. Parameter *Shown Rsp* displays set-point value of currently shown layer. A vertical bar below *Shown Rsp* parameter repeats graphically change of the Rsp from high down to low value. Information on time elapsed after the scanning start (*Elapsed time:*) and estimated time necessary to

finish current function (*Total time:*) is also available in the window. Button (Send this image in area control panel) sends the visible image to the area control panel to be used in further settings of site to be scanned. Stripe at the window bottom is used as a progress bar of the task execution.

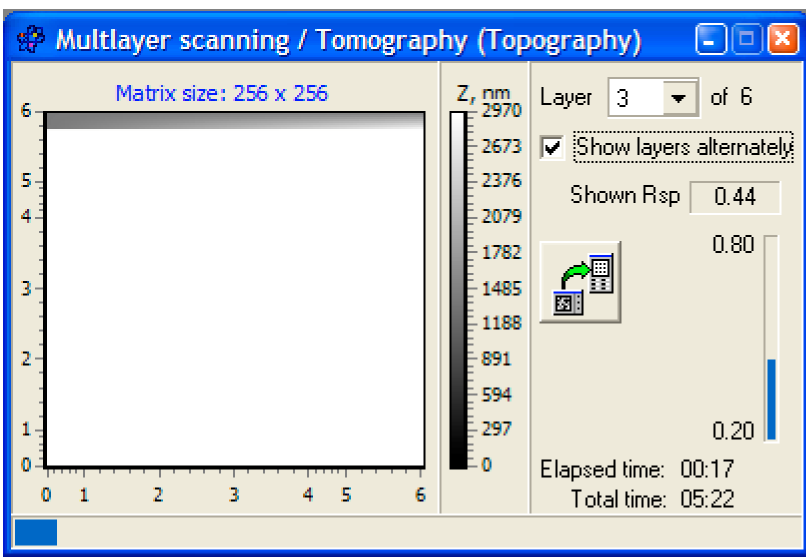


Fig. 2.17. AFM data visualization window at Multilayer scanning.

Type of the date to be shown in the visualization pane can be selected in context menu brought up by right click within the window area (Fig. 2.18). The context menu also provides opening of new visualization window (for example, for showing other type of measured data) and/or window for visualization of currently measured profile lines along the same fast scan line across the layers.

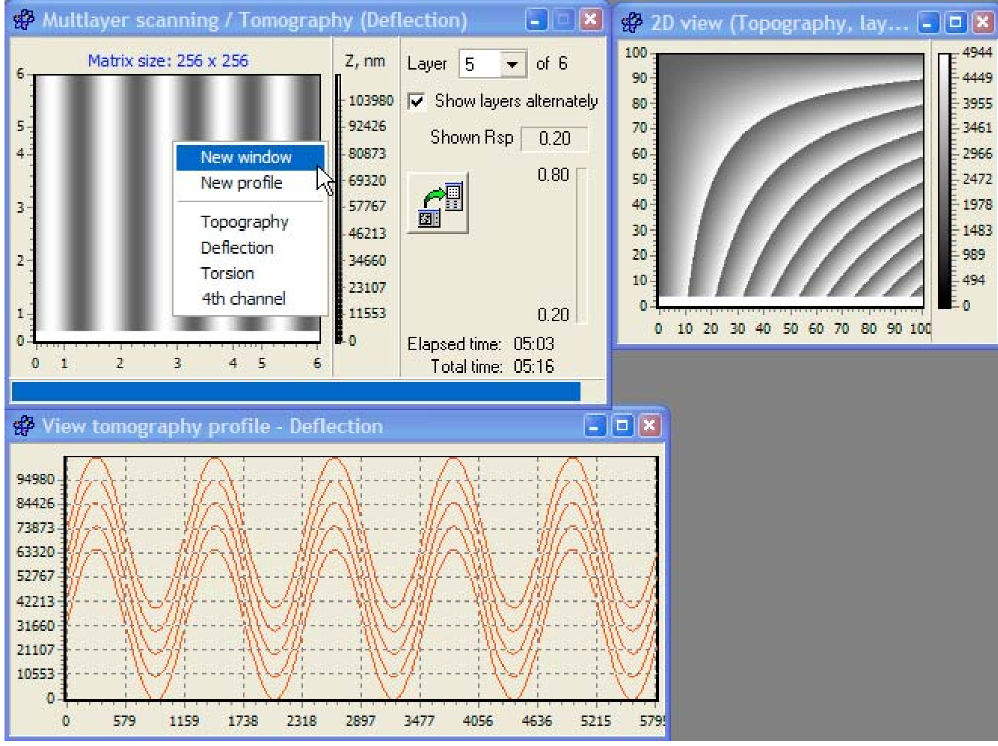


Fig. 2.18. Context menu of the AFM data visualization window at Multilayer scanning and opened child windows.

Context menus available in the child visualization windows allow selection of shown data type and in 2D view window, to select the number of layer to show.

2.10 Panel of calibration parameters

Panel ***Calibrate AFM Data*** (Fig. 2.19) is used to enter correct values for measurement system so that AFM files obtained with the instrument contain correct information on the surface topography and other parameters. The panel is activated by choosing menu item *Task > Calibrate*.

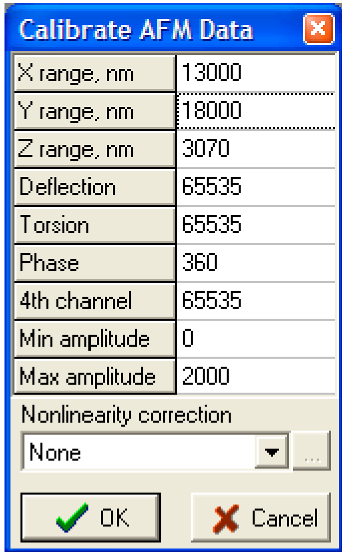


Fig. 2.19. Panel of the system basic calibration parameters.

Fields *X range, nm*, *Y range, nm* and *Z range, nm* contain information on the piezoscanner ranges of motion in corresponding directions. These values are calculated from the AFM images of the specialized test samples with regular features and known lateral and vertical parameters. For example, to calculate range in X direction it is necessary to count the number of the features in the AFM image (including the fractional ones) and multiply it by the features pitch size. For vertical range calibration it is possible to compare the height reported by the software with real parameters. In this case it is necessary to divide the existing Z range parameter by the height reported in the software and then to multiply the result by the real height value. This final result must be then entered in the field *Z range, nm*.

Parameters *Deflection* and *Torsion* describe number of bits covered with the ADC installed in the measuring system. For 16-bit ADC (like in this system) these values are 65535. *Phase* angle describes limits of the phase angle variation and usually it is 360. Parameter *4th channel* is reserved for optional functions and is set like *Deflection* and *Torsion*.

Parameters *Min amplitude* and *Max amplitude* set minimum and maximum values for the photodetector output signal. Usually, these parameters are set by the manufacturers at the instrument tuning.

Selector *Nonlinearity correction* allows to choose type of correction function that the instrument scanning system will activate to amend non-ideal behavior of the piezoscanner. This is a software correction that uses special equations to model the scanner tube's non-linear response to applied voltages and eliminate errors of the probe positioning. Available are *Simple cubic* and *Advanced cubic* functions of

nonlinearity correction. Choosing *None* option, no any correction of the tube piezoscanner motion will be provided at scanning.

Choosing one of the correction functions you need to assign parameters for the correction equations. To enter these parameters, bring up additional panels by pressing button [...] at right side of the *Nonlinearity correction* selector. Details of calculation of the correction equation parameters and handling of the additional panels will be described below in section 'Calibration of the AFM measuring system' and Appendix 1. Note, when any of the nonlinearity correction functions is selected, parameters *X range, nm*, *Y range, nm* in main calibration panel ***Calibrate AFM Data*** becomes unused as the system takes necessary data from the correction model.

2.11 Acquired data pane

Area in lower part of the main window serves as an organizer for the acquired images. Every time after finishing the measurement procedure a thumbnail presenting just measured AFM image is added to the pane. Text field under each thumbnail provides information on the number of the image taken during current session of the control software, scan area size (in micron) and name of the file where the AFM image was saved. If the AFM image present in the pane was not saved after acquisition, notification 'Not saved' is shown instead of file name. Clicking with right mouse button on necessary thumbnail call a context menu for the image (Fig. 2.20):

- *Show* – loads the AFM image in visualization window;
- *Save* – calls up the file saving dialog for the data saving on hard disk;
- *Delete* – deletes the AFM image from the pane and temporary buffer;
- *Save all* – saves all the images from the pane on hard disk using automatic naming;
- *Clear* – deletes all the images from the pane and temporary buffer.

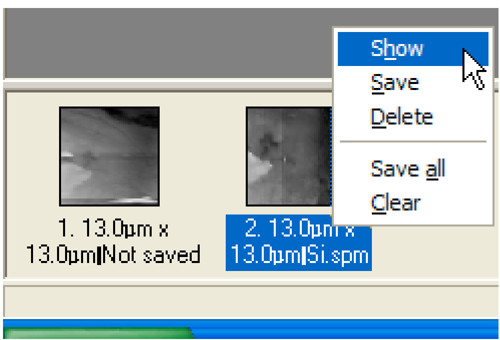


Fig. 2.20. A fragment of the acquired data pane with activated context menu

Note that all measured data are kept initially in SurfaceScan temporary buffer and are available for usual saving on hard disk while the software is running (i.e. till they are visible in the pane).

The acquired data pane is switched on and off by button in the toolbar or by menu item *View > Container*. The pane area can be resized if necessary by dragging its upper dividing border with mouse.

2.12 Panel of option settings

Menu command *File > Options* brings up panel of the software auxiliary options (Fig. 2.21). It helps to configure the software and change it appearance on corresponding pages of this dialog.

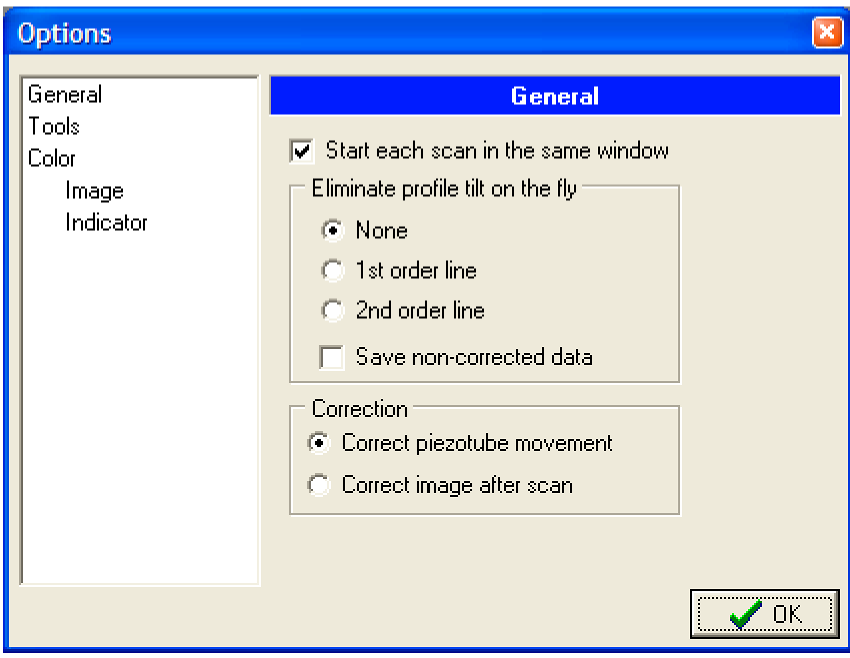


Fig. 2.21. SurfaceScan options panel with active General page.

Page *General* provides setting of following options:

- *Start each scan in the same window* – if activated, uses one visualization window for all scans;
- Section *Eliminate profile tilt on the fly* – on-line tilt subtraction off currently measured fast scan line. Available options are *None* (deactivated on-line tilt elimination), *1st order line* (subtraction of average straight line) and *2nd order line* (subtraction of average square parabola). Switch *Save non-corrected data* allows to save AFM data in the file without on-line tilt elimination (if previous option is active);
- Section *Correction* allows to set nonlinearity correction either directly during the imaging (*Correct piezotube movement*) or after the image acquisition (*Correct image after scan*). If no any nonlinearity correction model is set in calibration panel, section *Correction* is neglected.

Page Tools defines options for auxiliary tools available in the software bundle. Section *Video* defines what video system facility and visualization window will be used at pressing button in the toolbar. Selecting *Internal* source, you will need then choose the video signal driver from the list of available ones in the host PC pressing button Source. Built-in visualization facilities will be then run at pressing button in the toolbar. Instead, you can select *External* drivers and visualization window for embedded video system. In this case you will need to define path to corresponding application in the pane *Path* (you can use button ... to search the application on the host PC hard drive). Additionally, you can define custom caption for the video system visualization window in pane *Window caption*. Section *SurfaceView* allows to set the paths to SurfaceView software package. It will allow then quick launch of the SurfaceView processing and visualization package by pressing button in the SurfaceScan tool bar.

Section *Color* allows to assign custom colors for AFM images in the visualization window (in page *Image*). You can appoint custom colors for top level and bottom level. Page *Indicator* allows customization of color scheme for panel ***Indicator***.

3 INSTALLATION OF AFM NT-206

3.1 Placement of the AFM

3.1.1 General requirements for the AFM placement

For installation of the atomic force microscope it is necessary to prepare a special room where the instrument will operate. Main requirement of the AFM allocation is a minimum level of external vibrations influencing the scanning unit. Meeting of this condition will ensure steady work of the AFM and high reliability of received results.

Optimum place for the AFM installation and further operation is clean and dry room in the basement floor (closer to the building foundation) with area at least 10…20 sq.m. The room located far from roads with car, truck and railroad traffic is preferable.

Control electronic unit and host personal computer do not require special conditions of vibroinsulation, however they are a source of vibrations and therefore cannot be established on one table with the AFM scanning unit. Distance between tables is limited by length of cables connecting the AFM components.

It is recommended to place the AFM scanning unit on a separate vibration-proof table with a rigid frame and firm steel or stone cover. As the vibration insulator, can be used sheets of porous rubber placed under the table leg. The top surface of a table on which analytical scanning unit will be placed should be flat and strictly horizontal. Specially designed antivibration tables available at the market can provide high level of vibration insulation. The AFM scanning unit can be also placed on an active antivibration platform to suppress unfavorable vibrations. As an alternative for expensive antivibration devices, a spring suspension of the AFM scanning unit can also give good results in fighting against vibration. Figure 3.1 shows an example of design of frame for the AFM scanning unit suspension. Depending on the leg length, the frame can be placed either on the table top or on the floor.

3.1.2 Requirements to the room environment

The AFM operates under usual conditions. Nevertheless, it is necessary to maintain temperature and humidity of air at constant level and avoid their sharp changes. Temperature 22±4°C and the air relative humidity less than 50 % are recommended. Do not install the AFM near heating devices.

Controllable room environment is favorable, however keep in mind that airflows (drafts) negatively effect the measurement accuracy. Therefore it is recommended to prepare special hood to cover the scanning unit during the AFM operation and when it is out of operation (at storage).

There must be no any aggressive agents in the room air. The dust content in the air should be also decreased to a minimum. It is necessary to remember that atmospheric moisture and the pollution adsorbed on the scanned surface from the open air can critically influence the results of measurements in non-contact mode.

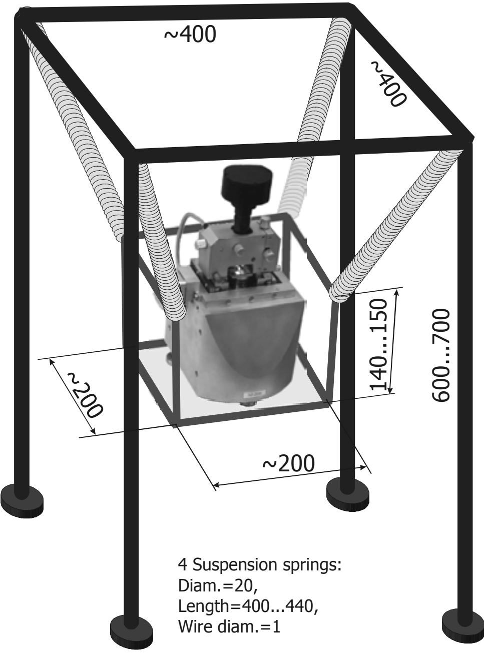


Fig. 3.1. Example of low-cost frame design for antivibration spring suspension of the AFM scanning unit

3.1.3 Requirement to an electrical network

The room prepared for the AFM installation should be equipped with an electrical network of an alternating current with voltage 220±10 V and frequency 50±5 Hz providing capacity not less than 500 VA. High-frequency voltage bursts of not more than 500 V are allowed in an electrical network to which the AFM is connected. For a guarantee of non-failure operation it is also desirable to use network filters to suppress high-frequency noise.

ATTENTION! During scanning any faults in an electrical network are inadmissible. Even short-term break in the power supply during the complex work can result in damage of the scanner, electronic systems and host personal computer.

To prevent the staff from an electrical shock and also to prevent the electronic equipment failure, the AFM must be reliably grounded. During the AFM operation please follow general rules of electrical device exploitation.

Remember that atomic force microscope is precise and high-sensitive device which requires careful operation and storage.

3.2 Connection of the AFM

After installation of the AFM components on working places it is necessary to connect them among themselves by cables from a complete set.

1. Using three specialized cables from the complete set, connect the AFM scanning unit with the control electronic unit. The cables are used for connection of high-voltage circuit, digital circuit and analog circuit.

ATTENTION! Watch carefully the use of cables from the AFM complete set on assignment only. Do not use other cables (not delivered in a complete set) instead of them. Incorrect use of the cables can result in failure of electronic systems both the AFM and other connected devices. Besides it can cause a fire.

2. Connect components of the host personal computer – monitor, keyboard, and mouse – to the system block. The detailed instructions on connection of the PC components look in the computer documentation.
3. Connect the AFM control electronic unit with the host personal computer using USB (A-to-B) cable.
4. Connect the AFM control electronic unit and host PC to an electrical network of 220 V / 50 Hz with the help of AC power cords. Be sure that the electrical network you are plugging the unit in is grounded and has corresponding contact.

4 GETTING READY FOR OPERATION WITH ATOMIC FORCE MICROSCOPE NT-206

4.1 Turning the AFM on and off

4.1.1 Turning the AFM on

After connection of the AFM components and plugging them to an electrical network, the complex can be turned on in the following order.

1. Turn on the host personal computer including the monitor.
2. Turn the AFM control electronic unit on by the button POWER on its front panel.
3. Start the AFM control software *SurfaceScan* on host PC.
4. Activate panel **Laser** in the AFM control software and turn the laser source on.

After that the complex is ready for further tuning and operation.

4.1.2 Turning the AFM off

The AFM should be turned off in the following order.

1. Carry out necessary procedures of the sample surface withdrawal off the probe moving the sample platform down in the *SurfaceScan* **Main** panel.
2. In the *SurfaceScan* **Laser** panel turn the laser source off.
3. Quit the AFM control software *SurfaceScan* saving necessary measured data. Finish all other programs run on the host computer.
4. Switch off the control electronic unit by the button POWER on its front panel.
5. Switch off the host computer carrying out necessary procedures stipulated by operating system ('Shut Down' in **Windows** Start menu).

4.2 Probe installation

AFM NT-206 is designed for use of commercially available probe chips with sizes 3.4x1.6x0.6 mm. For operation in dynamic mode probe cantilevers should have own resonant frequencies in a range 10–600 kHz. Note that probes with 'soft' cantilevers are intended for operation in static (contact) mode and probes with cantilevers having high force constant should be applied at operation in dynamic (non-contact or intermittent) mode. Specific characteristics of probes can be received from their original manufacturer, for example Mikromasch (www.spmtips.com), NT-MDT (www.ntmdt.com). Examples of design of conventional microfabricated AFM probe chips are shown in Fig. 4.1.

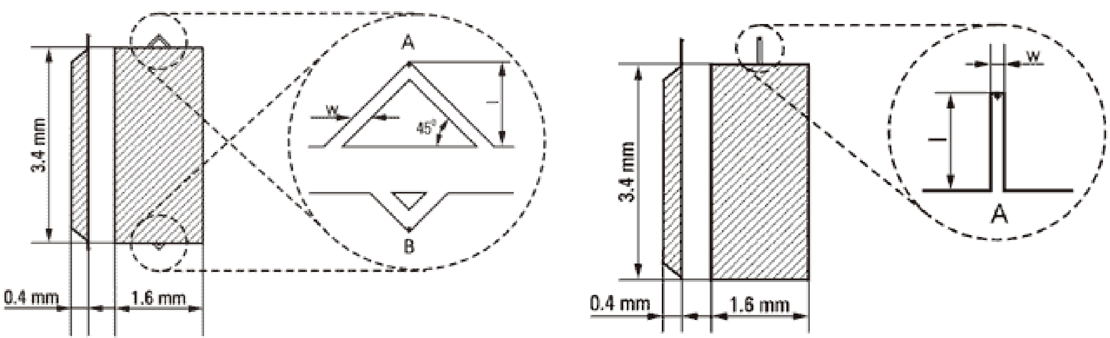


Fig. 4.1. Design of microfabricated AFM probe chips with triangular (left) and rectangular (right) cantilevers (taken from www.spmtips.com)

Microfabricated probe chips for operation in the AFM are installed in removable probe holder located at the bottom of the scanning unit measuring head. That way of probe changing/installation provides convenience for AFM users.

To remove the probe holder off the measuring head (Fig. 4.2)

1. Unlock the probe holder inside measuring head rotating the locking screw counter-clockwise till the probe holder will be released.
2. Take the probe holder handle with a fingers and pull it off the measuring head moving strictly parallel to the measuring head bottom.

Note that during the probe holder removal and insertion, probe tip must not touch solid surfaces. To prevent any contact of the probe tip with the sample surface, lower the sample as far as possible pressing button of sample platform withdrawal in **Main** panel of scanning control software (§2.1).

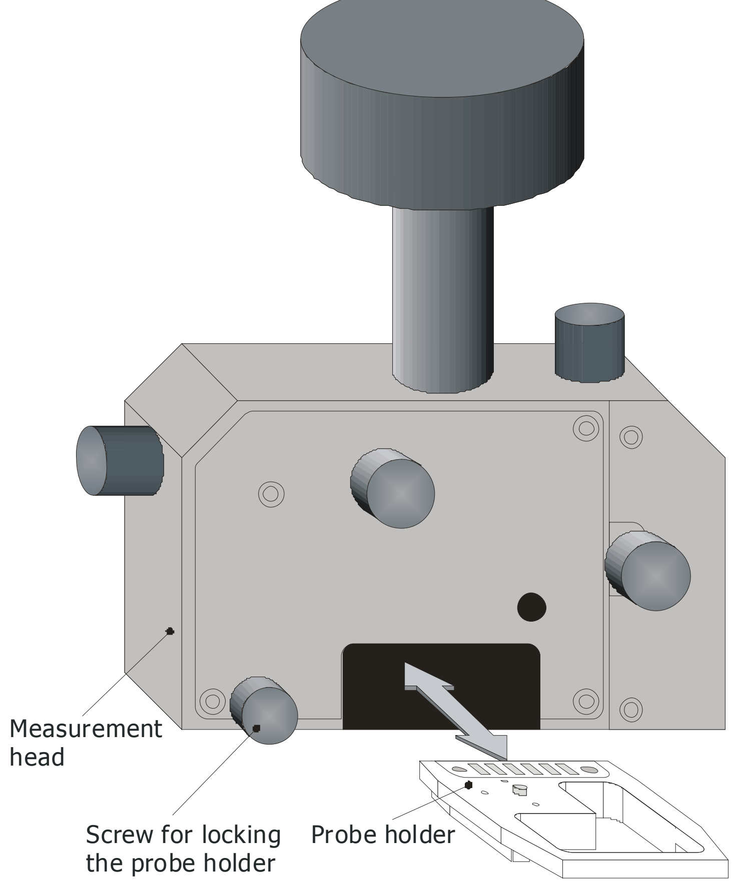


Fig. 4.2. Scheme of removal and insertion of probe holder off/in measuring head.

Figure 4.3 shows design of the removable probe holder used in AFM NT-206.

ATTENTION! Protect the probe tip against any touch with solids and therefore always place the probe holder on any surface (either for probe chip change or for storage) upside down (Fig. 4.3 right).

Nevertheless, remember that the probe holder is to be inserted into measuring head with upside up (Fig. 4.3 left).

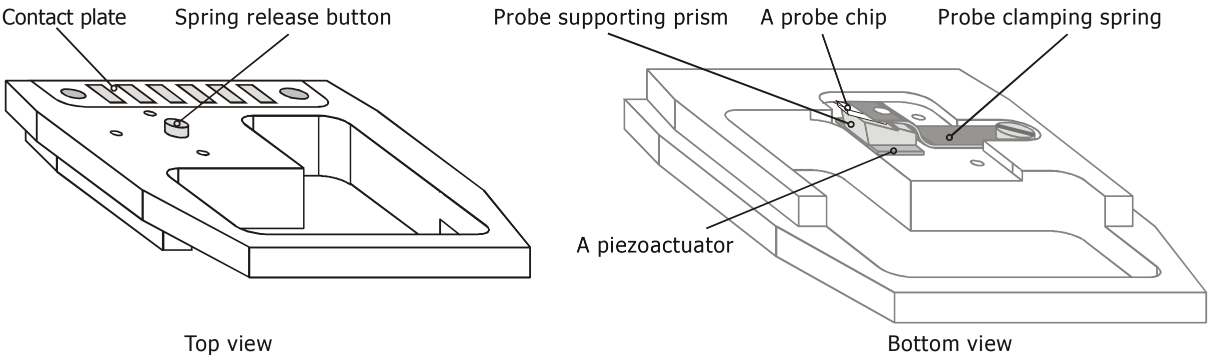


Fig. 4.3. Design of probe holder. Left picture shows the probe holder position at the insertion into measuring head; right picture shows the probe holder position at probe chip changing or storage.

To install/change the probe chip, follow scheme shown in Fig. 4.4:

1. Place the probe holder on table upside down. Slightly press the holder down with fingers so that spring release button lift the probe clamping spring.
2. Using tweezers remove old probe chip from under the spring.
3. Grip new probe chip with tweezers so that the tip intended for operation appeared between the tweezers with tip directed upward. Note that probe chips shipped in Gel-Pack boxes usually are placed namely with tip directed upward.
4. Keeping the probe holder pressed, carefully insert the gripped probe chip into space between probe supporting prism and the spring. Move the chip parallel to the prism working surface till the ledge.
5. Release tweezers and the probe holder.

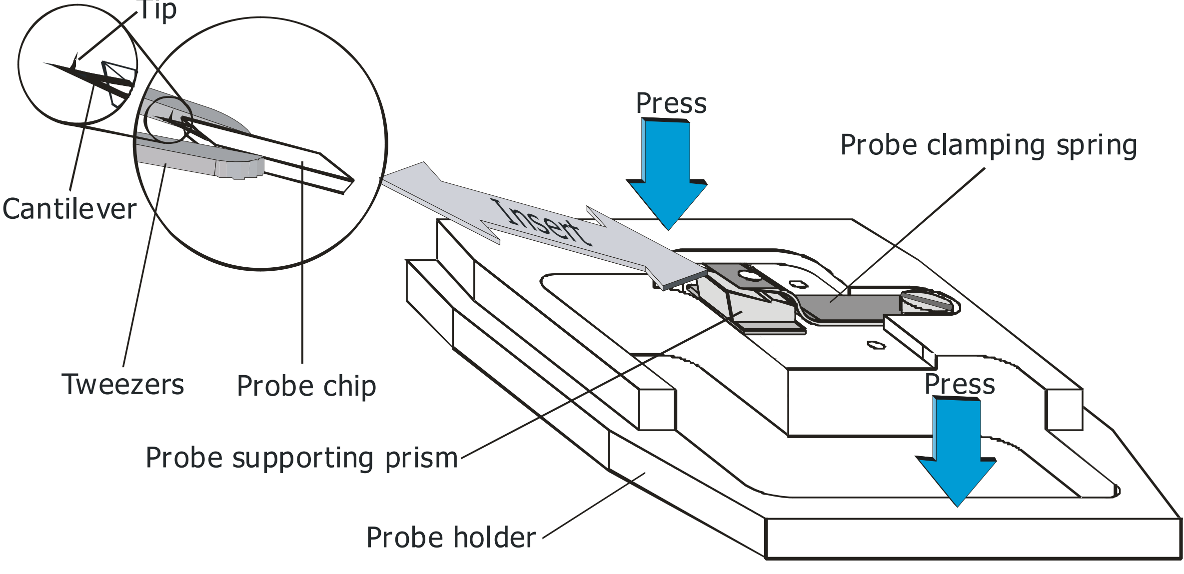


Fig. 4.4. Scheme of the probe chip changing/installation.

ATTENTION! After the probe installation/replacement it is necessary to tune the cantilever deflection detecting system as it is described below.

4.3 Tuning the detection system

The AFM detection system should be tuned after the probe replacement/installation and at wrong or unreliable functioning of the detection system. For tuning system of the cantilever deflection detection, knobs on the laser-beam detection unit are used (Fig. 4.5).

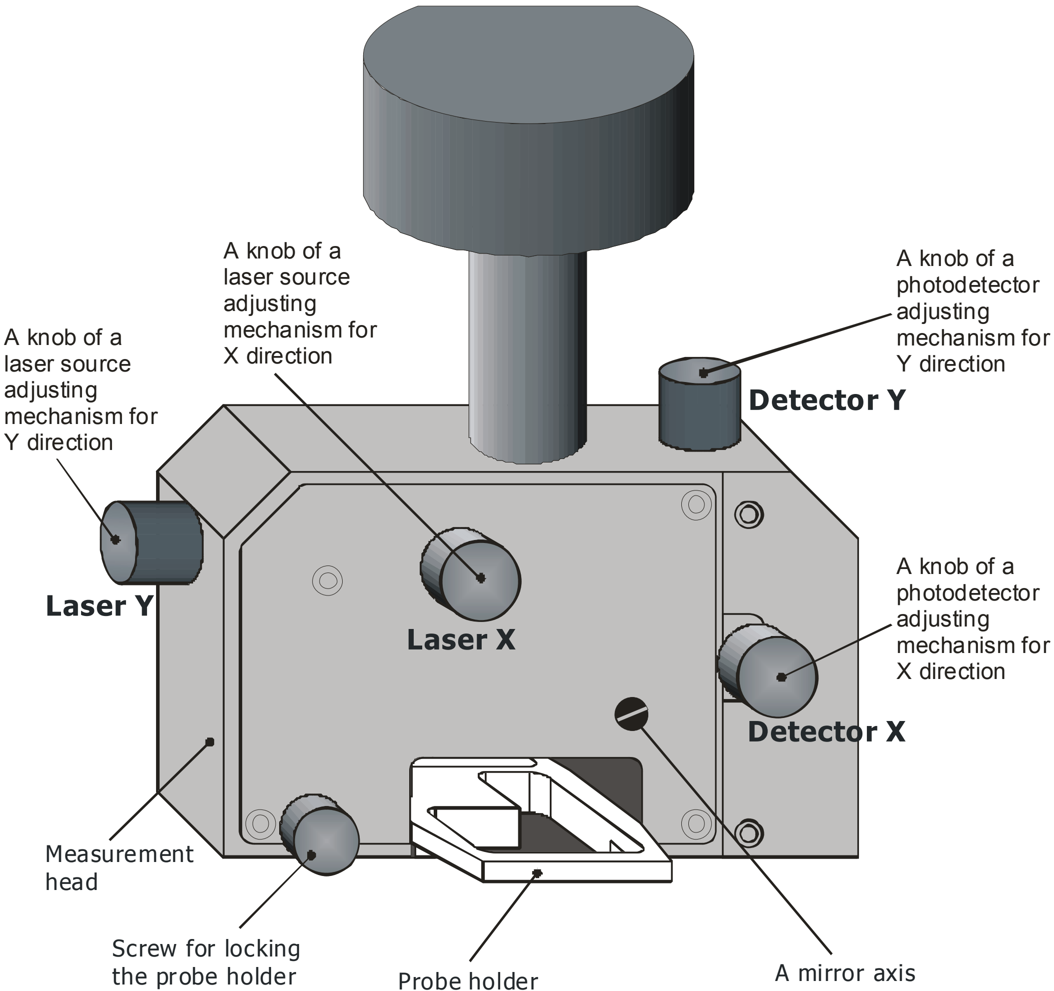


Fig. 4.5. Knobs of the measuring head used for tuning the AFM detection system.

The order of tuning is following.

1. Turn on the AFM, start the AFM control software and turn on the laser source in panel **Laser** of the software pressing buttons Laser and Display position (Fig. 4.6). The tuning of the detection system should be performed in the static mode of the AFM operation therefore it is necessary to select this mode in the panel **MAIN** of the AFM control

software or temporary switch to the static mode pressing button Temp. Static in panel **Laser**. Besides, the probe must be in a free state, i.e. not in the vicinity of the sample surface so that it does not deflect the cantilever.

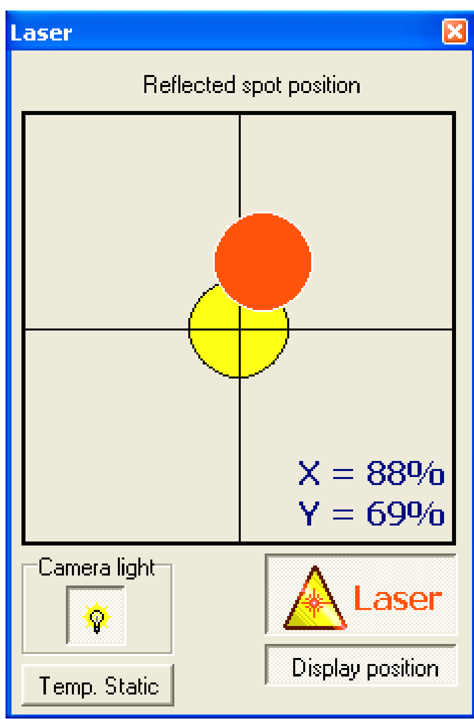


Fig. 4.6. Panel Laser with turned on buttons of laser source and reflected spot position.

2. Adjust the Set-point slider in the **FeedBack** panel of the AFM control software so that the Reference level indicator (Ref) (Fig. 2.3) was in the middle position or slightly lower.
3. Rotate knobs Laser X and Laser Y on the measuring head (Fig. 4.5) to adjust the laser source position so that light spot appeared on the rear side of the probe cantilever (Fig. 4.7). For proper positioning of the laser source, target the light spot at the free end of the probe cantilever. To facilitate the adjusting you can run the embedded video camera visualization software to watch the targeting procedure.

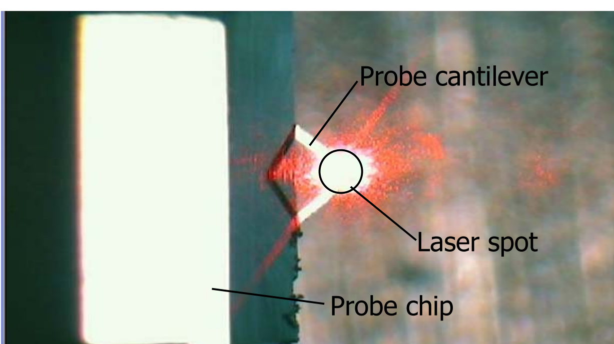


Fig. 4.7. Targeting the laser spot at the free end of probe cantilever. The picture captured with help of embedded video camera.

4. Rotate knobs Detector X and Detector Y on the measuring head (Fig. 4.5) to catch the PSPD position where it gets reflected from the cantilever light spot best of all. The reflected light spot should be as

closer to the center of PSPD as possible. It is recommended to adjust vertical position of the PSPD so that the reflected spot appeared slightly above horizontal central line of the visualization pane. It will ensure more reliable operation of the detection system after approaching the probe to the sample surface when the reflected spot will move slightly down due to the cantilever deflection.

5. To ensure correct adjustment of the PSPD position, check the range of the deflections variations. For that purpose, after finishing the PSPD positioning, rotate slightly knobs Detector X and Detector Y on the measuring head (Fig. 4.5) and check the movement of the light spot within the position visualization pane. Small clockwise and counterclockwise rotations should make the light spot picture to move in both corresponding directions (up and down or to the left and to the right) around the center of the visualization pane. If that does not happen, the PSPD was not correctly adjusted and laser spot simply is not in the PSPD center. In this case repeat the PSPD adjustment procedure.

4.4 Sample installation

Sample to be scanned should be placed on the sample platform (Fig. 1.2). The sample sizes should be within the diameter 30 mm and height 8 mm. If the sample is too small, it is recommended to place it on a substrate. However, total dimensions of a sample with a substrate should not exceed the specified sizes. To obtain high-quality AFM-image, the researched sample surface is to be parallel to the substrate bottom.

The sample platform is equipped with magnets and therefore samples or substrates of ferromagnetic materials can be placed on the sample platform top without additional fixation. Samples or substrates not attracted by the magnets are to be fixed on the sample platform top with alternative way, e.g. with help of double sided adhesive tape. So, it is recommended to use ferromagnetic (e.g. steel) substrates for all samples that are not attracted by the magnets embedded in the sample platform of the AFM.

Directly before installation of a sample clean it with solvents or in ultrasonic chamber to remove all stains that can worsen the measuring system functioning and spoil the scanning results.

Before sample installation on the sample platform it is necessary to provide enough space between the platform and probe to avoid the probe breaking. Therefore you should move the sample platform down to the lowest position with help of approaching/removal stepping motor. Besides, it is recommended to unfix the measuring head and move it forward in the dovetail (Fig. 1.2) before sample installation to void space for the sample handling. Alternatively you can remove the measuring head off the dovetail. To avoid the probe breaking at the sample mishandling at the installation, you can also remove the probe holder off the measuring head.

Keep in mind that positioning the area to be scanned in the sample platform center will result in lowest distortions of the AFM image at the measurement.

After the sample installation, install or return the measuring head on its working place repositioning it with the probe over the scanner (sample platform) center and then tightly fixing in the dovetail.

5 OPERATING ATOMIC FORCE MICROSCOPE NT-206

This chapter describes the procedures that should be carried out to measure sample. Before the beginning of work necessary preparatory operations described in Chapter 4 must be done in the following order.

1. Turn the AFM on including turning on the laser source (Fig. 2.5).
2. Check the probe and reinstall or replace it if necessary (§4.2).
3. Check the detection system tuning and tune it up if necessary (§4.3).
4. Install the sample (§4.4).

After finishing above procedures you need to choose task and operation mode for the AFM. Scanning across the matrix is the most common task for AFM allowing acquisition of topography and contrast images. Spectroscopy provides additional valuable information on the surface state and properties.

5.1 Static mode

5.1.1 Initial adjustments

Static mode is switched on in the ***Main*** panel of the AFM control software (Fig. 2.3 left).

In static mode the probe is set into contact with measured surface (therefore, static mode is usually called contact one). Main condition in this case is an ability of the measuring system to trace full range of the cantilever deflection at the scanning. So, tune properly the detection system before the scanning. For better operation it is possible also to lift the light spot on the PSPD (by about 50% of the spot diameter) rotating the *Detector Y* adjustment knob (Fig. 4.5).

Other preparation is in adjustment of the *Set-point* slider in the ***Feedback*** panel of the AFM control software (Fig. 2.9) so that indicator of current set-point value *Rsp* was in the middle position or slightly below it (Fig. 2.4 left). It is also recommended to set the feedback *Delay* slider to value 20—40 (about 10–20% of the whole range from minimum value).

5.1.2 Sample approaching

Before start of fine sample approaching, move the sample on sample platform to the probe using fast auto approaching. For that, set the *Drive delay* parameter in ***Main*** panel to low value (for example, 2.72 ms) (Fig. 2.3 left) and start Auto approach with button till the distance between probe and sample becomes about 1 mm. The operator from the scanning unit front side must carefully watch that process. To stop the fast approaching, use button *STOP* in the Main panel or *Esc* key on the host computer keyboard.

1. Set the *Drive delay* parameter in ***Main*** panel to high value (for example, 10.88 ms) to provide fine approaching speed.

2. Press button (TO) and wait until system automatically terminates the approaching.
3. If bar indicator *Z* is not in the middle of its range (Fig. 2.4 left), manually proceed approaching (if Z bar indicator is above the middle position) or slightly withdraw the sample off the probe (if *Z* bar indicator is below the middle position). Before running manual vertical movement of the sample platform, enter necessary number of steps that will be done by the stepping motor after the button pressing. It is recommended to enter numbers from 3 to 10. Then press button (TO) or button (OFF), correspondingly, to approach or to withdraw the sample. You can press the buttons repeatedly until bar indicator *Z* reach the middle of its range.

5.1.3 Scanning

Before the scanning, adjust the *Set-point* (panel ***Feedback***, Fig. 2.9) to necessary value. Remember, the lover is value of the *Rsp* bar (Fig. 2.4 left), the less range of the cantilever deflection (and, correspondingly, the higher force from cantilever will be exerted to the surface) will be kept by the system at scanning.

It is also recommended to check the value of feedback speed. Too high feedback speed (low *Delay* value in panel ***Feedback***, Fig. 2.9) will result in self-generation of the measuring system and appearance of artificial moiré pattern in the acquired AFM image.

The scan area parameters are managed from panel ***Area*** of the AFM control software (Fig 2.14 left).

1. Enter necessary values in the fields *Num points X*, *Num points Y*, *Step, nm*, *Run-in region*, *Delay, mks*.
2. Choose the scanning pattern in selector *Pattern*.
3. Mark the scanning area, if necessary.
4. Run the scanning procedure pressing either Start button in ***Main*** panel (Fig. 2.3) or button (Start scanning on the set matrix) in the SurfaceScan toolbar (Fig. 2.2).
5. The scanning process will be finished automatically and the control program will display appropriate message. To terminate the scanning process before the automatic finishing, press Stop button in the ***Main*** panel or button in the software toolbar.
6. After finishing the scanning, save necessary AFM images in files on a hard disk.
7. If necessary, scan other site of the installed sample. For changing the scan site, type number of steps not less than 50 in *Z Approach* area of ***Main*** panel (Fig. 2.3 left) and press button (OFF) to manually withdraw the sample off the probe. The bar indicator *Z* must extend to its full range. After the sample repositioning with the stepper motors using panel ***Drives*** (Fig. 2.15), you can proceed the measurements repeating the sample approach (§5.1.2) and scanning procedures.

5.1.4 Finishing the work

To finish the work on the AFM, following procedures must be done.

1. Stop current measurement if it was not terminated.
2. Set the maximum feedback speed (minimum *Delay*).

3. In *Z Approach* area of ***Main*** window (Fig. 2.3 left) type number of steps not less than 50 and press button (OFF). The bar indicator *Z* (Fig. 2.4) must extend to its full range. This will enable automatic withdrawal mode.
4. Press button (OFF) of *Auto* vertical movement (panel ***Main***, Fig. 2.3 left) to withdraw the sample platform down off the probe. You can select low value for the *Drive delay* (panel ***Main***, Fig. 2.3 left) for faster movement. Check visually that the probe tip is far enough from the sample surface. If necessary, remove the sample from the sample platform.
5. Check whether all necessary data collected in the ***Acquired data pane*** (Fig. 2.20, §2.11) were saved on hard disk and save them if not.
6. Turn off the laser source (release button Laser in panel ***Laser***, Fig. 2.5).
7. Turn off the control electronic unit by pressing POWER button on its front panel (Fig. 1.6).
8. Close the AFM control software.
9. Turn off the host computer.

5.2 Dynamic mode

5.2.1 Initial adjustments

Dynamic mode is switched on in the ***Main*** panel of the AFM control software (Fig. 2.3 right). Before switching to the dynamic mode operation it is necessary to tune the detecting system under static mode according to the procedure described in §4.3. After that you can switch to the dynamic mode operation. For checking the laser beam position on the PSPD (photodetector), you can temporary switch to static mode (press button Temp. static in **Laser** panel) being under dynamic mode.

In dynamic mode the probe is oscillating at its resonant frequency that increases significantly the measuring system sensitivity. However, that also demands additional tuning of the cantilever oscillation parameters.

Other preparation is in adjustment of the *Set-point* slider in the ***Feedback*** panel of the AFM control software (Fig. 2.9) so that indicator of current set-point value *Rsp* was in the middle position or slightly below it (Fig. 2.4 right). It is also recommended to set the feedback *Delay* slider to value 20—40 (about 10–20% of the whole range from minimum value).

5.2.2 Tuning the cantilever oscillation parameters

To tune cantilever oscillation parameters use panel ***Generator*** and additional panel ***Frequency Sweep*** of the AFM control software.

1. Adjust the *Amplitude* slider in the panel ***Generator*** for maximum.
2. Adjust *Phase* slider to 25% position.
3. Press the button Get Freq. Sweep to call out additional panel ***Frequency Sweep***.
4. If necessary, enter custom values in the fields *Start (Hz)*, *Stop (Hz)* and *# of points* of the additional window ***Frequency Sweep***.
5. Press button START in panel ***Frequency Sweep***. After finishing the frequency sweeping, the system will automatically detect the highest

peak at the amplitude response curve and will automatically set corresponding values of frequency and phase in panel ***Generator***.

6. If the automatically detected peak meets no your requirements, set your own frequency value by moving the cursor slider (Fig. 2.7, §2.4). You can also zoom on the region around the cursor position to get more precise frequency sweep for the site on curve under interest.

5.2.3 Sample approaching

Before start of fine sample approaching, move the sample on sample platform to the probe using fast auto approaching. For that, set the *Drive delay* parameter in ***Main*** panel to low value (for example, 2.72 ms) (Fig. 2.3 right) and start Auto approach with button till the distance between probe and sample becomes about 1 mm. The operator from the scanning unit front side must carefully watch that process. To stop the fast approaching, use button *STOP* in the Main panel or *Esc* key on the host computer keyboard.

1. Set the *Drive delay* parameter in ***Main*** panel to high value (for example, 10.88 ms) to provide fine approaching speed.
2. Press button (TO) and wait until system automatically terminates the approaching.
3. If bar indicator *Z* is not in the middle of its range (Fig. 2.3 right), manually proceed approaching (if Z bar indicator is above the middle position) or slightly withdraw the sample off the probe (if *Z* bar indicator is below the middle position). Before running manual vertical movement of the sample platform, enter necessary number of steps that will be done by the stepping motor after the button pressing. It is recommended to enter numbers from 3 to 10. Then press button (TO) or button (OFF), correspondingly, to approach or to withdraw the sample. You can press the buttons repeatedly until bar indicator *Z* reach the middle of its range.

5.2.4 Scanning

Before the scanning, adjust the *Set-point* (panel ***Feedback***, Fig. 2.9) to necessary value. Remember, the lover is value of *Rsp* bar (Fig. 2.4 right), the more cantilever oscillation amplitude suppression will be admitted and kept by the system at scanning (and, correspondingly, the higher force from cantilever will be exerted to the surface).

It is also recommended to check the value of feedback speed. Too high feedback speed (low *Delay* value in panel ***Feedback***, Fig. 2.9) will result in self-generation of the measuring system and appearance of artificial moiré pattern in the acquired AFM image.

The scan area parameters are managed from panel ***Area*** of the AFM control software (Fig 2.14 left).

1. Enter necessary values in the fields *Num points X*, *Num points Y, Step, nm, Run-in region, Delay, mks*.
2. Choose the scanning pattern in selector Pattern.
3. Mark the scanning area, if necessary.
4. Run the scanning procedure pressing either Start button in ***Main*** panel (Fig. 2.3) or button (Start scanning on the set matrix) in the software toolbar (Fig. 2.2).
5. The scanning process will be finished automatically and the control program will display appropriate message. To terminate the scanning

process before the automatic finishing, press Stop button in the ***Main*** panel or button in the software toolbar.

6. After finishing the scanning, save necessary AFM images in files on a hard disk.
7. If necessary, scan other site of the installed sample. For changing the scan site, type number of steps not less than 50 in *Z Approach* area of ***Main*** panel (Fig. 2.3 right) and press button (OFF) to manually withdraw the sample off the probe. The bar indicator Z must extend to its full range. After the sample repositioning with the stepper motors using panel ***Drives*** (Fig. 2.15), you can proceed the measurements repeating the sample approach (§5.1.2) and scanning procedures.

5.2.5 Finishing the work

To finish the work on the AFM, following procedures must be done.

1. Stop current measurement if it was not terminated.
2. Set the maximum feedback speed (minimum *Delay*).
3. In *Z Approach* area of ***Main*** window (Fig. 2.3 right) type number of steps not less than 50 and press button (OFF). The bar indicator *Z* (Fig. 2.4) must extend to its full range. This will enable automatic withdrawal mode.
4. Press button (OFF) of *Auto* vertical movement (panel ***Main***, Fig. 2.3 left) to withdraw the sample platform down off the probe. You can select low value for the *Drive delay* (panel ***Main***, Fig. 2.3 left) for faster movement. Check visually that the probe tip is far enough from the sample surface. If necessary, remove the sample from the sample platform.
5. Check whether all necessary data collected in the ***Acquired data pane*** (Fig. 2.20, §2.11) were saved on hard disk and save them if not.
6. Turn off the laser source (release button Laser in panel ***Laser***, Fig. 2.5).
7. Turn off the control electronic unit by pressing POWER button on its front panel (Fig. 1.6).
8. Close the AFM control software.
9. Turn off the host computer.

5.3 Two-pass mode

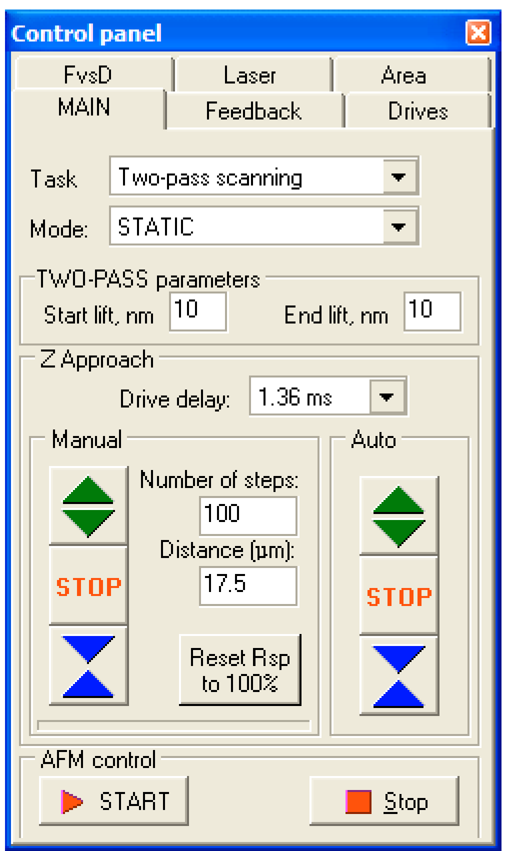
Two-pass scanning is a specialized SPM technique for measurement topography and then a contrast image, e.g. electrostatic map. First pass scanning is used to acquire topography AFM image. Then the system lifts the tip over the sample (or lowers the sample under the tip) and scans the same site repeating the site topography based on data obtained during the first scan (similar to constant force mode). Applying a bias voltage between probe tip and the sample, the instrument maps electrostatic forces in every measurement point.

For the two-pass scanning aimed on mapping electrostatic forces, a special measuring head and a probe holder (Fig. 4.3) must be used that provides electric insulation of the installed probe from the AFM case and application of bias voltage to the probe itself. Special measuring head and probe holder can be supplied from AFM NT-206 manufacturer. Control electronic unit also must be equipped with special circuits to support two-pass scanning with electrostatic forces mapping.

For electrostatic force mapping, you also need to use conductive probes (tips). Such specialized probes are made by applying conductive coating on usual probes and are available from their original manufacturer, for example Mikromasch (www.spmtips.com), NT-MDT (www.ntmdt.com). Note that any functional coating (in this case conductive one) increases the probe tip curvature radius and hence worsen the instrument spatial resolution.

Two-pass scanning is activated as a specialized **Task** in the ***Main*** panel of the AFM control software (Fig. 5.1 left). For mapping electrostatic forces *STATIC* mode should be selected in selector **Mode**. With selected *Two-pass scanning* task, a field below the **Mode** selector (*TWO-PASS parameters*) provides setting of an offset or lift distance that will be done before the second pass. This lift may be different at the beginning of the matrix and its end to incline the plane of second scan. If the start and end lifts are the same, plane of second scan will be parallel to the first one.

Additional parameter necessary for imaging electrostatic forces under Two-pass scanning is tip bias voltage that is defined in panel ***Feedback*** by slider *Tip voltage, V* (Fig. 5.1 right).



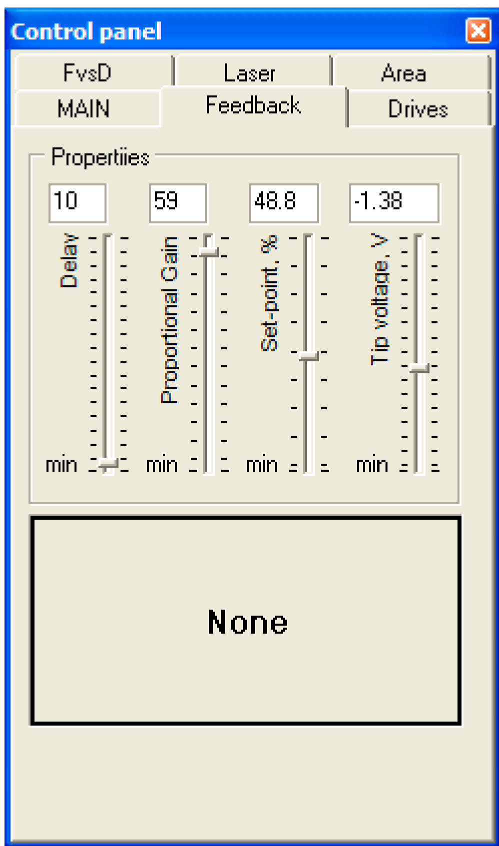


Fig. 5.1. Main panel of scanning control set for operation in Two-pass scanning mode (left) and panel of feedback parameters (right) used for setting bias voltage (slider Tip voltage, V)

After selection of the above **Task** and **Mode**, defining lifting distance before the second pass and *Tip voltage, V*, further AFM operation is similar to that under static mode described in §5.1. To start the measurement, you can press button START in panel Main, or press button in the toolbar, or select menu item *Task > Two-pass scanning*. Resultant data set will include topography image (at first pass) and contrast image (at second pass), e.g. electrostatic force map.

At *Two-pass scanning*, probe moves relative sample on following scheme. During first pass, probe moves along line of fast scan direction collecting topography height data and returns back to the line start point. Then it makes

second pass along the same line but lifting preliminary over the sample surface and moving parallel to first-pass repeating at constant lift distance the surface topography based on data collected during first pass (Fig. 5.2). During second pass, the system applies a bias voltage between tip and sample surface that means that the probe cantilever deflection will correspond to tip-to-sample electrostatic interaction. So, second pass provides data on electrostatic forces in every measurement point.

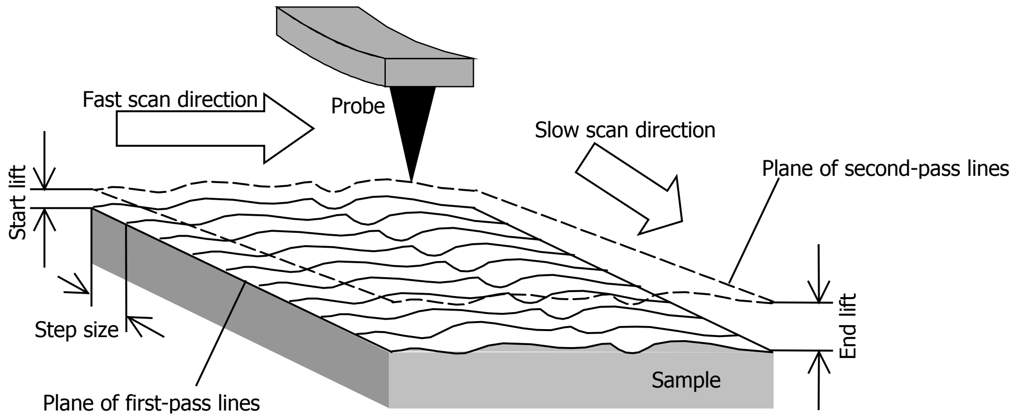


Fig. 5.2. Scheme of two-pass scanning.

After finishing second pass, the probe returns to the line start, approaches the surface again and makes a step along slow scan direction to next scan line. Then the system repeats the described measuring routine. If the start and end lift values are different, lift distance will change proportionally from line to line along slow scan direction. Note that lift distance between lines along the fast scan direction remains constant and changes only when the probe steps to next scan line. In this way, inclination of second-pass plane can be realized if it is necessary in the experiment.

5.4 Multilayer scanning

Multilayer scanning is a specialized technique for automated measurement of a set of AFM images at the same area with different set-point values. Each scan obtained with the same set-point value is counted as a layer. Change of the set-point parameter means that the system changes also contact force exerted by the probe on sample surface. This function can be treated as a kind of tomography for surface layers.

Multilayer scanning is started by pressing button or by choosing menu item *Task > Multilayer scanning*. In panel ***Main***, the function can be run by selecting **Task** *Multilayer scanning*, choosing necessary **Mode** (*DYNAMIC* or *STATIC*) and then pressing button START. Note that you need also preliminary to tune the instrument for operation under dynamic or static mode, correspondingly (see §5.1 and §5.2). Before running of multilayer scanning, additional panel for setting specific functional parameters ***Multilayer scanning parameters*** emerges (Fig. 5.3). It provides for assigning set-point for starting layer (*Start Rsp*), set-point for end layer (*End Rsp*), and number of the layers to be scan (*Number of layers*). Depending on these parameters, set-point values for other layers will be calculated proportionally. Note that set-point values in the parameters panel should be entered as fractions of 1 assuming that free state of the probe cantilever corresponds to 1 and full pressing to the surface corresponds to 0. Note that you

also can assign the same set-point value for the start and end of the function that will result in multiple (according to the set Number of layers) imaging of the same area.

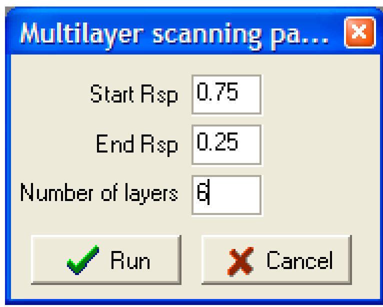


Fig. 5.3. Panel of setting parameters for automated multilayer scanning.

The measurement process is started after pressing button Run in panel ***Multilayer scanning parameters***. Specialized visualization window ***Multilayer scanning / Tomography*** will show the progress in acquiring either one layer or a sequence of all layers one by one (at checked option *Show layers alternately*). You also can select what type of measured data to show (in context menu at right click). Selector **Layer** allows to specify what layer to show in the visualization pane (at unchecked option *Show layers alternately*).

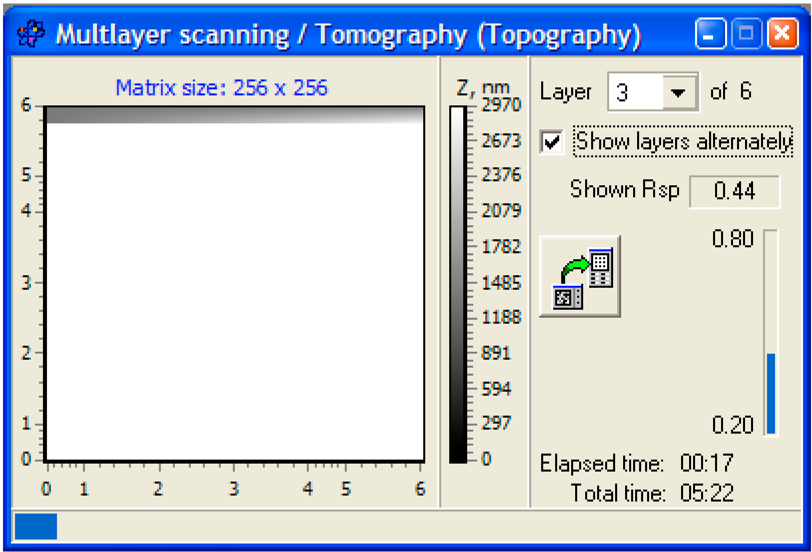


Fig. 5.4. AFM data visualization window at Multilayer scanning.

Implementation of the multilayer scanning procedure is similar to that at two-pass scanning. However, the difference is that probe during multilayer scanning repeatedly moves along the scan lines without physical lifting over the sample surface remaining in the contact with the surface at every pass. So, multilayer scanning function images the sample with probe moving practically in one plane parallel to its surface (providing no for any inclination). Multilayer scanning function does not provide also opportunity of a bias voltage application between a probe and sample.

After finishing of the multilayer scanning, data of each layer will be saved in separate SPM data file. Special list file of text format will be created simultaneously to describe all the saved SPM data files.

5.5 Force spectroscopy

Force spectroscopy function is used for fine tuning of the electronic measuring system (static force spectroscopy or Force-vs-Distance curve measurement) and as a specialized function for obtaining information on the sample surface properties (both static and dynamic force spectroscopy).

Specific settings for spectroscopy measurement should be made in panel of spectroscopy settings and control ***FvsD*** (§2.6). First of all you need to set necessary *Controlled parameter*. In most cases, *Distance* is used as a controlled parameter. Then enter necessary values in the table of parameters to set upper limit of the tube piezoscanner motion range (*Top*), its lower limit (*Bottom*), number of points on the measured curve (*Points*), number of measurements in each point (*Measurement*) and discretization steps between the measurement points (*StepMove*). Bar *Z Distance/Set-point* (at left side of the panel) graphically shows the set top and bottom boundaries relative full vertical motion range of the scanner. This sliders at the bar sides can be used for manual setting the upper (left slider) and lower (right slider) limits of the scanner vertical motion at the spectroscopy measurement.

Point within the scan area where the spectroscopy measurement will be done is defined in panel ***Area*** (in mode **Point**).

After adjustment of specific spectroscopy settings in panel ***FvsD***, and pointing out the measurement point, you can run the function. Types of plotted graphs obtained depending on combination of operation modes and controlled parameters are described in Table 5.1.

Table 5.1. Type of graphs plotted by **Spectroscopy in point** function.

Operation mode	Controlled parameter	
	Distance	Set-point
Static	Cantilever deflection vs. Probe-to-Sample Distance	Probe-to-Sample Distance vs. Cantilever deflection
Dynamic	Cantilever Oscillation Amplitude vs. Probe-to-Sample Distance **and** Cantilever Oscillation Phase Shift vs. Probe-to-Sample Distance	Probe-to-Sample Distance vs. Cantilever Oscillation Amplitude

5.5.1 Static force spectroscopy

Static force spectroscopy function is run through the menu item *Task > Spectroscopy in point* or by pressing button in the toolbar. From the ***Main*** panel, **Static force spectroscopy** function is available when **Task** is set to *Spectroscopy in point* and **Mode** is set to *STATIC*. When the function is started, visualization window ***View spectroscopy data*** is activated (Fig. 5.5)

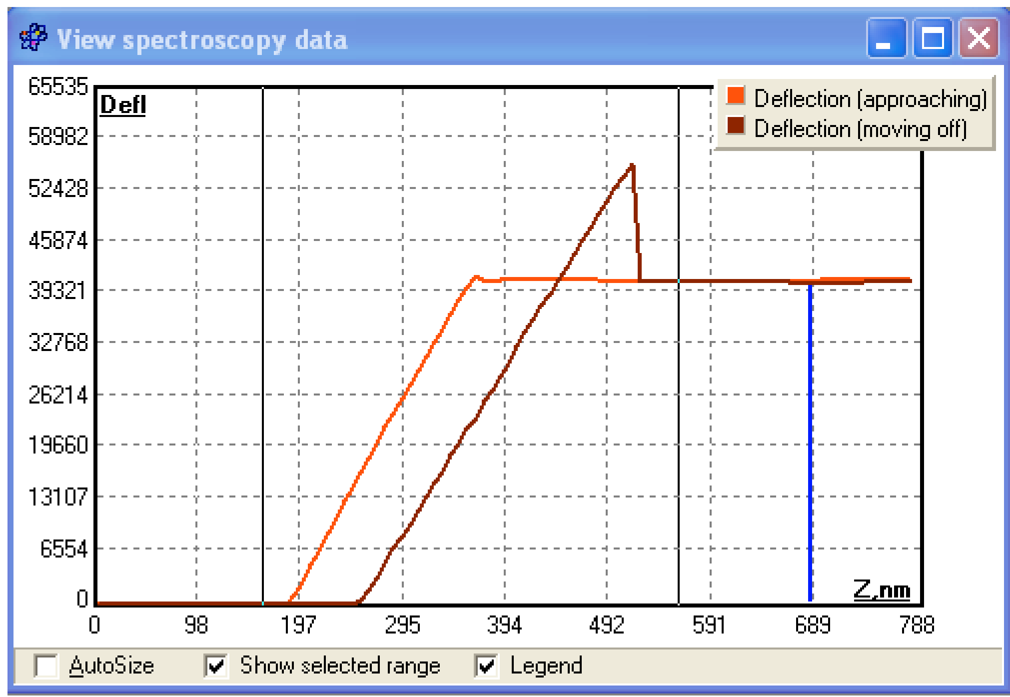
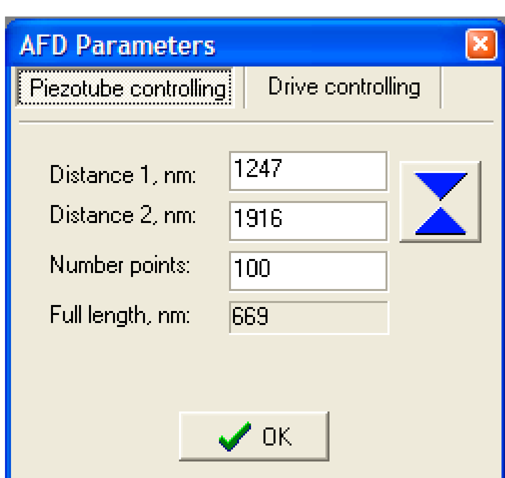


Fig. 5.5. Visualization window for advanced plotting of static force spectroscopy data.

After acquisition of the spectroscopy function graph, the system will stop the measurement. The measured data can be saved in a file through the File save dialogue.

5.5.2 Dynamic force spectroscopy

Dynamic force spectroscopy is started by pressing button in the tool bar or by choosing item *Task > Dynamic force spectroscopy*. To start the function from panel ***Main***, select **Task** *Spectroscopy in point* and **Mode** *DYNAMIC*. After the start, panel ***AFD parameters*** (Fig. 5.6) will be first activated where the way of probe-to-sample distance variation should be specified – by moving sample along Z-axis either by piezoscanner (mode *Piezotube controlling*, Fig. 5.6 left) or by vertical motion stepper motor (mode *Drive controlling*, Fig. 5.6 right).



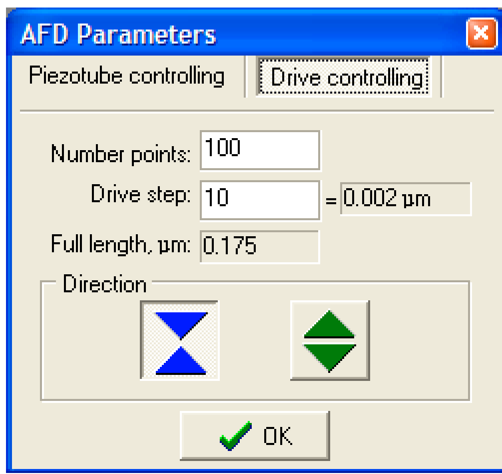


Fig. 5.5. Panel of settings for dynamic force spectroscopy with the distance control by piezoscanner (left) and vertical motion stepper motor (right).

In the *Piezotube controlling* mode, following parameters should be set:

- Distance 1 – start of the working region;
- Distance 2 – end of the working region;
- Number of points – number of measurement points on the distance axis;
- Full length – information about length of working region.

In the *Drive controlling* mode, you need to set following parameters:

- Number of points – number of measurement points on the distance axis;
- Drive step – number of steps performed by the vertical motion stepper motor between measurement points;
- Full length – information about length of working region;
- Direction – choose the direction for the stepper motor at which the Amplitude-Frequency-Distance characteristic will be measured (at approaching only or at withdrawal only to avoid backlash effect)

After setting necessary parameters in panel ***AFD parameters***, you can finally run the measurement by pressing button OK in the panel. Emerging visualization window for AFD function (Fig. 5.7) will show two 2D images:

left (*AFD*) – Amplitude (Z axis, refer to grayscale) as function of Frequency (X axis / horizontal) and probe-to-sample Distance (Y axis / vertical);

right (*PhFD*) – Phase shift (Z axis, refer to grayscale) as function of Frequency (X axis / horizontal) and probe-to-sample Distance (Y axis / vertical).

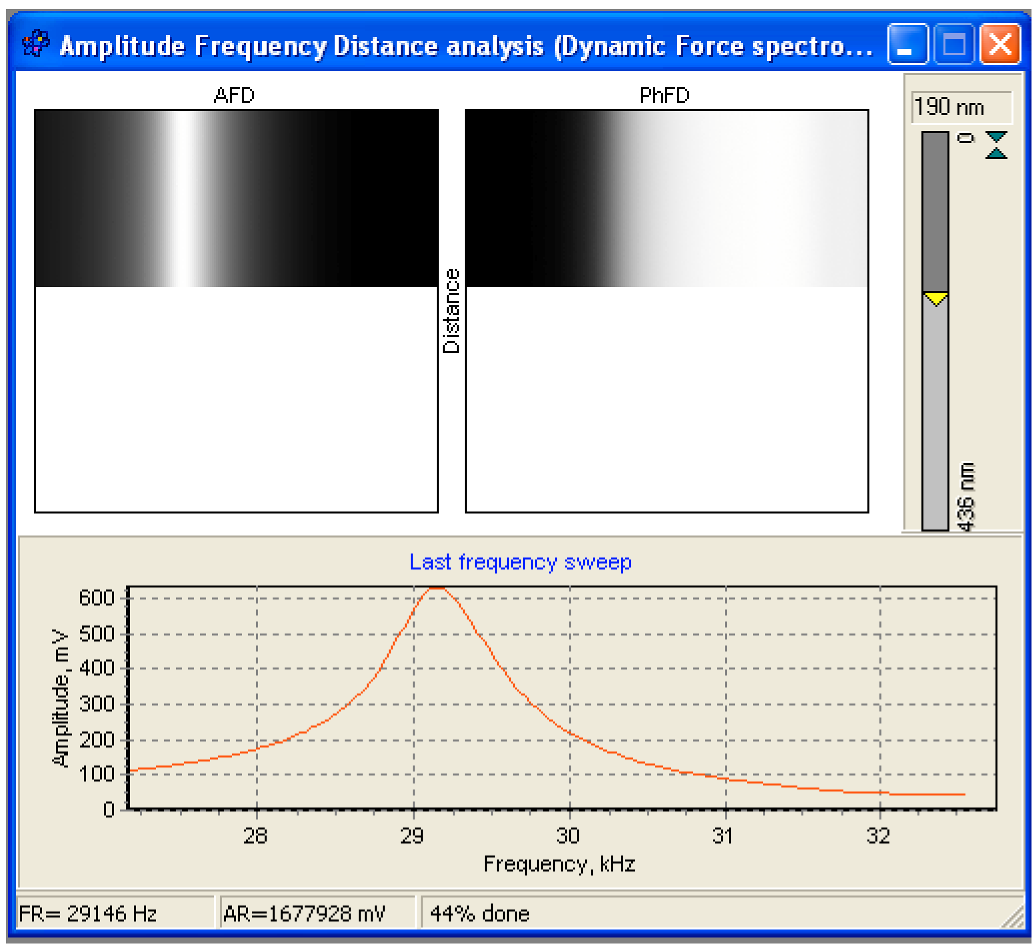


Fig. 5.7. Amplitude-Frequency-Distance analysis visualization window (visualization of dynamic force spectroscopy data).

After acquisition of the spectroscopy function plots, the system will stop the measurement. The measured data can be then saved in a file through the File save dialogue.

6 CALIBRATION OF THE AFM MEASURING SYSTEM

6.1 Defining basic calibration parameters

Calibration of the AFM measuring system is performed to determine coefficients used by the electronic systems for correct interpretation of vertical and lateral motions of the piezoscanner. Correct data obtained by the measuring system allow getting reliable information on the scanned objects.

It is recommended to calibrate system each time after the tube piezoscanner replacement and also at least once a week for checking up the earlier established constants (coefficients).

A set of test gratings should be used for calibration. The test gratings represent specially fabricated surface structures with periodic microstructures of a known geometry (step sizes and height of the microrelief features). The most known test samples sets are manufactured by NT-MDT and Mikromasch companies (Fig. 6.1).

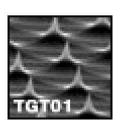


Fig. 6.1. SEM micrographs of the test gratings manufactured by Mikromasch Co.

From the AFM-images of test samples (Fig. 6.2) real sizes of the maximum scanning area are determined. The determined parameters should be entered in the fields *X range, nm*, *Y range, nm* and *Z range, nm* in panel ***Calibrate AFM Data*** (Fig. 6.3).

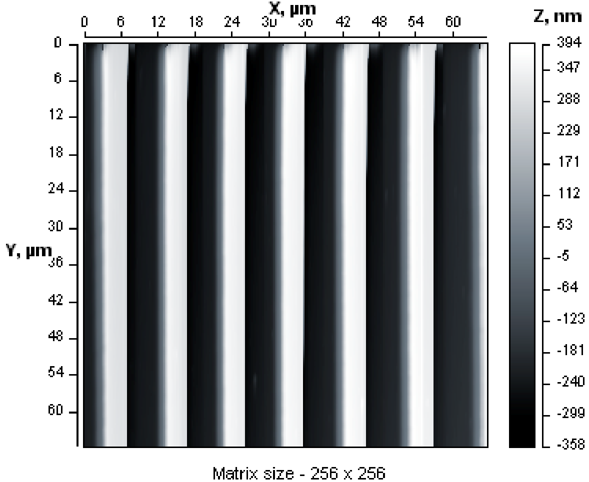


Fig. 6.2. AFM-image of the test grating

For example, to calculate range in X direction it is necessary to count the number of the features in the AFM image (including the fractional ones) and multiply it by the features pitch size.

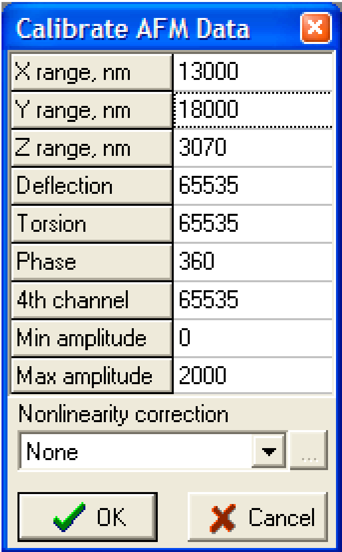


Fig. 6.3. Panel of the AFM main calibration parameters.

For vertical range calibration it is possible to compare the height reported by the software with real parameters. In this case it is necessary to divide the existing Z range parameter $Z_{current}$ by the feature height h_{image} reported by the software and then to multiply the result by real value of the feature height h_{real} (Fig. 6.4):

$$Z = Z_{current} * h_{real} / h_{image}$$

This final result must be then entered in the field *Z range, nm*. Analogous procedure can be also used for calibration parameters calculation for X and Y directions.

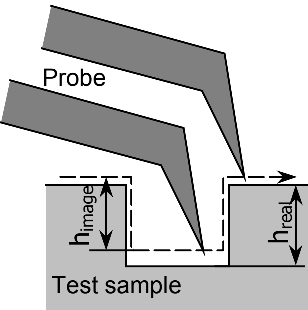


Fig. 6.4. Comparison of the reported and real height of the test sample feature

Parameters *Deflection* and *Torsion* in the ***Calibrate AFM data*** panel describe number of bits covered with the ADC installed in the measuring system. For 16-bit ADC (like in this system) these values are 65535.

Phase angle *Phase* describes limits of the phase angle variation and usually it is 360.

6.2 Nonlinearities of a piezoceramic scanner and their correction

For implementation of precision motions in scanning probe microscopes, piezoceramic movers are traditionally used. Piezoelectric ceramics directly transform an electric field applied to them to mechanical displacements – expansion or compression of the material (depending on a direction of electric field). Currently available PZT materials can achieve a strain on the order of 1/1000 (0.1%) when the maximum allowable field is applied.

In an ideal case the mechanical strain in piezoceramics linearly depends on the applied electric potential. The equation of a type

$$\sigma = d \cdot E,$$

where σ is a mechanical strain, E is an electric field, and d is coefficient of strain, describes ideal relation between a mechanical strain and the applied electric field in piezoceramic material. The coefficient of strain is characteristic for a specific piezoelectric material and differs for the same material when an electric field is applied in mutually perpendicular directions.

In practice mechanical response of piezoelectric ceramics to the applied electric field differs from ideal linear behavior. Owing to presence of such negative phenomena as intrinsic nonlinearity of a piezoelectric material, a hysteresis, creep, cross coupling and ageing, errors appear on measured SPM images. Figure 6.5 shows dependence of the piezoceramic material response on the applied voltage in real system and cumulative effect from a hysteresis, creep and cross coupling on the image during imaging of a single rectangular feature.

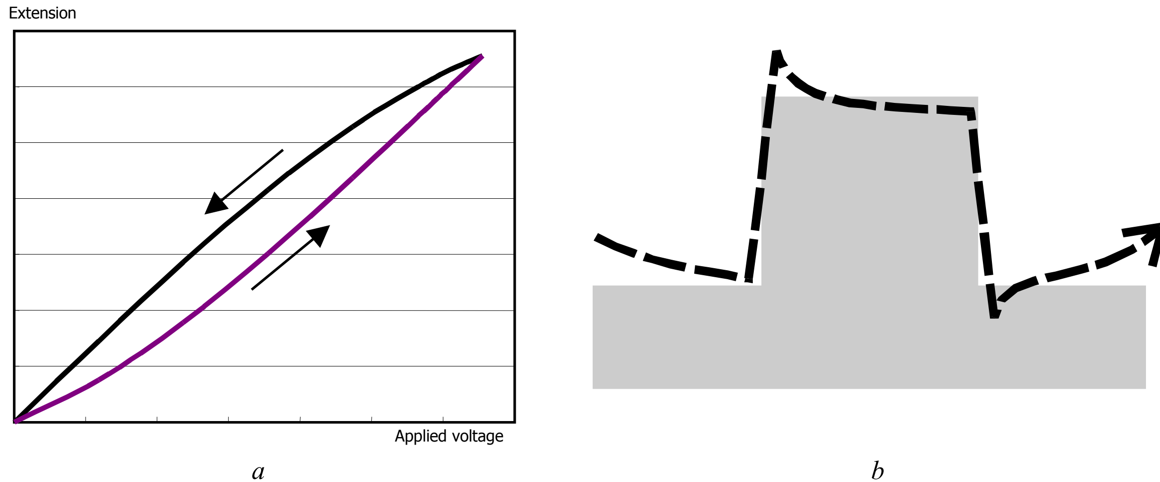


Fig. 6.5. Results of non-ideal behavior of piezoceramic material used as scanner: *a* – dependence of the piezoceramic material response on the applied voltage; *b* – influence of a hysteresis, creep and cross coupling of piezoscanner on the image of a rectangular feature in a vertical direction (axis Z).

Non-ideal behavior of piezoceramic material shown in Fig. 6.5 affects as well on movement of the scanner in a horizontal plane (plane XY). It is resulted in distortion of lateral sizes of objects that is distinctly visible on SPM images of regular structures with known geometrical parameters (e.g. test gratings). For example, in Fig. 6.6 strips at the beginning of scanning area are wider than at its end, however the real structure represents regular alternating rectangular (in cross-section) strips of equal width and equal period. This disadvantage distinctly appears after the scanning direction reversion.

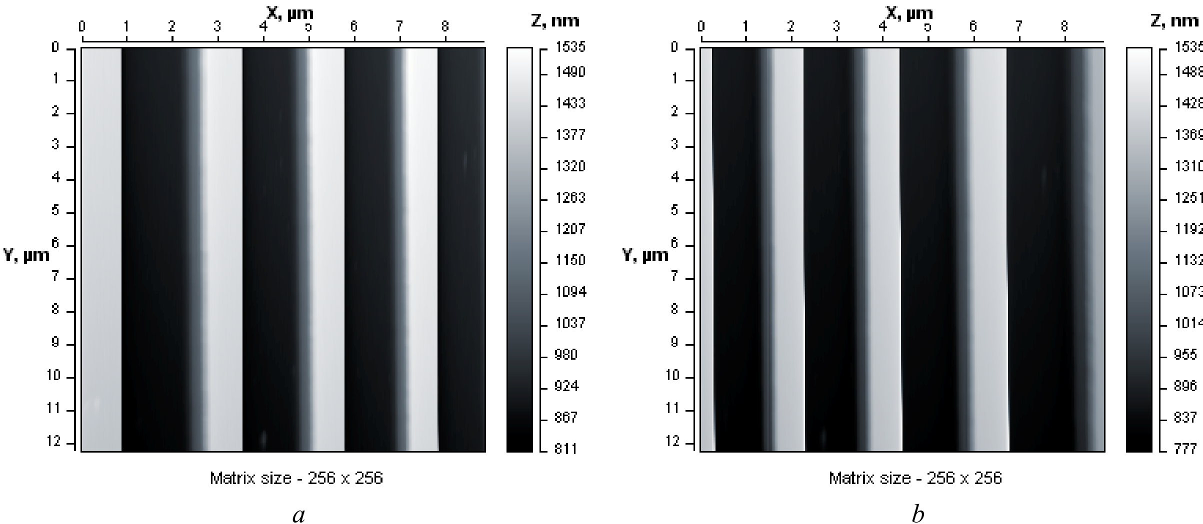


Fig. 6.6. Distortion of lateral sizes of regular test grating on the SPM image: *a* – the scanning area begins from the left side; *b* – the scanning area begins from the right side.

The same reasons – hysteresis, creep and cross coupling – result in dependence of a piezoscanner motion range on speed of applied voltage change. In real systems, that lead to coverage of unequal ranges in directions of fast and slow scan at imaging of rectangular area (if based on applied voltage data). So, along the fast scan direction the range of motion is less than along the slow scan direction as voltage to piezoscanner electrodes is applied and changes from a minimum up to a maximum faster (Fig. 6.7). Creep of the piezoceramics brings main contribution to the given error. Figure 6.7 shows that the scanner covers bigger number of the test grating periods along a slow scan direction than in case of setting the same direction as a fast scan direction.

a

b

Fig. 6.7. Dependence of a piezoscanner motion range on speed of applied voltage change: *a* – fast scan direction is along vertical axis; *b* - fast scan direction is along horizontal axis.

Measuring system of atomic force microscope NT-206 provides for software correction of described nonlinearities of the piezoscanner motion that allows to reduce distortions of lateral sizes of objects in the SPM images. Correction of nonlinearities is implemented by introduction of special adjusting functions into process of formation of managing potentials applied to the piezoscanner electrodes.

6.2.1 Simple cubic correction

Function of nonlinearity correction provides compensation of non-linear behavior of the piezoscanner by a variation of the actual voltage applied to the piezoscanner electrodes for driving its motion in a horizontal plane under the parabolic law (cubic polynom):

$$x_1 = ax_0^3 + bx_0^2 + cx_0,$$

where x_1 is the modified coordinate value used for calculation of the actual voltage on electrodes; x_0 is rating value of the coordinate; a, b and c are polynomial factors.

Such software correction at appropriate selection of the cubic polynom parameters allows to improve considerably accuracy of piezoscanner positioning in XY plane and to minimize a difference between measurement point steps in different regions of scanning matrix.

Simple cubic correction implies equal ranges of piezoscanner motion from the neutral position in directions +X, –X, +Y, –Y under the static application of the same voltage to corresponding electrodes. In this case the same correction model will be effective for mutually perpendicular directions of scanning. However, it is necessary to note that models (i.e. the correction equations) will differ for opposite directions.

The determined factors of cubic polynom are to be entered in corresponding fields of panel ***Simple cubic nonlinearity correction*** (Fig. 6.8). Factors of the polynom for direction of ascending bits (from 0 up to 65535) are to be entered in column *direction 0-1*, and factors of the polynom for direction of descending bits (from 65535 up to 0) – in column *direction 1-0* of area *Correcting function* in the panel.

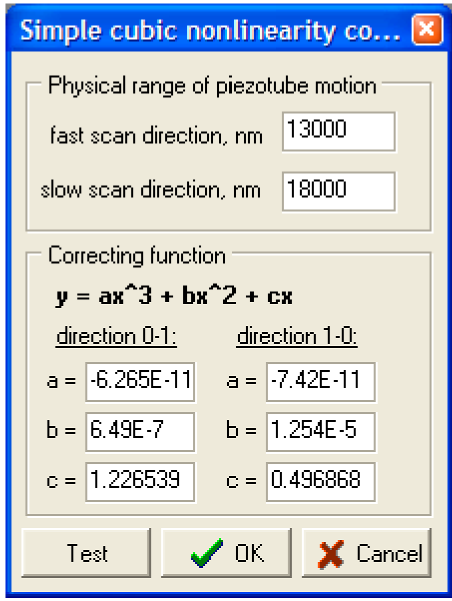


Fig. 6.8. The panel ***Simple cubic nonlinearity correction*** for setting of the correction function parameters.

Button Test in the panel brigs up an auxiliary window where the cubic curves with the set parameters are plotted for checking their correctness (Fig. 6.9). You can change the cubic polynoms parameters right in the fields in ***Curve*** window and check visually their correctness. To accept or discard the changes, press button OK or Cancel in the window.

Note that setting value 0 for factor a, you turn the cubic polynom into square polynom that is not so effective in the nonlinearity corection. The difference between cubic and square correction models is shown in Fig. 6.10.

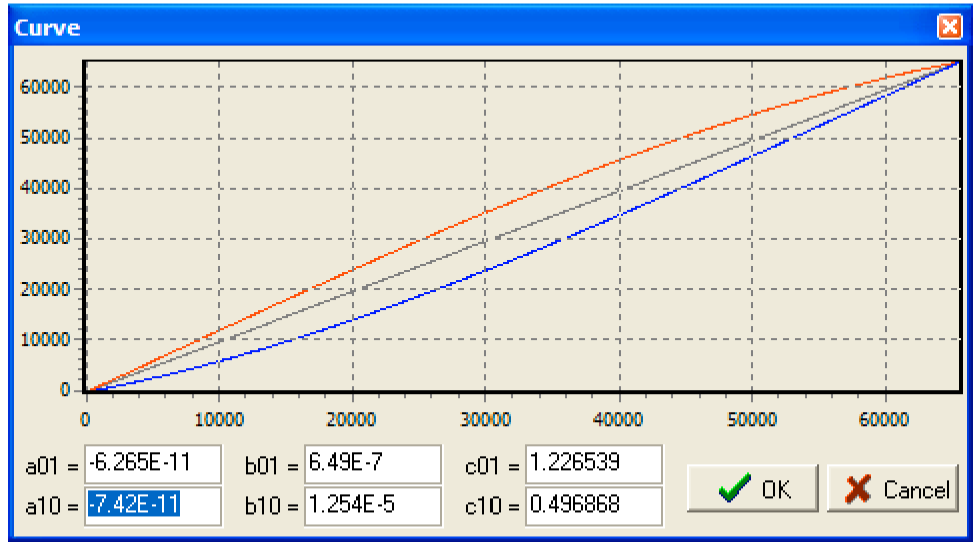


Fig. 6.9. Auxiliary window for plotting the correction equations curves.

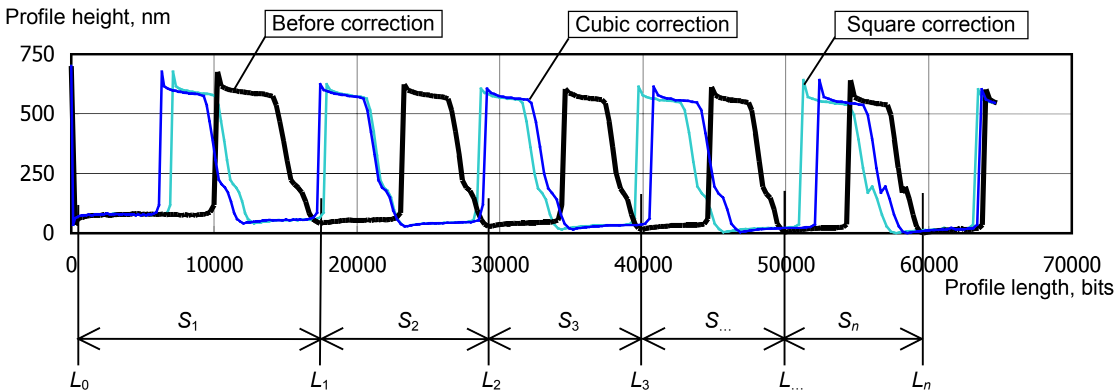


Fig. 6.10. Comparison of the cross-section profiles for test grating TGZ03 obtained before and after the application of correction functions to eliminate nonlinearities of the piezoscanner movement.

To calculate parameters necessary for simple cubic correction, only two scans can be done in mutually opposite directions (in ascending and descending bits). Third scan is to be done for determination of scan range for fast or slow scan direction (depending on direction chosen for first two scans).

For example, from the AFM image of a test grating in Fig. 6.7a it is possible to calculate a range of piezoscanner movement along a slow scan direction (along a horizontal axis). And analyzing Fig. 6.7b (the same site imaged with the changed fast scan direction) we can determine a range of piezoscanner movement along a fast scan direction. The analysis consists in counting up both the whole periods of a test grating and its fractional parts.

The determined ranges of piezoscanner movement for fast and slow scan directions are to be entered in corresponding fields (*fast scan direction, nm* and *slow scan direction, nm*) of area **Physical range of piezotube motion** in the panel ***Simple cubic nonlinearity correction*** (Fig. 6.8). After the parameters entering, the system will automatically correct a range of piezoscanner movement in slow scan direction (actually, proportionally to reduce it down to size of a fast scan range) so that the measured AFM matrix was really square in XY plane. That will minimize distortions of the lateral sizes of objects on a sample surface at measurements (Fig. 6.11).

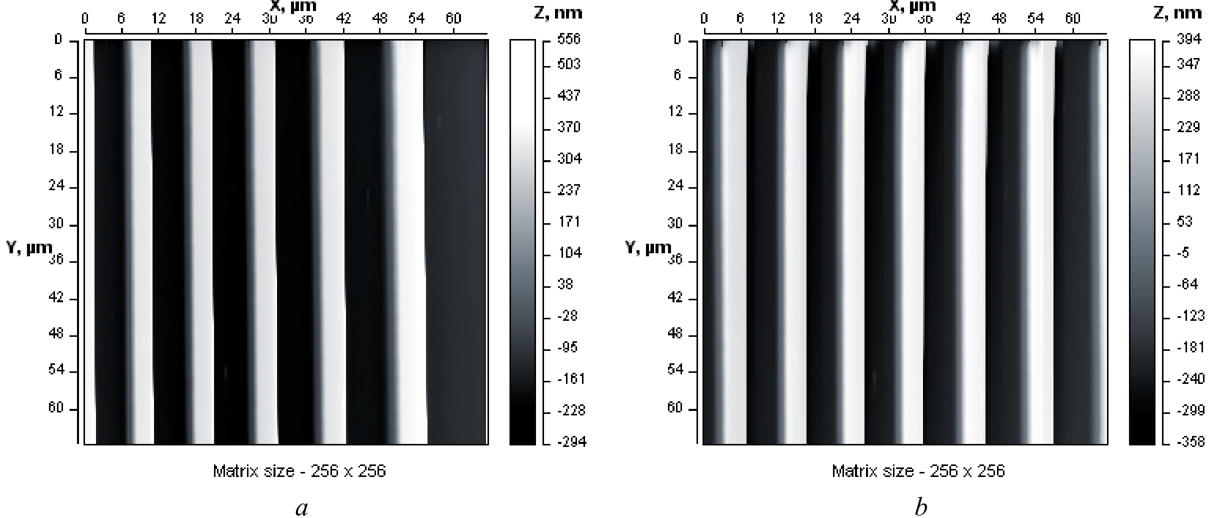


Fig. 6.11. Test scans of calibration grating TGZ03: a – the initial AFM image received without nonlinearity correction; b – the same site imaged with software correction of piezoscanner movement along horizontal axis (slow scan direction).

6.2.2 Advanced cubic correction

Function of the advanced cubic correction of the piezoscanner nonlinearity represents the generalized version of simple cubic correction. It means that the given function allows to compensate errors in the piezotube sectioning for electrodes, heterogeneity of the piezoceramic material and geometrical discrepancies of the piezotube manufacturing. In the practice, to define the factors for advanced cubic correction function demands carrying out of whole set of test scans. In particular, it is necessary to define factors for eight correction equations corresponding to various combinations of fast and slow scan directions, i.e. actually to analyze errors of piezoscanner movement for each of eight possible scanning patterns: , , , , , , , .

The defined factors of correction cubic polynoms and the measured ranges of piezoscanner movement are to be entered in the panel ***Advanced cubic nonlinearity correction*** (Fig. 6.12). Value of each parameter in the given panel as well as conditions of their definition are described in Table 6.1.

Button Test in the panel brigs up an auxiliary window where the cubic curves with the set parameters are plotted for checking their correctness (Fig. 6.13). This button is activated when you place the cursor in fields with the coefficient for cubic polynoms. After pressing button Test, one of four pairs of the correction curves will be plotted depending on the cursor location. You can change the cubic polynoms parameters right in the fields of ***Curve*** window and check visually their correctness. To accept or discard the changes, press button OK or Cancel in the window.

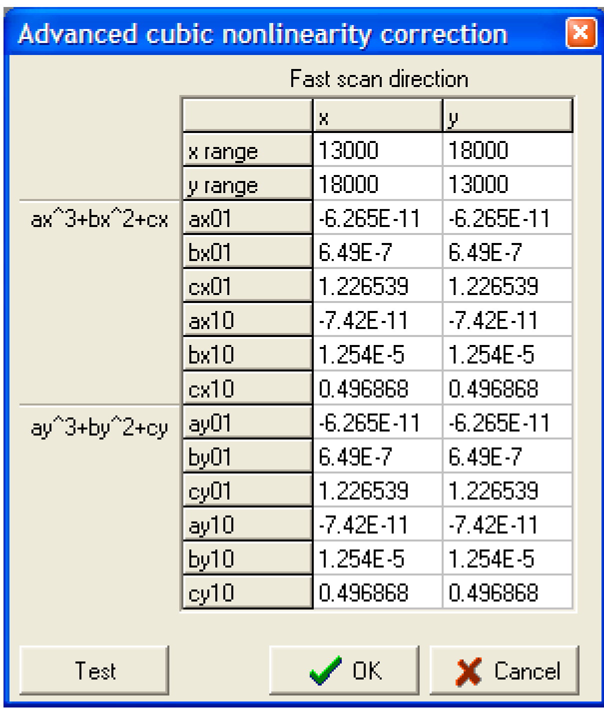


Fig. 6.12. The panel of setting parameters for the ***Advanced cubic nonlinearity correction***.

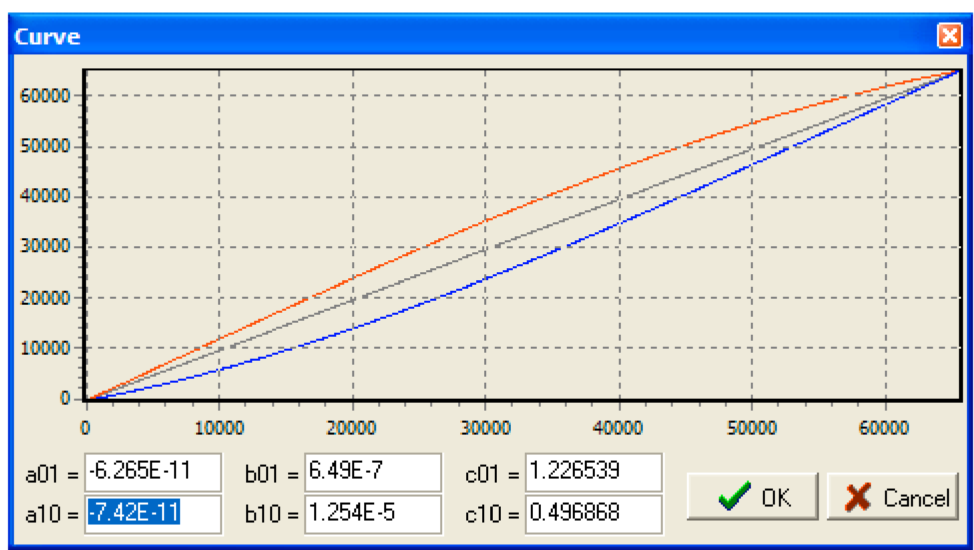


Fig. 6.13. Auxiliary window for plotting the correction equations curves.

Table 6.1. Description of parameters and conditions of their defining for entering cells in panel of parameters for advanced square correction.

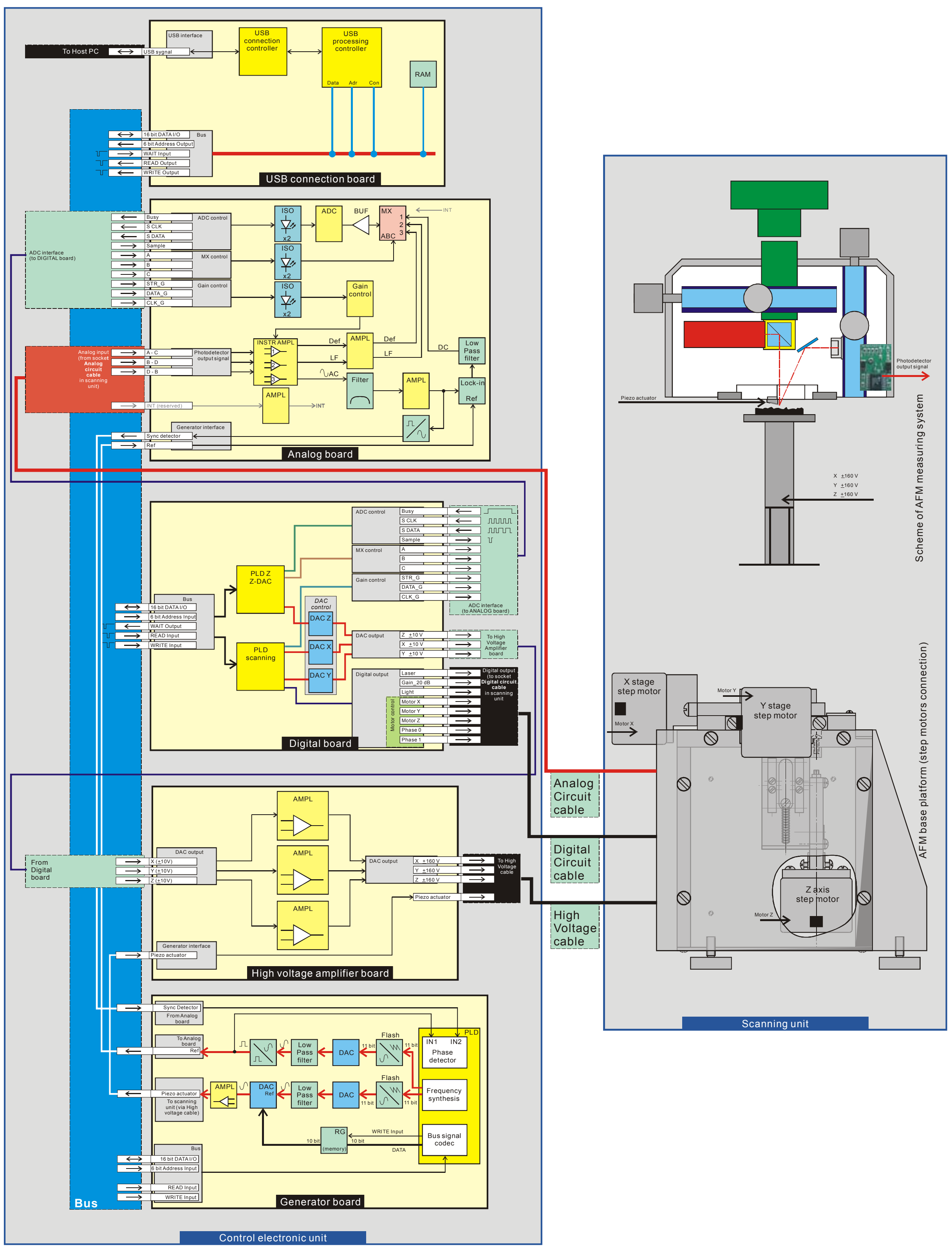
		Fast scan direction	
		x	y
	x range	Range of piezoscanner motion along X axis while this axis is set as fast scan direction. Measured at scanning patterns , , , .	Range of piezoscanner motion along X axis while Y axis is set as fast scan direction. Measured at scanning patterns , , , .
	y range	Range of piezoscanner motion along Y axis while X axis is set as fast scan direction. Measured at scanning patterns , , , .	Range of piezoscanner motion along Y axis while this axis is set as fast scan direction. Measured at scanning patterns , , , .
ax^3+bx^2+cx	ax01	Coefficient *a* of the cubic polynom function correcting piezoscanner motion along X axis at ascending bits and setting X axis as fast scan direction (correction in fast scan direction). Scanning patterns or .	Coefficient *a* of the cubic polynom function correcting piezoscanner motion along X axis at ascending bits and setting Y axis as fast scan direction (correction in slow scan direction). Scanning patterns or .
	bx01	Coefficient *b* of the cubic polynom function correcting piezoscanner motion along X axis at ascending bits and setting X axis as fast scan direction (correction in fast scan direction). Scanning patterns or .	Coefficient *b* of the cubic polynom function correcting piezoscanner motion along X axis at ascending bits and setting Y axis as fast scan direction (correction in slow scan direction). Scanning patterns or .
	cx01	Coefficient *c* of the cubic polynom function correcting piezoscanner motion along X axis at ascending bits and setting X axis as fast scan direction (correction in fast scan direction). Scanning patterns or .	Coefficient *c* of the cubic polynom function correcting piezoscanner motion along X axis at ascending bits and setting Y axis as fast scan direction (correction in slow scan direction). Scanning patterns or .
	ax10	Coefficient *a* of the cubic polynom function correcting piezoscanner motion along X axis at descending bits and setting X axis as fast scan direction (correction in fast scan direction). Scanning patterns or .	Coefficient *a* of the cubic polynom function correcting piezoscanner motion along X axis at descending bits and setting Y axis as fast scan direction (correction in slow scan direction). Scanning patterns or .
	bx10	Coefficient *b* of the cubic polynom function correcting piezoscanner motion along X axis at descending bits and setting X axis as fast scan direction (correction in fast scan direction). Scanning patterns or .	Coefficient *b* of the cubic polynom function correcting piezoscanner motion along X axis at descending bits and setting Y axis as fast scan direction (correction in slow scan direction). Scanning patterns or .
	cx10	Coefficient *c* of the cubic polynom function correcting piezoscanner motion along X axis at descending bits and setting X axis as fast scan direction (correction in fast scan direction). Scanning patterns or .	Coefficient *c* of the cubic polynom function correcting piezoscanner motion along X axis at descending bits and setting Y axis as fast scan direction (correction in slow scan direction). Scanning patterns or .
ay^3+by^2+cy	ay01	Coefficient *a* of the cubic polynom function correcting piezoscanner motion along Y axis at ascending bits and setting X axis as fast scan direction (correction in slow scan direction). Scanning patterns or .	Coefficient *a* of the cubic polynom function correcting piezoscanner motion along Y axis at ascending bits and setting Y axis as fast scan direction (correction in fast scan direction). Scanning patterns or .
	by01	Coefficient *b* of the cubic polynom function correcting piezoscanner motion along Y axis at ascending bits and setting X axis as fast scan direction (correction in slow scan direction). Scanning patterns or .	Coefficient *b* of the cubic polynom function correcting piezoscanner motion along Y axis at ascending bits and setting Y axis as fast scan direction (correction in fast scan direction). Scanning patterns or .
	cy01	Coefficient *c* of the cubic polynom function correcting piezoscanner motion along Y axis at ascending bits and setting X axis as fast scan direction (correction in slow scan direction). Scanning patterns or .	Coefficient *c* of the cubic polynom function correcting piezoscanner motion along Y axis at ascending bits and setting Y axis as fast scan direction (correction in fast scan direction). Scanning patterns or .
	ay10	Coefficient *a* of the cubic polynom function correcting piezoscanner motion along Y axis at descending bits and setting X axis as fast scan direction (correction in slow scan direction). Scanning patterns or .	Coefficient *a* of the cubic polynom function correcting piezoscanner motion along Y axis at descending bits and setting Y axis as fast scan direction (correction in fast scan direction). Scanning patterns or .

		Fast scan direction	
		x	y
		Coefficient *b* of the cubic polynom function correcting piezoscanner motion along Y axis at descending bits and setting X axis as fast scan direction (correction in slow scan direction). Scanning patterns or .	Coefficient *b* of the cubic polynom function correcting piezoscanner motion along Y axis at descending bits and setting Y axis as fast scan direction (correction in fast scan direction). Scanning patterns or .
	cy10	Coefficient *c* of the cubic polynom function correcting piezoscanner motion along Y axis at descending bits and setting X axis as fast scan direction (correction in slow scan direction). Scanning patterns or .	Coefficient *c* of the cubic polynom function correcting piezoscanner motion along Y axis at descending bits and setting Y axis as fast scan direction (correction in fast scan direction). Scanning patterns or .

It is necessary to note that after selection in panel ***Calibrate AFM Data*** (Fig. 6.3) one of functions for nonlinearity correction, the system stops using of parameters *X range, nm* and *Y range, nm* in the parental panel and calculates necessary values from the data described in corresponding correction model.

After finishing work and saving the obtained AFM images in files you can process, visualize and analyze the results with the AFM image processing software. For the files obtained with AFM NT-206 it is recommended to use SurfaceView software.

APPENDIX 1 Schematic diagram of AFM NT-206 control electronics



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