Chapter 2: AFM Hardware

1. Description

The Nanotec AFM mechanical system can be divided into two main parts, the chassis and the head. In the following images, a general view of the different components is provided. Labels provide a description of the different components:

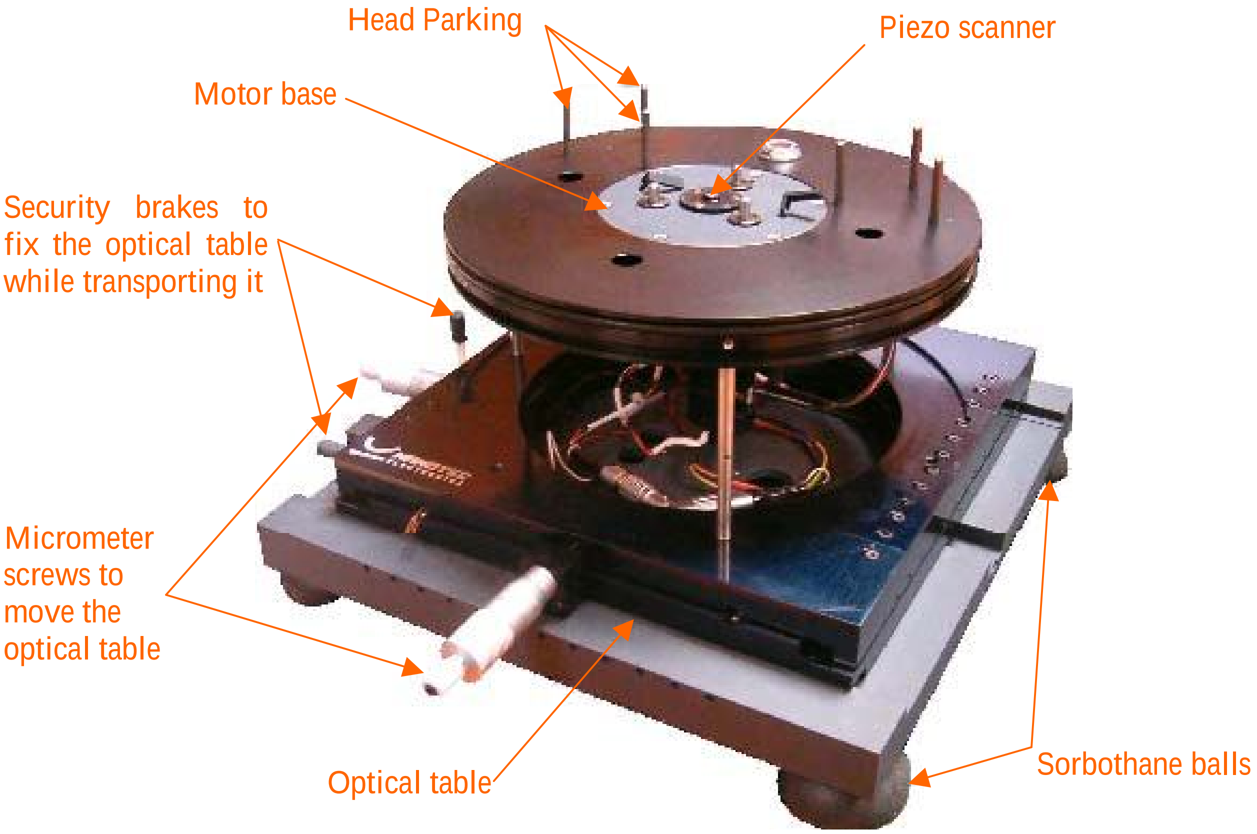


Fig.2.1 Chassis

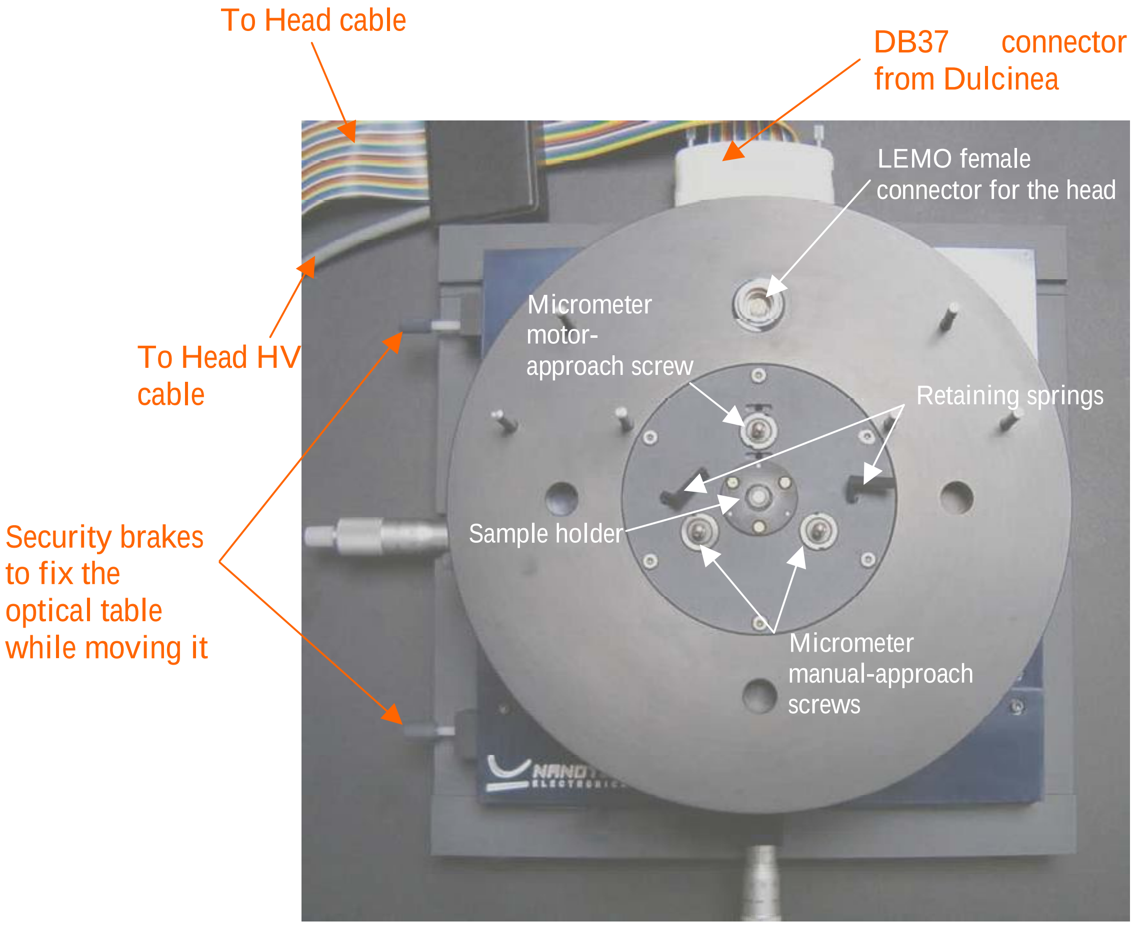


Fig.2.2 Chassis top view

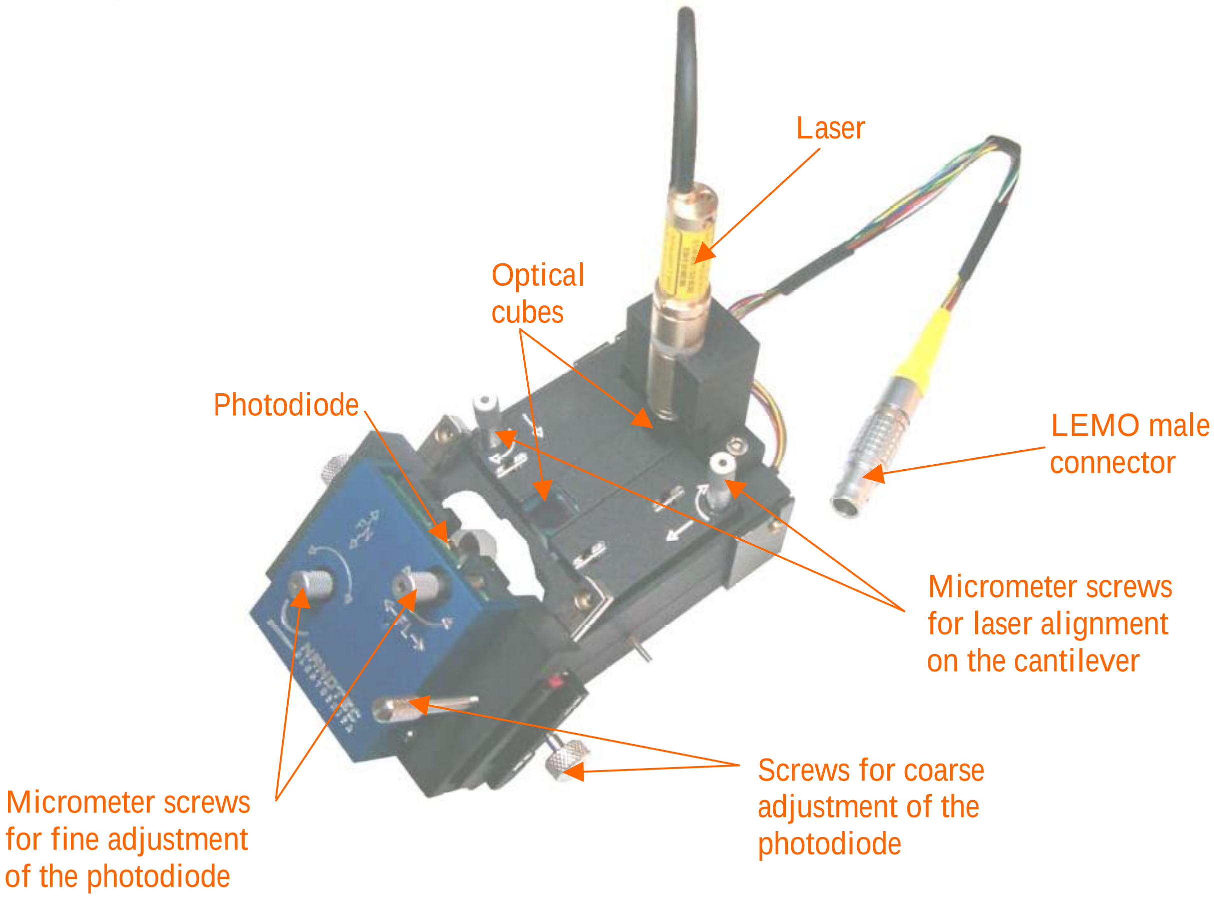


Fig.2.3 SPM Head

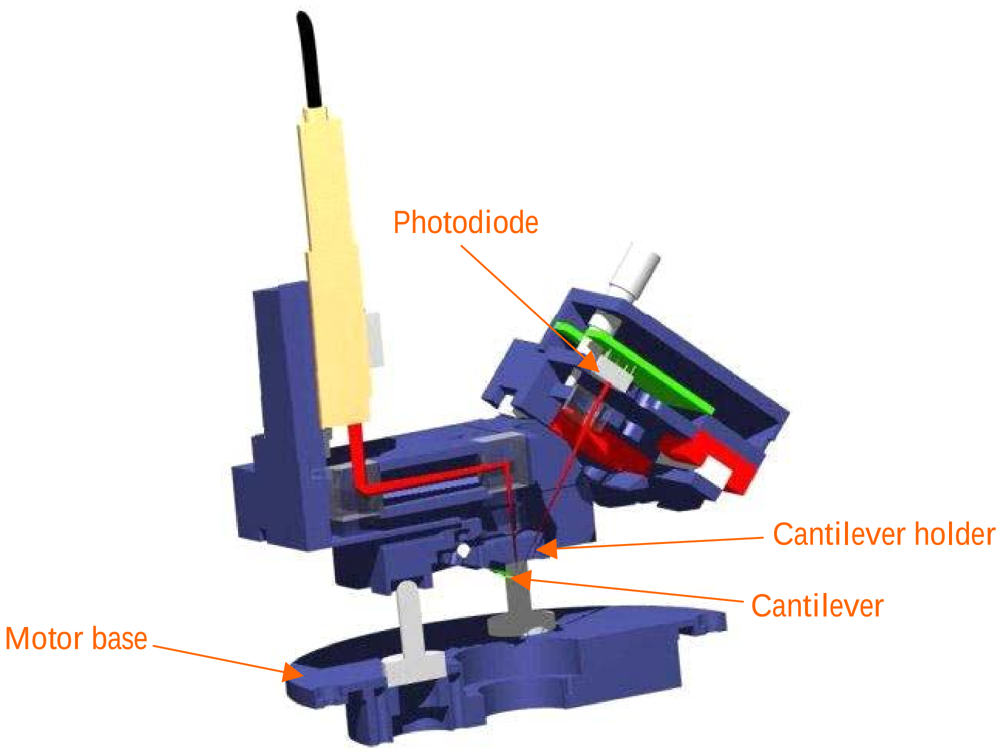


Fig.2.4 SPM Head cutaway view. Detail of the SFM head showing the laser path through the optical system (in red)

Fig.2.5 Piezo scanners (long and short)

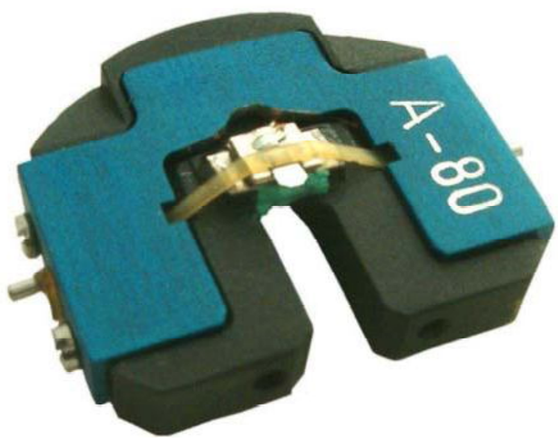


Fig.2.6 Cantilever holder

A glass cover (bell jar) is provided with the system to reduce acoustic and environmental noise, as well as to perform atmosphere control.

Fig.2.7 Glass cover

The Cantilever Exchange Bay (CEB) is a metallic base and fork designed for easy placement and removal of cantilevers.

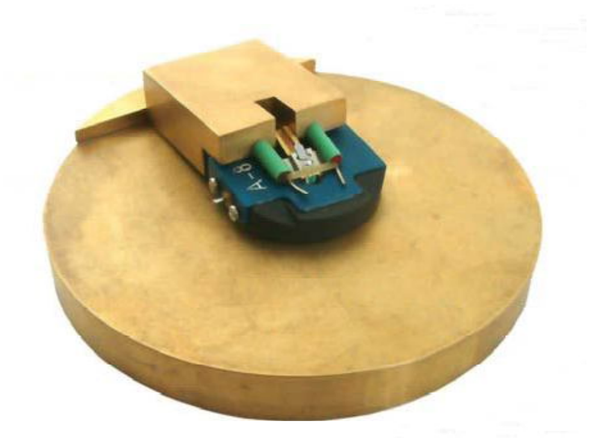


Fig.2.8 Cantilever exchange bay (CEB)

Other elements which are not shown in the images:

- Metallic cover for the chassis (you will see it in Fig.2.12).
- Standard cantilevers for starting up.
- Silver paint and scalpel to fix/remove the cantilever on/from the cantilever holder, in case you prefer this method instead of the mechanical one.
- Rubber strips for cantilever fixing
- Computer with DSP inside and computer monitor. CD with WSxM software and DSP drivers (already installed)

Once you have mounted a cantilever, you can place the cantilever holder in the head, as shown in the next image. Two magnets will hold it at the right position. (In case of MFM, there are no magnets, the cantilever holder is fastened by two clamps).The three ball system ensures a good stability for the cantilever holder.

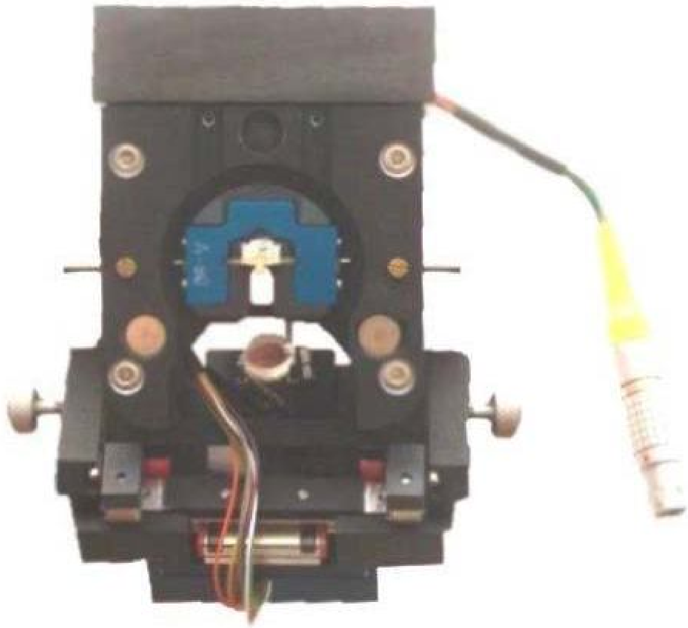


Fig.2.31 Cantilever holder in the head

- Finally, once you have properly assembled the AFM system (computer, Dulcinea and the hardware), you can check that everything is properly connected by switching on the system, running WSxM, turning On/Off the laser in the Photodiode Menu and moving the motor up and down with the commands Withdraw/Approach in the Approach Menu. To do this, follow these instructions:

1. Turn Dulcinea electronics on and run WSxM. You will find the following options:

Fig.2.32

2. Select the Data Acquisition option by pressing . Then the following icons will appear:

Fig.2.33

3. Check that the parameters of the system you are going to work with are suitable. For that, click on .

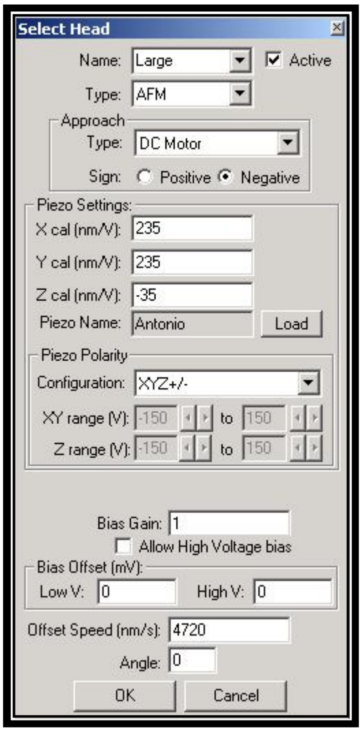


Fig.2.34

Select the piezo you are using, changing the calibration values if necessary. Your piezos have been calibrated at Nanotec, and the calibration values are written on a label attached to the piezo cables. (Please check that the sign of *Zcal* is correct. For Dulcinea users, it must be negative). The motor you have is a DC motor, Sign: Negative.

Make sure that the checkbox **'Active' in the top of the window is checked** before exit. If this box is not activated, your changes will not be updated.

Now click "OK".

Then press GO and Dulcinea electronics will initiate, enabling the rest of the menus:


Fig.2.35

4. Turn on the laser by clicking on . The Photodiode Menu will appear:

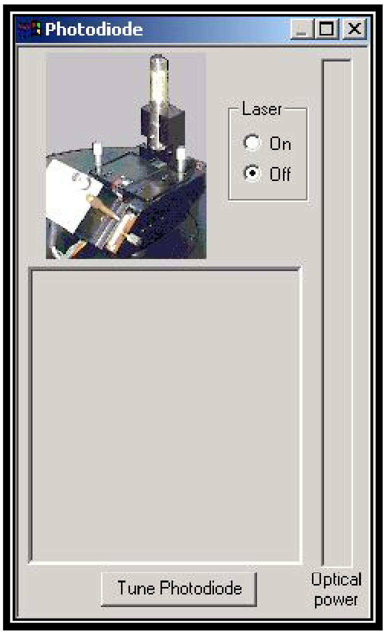


Fig.2.36

- Select *On* to turn it on. The laser should turn on. To turn it off, select *Off*.

5. Select the *Approach Menu* by pressing . You will see the window shown in Fig.2.37:

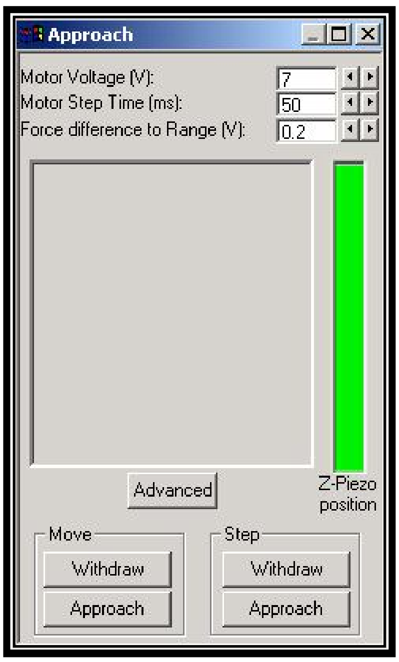


Fig.2.37

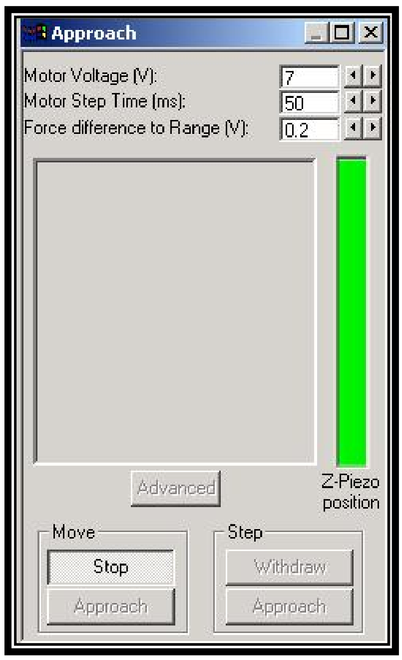


Fig.2.38

The *Approach Menu* controls the motor. There are two options, *Move* and *Step*.

Move: the screw rotates in a continuous movement.

- *Step*: the screw rotates in a discrete way, with short displacements in each ‘step’.

Press Move/Withdraw and the motor should start moving, raising the screw. To stop it, the Move/Withdraw button will change into a Stop button (see Fig.2.38). If you press Stop, the motor will stop.

While withdrawing, if the motor goes down (then it is approaching), it means that probably the motor connection (see Fig. 2.10) is connected the wrong way, so check it.

If the laser and/or the motor do not work, stop the acquisition, pressing 

. In Dulcinea electronics a shutdown message will be received, then turn it off.
Check all the system connections and make sure all of them are firmly fastened, especially the DB37 connector on the base of the hardware (see Fig. 2.13).

Repeat the above process and try again. The laser and the motor should now work.

- To finish with the AFM Hardware, we will discuss how to use the Retaining Springs (see Fig. 2.2).

Once you have placed a sample on the sample holder, you will position the AFM head (with the cantilever holder and a cantilever) on the micrometer approach screws (see Fig. 2.2). At this time, you have to use the Retaining Springs to fix the head to the chassis. These springs act as a final antivibration measure.

With one hand take the head, while with the other take a retaining spring, as shown in the next image:

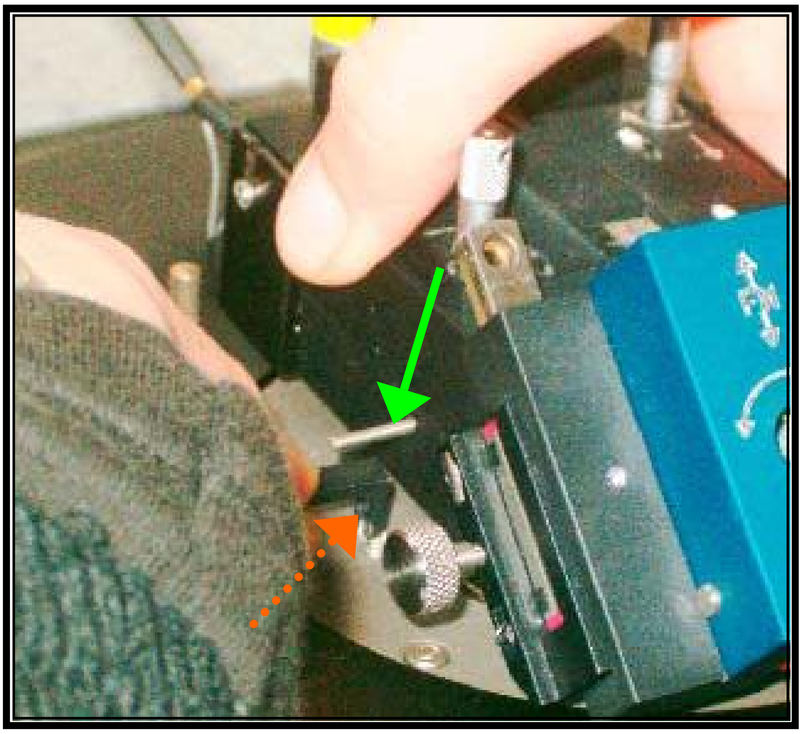


Fig.2.39

You will notice that the handling piece of the retaining spring, the L-shaped one, has a hole (see dotted arrow in Fig.2.39). You have to place the head side screw (see continuous arrow in Fig.2.39) in the retaining spring hole, as shown in the next image:

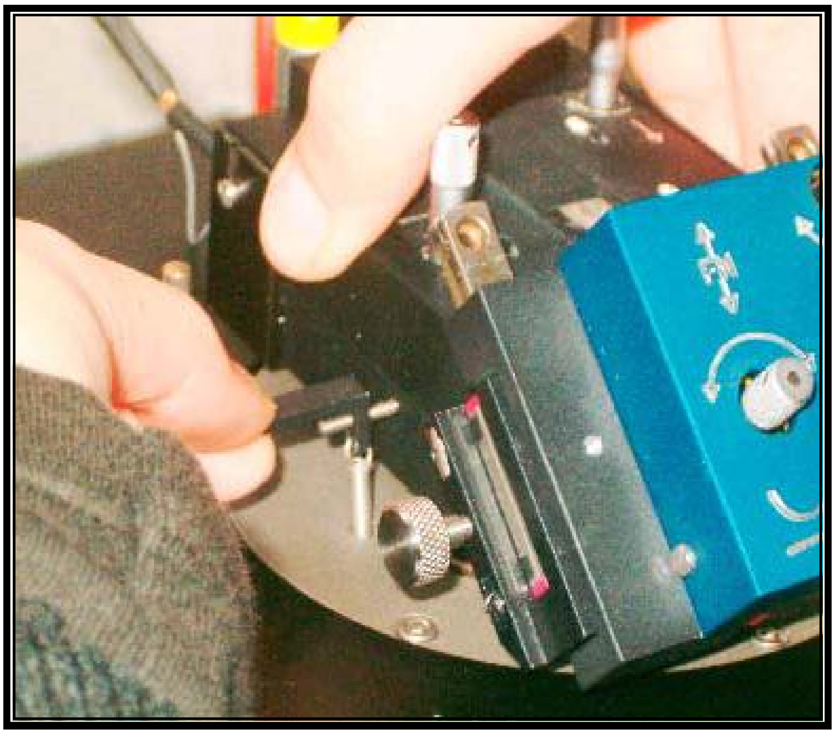


Fig.2.40

After placing one of the Retaining Springs, do the same with the other spring.

NOTE. While you place the first retaining spring with one hand, with the other one hold the head. If you are using a MFM head you have to be more careful. In this case, the head has no magnets, so it is not magnetically fixed to the chassis. When placing the Retaining Springs, while you place the first one with one hand, always hold the head with your other hand, and after placing this first retaining spring, do not let go of the head until placing the other one.

3. Safety instructions

If you have an optical table, remember to slacken the optical table brakes, in order to move the optical table with the micrometer screws.

Be very careful while placing (or changing) the piezoelectric scanner. It is one of the most fragile parts of the system.

Never try to disassemble any mechanical hardware or electronic component of the system without previous authorization from the manufacturer or authorized representative.

The micrometric motor-approach screw in the chassis (see Fig. 2.2) can also be moved by hand after pushing down the motor. If you move it in this way, make sure that after the movement the white, plastic coupling piece is perfectly aligned, otherwise, the micrometer screw will not move with the motor.

The AFM head can be safely handled as shown in the next figure:

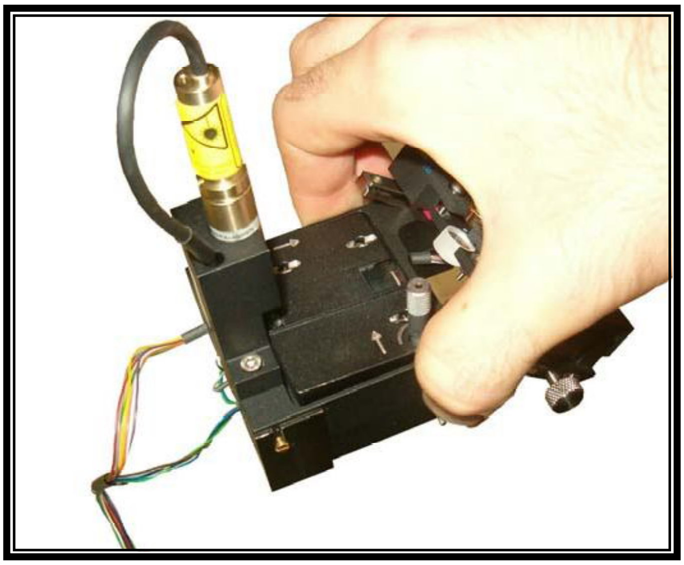


Fig.2.41. Handling the AFM head

Do not touch the optical parts in the AFM head (optical cubes, laser, photodiode…). Take special care not to touch the laser or its cable, since this might cause misalignment. It is also advisable not to touch the micrometer screws after you have positioned the laser on the cantilever and performed the photodiode tune.

If you use silver paint to fix the cantilever to the cantilever holder, do not use liquids to clean the silver paint from the holder. Particles of silver paint could get between the different parts of the holder producing undesired electrical contacts.

Chapter 4: First Use of the System

STARTING WSxM

1. Before turning on Dulcinea electronics, put the sample on the magnetic support of the piezo (or non magnetic sample holder in MFM case).

2. Make sure the height of the micrometer support screws is enough to hold the head above the sample without crashing the cantilever. Place the cantilever chip in the cantilever holder and then insert the cantilever holder into the head (see Chapter 2).

3. Turn Dulcinea electronics on and run WSxM. You will find the following options:

Fig. 4.1

4. Select the Data Acquisition option by pressing DA. Then the following icons will appear:

Fig. 4.2

5. Check that the parameters of the system you are going to work with are suitable. For that, click on .

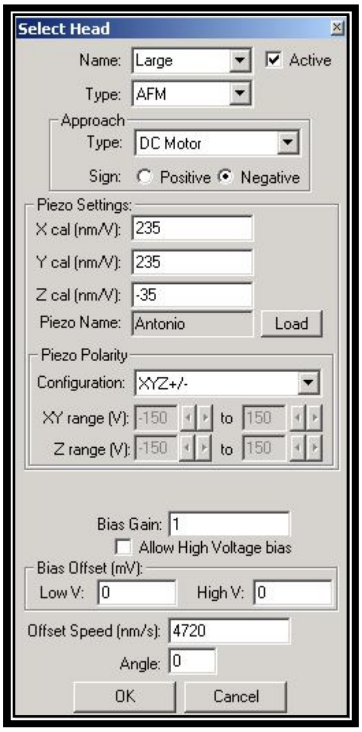


Fig. 4.3

Select the piezo you are using, changing the calibration values if necessary. Your piezos have been calibrated at Nanotec, and the calibration values are written on a label attached to the piezo cables.
(Please check that the sign of *Zcal* is correct. For Dulcinea users, it must be negative). The motor you have is a DC motor, Sign: Negative.

Make sure that the checkbox **'Active' in the top of the window is checked** before exit. If this box is not activated, your changes will not be updated.

Now click "OK".

Then press 

and Dulcinea electronics will initiate, enabling the rest of the menus:

Fig.4.4

LASER ALIGNMENT AND PHOTODIODE TUNE

6. Turn on the laser by clicking on . The Photodiode Menu will appear:

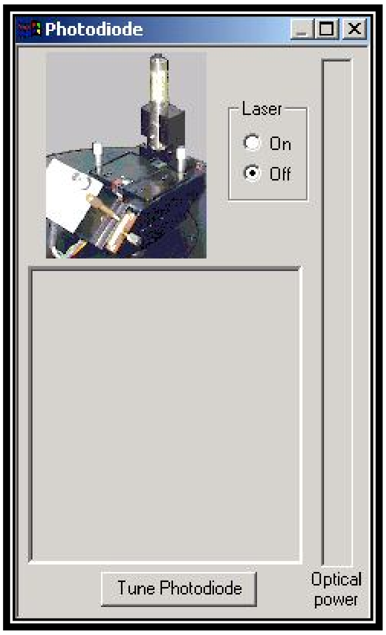


Fig. 4.5

Select *On* to turn it on.
Adjust the laser beam to be focused on the cantilever by using the micrometer screws closest to the laser (screws #1 and #2 in Fig. 4.13). You will know when the laser beam is falling on the cantilever because the typical diffraction pattern will appear.

To align the laser and to tune the photodiode, place the SPM Head on the Head Parking supports (see Fig.4.6).

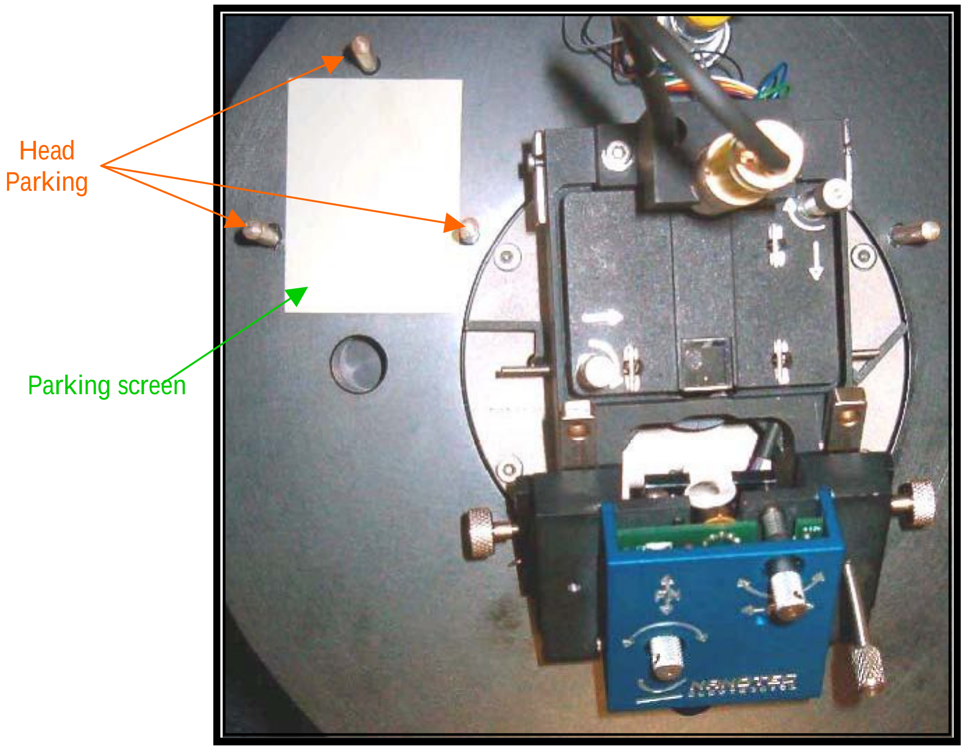


Fig 4.6

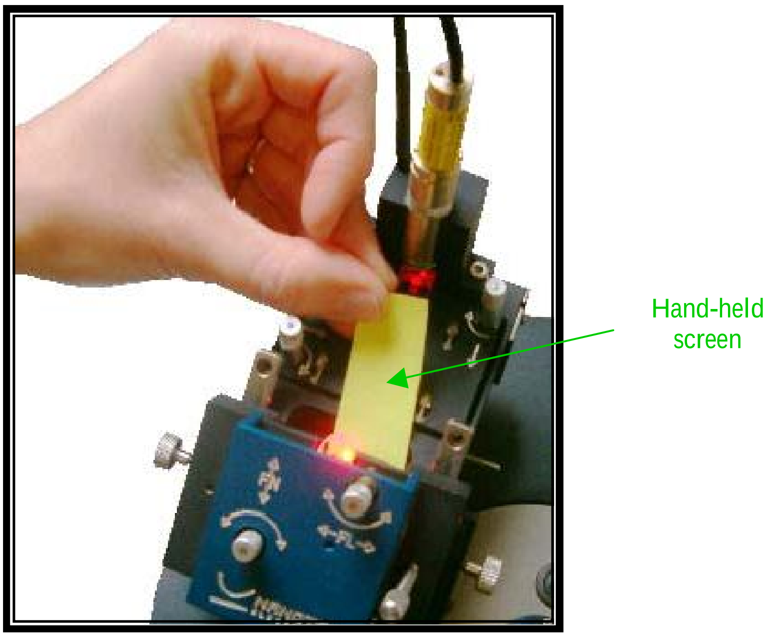


Fig. 4.7

Now follow these steps:

Place the laser beam on the chip which contains the cantilever, you will see just a diffuse red light on the parking screen and the shadow of the chip cantilever (Fig.4.8).

The approximate dimensions of the cantilever chip's shadow are 2 x 3 mm^2.

Then, move the laser beam along the chip (parallel to the cantilever, use screw #1, see Fig. 4,13) until arriving and surpassing the edge of the chip. You will know when you surpass it because you will see a clear spot under the cantilever holder (Fig. 4.9) (it is advisable to place a 'paper screen' at the base of the Head Parking, as shown in Fig.4.6).

Once the laser beam is beside the edge of the chip, move it perpendicular to the cantilever with screw #2, searching for the cantilever until you find its diffraction pattern.

To make the final adjustment, you can use a little piece of paper (Hand-held screen), placed as shown in Fig.4.7 to visualize the diffraction pattern. Move the laser perpendicular to the cantilever length (use screw #2) until it is positioned in the middle of the cantilever (diffraction pattern with maximum intensity). Then move the laser beam along the cantilever length (use screw #1) until the spot is at the edge of the cantilever (you will notice that because the diffraction pattern gets distorted, with 'rings' appearing in addition to the maximum).

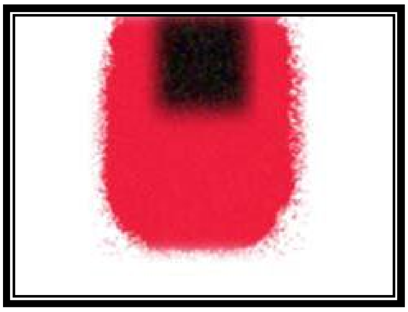


Fig. 4.8

Fig. 4.9

The next three diagrams shows an approximation to the diffraction patterns corresponding with the most usual cantilever geometries. Diffraction patterns for three of the most common cantilever geometries are shown.

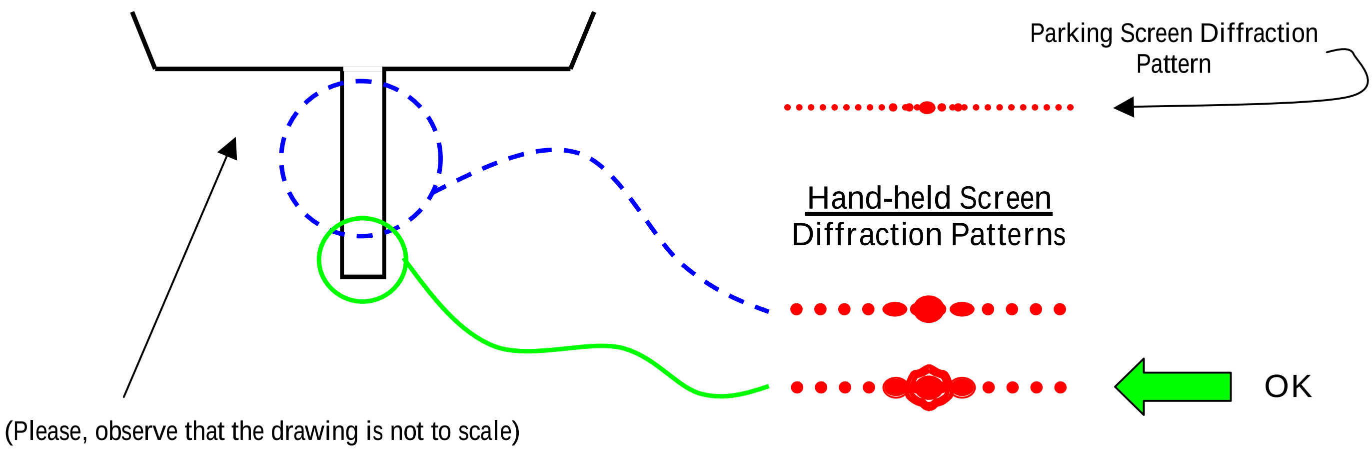


Fig. 4.10

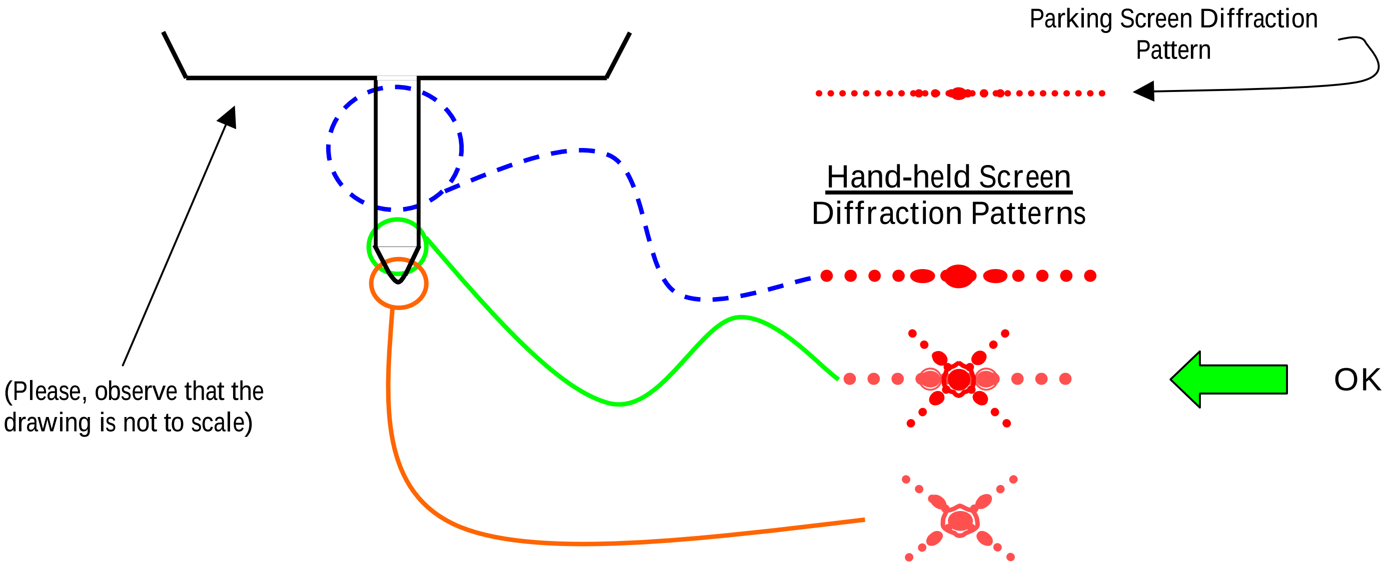


Fig. 4.11

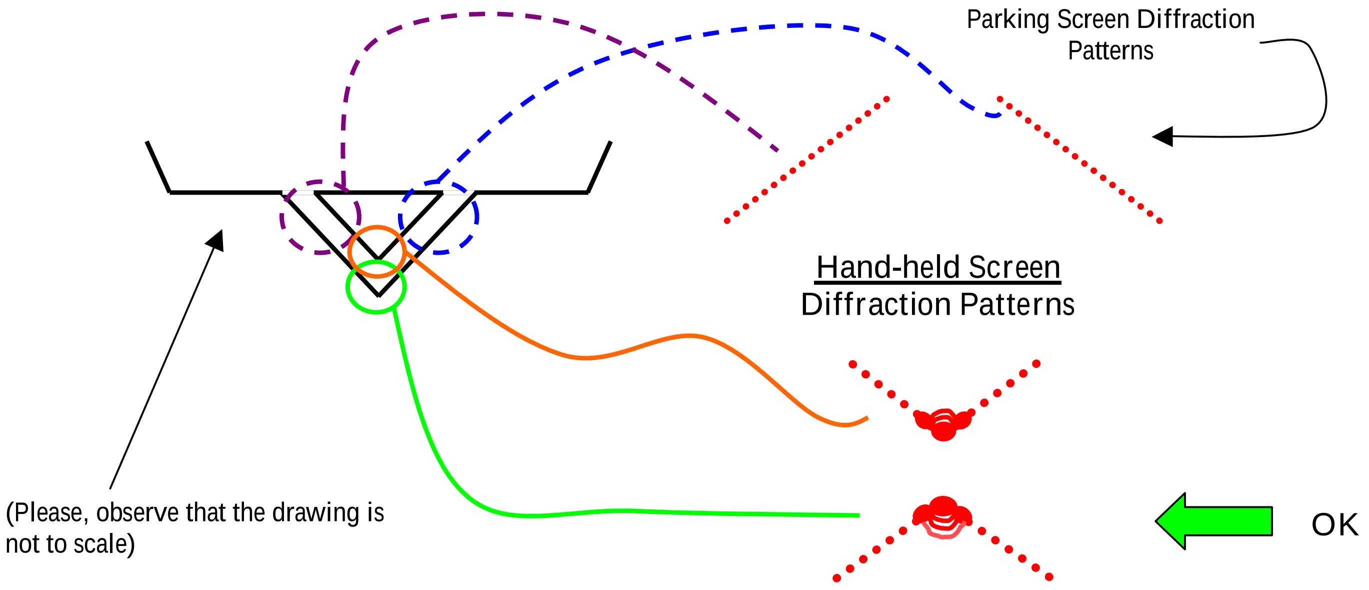


Fig. 4.12

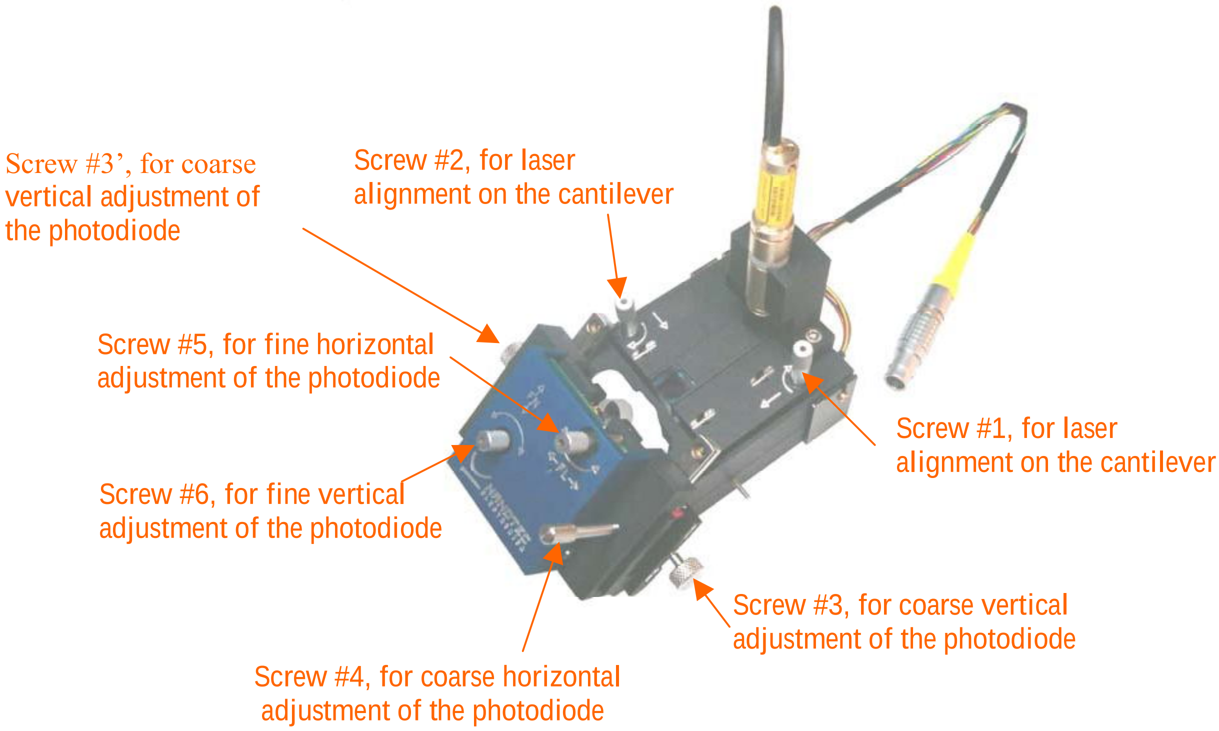


Fig. 4.13

7. Adjust the photodiode position in such a way that the laser spot reflected from the cantilever is centered on the photodiode. To do this click on Tune Photodiode.. A window to help you align the photodiode will appear.
   Two screws control the coarse movement (vertical movement, screws #3 and #3’, and horizontal movement, screw #4). The other two screws (horizontal movement, screw #5, and vertical movement, screw #6) control fine movement. The coarse movement allows you to position the whole photodiode holder with your hands (see Fig.4.15). The blue bar labeled Optical Power must be as high as possible and the red cross must be centered inside the blue square. Note that, when having some optical power, the green cross appears when the red cross is inside the blue square (see Fig.4.16). The green cross is a magnified view of the red cross.

   With the fine movement screws you can precisely adjust the photodiode making the red and the green crosses coincide by using screws #5 and #6 as shown in Fig.4.17.
   After this process, the blue bar in the Photodiode Menu, which corresponds to the total Optical Power, should be as high as possible (usually at least over the mid point) and the crosses in the photodiode window should be centered.

   (Do not worry if you do not have the maximum Optical Power. It depends on the laser adjustment, the optics in the head and the cantilever you are using, since they have different backside coatings)

NO INTENSITY

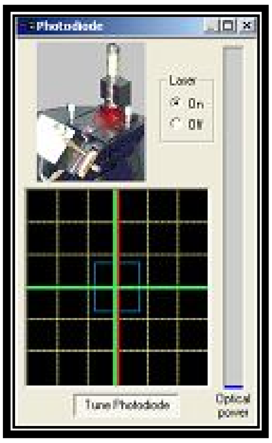


Fig. 4.14

BAD

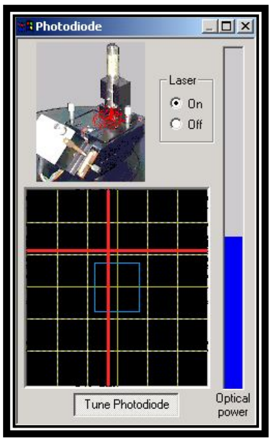


Fig. 4.15

BETTER

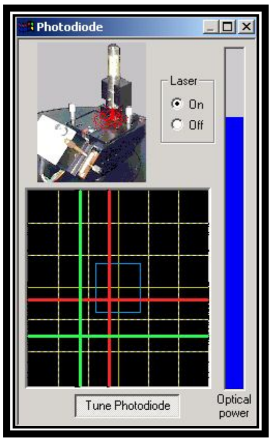


Fig. 4.16

BEST

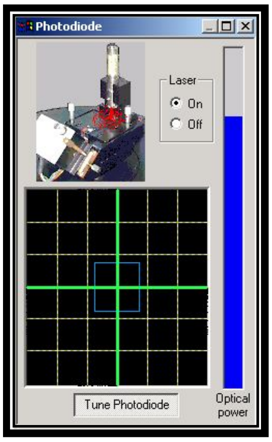


Fig. 4.17

(Notice in Fig 4.14 that if you do not have signal in the photodiode, red and green crosses appear centered, but you know there is no signal because there is no blue bar)

HEAD POSITION AND MANUAL APPROACH

8. Turn *Off* the laser (by clicking Off in the Photodiode window) and place the head above the sample (the head fixes to the support screws magnetically unless you are using a MFM). Make sure not to touch any head micrometer screws, in order not to change the previous laser tune, and also make sure not to crash the tip. If there is any doubt about crashing, raise even more the support screws before placing the head. Once it is placed, you can fix the head with the two L-shaped parts anchored to the base with springs (Retaining Springs, see Fig.4.18). Three micrometer screws placed in a triangular pattern make the head support, (see Fig. 4.18). The two screws at the front can be moved by hand, while the other is motorized and controlled through WSxM (but it can be also moved by hand, pushing the motor down with one hand and moving the screw with the other. If you move it in this way, after the movement, make sure the motor is well coupled to the micrometer. If not, the motor will not move the micrometer).

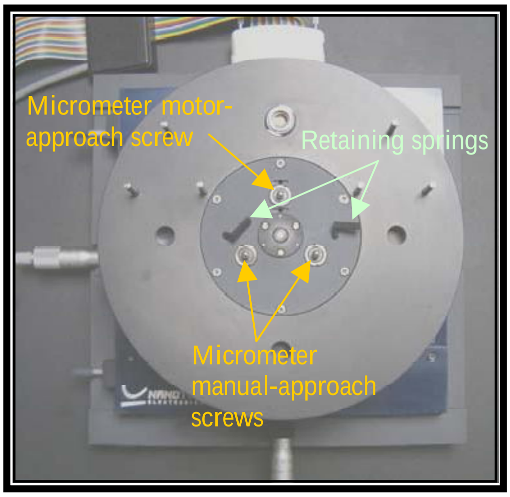
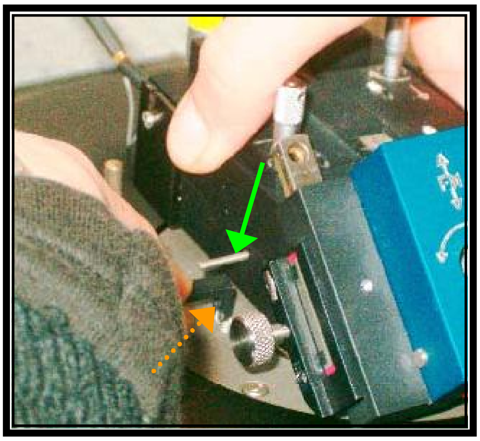


Fig. 4.18

To fix the Retaining Springs, follow the next instructions:



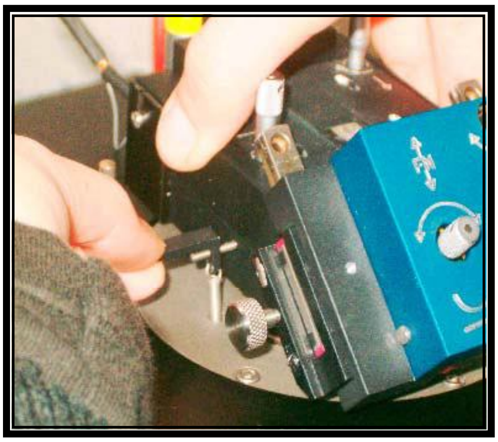


Fig. 4.19 With one hand steady the head, while with the other hold a retaining spring. You will notice that the L-shaped piece of the retaining spring has a hole (marked by the orange dotted arrow). You have to place the L-shaped piece into the side screw (marked with a continuous green arrow), using the retaining spring hole.

Fig. 4.20 After placing one of the Retaining Springs, do the same with the one on the other side.

NOTE. While you insert the first retaining spring with one hand, with the other hand you must hold the head. If you are using a MFM head you have to be more careful. In this case, the head has no magnets, so it is not magnetically fixed to the chassis. After placing the first retaining spring, always hold the head with the other hand, do not let go of the head until placing the second retaining spring.

9. Once you have secured the head, use the two manual screws to approach tip and sample until they are close, but without crashing. It is advisable to move them with your thumbs, as shown in the next images (see Fig.4.21 and 4.22). If you turn the screws clockwise the head will approach to the sample and if you turn them in the other direction the head will withdraw.

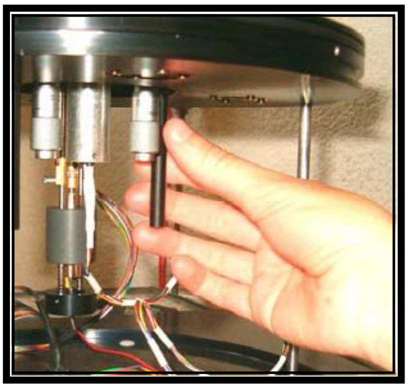


Fig. 4.21

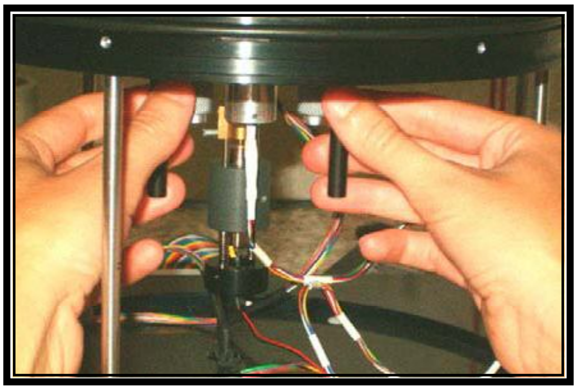


Fig. 4.22

10. Turn on the laser and check again the photodiode position. Once it is tuned, cover the AFM head with the glass cover.

Fig. 4.23

APPROACH IN DYNAMIC MODE

11. Select the Dynamic Menu by pressing . Then the following window will appear:

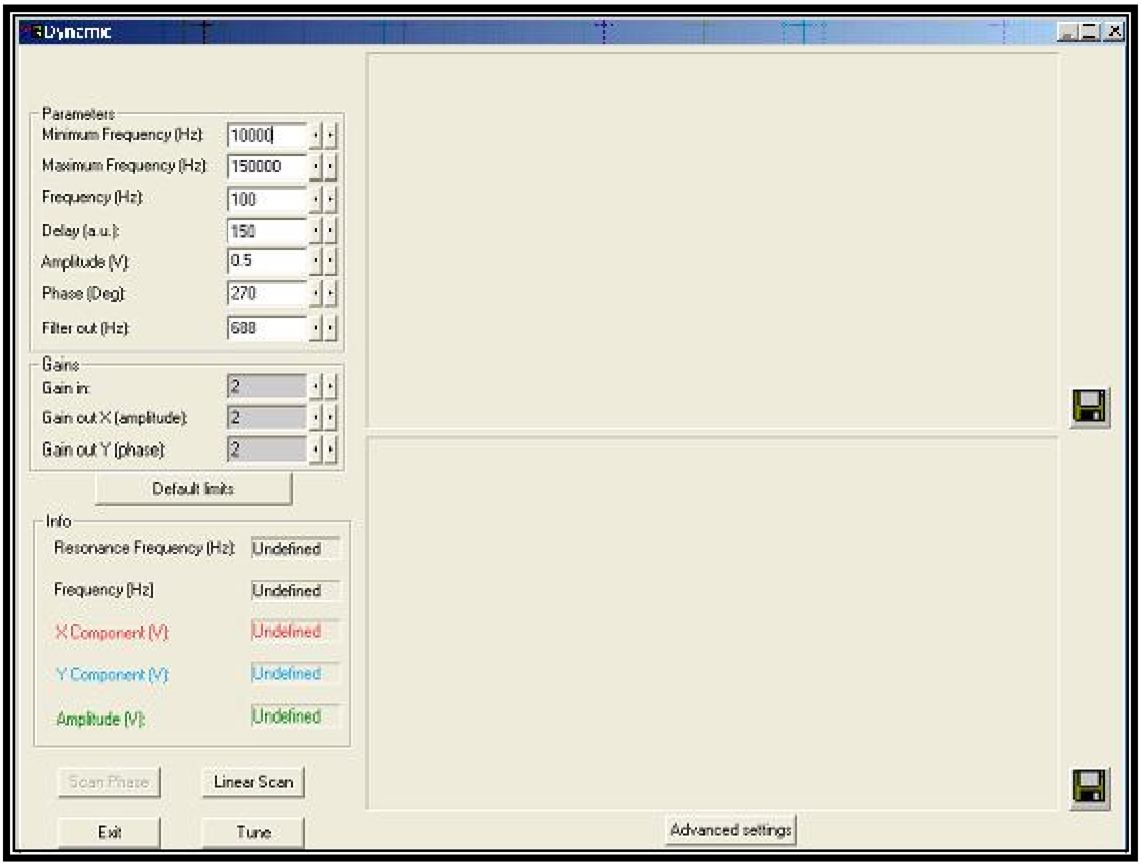


Fig. 4.24

12. Check that the parameter values are the proper ones for your cantilever and if not, change them.

> Usually, cantilever manufacturers specify the applications for each cantilever. While soft cantilevers (< 1 N/m) are commonly used in Contact mode, in some cases they can also be used in Dynamic modes.

The most important parameters are the Minimum and Maximum Frequencies, the Amplitude of the voltage applied to the cantilever driving piezo and the Delay. Briefly, the delay is the number of times the amplitude of the cantilever at the resonant frequency (X component) and its phase (Y component) are measured to obtain an average value.

You should know roughly the value of the resonance frequency of the cantilever you are using. In this way you can fit the limits of the frequency searching interval (Minimum and Maximum Frequencies) in a rational way. For example, for a cantilever with f $\cong$ 71 kHz (and k < 1 N/m), the default values in the

dynamic window should be OK (we will refer to this cantilever in following examples as cantilever_1). However, for one with f 250 kHz (and k 40 N/m) (cantilever_2 in following examples), you have to change, at least, the Maximum Frequency to, for example, 450000 Hz.
Another important parameter is the Amplitude of the voltage applied to the cantilever driver piezo. You have to select a value in order to get a reasonable resonance peak (see Fig.4.25b). It is recommended to start with a low value (0.25 V) and increase/decrease it if necessary, depending on how much you want the cantilever to oscillate. If the amplitude of the cantilever driving piezo is too large, your resonance peak would resemble that shown in Fig. 4.25a.
The other important parameter is the Delay. The system needs some time to perform a good dynamic tune. It is advisable to place a Delay value higher than 150.

(To learn more on Dynamic Mode, see Appendix A)

13. Once you have set the parameters discussed above, press Tune and WSxM will search automatically for the resonance frequency of the cantilever. The next figure shows two images as an example. The one in the left corresponds to a saturated resonance peak and the one in the right to a non-saturated resonance peak.

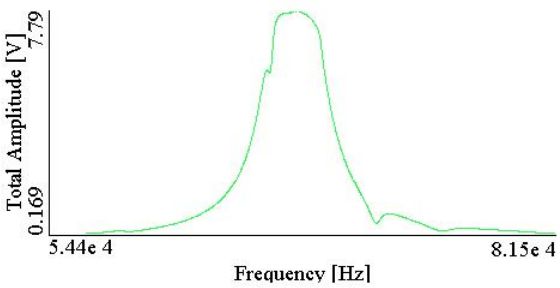


Fig. 4.25a

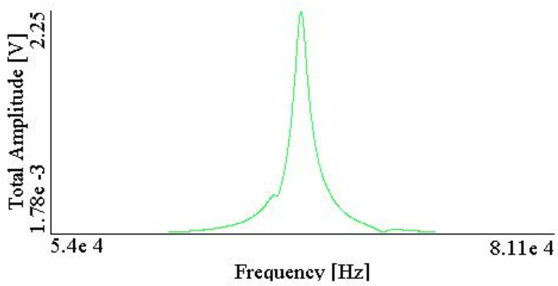


Fig. 4.25b

NOTE. The optimal Total Amplitude value for the cantilever to oscillate will depend on many parameters, including sample roughness and the selected cantilever. If the sample is very flat, you can usually use a small value, but if it is rough you should use larger ones (typical values range from 0.2 V to ≈ 5 V). It is advisable to use the lowest input Amplitude possible to avoid instabilities. To implement this, you can adjust the Gain in located in the dynamic window (see Appendix A).

Once you have found the cantilever's resonance frequency, check that it is similar to the expected value and exit the Dynamic Menu.

Once Dynamic Menu is closed, while measuring, you can see and change the Dynamic parameters by pressing the button (see Fig. 4.26, Dynamic Settings).

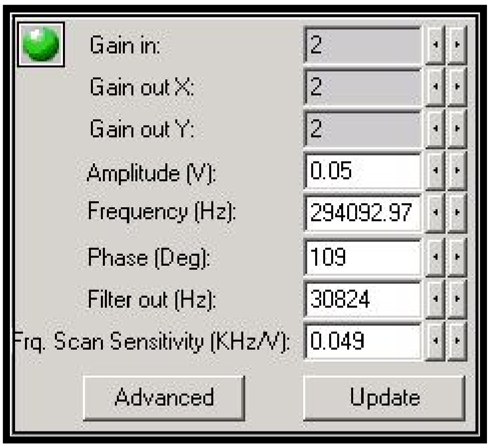


Fig. 4.26

14. In the Control Menu (see Fig. 4.27. This menu is usually already opened, button), insert the scanning Frequency (Freq (Hz)) and the Number of Points in one scan line.

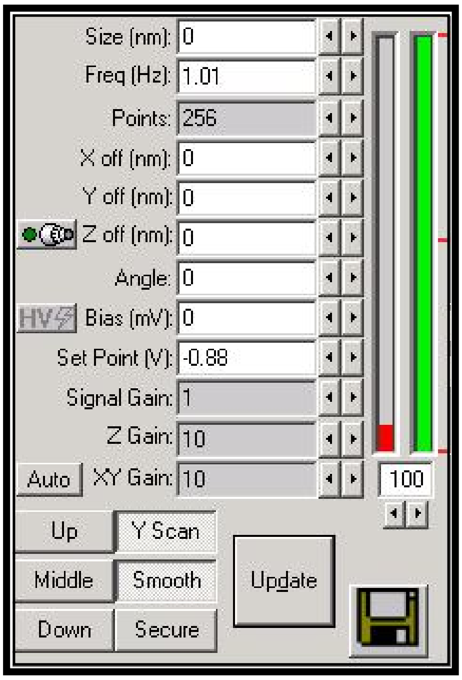


Fig. 4.27

- As a general rule, set the initial Frequency to 1 Hz and the Number of Points to 256 (Fields colored in grey must be changed using the arrows on their right. Some fields can be changed and the new value will be directly updated, and in other fields, when changing the value, the background turns yellow. When this happens, they must be updated by first pressing the Update button (or Enter key on the keyboard)).

(To learn more about the other parameters in Control Menu, see Appendix B)

15. In the Scan Options Menu (see Fig. 4.28. This menu is usually already opened, button ). Select *Dynamic* among the possible measurement modes. In case none of them is selected, the system will work in Contact Mode. The final configuration should be: *Dynamic: Yes*, *Jumping: No* and Retrace*: No*.

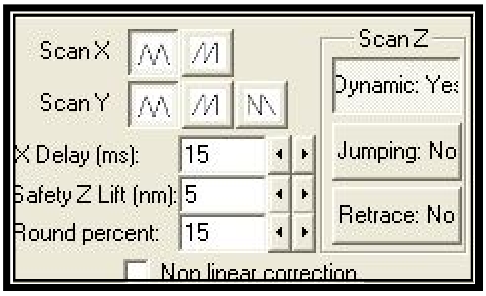


Fig. 4.28

Wait a few seconds to give time for the system to change into Dynamic Mode, and press Update in the Control Menu. Then the values of the different channels will be updated in the Channels Values Menu. This menu is usually already opened. If not, you can see it by pressing  (see Fig. 4.29).

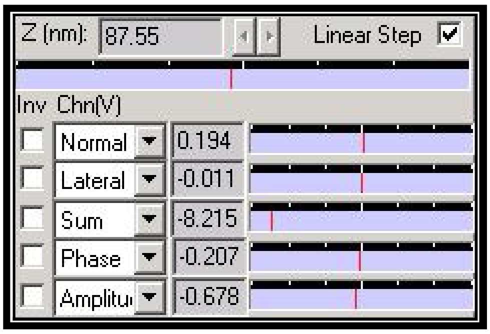


Fig. 4.29

- The Set Point value in the Control Menu (Fig. 4.27) will be used by the feedback system to control the tip-sample distance. In Dynamic Mode, the feedback channel is the Amplitude of the cantilever oscillation, CH15 (you can see it in the Feedback Menu, Fig. 4.30). The system keeps it constant, by comparing the Set Point value with the value from CH15 (you can see it in the Channels Values Menu, Fig. 4.29), changing the tip-sample distance to keep the Amplitude constant.

  To set an initial value for the Set Point, before approaching, check the Amplitude value (channel 15, CH15) in the Channels Values Menu (see Fig. 4.29).

  When you approach to the sample, the oscillation amplitude will decrease due to the tip-sample interactions but also due to the cantilever-sample interactions (the latter is a long range interaction with a low variation with the distance. For some cantilevers, this interaction can produce false stopping points when approaching). That is why you have to put an initial Set Point value lower than the amplitude shown in CH15, this implies a Set Point value closer to 0 than that found in CH15.

- If you are using a cantilever similar to cantilever_1, the initial Set Point value should be around 1/2 the initial value in CH15.
- If you are using a cantilever similar to cantilever_2, the initial Set Point value should be ≈ 3/4 the initial value in CH15.

16. In the Feedback Menu (see Fig. 4.30. This menu is usually already opened, button). Insert feedback parameters P and I (Proportional-Integral). As a general rule, take P = 20 and I = 10 as initial values.

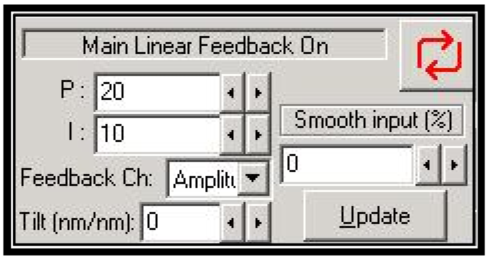


Fig. 4.30

17. Selecting the images to display.

- In the Viewer Options Menu (see Fig. 4.31. This menu is usually already opened, button). You will have:

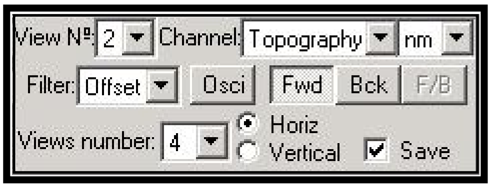


Fig. 4.31

The next figure summarizes (Fig. 4.32) the above discussion by showing a typical configuration for the screen with the most important menus opened.

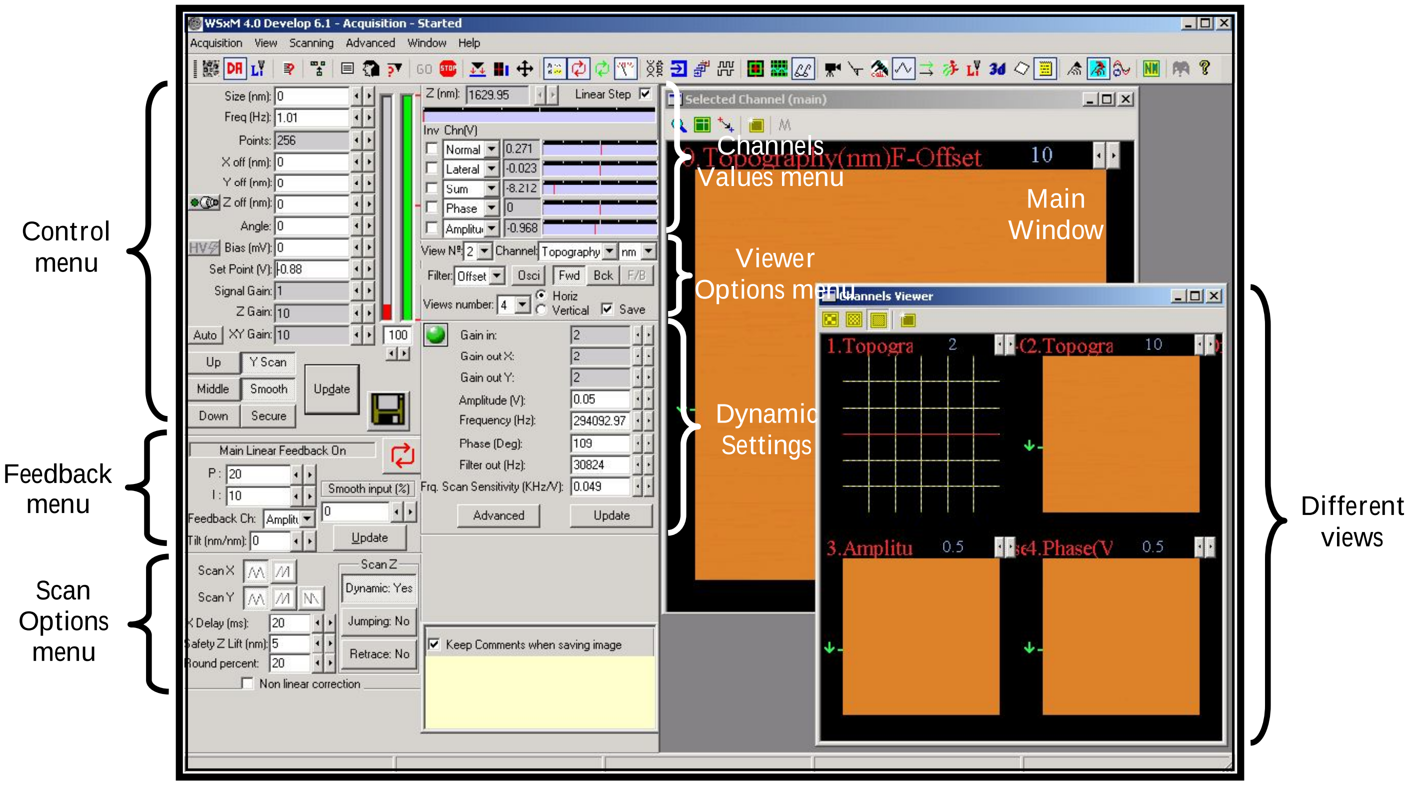


Fig. 4.32

In the Viewer Options menu, for each image, as initial settings, select the options shown in Fig. 4.32 (you can display the parameters controlling each view in the Viewer Options menu by just clicking on the corresponding image). For example, in Fig. 4.32 the parameters for View Nº2 are the ones shown in Fig. 4.31.

As another example, for view Nº1 we have: Channel: Topo (topography), Oscilloscope mode On (button Osci pressed), and Fwd/Bck signals at the same time On (button F/B pressed). There are two traces, one for the left to right scanning direction (called Forward, Fwd, colored in blue) and the other one for the opposite sense (Backward, Bck, colored in red)).

To activate a particular view in the Main window (View Nº0), double click in the view and WSxM will take it to the Main window.

(You can learn more about viewer options and other menus in the WSxM software manual)

18. Now is the time to approach tip and sample. Select the *Approach Menu* by pressing . You will see the following window:

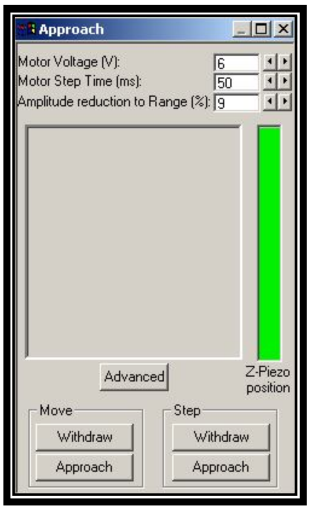


Fig. 4.33

The Approach Menu controls the motor. There are two options, *Move* and *Step*.

Move: the screw rotates in a continuous movement until it is "*in range*". The parameter to control the Move Approach option is *Amplitude reduction to range (%)*. You will change this value depending on the cantilever you are using and how careful you want to be while approaching. For example, with cantilever_1 it could be OK to use a value of 10% approximately, while with cantilever_2, which is more fragile than the other and usually has longer tips, a value of 5% should be OK. (For the latter case, since the tip is longer, the cantilever is further away from the sample while approaching, so the electrostatic interaction is lower, and almost all the amplitude reduction is due to the tip-sample interaction)

(As the amplitude will reduce constantly during the approach due to the long range cantilever-sample interaction, the *Amplitude reduction to range* tells the system to look for a sudden change of the Amplitude equal to that selected in this field)

Step: the screw rotates in a discrete way, with short displacements for each 'step'. The parameter to control the Step option is *Motor Step Time (ms)*. It is usual to use a value of 100 ms when tip and sample are still "far" and 50 ms when they are closer.

The other parameter you can change is *Motor Voltage (V)*, which controls the motor speed. It is usual to use a value of 6-8 V approximately.

19. Once the parameters are set, press Approach in the Move option. If Z Gain in the Control Menu is not 15 (the maximum one), WSxM will suggest you to change it to this value, to let the piezo move all the Z range if necessary. The screw will move until the tip is "in range". Then, the motor will stop and the piezo will extend/retract (you can notice this by looking at the vertical green bar shown in the Control menu and in the Approach Menu, which represents the Z-piezo displacement. If the piezo is fully extended, the green bar will be at its maximum. If the piezo is fully retracted, then the green bar will disappear. You will also notice it because there will be no topography Fwd/Bck traces).

How to know when the tip is close enough to the sample:
When the system is working properly, the Fwd/Bck traces should be similar. (At the beggining, before scanning (Size = 0), display the Topo view in oscilloscope mode with a viewing scale of 2 nm and Filter: Offset).
This means that the tip is close enough to the sample and the system has the proper feedback settings. Just after the whole approaching process, since the sample is not moving and the tip is just oscillating above the sample, there is no topography variation. This is why the Fwd/Bck traces should be flat and constant, equal to cero.

If the Fwd/Bck traces are not similar just after motor approach, you must make further adjustments. There is a number of possibilities to consider:

A- If the piezo is fully-extended (maximum green bar in the Control Menu and in the Approach Menu. You will also notice it because there will be no topography Fwd/Bck traces variation), continue to approach the tip toward the sample. For this,

- Use the Step option in the Approach Menu giving the necessary steps to center the green bar (it is advisable to get it centered while measuring because then the Z-piezo will move over the maximum range in both directions (up and down)).

- Increase the Set Point value (since it is negative, you have to change it to values closer to 0) until getting Fwd/Bck traces the same, reaching this state with a sudden flattening of them. If the piezo gets fully-extended again before the traces flattening, repeat the above process. When Fwd/Bck traces become equal, center the green bar by making step approaches. When the green bar is centered, close the Approach Menu.

B- If the piezo is not fully-extended, there are two possibilities:

- Fwd/Bck traces are flat and constant, having reached this state by the appearance of a sudden onset of flattening. The system is in the proper feedback range. Center the green bar by making step approaches/withdrawals and close the Approach Menu after the green bar is centered.

- Fwd/Bck traces are not flat and constant. Increase the Set Point value (since it is negative, you have to change it to values closer to 0). If Fwd/Bck traces get the same with a sudden flattening $\rightarrow$ OK, you are in the right conditions to measure. Center the green bar with step approaches/withdraws and close the Approach Menu. If the piezo gets fully-extended, go to case A.

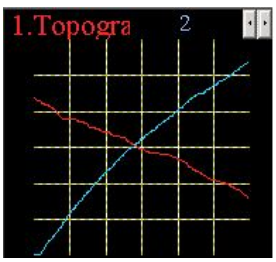


Fig. 4.34

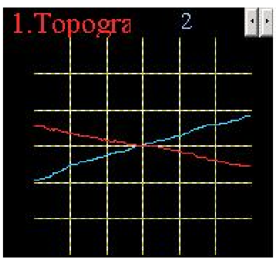


Fig. 4.35

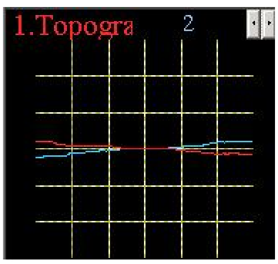


Fig. 4.36

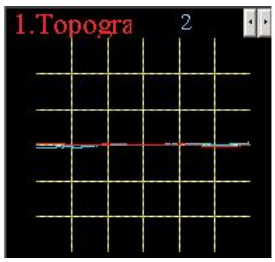


Fig. 4.37

Fig.4.34: after the motor Move approach stops, the system is 'in range', but tip and sample are not close enough.
Fig.4.35: after changing the Set Point and making some Step approaches, Fwd/Bck traces start to be flat and equal. Changing just a little more the Set Point will lead to a sudden flattening of Fwd/Bck traces.
Fig.4.36: Fwd/Bck traces after doing what has been said in Fig.4.35.
Fig.4.37: the system is in the proper feedback range, obtained after waiting one or two seconds from Fig. 4.36.

IMPORTANT: Once you have done the Motor Move Approach, then some Step Approaches and also some Set Point increments, if the system is not in the proper feedback range, you can set a scan size (for example 2000-3000 nm) and continue with the Approach. Instead of seeing a sudden flattening of Fwd/Bck traces, when the system gets the proper range you will see topography traces, which can be more visual to know when the tip is close enough to the sample.

NOTE. You can change the Set Point value directly, typing its value, but you can do it also using the arrows in the dialog box. You will get large value changes by clicking the arrow. To produce smaller changes, click the arrow while pressing SHIFT (or CRTL for even smaller ones). This is important, even more when you are very close to the right position between tip and sample, in order to achieve the proper Set Point value.
(All the parameters in WSxM can change in this way)

An alternative way of approaching tip and sample you can use in very special situations consists on increasing the Amplitude to the cantilever driving piezo, but this is a CRITICAL process. In case you do it, make sure you take low increments for the amplitude (for example, increments of 0.01 V and watching what happens).

Once you have the tip close to the sample, with Fwd/Bck signals equal and flat, it could happen that the green bar, which tells you how much elongated is your piezo scanner, is not centered. If the green bar is far away from the center and the Z Gain is 15 or 10, we do recommend to step the motor in the Approach Menu.

After scanning for a while, you may notice that the green bar has drifted from its centered position. You do not have to make Step approaches to re-center the green bar. Instead, you can use the Z offset (Zoff) in the Control Menu. There are two options, by software and/or by hardware.

To do it by hardware, first of all make sure the knob in Dulcinea is in the middle range ($\approx$ 5). Then enable the icon beside the Zoff, , and you will be able to center the green bar by turning the knob.

To do it by software, take a look to the Z values, on the top of the Channels Values Menu (see Fig. 4.29). This value is telling you the Z off in nm. Just add that number to your Z off and the green bar will be centered. As a general rule, anytime you want to center it, add the value you see in the Channels Values Menu to the current value placed in the Zoff dialog.

(For example, if Z value = -200 nm and you have a Zoff = 300 nm, to center the green bar you should place Zoff 100 nm)

APPROACH IN CONTACT MODE

20. In the Control Menu, set the initial scan Frequency to 1 Hz and the Number of Points to 256.

The Set Point value will be used by the feedback system to control the tip-sample distance. In Contact Mode, the feedback channel is the Normal Force, CH1 (you can see it in the Feedback Menu, Fig. 4.30). The system keeps it constant, comparing the Set Point value with the Normal Force value from CH1 (you can see it in the Channels Values Menu, Fig. 4.29), changing the tip-sample distance to keep the Normal Force constant.

To set an initial value for the Set Point, before approaching, check the Normal Force value (channel 1, CH1) in the Channels Values Menu (see Fig. 4.29). Since you have tuned the photodiode in the Photodiode Menu, making the red and the green crosses coincide, the Normal Force and the Lateral Force should be ≈ 0. Place the initial Set Point around 0.2-0.4 V, as shown in the next figure:

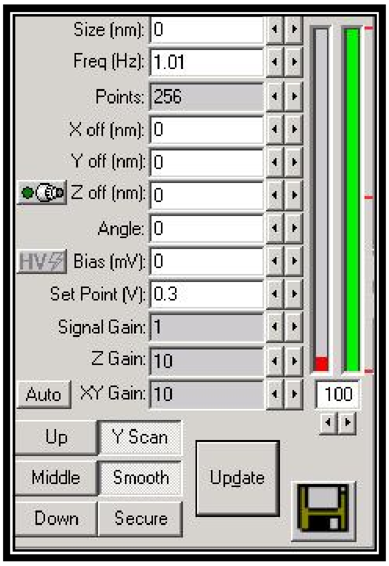


Fig. 4.38

21. In the Scan Options (see Fig. 4.39) select *Dynamic: No*, *Jumping: No* and *Retrace: No*. Then the system will work in Contact Mode.

(If you have not done a Dynamic tune, then the Dynamic Mode option will be disabled, as shown in the next figure).

In the Viewer Options (Fig. 4.31), for each image, as initial settings, select the options shown in Fig. 4.47. (How to do this is explained in step 17).

As you can see in Fig. 4.47, in Jumping Mode, the system is performing an F-Z curve at each point in the image. From this data it is possible to make Adhesion and Stiffness maps. This can be done by simply selecting Adhesion and Stiffness as channels to display.

29. Now it is time to approach tip and sample. The process is the same as in Contact Mode, so follow the instructions given in steps 23 and 24.

HOW TO ACQUIRE IMAGES

30. Once tip and sample are close enough and in the proper feedback range, start scanning. To do this, assign a value to the Size in the Control Menu (the resulting image will be a square, with the size you just specified equal to the length of one side).

It is advisable to start the scanning with the maximum Zgain, to allow the piezo to move over its entire range to avoid crashes. Enter a Size that is not too large (around 2000-4000 nm) by entering the proper parameters to obtain a reliable image before increasing the scanning Size.

It is very important to fit the value of XY Gain in the Control Menu to get the best resolution possible. Place the minimum XY Gain that WSxM allows. (Note that you can also use automatic XY Gain if you are using a Develop version of WSxM, then WSxM will do the work for you). You can learn more about the meaning of XY Gain, as well as the other Control parameters, by reading Appendix B.

You must understand that the Z Gain is also very important. Once you are scanning and obtaining images, it is very important to work with a Z Gain as low as possible to get the best possible resolution.

The Z values are monitored using an indicator bar in the Channels Values Menu (see Fig. 4.29). The width of this indicator bar displays the range of the data along the Z axis. If the indicator bar width is very small compared to the range of the scanner, you will observe an indicator bar that appears as a short vertical line (one-pixel in width, as in Fig.4.29). This means that your gain is large (you have a lot of extra range).

- To improve image quality you can, step by step, decrease the Z Gain. After each step, you will perhaps find out that you need to readjust the Z Offset.

- At one moment, you will see that the red vertical line for the Z value in the Channels Values Menu is not a line but a bar. As you lower the gain, the bar gets wider. That means that you are using a Z range comparable to the range of your data, so your image will be improved. Take care not to decrease the gain too much because this might move the tip out of range, you might obtain saturated data, or (much worse) you might crash your tip.

For more information about the XY and Z Gains, see Appendix D

31. In order to obtain good images you will need to adjust some parameters.

Dynamic and Contact Mode

The important parameters in these modes are Scanning Frequency (Freq (Hz)) and Set Point in the Control Menu, and the Feedback parameters P and I (Proportional-Integral) in the Feedback Menu (button).

- Increase/decrease the Set Point value to approach/withdraw tip and sample by piezo movements.
- You need to set a Frequency value which allows the system to react to the changes in the topography of the sample. Scanning frequency value is usually in the range from 0.5 to 2.5 Hz.
- In terms of Feedback parameters, first of all, it is usual to take $P = 2 \cdot I$ (but this is not a hard and fast rule). A higher value for the feedback (this means P and I higher) allows a faster response of the system. There will come a time, if these parameters are set too high, at which the system will begin to oscillate (in Dynamic Mode you can easily see this by looking at the Amplitude and Phase images, channels CH15 and CH16 respectively. In Contact Mode, it is useful to monitor channels CH1 and CH2, the Normal force and Lateral Force). It is important to find optimum values for these two parameters. They should be as high as possible, but without introducing spurious oscillations into the system.

Jumping Mode

The important parameters in this mode are Set Point in the Control Menu, Jump off, Jump sample and Control cycles in Jumping Parameters Menu and the Feedback parameters P and I in the Feedback Menu.

- Increase/decrease the Set Point value to approach/withdraw the tip and sample by piezo movement.
- As we have said previously, the Frequency value in the control Menu is not relevant. To control the speed of the system you must adjust the Jump off, Jump sample and Control cycles. All of them are inversely proportional to the scanning speed, so you can try to reduce them as much as possible, but you must allow the system to faithfully react to changes in the topography of the sample in order to obtain the best image possible.
- In terms of Feedback parameters, it is determined in much the same way as in Dynamic and Contact Mode.

HOW TO SAVE IMAGES

32. To save images, select the images you want to save by enabling the Save checkbox for each of them in the Viewer Options menu (see Fig.4.31). In the Acquisition Menu select Saving Options... (or click )

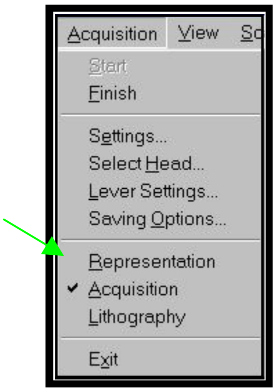


Fig. 4.48

A window will appear as shown in Fig.4.48. You can select the folder where you want to save the images, their name and a number counter which will appear in the image name and which will increase automatically each time you save an image. The extension in the image file name will show the type of image acquired and if it has been acquired using the Fwd or Bck signal. For example, *.f.top means a Fwd Topography image, *.b.ch15 means a Bck Amplitude image, *.f.ch16 means a Fwd Phase signal image, *.f.ch1 means a Fwd Normal Force image, and *.b.ch2 means a Bck Lateral Force image.)

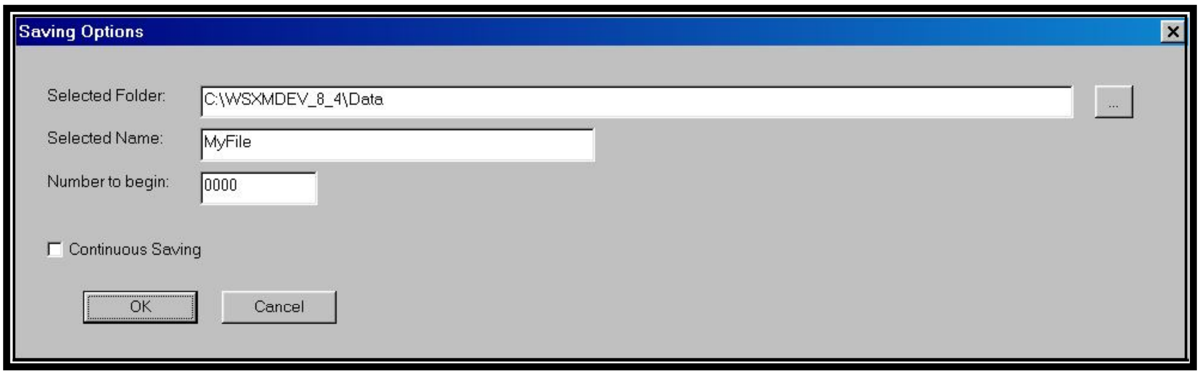


Fig. 4.49

Once you have selected a folder, specified a name for the images, and selected the ones you want to save by pressing  in the Control Menu, the Save icon will turn yellow, as well as the headings of the images to be saved. Note that when the Save button is not pressed, these headings are red, and the ones which will not be saved are blue. When the scanning reaches the end of the scanning square (top or bottom), the images get saved and the Save button switches off.

If you select Continuous Saving, the save button will change into  and after pressing it, the system will not switch it off until after sequentially saving your files.

When the Continuous Saving option is selected, the selected images will be saved every time the scanner reaches the top and the bottom of the scanning square.

TURNING OFF DULCINEA

33. Stopping the acquisition and turning off the system.

BEFORE TURNING OFF Dulcinea electronics ALWAYS EXIT WSxM.

To exit WSxM, stop scanning. This is easily accomplished by entering a value of 0 to the Size in the Control Menu.

- After the scanning has stopped, move away the sample from the tip using the Approach menu by clicking Withdraw in the Move option, allow the tip to withdraw a reasonable distance, and turn off the motor (The Withdraw button will change into a Stop button and you will have to press it to stop withdrawing). Using the two micrometer screws (see Fig. 4.22) withdraw totally the tip from the sample. Leave the Feedback parameters on P = 20 and I = 10.
- Put the X, Y and Z offsets to 0.
- Just in case, leave the gains on 10 (if not, while closing WSxM, this will automatically occur).

Once you have completed these steps, you can finish the acquisition, by pressing the STOP button . In principle it is not necessary to switch off Dynamic Mode (if it is ON) or to turn off the laser. WSxM will automatically perform these tasks. A shutdown message will appear on the front screen of Dulcinea. Then you can turn Dulcinea off.

Appendix A: Dynamic Menu

When pressing Tune in the Dynamic Menu, WSxM will go through different kinds of scans to find the resonance frequency.

First, it will make a scan over the frequency range selected by the user on a logarithmic scale, that way it will roughly find the resonance frequency. Secondly, it makes a linear scan over a shorter frequency range, set by the results of the first scan, to fine tune the resonance frequency.

Then it performs a phase scan to determine the phase of the incoming signal. The ultimate result is a determination of the amplitude of the oscillation and its phase. The Nanotec system assigns the phase signal as the input to Channel 16, and the amplitude as the input to Channel 15.

When performing the phase scan, the resonance frequency might change. Therefore, to finish the search, WSxM goes through a last linear scan to get the actual resonance frequency.

The values shown in the parameter boxes will usually be different from those set at the beginning. They will be the last parameters determined from the last scan.

You can make WSxM repeat any of these processes separately by using the buttons on the left bottom corner, Scan Phase and Linear Scan.

- Minimum frequency: Enter the lower limit for the frequency range over which the resonance frequency is going to be searched.

- Maximum frequency: Enter the higher limit for the frequency range over which the resonance frequency is going to be searched.

- Frequency: WSxM will display in this box the value of the active frequency.

- Delay: The number of times the amplitude of the cantilever at the resonant frequency (X component) and its phase (Y component) values are measured to obtain an average value. Setting the delay properly insures you obtain an accurate value for the amplitude (square root of the square of these values) of the signal from the dynamic board.

- Amplitude: Amplitude of the excitation applied by the dynamic board to the dither piezo in the cantilever holder. If the tip were free (oscillating without feedback), increasing this amplitude would result in a larger oscillation of the cantilever. However, because of the feedback attempts to maintain a given set point amplitude, increasing the oscillation causes the tip to approach the sample since the feedback attempts to keep the amplitude constant.

- Phase: Phase difference between the oscillation of the cantilever and the signal applied to the dither piezo.

- Filter out: Upper limit for the low pass filter used to eliminate high frequency noise that may be present in the signal going to the dynamic board. A typical value is about 8 KHz.

- Gain in: Amplification factor of the normal force signal coming from the head to the dynamic board. You should increase the gain if the output signal (from CH15 or CH16) is too low (for example if the output signal is smaller than 0.3 V).

- Gain out: Amplification factor of the signal coming out of the dynamic board and going to the DSP. You can use it for the same reason you use the Gain in amplification. It is better to use the Gain in amplification because the dynamic board works with the amplified signal. Be careful not to saturate the output.

- Default limits: Click on this button to set the WSxM default values for the Max and Min frequencies.

Info box: In this box WSxM will display information about the normal force signal coming out of the head into the dynamic board.

- Resonance Frequency of the cantilever oscillation.

When running the cursor over the graphs it will turn into a crosshair. Use it to click on any point you want to obtain numeric information. WSxM will provide you with the following information about the point:

- Frequency value of the point selected by the cursor.
- X component of the signal coming out of the dynamic board plotted as a vector. It is written in red because it corresponds to the red curve in the upper window.
- Y component of the signal coming out of the dynamic board plotted as a vector. It is written in blue because it corresponds to the blue curve in the upper window.
- Amplitude of the signal coming out of the dynamic board plotted as a vector; therefore, its value is the square root of the squares of the X and Y values. It is written in green because it corresponds to the green curve in the lower window.

Use the buttons on the bottom of this box to perform a Phase Scan or a Linear Scan independently of the other scans. You can use them to fine-tune the frequency of resonance, or if you have lost the resonance frequency for any reason and you do not think it is necessary to go over every step of the tuning.

When working on Dynamic Mode, the phase is set in such way that the X component (amplitude) is negative. Increasing the Set Point (bringing it closer to zero) therefore moves the tip closer to the sample, as is the usual case in SPM.

Appendix B: Basic Channels Viewer and Control commands

Size: determines the size of the portion of the sample that will be scanned.

Freq: determines the frequency, in Hz (lines per second i.e. 1Hz means one line per second), at which the sample will be scanned. It is proportional to the speed at which the tip will move across the sample.

Points: determines how many data points will define the image. Start with a low number of points if you plan to test a new or different feature. That way, the test scanning will take less time.

X and Y off.: determine the X and Y offsets on the sample. You can view the portion that is being scanned using the Position Window (see Fig. B.1 below).

Z off.: determine the Z offset on the sample.

Angle: determines the angle in the X-Y plane at which the sample will be scanned. The effect of changing the angle can be viewed using the Position Window.

Bias: use it to set the voltage between the tip and the sample (if you have a conducting tip). The voltage will be applied to the tip.

Set Point: determines the reference normal force between the tip and the sample, or the reference tunnel current for STM. Depending on the mode that is being used, the Set Point has negative or positive values. When working in Dynamic Mode, it is negative, and the closer to zero it is, the closer the tip is to the sample. In Contact Mode, the value should be positive, and the bigger it is, the harder the tip is pressing against the sample. Usually, the Set Point is displayed in volts, or nA for STM, however, when Force Calibration has been applied, it may also be displayed in nN or in nm. If you enter a value too high, WSxM will warn you, and will set an allowed Set Point value.

Signal Gain: determines the gain for the incoming signal to Dulcinea. This Gain should not be modified unless, for some reason, the incoming signal is extremely low. There are only four allowed values for this box: 0.654, 1, 5 and 9.808.

Z Gain: determine the factor by which the Z signal will be amplified in Dulcinea. There are six allowed values for this box: 0.06, 0.29,1, 5, 10 and 15. Use a value that suits the Z scale of the sample. If you do not know the scale (as is customary for the first time the sample is scanned), use the highest value and modify it as needed when scanning.

XY Gain: determine the factor by which the X and Y signals will be amplified in Dulcinea. As for Z Gain, there are six allowed values for this box: 0.06, 0.29,1, 5, 10 and 15. Use the minimum value that allows you to scan over the desired area of the sample. The maximum area allowed on the Position window is determined by this value. Please observe that in order to obtain large scanning areas with a piezo, high voltages have to be applied.

The buttons in the low part of the box are used as follows:

Up, Middle and Down: click on them when you want the tip to move to the upper, middle or bottom part of an image while you are scanning. They are useful when modifications to the scan parameters have been done while the tip is scanning.

Y Scan: this button is pressed by default. It makes the tip scan in the Y direction. If this button is not pressed the scanning will be only done in the X direction. If the Y scan is deactivated, the scan will be done over the same line (on the X direction) every time. This feature can be useful when a particular feature on the substrate is being investigated as a function of time.

Smooth: During normal operation, at every scanned point, several measurements are acquired but only one is selected to represent a data point. If this option is selected, WSxM will use an average of all of the measurements taken as the representative data point. In most cases it is better to use this mode when acquiring data.

Secure: use this button to withdraw the tip when needed. This is done by retracting the Z-piezo, preventing the tip from crashing into the sample during times when the stability of the AFM head is being disturbed. While withdrawal is being done, WSxM will show a notice box in the screen. To elongate the Z-piezo after the changes have been done, click on Update or click on Secure again.

There are two bars on the right of the box:

The green bar on the right monitors the Z-piezo elongation. Since the best position for scanning is the midway position, a red mark is used to indicate this optimal spot.

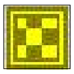
The red bar on the left monitors the error achieved when measuring. This error represents the difference between the Set Point and the actual value of the normal force. The lower this bar is, the more accurate scan you get. There may be many contributions to this error. The error scale number is the one in the box below the two bars. It represents the scale at which the error bar is shown. You can change its value either by entering it in the box, or by using the back and forth buttons on the right of the box. Using them, you will get a change in one unit if the number is higher than two, and a 10% change for the other values, no matter whether the CTRL or SHIFT keys are pressed or not.

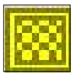
Some of the parameters discussed above are set by default by WSxM. Usually, the default values are the ones you entered when you last used the program. To change a parameter, just type a new value into the dialog box associated with the parameter. Any modifications entered into a dialog box, are highlighted with a yellow background until they are implemented.

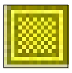
IMPORTANT: To make any modifications effective, you have to click on the Update button located in the lower part of the box. The changes can be implemented by pressing Intro immediately after the change is entered. Otherwise the background will remain yellow and no changes will be made to the existing scanning parameters.

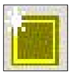
The updating will take an amount of time required for the tip to finish scanning the current line. However, if you change the Set Point or the Bias value by using the cursor, the update will occur automatically as soon as the tip finishes scanning the current line. In this case, the Update button does not need to be clicked.

Quality representation buttons: Use an appropriate quality representation when changing the size of your windows.


Low quality representation: WSxM plots one fourth of the data points on each line.

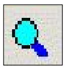

Medium quality representation: WSxM plots one half of the data points on each line.

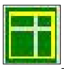

High quality representation: WSxM plots every data point on each line.


Repaint: Often, the scale of an image is changed in the course of a scan. All scan lines after the change will acquire a new look since the color scale has been modified. To update the entire image, you can the repaint button.

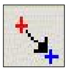
Scale: The scale associated with each of the images is displayed in the right hand side of the top banner that contains the names of the views. You can change each of these values by typing in the desired value or you can use the arrow buttons located to the right of each number. These values are only used for real time imaging and do not affect the data saved in the hard disk.

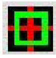
The icons on top of the image in the main window are used as follows:


Zoom: use it to zoom in on an image. Click on its icon, and select the center of the square region that is going to be zoomed by clicking on it. On the Status bar two boxes will show you the matrix and the real points over which the cursor is positioned. Click the mouse button again and the zooming process will begin. WSxM will start scanning the zoomed portion of the image, therefore the Size and the Offsets on the Control Menu will change.


Measure: use this command to measure over the image. On oscilloscope view, it is used to measure the horizontal and vertical distance between two points on the profile of the sample. Click on this icon and select the two points by moving the markers over the profile. The vertical and horizontal distances will be displayed on the status bar.

When using this command on an image view, the status bar will display the matrix coordinate (equivalent to pixel coordinates) and the real coordinate (equivalent to the spatial coordinates). To measure distances between two points, click on one point and extend the line to the other one. The status bar will also display the modulus of the vector between the two points (length of the line between the two points), and if you draw more than one line, the angle between both lines will also be shown.

 Center: Use it to redefine the center of the portion of the sample being scanned. On the Status bar two boxes will show you the matrix coordinate (equivalent to pixel coordinates) and the real coordinate (equivalent to the spatial coordinates) where the cursor is positioned. Click on this icon and then click on the point you want to define as the new center of the image. WSxM will re-center the image. You can also redefine a new center using the features of the Position Window.

To open the Position Window, press  in the toolbar. The following graph will appear:

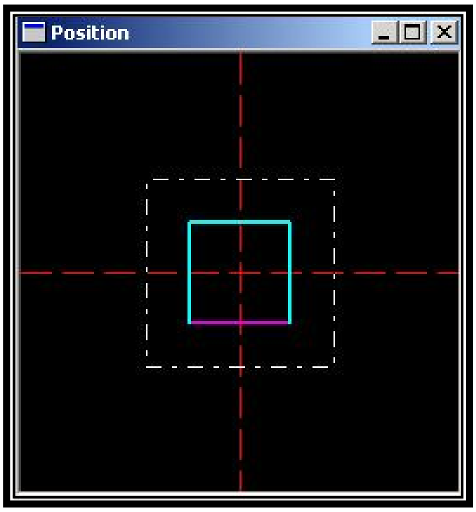


Fig. B.1

Use this window to visualize and change the area over which you are scanning. Use it also to check the orientation of your sample and the size of the area you are scanning.

The dashed square represents the maximum area that can be scanned (given the selected XY Gain on the Control Menu) whereas the blue square represents the area that is actually being scanned.

-To change the size of the scanned area, use Size in the Control Menu.

-To change the maximum area that can be scanned, use XY Gain in the Control Menu. This will force the dashed square to change its size.

-To change the angle of the scanned area, use Angle in Control Menu. One of the sides of the square has a different color. This feature is used as a reference line that allows you to determine the angle you are scanning with. (0º is when this side is at the bottom)

-To change the portion of area over which you are scanning, click once on the point where you want to go. If you have clicked on the wrong point, double-click on any point to return to the original point.

These actions will be displayed in a yellow square, showing the change made, but they will not be updated until you click Update in the Control Menu. The change of position will be shown on the Control Menu automatically, displaying the new X-Y Offset values. When you click Update a progress bar will show you the progress of the Offset movement, and it will also be represented as the movement of the yellow square. When all the parameters have been updated, the computer will continue measuring.

Appendix D: XY and Z Gains

In any digital acquisition system, in order to obtain data with the best resolution, you should take care that the data you want to measure fits as well as possible into the range of your system. In this way you will avoid digitalization problems.

The Dulcinea SPM controller is based on 16-bit DACs (Digital to Analog Converters) and ADCs (Analog to Digital Converters). This means that for any continuous value that you enter, the maximum number of different values will be 2^{16}= 65536.

Those 65536 different values are correlated to voltage values between -10V and +10V. With the maximum gain (15) you can produce up to +/-150V. If the topography you want to measure is rough (i.e. one micron), your measurements will use about 10000 different values, so you will get good data, but if you want to measure very small features (like 1nm heights), the data will have only 10 different values, so you will not have very good data, and you will find that the data is limited by your digital system resolution.

So, the ideal way of measuring small features is to have a small voltage range, like 5-10 times the range of your data (it is better not to adjust it too much because you could get out of range), but you would like this small voltage range to be centered around the maximum limits set by your piezo elongation. This is why it is so important to center the green bar and reduce the XY and Z Gains.