MFP 3D Scanning Probe Microscope

User Guide

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Asylum Research

an Oxford Instruments company

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Introduction

The MFP-3D Atomic Force Microscope (SPM) manual comes in volumes. To date these volumes are:

Part I *Basic Operation Guide and Tutorials.* This part has detailed step by step tutorials on how to image basic sample topography in air and fluid. If you do not know which part of the user guide is for you, this is probably it.

Part II *Advanced Imaging and Accessories.* This part covers the use of advanced hardware accessories such as fluid cells and sample heaters.

Part III *System Safety, Specifications, Set-Up, and Relocation.* This part covers placement and set-up of the instrument, essential safety information, and shipping/packing instructions.

AR Software Version It is assumed that AR Software version 13 or later is installed on your system. To download the latest software, please register at our support site: http://support.asylumresearch.com.

Getting Help There are many ways to get help with your Asylum Research instrument, and it is always free:

- Join the support site and download software, current manuals, and ask questions in our user forum. http://support.asylumresearch.com. Note that all Asylum scientists are forum members and frequent contributors.
- E-mail us at support@asylumresearch.com.
- Call your local office or distributor.
- Call us at +1-805-696-6466. During US west coast business hours you will get a human being to speak with. After hours you still have a good chance of catching one of our scientists. Within the US you can call our toll free number if you wish (1-888-472-2795).
- If necessary we can initiate a remote session and have one of our scientists operate your AFM over the internet.

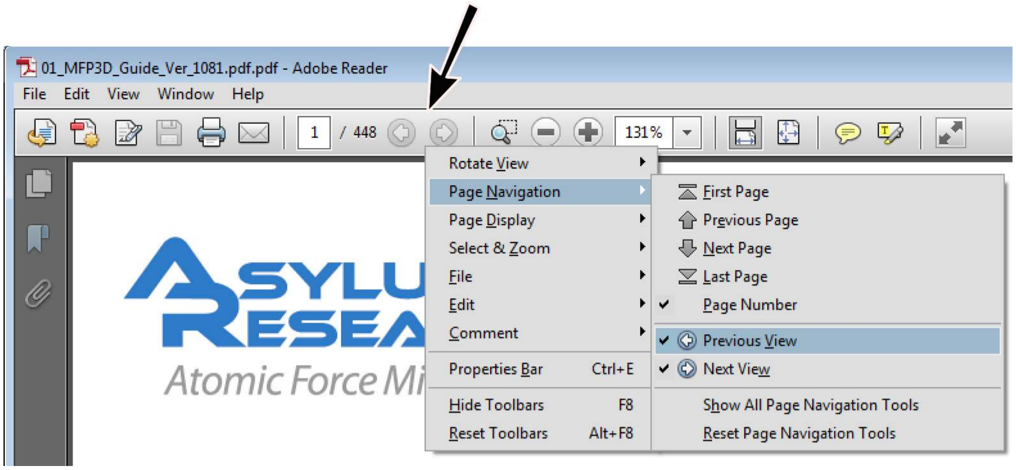
Updates to the Manual Bundled with the software updates.

PDF reader setup

This document makes frequent use of links from one section to another. This reduces repetition of material, but does require some flipping back and forth. To make this process easier, please make the following adjustments to your pdf reader.

Adobe Reader (PC or Mac)

1.

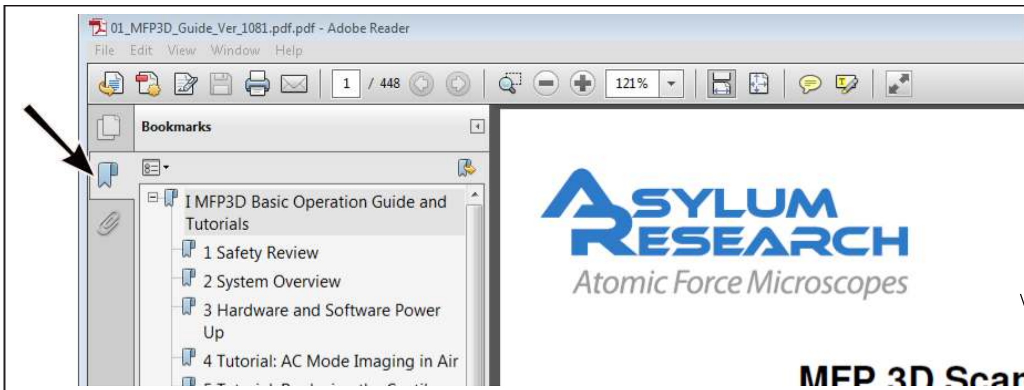


Add Page Navigation:

- Right click on the toolbar.
- From the pop-up menu, select *Page Navigation*.
- From the sub pop-up menu select *Previous View* and *Next View*.
- This will place two buttons (see the arrow in the figure above) in the toolbar which function like the *Back* and *Forward* buttons on any web browser.

2. When reading a section in the manual which refers to another page, click on the link to jump to another page. When done reading, click the *Previous View arrow* in the toolbar to go back to the original page.

3.

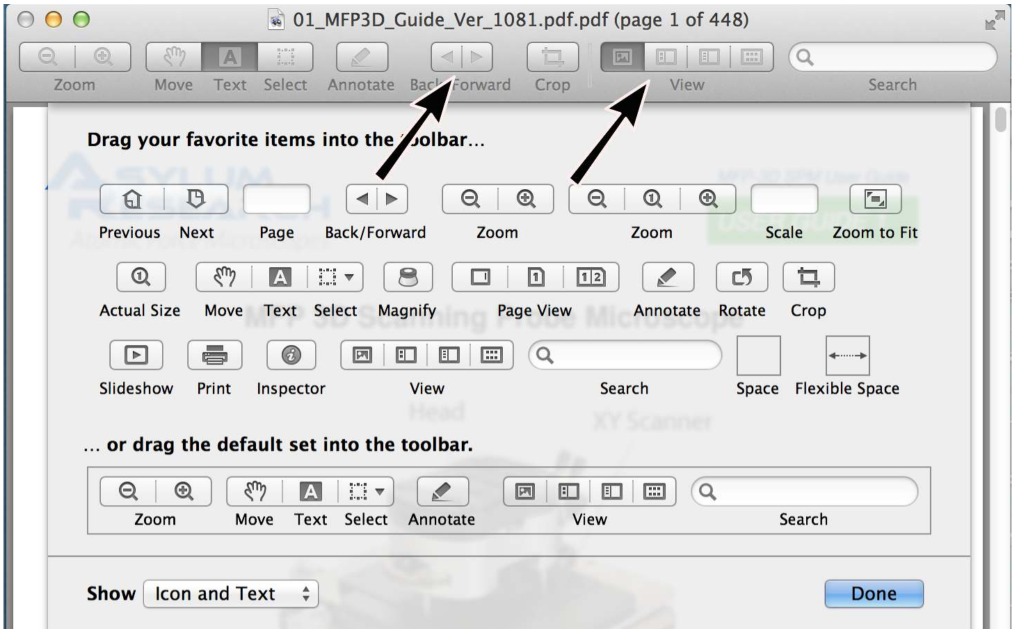


Bring up the table of contents:

- Click the icon indicated by the arrow in the figure above.
- Keep the table of contents at the left of the screen to navigate the manual.

4. Adobe Reader should remember these changes the next time the program is opened.

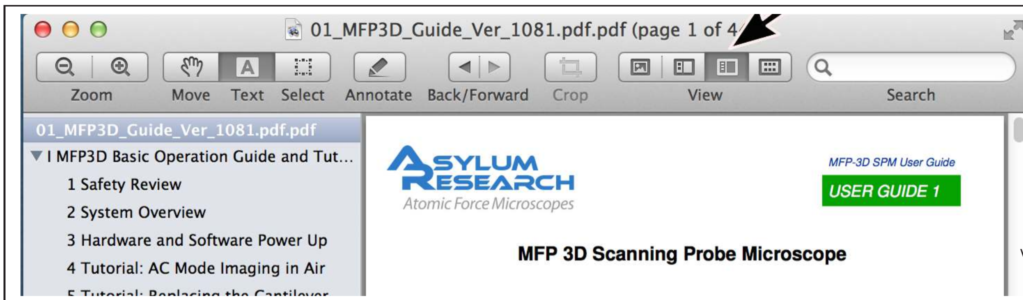
Preview (Mac)

1. 

Add Back/Forward and View buttons:

- Right click on the toolbar.
- Drag the *Back/Forward* and *View* tools into the toolbar.
- Click *Done*.

2. When reading a section in the manual which refers to another page, click on the link to jump to another page. When done reading, click the *Back Arrow* in the toolbar to go back to the original page.Appication

3. 

Bring up the table of contents:

- Click the icon indicated by the arrow in the figure above.
- Keep the table of contents at the left of the screen to navigate the manual.

4. The Preview Application should remember these changes the next time the program is opened.

Part I

MFP3D Basic Operation Guide and Tutorials

Part I: Who is it for? After the MFP-3D AFM has been professionally installed in your lab, and you or someone in your facility has completed the inital training (at the time of the installation), this volume will be the principal reference for operating the instrument. Although this volume is written with the novice user in mind, experienced users should complete the basic imaging tutorial at least once before attempting to use the MFP-3D.

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1. Safety Review

CHAPTER REV. 1576, DATED 08/28/2013, 12:12. USER GUIDE REV. 1590, DATED 08/30/2013, 12:47.

It is recommended that everyone who uses the MFP-3D AFM read Chapter 11 on page 135 at least once. As a reminder, here are the important points:

- The AFM head contains a laser-like SLD light source. The light is in the near infrared so you cannot see it with your eye, and your blink reflex will not protect you. The beam is diverging, so it is only intense enough if viewed though an appropriate magnifier (an unlikely event) or if your eye is brought very close to the location of the cantilever (also an unlikely event). The head contains tilt switches which turn the light source off if it is not standing upright on its legs. So in general, the light is a relatively weak and diverging beam which is only on when the head is in a level position, with the beam shining downward.
- The AFM's XYZ piezos operate on voltages up to 165 V_{DC}, and with sufficient current to be harmful to human life. Note that the cables connecting the controller to the base and the head and scanner to the base carry these voltages. Do not pinch or cut these cables. Turn off the controller before disconnecting any of these cables. It is safest to plug them all in and then turn on the controller. Also do not remove any covers from the controller or other instrument components while the controller is turned on or plugged into an AC outlet. Dangerous voltages are exposed with the covers removed.
- Respect the weight of the AFM head as you handle it, the original model heads weighs 14 pounds, and can be difficult to lift with one hand. Get a good grip on the head with both hands when removing it or carrying it around. If dropped on your hand or foot (even from a small height) it could cause injury.

In a nutshell, this is an industrial/scientific research grade instrument. While it is quite safe, even compared to an electric drill or home cooking stove, there are a few possible dangers of which the user should always be aware.

2. System Overview

CHAPTER REV. 1587, DATED 08/30/2013, 11:42. USER GUIDE REV. 1590, DATED 08/30/2013, 12:47.

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2.1.1 Major Hardware Components 5
2.1.2 AFM Head Controls 7
2.1.3 AFM Base Controls and Components 7

This section will establish names for the various parts of your AFM system. The system should have been set up, connected, and tested by an Asylum Research scientist. For more information on troubleshooting any connections, please refer to Chapter 6 on page 54.

2.1. Basic MFP-3D SA Hardware

2.1.1. Major Hardware Components

The MFP-3D Stand Alone (SA) AFM system and its various components are shown in Figure 2.1 on page 6, and explained briefly (in alphabetical order) below:

Acoustic Enclosure Also called “the hood”. A heavy steel chamber with special acoustic damping materials and vibration isolating pads under the legs. Keeps lab noise and vibrations from affecting high resolution AFM images. Also shields the instrument from air currents which degrade imaging stability. The typical lab will require an acoustic enclosure to get the best performance out of the MFP-3D AFM.

AFM The parts sitting inside the enclosure are typically referred to as the AFM. The main components are, from top to bottom (also see Figure 2.2b on page 7):

Head The AFM component which holds the cantilever chip and contains the optical lever detection system, and electronics and the vertical (Z) motion actuator and sensor. In short, it moves the cantilever vertically as the sample moves laterally beneath it. It also contains optics for illuminating and optically imaging the sample and cantilever from above.

Scanner The AFM component which holds the sample and scans it laterally in X and Y beneath the tip. It contains piezoelectric actuators, flexure based translations stages, and high resolution position sensors.

Base The metal plate on which the head and scanner sit. It typically contains a rudimentary optical microscope with CCD cameras and sample illumination controls for optically viewing the sample and cantilever. It also contains critical signal conditioning electronics for the scanner and acts as the electronic hub for connecting the controller to the scanner and head and it routes CCD output to the computer.

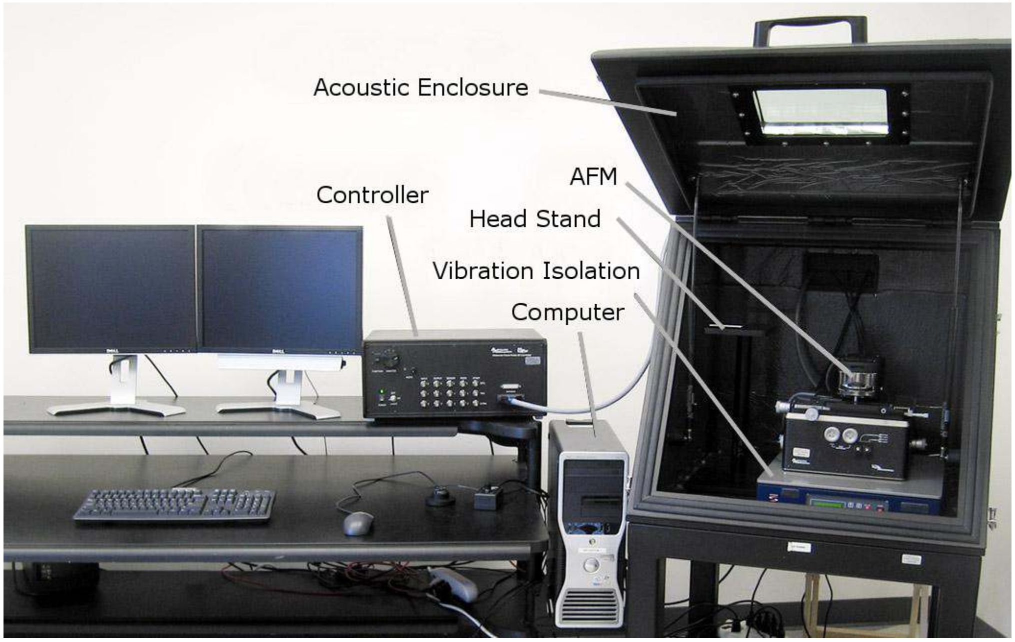


Figure 2.1.: Ideally the MFP-3D AFM with Stand Alone Base is set up as shown, with the controller and computer on one table and the AFM inside an acoustic enclosure. Note that newer systems operate with the ARC2 controller (see **??** on page **??**).

Computer The computer is the primary interface for controlling the microscope and its main communication is via a USB1.1 connection to the ARC2.

Controller The controller houses power supplies and the necessary electronics for controlling the scan motion and acquiring image data from the microscope. Your MFP-3D AFM system will be equipped with a black MFP-3D AFM controller or the newer ARC2 SPM controller (see Figure 2.2a on page 7). Either will work identically with the AFM and Software discussed in this user guide.

Fiber Lite Halogen dimming light source with fiber optic light guide. Connects to the base and illuminates the sample for optical viewing.

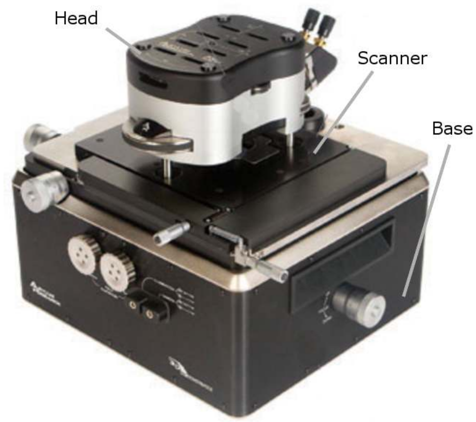
Head Stand Platform attached to the side of the acoustic enclosure. A place to store the head when loading samples or changing cantilevers. The rear legs of the head should be placed in the two holes at the back of the head stand.

Vibration Isolation Typically an active vibration isolation table and occasionally a passive vibration isolation platform. In most labs this is essential equipment for high resolution imaging.

Q SA or “Stand Alone”, what does that mean?

A “Stand Alone” refers to the optical microscope on which the AFM head and scanner rest. In this case it is a compact, purpose-built microscope also referred to as the “Stand Alone Base”. The other option is a third party (Olympus, Nikon, Zeiss) inverted optical (IO) microscope with a custom Asylum Research Base plate mounted on top to support the AFM head and scanner. That custom base plate is typically called the IO base (IO = Inverted Optical). So the IO Base is designed to go with an IO microscope while the Stand Alone base, well, stands alone.

(a) Newer MFP-3D systems ship with the ARC2 controller



(b) Basic AFM Components

Figure 2.2.: Some Instrument Details and Names.

2.1.2. AFM Head Controls

The controls on the AFM head are as follows, in alphabetical order (See Figure 2.3 on page 8):

Front leg thumb wheel Clockwise motion lengthens the leg and raises the cantilever and head away from the sample. Also changes the level (pitch) of the head.

LDX thumb wheel Moves the laser spot along the length of the cantilever. Counterclockwise rotation moves the spot from the cantilever base to the tip, as indicated by the graphic on top of the head.

LDY thumb wheel Moves the laser spot perpendicular to the length of the cantilever. Counterclockwise rotation moves the spot as indicated by the graphic on top of the head.

PD thumb wheel Centers the reflected beam on the head's photo diode detector. This is also known as "zero-ing the cantilever deflection".

Rear leg thumb wheels Clockwise motion lengthens each leg and raises the cantilever and head away from the sample. Can change the level (roll) of the head.

Top view objective focus wheel Focuses the top view optical image of the cantilever or sample.

XY mirror movement Translates the top view optical image of the cantilever or sample.

2.1.3. AFM Base Controls and Components

The controls and features on SA base are as follows (See Figure 2.4 on page 9):

Aperture Diaphragm A knurled metal ring around the entry point of the optical fiber illumination. Controls the amount of light that enters the base. Used for adjusting contrast and light intensity.

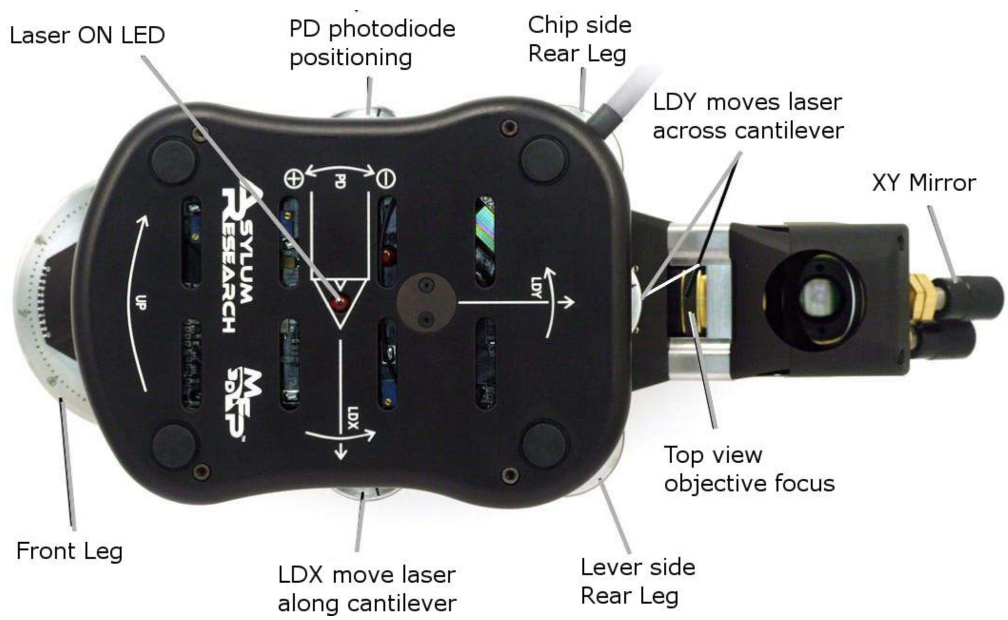


Figure 2.3.: Top view of the AFM head with named controls. Note the cantilever shape in the middle (same orientation as the real cantilever) and the LED at the tip of this lever. The red LED lights up when the laser is on (but not necessarily focused on the tip).

Base Plate Top surface of the SA base on which the head and scanner sit.

Bottom and Top View Field Diaphragm Diaphragms used to enhance contrast on the top and bottom view images.

Bottom View Focus A large knob which focuses the bottom view objective.

Camera Selector Directs the image from the top or bottom view objectives to the CCD camera built into the base.

Driver Bar Pushes the scanner for XY sample alignment.

Illumination Selector Directs illumination to the top or bottom of the sample. For instance, top view on an opaque sample will require top illumination, but a transparent sample will require bottom view illumination.

Leg Hole Holes in the scanner through which the legs on the head can rest on the base plate.

Magnetic Sample Clamp Magnets (part number 910.004) provided with your system for holding microscope slides to the scanner top plate.

Optical Align X and Y Controls the movement of the entire base plate relative to the base and the bottom view microscope objective. A way to translate the cantilever and sample in the field of view of the bottom view camera.

Optics Window Directs light and images between the base and head. The top view objective is only half a microscope. The other half resides in the base.

Sample Typically mounted on a standard microscope slide.

Sample Align X and Y Controls the lateral movement of the entire scanner. Used to move the sample relative to the cantilever, to select a place to image.

Figure 2.4.: Controls on the SA Base. Missing from view are (on the left) the aperture diaphragm which is a knurled ring around the entry point of the fiber optic illumination and (on the right) a large knob for focusing the bottom view objective.

Scanner Electromechanical scanning stage which moves the sample laterally in X and Y beneath the head and cantilever.

Scanner Top Plate Moving part of the scanner onto which samples are placed.

3. Hardware and Software Power Up

CHAPTER REV. 1586, DATED 08/30/2013, 10:33. USER GUIDE REV. 1590, DATED 08/30/2013, 12:47.

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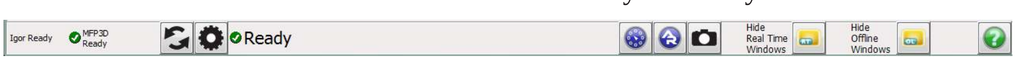
3.1.2 Status Bar 13

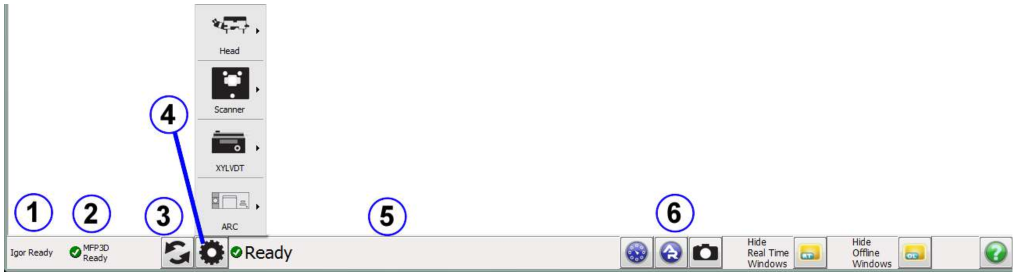
Before you start any of the following tutorials, the system must be properly started up.

Before you start: We assume you understand the aspects of running this system safely: (Chapter 11 on page 135)

1. Turn on and enable the active vibration isolation platform under your AFM if you have it.
2. In no particular order, boot up the computer and turn on the MFP-3D AFM by depressing the power switch on the front of the controller (ARC2 or MFP-3D model). When all is working properly a green light should show on the face of the controller.
3. Double check that the laser key on the controller is in the ON position. Then double check that the red LED light on top of the AFM head is on.
4. Locate the shortcut to the software on the desktop, and double click on the icon to start the software.
5. **System check:**
   - During initialization the software will not be responsive. Look at the bottom status bar for the initializing message.

   - When the software is done the status bar will say it is ready.



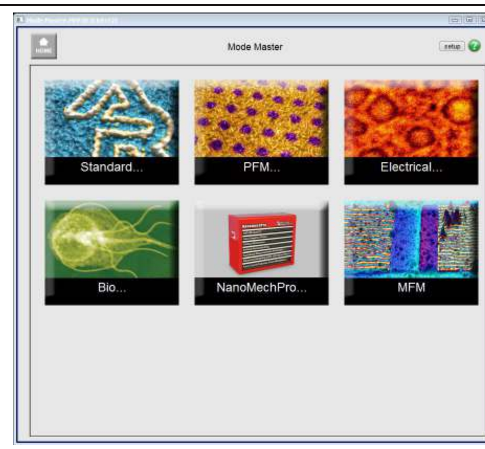


6. **System check:**

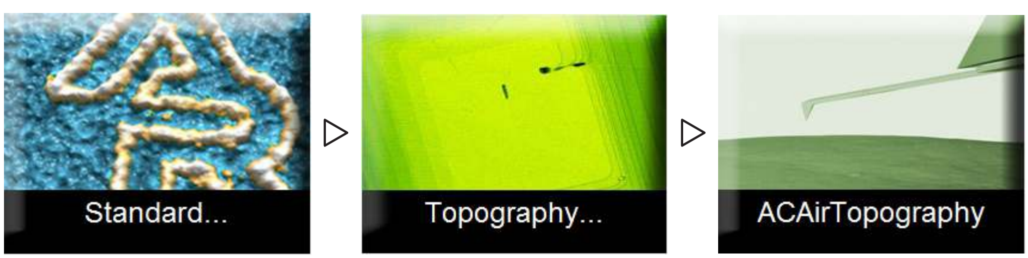
- At the bottom of the software you will find the status bar.
- These areas will be described in more details in Section 3.1.2 on page 13.
- Location 1, 2 and 5 should read Ready
- If some components are reported missing, check their connections. Once you have the cables secured and powered, click on the rescan bus (3). If that does not solve the problem, please contact support.

7. **The Mode Master window:**

- The software should now be showing the mode master window.
- If not, click s the Mode Master button at the bottom of the screen: .



8.



Select Mode:

- Select *Standard* ▷ *Topography* ▷ *ACAirTopography*
- The screen will now re-arrange and present all the controls necessary for this type of AFM imaging.

3.1. The Igor Pro Software Environment

The Asylum Research software is primarily written within the programming environment of the commercially available software package Igor Pro, which is developed by WaveMetrics. Igor Pro itself has nothing to do with scanning probe microscopes. Rather it is a stand alone program that has extensive scientific graphing, data analysis, image processing and macro programming capabilities.

Tip	The “Volume I - Getting Started” manual found on the WaveMetrics website (www.wavemetrics.com) takes two to three hours to complete and is an excellent way to learn about the basic graphing and analysis functionality of Igor Pro. Although it is not necessary to complete the Igor Pro portion of the “Getting Started” manual at this time, it is a highly recommended part of all new user training.

When you launched the software you opened an Igor Pro “Experiment” in which extra software specific to the operation of the AFM has been loaded. An Igor pro experiment is the file that saves the state of Igor Pro.

Figure 3.1.: Typical start up screen for the Asylum Research SPM Software, after the mode master panel has been closed. A few image panels have been left off the right of the screen, which usually extends across the second monitor of your system.

Refer to the screen shot in Figure 3.1 on page 12 as we introduce the various controls and data displays for the often used AC Mode imaging technique. We’ll go clockwise from the upper left. (Note that if you are viewing this file on a computer, you can zoom into the screen shot for a closer look.)

Master Panel Upper left hand window (Ctrl + 5). It has five tabs with controls and data displays for:

Main AFM imaging, see Chapter 4 on page 15.

Thermal Cantilever thermal spectroscopy see the ARApplicationsGuide.pdf, Section on spring constant calibration.

Force Cantilever force vs distance curves.

Tune Cantilever resonance tuning, see Section 4.7 on page 33.

Fmap Maps of force vs distance curves.

Master Channel Panel (Ctrl + 7) During imaging, multiple data streams, such as height, cantilever amplitude and phase, return from the AFM to the computer. This panel contains information about those data streams and allows for some real time scaling and processing.

History Window (Ctrl + J) Also known as the Igor Command line window. On occasion items executed by clicking software buttons will generate some output here. Power users will type commands at the command line to accomplish a variety of advanced tasks. If you followed the Igor getting started recommended in the Tip on page 12 you will know all about this window.

Sum and Deflection Meter (Ctrl + 6) Also called the S&D Meter. A real time display of various data such as cantilever deflection, amplitude, piezo voltage, and various other user definable channels. Also contains buttons for engaging and withdrawing the AFM tip.

Image Windows For each active channel on the Master Channel Panel, one image will appear on the screen. They balloon to proper size as soon as scanning starts. The windows display in real time, line by line, the sample topography (height), phase, amplitude, voltage, or any other measured quantity, acquired as the sample is scanned. There is usually one such window per active tab in the Master Channel Panel (Lower left hand window). While these windows are primarily a data displays, right clicking with the mouse can activate various commands such as zoom and translate. A white area at the bottom of this window shows you a real time “oscilloscope view” of the most recent line of image data, which is very useful when tuning imaging feedback parameters.

Q Oops! I accidentally closed one of the control panel windows. How do I get it back?

A You can re-activate the panels via *AFM Controls* in the menu bar.

Q How do I get the mode master panel to appear again?

A Click on the on:  button near the bottom of the screen. When you select a new mode, the appropriate windows will appear and the SPM controller will re-configure itself accordingly.

3.1.1. Menu Bar

Along the top of the screen. There are many more controls which can be invoked by items in the menu bar. Menu items to the left are typically standard Igor Pro items, with some Asylum Research functionality. Items to the right of the help menu are exclusively AFM related.

3.1.2. Status Bar

Along the bottom of the screen. Icon controls relate to the status of connected instrument components. The low level software version is also displayed.

While we do not want to get bogged down with the details of all of these controls, it is good to have a basic grasp.

1 Igor Pro Status If Igor is ready to accept a software request from you, it will say Ready. If it is busy calculating it will show an Abort Button and a rotating quartered circle.

2 System Status If you are missing hardware, or there is a critical error, it shows up here.

3 Rescan Smarstart Bus Click when adding new components to the system (heaters, different cantilever holders, etc.).

4 Device Manager Click on this gear icon to see what components are communicating with the controller. Furthermore, individual information (temperature, serial number, etc.) on each component can be accessed by clicking the triangular button to the right of each component icon.

5 Current OperationDisplays what operation the system is currently preforming, thermals, scanning, etc. Some actions have progress bars that show up here, and additional warnings can show up here as well (hard drive filling up).

6 Buttons

Mode Master

Master Panel

Video Window

Hides / Shows Real Time Windows

Hides / Shows Offline Windows

Help Browser

Realtime? Offline?

These terms have been around for a long time in image processing and acquisition system. Offline has nothing to do with network connection.

Realtime Window Displayed data that are in the process of being acquired.

Offline Window Displayed data from a saved file.

4. Tutorial: AC Mode Imaging in Air

CHAPTER REV. 1589, DATED 08/30/2013, 12:14. USER GUIDE REV. 1590, DATED 08/30/2013, 12:47.

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This tutorial provides a quick path to learning the basic operation of the MFP-3D AFM. The tutorial lists a set of steps that will teach a new user, with a minimal to basic understanding of AFM operation, how to

- Load a probe into the cantilever holder
- Place the head onto the stage
- Align the spot onto the cantilever
- Select a cantilever drive frequency
- Engage the tip on a standard sample

Before you start:

- This tutorial is designed to be performed, not merely read. If possible, it is advised take the tutorial under the supervision of an experienced user.
- We assume you understand the aspects of running this system safely: (Chapter 11 on page 135.)
- You are familiar with the basic names of the hardware components and software controls (Chapter 2 on page 5.)
- You have powered up the System and Launched the Software: (Chapter 3 on page 10.)

Note The MFP-3D is a research grade instrument and improper use of the instrument can cause damage to the instrument and/or injury to the user. This tutorial will take approximately 3 hours the first time.

Note	There are many ways to skin a cat. There are also many ways to operate the MFP-3D AFM. These instructions assume that the AFM was left in some unknown state of alignment by a previous user. Once you have gone through the process a few times, you will find that some steps can be skipped or re-arranged to best suit your style. In Chapter 5 on page 47 there is a reduced set of steps which are applicable to changing a cantilever on a system which you have already aligned for your sample and needs.

4.1. Required Materials

- Cantilevers: You will need to collect several AC160TS or AC240TS cantilevers, which are manufactured by Olympus. The AC160TS has a spring constant of ~42N/m and a resonant frequency of ~300 kHz. The AC240TS has a spring constant of ~2N/m and a resonant frequency of ~70 kHz. Both are used for AC mode imaging in air. Every AFM ships with a package of AC160s and AC240s, but if these cantilevers are unavailable any cantilever with a similar spring constant and resonant frequency should work fine see `http://www.asylumresearch.com/ProbeStore/TYPE?Entry=JustLooking#AC%20MODE%20(AIR)`.
- Sample: The tutorial will use the Asylum Research calibration grating that ships with every system (part number 900.237). It is mounted on a standard glass microscope cover slide.
- Sharp tipped tweezers (some people prefer straight tips, others prefer curved).
- Small Phillips (+) screwdriver.

4.2. Loading the Cantilever

4.2.1. Nomenclature

Please refer to Figure 4.1 on page 17 for the names of all the parts in the cantilever holder. For overall AFM system nomenclature, please refer to Chapter 2 on page 5.

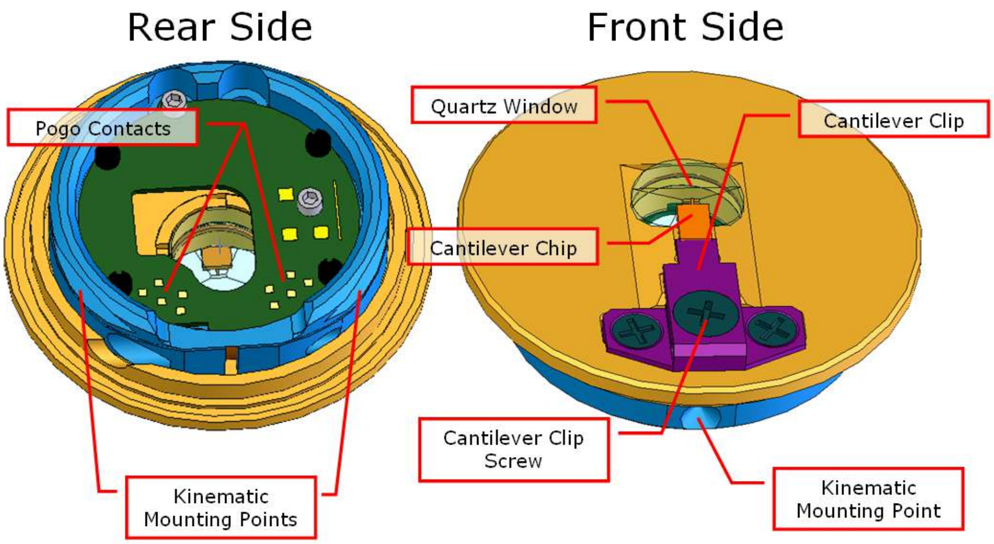


Figure 4.1.: Standard cantilever holder nomenclature

4.2.2. Instructions: Preparing the Holder

Note on Color	The cantilever holder in the following photos is translucent (Kel-F). Yours may be Blue (PEEK) or Tan (PEEK). The procedure is the same, regardless of color.

1.

Prepare cantilever mounting work area:

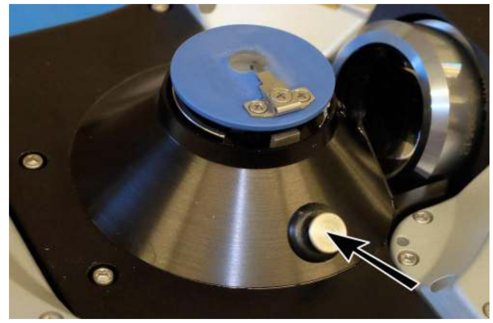
- Set out your cantilever changing stand, tweezers, and box of cantilevers on a clear work surface, preferably close to the AFM so you can easily wheel your chair over.
- A low power binocular dissection microscope with light source is recommended.

2.

Remove the cantilever holder from the head:

- Place the AFM head upside down (usually on the metal platform or “head stand” next to the AFM.)
- Depress the button on the head.
- Gently lift the cantilever holder straight up out of the head and carry it to your cantilever changing area.

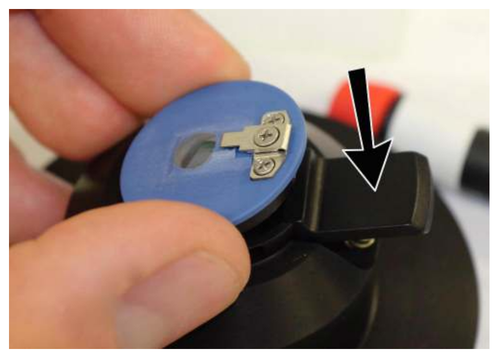
Note Older model AFMs may have a “rubber dome” covering this button.



3.

Mount the cantilever holder:

- Orient the cantilever holder with the clip’s screws towards the lever on the stand.
- Press the lever on the stand down, as shown.
- At the same time, angle the cantilever holder into the stand. Two fixed balls in the stand, opposite the lever, must match up with the two matching kinematic mounting points on the cantilever holder.
- Lower the cantilever holder so the final kinematic mounting point lines up with the ball on the stand’s lever, then release the lever.
- Inspect that the cantilever holder sits flat in the stand and that all the balls sit properly in the mounting points.



4.

Prepare your tweezers:

- Locate tweezers with straight sharp tips. This technique does not work well with curved tweezers.

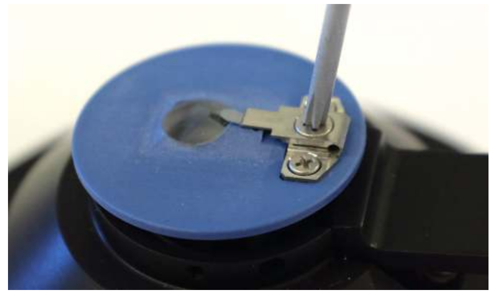
Good Habit Cleaning the tweezer tips with alcohol will prevent cantilevers from sticking.

5.

Remove the used cantilever:

- Loosen the middle screw on the clip about one turn, just to the point of freeing the cantilever.
- Remove the old cantilever with tweezers.

Good Habit Blow the area under the cantilever clip clean with *clean* compressed air. Bits of silicon and other debris can lead to a poorly seated cantilever and poor quality AC mode images.



Note The following steps suggest a certain method of inserting the cantilever. A quick poll at Asylum Research showed that nearly every veteran AFM operator has their own way of doing this. Please see Section 4.10.1 on page 39 for more insights. Also ask your lab mates, or practice yourself with some old cantilever chips.

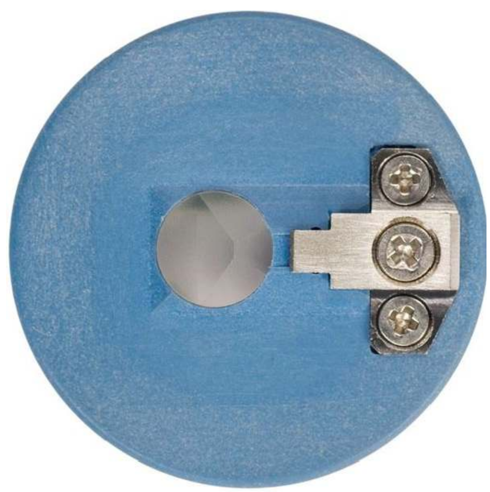
6.

Prepare for cantilever mounting:

- Orient the cantilever holder in front of you as shown.
- Open the box of levers with the tips pointing to the left.
- With the tweezers in your right hand, pick up a lever. Some find it works best to hold the tweezers perpendicular to the tabletop when picking up the lever.

Note If you are left handed, you may want to reverse this process. The tweezer is usually best held in your dominant hand.

Note Close the cantilever box now. The longer you wait, the more likely you will one day put your hand into a box of 30 pristine cantilevers.

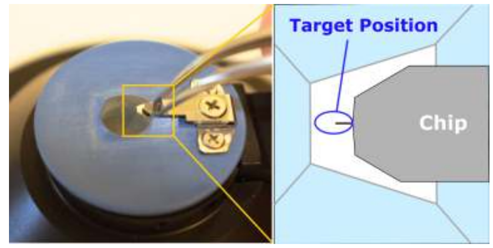


7. Close the cantilever box now. The longer you wait, the more likely you will put your hand in it later and break 30 tips at once.

8. **Insert the new cantilever:**

- With tweezers, slide the cantilever chip under the clip. Resting your wrist on the table helps keep it stable.
- Position the cantilever as shown in the clear trapezoidal shaped quartz optical window. You can do this by letting go of the chip and nudging it around with the tweezer tips.

Note Do not push the cantilever chip too far back. This can cause misalignment. We'll check for this in a few steps.

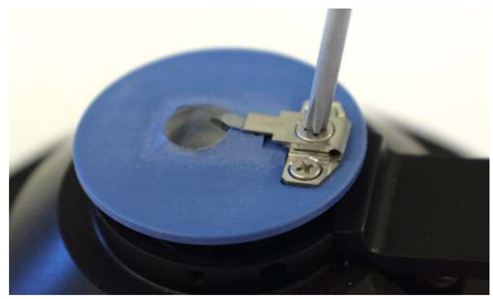


Note The quartz window is resilient to scratching from tweezers, so do not be paranoid.

9. **Tighten the screw:**

- Gently tighten the clip's screw.
- The chip should not be able to move if nudged with the tweezers. Firmly mounted probes will perform best during AC mode imaging.

Note Do not over tighten the clamp on the cantilever holder - this can crush the chip, strip the screw threads and / or result in an excessively bent clamp.



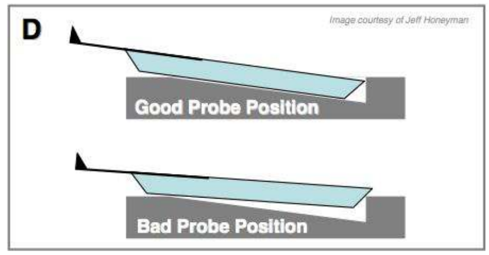
10. Close the cantilever box if you did not already do so.

4.2.3. Mounting the Cantilever Holder

1.

Inspect the cantilever “seating”:

- Hold the changing stand so you can look from the side between the cantilever clip (a low power microscope or a jeweler’s loupe, 10× is recommended).
- Check that the cantilever chip is parallel to the mounting surface and glass prism facet.
- If the probe is mounted too far back, it causes an improper angle, and you will not be able to align the laser when the cantilever has been loaded into the AFM. (See Section 2 on page 29 for an example of improper alignment). Correct the position by loosening the screw and moving the cantilever forward in the pocket. Tighten the screw and inspect the “seating” again.



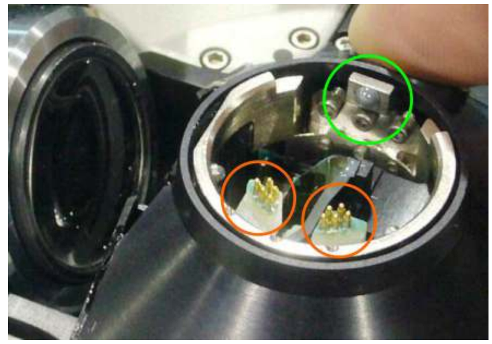
2.

Install the cantilever holder on the head:

- Remove the cantilever holder from the stand by depressing the lever. Take the holder over to the head.
- Insert the cantilever holder into the head. This action is similar to using the changing stand (See Step 3 on page 18) except the rubber dome on the head replaces the lever on the stand.

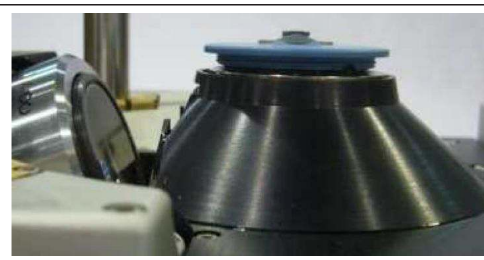
Warning

- Unlike the changing stand, the AFM head has a number of spring loaded electrical contacts called “pogo pins.”
- Take care not to touch these contacts with the cantilever holder during installation.
- While it is not likely that the contacts will bend or fail, some of them do carry low voltages which could short out via the cantilever holder. To prevent this, current cantilever holders have a black non conductive coating on the rear side metal parts. Be more cautious if your cantilever holder is older with uncoated metal parts.



3. **Inspect mounting of the cantilever holder:**

- The cantilever holder should sit perfectly level with the top and bottom planes of the head.



Tips & Tricks Please see Section 4.10.1 on page 39.

4.3. Head and Sample Placement

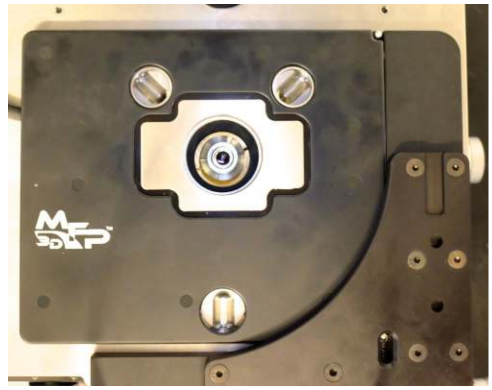
Refer to Section 2.1.2 on page 7 and Section 2.1.3 on page 7 to look up the names of various head and base controls.

4.3.1. Instructions: Head and Sample Placement

1.

Prepare the scanner:

- Remove any sample that may be on the scanner.
- Looking from above, turn the XY sample alignment micrometers (thin knobs) until the divots or grooves in the base plate are aligned over the leg holes in the scanner.



Note Base plates prior to 2009 usually only have divots for the rear legs. Current model base plates have one groove for each leg.

2.

Place the head on the base:

- Firmly grip the head and place it on the base. Each leg goes through one of the leg holes in the scanner.
- Since no sample is present there is no worry about crashing the cantilever into anything.

3. **Adjust the legs on the head:**

- Look for clearance between the scanner top plate and cantilever.
- Turn the thumb wheels that control the legs to create sufficient space for the sample. Seen from above, clockwise motion raises the head; see the arrow on the top of the head for guidance.
- The goal is to have at least 1mm of clearance for the cantilever when the head is first set down over the actual sample. Be conservative on your first attempts. If you are worried, wheel the legs all the way up.
- In the process try to end up with the head reasonably level.

Tip A white piece of paper taped to the back of the hood makes for a good background against which to see the cantilever holder.

4. Remove the head from the base and place it to the side (preferably on the head stand).

5. **Place the sample on the scanner:**

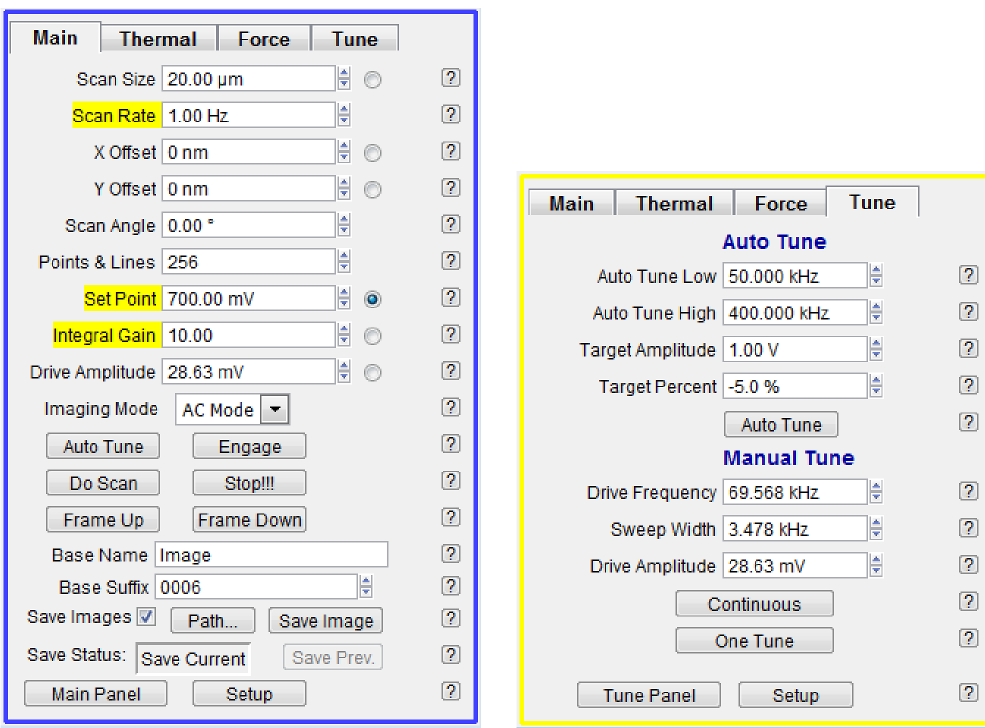
- Locate the microscope mounted calibration grating (part number 900.237) that shipped with your AFM.
- Wipe the scanner top plate clean of any particles.
- Place the microscope slide on the scanner top plate, center it over the hole.
- Place the magnetic sample clamps as shown.

6. **Visually lower the head over the sample:**

- Place the head on the base. As shown on the right, place the rear legs first, and then gently touch down the front leg while looking for clearance between tip and sample.
- If it looks like the tip might crash, remove the head, place it on the head stand, extend the legs a little, and try again. Be conservative.
- Once the head is standing on the base, adjust the legs to lower the head so there is about a millimeter of clearance between tip and sample.

4.4. Software Prep

1. If you have not done so already, open the software as shown in Chapter 3 on page 10.



(a) Master Panel, Main Tab. **(b)** Master Panel, Tune Tab.

Figure 4.2.: Main tab and Tune tab of the Master Panel

4.5. Head and Base Optics Alignment

Refer to 2.1.2 and Section 2.1.3 on page 7 to look up the names of various head and base knobs.

Note While the majority of AFM systems sold by Asylum Research have top view optical capability, there are some systems in the field which do not. If your head or base are lacking the top view focus adjustment and XY mirror adjustments in Figure 2.3 on page 8, please skip this section.

1.

Open the live video window:

- Turn on the computer, and open the Asylum Research AFM software.
- In the software, click the *Camera* icon on the bottom status bar.

-OR-

- From the menu bar at the top, select *AFM Controls* ▷ *Other* ▷ *Live Video*.
- The video window has its own menu bar. Check that
  - *Source* ▷ *Composite (For SA Systems)*
  - *Source* ▷ *SVideo (For IO Systems)*

2.

Adjust the base optical path:

- Rotate the rightmost field diaphragm knob fully counterclockwise. This illuminates a maximum area around the cantilever.
- Pull out both illumination and camera controls to route light and viewing to the top of the sample.
- Turn the knurled ring around the entry point of the fiber optic bundle (at the left of the base) fully counterclockwise to admit maximum light into the base.

Note Once you have an image of the cantilever you can adjust the diaphragms for better contrast.

3.

Turn on the Fiber Lite:

- Turn on the Fiber Lite.
- Turn the tethered dimmer control to 50%.
- The Live Video window should become brighter and there should be light visible on the sample and the cantilever.

4.

Adjust Top View focus and mirror:

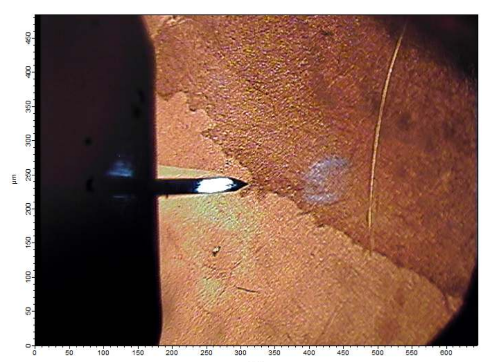
- Adjust the focus ring on the “tail” of the head.
- Adjust the two thumbscrews at the end of the “tail” to *center* the cantilever in the on-screen video image.

Note Typically the adjustments should be minor since the cantilever is always in nearly the same place on the cantilever holder. You may have to hunt a bit for a good image.

5.

Improve image contrast:

- Adjust the top view field diaphragm on the base and observe. Smaller aperture typically produces better contrast. It is common to leave some of the diaphragm showing in the image.
- Adjust the aperture diaphragm (knurled ring at the fiber lite entry point on the base).
- Adjust the intensity on the Fiber Lite if necessary.



Tips & Tricks Please see Section 4.10.2 on page 41.

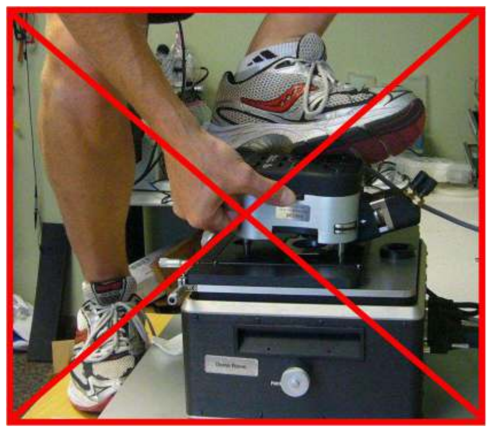
4.6. Aligning the Laser

With a good video view of the cantilever in the live video window, we can proceed with aligning the spot onto the cantilever. Refer to 2.1.2 and Section 2.1.3 on page 7 to look up the names of various head and base knobs.

Note	When a “laser” is mentioned in the text, it actually refers to a super luminescent diode (SLD, emits at ~860 nm). The SLD is a cousin of the solid state laser, but different in that it produces fewer artifacts during imaging and force curves.

Easy does it!

- When adjusting any of the head’s thumb wheels, if you feel resistance turning them, DO NOT FORCE IT. It is probably at the end of its travel. If you over torque, it becomes very difficult to reverse direction, OR the belt that is attached to the knobs to turn the pivot points on the optical assembly can get irreversibly damaged, and it will have to be repaired at the factory.
- Use a gentle touch when adjusting the LDX, LDY & PD knobs.



1. **Turn on the laser:**

   - Turn the laser (SLD) key on the controller to the ON position. Check that the LED on top of the head is ON.

   Note With the ARC2 Controller, if the Igor software is closed the laser will be off.

   Note If the system will not be in normal use for long durations (greater than several days), we recommend that the SLD be turned to the OFF position to preserve its lifetime. For day to day use the laser is better left ON. Each time the laser is turned on or off, the head must thermally equilibrate for several hours, which can lead to unwanted drift during imaging.

2.

Adjust the fiber light intensity:

- Turn down the power of the Fiber Lite to zero and then *just slightly* back up again to the point where a decent image of the cantilever appears again.

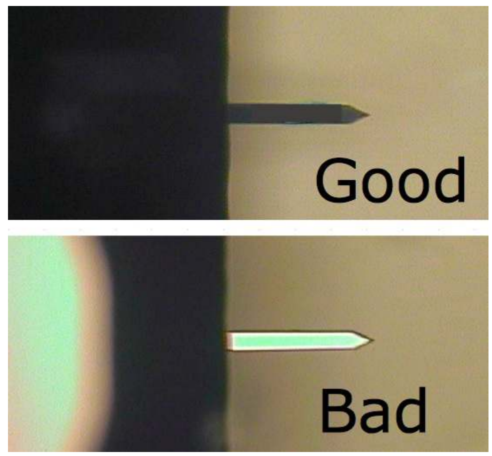
Note You may also see blue spots, which are either the laser spot itself or its reflections. The brightness of the image on the screen may not change much as you turn the fiber lite control. This is due to the auto gain control in the camera which makes up for the changes in brightness. What you will notice is an apparent change in the brightness of the laser spots. The key is to allow just enough light into the camera so there is a good balance between fiber light intensity and laser light intensity.

Tip Inspect cantilever seating:

You can judge the angle of the cantilever by looking at the reflected white light.

Dark = Good: A dark outline of the cantilever and chip, as seen in the top image, indicate good chip alignment.

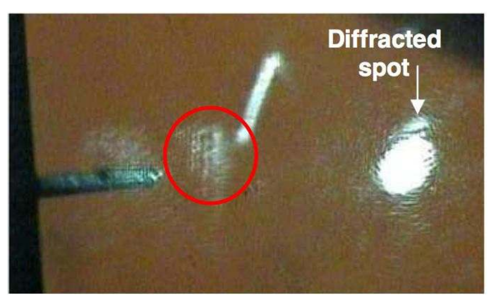
Bright = Bad: If you see a bright cantilever AND chip, as seen in the lower image, you have an issue with an improperly seated cantilever (See Step 1 on page 21)



3.

Practice moving the laser spot

- Observe the live video screen while doing the following:
- Rotate LDY clockwise (CW) until it reaches the end of its range and you feel some resistance. Then, while counting the number of turns, go completely counterclockwise (CCW) to the other end. Now go CW again, but half the counted number of turns. The laser is now near the center of its Y range.
- Turn LDX CCW until the end of its range, which will put the spot beyond the right end of the screen.
- You may see some spots moving around on the live video window. Get a feel for how they move while you rotate the wheels.



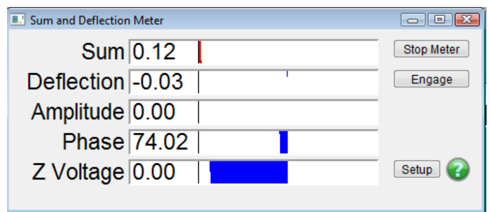
Note

Due to multiple reflections from various optical components inside the AFM head, there are often multiple spots visible on screen. The brightest spot is not always the correct one, and may be a “phantom” reflection. In this tutorial, chances are the sample is still quite far away from the cantilever, and there is no way to actually see any spot that is not on the cantilever. Please follow the steps below as a recipe for finding the right spot.

4.

Sum and Deflection meter

- Locate the sum and deflection meter (Ctrl + 6).
- Make sure the button to the right of the SUM signal says *stop meter*. If the button says *start meter*, click on it so the meter starts running.
- The SUM signal displays the total laser light reflected from the cantilever. It should have a near zero value based on the laser position from the previous step.
- The SUM signal will be the test for seeing if the real spot was moved onto the cantilever.



5.

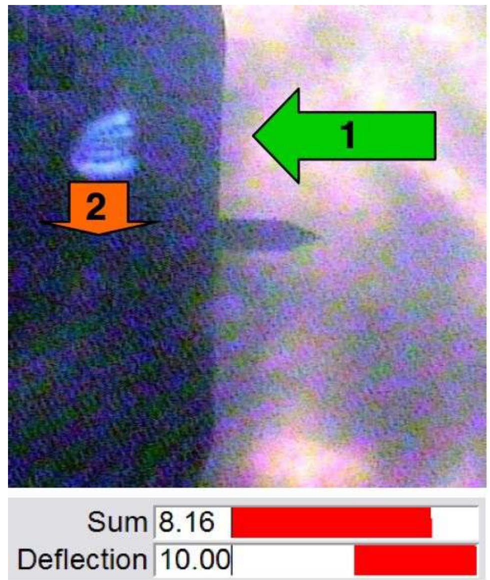
Steer the laser spot onto the cantilever chip (substrate).

(1) Rotate LDX clockwise while observing the SUM meter. Most likely the SUM will go up above 6 when reflected off the chip. It is at the same angle as the cantilever and perfectly angled to reflect light back into the detector.

Note There is a small chance that you will actually hit the lever. If you see this happen on the video screen, you can skip the next two steps.

- You should see a spot on the substrate. If not, lower the Fiber Lite intensity a bit.
- Move LDX some more to see the spot moving.

(2) Now move LDY until the spot is in line with the long axis of the cantilever. The SUM should remain high.

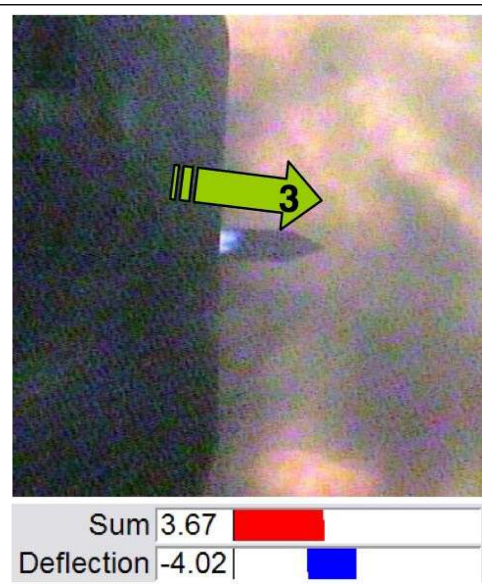


6.

Steer the laser spot on the cantilever

(3) Turn LDX counterclockwise to move the spot out along the base of the cantilever and to the tip.

- You will see the sum signal go very low and the spot disappear from view for a moment as the beam traverses the sloped area of the substrate.
- Adjust LDY as necessary to keep the spot centered on the cantilever.
- The SUM should end up a bit lower than it was in the last step.

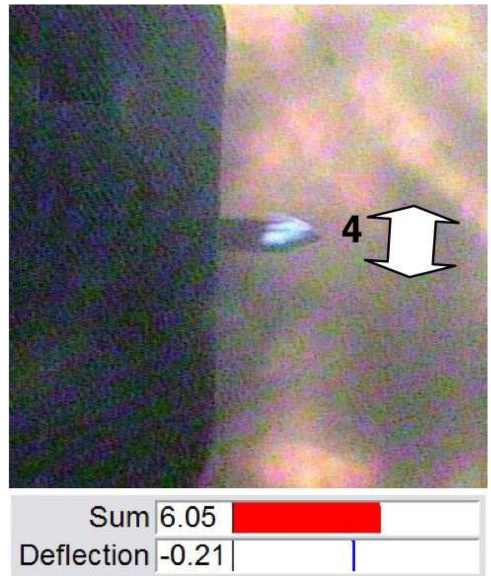


7.

Adjust LDY and maximize SUM

(4) Turn LDY back and forth to observe the SUM fluctuating and the spot going on and off of the lever.

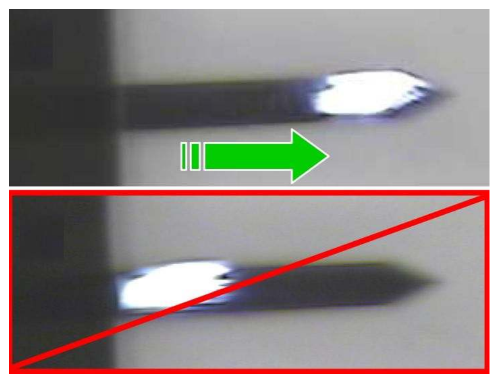
- Leave LDY where the SUM is highest.
- The spot should now be near the end of the lever, centered, and ready for AC tuning.



8.

View your final alignment

- From the live video window menu bar, select *Magnify.*
- This will zoom in on the center portion of the video window.
- Fine tune your final laser spot position near the end of the lever if necessary. Maximize the SUM while moving LDY.



9.

Zero the deflection

- Note the deflection level in the Sum and Deflection meter.
- Use the PD thumb wheel on the head to zero the deflection. If the display indicates blue (negative) then rotate the thumb wheel counterclockwise. Go clockwise if it is red.
- This action steers the reflected beam so it is centered on the photo detector.

Tips & Tricks Please see Section 4.10.3 on page 42.

4.7. Tuning the Cantilever

The tutorial steps given are with an AC160TS. The stiffer, higher resonance frequency of the AC160TS cantilever makes it easier to track the large hard features of the calibration grid. However, similar results can be obtained with the AC240TS, which is the tip of choice for biological and soft samples, or samples that do not have large changes in topography.

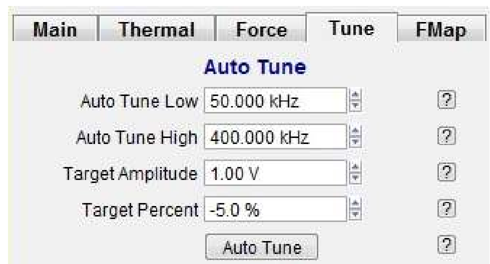
1.

Initiate cantilever tune:

- Select the Tune tab in the master panel (Figure 4.2b on page 25).
- Set the four auto tune parameters (*Auto Tune Low*, *Auto Tune High*, *Target Amplitude*, *Target Percent*) as shown to the right.
- Click the *Auto Tune* Button.

-5%: Amount the drive frequency will be below the maximum. This helps ensure that the tip will remain in repulsive mode when engaged.

50 kHz and 400 kHz: The default *Auto Tune Low* and *High* values accommodating most common commercially available AC mode cantilevers (in air).

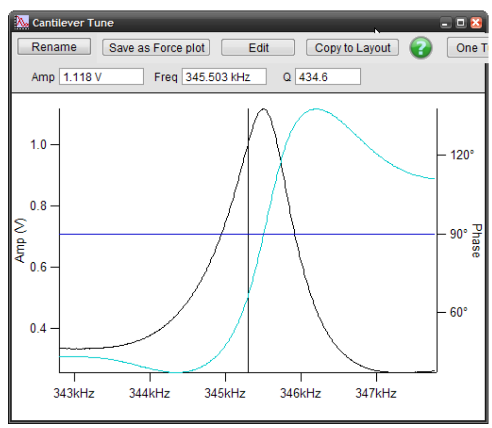


2.

Observe tune result:

- A graph will pop up with the tune result.
- The resonance curve should peak around 200-400 kHz.
- The relevant parameters, *Drive Frequency*, *Drive Amplitude* and *Phase offset*, are automatically set.
- After inspecting and confirming that the the amplitude and phase curves look good, you can close the graph.

Note For the AC240TS, the resonance curve should peak around 70 kHz.



Note Cleaner tunes can be obtained by blowing the cantilever holder with compressed air prior to loading cantilever to get rid of any left over silicon/glass debris.

Tips & Tricks Please see Section 4.10.4 on page 43.

4.8. Landing the Tip

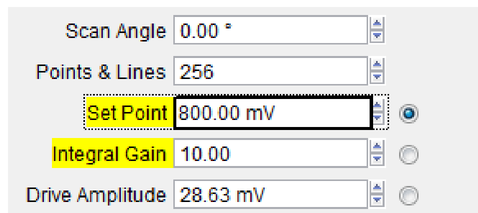
Hard vs. Soft

The following steps are for the “hard engage”. This is an easy-to-master and perfectly acceptable method of engaging the tip on the surface. In cases where a super sharp tip is required, we recommend you master the somewhat more elaborate “Soft Engage” method, described in Section 4.10.6 on page 44.

1. **Set the feedback setpoint for hard engage:**

Note: For better tip preservation, consider the more elaborate Soft Engage Section 4.10.6 on page 44.

- Set the *Setpoint* value to 80% of the free air amplitude. Typically the amplitude away from the surface is 1 volt, after a standard autotune, which would call for an initial setpoint of 800 mV.
- All the other parameters should already be set from tuning the cantilever.



2. Click the *Engage* button in Sum & Deflection Meter window. The Z Piezo meter will extend red all the way to the right of the meter (150V).

3. **Wheel down until ’beep’:**

- Slowly turn the front thumb wheel counterclockwise to lower the head towards the surface.
- Observe the amplitude and slow the wheeling when the amplitude starts to decrease. The amplitude decreases before contact due to air damping between lever and surface.
- When the computer beeps stop, the tip has contacted the surface.

4. Move the front thumb wheel until the Z voltage registers about 70V (in the blue). This brings the Z piezo to its midpoint.

5. Hit the ‘Withdraw’ button on the *Sum and Deflection Panel*. This will save the tip from jostling during the next step.

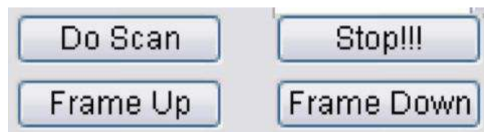
6. Close the acoustic enclosure. At this point manual interaction with the instrument is at an end. The tip is still above the surface and the vibrations of closing the hood will not damage it.

Tips & Tricks Please see Section 4.10.5 on page 44.

4.9. Start Imaging

1. **Start the scan:**

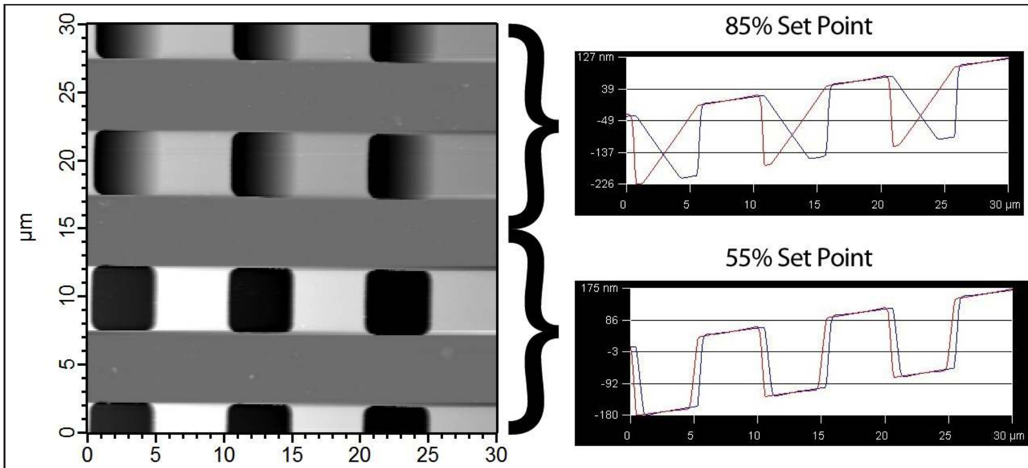
- Click the *Do Scan* button (or Frame Up or Frame Down) on the *Main Tab* in the *Master Panel*. The tip will begin scanning from the top or bottom of scan area. The red marker to the left of each image window indicates the current scan line.



2. Look at the Height Channel image (ignore amplitude and phase for the moment) and locate the blue and red scope traces beneath it. These are the last collected trace and retrace scan lines. The tracking should look nearly identical to the retrace. For the calibration grating sample, they should look like a square wave. To achieve this, some adjustment of the parameters is usually needed.

Note Wait until the tip is actually scanning over some pits in the calibration grating. There is not much to image on the plateaus in between the pits. This is a good time to turn off the slow axis, see Section 4.10.7 on page 45.

3.

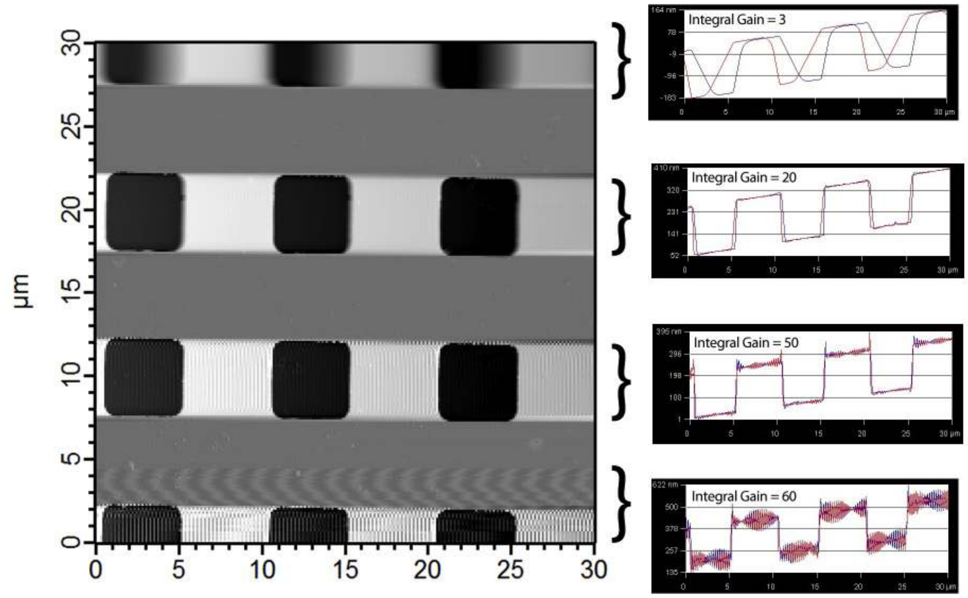


Setpoint Voltage

- The *Setpoint Voltage* generally needs adjustment:
- Decrease the *Setpoint Voltage* value to increase the force applied to the sample, and to improve the tracking.
- Higher *Setpoint* voltages may help preserve the tip apex, but may not allow proper tracking of the surface.
- For this example, use a *Setpoint* between 600-750mV.
- Practically speaking, amplitude setpoints from 20-75% of the free air amplitude will put you in repulsive mode, which tend to track well, but may wear down your tip.

Advanced Note	Adjusting the initial setpoint while scanning as described here is more to illustrate things. Typically experienced users do this during the engage process, where you engage on the surface, then decrease the setpoint until the Z does not move much.

4.



Integral gain adjustment:

- Increase the *integral gain* to improve the tracking, but at a certain level the signal will start to ring.
- Decrease gain until ringing ceases in trace and retrace.

Note There is a slight offset between the trace and retrace lines in the graph. Good tracking means that they should have similar shapes, not necessarily perfect superposition.

Note When adjusting *integral gain*, another channel to look at is the amplitude image. Feedback oscillations are easily detected in the amplitude image because it is an image of the feedback loop error.

5.

Scan rate adjustment:

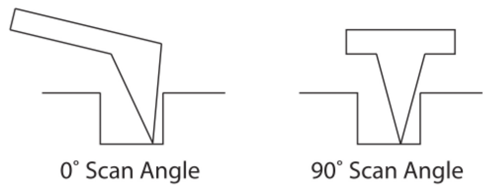
- If tracking still seems to be an issue, try lowering the *Scan Rate*. Slowing the *Scan Rate* down will help the feedback keep up with the image features.
- The Scan Rate cannot be updated during imaging like other imaging parameters. You must click *Frame Up* or *Frame Down* buttons to initiate the newly entered scan rate.

Note Too slow of a scan rate can introduce image artifacts due to thermal drift.

6.

Scan angle adjustment:

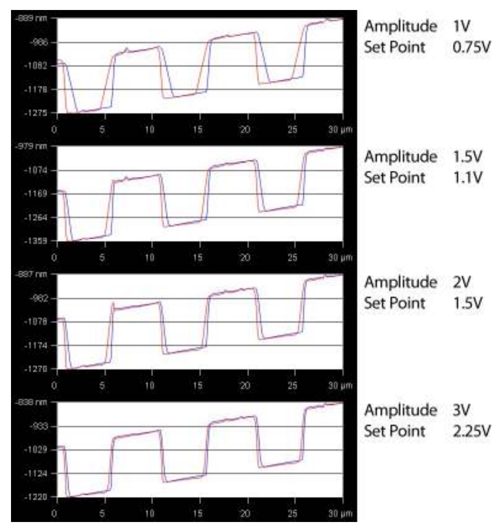
Note For the Olympus AC160 and AC240 cantilevers, the tip will be symmetric or asymmetric based on the scan angles shown on the right. For a better representation of side walls 0º scan angle should be used. However, tracking could be difficult due to the steep edge of the tip. Better tracking could be achieved with a 90º scan angle. This is one example; refer to cantilever documentation for different tips.



7.

Drive amplitude adjustment:

- The *Drive Amplitude* can be adjusted to increase the amount of drive to the shake piezo which increases the amplitude of the cantilever.
- Try different combinations of Free Air Amplitude (tip far away from surface) and *setpoint*. For educational purposes, the *setpoint* was kept at 75% and the *integral gain* at 10 to show the advantage of hitting the sample harder with bigger amplitudes to get better tracking.
- To change the amplitude, click *Stop* and either click *Auto Tune* with the new *Target Amplitude* or increase the *Drive Amplitude* manually.

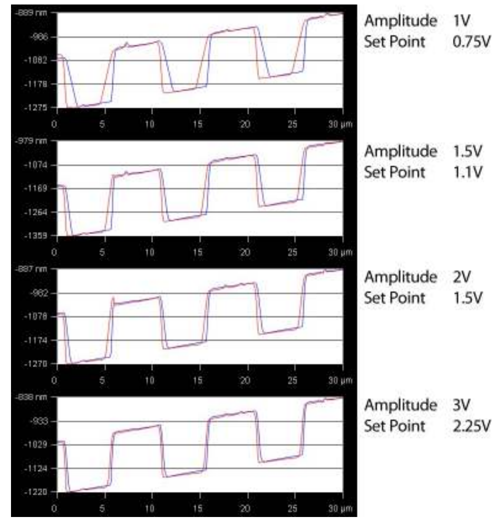


8.

Tracking improvement:

- When the tip is tapping harder, the cantilever becomes more responsive to changes in height, which improves tracking.
- Bigger amplitudes can help the tip stay in repulsive mode. Please refer to *SPM Applications Guide, Chapter: AC Mode Theory* for more information.
- When imaging sticky samples, larger amplitudes help the tip escape the forces of the sample.

Note You could also simply increase the *Drive Amplitude* however, be aware of the setpoint. It is often good to maintain a constant setpoint ratio, the ratio of the setpoint to the free air amplitude.



Tips & Tricks Please see Section 4.10.7 on page 45.

4.10. AC Mode Imaging Tutorial Tips & Tricks

4.10.1. Loading the Cantilever Tips & Tricks

If everything went according to plan, then this section can be skipped (or only read once to learn a few tips). What follows is not strictly part of the necessary instructions.

Q What's the harm in forcefully tightening the screw which clamps the cantilever?

A Over tightening can strip screw threads or result in excessive bending on the tongue of the clip, which can cause issues with obtaining suitable deflections with cantilevers of unusual thicknesses.

Q Which Cantilevers can I use with the MFP-3D?

A The MFP-3D cantilever holder accepts virtually all brands of commercially available probes.

Q What's the best way to clean the cantilever holder?

A The safest way is to use a cotton swab (Q-tip) and some alcohol.

Tip Fitting unusually thick cantilever chips under the clip:

When switching from silicon cantilevers (with thin silicon chips) to silicon nitride levers (with thick glass chips) you may notice that the cantilever holder clip does not open enough to let the lever slide in. Here’s the remedy:

- Unscrew the center screw an extra turn or two. Do not screw it all the way out since it will prevent you from bending the clip too far in the next step.
- Use tweezers or a small flat-head screwdriver to GENTLY pry up on the tongue near the base. In our experience it is best to start lightly, try for fit, and repeat a bit more forcefully until the clip stays open high enough to fit the thicker substrate.

Tip There is evidence that static charges can create such large fields at the tip of a lever that they are dulled just by handling from corona discharge. Consider wearing a grounding wrist strap and using a grounded work surface if your work requires the sharpest tips possible.

Tips

Some tips on successfully handling cantilevers.

- Use good tweezers. The cost of good tweezers is easily justifiable considering the cost of cantilevers. Some people swear by the curved tweezers; some prefer the straight ones. Remove any sticky residue by cleaning the tips of the tweezers with an alcohol soaked lint free cloth.
- Keep your box of cantilevers close to the cantilever holder when loading the holder. It is nice to do most of the work with the wrist.
- Rest as much of your arm on the table as possible for stability. For added stability you can use your non-dominant hand to stabilize the hand holding the tweezers.
- Roll cantilevers off of the sticky gel instead of trying to lift them straight up. Roll to the side to protect the levers themselves.
- Grab the substrates a little forward (toward the cantilever) of the middle. If you pick up the back side first, you run the risk of breaking the lever.
- Set the cantilever down in an intermediate location to allow you to get a new grip before loading it into the holder. This is not always necessary, but it is nice to have a place available for an emergency landing if needed. You may also take this opportunity to close the box of unused levers.
- Practice with dead cantilevers. Keep your used levers and practice moving them from one side of a box to another, trying to maintain an orderly pattern.

4.10.2. Head and Base Optics Alignment Tips & Tricks

Tip Using the live video window when placing the head:

If your head mirror and focus are already aligned when you change samples, it can be useful keep an eye on the live video as you put the head in place. By doing this, you can view whether or not the lever will crash while placing the head.

Tip Getting more consistent head placement:

Each time the head is placed into the divots on the base, it does not land in exactly the same place. It may even settle a little over time, leading to unwanted movement of the cantilever during imaging.
We have found that pressing down on the head while applying a counterclockwise rotational force at the same time greatly improves absolute placement position. This will also prevent most settling effects.

Tip Streamlined head placement process:

Experienced users at Asylum Research will skip a few of the above steps:

- Eyeball the sample thickness and guess at the leg lengths and adjust with the head removed from the scanner.
- Place the sample on the scanner.
- Place the head on the scanner while propping a thumb between the head and scanner, holding the tip about 1mm above the sample, while wheeling down the front leg until it touches down

4.10.3. Aligning the Laser Tips & Tricks

Tip	The correct laser spot will show some elongation along the length of the cantilever. If a spot without this elongation is seen, it is a "phantom" spot and will give no Sum voltage in the S&D meter even though there appears to be a spot on the end of the cantilever.

Tip	In some cases the correct spot may appear to be off the cantilever while there is a large SUM signal. This is usually due to poor focusing. Adjust the head's top view objective focus wheel to correct.

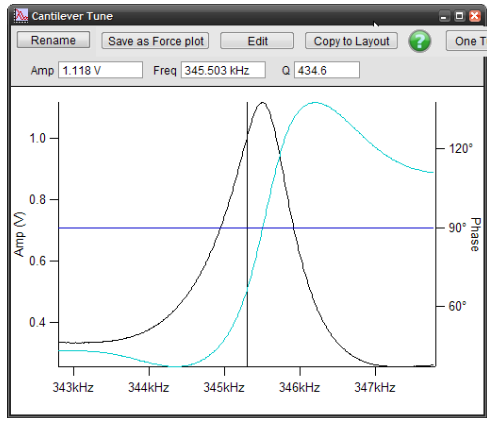
Tip	If there is any question if the spot is aligned on the cantilever or the probe substrate, there is a very easy way to tell - do a thermal tune! (See[a]) If the SLD spot is on the chip, there will not be any resonant peak (with significant amplitude or Q) in the thermal. This is especially useful for systems without top view optics.

[a] *SPM Applications Guide, Chapter: Thermal Tuning..*

4.10.4. Tuning the Cantilever Tips & Tricks

Tip How to Save Tune plots?

- Click *Save as Force Plot*. The saved tune can then be reviewed in the Master Force Panel.
- Click *Rename*. The graph is saved in a separate window. Subsequent tunes can be overlaid on top of each other if they are given the same name or saved in a new graph when given a new name.
- Click *FTP*. This saves the experiment on the computer in a Temp Folder. This allows you to upload the file to the Asylum Research FTP site for discussion with Asylum Research technical staff.
- Click *Layout*. This appends the graph to a layout.



Tip Drive Amplitude too high or too low?

If the drive amplitude is greater than ~1V or you do not see a clean tune, then the coupling to the tip may not be sufficient.

- Loosen and re-tighten the screw or move the chip. Mostly likely the probe chip was seated improperly under the clamp.

If using high aspect-ratio tips, there is a chance the Q (Quality factor) of the cantilever will be so high that the drive amplitude will be very low, and a message will come up during the Auto Tune that says it is having difficulty completing the Auto Tune. There are a few things you can do to get around this:

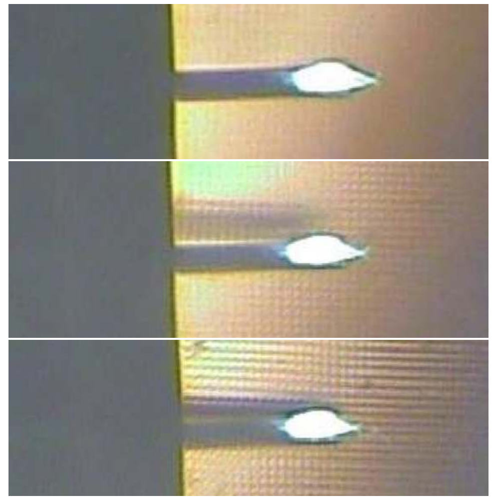
- Manually increase the Drive Amplitude in the *Tune* tab, click *One Tune* and it should work.
- Click *Center Phase* if using *One Tune*.
- Use Negative Q Gain. See *SPM Applications Guide, Chapter: AC Mode Imaging* for more information.

4.10.5. Landing the Tip Tips & Tricks

Tip If the sample is reflective, the shadow of the cantilever can be seen in the top view CCD camera image as it approaches the surface of a calibration grating.

Images (from top to bottom):

- No cantilever shadow is visible because the tip is too far away from the surface.
- Moving tip towards the surface, cantilever shadow appears, surface coming into focus.
- Moving tip closer to the surface, the cantilever almost eclipses the shadow. The surface is in focus.



4.10.6. Hard and Soft Engage Techniques

The soft engage technique is an advanced method that provides the softest possible engaging of the tip. With this method you can preserve even the sharpest, most fragile of tips, which will provide you with the sharpest of images. This method is more advanced, but with some practice can be done fairly quickly.

4.10.6.1. Hard engage method

1. Click 'Engage' to fully extend the Z piezo.
2. Wheel down the large thumbwheel.
3. Slow down when the amplitude starts to decrease. The cantilever is starting to respond to long range tip sample forces.
4. Wheel down very slowly until the beep.
5. Wheel down slowly until the Z voltage is 70V.
6. Decrease your setpoint a click or 2 (down arrow to the right of setpoint control), make sure Z does not move much. This confirms that the tip is firmly on the surface.

4.10.6.2. Soft Engage Method

1. Enter a setpoint of 85% of the free air amplitude, click 'Engage' to fully extend the Z piezo.
2. Wheel down the large thumbwheel.

3. When the cantilever starts to feel long range forces, the amplitude decreases (as the thumb-wheel turns) until the setpoint is reached. At that point the feedback will start retracting the piezo (software beeps) as the head continues downward.
4. Stop wheeling when the Z voltage indicator approaches 30V.
5. Gradually decrease the setpoint and watch the Z voltage increase in response as the tip extends toward the surface. Stop decreasing the setpoint when the Z voltage stops responding (the tip has reached the sample surface and you are done) **- OR -** when the Z voltage exceeds 100V. A more responsive phase signal is another indication that the tip is on the surface.
6. If the Z piezo kept extending past a value of 100V, start wheeling down the head and go back to step 4.

It is uncommon to repeat steps 4 and 5 more than once. If so, you may want to consider using a lower initial setpoint relative to the free amplitude.

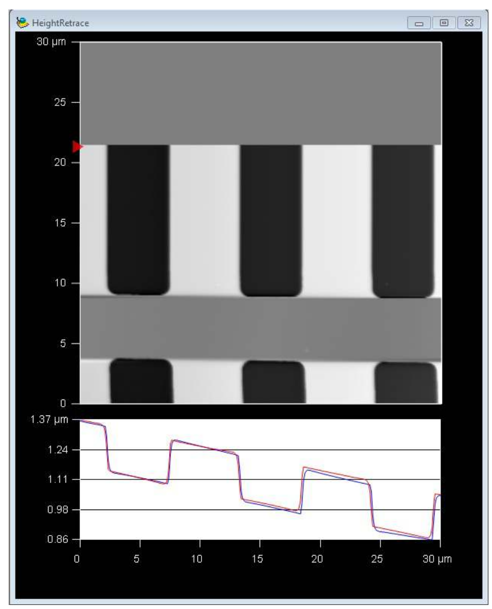
If you end up with a good engage, but with Z outside 70±20V, see Section 6.2.2 on page 55 for a softer centering of Z.

4.10.7. Start Imaging Tips & Tricks

Tip Adjusting scan parameters with *slow scan disabled*:

When the *Slow Scan Disabled* checkbox (on the main tab of the master panel) is checked, the tip scans the same line repeatedly. This is easier for comparison when optimizing parameters as the features will be the same from scan line to scan line.

- Increase the integral gain until oscillations are seen in the trace and retrace lines for the height channel.
- Reduce *Integral Gain* until oscillations disappear.
- Adjust *Setpoint* and ‘Drive Amplitude’ until good tracking occurs.
- ‘Scan Rate’ and *Scan Angle* can be adjusted to further improve image quality.
- Un-check it once you have your imaging parameters where you want them.



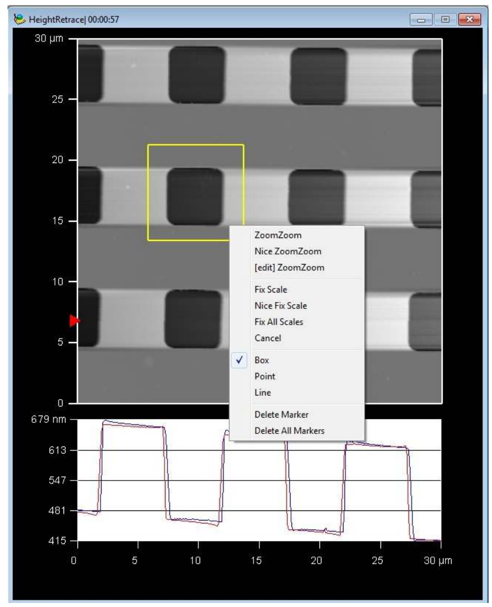
Tip Delay Update:

- The *Delay Update* check box allows the user to change the parameters during a scan. The changes you make will take effect at the beginning of the next frame.
- During the period before the update is performed, the parameters changed will be highlighted in a light blue color.

Tip Zoom:

This will stop the current image and restart imaging a smaller selection.

- To scan a selected area, drag a box.
- Right click and select *ZoomZoom* to scan the selected area, *Nice ZoomZoom* to zoom an area to the nearest rounded number, or *[edit] ZoomZoom* to type an exact scan area.



Tip Proportional Gain

- Adjusting the *Proportional Gain* does not generally improve the imaging - this is because the frequency range of the scanner is below the range where the proportional gain can contribute.
- For most samples, keep *Proportional Gain* at 0. The exception to this rule is when very large or sharp topography features are present, and the feedback loop needs to react very quickly to the sample surface.

5. Tutorial: Replacing the Cantilever

CHAPTER REV. 1578, DATED 08/29/2013, 22:20. USER GUIDE REV. 1590, DATED 08/30/2013, 12:47.

Chapter Contents

Before you start:

- We assume you have followed the tutorial in Chapter 4 on page 15, which finishes with AFM images being collected. This tutorial picks up at that point.

The previous tutorial assumed that you found the instrument in a completely unknown state and included many alignment steps which do not apply to a typical situation, such as changing a cantilever and resuming scanning on the same sample. Scanner alignment, optical alignment, and even most scanning parameters should already be ready for imaging in most cases.

This tutorial assumes the starting point where the last tutorial ended up: imaging the calibration grating sample in AC mode. When finished, it will leave you at the same point again, scanning the same sample, but with a fresh cantilever.

1. Halt the scan by clicking the Stop!!! button in the Main tab of the Main Panel. This will retract the tip from the surface and stop the XY scanning of the sample.
2. Open the acoustic enclosure.
3. **Wheel up one full turn:**
   - Wheel the front leg up one full revolution clockwise to raise the cantilever about 100 µm above the sample surface.

4.

Remove the cantilever holder from the head:

- Place the AFM head upside down (usually on the metal platform or "head stand" next to the AFM.)
- Depress the rubber ball on the head.
- Gently lift the cantilever holder straight up out of the head and carry it to your cantilever changing area.

5.

Mount the cantilever holder:

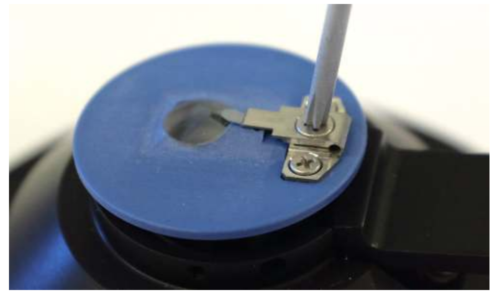
- Orient the cantilever holder with the clip's screws towards the lever on the stand.
- Press the lever on the stand as shown.
- At the same time, angle the cantilever holder into the stand. Two fixed balls in the stand, opposite the lever, must match up with the two matching kinematic mounting points on the cantilever holder.
- Lower the cantilever holder so the final kinematic mounting point lines up with the ball on the stand's lever, then release the lever.
- Inspect that the cantilever holder sits flat in the stand and that all the balls sit properly in the mounting points.

6.

Remove the used cantilever:

- Loosen the middle screw about one turn, just to the point of freeing the cantilever.
- Remove the old cantilever with tweezers.

Good Habit Blow the area under the cantilever clip clean with *clean* compressed gas. Bits of silicon and other debris can lead to a poorly seated cantilever and sub-optimal AC mode images.

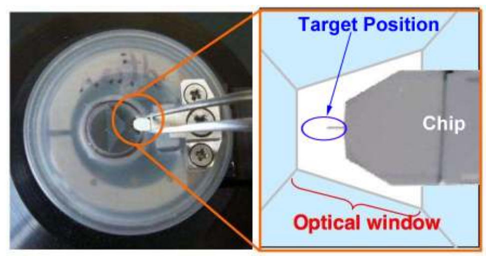


7.

Insert the new cantilever:

- With tweezers, slide the cantilever chip under the clip.
- Center the cantilever tip (approximately) in the clear trapezoidal shaped quartz optical window.

Note Do not push the cantilever chip too far back. This can cause misalignment. We'll check for this in a few steps.



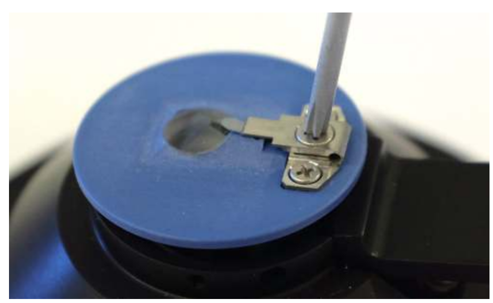
Note The cantilever holder was designed to be resilient, so do not worry about scratching it with tweezers.

8.

Tighten the screw: Gently tighten the clip's screw.

- The chip should not be able to move if nudged with the tweezers. Firmly mounted chips will perform best during AC mode imaging.

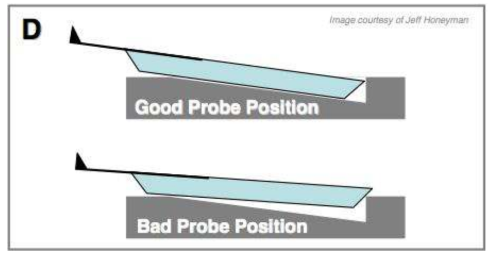
Note Do not over tighten the clamp on the cantilever holder - this can crush the chip, strip the screw threads and / or result in an excessively bent clamp.



9.

Inspect the cantilever seating:

- Hold the changing stand so you can look from the side between the cantilever clip (a low power microscope or a jeweler's loupe, 10× is recommended).
- Check that the cantilever chip is parallel to the mounting surface and glass prism facet.
- If the probe is mounted too far back, it causes an improper angle, and you will not be able to align the laser when the cantilever has been loaded into the AFM. (See Section 2 on page 29 for an example of improper alignment). Correct the position by loosening the screw and moving the cantilever forward in the pocket. Tighten the screw and inspect the "seating" again.



10.

Install the cantilever holder on the head:

- Remove the cantilever holder from the stand by depressing the lever. Take the holder over to the head.
- Insert the cantilever holder into the head. This action is similar to using the changing stand (See Step 3 on page 18) except the rubber dome on the head replaces the lever on the stand.

- Pulling or jiggling the cantilever holder should result in no motion.

11.

Place the head on the base:

- Firmly grip the head and place it on the base. Each leg goes through one of the leg holes in the scanner.
- Since the sample is the same as when the head was removed and the front leg was wheeled up to a safe height, there is no worry of crashing the tip.
- Place a hand on the head and press down while slightly rotating counter clockwise. This helps ensure consistent seating of the head on the base.

12.

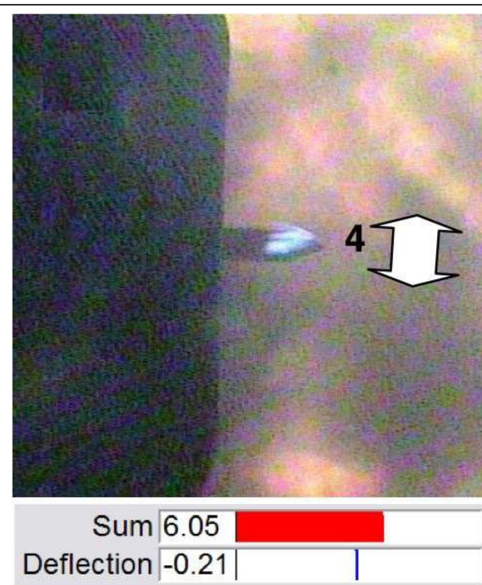
Open the live video window:

- In the software, click the Camera icon at the lower left hand side of the window
- If necessary turn on the Fiber Lite and turn the XY mirror adjustments on the "tail" of the AFM head. The next step requires a visual of the cantilever.

13.

Center the laser on the cantilever:

- Using the LDX and LDY controls, center the laser on the cantilever holder.
- A high Sum signal assures that there is not a phantom spot on the lever.

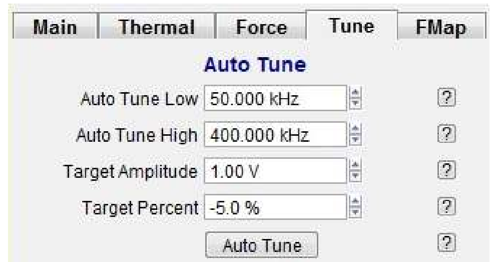


14. **Zero the deflection**

- Use the PD thumb wheel on the head to zero the deflection.

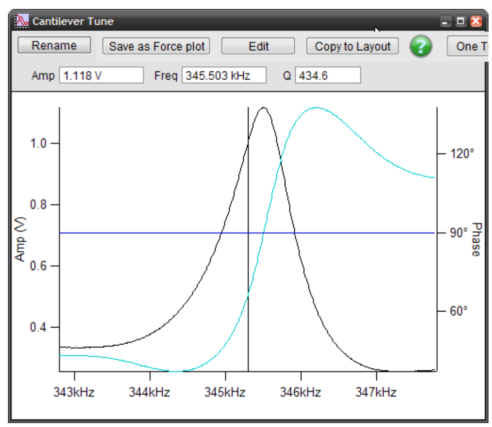
15. **Initiate cantilever tune:**

- Select the Tune tab in the master panel (Figure 4.2b on page 25).
- Set the four auto tune parameters (*Auto Tune Low*, *Auto Tune High*, *Target Amplitude*, *Target Percent*) as shown to the right.
- Click the *Auto Tune* Button.



16. **Observe tune result:**

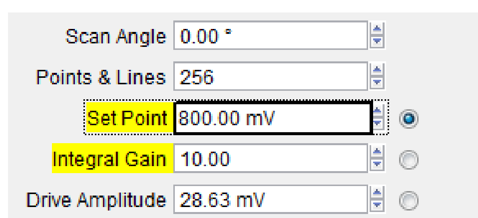
- A graph will pop up with the tune result.
- The resonance curve should peak around 300kHz for an AC160. For an AC240, the curve will peak around 70kHz.
- The relevant results are automatically stored. After inspecting the amplitude and phase curves to confirm that they look "clean", you can close the graph.



17. **Set the feedback set point for hard engage:**

Note: For better tip preservation, consider the more elaborate Soft Engage: Section 4.10.6 on page 44.

- Set the *Set Point* value to *800mV* for typical cantilevers such as AC160TS or AC240TS, the first item highlighted in yellow to the right.
- All the other parameters should still be fine from the scanning before replacing the cantilever.



18. Click the *Engage* button in Sum & Deflection Meter window. The Z Piezo meter will extend red all the way to the left of the meter (150V).

19.

Wheel down until beep:

- Slowly turn the front thumb wheel counterclockwise to lower the head towards the surface.
- Observe the amplitude and slow the wheeling when it starts to decrease by a few percent. (Amplitude decreases before contact due to air damping between lever and surface.)
- If your computer speakers are on, then you can listen for a beep to know when you have contactact the surface. Otherwise you will have to keep one eye on the Z voltage to see when it moves back from +150.

Note This is the hard engage. For the soft engage please see Section 4.10.6 on page 44.

20. Move the front thumb wheel down until the Z voltage registers about 70V (in the blue). This brings the Z piezo to its midpoint.

21. Hit the 'Withdraw' button on the *Sum and Deflection Panel*. This will save the tip from jostling during the next step.

22. Close the acoustic enclosure. At this point manual interaction with the instrument is at an end. The tip is still above the surface and the vibrations of closing the hood will not damage it.

23.

- Click the *Do Scan* button (OR *Frame Up* or *Frame Down*) on the Main Tab in the Master Panel. The tip will begin scanning from the top or bottom of scan area.

6. Troubleshooting

CHAPTER REV. 1585, DATED 08/30/2013, 10:11. USER GUIDE REV. 1590, DATED 08/30/2013, 12:47.

Chapter Contents

6.1 Laser alignment without top view optics 54
6.2 Centering the Z Piezo Range After Contact with the Surface 55
6.2.1 Brute Force Z Centering 55
6.2.2 Gentle Z Centering 55
6.3 Various issues 56

In no particular order a variety of trouble shooting advice related to things discussed in this manual.

6.1. Laser alignment without top view optics

For the AFM heads without top view optics, or the situations where one may want to set up the cantilever without having to place the head on the base, there are a few options.

The simplest method is to look only at the SUM signal. Since the general position of the cantilever and chip are always the same in the field of view, one can quite successfully imagine its position as seen in Steps 3 through 7, starting on page 18.

A simple tool called an IR card can greatly reduce the guesswork. Note that as of June 2009, IR cards are no longer shipped with our AFM systems, but they are still available for those who request them. The IR card needs to be charged up in daylight or fluorescent light. Any IR beam that then falls on the card will manifest itself as a red dot. If the dot sits in one place for too long, it will fade unless the card is moved a little, or the card is charged up again.

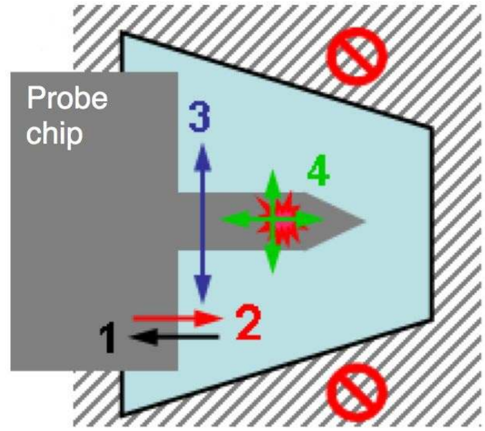
1.

Set up the head and IR card

- Place the head (with cantilever holder and cantilever) on the head stand next to the base.
- Slide the IR card under the head as shown.

2. **Move the laser onto the lever**

   - The figure to the right shows the motions in numerical order and where you should imagine the spot to be.
   - Observe the red spot on the card and associate it blinking in and out of view with your mental picture
   - Look at the SUM meter on the computer and maximize it when you think you are the end of the lever.



3. A successful positioning will result in a red spot on the IR card which looks split since its center is obscured by the cantilever. A slight movement of LDY away from the lever should reduce the SUM to near zero and make the spot on the IR card light up brightly again.

6.2. Centering the Z Piezo Range After Contact with the Surface

Ideally the Z voltage as read in the Sum and Deflection voltage falls in the middle of its range. The piezo response is most linear in the center of the range, and the LVDT signal has the lowest noise. Being in the center of the range also gives an equal amount of vertical travel for a potentially unknown sample topography and mechanical and thermal instrument settling.

As mentioned earlier, if the voltage upon contact falls in the range of 50-90V, then it is probably not worth making any adjustments. If it falls outside of this range, you have two options:

6.2.1. Brute Force Z Centering

1. While monitoring the Z voltage on the Sum and Deflection Meter, gently turn the front thumb wheel on the head. The tick marks on the wheel correspond to about 1 micron of Z motion. Turn the wheel until the Z voltage is centered in its range.

Note This can damage your tip. The feedback loop reacts to an error signal, and as you are approaching the sample, it is accumulating error of one sign. Once you reach the surface, you need to exceed the setpoint, to produce an error signal of the opposite sign.

6.2.2. Gentle Z Centering

1. Note the current Z Voltage, and subtract this number from 70V. Example: If the voltage reads 30V, your answer is 70V-30V = 40V.
2. Divide this number by 10V/µm (the standard Z range is about 15 µm spread over about 150V). In our example we get +4 µm . This means we need to raise the center of the cantilever holder by 4 µm to land the Z voltage at 70V.

3. You could also run this from the command line (Ctrl + J), Print (70-td_RV(“Height”))/10, which will print out the number of µm you need to move, the sign will tell you if it is up or down.

4. **Locate the Large Thumb Wheel Markings:**

    - Locate the markings on the large thumb wheel on the head. On older AFMs it will look as to the right. On newer models the tick marks on the black portion have been removed.
    - Locate any tick mark you like on the black portion. Ticks on the wheel correspond to approximately 1 µm of Z travel at the cantilever.

5. Click the *Withdraw* Button on the Sum and Deflection Meter Panel. This pulls the tip from the sample.
6. Rotate the large thumb wheel by the appropriate amount based on what you calculated in the earlier steps. For our example we rotate clockwise so that 4 tick marks on the silver wheel pass one of the tick marks on the black part.
7. Click the *Engage* button on the Sum and Deflection Meter Panel. Check to see that the Z voltage is now around 70V.

Since the tip was withdrawn from the surface before the front leg of the AFM was adjusted, this method avoids laterally raking the tip across the sample surface.

6.3. Various issues

No significant Deflection voltage, or very low Sum voltages: Typically either the cantilever is not seated in the pocket properly, or some debris may be acting as a fulcrum, moving the orientation of the lever out of the proper plane.

- The probe may be bad (i.e., has a bend/sag that does not allow the SLD beam to bounce off of it properly).
- There may be no cantilever on the probe (verify in CCD camera; or perform Thermal Tune). The signal may be coming from reflection off the probe chip.

Values of NaN in S&D Meter: This means not a number. What may have occurred is a slight grounding issue at the cable plug interfaces. Sometimes the grounding clamps may need a better bite into the outer ground frame of the plug. Try checking the connection.

Reducing abuse on the head cable

- Be careful not to torque/twist the cable to the head: always follow the same rotation path that you took the head off with. The head cable should only experience 180 ° of rotation in its regular on stage, off stage cycling. Continual twisting of the head can:
- Break down the head cable over time.

7. Tutorial: Contact Mode Imaging in Air

CHAPTER REV. 1590, DATED 08/30/2013, 12:47. USER GUIDE REV. 1590, DATED 08/30/2013, 12:47.

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Contact Mode AFM, also known as constant force mode, is one of the more commonly used imaging modes in AFM. It is often used in imaging hard materials, in some electrical techniques, and in imaging biological materials - e.g. cells under low setpoint force and scan range.

7.1. Required Materials

- Cantilevers: Any standard contact cantilever will work. A list of contact cantilevers we offer can be found here: Contact Cantilevers.
- Sample: The tutorial will use the Asylum Research calibration grating that ships with every system (part number 900.237). It is mounted on a standard glass microscope cover slide.
- Sharp Tipped Tweezers (some people prefer straight tips, others prefer curved).
- Small Phillips (+) screwdriver.

7.2. Instrument Setup

Several of the initial steps have already been explained in the AC Mode Imaging Tutorial chapter. Click the links contained in the steps below to refresh your memory on these processes.

1. For loading the cantilever, see Section 4.2 on page 16.
2. For mounting the cantilever holder, see Section 4.2.3 on page 21.
3. For head and sample placement, see Section 4.3 on page 22.
4. For aligning the laser, see Section 4.6 on page 28.

7.3. Software Prep

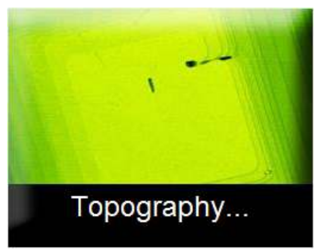
1. Start up the Asylum Research AFM software.

2. **Select Contact Mode Imaging:**

   - The software should now be showing the Mode Master home window.
   - If not, click the 'Mode Master' button at the bottom of the screen: .
   - CIn this example we will start with contact topography (see below).

   Note For imaging cells, a more appropriate template can be found by clicking on *Bio*, then on *ContactCell*.

3. 

▷


▷


   Select:

   - Select *Standard* ▷ *Topography* ▷ *ContactModeTopography*
   - The screen will now re-arrange and present all the controls necessary for this type of AFM imaging.

7.4. Tip Engagement

1. With a properly loaded cantilever, adjust the Photodetector (PD) to 0 volts or a slightly negative value. The slight negative free air deflection will place the SLD spot in the middle of the PD (where the range is more linear) when the tip is engaged.
2. To conceptually aid the selection of a Setpoint voltage, a qualitative depiction of cantilever deflection vs. tip-substrate distance is shown in Figure 7.1 on page 60. In contact mode the AFM will try to maintain the measured deflection equal to the setpoint. The greater the setpoint voltage is (above the free air deflection voltage), the greater the force applied by the cantilever to the sample. To know exactly how much force is being applied during imaging, the cantilever spring constant must be determined. This will be not be necessary for this tutorial.
3. Choose a setpoint voltage that is more positive than the free air deflection value in the SUM and Deflection (S&D) meter. In Figure 7.2 on page 60, the free air deflection is -0.20 V:

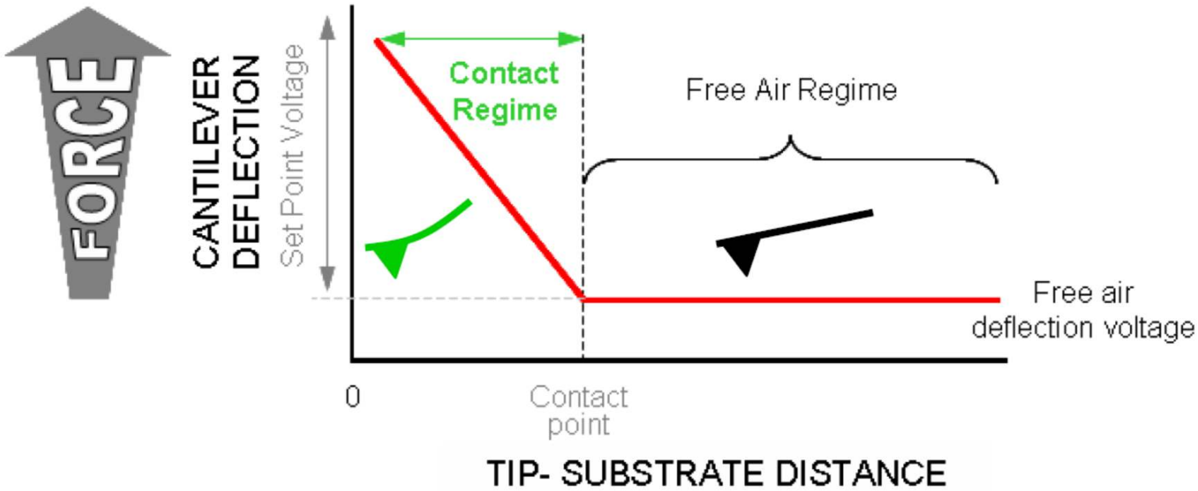


Figure 7.1.: Deflection vs. Distance

therefore a setpoint voltage of -0.19V or more is needed to engage the tip. Setpoint voltages just positive of the free air deflection mean the tip will apply low force to the sample or will false engage, while setpoint voltages much more positive than the free air deflection voltage mean the tip will apply greater force to the sample. A .5V - 1V setpoint should be suitable for this tutorial. So you would want a setpoint of about .3V to .8V in this case.

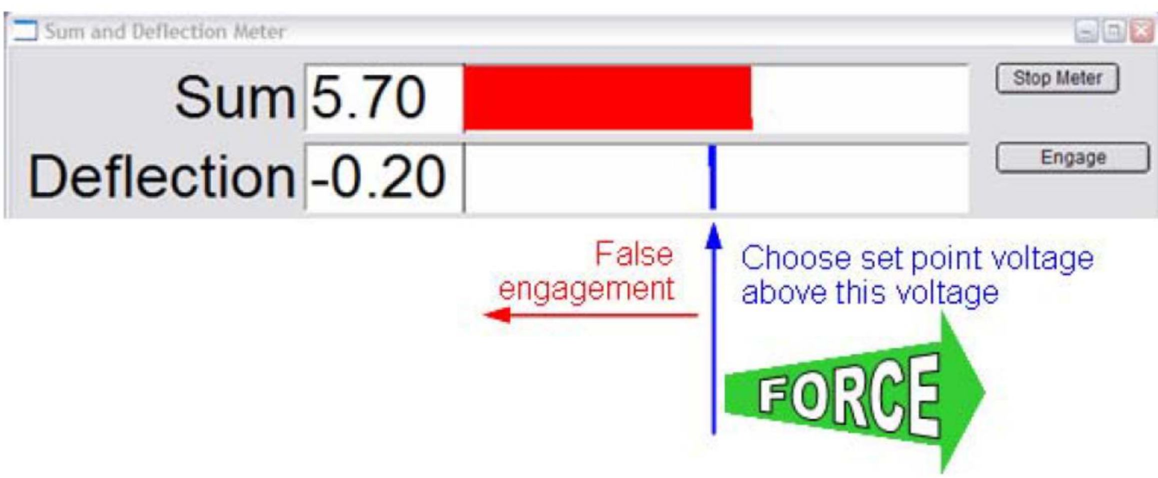


Figure 7.2.: SUM and Deflection Window

4. Click 'Engage' in the Sum and Deflection window. Assuming the cantilever is high enough above the sample, the Z voltage should go all the way to 150V. The Z feedback loop is trying to maintain the setpoint by changing the voltage to the Z actuator. The more voltage the feedback loop applies to the Z actuator causing it to extened the higher deflection value it expects. Since we are too high above the sample, the deflection never changes towards the setpoint and the Z voltage increase to its maximum value.
5. Slowly turn the thumbwheel counter-clockwise, propelling the cantilever towards the surface

at a rate of several microns per second. When the cantilever comes into contact with the sample the deflection should very quickly hit the desired setpoint. You will hear a chime sound from the computer when this happens. You will also notice the Z voltage decreasing. The more you thumbweel down the more the Z actuator needs to retract to maintain the setpoint and thus the Z voltage decreases. It is good practice to turn the thumbwheel until you have Z voltage around 70V. Centering the Z voltage ensures you have ample room on either while imaging. As you are imaging, peaks will requires a lower Z voltage, and valleys will require a higher Z voltage.

6. At this point hit the *withdraw* button, so the cantilever is not in contact with the sample. You may then close the accoustic hood. If you do this while engaged you risk ruining or dulling your cantilever.

Note If you have the volume up on the transducer (front of controller, headphones plugged in), you can hear a frequency change as engagement occurs- it will sound like static and will change to a dampened sound when in contact.

Gentle Engagement: The gentle engage is much more time consuming, and generally not required. Contact mode is typically fairly rough on the cantilever, and most of the time you don't care if the tip gets blunted in this process. If you do care about preserving the tip sharpness in contact mode, you should first consider doing the soft engage in AC mode, and then switching to contact once you have found the surface, seeSection 4.10.6 on page 44. If AC mode is problematic for you, you can try this adapted contact mode soft engage:

1. A simple gentle engage is to select a Setpoint slightly greater than the free air deflection, as described previously.

2.
   - An even more gentle engagement occurs by wheeling down 10 µm, then clicking *Engage*.
   - If the tip does not engage, click the *Withdraw* button, wheel down another 10 µm, and repeat.
   - Notice that each graduation on the front thumbwheel is 1 µm.

3. Once feedback has been activated, continue to lower the head with the front thumbwheel to ~ 70 V (i.e. no color in Z-Piezo meter). This indicates that the piezo is in the middle of its Z- range (~ 7.5 µm standard head; ~ 20 µm extended head).

4. At this point the tip is engaged and just sitting on the surface- it does not begin rastering until you tell it to do so. You can now begin imaging or determine the Spring Constant, see[1].

5. If the Z-piezo voltage is railed all the way blue (-10 V) upon clicking simple engagement, the piezo is fully retracted because it thinks it has crashed. This indicates a false engagement, and adjustment must be made to the Setpoint voltage to allow extension of the piezo. This often occurs when imaging in fluids or in high humidity, or with too low a Setpoint voltage (i.e. low force).

[1] *SPM Applications Guide, Chapter: Thermal Tuning..*

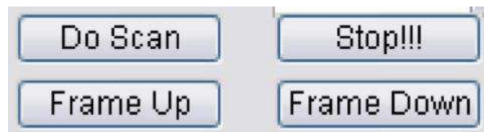
6. Check if the acoustic hood door hatch is still open. If it is, follow these steps to preserve the tip’s apex while shutting the door:

   - Click on the *Withdraw* button.
   - Close the hood door.
   - Click on the *Engage* button.
   - Proceed with scanning.

7.5. Start Imaging

1. **Start the scan:**

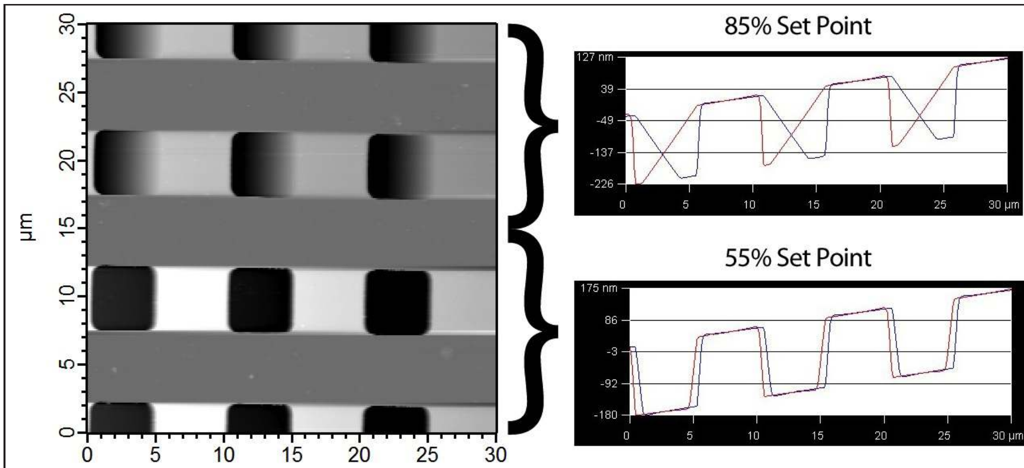
   - Click the *Do Scan* button (or Frame Up or Frame Down) on the *Main Tab* in the *Master Panel*. The tip will begin scanning from the top or bottom of scan area. The red marker to the left of each image window indicates the current scan line.



2. Look at the Height Channel image and locate the blue and red scope traces beneath it. These are the last collected trace and retrace scan lines. The tracking should look nearly identical to the retrace. For the calibration grating sample, they should look like a square wave. To achieve this, some adjustment of the parameters is usually needed.

   Note Wait until the tip is actually scanning over some pits in the calibration grating. There is not much to image on the plateaus in between the pits. This is a good time to turn off the slow axis, see Section 4.10.7 on page 45.

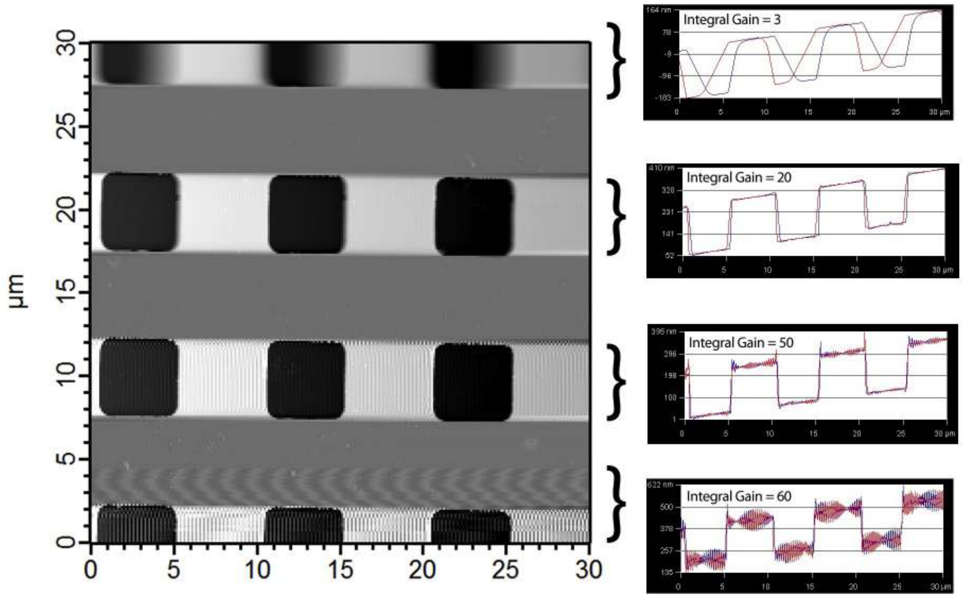
3.



Setpoint Voltage The *Setpoint Voltage* generally needs adjustment:

- Increase the *Setpoint Voltage* value to increase the force applied to the sample, and to improve the tracking.
- Lower *Setpoint* voltages may help preserve the tip apex, but may not allow proper tracking of the surface.
- For this example, use a *Setpoint* between .5V - 1V.

4.



Integral gain adjustment:

- Increase the *integral gain* to improve the tracking, but at a certain level the signal will start to ring.
- Decrease gain until ringing ceases in trace and retrace.

Note There is a slight offset between the trace and retrace lines in the graph. Good tracking means that they should have similar shapes, not necessarily perfect superposition.

Note When adjusting *integral gain*, another channel to look at is the deflection image. Feedback oscillations are easily detected in the deflection image because it is an image of the feedback loop error.

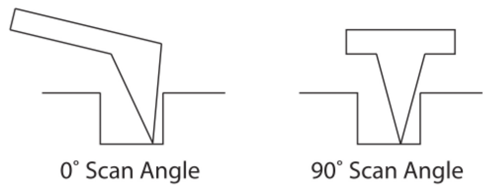
Scan rate adjustment:

- If tracking still seems to be an issue, try lowering the *Scan Rate*. Slowing the *Scan Rate* down will help the feedback keep up with the image features.
5.
- The Scan Rate cannot be updated during imaging like other imaging parameters. You must click *Frame Up* or *Frame Down* buttons to initiate the newly entered scan rate.

Note Too slow of a scan rate can introduce image artifacts due to thermal drift.

6. **Scan angle adjustment:**

Note For the Olympus AC160 and AC240 cantilevers, the tip will be symmetric or asymmetric based on the scan angles shown on the right. For a better representation of side walls 0º scan angle should be used. However, tracking could be difficult due to the steep edge of the tip. Better tracking could be achieved with a 90º scan angle. This is one example; refer to cantilever documentation for different tips.



8. Tutorial: AC Mode Imaging in a Liquid Droplet

CHAPTER REV. 1586, DATED 08/30/2013, 10:33. USER GUIDE REV. 1590, DATED 08/30/2013, 12:47.

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AC mode in liquid is frequently used to observe structures, predominately biological in nature, in their native environments. AC mode is often the preferred technique over contact mode due to the reduction of the vertical (applied) forces and the elimination of the lateral forces.

This tutorial focuses on the simplest experimental setup, i.e. a small droplet of liquid sitting on a microscope slide. Once you have mastered this tutorial, you can move on to more advanced accessories, such as:

Fluid Cell Lite: For general purpose imaging with an evaporation shield and thin glass coverslips. See **??** on page **??**.

Closed Fluid Cell: Similar to the Fluid Cell Lite, but with the ability to seal and allow general liquid exchange under slight pressure. See **??** on page **??**.

Bioheater: Also for general purpose imaging, but with an immersion heating element. See **??** on page **??**.

Petri Dish Holder: For imaging in a variety of cell culture dishes. See **??** on page **??**.

Petri Dish Heater: Similar to the Petri Dish Holder, but with heated temperature control ability. See **??** on page **??**.

Cooler Heater: For imaging in drops or small volumes with cooling or heating, but without bottom view access. See **??** on page **??**.

MicroFlow Cantilever Holder: For use with all of the above sample types, plus the ability to exchange 50 µL liquid volumes near the AFM tip. See **??** on page **??**.

Tip	If you prefer imaging in liquid, consider the iDrive cantilever holder (see **??** on page **??**). It excites the cantilever magnetically and does not suffer from the "forest of peaks" phenomenon. Autotune (see Section 4.7 on page 33) immediately works in liquids and Q-control also works quite well. For more information also read *SPM Applications Guide, Chapter: iDrive Imaging*.

8.1. Prerequisites

This is a somewhat advanced imaging mode. You must be familiar with the AC Mode imaging in air tutorial (Chapter 4 on page 15).

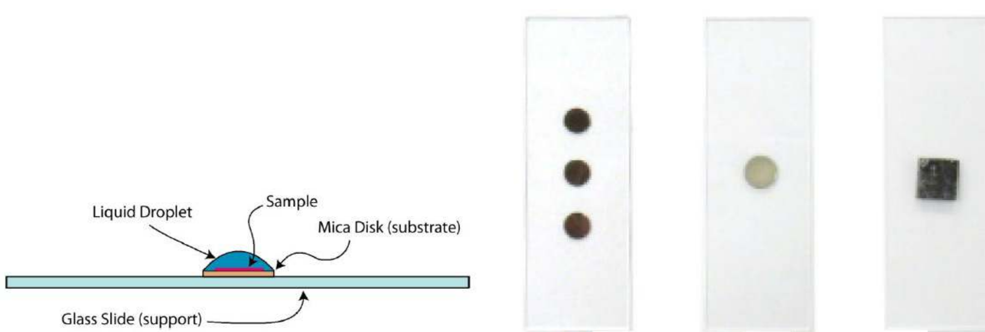
8.2. Terminology

Sample Material to be imaged (molecules, cells, etc.)

Substrate Surface on which the sample is immobilized — typically mica, graphite, gold, glass, etc. The substrate is attached to the support.

Support The support (generally a glass slide) is mounted on the AFM.

Some examples of typical mounted samples are shown in 8.1.



(a) Schematic Sample Mounting.

(b) Sample mounting examples: Gold on glass, mica disc glued on glass, HOPG glued on glass.

Figure 8.1.: Sample mounting examples.

8.3. Sample Prep

Common sample substrates include mica, graphite (Highly Ordered Pyrolytic Graphite or HOPG), silicon or gold, or on a rougher substrate such as glass if the sample is larger, such as living cells. The substrate may be attached on a glass slide or its equivalent (See Figure 8.1b on page 67).

Warning	Do not spill liquids on your AFM head or scanner, as this can lead to damage. Please read the following before you proceed: • **??** on page **??**

1. Prepare the substrate

   - If using mica as a substrate, a "hole punch" (for example: Precision Brand, #40110 or McMaster - Carr's Shim - stock or Gasket/Washer Punch sets, #s 3472A11, 3430A12, 3430A15) may be used to quickly make the discs. It is inadvisable to use scissors to cut the mica as that may induce the crystal layers to separate, which will in turn allow liquid to leak through the layers and peel off the top layers during imaging. Alternately, it is possible to buy pre - made mica discs (from Ted Pella, Inc. for example).
   - Use a small drop of epoxy (or any adhesive that does not dissolve in water) to immobilize the substrate on the slide. Double-sided tape should be avoided, it commonly caused large scale drift problems when used to attach substrates to the support.

2. Prepare the support

   - To stop the liquid from spreading on the support, which could contaminate the sample if the support is not clean, a hydrophobic film may be deposited around the substrate. Use any of the following for this purpose:
   - PAP pens are very convenient for this purpose. Electron Microscopy Sciences AQUA–HOLD Pap Pen.
     - Teflon tape, such as 7562A17 from McMaster Carr.
     - Parafilm.
     - PTFE printed slides, available from Electron Microscopy Sciences. They have a wide selection to choose from, but #63419-12 is the most appropriate for our system.
     - Dow Corning High Vacuum Grease(formerly 976V vacuum grease) works very well to "paint" a barrier on a glass slide. To do this, you can fill a small syringe with the grease and use a blunt needle to dispense it onto the slide.
     - SecureSeal Spacers from Grace Biolabs: SS1X20-SecureSeal Imaging Spacer, or also PCI-0.5-CoverWell Imaging Chambers.

Note See 8.2 for photos of some of these listed examples.

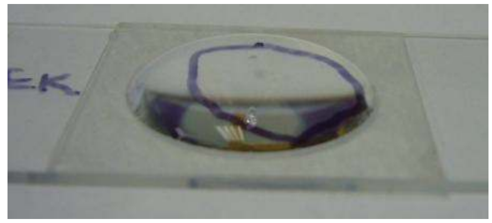
3. Prepare the sample

   - Immobilize the sample on the substrate. Typically this step involves depositing a drop of the sample onto the substrate and letting it incubate for a period of time. Set the sample aside if incubation is required.

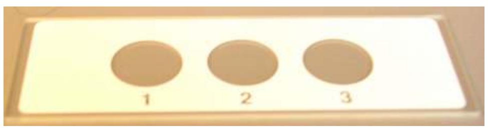
4. Prepare the solution

Things work better if the solution is at room temperature, there will be less thermal equilibration then if the solution came out of the refrigerator.

(a) Grace Biolabs Secureseal.



(b) Grace Biolabs Secureseal in action.



(c) PTFE slide #63419-12.

(d) Grease barrier on a slide.

Figure 8.2.: Various water barriers on slides.

8.4. Prepare the AFM Head (Dry Run)

This process is very similar to that of AC mode imaging in air:

- Loading the cantilever holder (Section 4.2 on page 16).
- Mounting the cantilever (Section 4.2.3 on page 21).
- Head and sample placement (Section 4.3 on page 22).

Since that has been covered in detail, the remainder of this section will only cover the major steps:

1. **Choose and Insert a Cantilever Chip**

- Insert the probe into the holder.
- Select a low spring constant cantilever. For example, silicon nitride cantilevers, like the short, 40 µm Biolever Mini (BL-AC40TS) from Olympus, are a good choice for AC mode in liquid. Please visit our probe store where you can browse by application type if you are in need of cantilevers: http://www.AsylumResearch.com/ProbeStore

2. **Place the support on the scanner:**

- Put a spare dry substrate/support onto the scanner and hold it in place with the magnets.

3. **Lower the AFM Head**

- Before lowering the head, make sure that its legs have been raised sufficiently to prevent crashing the cantilever (or even the cantilever holder) onto the surface.
- If using the shorter, 40 or 60 µm Biolever it is recommended that the user angle the head so that lever side rear leg is slightly lower than the other two legs. This will ensure that the small cantilever will be the first thing to contact the surface, instead of the cantilever chip or the longer Biolever.
- For other cantilevers, such as the Olympus TR400 or TR800, the head should be more or less level.

4. **Position the laser spot:**

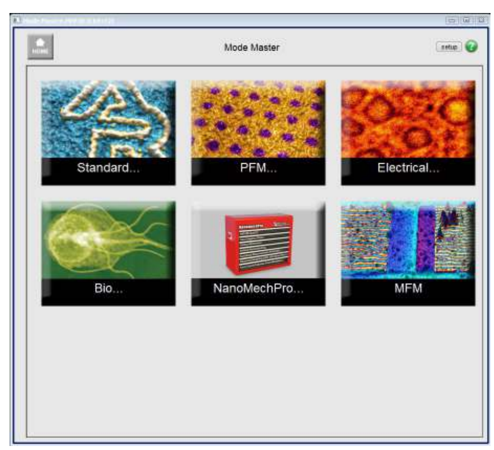
- It is easier to position the light beam on the cantilever in air, before the cantilever is placed in the liquid.
- If the MFP - 3D - BIO ™ is being used, a CCD camera may be plugged into the inverted optical microscope, or you can use the standard camera attached to the Top View IO pillar.
- In any case, once a good video image of the lever is obtained, put the laser spot on the lever.
- The SUM signal obtained on silicon nitride cantilevers, despite their gold coating, is typically lower than on silicon cantilevers (between 3 and 6 volts).

8.5. Software Prep

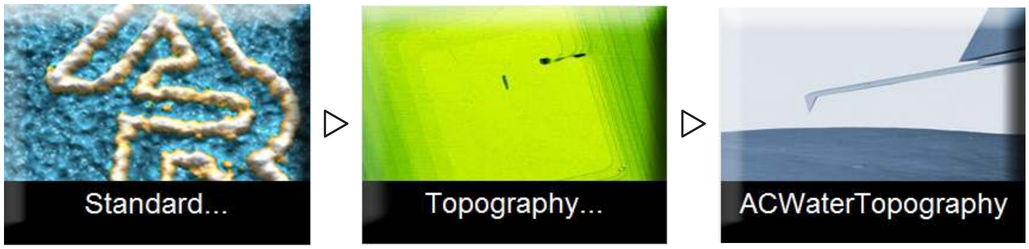
1. Start up the software as described in Chapter 3 on page 10.

2. **Select your mode:**

- The software should now be showing the mode master window.
- If not, click the Mode Master button at the bottom of the screen: .
- In this example we will start with AC water topography (see below).



3.



Select:

- Select *Standard* ▷ *Topography* ▷ *ACWaterTopography*
- The screen will now re-arrange and present all the controls necessary for this type of AFM imaging.

8.6. Place head above the wet sample

1.

Place the sample on the scanner.

- Now that everything is aligned, remove the head and dummy sample.
- Place the actual sample which may have already been wet and incubating. If it is still dry, add enough water to make a drop about 1cm in diameter (see Figure 8.2b on page 69). In the case of a mica disc substrate, surface tension should keep the drop from spilling over (see Figure 8.1a on page 67)

Note Make sure the support does not touch the black part of the scanner since only the central silver part scans in the X and Y directions.

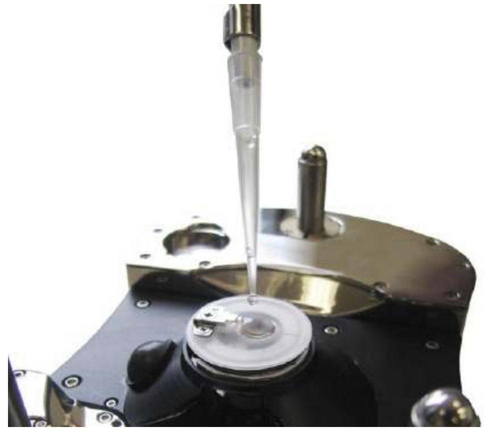
Note As stated previously, be sure to angle the head accordingly if using the 40 or 60µm Biolever Step 3 on page 70.

Wet the Cantilever

2.

- To wet the cantilever using a pipette, put 2 or 3 drops of liquid between the lever and the cantilever holder. You can place one drop at the corner of the chip, and pull it slowly and gently towards the lever to pull the drop under the lever. Don't flood the head, just a few drops, liquid in the head electronics is, really bad.
- When liquid gets into the head, immediately power it down by turning off the controller. Set the head right side up and remove the cantilever holder. Dry any visible liquid and let the head dry out. Extra care should be taken the next time you use the head to ensure it is working properly.

Note This step is optional, but highly recommended since it reduces the risk of creating air bubbles on the cantilever, and fills the space between the substrate and the bottom of the cantilever holder with liquid.

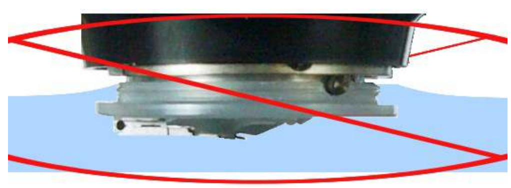


Place the AFM head on the stage or base

3.

- Make sure the sample, substrate and cantilever chip are totally immersed in liquid. This is important, since the liquid will not always fill the whole space between the cantilever chip and the holder. If this happens, the the laser beam will not reach the photodetector.

Note Also beware of using too much liquid, as it should never spill around the cantilever holder or onto the electronics behind it.



Realigning the Laser Beam Once the cantilever has been fully immersed in liquid, the SUM signal will disappear. This is because the optical path is different due to the change in the index of refraction. The light beam needs to be redirected to the lever to regain the signal.

4.
- Turn LDX clockwise. The SUM signal should increase to its maximum value.
- Typically, the value will be lower than it was in air. Typical values for silicon nitride cantilevers in liquid are between 3 and 4V.
- You may also want to refocus the video view once you are in liquid.

Trouble? **For AC Mode in Liquid Troubleshooting topics see** **Section 8.10 on page 78****.**

8.7. Cantilever Tune

Tuning in liquid is more difficult than in air. There is coupling between the liquid and the cantilever, and possibly the cantilever holder and other components as well. This creates multiple peaks (a “forest of peaks”) which makes choosing the correct peak difficult.

For more details on how to tune a cantilever from a thermal, see *SPM Applications Guide, Chapter: Thermal Tuning*.

Here we will go through a quick guide on how to work with the Biolevers 150 in water.

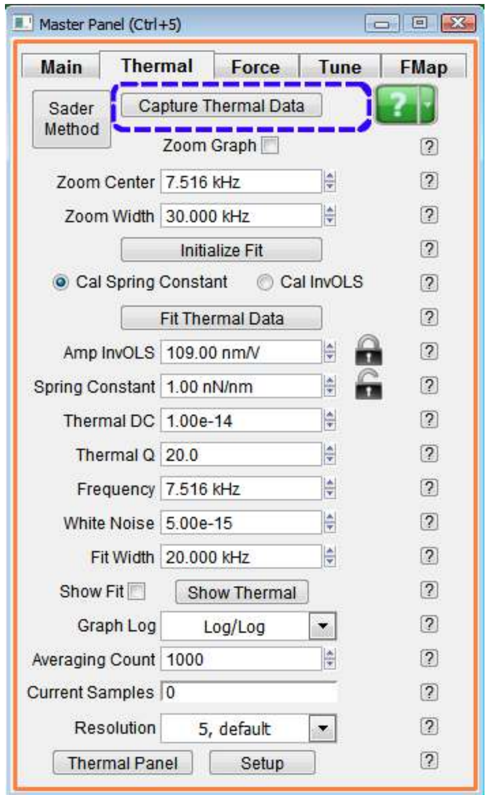
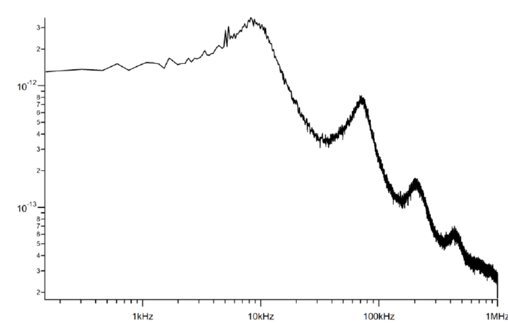


Figure 8.3.: Master panel, Thermal tab

1. **Do a thermal:**
   - In the *Master panel* (Ctrl + 5), select the Thermal tab (See Figure 8.3 on page 74) .
   - Then click on *Do Thermal* (Ctrl + 2).

2. **The resulting spectrum:**
   - There should be a broad peak around the resonance frequency of the cantilever.

   Note If the value of the resonance frequency in liquid is unknown, it is (very approximately) 1/3 of its value in air. For example, when using a 60µm long Biolever from Olympus, has a nominal air resonance of 37 kHz, the peak in water is at about 8 kHz.



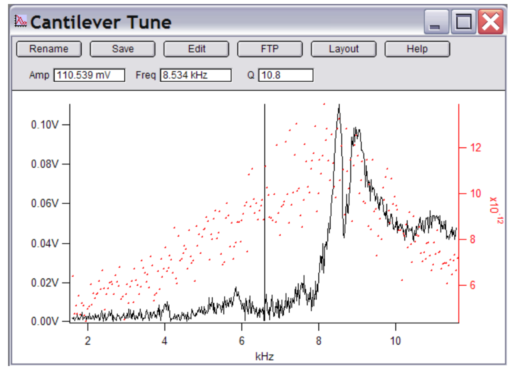
3. Zoom in on the peak, and fit it. If the fit is decent, right click on the thermal and select Move Freq and Phase to the tune.

4. **Set up the tune:**

- In the Master panel, select the 'Tune' tab.
- Near the bottom, expand graph, turn on 'Append Thermal'.
- Then, set the 'Sweep Width' to 20 or 30 kHz.

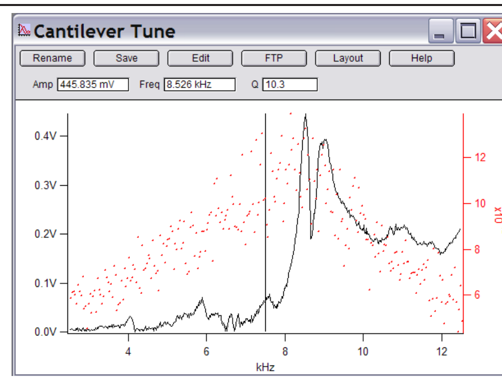
5. **Click on 'One Tune' (Ctrl + 4)**

Note The the "forest of" peaks vary greatly from experiment to experiment.



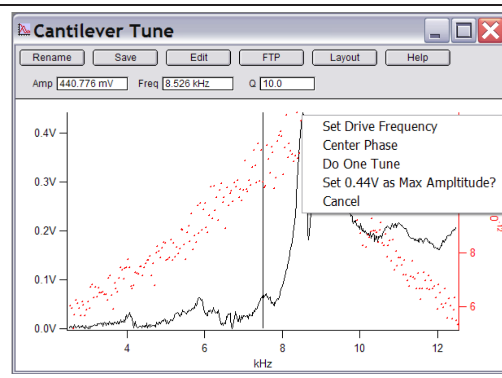
6. **Try a higher drive amplitude:**

- If the signal noise is low, you can increase the *Drive Amplitude*, and click *One Tune* (Ctrl + 4) again.



7. **Select a peak:**

- Choose the most prominent peak that overlaps the thermal. Right click just left of that peak.
- Choose 'Set Drive Frequency As' .



8. Click the 'Center Phase' button . This will center the phase at 90°on resonance. This allows you to monitor whether the tip is in the attractive or repulsive regime. However, this does not hold as true in liquid (using shake piezo drive) as it does in air.

Tip	If you prefer imaging in liquid, consider the iDrive cantilever holder (see **??** on page **??**). It excites the cantilever magnetically and does not suffer from the "forest of peaks" phenomenon. Autotune (see Section 4.7 on page 33) immediately works in liquids and Q-control also works quite well. For more information also read *SPM Applications Guide, Chapter: iDrive Imaging*.

8.7.0.1. Change the R Filter Value

1. Change the value of the Feedback filter on the main tab (may need to use setup to show the control) to 500 Hz.

This digital filter is applied to the AC signal coming from the photodetector. It has to be at a different value when working at these relatively low frequencies. In contrast, the R value should be 1500Hz (1.5 kHz) for AC mode in air.

8.8. Choose Imaging Parameters

The values below are only suggestions and may be optimized later with some user experience. (See Figure 8.4 on page 76) Return to the Master panel and review and adjust each parameter as follows:

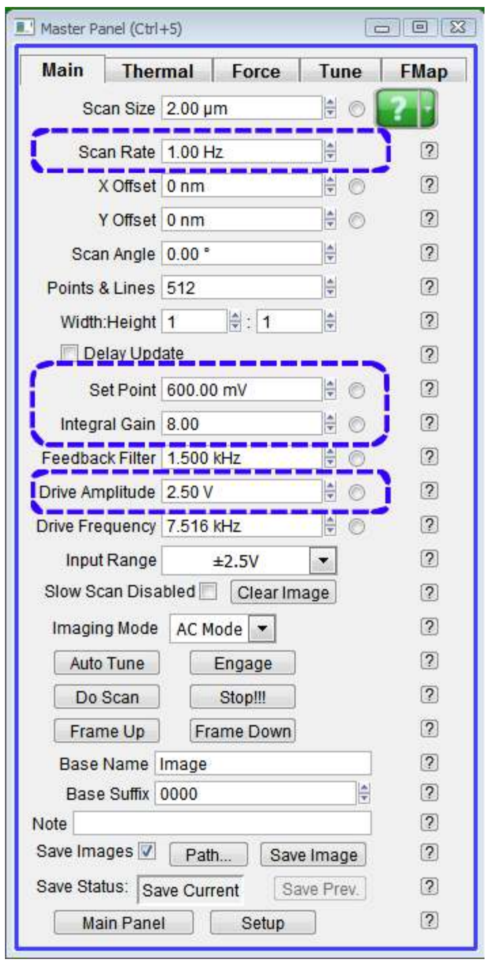


Figure 8.4.: Master Panel Main Tab

8.8.1. Drive Amplitude

This parameter determines the free amplitude of oscillation. When imaging most biological samples in liquid, smaller oscillation amplitudes are better. Typical small values are 0.7 to 0.9V. For harder surfaces like biomaterials (polymers, ceramics, metals) a free amplitude of 2V can be used. If the sample is sticky, it may be better to use higher values.

8.8.2. Setpoint

The setpoint has to be smaller than the free amplitude - typically about 80% of the free amplitude. In order to be gentle when imaging soft samples, it is preferable to use a setpoint value close to the free amplitude. For example, when imaging DNA in liquid with a free amplitude of 0.8V, the setpoint should be 0.6V.

8.8.3. Scan Rates

The typical scan rate in liquid is 1Hz, although some samples may require lower speeds. For example, living cells can require 0.2 Hz.

8.8.4. Integral Gain

Start with a value of 10 and optimize the gain constantly while imaging. Typically, you should increase the value until noise in the amplitude is visible, then reduce the value until the noise disappears. This value is ideal for optimal tracking of the sample. Note that Proportional Gain is less effective and can be set to 0V most of the time. Drive frequency was already chosen when the cantilever was tuned. The other parameters should be similar to those for AC mode in airChapter 4 on page 15.

8.9. Engage

The engagement procedure is the same as in air. Below is a brief reminder of the engagement process. For more detail on engagement, please see Section Section 4.8 on page 34 for the so-called “Hard Engage.” Better yet, see Section 4.10.6 on page 44 for the “Soft Engage”, which is much gentler on your tip.

1. In the Sum and Deflection Meter panel, click on the ‘Simple Engage’ button.
2. Carefully lower the head until you hear the audible engage notification and the Z voltage is centered at approximately 70V.
3. Using the Trace/Retrace graph as a guide, decrease the set-point until the tip is tracking the surface well.
4. Adjust the Integral Gain and Scan Rate as needed.

8.10. Troubleshooting

8.10.1. Bubbles

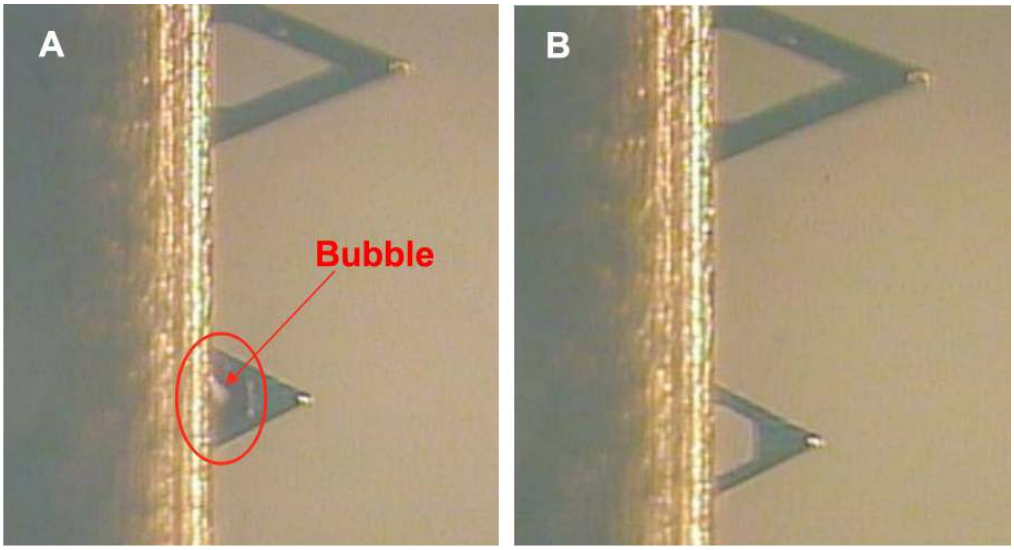
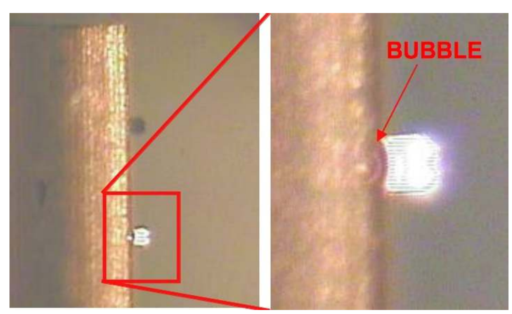


Figure 8.5.: (A) bubble trapped between the legs of a triangular cantilever, and (B) view with the bubble absent.

An air bubble may get trapped somewhere by the cantilever, which will eventually compromise the deflection signal because the bubble may migrate. It is best to get rid of these bubbles before imaging.

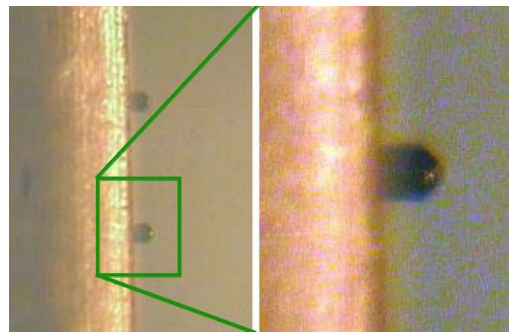
1. **Observe a bubble:**

   - On a triangular lever the bubble may look as it does in Figure 8.5 on page 78.
   - Very floppy cantilevers may be deflected due to the surface tension from a bubble. This can angle the lever so it reflects a lot of illumination, as seen in the image to the right.



2. **Lift the head:**
   - Gently lift the front of the head up, pivoting on back legs, such that the cantilever holder comes out of the liquid.
   - Plunge it back into the liquid.
   - If necessary repeat a few times.

3. **Observe to see that the bubble is gone:**
   - A dark lever indicates that there is no longer a bubble.



4. If the bubble is not removed after trying multiple times, lift the head up off the stage, place on its side and dispense some imaging liquid to remove the bubble with the force of the liquid under gravity.
5. Re-wet the tip and place back on stage. Try again.

8.11. Maintenance

At the end of your experiment, remove the cantilever (it is advisable to discard it) from the holder and clean the holder. There are multiples ways of cleaning the cantilever holder: the following list describes only some of the available methods.

- Use soapy water and gently rub the holder with your finger, preferably while wearing gloves. Make sure not to scratch the glass window through which the light beam travels. Rinse copiously with deionized water.
  - Optionally, you can followed that by two additional steps: a rinse with 70% ethanol in water, and a final rinse with deionized water.
- Immerse the top of the holder (the Kel - f part) in ethanol and sonicate for 2 minutes.
- Use a gentle plasma treatment: 30s at 50W and 0.15 torr.

Note Cantilevers are difficult to clean. You can try ozone treatment for 1 min, or plasma treatment, as mentioned above. Some authors also use piranha solutions, which is **very dangerous, DO NOT** use piranha solution without proper safety equipment and training.

8.12. Troubleshooting

8.12.1. Difficulties with Soft Engage

The soft engage is difficult in air, in liquid is can be even more difficult.

You should be proficient with soft engage in air (see Section 4.10.6 on page 44), before you attempt to engage with the soft engage in liquid. But some additional things to consider when doing a soft engage in liquid.

1. As you thumbwheel down, you will notice that the Amplitude value in the S&D Meter is **increasing** instead of the expected decrease. This is (believed to occur) because of the liquid being compressed between the tip and sample from the oscillating shake piezo in the cantilever holder, effectively imparting a larger Free amplitude onto the cantilever as it approaches the surface.
2. Use the Hamster wheel to occasionally decrease the Drive amplitude to maintain the proper setpoint ratio (i.e., ~95% of the free air amplitude).
3. Slowly decrease the setpoint voltage with the Hamster Wheel such that the tip 'hard' engages on the surface.
4. Move piezo into middle of Z range (~70 V).
5. Start scanning.

8.12.2. Tuning imaging parameters in liquid:

Tuning the imaging parameters in liquid can also be a little trickier than in air. We suggest exercising patience, especially when imaging soft biological samples because this should be done at low scan rates (< 0.5Hz), increasing acquisition times.

Although calibration grids are also great for learning how to image, it is NOT a good idea to put water onto the provided 10 µm calibration grid, they are never the same after that.

NOTE: Depending on the sample, obtaining really good tracking is usually NOT a frequent occurrence when imaging in liquid. When you get something that looks real, go with it.

It is also possible to image at very low Drive Amplitude and setpoint voltages. The problem is that you may not be able to engage with low amplitudes. The trick to this is once the tip is engaged and imaging, slowly step down the setpoint and Drive Amplitudes iteratively. It can take a while, but the results can be very good - lower tip oscillations mean less sample perturbation (especially with cells and other bags of water).

Additionally, the Drive Frequency can be adjusted a small amount (using the Hamster wheel works well for this) until the better imaging is obtained.

Part II

Advanced Imaging Hardware

Part II: Who is it for? Once you have become familiar with basic imaging, as described in the tutorials in I, this manual will guide you through the many advanced accessories which the MFP-3D offers. For example, to collect images on samples heated above 200° C, a Polymer Heater and Environmental Controller are required. Use of such accessories will be described in this manual.

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9. Conductive AFM (ORCA) Hardware

CHAPTER REV. 1580, DATED 08/30/2013, 06:11. USER GUIDE REV. 1590, DATED 08/30/2013, 12:47.

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This chapter describes the hardware required to perform conductive AFM with the MFP-3D AFM. Conductive AFM Theory and SPM software instructions are described in another manual: *SPM Applications Guide, Chapter: Condcutive AFM*.

9.1. Prerequisites

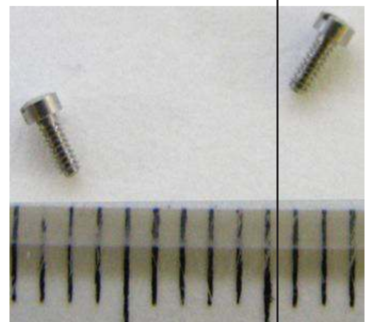
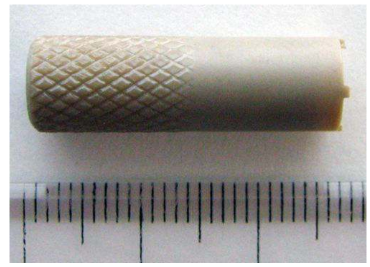
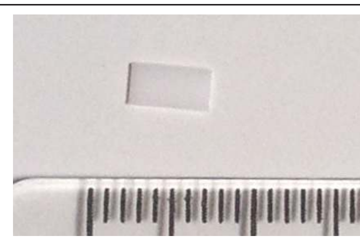
Conductive AFM Imaging is a fairly advanced technique. It is assumed that you are proficient at:

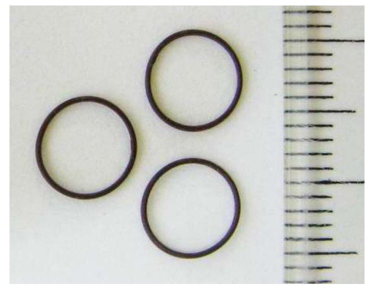
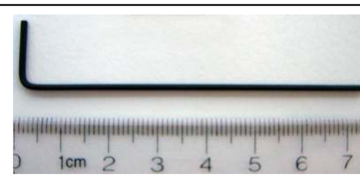
- Basic AFM Safety (Chapter 11 on page 135).
- AC Mode Imaging in Air (Chapter 4 on page 15).
- Contact Mode Imaging, described in another manual: *SPM Applications Guide, Chapter: Contact Mode Imaging*.

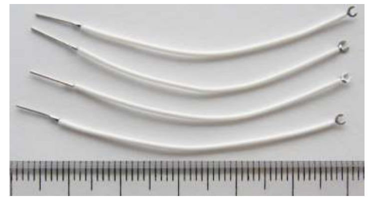
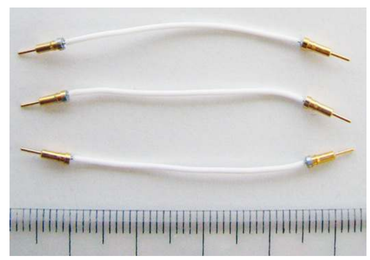
9.2. Parts List

The following list contains all of the parts in your accessory kit. The table is useful as a visual table of contents with links directing you to the specific uses of each part. When ordering parts, please refer to the part numbers in the second column.

This kit has asylum part number 900.231.

Itm	Part #	Item Description	Qty	Picture
1	001.FILL #000 - 120 X 0.094 SST	000-120 X 3/32" Fillister Head Stainless Steel Screws. Use with screwdriver 290.110. A few are included since these screws, while standard, can be tricky to find outside the USA.	2	AC160TS or AC240TS 
2	111.725	Fluid Cell Ring Tool. Used to adjust retaining retaining ring . Used only during disassembly.	1	
3	111.737	Modified 0-80 Screw. Used to attach the cantilever clip to the body. Note that these screws have been machined to a nonstandard length. You must only use this Asylum part number.	4	
4	111.738	Modified 1-72 Screw. Tighten the cantilever under the clip. Note that these screws have been machined to a nonstandard length. You must only use this Asylum part number.	5	
5	112.495.02	Coupling Pad 0.015". Ensures the mechanical contact between the AC mode shake piezo and the cantilever holder. Without this pad, AC mode imaging is not possible.	5	
The scale in the photos is in cm and mm.				

Itm	Part #	Item Description	Qty	Picture
6	208.06	SCMagnet .17” Diameter X .200” L Unpainted		
7	230.011	O-Ring, 0.244” ID X 0.016”CS, Viton, 55 Durometer.	5	
8	290.106	#00 Phillips WIHA Screwdriver 261 PH 00 X 40. Used on a regular basis when inserting and removing cantilevers.	1	
9	290.110	WIHA Screwdriver, Flat Tip 260 1,5 X 40. Used only during disassembly.	1	
10	290.116	0.050” Ball End Allen Wrench. Used when disassembling the cantilever holder for cleaning.	1	
11	290.160	Leitsilber Conductive Paint, 0.5 Oz.	1	
12	439.028	Micro Alligator Clip.	1	
The scale in the photos is in cm and mm.				

Itm	Part #	Item Description	Qty	Picture
13	448.017	Orca Wire Assembly	1	
14	448.018	500MΩ ORCA Test Resistor Assembly.	1	
15	448.021	1.5” ORCA sample holder wire assembly.	1	
16	803.OLY. AC240 TM	Olympus Electri-Levers, Model AC240TM.	1	
17	900.150	ORCA (Electro Contact) Sample Holder.	1	
The scale in the photos is in cm and mm.				

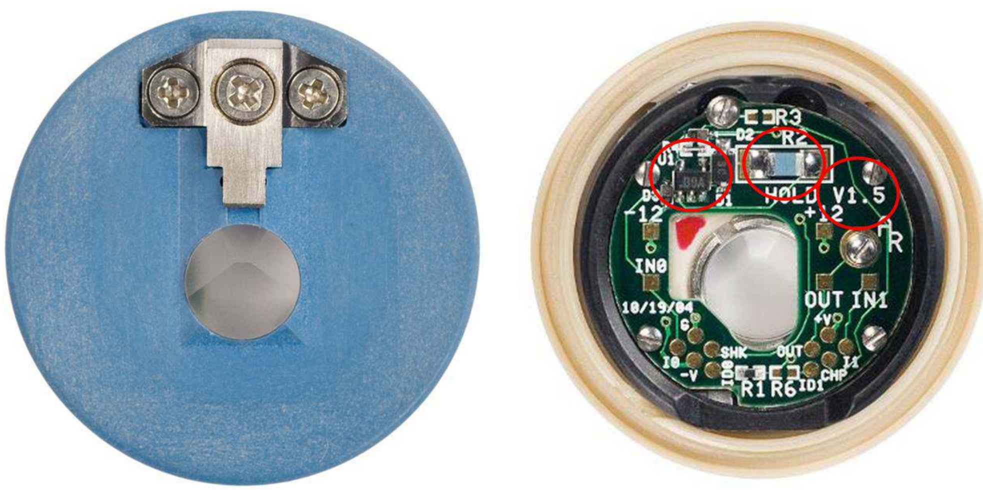
9.3. ORCA (Conductive AFM) Cantilever Holders

The ORCA conductive AFM cantilever holder can, via a small tether wire, apply a software controlled voltage to an electrically isolated sample. The on board electronics hold the tip at virtual ground and measure the current flow between tip and sample using a low noise transimpedance amplifier (current to voltage converter) built into the cantilever holder.

The ORCA cantilever holder is identical to the standard cantilever holder in nearly all respects. It can be used for contact mode and AC mode imaging, as well as in fluid (when not performing current measurements). It is disassembled and cleaned in the same way. However, since the metal clip is part of the current measurements system and sits at virtual ground, it cannot be used for techniques which require the application of a DC tip bias voltage (like KPFM, see *SPM Applications Guide, Chapter: Kelvin Probe Microscopy*).

The orca cantilever holder comes in various varieties described in the next few sections.

9.3.1. Standard ORCA Cantilever Holder



(a) Front side.

(b) Back side and identifying features. The circled components are only present on the ORCA cantilever holder, and not on the standard cantilever holder.

Figure 9.1.: Standard or Single Gain ORCA Cantilever Holder.

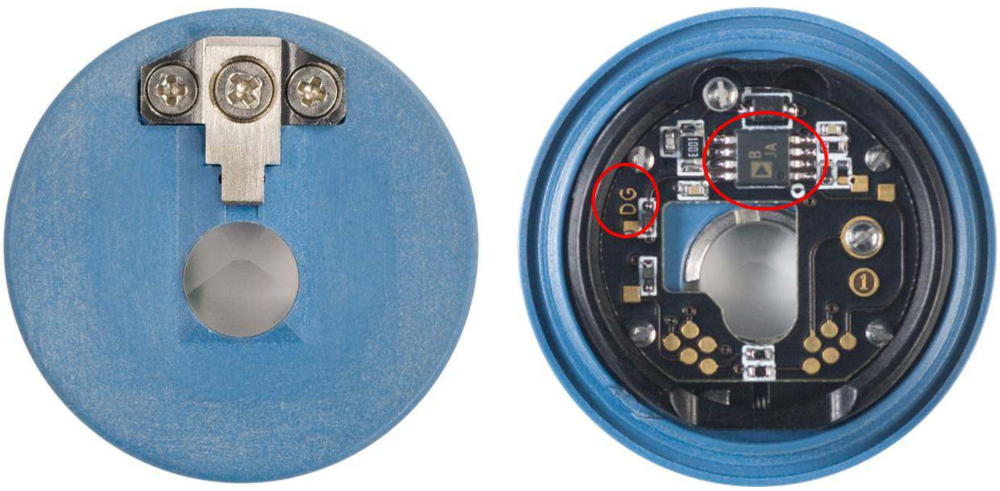
The standard (Single Gain) ORCA cantilever holder can be purchased in a variety of preconfigured current ranges. At the time of purchase you will need to select the one appropriate for your experimental requirements.

- The ID is the number printed on the side of the black ring on the circuit board side of the cantilever holder.
- Test resistors are provided for testing the operation of the transimpedance amplifier.

Part #	Gain R	ID	Sensitivity	Current Range	Typical Noise (1kHz BW)
908.027	500kΩ (5e5)	6	2µA/V	±20 µA	1nA
908.028	5MΩ (5e6)	7	200nA/V	±2 µA	75pA
908.029	50MΩ (5e7)	8	20nA/V	±200nA	3pA
908.036	500MΩ(5e8)	3	2nA/V	±20nA	1pA
908.030	5GΩ (5e9)	9	200pA/V	±2nA	0.5pA

9.3.2. Dual Gain ORCA Cantilever Holder

The Dual Gain ORCA cantilever holder is almost like owning two standard ORCA cantilever holders in one package. It has a current to voltage converter for the low gain stage followed by a gain of 1000 for the high gain stage. Both outputs are available simultaneously, though usually only one is meaningful at any given time. This does come at the expense of some added noise in the high gain measurements.



(a) Front side. **(b)** Back side and identifying features.

Figure 9.2.: Dual Gain ORCA Cantilever Holder.

- The ID is the number printed on the side of the black ring on the circuit board side of the cantilever holder.
- Test resistors are provided for testing the operation of the transimpedance amplifier.

Part #	Gain R	ID	Sensitivity	Current Range	Typical Noise (1kHz BW)
908.xxx	1kΩ	29	1mA/V	±10mA	150nA
	x1000		1µA/V	±10µA	1.5nA
908.067	20kΩ	40	50µA/V	±500µA	7.5nA
	x1000		50nA/V	±500nA	75pA
908.045	100kΩ	22	10µA/V	±100µA	1.5nA
	x1000		10nA/V	±100nA	15pA
908.051	1MΩ	14	1µA/V	±10µA	150pA
	x1000		1nA/V	±10nA	4pA

9.3.3. Identifying your ORCA holder

You can visually identify your type of cantilever holder from the previous sections and by looking for an ID number on the cantilever holder ring and look it up in the tables.

If you have a functioning MFP-3D nearby, you can simply attach the cantilever holder to the AFM head (see Step 2 on page 21) and use the software to identify the type from the *programming* ▷ *Cantilever and Sample Holder panel* menu. Every MFP-3D cantilever holder type has a unique electronic ID.

9.3.4. Attaching the Bias Wire

Once you have identified your ORCA holder and the software has recognized the sensitivity, verify that there is a bias line attached to the holder. These are the white wires in Figure 9.3 on page 90. If such wire is not present, please follow the steps listed below.

Please refer to the parts list (Section 9.2 on page 83) for more information on part numbers mentioned in these steps.

1. Place the ORCA holder with the circuit board facing up.
2. Locate the small slotted screwdriver (part 290.110) and a spare bias wire (448.017).
3. **Attach the bias wire:**
   - Loosen by a few turns the screw which in the photo has the bias wire leading to it.
   - Position the C shaped ring on the wire under the screw and tighten the screw until snug.

   Note The screw at the top must be present since it connects the circuit to the metal clip on the other side of the cantilever holder. The other four screws only keep the circuit board attached to the cantilever holder.

9.3.5. Testing the ORCA holder

For a multi user facility, it is a good idea to test the ORCA holder before use each time a new experiment is attempted. For a single group system, this is probably not necessary. For older ORCA holders that do not have painted rings on the metal part of the holder (see Figure 9.3 on page 90), caution should be used in loading the holder into the head. If the holder is rotated so that the wrong pogo pins are shorted, the op amp can be damaged and will have to be replaced. Holders with painted rings will not have this problem.

To test the holder:

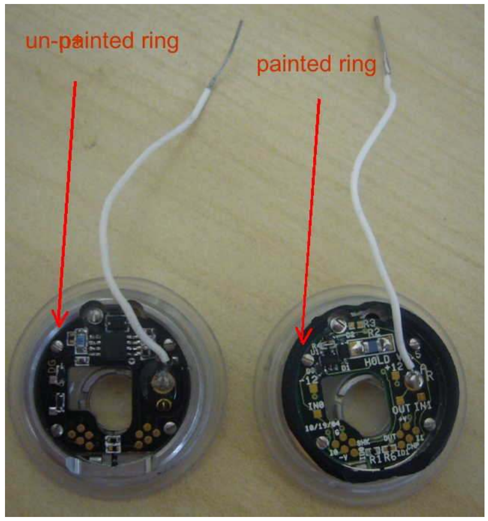


Figure 9.3.: For ORCA holders without the painted ring, please use caution in loading them into the head, as the metal ring can short the op-amp.

1. See Figure 9.4 on page 91. Locate the 500 MΩ resistor in the ORCA kit, and connect it between the cantilever holder and the bias wire. A convenient way to do this is to put the wire end of the resistor through the small loop in the cantilever clip. Use the alligator clip included with the ORCA kit to connect the bias wire to the resistor. Make sure the clip does not short out on the head. One way to be sure this does not happen is to slide a piece of paper between the clip and the head.
2. Note that for the ORCA holder with sensitivity 1nA/V you will need a 500kΩ resistor. For the dual gain, we typically use a 10MΩ, as that will test both gain stages.
3. Once the resistor is in place, open the software. From the menu bar, select *AFM 3D controls ▷ DoIV panel*.
4. Set the amplitude to 1 V, frequency to 1 Hz. Set the function to 'ARDoIVTriangle', and click 'display'. This will show the waveform that will be used to test the resistor.
5. Click 'do it'.
6. Display the curve.
7. The curve should be linear, and the slope should equal the resistance of the test resistor.

A more complete description of current-voltage curves is given below in the I-V curve section in the *SPM Applications Guide, Chapter: Condcutive AFM*.

9.4. Sample mounting

Samples must be less than a few cm in diameter and preferably less than 1mm thick.

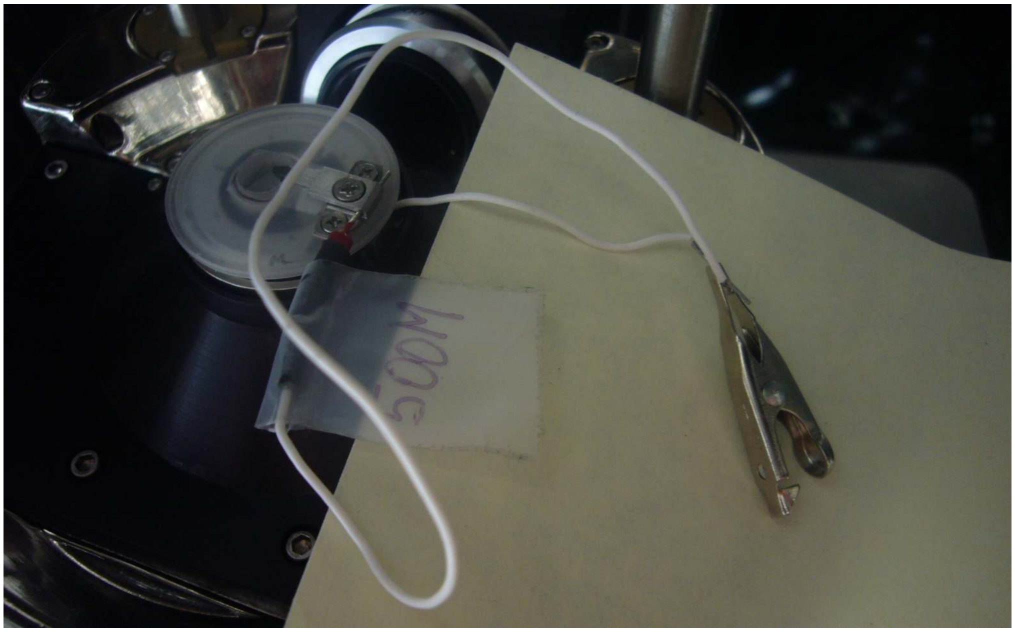
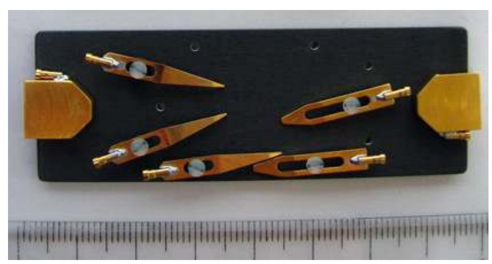
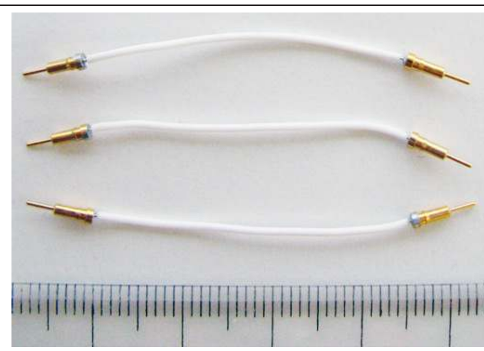


Figure 9.4.: Connect the test resistor in between the bias wire and the probe clip as shown

1. **Mount the sample:**
   - Locate the sample mount (900.150). It is made of aluminum with an anodized non conducting surface. Remove and store any excess clips and plastic screws.
   - Use one of the supplied clips to clamp your sample against the plate. The tip of the clip must make contact with the conducting top surface of the sample.

2. **Connect the clip to the magnet:**
   - Locate a jumper wire (448.021) to connect the end of the clip to one of the magnetic gold plated blocks.

3. Place the whole sample mount on the MFP-3D scanner plate. See Figure 9.5 on page 92 for an example a mounted sample with the jumper wire attached.

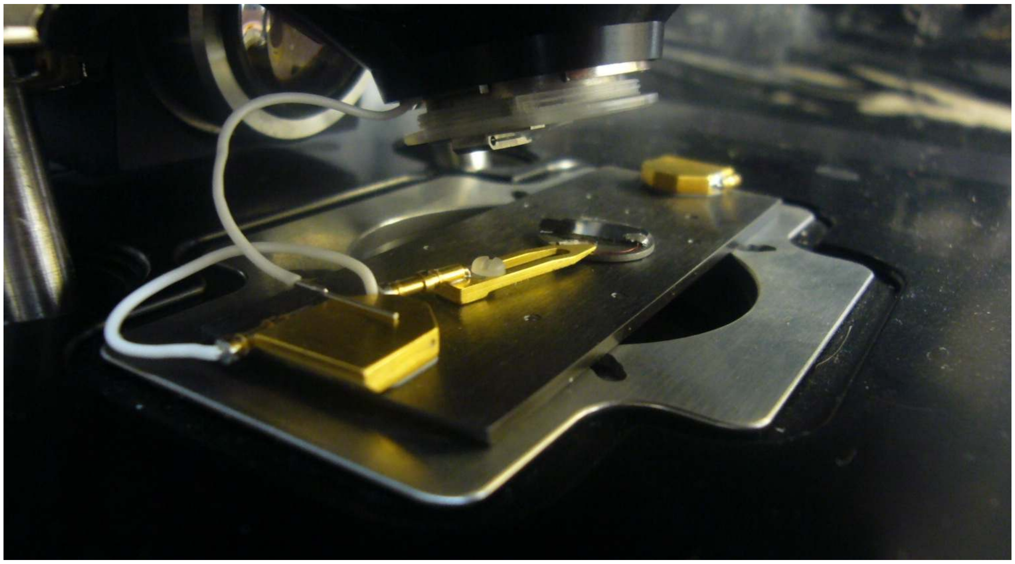


Figure 9.5.: Connect the bias wire that drops from the cantilever holder down to the magnet on the ORCA sample holder magnet as shown.

9.5. Inert atmospheres

For conductive imaging in inert atmospheres, please consider the closed cell specifically designed for that purpose .

9.6. Engaging the tip on the sample

1. Adjust the legs of the MFP-3D head so that the tip will sit at least a few millimeters above the sample when the head is placed over the sample.
2. Check that the bias wire sticking out of the cantilever holder is facing toward the rubber button which releases the cantilever holder.
3. When the head is placed over the sample, the end of the bias wire should magnetically attach to the gold plated magnetic block at the edge of the sample mount. See Figure 9.5 on page 92.
4. The bias wire now applies voltage via the metal block, to the clamp, to the sample. When the tip (held at virtual ground) touches the sample, current flows from the surface of the sample into the tip and is measured by the amplifier on the cantilever holder circuit board.

Warning	The black anodization on the sample mount must remain pristine to prevent electrical connections between it and the the top of the scanner. Please use it carefully and store it safely when it is not in use.

9.7. Conductive AFM Imaging

The specifics of conductive AFM imaging are describe in another manual: *SPM Applications Guide, Chapter: Condcutive AFM*

10. Variable Field Module 2 (VFM)

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10.1. Overview

Note	This chapter was written on the second generation VFM2 model. For a discussion about differences of the previous VFM model, please see 10.13.

10.1.1. Prerequisites

Imaging with applied magnetic fields is a fairly advanced technique. It is assumed that you are proficient in:

- Basic AFM Safety (Chapter 11 on page 135).
- AC Mode Imaging in Air (Chapter 4 on page 15).
- Magnetic Force Microscopy, which is described in *SPM Applications Guide, Chapter: Magnetic Force Microscopy*.

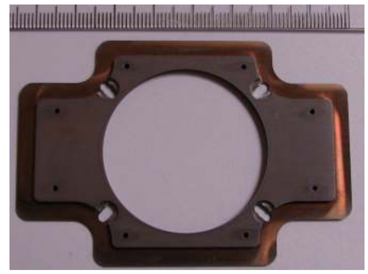
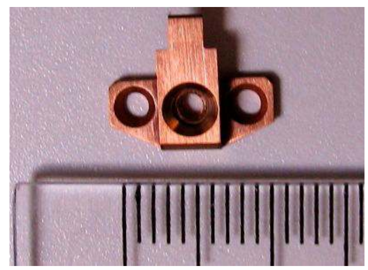
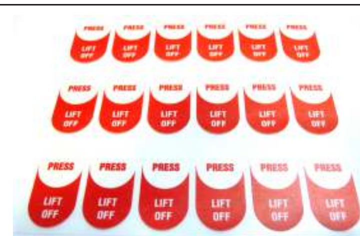
10.2. Parts List

This table lists all relevant parts, with photos and links to the relevant parts of the documentation which describe how to use them. All parts and assemblies have six digit Asylum Research part numbers. If you ever see such a number in the text and do not know what it refers to, go to the top of this document and run a search for that number and you will find it in the list.

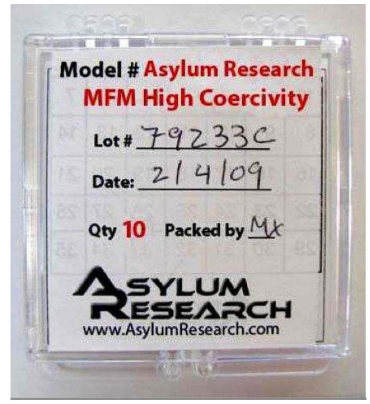
Before you begin, please check that you have the following components and tools. If you are missing anything or have questions about obtaining consumables, please contact Asylum Research for assistance.

Note Many of the items below are part of the VFM2 accessory kit (Asylum Research Part #900.244).

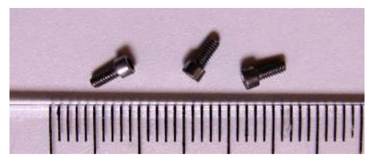
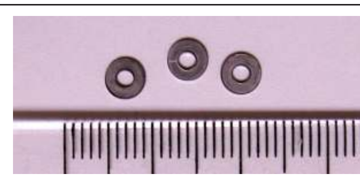
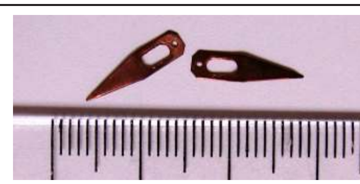
Itm	Part #	Item Description	Qty	Picture
1	111.737	Modified 0-80 Screw. Used to attach the cantilever clip to the body. Note that these screws have been machined to a nonstandard length. You must only use this Asylum part number. Item J in **??** on page **??**.	2	
The scale in the photos is in cm and mm.				

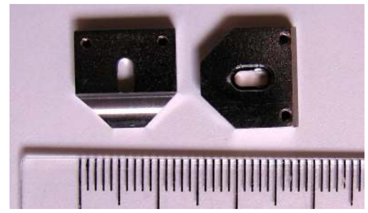
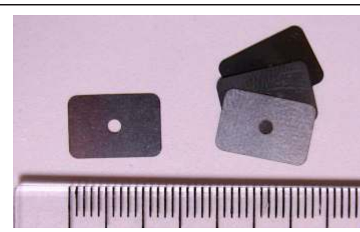
Itm	Part #	Item Description	Qty	Picture
2	111.738	Modified 1-72 Screw. Used to tighten the cantilever under the clip. Note that these screws have been machined to a nonstandard length. You must only use this Asylum part number. Item H in **??** on page **??**.	1	
3	112.041	VFM Scanner cover plate. Allows the VFM to be attached to the AFM scanner. See Section 10.5 on page 107.	1	
4	112.966	Screw down spring clip, non magnetic Beryllium Copper. See Step 8 on page 105.	1	
5	249.033	Adhesive tab sheet. You may order more from Ted Pella, part 16079. Can be used to stick flat samples on top of the VFM pole pieces. See Section 10.9.6 on page 126.	2	
6	290.102	Tweezer, Curved Sharp, Standard Grade. Typically used for handling samples and the small screws supplied with the VFM.	1	
7	290.114	Screwdriver, Slotted, 3.0 mm Width. Wiha 260 3,0 X 50. Used to mount the VFM to the scanner. See Step 5 on page 102.	1	

The scale in the photos is in cm and mm.

Itm	Part #	Item Description	Qty	Picture
8	805. ASYMFM. HC	Asylum Research high coercivity MFM cantilever. A useful cantilever for MFM imaging. See Section 10.3 on page 100.	10	
9	805. ASYMFM. SMPL	Asylum Research MFM sample pack. 5 EA of STD, HC, HM, LC, LM cantilevers, 25 in all. A useful collection of cantilevers for MFM imaging. See Section 10.3 on page 100.	1	
10	908.026	Leg extender assembly for most current model MFP3D AFMs. See Step 6 on page 103. * The correct leg extenders will be shipped to you based on your AFM serial number.	1*	
11	908.052	Kinematic leg extender assembly for most MFP3D AFMs prior to Dec. 2008. See Step 6 on page 103. * The correct leg extenders will be shipped to you based on your AFM serial number.	1*	
12	916.016 + 112.014	Objective removal tool and dummy objective. Used to remove the bottom view objective from the scanner. Its use is described in Step 3 on page 102.	1	

The scale in the photos is in cm and mm.

Itm	Part #	Item Description	Qty	Picture
13	449.011	Cable CB25M-DB25F, 2 meters, unmodified. See Section 10.4.1 on page 105.	1	
14	BHCS 0-80 X 1/8" SS	0-80 X 1/8" button head cap screws, stainless steel. Use 0.035": Allen Driver (290.104). Used to fasten the clips (112.959) or the ground wire (448.114 and see Step 3 on page 128).	8	
15	SHCS 0-80 X 1/4" SS	0-80 X 5/32" socket head cap screws, stainless steel. For holding down the pole pieces with few or no shims. See Section 10.9.2 on page 121.	8	
16	SHCS 0-80 X 3/16" SS	0-80 X 3/16" socket head cap screws, stainless steel. For holding down the pole pieces when using many shims. See Section 10.9.2 on page 121.	8	
17	SHCS 0-80 X 5/16" SS	0-80 X 5/16" socket head cap screws, stainless steel. Spares for attaching the scanner top plate 112.041. Use with a #0 washer (next item in the list). See Section 10.5 on page 107.	8	
18	#0 FLAT WASHER MS801	Number 0 stainless steel washer, Spares for attaching the scanner top plate 112.041 (see Section 10.5 on page 107). Use with the previous item.	8	
19	112.959	Beryllium Copper Clip. Used with BHCS 0-80X1/8" SS screws. See Section 10.9.6 on page 126.	5	
The scale in the photos is in cm and mm.				

Itm	Part #	Item Description	Qty	Picture
20	113.672	Low profile pole pieces. Attach with SHCS 0-80X5/32" SS. See Section 10.9.2 on page 121. Note, not compatible with earlier VFM stages. See Section 10.13 on page 129.	2	
21	114.250	High profile pole pieces. Obsolete, but they were included in a few VFM2 models.	2	FIGURE NEEDED
22	290.111	0.050”: Wiha Allen Driver 263 1,3 – 0.05” X 40. For most socket head screws on the VFM2. Typically used to remove the pole pieces. See Section 10.9.2 on page 121.	1	
23	290.104	0.035”: Wiha Allen Driver. For the screws (BHCS 0-80X1/8" SS) that fasten the clips. See Section 10.9.6 on page 126. (112.959) or the ground wire (448.114 and see Step 3 on page 128).	1	
24	114.645	0.003” (75 µm) thick shim stock. Used for spacing the pole pieces when using large flat samples. See Section 10.9.2 on page 121.	30	
25	900.056.1	VFM2 controller box. Connects between the AFM controller and the VFM2 sample stage. See Section 10.4.1 on page 105.	1	
The scale in the photos is in cm and mm.				

Itm	Part #	Item Description	Qty	Picture
26	900.251	VFM2 Sample Stage - the subject of this chapter.	1	
27	279.061	Objective Storage Case. Used to store the bottom view microscope objective after removal with tool 916.016 as described in Step 3 on page 102.	1	
The scale in the photos is in cm and mm.				

10.2.1. Temperature Sticker

The VFM2 contains magnetic materials which can lose their "potency" if exposed to temperatures above 80°C. Please inspect the sticker attached to the VFM cable. If the sticker has turned black indicating temperatures in excess of 80°C, please test the ability of your VFM to reach its specified maximum field (see Section 10.9.4 on page 122). Note that the VFM2 should never be stored or transported in such a way that the temperature exceeds 80°C. While it is not likely, the interior of a car or shipping container can reach such temperatures in sunny weather. Please contact Asylum Research Support if your VFM stage appears to have been exposed to high temperatures or does not meet its maximum field specification.

10.3. AFM and MFM in an Applied Magnetic Field

A powerful tool for understanding the behavior of a magnetic sample is an applied field. Applying a field may prove useful in applications such as imaging the domain reversal behavior of a ferromagnetic thin film, studying magnetic field dependent resistance in sensor devices, or imaging magnetic particles that have been used as biological tags. The bibliography at the end of this note gives a partial list of references where researchers have used an applied field in magnetic force microscopy (MFM) studies.

MFM imaging in an applied magnetic field can actually complicate the interpretation of your images significantly. In addition to the sample behavior being field dependent, the magnetic state of the MFM tip can also change in an applied field. One way to simplify interpretation in an applied field is to use a tip with a coercivity (or switching field) that is very different from that of the sample, either much lower or much higher. Then, when the contrast is changing, one can be relatively confident of the origin of the change. For this reason, super paramagnetic tips or very high coercivity tips can be useful for applied field imaging. For applied field MFM work, we generally recommend starting with high coercivity MFM cantilevers such as the type ASYMFMHC. These cantilevers have coercivities greater than 5,000 G and therefore will not be re-magnetized by use with the VFM. For your specific application, do not hesitate to contact Asylum Research if you would like further information.

10.3.1. How it works

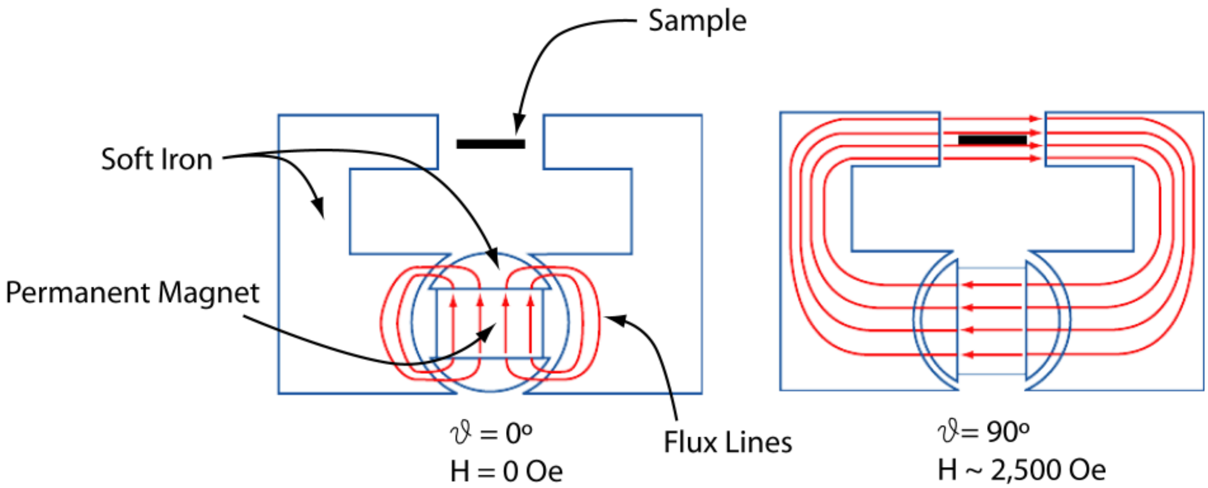


Figure 10.1.: How it works: A rare earth permanent magnet is at the heart of the VFM. The strength and sign of the magnetic field applied to the sample depends on the rotation angle of the magnet. When the magnet is at 0° or 180°, the magnetic flux is shunted away from the sample by the soft iron armature and pole pieces. As the magnet rotates, more and more flux is channeled instead through the sample. At 90° and 270°, the field magnitude is maximized.

The Asylum Research Variable Field Magnet (VFM) module relies on a rare-earth permanent magnet to apply a field to the sample. By rotating the magnet, different amounts of magnetic flux can be channeled through the sample. Referring to Figure 10.1 on page 101, the flux through the sample is maximized when the magnet is oriented at 90° and 270° and minimized when the magnet is oriented at 0° and 180°. By using permanent magnets we avoid using electromagnetic coils that can require significant current to maintain a large magnetic field. This current inevitably leads to unwanted joule or resistive heating. Heating can degrade the performance of the AFM as well as change the physics of the sample being studied. A motor controls the magnet rotation. Motion of the motor is controlled through menu settings in a control panel within the MFP-3D/Igor Pro software interface, detailed below. The software uses the signal from a magnetically sensitive sensor embedded close to the sample mounting area to control the desired field strength of the VFM stage to within ± 1 G. The software feedback control can also be disabled to allow the user to manually control the VFM field strength.

10.4. Installing the Hardware

1. Lower the bottom view objective as far as it will go. Use the fat micrometer on the lower right hand side of the base (See Figure 2.4 on page 9).

2. **Determine if the objective retracted enough**

- Determine if the objective retracted completely below the top surface of the base. If you are not sure, remove the scanner (Step 2 on page 107) and place something flat over the objective hole to see if it sunk completely below the surface.
- IF the objective is below the surface, THEN skip the next step and go to step 4
- IF the objective still protrudes above the plate for some reason, THEN follow the next step: objective removal.

3. **Remove the bottom view objective (if needed)**

- Locate the objective removal tool and cover (), and the objective storage case (279.061).
- Using only finger pressure, use the tool to unscrew the objective and place it in the storage case.
- Use the tool to place the cover over the threaded hole in the AFM base. Only tighten very gently.
- Replace the scanner if necessary (Step 10 on page 109).

4. **Install the VFM scanner top plate (if needed)**

- If it is not already installed, replace the scanner top plate with the one supplied with your VFM (112.041). It has four oblong slots that are not present on the standard model.
- Please read Section 10.5 on page 107 for directions on this process.

5.

Mount the VFM onto the Scanner

- Using screwdriver 290.114, **carefully** align the slots of the four screws with the white lines on the VFM.
- Place the VFM onto the scanner in the orientation shown to the right. If necessary, adjust the screws slightly so they properly engage the slots in the scanner plate.
- Rotate all screws by 90° to lock the VFM down.

6.

Determine the need for leg extenders

- If the three legs on your AFM head do not have a groove just above their spherical tips, then you need to extend the length of the legs being used. Skip to the next step and install the supplied leg extenders.
- If there are grooves on the legs, these indicate a newer model of AFM head with longer travel on the legs. If your sample is less than 1mm thick, then you will not require leg extenders. To be sure this is the case, please follow the procedure below.
  - Extend all three legs to their full extent and place the AFM head (with cantilever holder in place) over the mounted VFM.
  - First seat the rear legs, then carefully lower the seat to the front leg while looking at the clearance above the VFM.
  - There should be a few millimeters of remaining space. Judge whether or not this space is enough to accommodate your sample thickness. Typically there should be a few millimeters of clearance and you should not have to install leg extenders. A bit more detail follows:
  - The clearance above your sample may fall into three categories:
    - If the sample surface sticks up higher than the highest possible position of the AFM head, installation of leg extenders will be required. Skip to the next step for instructions. Note that samples extending above the VFM pole faces are not very well suited due to field gradients. Please read more on optimal sample mounting in section Section 10.9 on page 120.
    - If there are a few millimeters of clearance, you cannot use leg extenders. Once you install them you may find that the head will not be able to go low enough to reach the sample. Do not install the leg extenders if this is the case.
    - There is a small window (about a 1mm range) of overlap where you can engage a sample either without leg extenders but with the legs fully extended, or with leg extenders with the legs fully retracted. We recommend that you do not use the extenders if it is not required.

7.

Install the leg extenders (if needed)

- Slide the leg extensions over the ends of the head legs.
- If one leg extender is shorter than the others, place it on the front leg.
- Push the extensions on the head legs until the balls on leg ends fit into the cupped surface inside the extension.
- Secure the extensions to the legs by gently tightening the two hex screws on each extender.

8.

Replace the cantilever holder spring clip

- Using a small Phillips screwdriver, remove the two outer screws.
- Lift the clip off and store in a safe place.
- With the same screws, affix the new Beryllium Copper clip (112.966). Do not over tighten the screws. Spare screws are in your kit (111.737).
- If the center screw is not yet present, install it now (item 111.738).

Note The center screw is larger than the outer screws. Do not mix them up.

The standard spring clip that holds the cantilever is slightly magnetic and leads to unwanted field gradients and poor magnetic field sensor readings. We have provided a nonmagnetic clip made of beryllium copper that can be substituted when using the VFM.

When done with the VFM experiments, we recommend that you replace the original steel clip. The BeCu clip may corrode if it is used in fluid

10.4.1. Installation – Electrical connections

While not strictly necessary, it is good practice to turn off your AFM controller before making these connections.

The Variable Field Magnet (VFM) connects to its interface box that is in turn connected to the expansion port of the MFP 3D controller using the supplied DB25 cable (449.011). The connections are illustrated in Figure 10.2 on page 106

Figure 10.2.: TheVFM sample stage plugs into the 9-pin connector on the VFM controller box. This in turn plugs into the 25-pin expansion connector on the front of the MFP-3D controller. This photo shows the older MFP-3D controller. The newer ARC2 controller can be used as well.

We typically leave the controller box outside of the acoustic enclosure and simply let the black cable between the VFM and the controller box hang from the front of the enclosure. The cable can be safely pinched between the sealing gasket of the hood's front door.

When the controller is turned on, a bright blue light should shine from the small circuit board between the pole pieces.

It is acceptable to have the cable between the VFM and its controller box hanging out of the front of an acoustic enclosure. The cable is thin enough to be pinched between the enclosure door seal. You may also route the cable through the proper cable clamps, but it is not strictly necessary, and probably only advisable for cases where the VFM stage is used a lot.

10.5. Changing the Scanner Cover Plate

This section assumes the VFM scanner top plate is not installed. As described before (See Step 4 on page 102), it has four oblong slots which the VFM latches onto. If your lab never deals with samples in fluid, it is perfectly fine to leave this plate attached indefinitely. Otherwise, fluid can leak through the holes and bypass the scanner liquid shield, so it is recommended to replace the original scanner plate when you are finished with the VFM experiments.

If the VFM was delivered separately, the scanner's sample stage plate needs to be replaced.

The following instructions only apply to customers who have the latest version of MFP-3D scanners, which began shipping on February 1st, 2006. They are easily distinguishable from the older version, in that they provide access to the four additional screws around the center hole. For older models, contact Customer Service at 1-888-472-2795 for assistance (Figure 5).

Note: The four additional holes to mount the VFM also create four additional locations for fluid to leak into the scanner. Please remove and replace the original sample stage if the VFM is not going to be used for extended periods of time.

1. Before changing anything, measure the hysteresis for both X and Y (See Section 10.5.1 on page 109). Make note of the results, preferably with screen captures or saving of graphs.

2. **Remove the scanner**

   - To release tension on the scanner spring, translate the scanner as far forward as possible.
   - Unplug the scanner cable from the base of the microscope.
   - Gently tilt the scanner upward from the AFM base (held down by magnets) and disconnect the retaining spring that holds it to the base. Hold your finger on the spring to keep it from jumping away.

3. Lay the scanner down on a clean flat surface.

4.

Remove the scanner top plate

- Use the 0.050” Allen tool (290.111), to remove the eight screws (0-80 X 5/16") and washers (#0) from the scanner bottom. Be careful not to lose the screws and washers. If necessary, spares are included with your kit. Use tweezers to handle the parts.
- It is best to completely remove all the screws to be certain that none are still holding onto the plate.
- Lift the scanner up, leaving the scanner top plate behind. If the plate sticks, turn the scanner over and remove the plate with your fingers.

Note Scanners delivered prior to 2008 may be missing access holes for the outer screws. If this is the case, please contact the Asylum Research support department about obtaining a new cover plate with the access holes.

5.

Clean the water shield

- Clean the water shield and exposed stage parts with a cotton swab and alcohol as needed. Some residue from prior spills may be present in labs that perform imaging in liquid.
- The photo to the right shows a clean scanner and liquid shield (black plastic ridge adjacent to visible metal cross).

6.

Prepare the new scanner top plate

- Place the new scanner top plate upside down on your working surface.
- Place scanner on top of the plate (bottom of scanner facing upward) and slide it around to visually center the 8 screw holes.

7. **Install the screws and washers**
   - Partially thread in all 8 screws.
   - Center the screw heads as best you can.
   - Gently tighten all the screws in a "star pattern" alternating screws that are diametrically opposed.

   Note Be careful not to over torque screws when tightening.

8. Replace the scanner on the AFM base and plug it in. At this point, it is not necessary to attach the spring to the driver bar since this process may require a few iterations.

9. **Measure the XY hysteresis**
   - Follow Section 10.5.1 on page 109.
   - If any of the three hysteresis values are within 5% of the previously measured values, you are done and can proceed to the next step.
   - If any of the new values exceed the old ones by 5%, the stage plate is likely rubbing the water shield. In this case, remove the scanner and loosen the eight screws until the top plate slides freely.
   - Attempt to center the plate again and tighten screws as instructed in the previous steps.
   - Repeat the XY hysteresis measurement again until you pass the 5% test. Feel free to call Asylum Research if you are having trouble.

10. **Replace the scanner**
    - Place the scanner on the AFM base in the same tilted manner that was used when removing it.
    - Reconnect the spring between the pin on the scanner and the pin on the micrometer driver bar.
    - Tilt the scanner back gently until it lies flat and move the micrometers until the grooves (or divots, depending on the vintage of your MFP-3D) in the baseplate are centered over the three holes in the scanner.
    - Plug the scanner cable connector back into the AFM base.

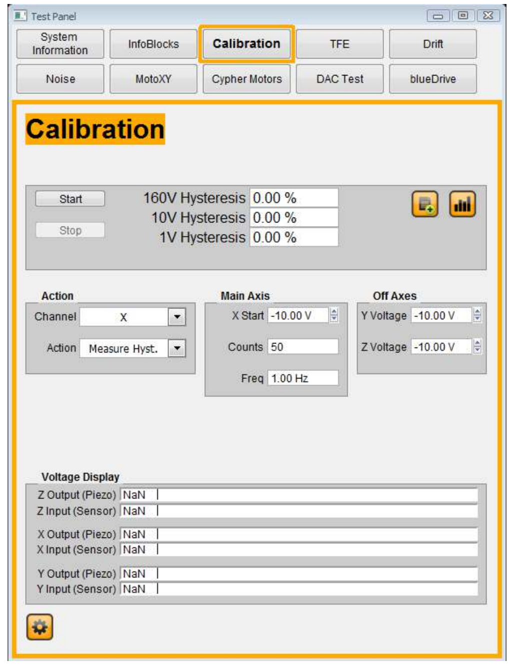
10.5.1. XY Scanner Hysteresis

This procedure measures the hysteresis of the XY scanner (piezos and mechanical assembly). The measurement is done off the surface; no tip or sample is required. In fact, the AFM head does not need to sit on the scanner at all. The X and Y piezos are exercised in open loop (no feedback from sensors) through three voltage ranges and the hysteresis for each is calculated from the corresponding sensor data.

1. Load the test procedures by selecting *Programming* ▷ *Load test procedures* from the main menu bar.. The word *Testing* will appear on main menu bar.

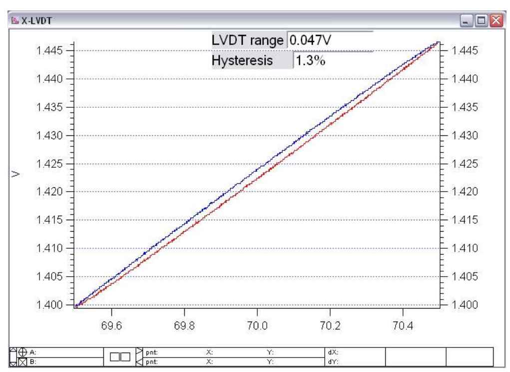
2. **Bring up the Hysteresis Measurement Panel**

   - Select the 'Calibration tab'.
   - Set Channel to X-axis.
   - Set Action to Measure Hysteresis.
   - Set Frequency to 1 Hz.
   - Set Cycles to 50.



3. **Collect the X axis hysteresis plot**

   - Click Start. The piezo cycles 50 times through each of three voltage ranges: 160, 10, and 1 V.
   - A graph of the sensor (LVDT) signal vs. piezo drive voltage appears.
   - As the piezo begins to move, its range increases. Wait for the LVDT range to stabilize (about 50 cycles), and then click Start again. The measurement is complete when the Stop button changes to Start.
   - Write down hysteresis values for the three voltages.



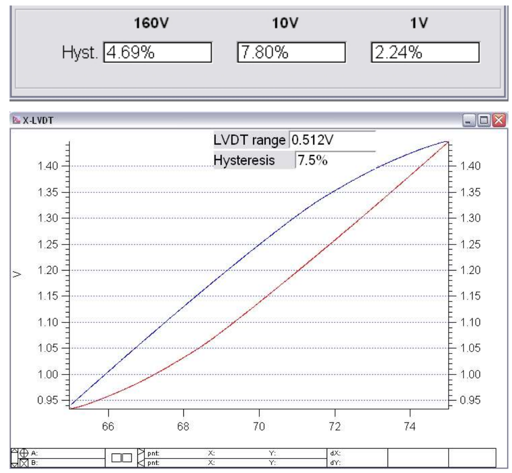
4. Change the Channel to Y-axis and repeat the previous step.

5. **Evaluate Hysteresis Results**

Good Acceptable hysteresis for X and Y should be less than or equal to 5% for 160 V, 4% for 10 V, and 3% for 1 V. It is typical for Y to have a slightly larger hysteresis than X due to the greater mass the Y scanner moves.

Bad It is more common for the 10 and 1 volt ranges to fail when there is rubbing. Bad values and a bad graph are shown to the right.

If the hysteresis is above spec, the moving component of the scanner (stage top plate) is likely rubbing against the housing or has some other mechanical interference.



10.6. Software Tutorial

This tutorial can be performed with the VFM sitting on the bench top, as long as it is connected as shown in Figure 10.2 on page 106.

Turn your controller back on or rescan the smart start bus (see Step 6 on page 10).

The control panel for the VFM (Figure 10.3 on page 112) will automatically appear once the software is started, as long as it is connected to the MFP3D controller. The panel can also be displayed by selecting *AFM controls ▷ VFM panel* from the main menu bar.

A complete description of each control parameter in the panel can be found by clicking on the box with the question mark next to the parameter of interest.

This tutorial gives instruction for a few rudimentary tasks to demonstrate the controls.

1. The panel should start out as it appears in Figure 10.3 on page 112, with mode and feedback turned off. Your field may be reading a different value than that in the figure, depending on the rotor position of the VFM when it was last used.
2. Make sure the pole pieces are 3mm apart for the following examples to function. Use the supplied 0.050” allen driver (290.111) to move the pole pieces. Also see Section 10.9.4 on page 122.
3. Click the More button next to “Live Graph” three times. This will bring up a realtime record of field, motor speed, and field setpoint.
4. Set the ramp rate to 3000 G/m, target field to 2000 G, and Error Tolerance to 5.0.
5. Set Feedback to On and Mode to On. The motor should start turning and the values on the graph will change. Wait until the field settles down to 2000G.
6. Set Feedback to Off and Mode to Off.
7. Click the Clear button next to “Data History” to clear the graph.

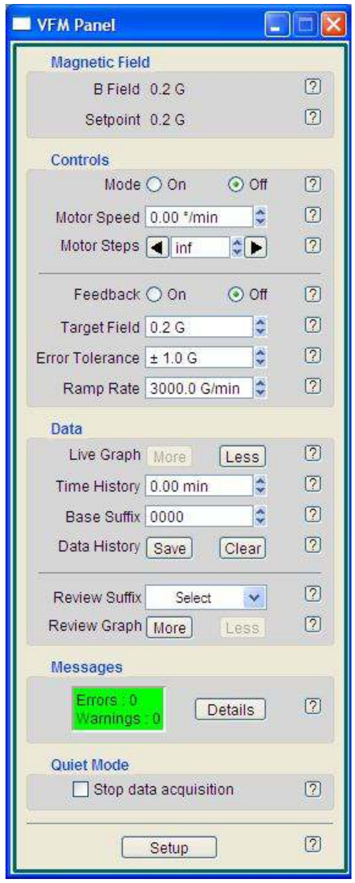
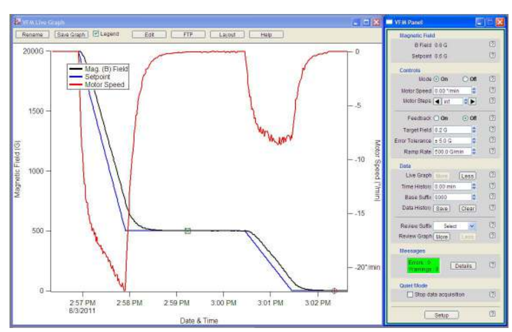


Figure 10.3.: The VFM panel. A complete description of each control parameter in the panel can be found by clicking on the box with the question mark next to the parameter of interest.

8.

Controlled Field Ramp

- Set the ramp rate to 2000 G/m.
- Set the Target Field to 500 G.
- Click 'Feedback On' and 'Mode On'.
- The motor will execute a controlled field reduction and gently stop at 500G. Once it reaches the target value within the set error tolerance, it will turn the feedback off and the motor speed to zero.

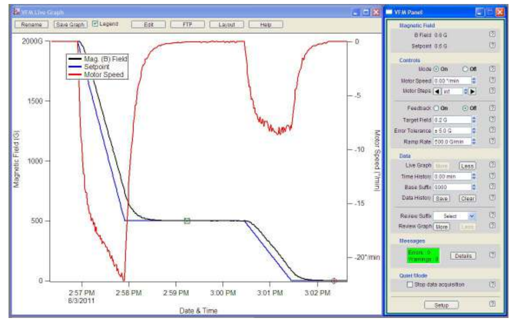


Note If the error tolerance is too narrow, the motor will never stop adjusting and may cause imaging noise. Always turn the mode to off before imaging if you are uncertain.

9.

Controlled Field Ramp, continued

- Set the ramp rate to 500 G/m.
- Set the Target Field to 0 G.
- Click Feedback On and Mode On.
- The motor will execute a slower ramp down to zero.

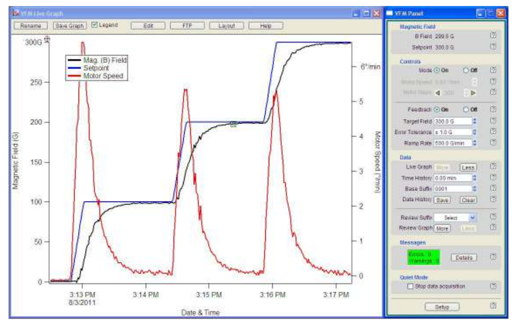


10.

Changing the field by 100 G steps

- Set the Target Field to 100 G.
- Set Feedback On and Mode On.
- Observe and repeat at 100G increments to produce the graph to the right.

Note A real ramp never quite executes. The feedback control parameters are set conservatively. If faster settling times are needed, please contact Asylum Research, or read on for more suggestions.



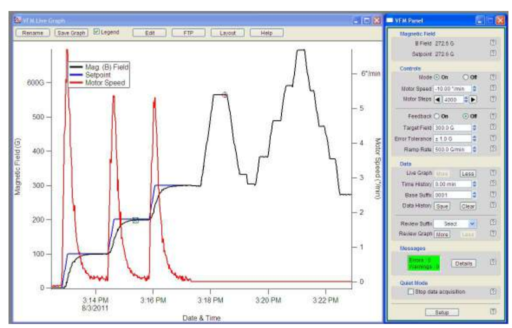
11.

Changing the field by motor steps

- Set Feedback to OFF.
- Set Motor speed to 10 °/minute.
- Enter 10,000 steps.
- Click on the RIGHT arrow next to Motor Steps.

The motor turns on immediately, executes its steps, and stops. The graph shows the field history.

- Click on the LEFT arrow next to Motor Steps.



Note The field stops short of where it was before. This is due to backlash in the motor's gearbox. We had continued with a number of 4000 step positive increments followed by negative 4000 step increments. The settling time is faster but the benefits of feedback control, like backlash elimination, are compromised.

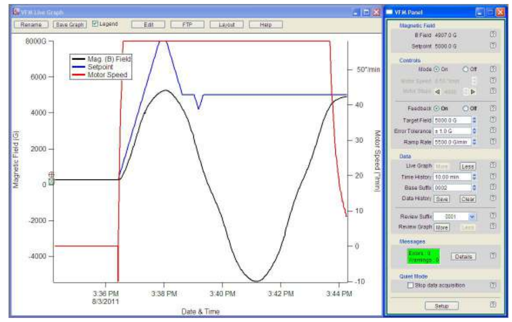
12.

Setpoint out of range

- Set Ramp Rate to 5500G.
- Set Target Field to 8000G.
- Turn Mode and Feedback to On.

For a while the motor tries to keep up with the rising setpoint, but eventually the VFM2 reaches the maximum field for the given 3mm pole face separation. In any case, we chose a setpoint too high and the motor will keep spinning forever trying to reach it.

Note The setpoint was reduced to a reachable 5000G after the field had reached its maximum. The VFM can only operate in the positively sloped region of field vs motor direction. Even though it might reach its setpoint, it will complete one more full rotation until it is back in the positively sloped area before slowing the motor to land at 5000G.



10.7. Field Gradients

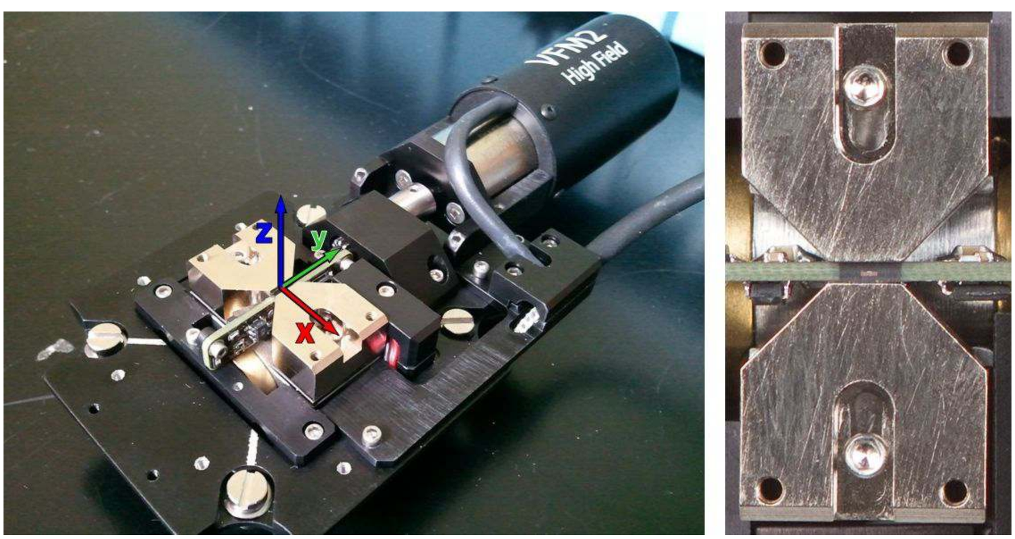


Figure 10.4.: Coordinate Axes defined and the field orientation. Positive sensor values are defined as B field components along the positive X-axis. To the right, a close up view of the preferred origin for imaging, which lies directly over the field sensor, highlighted as a tiny white line between the pole faces.

VFM2 vs VFM	This discussion largely focuses on the magnetic sensor of the VFM2. The original VFM had a larger sensor which was located much farther away from the sample. Please see Section 10.13 on page 129 for further discussion about their differences.

Proper sample mounting is only possible with some understanding of the magnetic field gradients produced by the VFM. In an ideal world, the field would be very uniform and the magnetic field sensor would be only few microns long, separated from the imaging region by only a few microns. In reality, the sensor is hundreds of microns on a side (with an active measuring area of 70 by 70 microns) and is embedded in a package which adds at least several hundred more microns to its size, and the sample thickness will likely add hundreds more microns. As shown later in more detail, the field can change by 1000's of Gauss over this distance.

To overcome this problem of not being able to put the sensor directly in the same place as the imaged surface of the sample, we take advantage of the symmetry of the field. With proper sample and pole face placement, the relative locations of sensor, sample, and pole faces can maximize the likelihood that the sensor is registering a meaningful field.

Figure 10.4 on page 114 defines the coordinate system of the VFM. It also shows the exact position of the magnetic sensing element, aligned with the bottom edge of the pole pieces. The origin of the coordinate axes has been placed in the plane of the tops of the pole pieces and directly above the center of the sensing element. This is the optimal position for the sample's top surface.

Figure 10.1 on page 101 shows how the VFM routes flux from a permanent magnet to the sample. This cartoon shows the field lines as perfectly parallel and uniform and the sample not accessible for imaging. A more realistic depiction can be seen in Figure 10.5 on page 116. The scale of the pole faces is 1.5mm tall and 3mm wide.

Some observations:

- The field decreases in strength away from the area between the pole faces (we'll quantify this shortly).
- At x=y=0 the field is horizontal (parallel to x), which is also the only component the sensor can measure. Moving away from the origin along the x axis (and to a lesser extent along y) the field vector will gain other components and rotate away from its direction at the origin.
- The sensor is placed so that it measures a field which is a mirror image of the field at the origin. Asylum Research individually aligns the sensor position on each VFM so that it is aligned with the bottom edge of the pole faces.

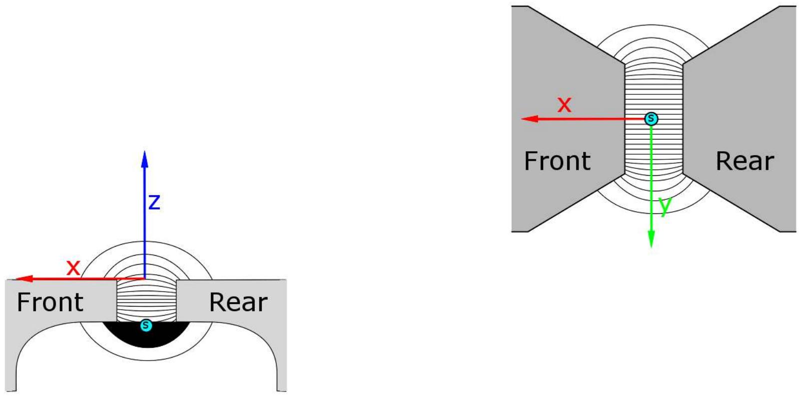
Some conclusions:

- Place the area of the sample to be imaged as close to the origin as possible and it will enjoy:
  - "Horizontal" applied field.
  - Fields which are very close to what the sensor measures.

These observations do not change with larger pole face separations; only the field values and the field gradients will reduce in size.

10.7.1. Vertical Field Variation

To take a more quantitative look at the field profiles and gradients, we mounted a magnetic field sensor on an XYZ translation stage and made various measurements of the field along the X, Y,



(a) View from +y to the origin. **(b)** View down from +z to the origin.

Figure 10.5.: Cartoons of the approximate fields between the pole faces. On the left, a side-view section, on the right a top down view. “s” denotes the position of the field sensor’s active element. The origin was chosen at the optimal point for imaging. The central position of this point will maximize the field along x and minimize the other components. The origin also best mirrors the sensor position so the field measurement is as accurate as possible.

and Z axes. Note that the sensor was oriented to measure only the field component parallel to the X axis, or B_x.

Figure 10.6 on page 117 shows B_x for various separations of the pole faces on a VFM2 set to maximum field strength. Lets dissect a few of the curves. The yellow (top) curve with triangle markers shows data gathered with the pole faces as close as possible, touching the sensor circuit board between them. At Z=0, B_x is slightly more than 1 Tesla. Note that when this VFM is placed on the scanner, the field drops a bit. This experiment was performed on the bench top. Going down into the shaded area (indicates the sensor is going between the pole faces) the field rises, and then falls again as the sensor emerges from between the pole faces. The symmetry of the field caused us to choose the sensor position at Z=-1.5mm, which does a respectable job of matching B_x at Z=0.

Going up from Z=0, the field falls quickly. Only 500 microns above the pole faces, it has dropped to a little over 6000 G. The implication is that if you are studying a sample which is 500 microns thick and set it flat on top of the pole faces, your maximum field can only be 6000 Gauss. You will have to cut the sample smaller so it can fit between the 1mm separated pole pieces to get to closer to the VFM’s maximum field.

Lets look at the brown curve with circular markers (one up from the bottom). The magnet orientation was left in the same position, but the pole faces were separated from 1mm to 3mm. The maximum B_x at Z=0 has dropped to ~4000 G, but the field gradients are also significantly less. B_x at Z=0.5 is now ~3000 G. Smaller gradients tend to make for better measurements. To conclude, it is always best to separate the pole faces as far as possible depending on your maximum field

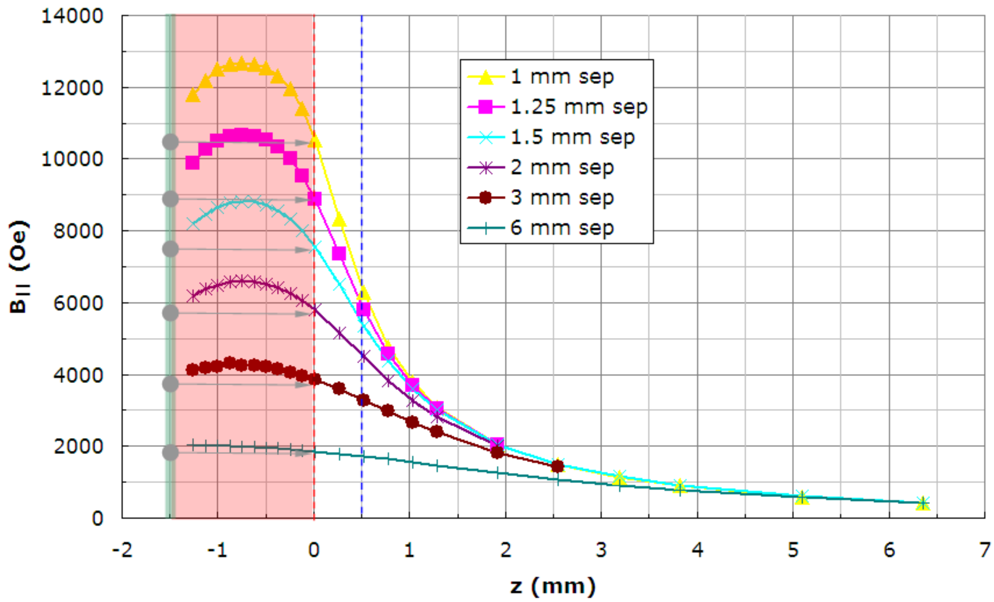


Figure 10.6.: Magnetic field component parallel to the x-axis as a function z position above the pole faces in a VFM2 set to maximum field strength. Different curves represent different pole face separations (see legend). The shaded area is the volume between the pole faces. The red dashed line (z=0) indicates the preferred plane for a sample surface to be imaged. The blue line (z=0.5) indicates a sample which is 0.5mm thick. The broad green line indicates the position of the Hall sensor attached to each VFM2. The gray arrows connect the field measured by the sensor to the field experienced by a sample mounted flush with the pole pieces.

requirements.

10.7.2. Fields vs pole piece separation and vertical gradients

Figure 10.7 on page 118 summarizes some key information from the family of curves in Figure 10.6 on page 117. For various pole face separations it shows:

- The maximum B_x at Z=0, i.e a sample clamped between the pole faces so its top surface is flush with the tops of the pole pieces. Use this curve to determine the pole face separation needed, based on your maximum field requirements. Always choose the largest separation possible.
- The maximum B_x at Z=0.5mm, i.e a larger sample, 0.5mm thick, sitting on top of the pole faces.
- The approximate field gradients at Z=0.

10.7.3. Lateral Field Gradients

B_x variations along X and Y in the plane of the pole faces (Z=0) were also measured for a pole face separation of 3mm. The results are shown in Figure 10.8 on page 119.

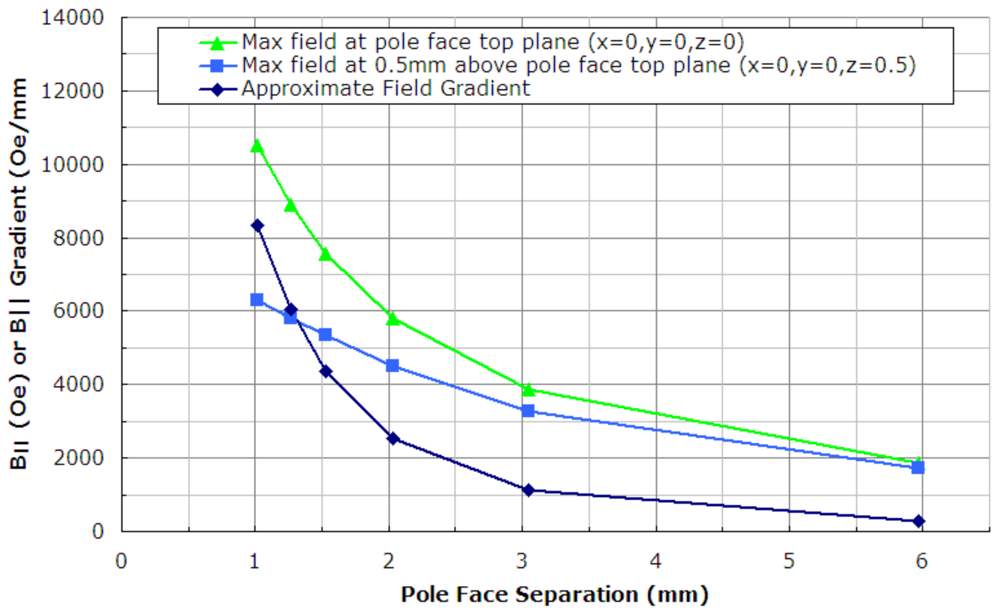


Figure 10.7.: Maximum field along the x-axis measured at the origin (sample in plane with pole face tops) and 0.5mm above (0.5mm thick sample resting on pole face tops). Also, the approximate field gradients at each point for Z=0.

The main observation is the nearly zero gradients in B_x as long as the imaging region is within 0.25mm from X=Y=Z=0.

10.8. Things to keep in mind

10.8.1. Samples' effect on the field

A magnetic sample can be a bridge for magnetic field lines from one pole piece to the other. The sensor placement at the "mirror image" of the sample assumes the field is symmetric at the upper and lower edges of the pole faces. Placing a piece of magnetic material (i.e. the sample) will break that symmetry and will direct flux through the sample and away from the sensor. Luckily the effect is negligible for most samples.

A suitable test is to set the field at a relatively high value (we chose 5000 G with an approximately 2mm pole face spacing) and to monitor the sensor reading for a minute or so. Then place the sample on top of or in between the pole pieces. If the field changes measurably, then the field experienced by the sample will no longer equal the field measured by the sensor. Here are the results for four materials:

Sample	Effect
8mm wide piece of video tape	no measurable effect
8 x 8mm piece of hard drive platter	no measurable effect
4mm wide strip of 1 micron thick amorphous cobalt alloy	5 G (0.1%) drop in measured field
5mm wide strip of 0.25mm thick magnetic steel	100 G (2%) drop in measured field

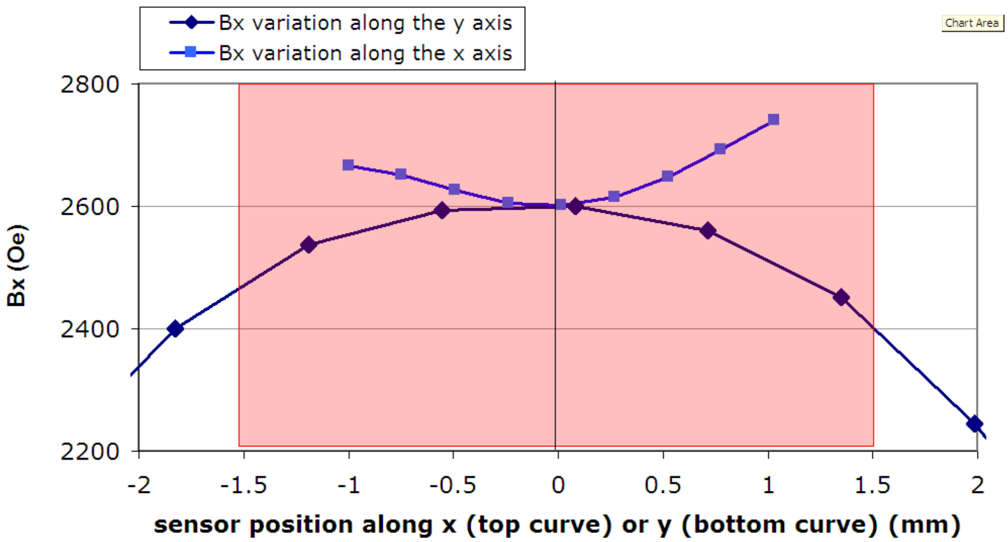


Figure 10.8.: Variation of the x component of the magnetic field along the x and y axes (with z=0). Pole faces were separated by ~3mm. x-axis data cannot extend the full 3mm range due to the sensor plastic enclosure hitting the pole faces. The pole faces are also 3mm wide andF so the red area indicates measurements taken with the sensor in the gap between the faces.

In the last case, it is not clear that the 2% drop at the sensor implies a 2% increase at the sample, but at least it gives some cause for further investigation. The best course of action is probably to substantially reduce the size of the sample and repeat the test until the presence of the sample has little or no effect on the sensor reading.

A good indication that there is going to be an effect is when the sample is noticeably attracted to the gap between the pole pieces. This can best be felt with the VFM set to a high field value.

10.8.2. Scanner's effect on the field

If you set the VFM to its maximum field and then place it on the scanner, you may notice a drop of about 10%. This is due to magnetic field lines under the VFM "short circuiting" via the magnetic steel inside the scanner. If you must have more field than the reduced maximum, contact Asylum Research to fashion a spacer to mount the VFM a little higher on top of the scanner.

Also beware that if a sample is very near some maximum field it should not exceed, be sure to reduce the field before removing the VFM from the scanner, or there may be a sudden 10% jolt in increased field.

10.8.3. Temperature Effects

The strength of the permanent magnets used in the VFM vary with temperature. While the effect will be relatively small, you may notice that the sensor reads a lower field value once the AFM warms up the inside of its acoustic enclosure. Also, for long term measurement, it is possible that there will be a small field variation due to daily temperature changes of the lab. Most labs with proper air conditioning should not notice this effect.

10.9. Sample mounting

(a) Side view of a small sample between the pole faces.

(b) Side view of a large flat sample on top of the pole faces. The sensor reads true when the spaces marked with Delta are equal.

Figure 10.9.: Side views showing a small sample mounted between the pole faces with its top surface flush with the top of the pole faces. This allows for the maximum field. In sub figure B, a larger flat sample sitting on top of the pole faces is shown. The max field is less and the distance from the top edge of the pole faces to the top of the sample needs to equal the distance from the bottom edge of the pole faces to the sensor (The two Delta spaces).

As described in Section 10.7 on page 114 (if you did not read this, you should, in order to correctly interpret the sensor readings) the magnetic field sensors sit below the sample at a position where the field strength mirrors that experienced by the sample.

10.9.1. Small Samples (best)

As shipped from the factory, the pole pieces are configured for a sample which can be mounted as shown in Figure 10.9a on page 120. The sample should be thin enough to fit on top of the sensor bridge without rising above the top surface of the pole pieces.

To achieve the highest possible field, the sample should be narrow enough to allow the pole pieces to slide all the way together and touch the sensor bridge. The sample may have to be clamped between the pole faces to keep its top surface flush with the tops of the pole pieces. A few small dots of five minute epoxy or some wax may come in handy when mounting the sample.

Note that keeping the sample small has other advantages, as described in Section 10.8 on page 118

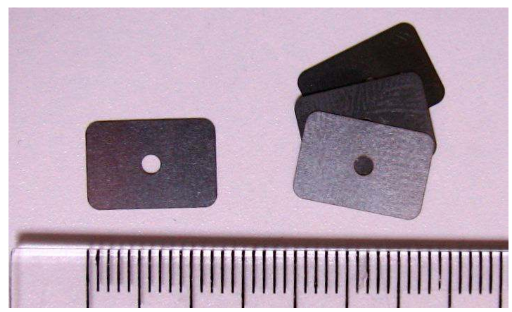
WARNING	The sensor bridge is somewhat fragile. It is made of epoxy and fiberglass. Do not cover it with paint, glue, or other contaminants. While you can clean it with a mild solvent such as isopropyl alcohol, but you should NOT scrape it with sharp objects such as tweezers, scribes, or scalpels.

10.9.2. Larger Thin Samples (good)

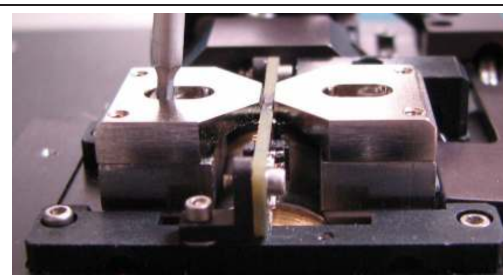
Often a sample will be in the form of a thin film on a wafer substrate. If very high fields are not necessary, or it it is not possible to dice the sample into the preferred 1mm wide strip, then one can proceed by mounting the sample on top of the pole faces as shown in Figure 10.9b on page 120. See the steps below to mount the sample and properly adjust the field sensor:

1. Measure the sample thickness with an accuracy of 25 µm (0.001 inches).
2. Divide the thickness in microns by 75 and round to the nearest integer. For instance, a 300 µm silicon wafer results in 4, a 500 µm wafer gives 7. This is the number of shims (per side) you will need in step 4.
3. If the VFM was not already at a very low field, please see Section 10.6 on page 111 and set the VFM to zero field. This will make it easier to remove the pole faces without suddenly snapping together and possibly damaging the sensor bridge.
4. **Gather shims:**
   - Choose twice that number of shims calculated in step 2. (114.645).
   - Divide the shims into two equal stacks.

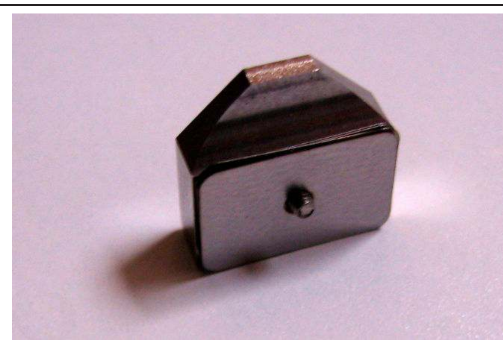
   Note These shims were cut from 75 µm thick magnetic stainless steel.



5. **Remove the pole pieces:**
   - Using the 0.050” allen driver, remove both pole pieces and set aside.

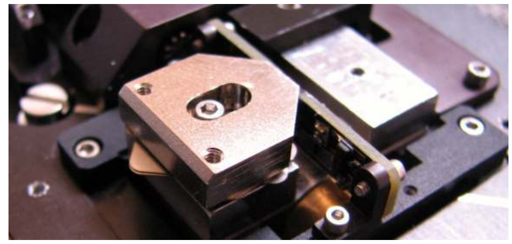


6. **Place the shims under the pole piece:**
   - Align the shims under the pole piece.
   - Use the screw to keep the shims centered as shown.



7. **Replace the pole pieces:**

- Place the pole piece back on the VFM, while keeping the shims against the pole piece.
- Tighten the screw with a few turns.
- Nudge the shims to rotate them flush. The photo on the right shows shims in need of adjustment.
- Position the pole face at the desired distance from the sensor bridge.
- Tighten the screw until it is snug, taking care not to misalign anything.



8. Repeat this process for the other pole face, making sure the two pieces are equidistant from the sensor bridge.

NOTE	For thick samples, you may need so many shims (we allow for up to 1.5mm total) that the screws which hold the pole pieces down will no longer reach. In that case, your kit contains some longer screws (see the parts list). Store the other screws in the parts kit. They are easily obtained in the US, but cannot be found internationally.

10.9.3. Large thick samples (discouraged)

Samples thicker than a few mm should be cut down to a smaller size in order for the VFM to work properly. Contact Asylum Research and we can help you solve your sample mounting problems.

Note that bulk magnetic samples thicker than even a fraction of a millimeter will distort the field so the sensor reading is no longer reliable. Please see Section 10.8 on page 118 to determine if your sample is affecting the sensor reading.

10.9.4. Checking the Maximum Field

Note The pole pieces on the original VFM should not be separated. For more discussion, see Section 10.13 on page 129.

As discussed at length in Section 10.7 on page 114, unwanted field gradients are reduced by separating the pole pieces. Please follow these steps to accomplish this.

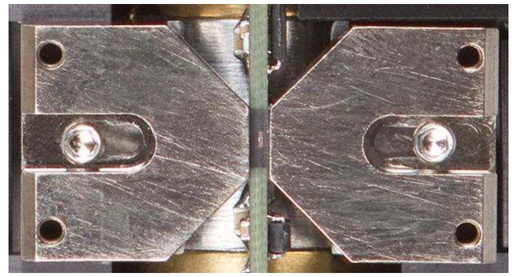
1. Determine the maximum field your experiments will require. This should be done with the VFM mounted in the AFM since the AFM reduces the field a little. See Section 10.8 on page 118.

2.

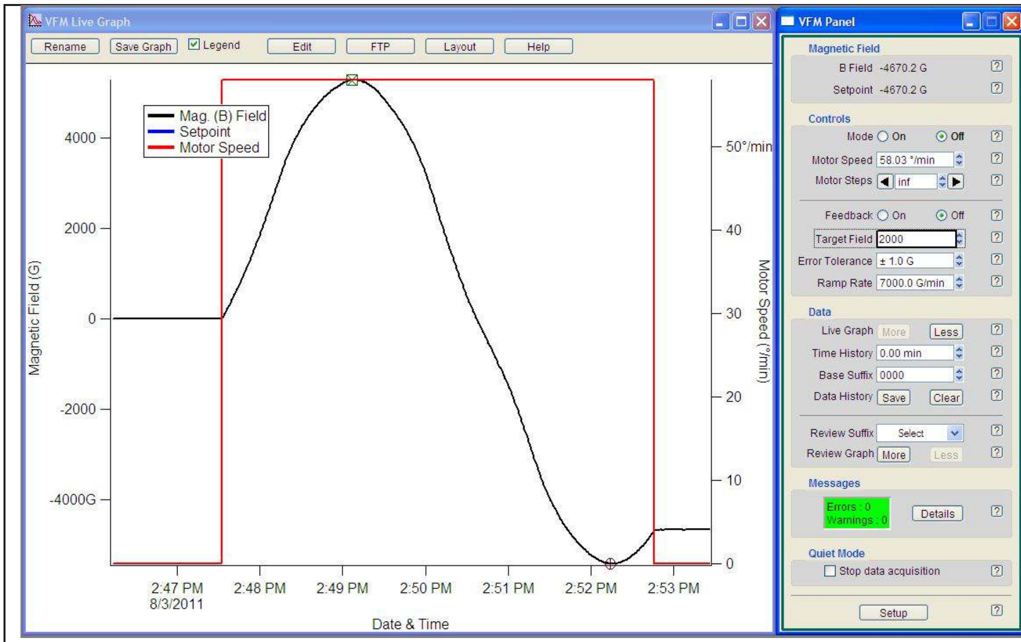
Start the pole pieces in a close position:

- Loosen the two screws shown to the right using the 0.050” Allen tool.
- Move the pole pieces so they are touching the sensor bridge.

Note If there are enough shims raising up the pieces, then manually adjust them so that seen from above, it looks like the photo.



3.



Explore the VFM field extremes

- Set the feedback and mode to off.
- Set the motor speed to 100. This is beyond the max and it will automatically change to the maximum allowed value instead.
- Set the motor steps to “inf” it is not already so.
- Set the mode to on.
- Next to Live Graph click “more” a few times.
- Next to data history click “clear”
- Observe the field sensor values until the maximum and minimum field have been reached.
- Set the mode to off, preferably when the field is still at maximum or minimum.

4. If the maximum field reached is more than what you need, we advise that you separate the

pole pieces a little to reduce field gradients and the error in the sensor reading. Remember, if the vertical sample position is off by even 50 µm when operating in the strongest field (smallest pole face separation), you may have absolute error in field reading by hundreds of Gauss.

Note Moving pole pieces at high field levels can be somewhat challenging since the pole pieces strongly attract each other. One may have to rotate to a lower value first, move the pole pieces, and then go back to see what the maximum has changed to. Remember that a pole piece snapping against the sensor bridge can cause serious damage.

The goal is to get the maximum separation while still achieving the required fields. As mentioned before, this minimizes gradients and maximizes the likelihood that the field sensor will give an accurate reading of the field your sample will experience.

10.9.5. Centering the Sample

As explained in Section 10.7 on page 114, the sensor reading is best represented at a point directly above the sensor, in the plane formed by the tops of the pole pieces. Please follow these steps to center the VFM with respect to the cantilever tip.

1. Follow the hardware installation instructions in Section 10.4 on page 101. Have the legs extended to the point where the cantilever clip is a few millimeters above the top of the VFM pole pieces.
2. With the 0.050” allen tool, remove both pole pieces and set them aside. Note that it helps to have the field set to a low value or the pieces will snap together when the screws are loosened.
3. Put a cantilever (this can be an old one) in the cantilever holder and place the head on the AFM base.
4. Align the head optics until you have a clear and centered image of the cantilever. See Section 4.5 on page 26 for more information. Try to have the head relatively level.
5. Press down on the head and exert force with a clockwise twisting motion. This seats the head firmly in the grooves. If you repeat this same twisting pressure each time, you will greatly improve your odds at placing the head so the cantilever ends up in the same area.
6. **Coarse center the VFM sample stage**

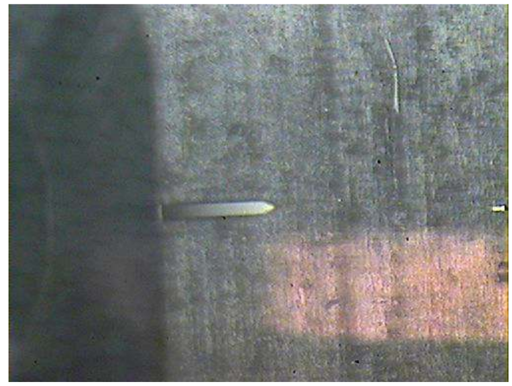
   - Using the sample align-x and y micrometers (see Figure 2.4 on page 9) center the cantilever as best as you can above the center of the sensor circuit board.

   Note The small white dash was added to the image to indicate the top down view of the sensor’s active area.

7. **Lower the head**

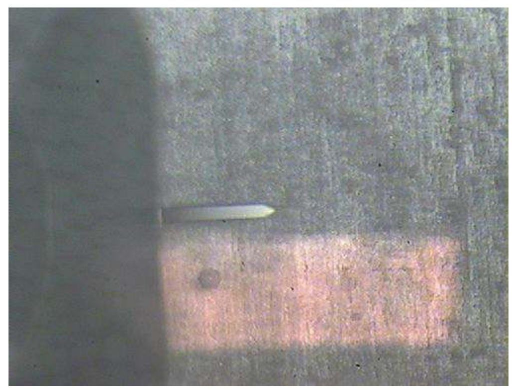
- While looking at the video image of the cantilever, lower the AFM head by moving all three legs.
- Notice that as you lower only one leg, the tip will move from the center of the video image. Adjust the other two legs to bring the image back to center. The image is centered when the head is lowering without tilting.
- Once you start to see a blurry image of the sensor circuit board, start hunting around with the sample align XY micrometers until you see something like the picture to the right.



Note Do not go down too far or the lever will crash. Using an old lever is recommended for beginners.

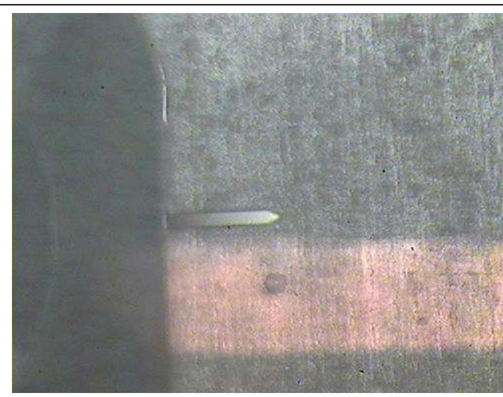
8. **Explore the width of the sensor.**

- Using the x-align micrometer, explore the left and right edges of the light colored area. This area is a metal tab which holds the magnetic field sensor. The sensor is about as wide as the length of the cantilever and mounted on the back side of the tab, as seen from the front of the AFM.



9. **Center the tip over the sensor**

- Finally, move align-x and y until the tip is at the upper edge of the metal tab and centered between the left and right edges. At this point you have found X=Y=0 and the tip is directly over the active area of the magnetic field sensor.



10.	**Raise the head without tilting.** • Place a marker on the computer screen directly over the tip of the cantilever in the video image. This can be the mouse pointer, a piece of tape, or the corner of a post-it note. • Raise the head a few millimeters using all three legs, keeping the cantilever tip centered on your marker. This means the head is raising straight up and the tip is starting at X=Y=0.
11.	**Mount the sample, replace the head for imaging** • Once you have a few mm of clearance, remove the head, replace the pole pieces, and mount your sample. • Replace the head using the usual twisting pressure. Hopefully the cantilever is still near the marker on your screen. • Lower the head while keeping the tip centered on your marker. Once you are close to engaging the sample, you can remove the marker and proceed with regular imaging. • This was our best attempt at keeping X=Y=0 directly above the magnetic field sensor, for the most accurate field readings of the area that will be imaged.

10.9.6. Flat Sample Mounting

Preferably use the clips (112.959) and short button head screws and the 0.035" allen driver (290.104) supplied with the kit.

If the sample is too small for the clips to reach it, use the sticky tabs (113.672). Note that the sticky tabs may cause some thermal drift and you must take the thickness of the glue into account when determining the number of shims to use when raising up the pole pieces (see 10.9.2).

10.10. Imaging

There are no particular requirements with regard to imaging. Most often one will perform Magnetic Force Microscopy (see *SPM Applications Guide, Chapter: Magnetic Force Microscopy*), but sometimes one might also perform Piezo Force Microscopy (See *SPM Applications Guide, Chapter: PFM Using DART* or *SPM Applications Guide, Chapter: Single Frequency PFM*). PFM might be done with the optional VFM High Voltage Kit: Section 10.12 on page 127.

10.11. Storage

- If you replaced the objective with the dummy, your lab mates will be thankful if you replace the objective again. See Step 3 on page 102.

- If others in your lab work with fluids around the AFM, we recommend that you remove the VFM compatible metal plate(112.041) from the top of the scanner and put the original one back. Please follow the steps in Section 10.5 on page 107.
  - Also if you installed the BeCu clip on the cantilever holder, consider replacing it with the original and storing the BeCu clip with the VFM. See Step 8 on page 105.
- Put everything back into the VFM storage box and attach the stage to the controller box. Store the cable with the VFM.

10.12. High Voltage Kit

Note The high voltage kit is only compatible with the VFM2, it is not compatible with the original VFM. You would need to contact Asylum Research to inquire about upgrading an existing VFM to a VFM2 to operate with the High Voltage Kit.

10.12.1. Parts list

Itm	Part #	Item Description	Qty	Picture
1	448.114	Ground wire to connect between high voltage contact and pole piece. Two spares and two pins in case you want to make your own wire to attach directly to your sample.	3	
2	900.255	High Voltage Contact for the VFM2	1	
3	SHCS 0-80 X 5/16" SS	0-80 x 5/16” SCHS SS screws for attaching the HV contact assembly to the VFM2 stage.	12	

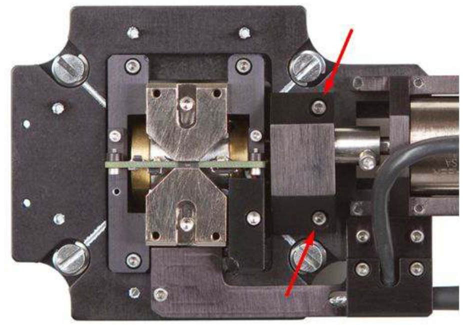
10.12.2. Installation

1.

Remove the gear cover

- Use the 0.050” allen driver (290.111) and remove the two screws indicated.
- Remove the cover and screws, and store them in your VFM kit.

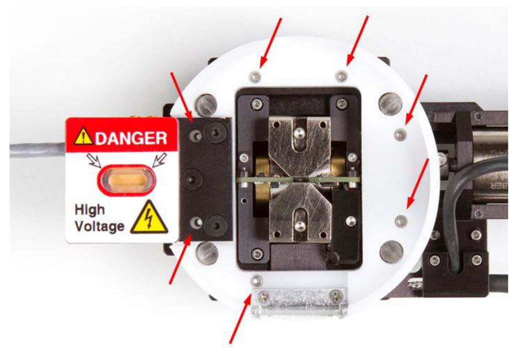
Note Replace this cover when you remove the high voltage contact. If it is not replaced and a bit of hard sample falls between the gears, it can seriously damage the VFM’s motor.



2.

Attach the high voltage contact

- Position the contact module as shown.
- Using 0-80 X 5/16” screws and the same allen tool as above, put in at least four screws, or all 7 if you wish to be more thorough.

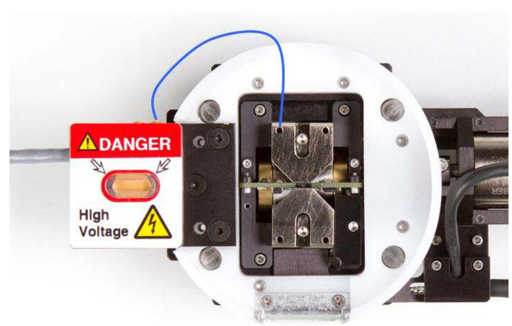


3.

Connect the ground wire

- Take wire 448.114 and plug the gold end into the socket.
- Using the small button head screws (BHCS 0-80X1/8" SS) and 0.035” allen tool 290.104, attach to the pole piece as shown.

Note Both pole pieces are electrically isolated from the rest of the VFM and AFM. The ground wire is the only reference the sample has to ground.



General sample mounting is described in Section 10.9 on page 120. Depending on your application you may need to make certain that the sample has (or does not have) a good electrical connection to the grounded pole pieces. We have supplied a few extra ground wires and pins in case you want to arrange for a wire directly to your sample.

Please refer to **??** on page **??** for instruction on connecting to the high voltage amplifier and information on high voltage imaging techniques.

Note The HV220 and VFM controller boxes both need to be connected to the AFM controller (ARC2 or MFP-3D). This is accomplished by “daisy chaining” the controller boxes together. First connect one to the AFM controller and then connect the second to the output of the first. The order of HV220 and VFM controller does not matter.

10.13. VFM vs VFM2

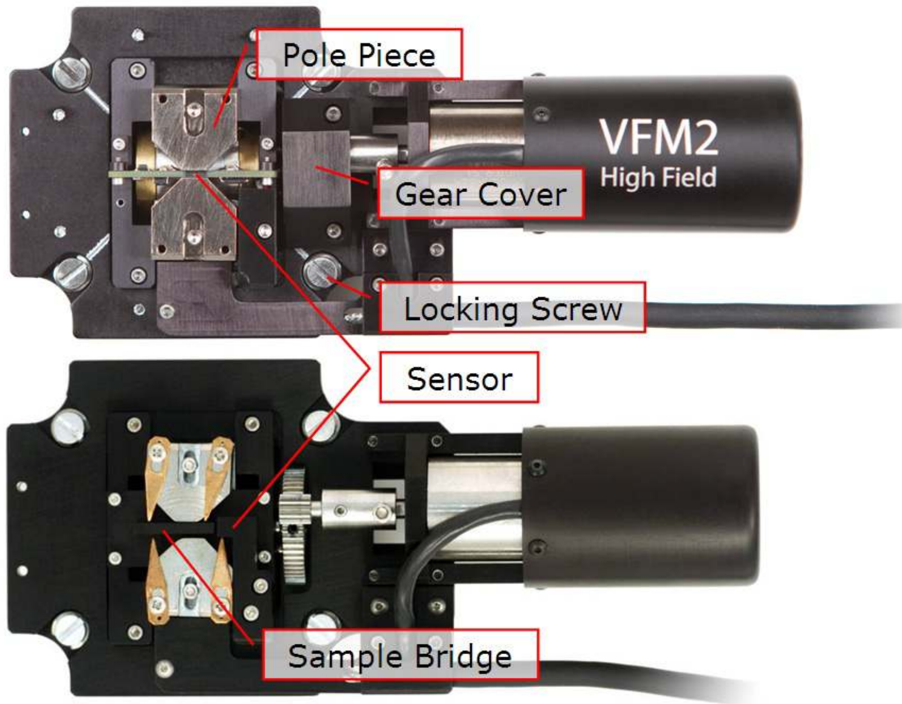


Figure 10.10.: Some of the basic components of the VFM defined. Also a side by side comparison of the samples stages of the VFM and the VFM2-Tesla. The original VFM can be distinguished by the lacking text on the motor cover, no gear cover, and no small sensor circuit board between the pole pieces.

10.13.1. Basic Differences

	VFM	VFM2-Tesla	Notes
Max Field	<=2500G	>9000G	
Sensor Position	Off to the side	Under Sample	VFM2 sensor makes a much better estimate of the field.
Sensor Range	<=2500G	>10% over max field	VFM2 sensor has more headroom and better linearity.
Sensor Resolution	~1G	~0.5G	VFM2 has an improved 16 bit sensor ADC.
Movable Poles	Yes*	Yes	*Moving the poles from the closest spacing renders the sensor calibration incorrect.
High Voltage	No	Yes	VFM2 high voltage accessory attaches to the Samuel stage. Not available for the VFM for safety reasons.
Field Gradients	Strong	Weaker-Stronger	Typically field gradients go up as pole pieces are brought closer. See Section 10.7 on page 114.

The original VFM had its sensor located away from the sample (See Figure 10.11 on page 131). At the time this was due to a lack of sensors small enough to fit under the sample. The VFM was calibrated once with a larger calibrated sensor between the pole pieces and this value was tabulated against the VFM's built in sensor. As long as the orientation of the pole pieces stayed fixed as they were during calibration, the remote sensor gave a reasonably accurate value of the field. This had a number of requirements:

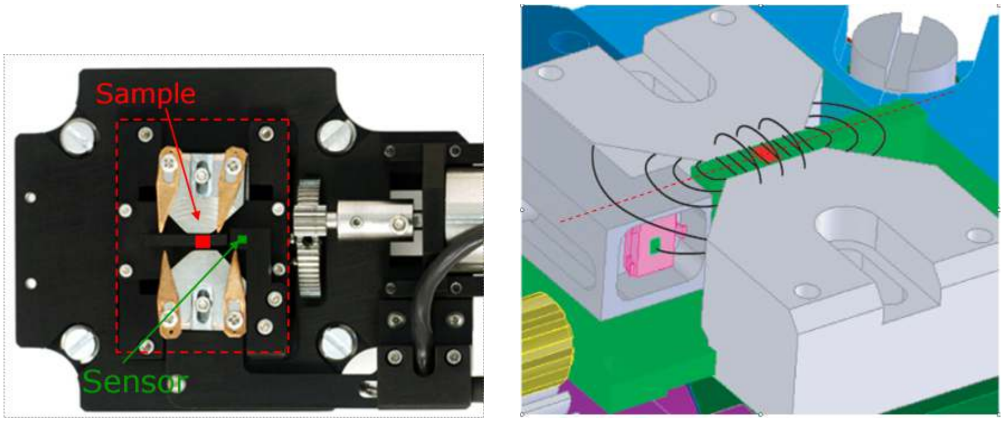
- The pole pieces could never be moved.
- The sample had to fit between the pole pieces so that the sample top surface was flush with the top of the pole pieces.
- If the sample had any substantial volume and was ferromagnetic, the subsequent field distortion was enough to render the sensor calibration ineffective.

The only advantage to the old setup was the absence of a sensor bridge directly below the sample. One could remove the otherwise inert bridge between the pole pieces and put a rather thick sample in between, as long as it was no more than 1.5mm wide.

The VFM2 improves this situation by placing the sensor much closer to the sample, in a place where the field has a higher degree of symmetry, allowing the use of shims (see Section 10.9.2 on page 121) to keep the sensor reading very close the field values near the area being imaged.

The VFM2 also allows the pole pieces to be moved. As long as they are placed symmetrically on either side of the sensor, measurements will remain valid.

Please contact Asylum Research if you would like a quote to upgrade your original VFM to an VFM2.



(a) Sample and sensor positions for the original VFM.

(b) Artistic rendition of the field lines in the original VFM. Sample position is red, sensor position is green.

Figure 10.11.: The original VFM had the sensor positioned far away from the sample.

10.13.2. VFM2 evolution

The pole pieces of the VFM2 have evolved somewhat until they settled at the design shown in this document. Initially they were taller and the metal parts of the VFM itself were lower. The shims can still be applied to this situation. For reasons related to manufacturing processes, the final design of the pole faces. A few VFM2s with these thicker pole pieces were released into the field.

10.14. Scientific References

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Part III

Safety, Specs, Setup, and Shipping

Part III: Who is it for? Every new user should read the safety section at least once. If you need to move your AFM or ship it to Asylum Research for any reason, please consult this manual. Beyond that, this part of the manual will probably not see much day to day use.

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11. MFP-3D Safety

CHAPTER REV. 1523, DATED 08/20/2013, 11:38. USER GUIDE REV. 1590, DATED 08/30/2013, 12:47.

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11.1. Light Source Safety

11.1.1. The MFP-3D Super Luminescent Diode

The MFP-3D head uses a super luminescent diode and is classified as an IEC class 1M laser product that complies with 21 CFR 1040.10 and 1040.11, except for deviations pursuant to Laser Notice No. 50, dated 24 June 2007. Complies with IEC/EN 60825-1, Ed.2:2007.

Attention	Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure.

Figure 11.1.: Light Source Warning label

The output under the specified measurement criteria could be up to 0.78 mW at 850 nm.

11.1.2. Laser Safety Precautions

Do not tamper with the following safety measures. Tampering with the following may result in eye injury.

11.1.2.1. Tilt Switch

When the MFP-3D head is tilted by 30° or more from its position during scanning the light source switches off.

11.1.2.2. Light Source Remote Jack

The light source remote jack is located on the back of the controller, in an upper corner. When connected, this jack allows the MFP-3D light source to automatically shut off under specific conditions (i.e. foot/hand switch). If you do not intend to use this jack as an automatic shutoff circuit, the light source remote plug, provided with the MFP-3D, shorts these two conductors, which enables the light source.

11.1.2.3. Light Source Lock Switch

The key on the front of the MFP-3D controller allows the operator to turn the light source on and off by turning the lock vertically to power on and horizontally to power off.

Warning	Viewing the laser output with certain optical instruments (eye loupes, magnifiers, and microscopes) may pose an eye hazard. If you have an Inverted optical system, please make sure that the Infrared cutoff filters are inplace in the binocular view peices and in the filter slot beneath the turret.

11.1.2.4. Shutter

Some commercial inverted optical microscopes—such as the Olympus IX Series —have a shutter that allows the operator to choose to exclude all light from the optical path.

11.2. Power Supply Safety

Both

Warning	The MFP-3D system uses high voltages and currents of up to 165V, 0.5A. Use caution when handling system pieces to avoid electrical injury

the MFP-3D controller and the computer provided with your MFP-3D are configured for the standard power used in your location. However, you should check the configuration before connecting the computer and MFP-3D controller to a power source. If there is a problem with the power configuration, please contact Asylum Research using the information provided in Chapter on page iii

11.3. Labels

The following labels appear on the MFP-3D controller:

Identification Label The serial number identification label is located on the back of the MFP-3D controller at the bottom center or at the top right as seen from behind on the Arc2 Controller. You may need to remove the stored hamster cover to see it.

Warning	Connecting a computer or MFP-3D controller configured to run using low-voltage power (100-130V) to a high-voltage power source (200-240V) is likely to cause serious damage to the equipment and will void the warranty.

Warning	Power cables are supplied by Asylum Research for MFP-3D installations in the USA. For installations in other locations, your distributor may supply the power cables. If no power cables are supplied, obtain grounded power cables that fit the power connectors on the computer and monitor and your power outlets.

Warning	Do not attempt to open the MFP-3D head or the Stand-Alone base. Doing so will negate the product warranty.

12. Installation

CHAPTER REV. 809, DATED 11/29/2011, 09:43. USER GUIDE REV. 1590, DATED 08/30/2013, 12:47.

Currently the AFM should only be installed by personnel certified by Asylum Research and its affiliates. Even if it is relocated within your laboratory, we cannot guarantee it will meet published specifications unless we are involved. By all means call Asylum Research if you have any questions. Support calls are always free and chances are we can direct you through the process of installation and testing of specs over the phone.

13. Shipping

CHAPTER REV. 1143, DATED 04/03/2013, 10:45. USER GUIDE REV. 1590, DATED 08/30/2013, 12:47.

Shipping should be done in the original cartons. If you cannot find them or did not save them, please contact Asylum Research and we can supply you with new cartons. Also note that there are some parts of the instrument (such as movable optics in the AFM head and floating components in vibration isolation stages) which must be locked down in preparation for shipping or else instrument damage may result. Please contact Asylum Research and we will help you. Calling or e-mailing our technical support is always free and we are happy to assist.

Part IV

Bibliography, Glossary, and Index

Bibliography

Cited Scientific References

Cited Asylum Research Documents

SPM Applications Guide, Chapter: AC Mode Imaging.

SPM Applications Guide, Chapter: AC Mode Theory.

SPM Applications Guide, Chapter: Condcutive AFM.

SPM Applications Guide, Chapter: Contact Mode Imaging.

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SPM Applications Guide, Chapter: Kelvin Probe Microscopy.

SPM Applications Guide, Chapter: Magnetic Force Microscopy.

SPM Applications Guide, Chapter: PFM Using DART.

SPM Applications Guide, Chapter: Single Frequency PFM.

SPM Applications Guide, Chapter: Thermal Tuning.