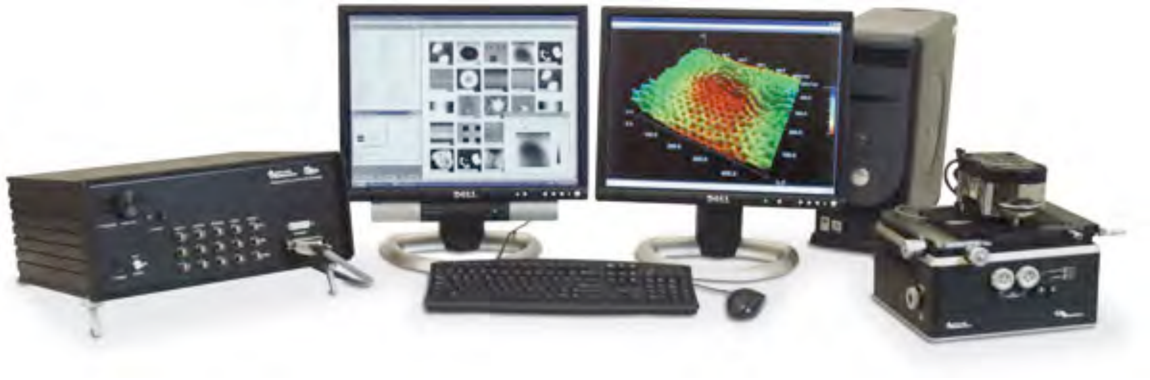
Troubleshooting and Maintenance Chapter

This chapter provides information relevant to the upkeep, troubleshooting, and repair of the MFP-3D system and its components. This includes instructions for calibration and noise measurements; procedures for changing, disassembling, and cleaning parts; discussions on preventing/handling fluid spills; and many other procedures and discussions to help solve, identify, and avoid common problems. The chapter is divided into the following sections:

1. **System**
2. **Head (includes Cantilever Holder)**
3. **Scanner**
4. **Base**
5. **Controller**
6. **Software**

Please contact Asylum Research at 888-472-2795 or email us at support@asylumresearch.com if you have any technical support questions.

The System



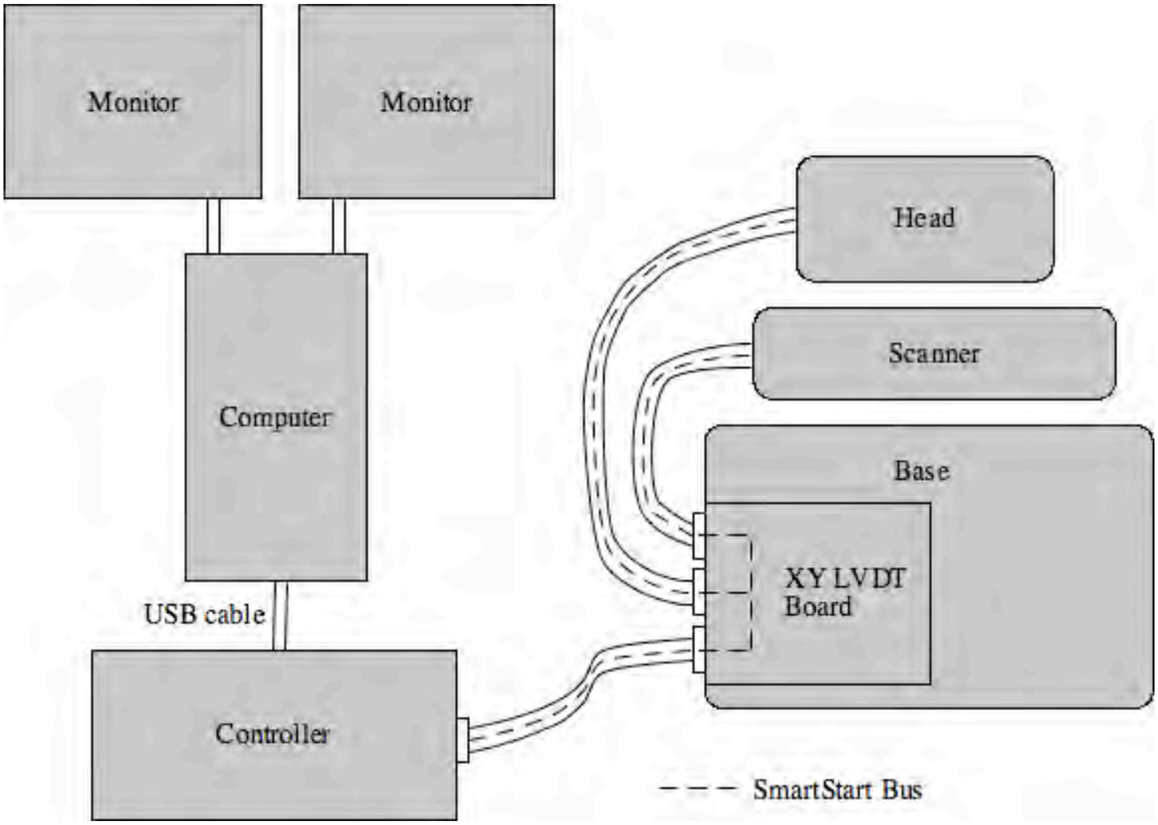
I. Introduction

In this section some general information is given about the system components. A checklist is provided for assessing the health of the entire system (performance and calibration). Procedures for the two deflection noise tests that are the most comprehensive indicators for the system's achievable resolution are provided, followed by a discussion of troubleshooting the noise. There is a reference list of common problems - each symptom has a list of possible causes and where to find further information in this chapter. Instructions are given for testing for shorted piezos. Finally, guidelines for shipping the system or a component and instructions for setting up after a repair are given.

II. System Components

The MFP-3D system is comprised of the microscope (head, scanner, and base), a computer (and monitors), and a controller. A DSP in the controller is used for all the realtime computing, so only the resulting data are passed to the computer. A USB cable connects the controller and computer. The scanner and head connect to the controller via the XY LVDT board housed in the base.

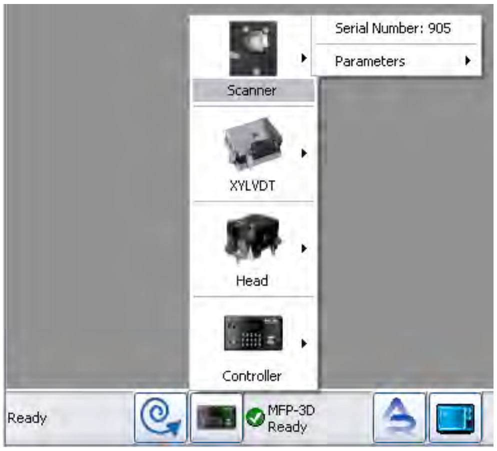
<u>System Components Diagram</u>



SmartStart

The SmartStart Bus (sometimes called the Multi-Drop Bus) is a serial communication line that runs through the cables connecting the microscope components (head, scanner, or other peripherals) to the controller. SmartStart identifies each component by its serial number and associated parameters such as calibration (most of the parameters can be viewed in the InfoBlock). This information is stored locally in the hardware of each component, making the components "plug and play". SmartStart reads the component information every time the controller is powered on.

The Rescan button on the bottom toolbar forces SmartStart to re-read the component information. It must be run every time any component is disconnected and reconnected.



The devices detected by SmartStart can be seen by clicking on the device button to the right of the Rescan button on the bottom toolbar. You can go to any of the devices to view its information (calibration, serial number, etc). All the devices detected by SmartStart show up on this list. If a component does not show up, rescan. If it still does not show up, check the cable to make sure the device is firmly plugged in.

III. Performance and Calibration

It can be useful to run through a diagnostic of your system to verify that everything is working well or to help troubleshoot a problem of unknown origin. The checklist below is a guide to checking the health of your system including calibration, noise, other performance characterizations such as hysteresis. If a problem appears to be related to a specific component, such as the scanner, then skip directly to that section. If the system is working fine but you want a general maintenance plan, it is recommended to run through the diagnostic every 6 months.

System Diagnostic Checklist

1) Check the deflection noise, as described below in this section. This includes:
    i) InvOLS Calibration
    ii) Optical Lever Noise
    iii) System Noise
2) Check the scanner, as described in the Scanner/Calibration & Performance section. This includes:
    i) XY Sensor Range
    ii) XY Scanner Hysteresis
    iii) XY Sensor Calibration
    iv) Scan Range
    v) XY Sensor (LVDT) Offsets
    vi) XY Piezo Calibration
    vii) XY Sensor Noise
3) Check the Z stage, as described in the Head/Calibration & Performance section. This includes:
    i) Z Sensor Range
    ii) Z Calibration
    iii) Z Sensor Noise

For all procedures, first read through the relevant Software/Test Panel section to become familiar with the parameters and functions used in the instructions.

Deflection Noise

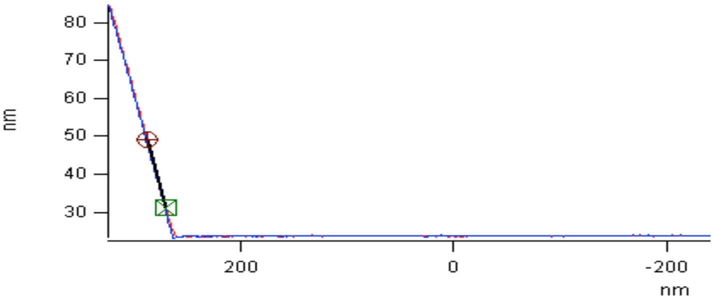
In addition to cantilever tip sharpness, one of the fundamental limits of an AFM's resolution is its system noise. This noise can be electronic, vibrational, or acoustic in nature. One can quantify and identify the total background noise affecting the system through two basic noise tests - Optical Lever noise and System noise. These two tests measure the cantilever's deflection with the tip away from a surface and in contact with a surface, respectively.

InvOLS Calibration

Any measure of deflection noise first requires that the INVerse Optical Lever Sensitivity (InvOLS) be measured. InvOLS is simply the ratio of the cantilever's Z-position measured from the Z-sensor, to the cantilever's deflection measured in volts from the quad photodetector. The InvOLS is critically dependent on the cantilever's exact position and the light source's position on the cantilever (as well the type of lever used). Thus it is important not to change these between calibrating the InvOLS and conducting the Optical Lever and System noise tests.

The procedure for calibrating InvOLS is as follows:

1) Load an Olympus TR800 (100 um, k=0.61 nN/nm) or equivalent cantilever.
2) Align the light source on the cantilever.
3) Engage the tip on freshly cleaved mica or graphite in contact mode.
4) Perform a force curve.
5) Press Ctrl-I to bring up the Igor cursors.
6) Place the cursors A and B in the linear deflection region of the force curve. This region is close to the point of contact with the surface.



7) From the 'Set Sens' pull-down menu in the Force Panel, select 'Deflection.'
8) The 'Defl InvOLS' field will update to reflect the appropriate value. Typically, it will be ~20-35 nm/V for this particular type of cantilever.

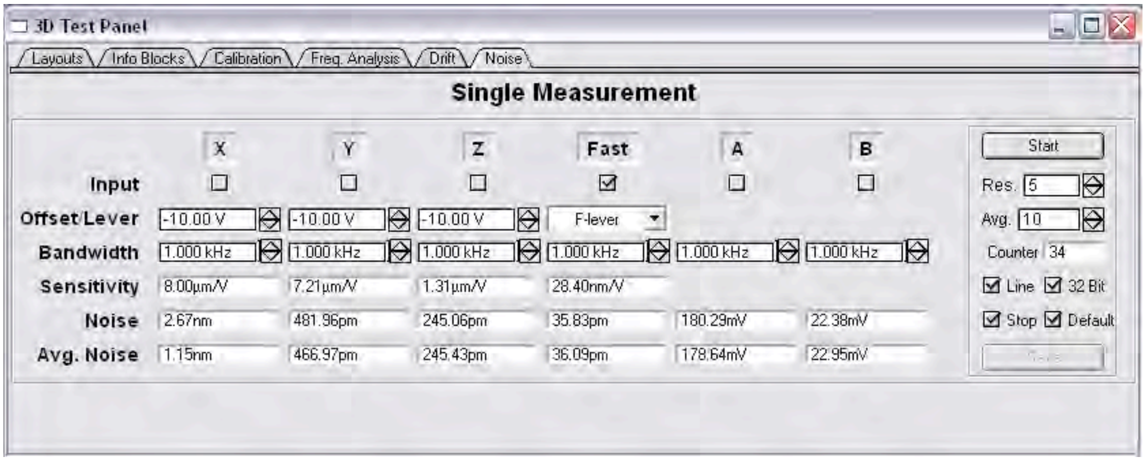
Optical Lever Noise

The purpose of this test with the cantilever tip away from the surface is to evaluate the inherent noise in the optical detection system. This is the fundamental limit of the smallest deflection signal detectable by the AFM.

The biggest contributor of noise in this test comes from the AFM's light source, a Super Luminescent Diode (SLD). Minute changes in the SLD light are represented as deflection noise in the optical detection system. Noise in the photodiode and other electronics also contribute to the optical lever noise.

The MFP-3D AFM is tested at Asylum Research to a specification of under 30pm of Optical lever noise, using a 100 um long Olympus TR800 cantilever. Note that results may vary depending on the lever used.

Using the same cantilever and light source alignment as for the InvOLS:
9) Go to Programming → Load Test Procedures.
10) Go to Testing → Test Panel.
11) Select the Noise tab.

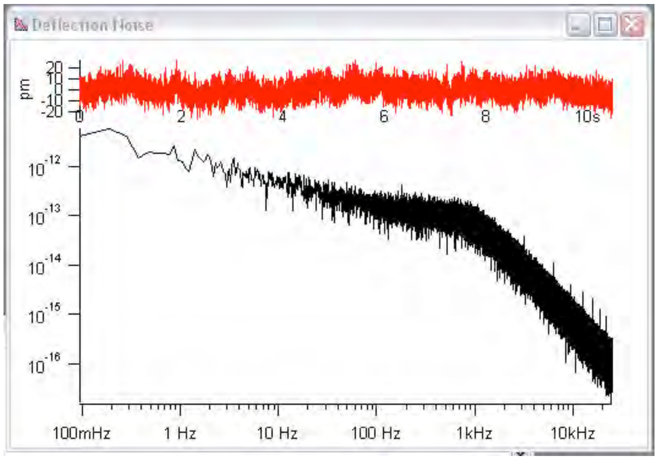


	X	Y	Z	Fast	A	B
Input	☐	☐	☐	☑	☐	☐
Offset/Lever	-10.00 V	-10.00 V	-10.00 V	F-lever		
Bandwidth	1.000 kHz	1.000 kHz	1.000 kHz	1.000 kHz	1.000 kHz	1.000 kHz
Sensitivity	8.00µm/V	7.21µm/V	1.31µm/V	28.40nm/V		
Noise	2.67nm	481.96pm	245.06pm	35.83pm	180.29mV	22.38mV
Avg. Noise	1.15nm	466.97pm	245.43pm	36.09pm	178.64mV	22.95mV

Res. 5
Avg. 10
Counter 34
☑ Line ☑ 32 Bit
☑ Stop ☑ Default

12) Select 'Fast' Input checkbox.
13) Bandwidth should be set to 1 kHz and Res to 5. Sensitivity should be equal to the calibrated InvOLS value. Avg should be set to 10.
14) If the tip is in contact with the surface, click on the Simple engage button followed by the 'Stop!!!' button to disengage the tip. The Z-voltage in the Sum and Deflection meter should go to 0 V.
15) Click 'Start' in the noise test panel to begin the measurement.

The measurement will end automatically once 10 runs are completed (indicated by the counter). The Avg. Noise in the Fast column is the result.



Off-Surface Noise Plot

An example off-surface noise plot with both time and frequency domains shown. Note that there are no dominant peaks in the spectrum.

System Noise

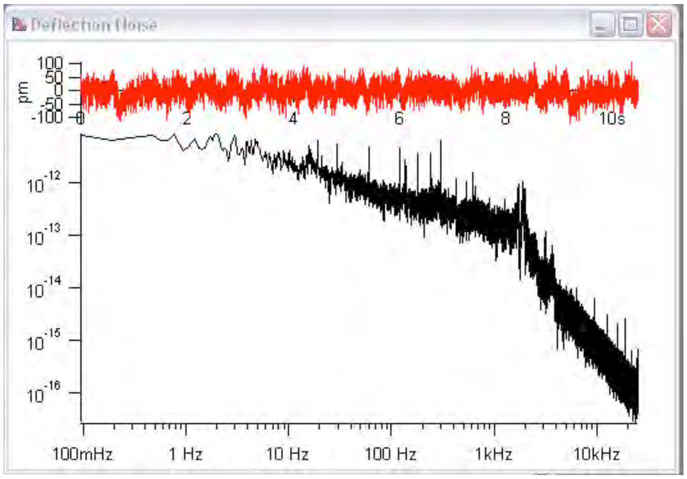
The purpose of the deflection noise test with the cantilever tip in contact with the surface is to evaluate the vibrational and acoustical noise in the system. The result is the performance limit of the AFM in its current environment and is an indication the smallest resolvable height feature.

In this test, the tip is contact with the surface with the Z feedback gain set to a minimum value. In this way, environmental noise disturbance in the form of floor vibrations or acoustical transmission directly result in a real cantilever deflection and contribute to the system noise level.

The MFP-3D AFM is tested at Asylum Research to a specification of under 60 pm of system noise, using a 100 um long Olympus TR800 cantilever. Note that results may vary depending on the lever used and the environmental conditions.

Using the same cantilever and light source alignment as for the InvOLS:
16) Engage the tip on freshly cleaved mica or graphite in contact mode.
17) Set ‘Integral Gain’ in the ‘Main’ tab of the Master Panel to 0.01.
18) Click ‘Start’ in the noise test panel to begin the measurement. (Use the same settings as in the Optical Lever test)

The measurement will end automatically once 10 runs are completed. The Avg. Noise in the Fast column is the result.



On-Surface Noise Plot

An example of a System Noise plot. An ideal plot would show little or no increase in noise compared to the Optical Lever Noise test. However, in actuality there is always additional noise.

Troubleshooting Noise

If the noise levels are very high, the noise plot can be used to troubleshoot and identify sources of noise in the system. The frequency domain representation of the noise, or the Power-Spectral Density (PSD), can be used to identify the type and magnitude of the noise source.

Typically, there are two types of characteristic noise that show up in the PSD. Sharp peaks are indicative of highly periodic disturbances such as electrical noise from a power source, or vibrations generated by equipment with motors that operate at a constant RPM such as pumps, compressors, fans, etc. Electrical noises are highly periodic and will typically be at 50 or 60 Hz and multiples of this power line frequency.

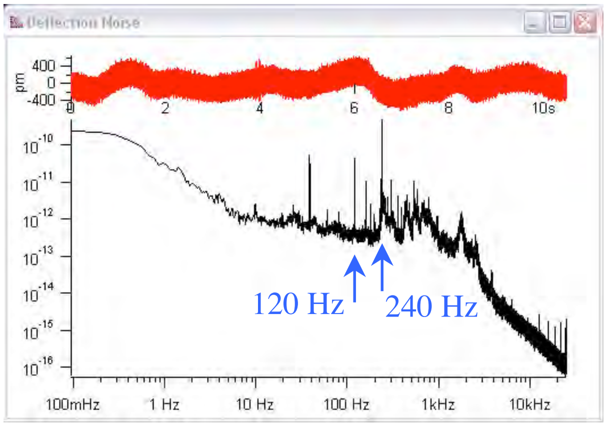
Broad peaks are indicative of non-periodic disturbances. Examples of this include random room acoustics, air handling systems, mechanical resonances in the building, footsteps from a busy hallway outside the lab, and street traffic.

The set of headphones that shipped with the system can be plugged into the audio jack of the controller to listen to the deflection noise. In many cases, this tool can be used to isolate the particular source of the noise. *For more on using the audio jack, see the Controller/Audio Jack section.*

One common cause of system noise is vibrations in your lab coupled into the microscope through the main cable. The cable clamp on the hood is designed to prevent the vibration of the cable from continuing up to the microscope base. To check if the cable clamp is functioning properly, listen to the headphones while running the system noise test. Touch the cable on the outside of the hood - grasp the cable to use your hand as damping or move the cable around. If you hear the noise decrease, then the cable clamp is not doing its job correctly. The foam should be replaced in the clamp (Asylum Research can supply new foam if needed). If you can slide the cable through the clamp by pulling with your hand, then the foam is definitely bad. Often, if there is large noise at twice the power line frequency the cable clamp is the problem.

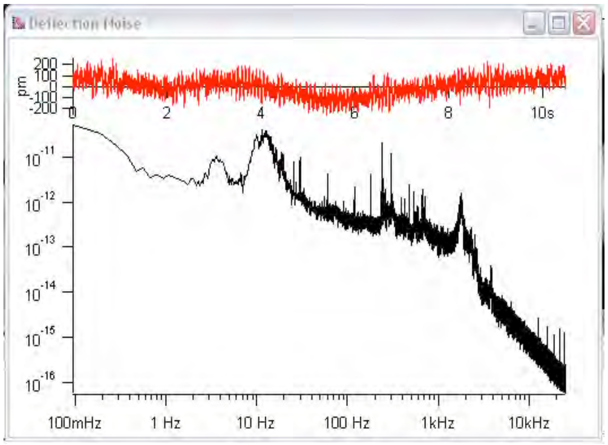
When troubleshooting system noise, keep in mind that the source of the noise may not be within close proximity to the AFM. It may be generated from something on a different floor in your building or in a room adjacent to the system.

<u>System noise plot with highly periodic noise</u>



This example of a System noise test includes vibrations coming from the fan of a fiber optic light source. The light source was intentionally placed next to the AFM and allowed to touch the side of the vibration isolation system. The transformer inside the light source creates strong 120, and 240 Hz peaks as well as the broader peaks from the blades of the cooling fan making audible noise.

System noise plot with less periodic noise



This example of a System noise test was done with the vibration isolation system incorrectly balanced so the AFM was not floating. The door of the acoustic enclosure was also opened to the room. The broad noise peaks around 4 and 12hz are probably floor vibrations in the building. The small increase of higher-frequency broad noise peaks is from ambient room conditions (acoustics).

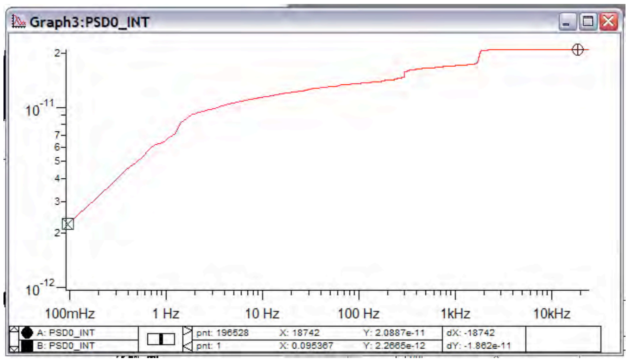
Further PSD Analysis

The amount of noise contributed to the overall average noise by a given peak in the PSD can be quantified. Through a short series of Igor commands integrating the PSD will allow you to measure the relative contribution of energy from a given frequency to the total amount of measured noise. The procedure for integrating the PSD from a noise test is as follows:

Note: Software versions 060531+0021 and newer have the integrated noise plot overlayed onto the PSD plot. . This procedure allows you to manually create the plot although updating your software is recommended.

1) Perform a System noise test with the ‘Stop’ checkbox checked. The ‘Save’ button will highlight after the number of tests are reached in the ‘Avg.’ menu item.
2) Click on the ‘Save’ button to save the noise data acquired during the test. Note that two warning messages may appear. Continue through the messages by selecting OK.
3) Open the Igor data browser by selecting ‘Data’ → ‘Data Browser’ from the upper pull down menu.
4) Expand the subdirectory tree to locate the PSD wave inside the Root\TestResults\Noise\FastIn folder. Note that subsequent system noise tests will overwrite the data in the Fast In folder if you save them. Renaming the Fast In folder before saving further tests will retain data from multiple tests.
5) Click and drag the red arrow on the left edge of the data browser window to point at the Fast In folder.

6) Select the PSD wave and click on ‘Edit’ → ‘Duplicate’. The file PSD0 will be created.
7) Enter the following on the Igor command line: PSD0=PSD0^2.
8) From the upper pull-down menu, select Analysis → Integrate. Select the PSD0 wave from the source selection and click on ‘Do it’. A new wave named PSD0_Int will be created.
9) Right click on the PSD0_INT wave and select ‘Display’
10) Double click on either axis of the graph to bring up the Modify axis window. Select the Axis tab and change both the bottom and left axes from Linear to Log.
11) Activate the Igor measurement markers on the graph by pressing the Ctrl - i keys.
12) Placing one of the markers on the graph at the point where the X axis is 1khz will measure approximately the same noise value as recorded in the Average noise measurement.
13) Examine the graph for abrupt steps in the slope of the data. These steps represent greater contributions of vibrational noise at a given frequency in the PSD spectrum. Use both markers to measure the amount of the step as compared to the value you measured at 1khz. A step containing a value of greater than 10% of the total noise is likely to be a high contributor to the overall noise of your system.



A: PSD0_INT | pnt: 196528 | X: 18742 | Y: 2.0887e-11 | dX: -18742
B: PSD0_INT | pnt: 1 | X: 0.095367 | Y: 2.2665e-12 | dY: -1.862e-11

IV. Troubleshooting

Common Problems Reference List

Below is a list of common problems. Possible causes are listed in the best order to troubleshoot the issue.

Low/no sum signal:

(1) Poorly installed cantilever
Head/Cantilever Holder/Troubleshooting/Installing Cantilevers
(2) Damaged cantilever slot

Head/Cantilever Holder/Maintenance/Inspection/Damaged Cantilever Slot

(3) Dirty optics
Head/Cantilever Holder/Maintenance/Routine Cleaning

(4) Light source failure
Head/ Light Source (SLD) Failure

Difficulty tuning the cantilever:

(1) Poorly installed cantilever
Head/Cantilever Holder/Troubleshooting/Installing Cantilevers

(2) Damaged cantilever slot
Head/Cantilever Holder/Maintenance/Inspection/Damaged Cantilever Slot

(3) No drive-coupling pad
Head/Cantilever Holder/Important Design Changes/Drive-Coupling Pad

(4) Dirty optics
Head/Cantilever Holder/Maintenance/Routine Cleaning

(5) U29 Damaged
Controller/Troubleshooting/Checking U29

Difficulty aligning the light source on the cantilever:

(1) Poorly installed cantilever
Head/Cantilever Holder/Troubleshooting/Installing Cantilevers

(2) Damaged cantilever slot
Head/Cantilever Holder/Maintenance/Inspection/Damaged Cantilever Slot

(3) Belts on head thumbwheels have slipped
Head/Thumbwheels

Difficulty zeroing the deflection:

(1) Poorly installed cantilever
Head/Cantilever Holder/Troubleshooting/Installing Cantilevers

(2) Damaged cantilever slot
Head/Cantilever Holder/Maintenance/Inspection/Damaged Cantilever Slot

(3) Belts on head thumbwheels have slipped
Head/Thumbwheels

Difficulty engaging (Z voltage jumps immediately to –10 V):

(1) Shorted Piezo
System/Troubleshooting/Testing for Shorted Piezos

Testing for Shorted Piezos

The following procedure will allow you to diagnose the MFP 3D system if you suspect that one of the piezo actuators in the instrument is not moving.

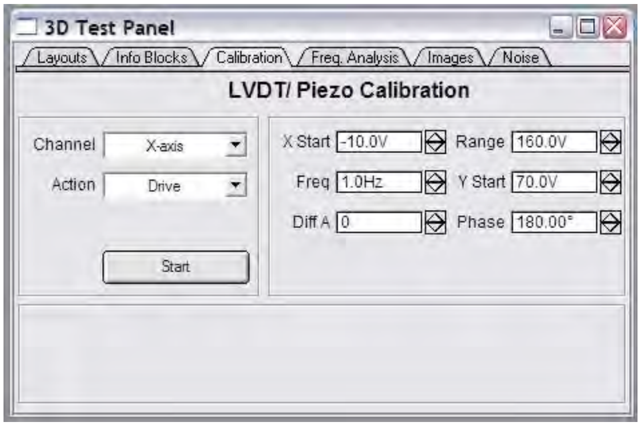
One of the most common symptoms of this type of failure is that the Z control voltage immediately jumps to -10 V while trying to engage the tip onto the sample surface. The reason for this is because the Z piezo electric assembly is not moving the AFM tip in response to the control signal applied by the software.

The control system has built in protection that will shut down the high voltage power if any of the piezo assemblies (X, Y or Z) become shorted. Therefore, it is possible for the X-Y scanner to develop a short circuit and directly affect the Z motion in the head.

A) Determine if the piezo assemblies are working correctly

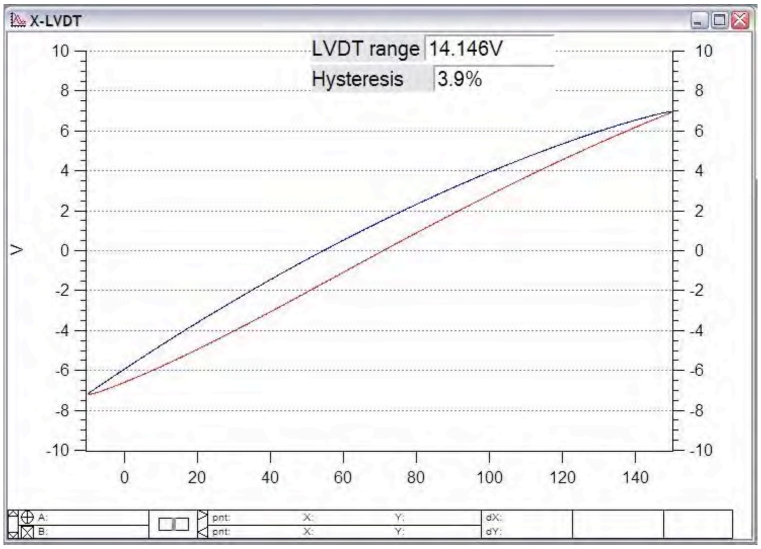
The MFP 3D software has built in test routines that allow you to send control signals to the various piezo assemblies and measure their movement.

1. Raise the tip above the sample surface so that you are sure that it will not come in contact during testing.
2. Load the test software by selecting Programming>Load Test Procedures. The word Test will appear on the main command line.
3. Click on Testing>Test Panel to display the test controls.
4. Select the tab labeled Calibration.
5. Select the channel to be tested in the Channel menu item.
6. Select "Drive" in the Action menu item.
7. Set the Start to –10 V and the Range to +160 V
8. Click on the Start button to begin the test.



Channel: X-axis
Action: Drive
X Start: -10.0V
Range: 160.0V
Freq: 1.0Hz
Y Start: 70.0V
Diff A: 0
Phase: 180.00°

A graph of the LVDT sensor versus controller drive voltage will appear. The normal output level for the Z channel is 12 V. The voltage should also be centered about 0 V. The X-Y channels should read 14 V centered about 0 V.



LVDT range 14.146V

Hysteresis 3.9%

9. Check each channel for proper signal activity on the LVDT sensors.

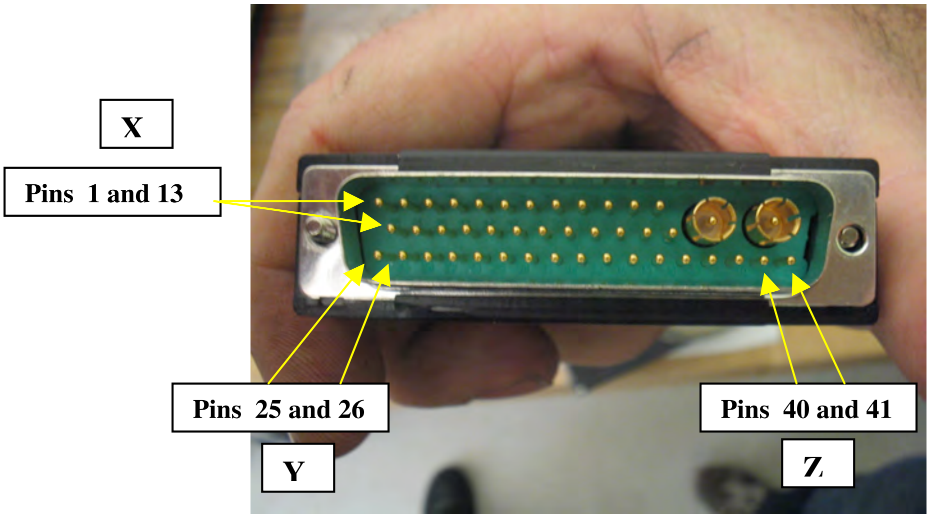
If all three axes are displaying the correct signal levels then they are working correctly.

If there is no signal from any or all of the channels then continue with this document.

B) Measure the piezo assemblies for short circuits

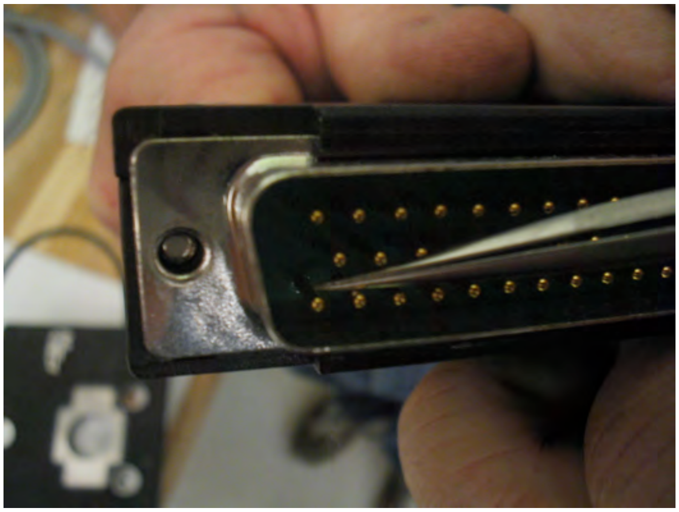
Testing the piezo assemblies is done by measuring their resistance and the capacitance through the pins in the main controller cable. Since the piezo assemblies are basically large capacitors, it is important to discharge any stored charge they may have before making the measurements.

1. Turn the controller power off.
2. Unplug the main controller cable from the front of the controller. You should see a see a series of three rows of male pins plus with two male coax connectors in the plug.



The pins to be tested are 1 and 13 for X. Pins 25 and 26 are Y. Pins 40 and 41 are Z.

3. Briefly short pins 1 and 13, 25 and 26, 40 and 41 together. A pair of tweezers will work well for this. This step will discharge any stored charge in the piezo elements.



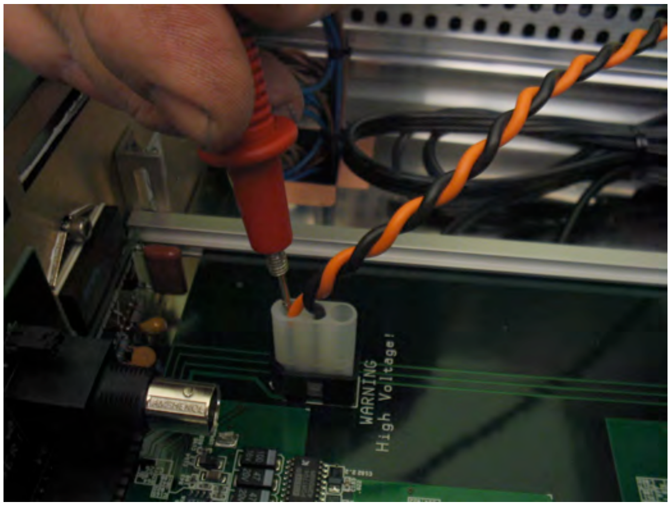
4. Use an Ohmmeter to measure the resistance between pins for the X, Y and Z piezo assemblies. The resistance of the all the piezos should be greater than 1 MΩ. A shorted or damaged piezo will have a resistance between 5k and 0 Ω. If you see a definite low resistance value, it is most likely that you have identified the bad piezo. If you are not certain, or want to confirm with a second test, you can measure their capacitance.
5. Measure the capacitance of the piezo assemblies. The typical capacitance of the X and Y piezos is 4.5 μF. The typical capacitance of the Z piezo is 1.5 μF.

C) Testing the controller if you have found a bad piezo assembly

If you have identified a bad piezo assembly, it is possible that further damage may have occurred in the controller electronics. The power supply in the microscope controller has over-current protection circuitry. Depending on the conditions of the short circuit, the high voltage amplifier of the damaged piezo channel and the power supply may have damage.

Caution: You will be measuring high voltages up to +165 VDC.

1. Remove the top cover of the controller. The instructions for doing this are in the Controller section of this chapter.
2. Disconnect the main controller cable from the controller if it is not already done from the piezo testing.
3. Turn the controller power on.
4. Locate the high voltage power lead (Orange and Black wires twisted together) on the main electronics board. Measure the voltage on the orange wire while it is connected to the main board. The correct voltage should be +165 VDC +/-5 V. A standard voltmeter probe will fit in the plug with the wire.



If the voltage on the orange wire is higher than +165 V, the power supply is blown and requires repair. No further testing can be performed. Typically, a blown supply will read about 270 VDC.

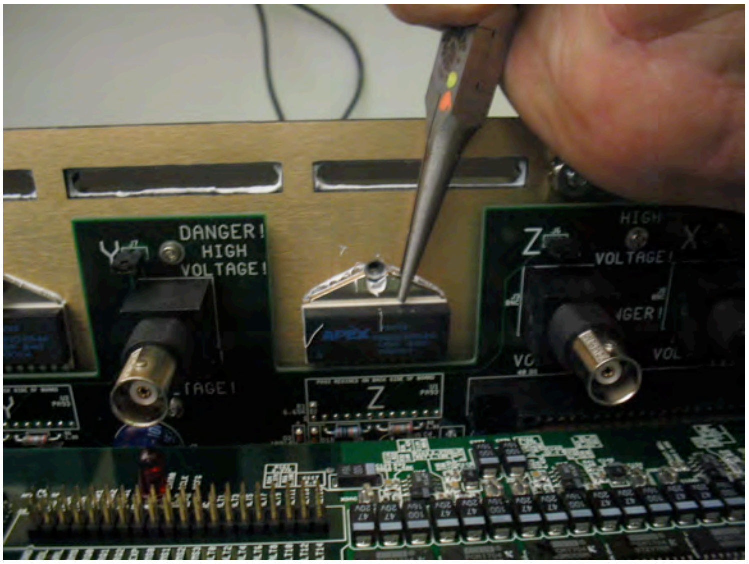
If the voltage on the wire reads 0 V then the protection circuitry has activated or the fuse (F1) is blown. (See fuse location in Controller section of this chapter)

5. If the orange wire reads 0 V and you have confirmed that F1 is good, turn the controller power off and unplug the high voltage (orange/black wires) wiring from the main controller board. Allow about 1 minute for the protection circuitry to reset and then turn the controller power back on. Measure the voltage on the orange wire. If the voltage is now reading +165 VDC then the protection circuit

has worked and the power supply is good. Most likely one of the high voltage amplifiers is damaged.

A shorted piezo can cause a large current surge through the high voltage amplifier that sends it power. In many cases, the surge in current will damage the amplifier and cause the protection circuit in the power supply to activate. If you have determined that one of the piezo elements is bad and the protection circuit has activated, the defective amplifier on the channel with the bad piezo may be removed and the controller may be tested further. Turn the controller power off and continue to step 6.

6. Remove the amplifier from the specific channel you suspect is bad. Each high voltage amplifier is labeled on the back panel circuit board. The amplifier is socketed and is held in with a single screw. Use a 7/64" hex wrench to remove the screw and use a pair of needle nose pliers to gently pull the amplifier up and out of its socket.



7. Once the amplifier is removed, reconnect the high voltage cable to the main controller board and measure the orange wire for the proper voltage.

If the voltage on the orange wire is 0 V then no further testing can be done. The controller needs repair.

If the voltage on the orange wire is now +165 VDC then continue with this procedure to test the drive signals of the other two axes of the controller.

Testing the high voltage drive signals in the controller

1. With the main microscope cable disconnected from the front of the controller, turn the controller power on and start a new experiment in Igor.

2. Open the test panel by following the instructions outlined in the previous section, "**Determine if the piezo elements are working correctly**". Do not start ramping the voltage.
3. Set the Channel to one of the two remaining axes that are not affected by the damaged piezo.
4. Change the Start Voltage to 0 V and measure the actual voltage on the corresponding BNC connector located on the back panel PC board.
5. If the voltage correctly measures 0 V, change the start voltage to +150 V and confirm that the voltage changes to +150 V on the BNC connector.
6. Change the start voltage to –10 V and measure the BNC for the correct voltage.
7. Change the Channel to the other axis not affected by the damaged piezo and repeat steps 4-6.

If both of the remaining channels produce the correct control voltages then the controller is good except for the amplifier chip that was damaged from the damaged piezo assembly. The following steps in this procedure will determine if the piezo assemblies in the two remain axis are correctly functioning.

Retesting the remaining channels

1. Turn the controller power off.
2. Reconnect the main controller cable to the front of the controller.
3. Confirm the microscope head and scanner are connected to the base. It is okay to reconnect a scanner or head with a bad piezo if the amplifier in the controller was removed from the bad channel. Removing the amplifier essentially disconnects the bad piezo from the instrument.
4. Turn the controller power on.
5. Repeat steps 7-9 in the section "**Determine if the piezo assemblies are working correctly**"

If both of the remaining channels produce the correct signal waveforms then you have successfully isolated the problem with your system.

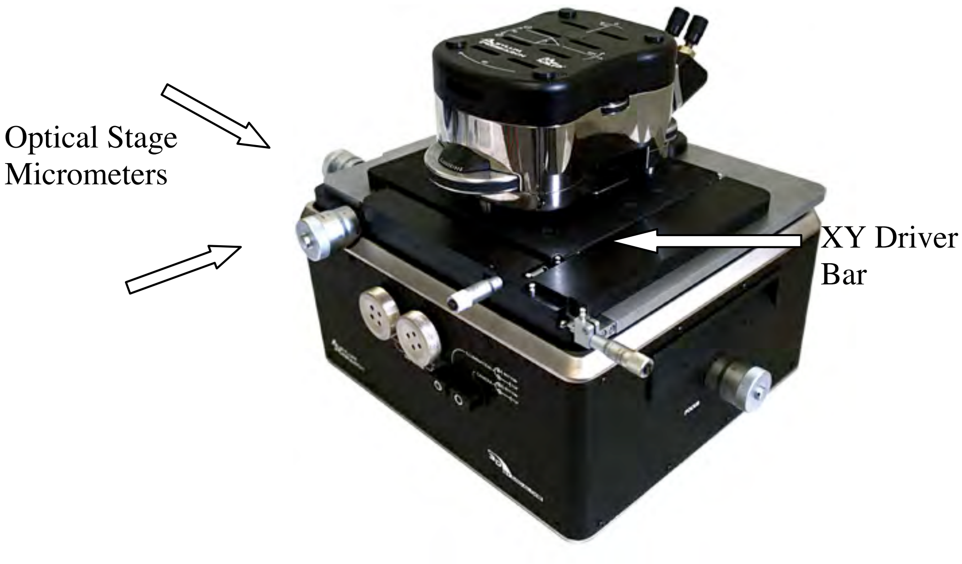
V. Shipping Instructions

When shipping any part of the MFP-3D system, it is best to use the original packaging. Call the factory for replacement packaging if needed.

There are several items that require special attention to avoid damage during shipment:

1. Optical Stage on Base

   Before shipping the base, turn the large micrometers of the optical stage clockwise until they are all the way in (do not over-torque). This keeps the stage plate from moving during travel.

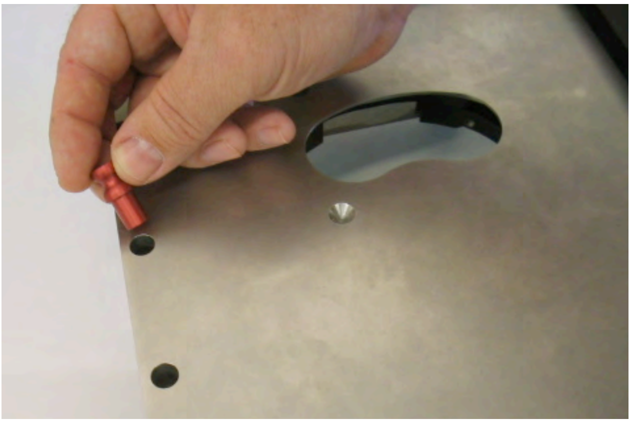


2. XY Driver Bar on Base

Before shipping the base, remove the XY driver bar. It is held magnetically to the base and simply lifts off. (There are several models of bases and drive bars; yours may not look the same as the one pictured above.)

3. Olympus Base Plate Dowel

A red shipping dowel pin is used to restrain the top plate on Olympus IO bases.



4. Head Mirror

The top view optics assembly in the head has a mirror that needs to be restrained before shipping. Crumple up a couple tissues and put them against the mirror. Tape over the hole with tape.

Some items need to be sent back with another part:

1. If the scanner is sent in for repair, the LVDT board in the base must be returned with it (see the Base/Removing the XY LVDT Board section for instructions).
2. If the head is sent in for repair, the cantilever holder must be returned with it.

VI. Set-up After a Repair (Parm Panel)

Each of the main components in the MFP-3D system contains built-in memory that stores information specific to its construction. During the repair of the device you returned to us, the calibration may have been changed. If this has happened, the software will automatically sense any changes and display a window labeled Parm Panel.

The Parm panel displays a list of calibration parameters for each device in your system. The parameters highlighted in red are the ones that the software has seen as changed. In order to optimize your system you need to teach the software the new values. This will only need to be done once. Please follow the steps below.

1. Reconnect the device that was repaired.

2. Turn the controller power on.

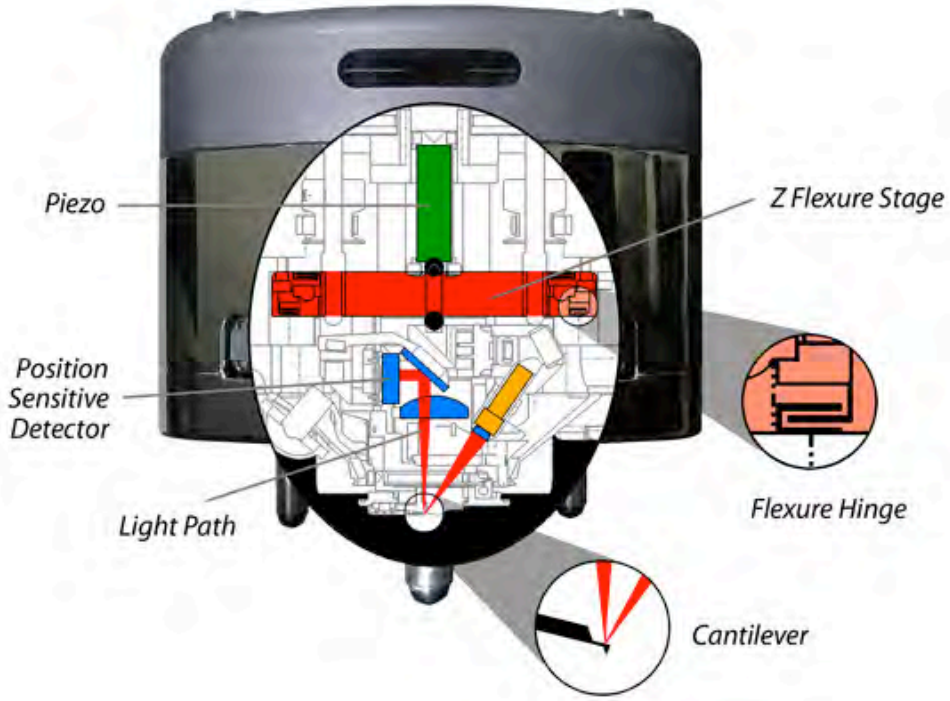
3. Start a new experiment. A window called Parm panel will appear. This is due to the system sensing the different calibration parameters. If the Parm panel does not appear, no action is needed to use your system – disregard the rest of this procedure.

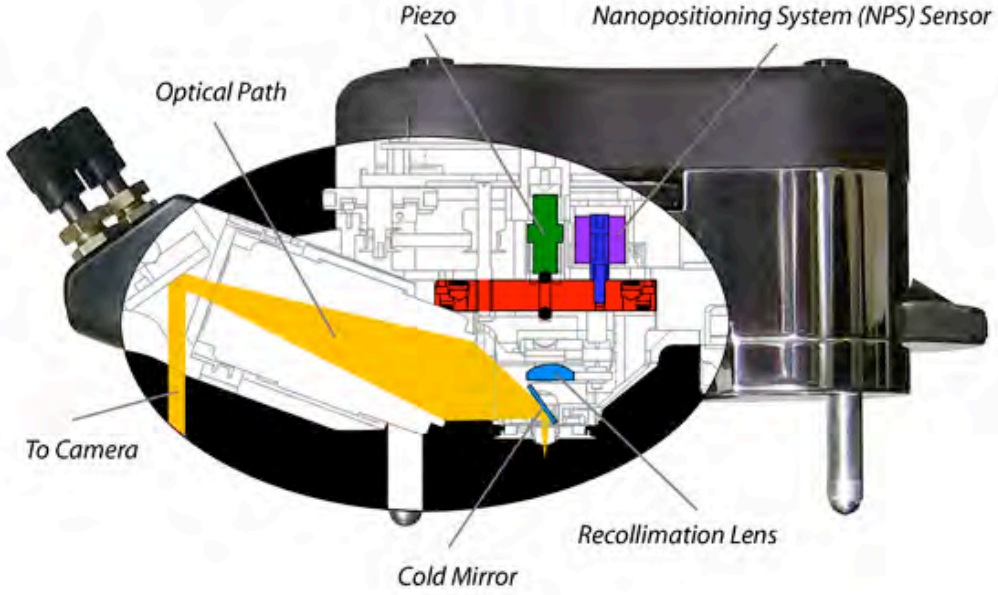
4. Click on the "**Move**" button in the **Hardware** column for each item that is highlighted in red. This transfers the new parameters from the device into software memory. (The "Use this" column).

5. Click on the "**Use the "Use This" values**" button. This tells the software to use the new calibration parameters when scanning but does not permanently save them.
6. Click on the "**Save the "Use This" values to software**" button. This saves the calibration parameters to the hard disk.
7. Close the parm panel window. The new calibration parameters should now be stored for future experiments.

The Head

MFP-3D Scan Head





I. Introduction

The head contains most of the basic components of the AFM: the Z stage (piezo, flexure, and position sensor) and the detection system (SLD light source, optics, photodiode sensor, and the cantilever holder). With so many key elements the proper functioning of the head is critical to the health of your MFP-3D. The cantilever holder has the most maintenance and troubleshooting issues to be aware of. There are a lot of components in a small space and the user interacts with the holder every time the AFM is run. It is also important to understand how to check the performance and calibration of the Z stage since all height data is generated from it.

If for any reason the head has to be sent in for repair, the cantilever holder must be sent in with it so that the head optics can be realigned to match the holder.

II. Performance and Calibration

The calibration of the Z sensor (also called LVDT) is set using an interferometer and thus cannot be done outside the factory. The sensitivity of the Z sensor changes extremely little over time so this is rarely an issue. It is useful to check that the Z sensor is generally functioning properly and its calibration can be verified using a less precise method (against a calibration sample rather than an interferometer). The sensitivity of the Z piezo does change with time, but the Z piezo (height) is calibrated based on the Z sensor so it can be done outside the factory. Finally, the noise of the Z sensor can be measured to verify performance. All these instructions are given in the procedures below. Further troubleshooting should be done with support from the factory.

Problems related to the Z stage often cause strange behavior during engage. For example, as soon as the tip engages the Z center voltage goes immediately to -10 V.

<u>How to check and maintain the performance of the Z Stage:</u>

Recommended every 6 months or if you suspect Z related problems.

Problems related to the Z stage often cause strange behavior during engage. For example, as soon as the tip engages the Z center voltage goes immediately to -10 V.

1. Check Z sensor range.
    a. If does not pass, contact the factory.
2. Check Z calibration (sensor and height).
    a. If sensor does not pass, contact the factory.
    b. If just the height does not pass, calibrate the height.
3. Check Z sensor noise.
    a. If does not pass, contact the factory.

For all procedures, first read through the relevant Test Panel section to become familiar with the parameters and functions used in the instructions.

Z Sensor Range

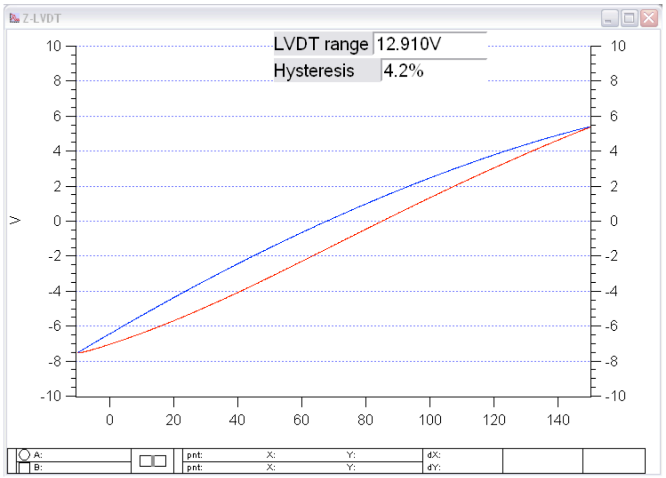
This procedure measures the voltage of the z sensor while the z piezo is exercised in open loop through its full range. The measurement is done off the surface; no tip or sample is required. The range and endpoints of the sensor data are verified.

- Open the Test Panel and select the Calibrate tab.

LVDT/ Piezo Calibration

Channel Z-axis
Action Drive
Z Start -10.0V
Range 160.0V
Freq 1.0Hz
Diff A 0
Phase 180.00°

- Set the parameters as follows:
    - Channel = Z-axis
    - Action = Drive
    - Z Start = -10 V
    - Range = 160 V
    - Frequency = 1 Hz
    - ***Do not change Diff A and Phase!*** They are set at the factory and should not to be changed by the customer.
- Click Start.
- A graph of the sensor (LVDT) voltage vs. piezo drive voltage appears.



LVDT range 12.910V

Hysteresis 4.2%

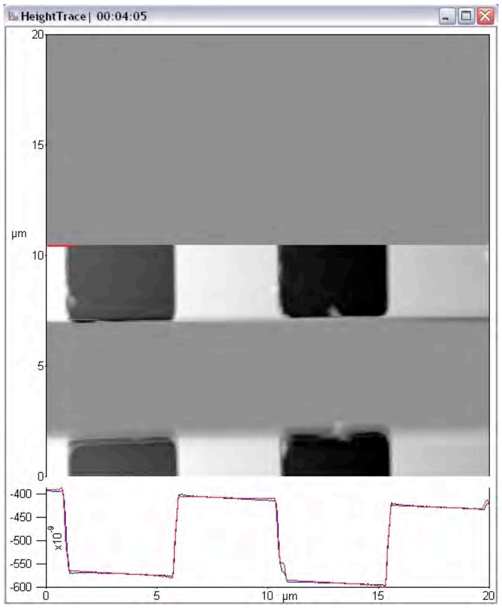
- Results:
    - The Z sensor (LVDT) range is typically 12 V; the output range is set at the factory during calibration. If the range is not between 11 and 13 V check the Z sensor calibration as described below.
    - The endpoints of the Z sensor range are typically at +/- 6 V with the center at 0 V. It is common for the center to be off by a volt due to mechanical changes in the head over time. If either endpoint is outside of +/-9 V, contact the factory.

Z Calibration

1) Check Z Sensor and Height Calibration

This procedure checks the calibration of the Z sensor to within the accuracy of the standard calibration sample and the calibration of the Height relative to the Z sensor. The calibration sample is scanned in contact mode. The depth of the pits is measured on a histogram of Z Sensor and Height.

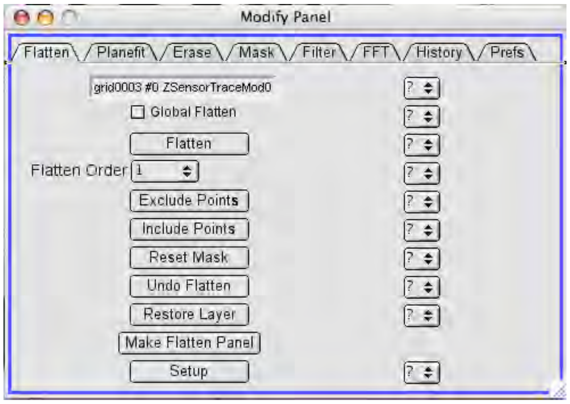
- Engage in contact mode on the 10 x 10 um calibration sample.
- Set the Scan Size to 20 um.
- Set the Scan Rate to 1 Hz.
- Set the Scan Points and Lines to 512.
- Make sure the Z Voltage is near 70 V.
- Set Height and Z Sensor as channels 1 and 2.
- Adjust feedback (Set Point, Gains) as needed to get good tracking of the sample.



- Save an image.

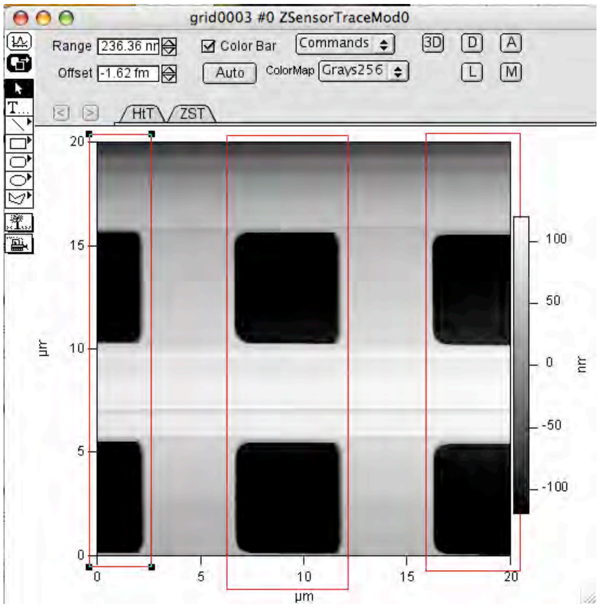
Before measuring the depth of the pits, the image is flattened to remove sample tilt and any line to line scan artifacts. A mask is used to select only data from the top surface of the grating on which to perform the fit. Then the data is put into a histogram to make the depth measurement.

- Create Mask:
    - Open saved image.
    - From the MFP IP menu select Modify Panel or click on the 'M' above the image
    - Select the Flatten tab.



-
    - Click Exclude Points.
    - Next to image, click on the rectangle icon if not already selected. ▭

- Draw boxes on image to exclude all the pits. Each box should span the entire image vertically and contain a column of pits. Leave a clear margin between the boxes and the pits.



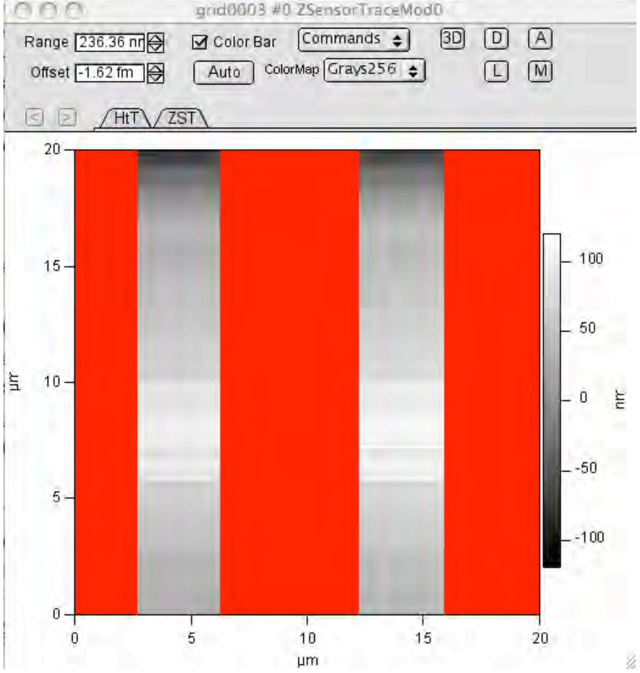
Range 236.36 nr

Offset -1.62 fm

☑ Color Bar

ColorMap Grays256

- If you need to readjust the box size/position, click on the select icon and drag box corners.
- When boxes are in place, click Make Mask.
- To clearly visualize the mask, it is useful to select the FillMask option on the Mask panel so that the excluded data points are filled in red.



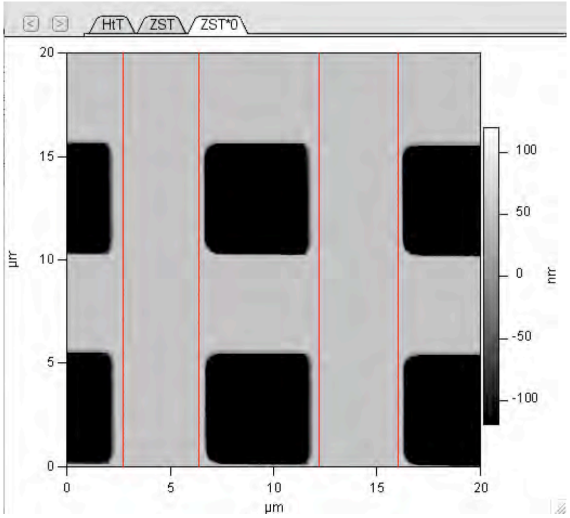
Range 236.36 nr

Offset -1.62 fm

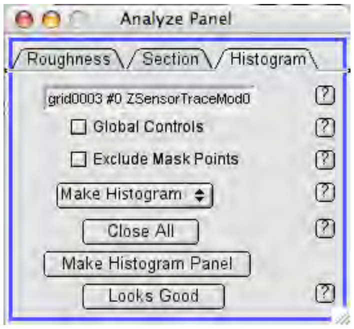
☑ Color Bar

ColorMap Grays256

- Flatten image:
  - Set Flatten Order to 1.
  - Click Flatten button. Any sample tilt and horizontal banding should be removed.

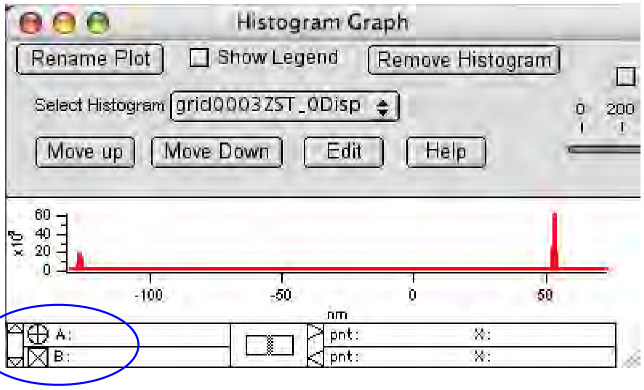


- Make histogram & depth measurement:
  - From the MFP IP menu select Analyze Panel or click on the ‘A’ above the image.
  - Select the Histogram tab.
  - Click Make Histogram>New



grid0003 #0 ZSensorTraceMod0

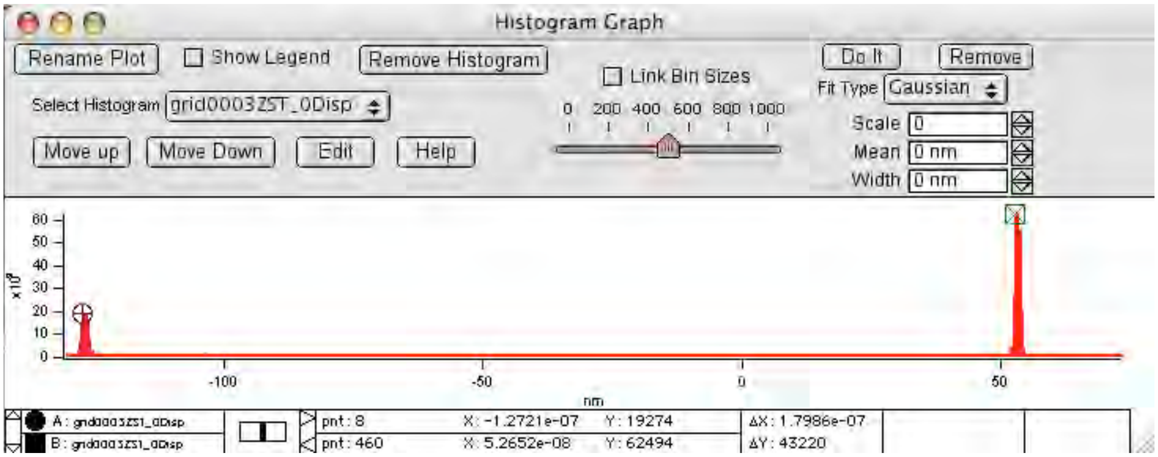
  - A histogram graph appears.



Select Histogram grid0003ZST_0Disp

Measurement Cursors

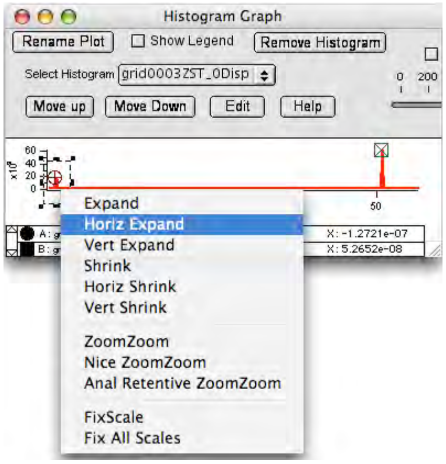
- Click ctrl-I while on the graph area to get measurement cursors.
- Click & drag on cursor A to place it on first peak in histogram. ⊕
- Use left/right arrow keys to move cursor onto highest bin within peak.
- Place cursor B on highest bin of second peak. ☒



Select Histogram grid0003ZST_0Disp
Fit Type Gaussian
Scale 0
Mean 0 nm
Width 0 nm

A: grid0003ZST_0Disp pnt: 8 X: -1.2721e-07 Y: 19274 ΔX: 1.7986e-07
B: grid0003ZST_0Disp pnt: 460 X: 5.2652e-08 Y: 62494 ΔY: 43220

- If it is not clear which bin is highest in a peak, expand the graph horizontally around the peak for a better view.

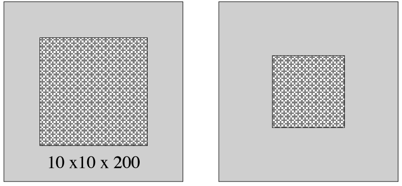


- Result: ΔX is the depth of the pits (179.86 nm for Z Sensor in this example).
- Repeat procedure to get depth for 2nd channel (Height).

The Z sensor is calibrated at the factory using an interferometer. The calibration of the sensor is done at a nominal temperature of 33° C. This is the typical operating temperature of the AFM head inside of an acoustic isolation hood. Variations in ambient temperature will affect accuracy of the calibration by approximately 1%. The 10 x 10 um calibration sample has a nominal pit depth of 180 or 200 nm, depending on the type*, accurate to +/-3%. If the Z Sensor depth is off by more than +/-3% from the nominal value using this method, contact the factory.

Height (Z piezo) is calibrated relative to the Z Sensor. If the Height depth is different from the Z Sensor depth by more than 1%, you may follow the Height calibration procedure below. Note that the Height calibration is done only at the center of the Z piezo range of travel (70 V). Piezos are hysteretic and the sensitivity varies significantly throughout the range, so the error is greater away from center.

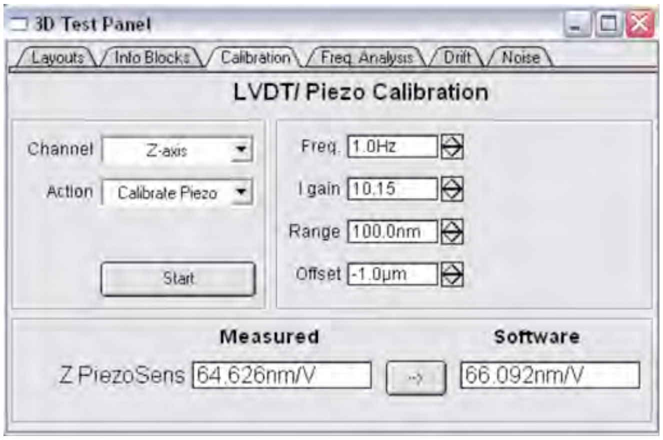
*The two types of calibration samples can be distinguished by the size of the patterned area. Both samples are 1 cm^2 in area. The 200 nm sample has a patterned area of 6 mm^2 while the 180 nm sample has a patterned area of 4 mm^2. The 200 nm sample also has the dimensions etched along one edge.



200 nm sample 180 nm sample

2) Calibrate Height

This procedure calibrates the Height (Z piezo) relative to the Z Sensor. The measurement is done off the surface; no tip or sample is required. The Z piezo is in closed loop feedback from the sensor. The piezo is extended to the middle of its range and driven through 100 nm of motion as seen by the sensor. The piezo sensitivity is calculated from the voltage required for the excursion.



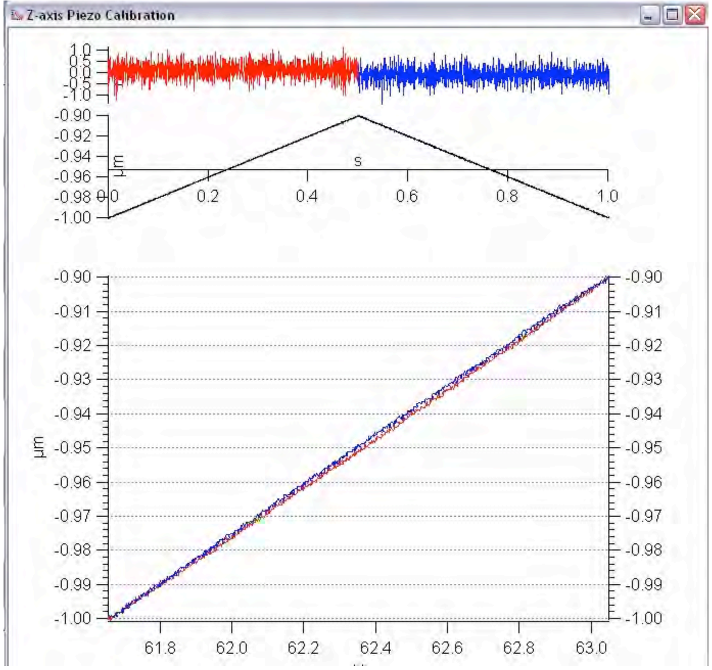
LVDT/ Piezo Calibration

Channel Z-axis
Action Calibrate Piezo
Freq. 1.0Hz
I gain 10.15
Range 100.0nm
Offset -1.0µm

	Measured	Software
Z PiezoSens	64.626nm/V	66.092nm/V

- Open the Test Panel and select the Calibration tab.
- Set parameters:
  - Channel to Z-axis
  - Action to Calibrate Piezo

  - Frequency to 1 Hz
  - I gain – Do not change. Set at factory during full calibration (typically 10.15).
  - Range to 100 nm
  - Offset to –1.0 um
- Click Start.
  - The piezo cycles through 100 nm excursions. A new Z Piezo Sensitivity is measured each cycle. Allow the software to cycle the Z piezo several times until the measurement stabilizes.
- A graph window opens with 3 plots.
  - Top plot is the error signal.
  - Middle plot is Z sensor vs. time.
  - Bottom plot is Z Sensor vs. Z Piezo voltage.
    - The Z Piezo Sensitivity is the slope of this line.



- Click Stop.
- Click the arrow button to move the measured sensitivity into software memory.

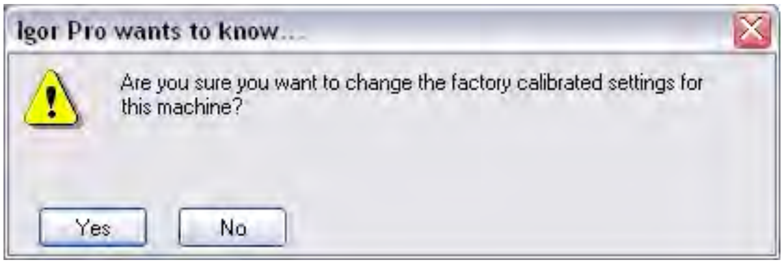
  -->

WARNING!!

Changing values in Info Block causes permanent changes to the hardware calibration. Only make changes specifically detailed here and only do so once you are confident of your work. Other changes can cause physical damage to the system.

- To write the new Z Piezo sensitivity to the hardware in the head:
  - Select the Info Blocks tab.
  - Set Device to Head.

    - For Action, select Local <- Software. If Action is already set to Local <- Software, you must reselect it. Confirm that the Z Piezo Sensitivity value is now the same for both Local InfoBlock and Software.
    - Change Action to Write InfoBlock.
        - Select Yes on the warning dialog to continue.



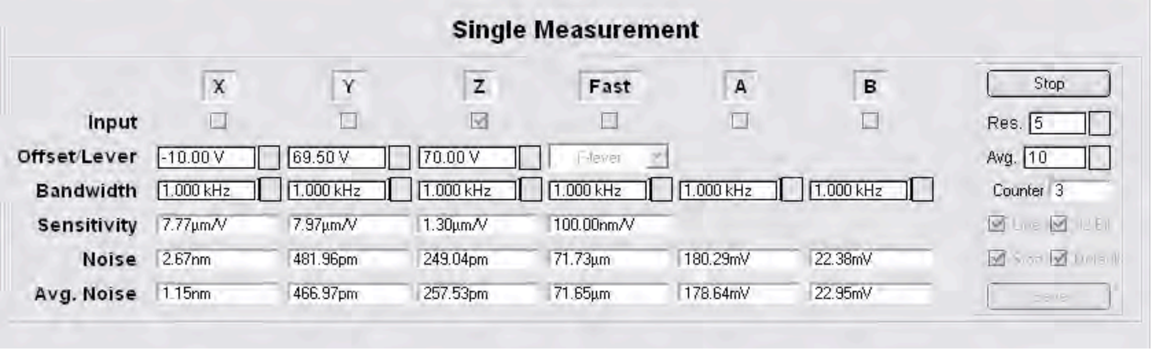
Igor Pro wants to know...

Are you sure you want to change the factory calibrated settings for this machine?

    - Reselect Action to Write InfoBlock
        - Select Yes on the warning dialog (same as above) to make the change final.
        - A success dialog will appear.
        - Verify the change by checking the new sensitivities appear in both Local InfoBlock and Software.

Z Sensor Noise

This procedure measures the noise of the Z sensor (also called the Z LVDT). The measurement is done off the surface; no tip or sample is required. The Z piezo is in open loop (no feedback from the sensor). The Z piezo is extended to approximately the middle of its range by applying a constant voltage of 70 V throughout the measurement.



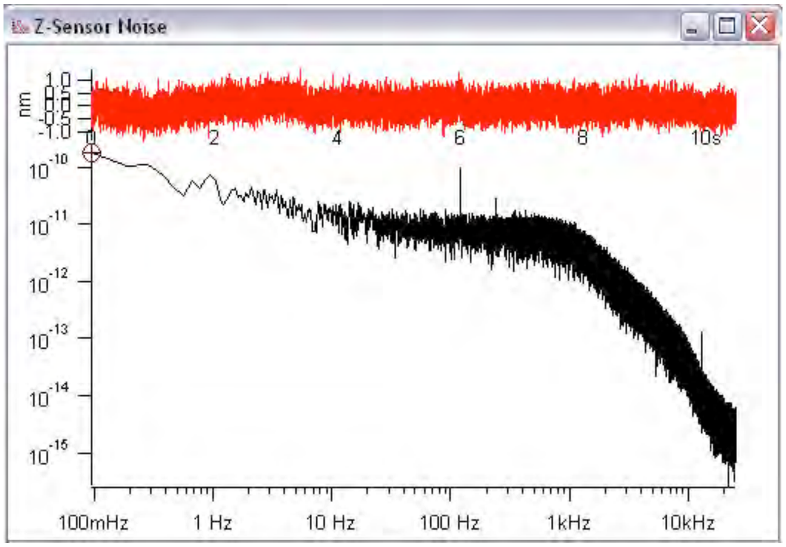
Single Measurement

	X	Y	Z	Fast	A	B
Input	☐	☐	☑	☐	☐	☐
Offset/Lever	-10.00 V	69.50 V	70.00 V	F-lever		
Bandwidth	1.000 kHz	1.000 kHz	1.000 kHz	1.000 kHz	1.000 kHz	1.000 kHz
Sensitivity	7.77µm/V	7.97µm/V	1.30µm/V	100.00nm/V		
Noise	2.67nm	481.96pm	249.04pm	71.73µm	180.29mV	22.38mV
Avg. Noise	1.15nm	466.97pm	257.53pm	71.65µm	178.64mV	22.95mV

Res. 5
Avg. 10
Counter 3

- Select the Noise tab on the 3D Test Panel.
- Set the parameters up as follows:
    - Input to Z
    - Offset to 70V
    - Bandwidth to 1.0 kHz
    - Res. to 5
    - Avg. to 10

    - Verify Line, 32 Bit, Stop, and Default options are selected
- Click Start.
- A window with 2 graphs will appear.

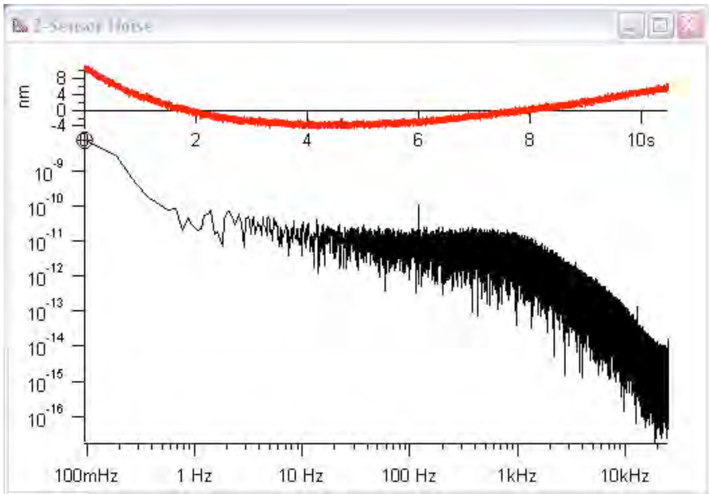


    - The top red plot is the Z Sensor signal versus time for the last data set.
    - The bottom black plot is the average PSD of all the Z Sensor data sets collected so far in the experiment (indicated by the Counter).
- Once 10 data sets are complete, the experiment will automatically stop.

The Average Noise for Z should be 300 pm or less for this bandwidth of 0.1 Hz to 1 kHz. If it is outside this spec, contact the factory.

Notes:

- For general troubleshooting it may be sufficient to use a reduced bandwidth (Res. of 3 or 4) for quicker results.
- When the 70 V offset is applied, the Z piezo position can creep/drift for a very short time if this was not the previous Z voltage. This is generally not a concern because the creep fades so quickly. If however you see bow in the Z Sensor plot or the Noise value is high for the first measurement or two, then you must wait for the creep to settle out (~ 30 seconds) and restart the measurement.



III. Light Source (SLD) Failure

The light source in the optical lever detection is a super luminescent diode (SLD). When the SLD goes bad it slowly loses power and gets progressively dimmer rather than suddenly turning off. If the sum signal is significantly less than normal on a standard cantilever the SLD may be bad.

The optical power of the SLD is adjusted at the factory to get 8.5 V of sum signal on an AC160 Si lever, which corresponds to roughly 1 mWatt. If you suspect that the SLD may be going bad, install an AC160 lever and align the light source as usual (at the end of the cantilever, positioning for maximum sum). If you do not get close to 8.5 V sum:

1. Check that all optical surfaces on the cantilever holder are clean.
2. Check that the top view mirror in the head is clean.
3. Power off the SLD for ~10 seconds using the key on the front of the controller. If there is a temporary recovery of light/sum when the power is returned on (which subsequently fades back to the diminished level), the SLD is bad. If you do not see this behavior then the state of the SLD is indeterminate.
4. If available, use a power meter to measure the SLD output. Measure the power with the cantilever holder removed. It should be close to 1 mWatt.

If you think you have a bad SLD contact the factory. For replacement, the head and cantilever holder need to come back as a set.
If the sum is still low, but it does not appear to be a bad SLD, the cantilever holder may need to be disassembled and cleaned (see Cleaning in the Cantilever Holder section).

IV. Cantilever Holder

The cantilever holder may be small but it is a key component of the AFM. There are numerous maintenance and troubleshooting issues that it are important to be aware of, including some design updates. The holder is handled nearly every time the AFM is run and it comes in contact with the liquid in fluid experiments, so cleaning is indispensable. Because the angle of the cantilever is central to the optical lever detection scheme, the slot needs to be intact and the lever installed properly. These, along with other common problems and useful information, are covered in this section.

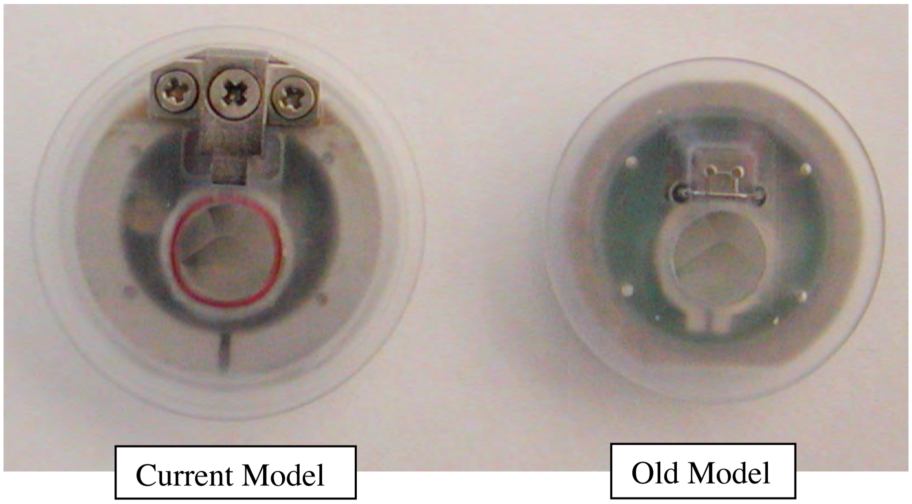
Except where noted, all instructions and information in this section are correct only for the current model cantilever holder.

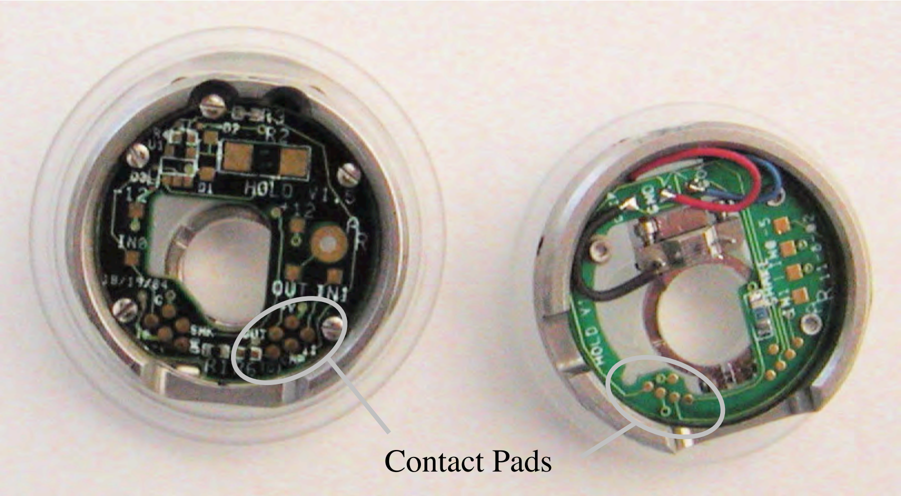
This Cantilever Holder section contains:

General Information

Models & Head Compatibility

There have been 2 models of cantilever holders for the MFP-3D. They are easily distinguishable from either side.

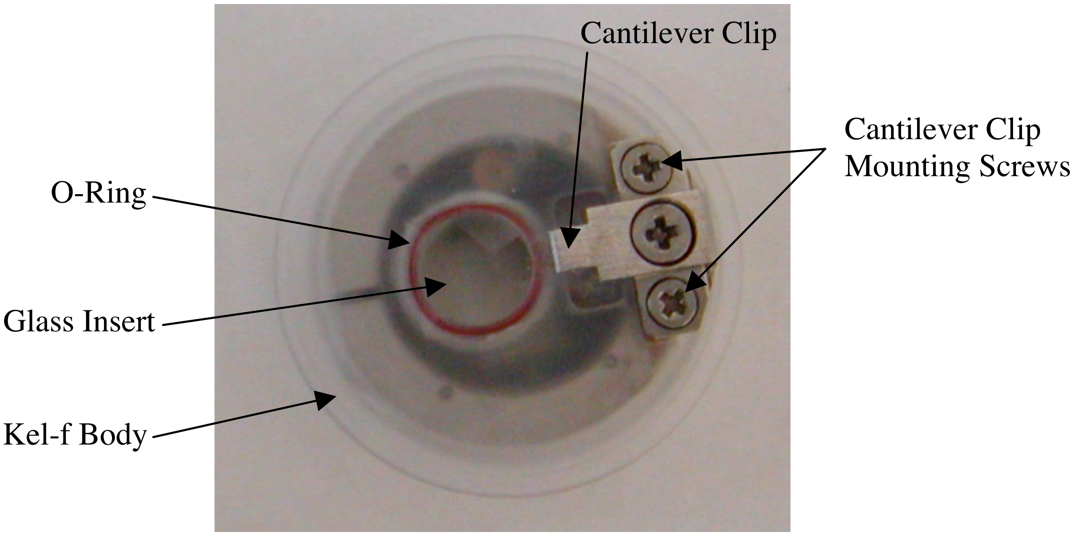




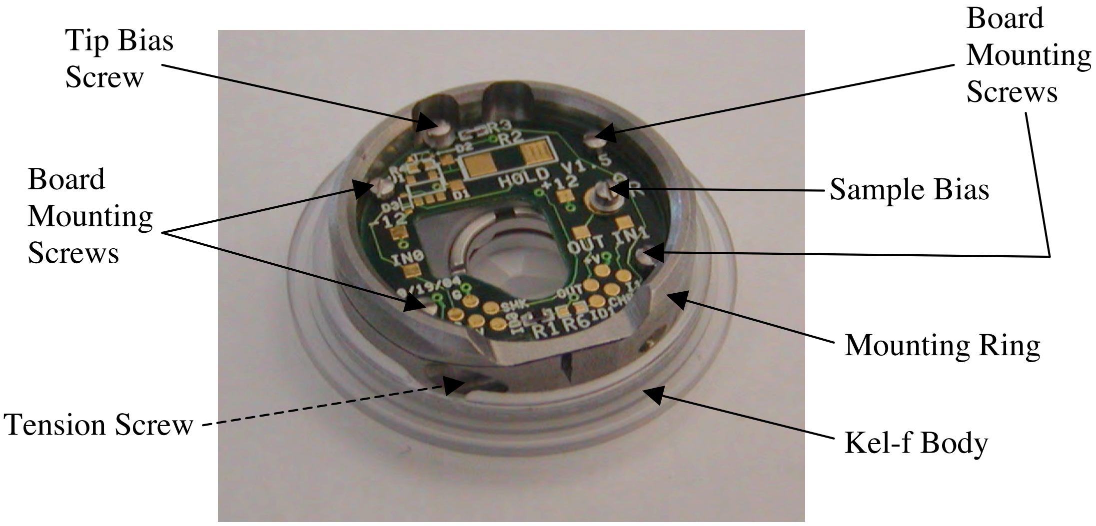
On the backside of each holder there are two sets of 5 contact pads. The pattern of the contact pads is different on the two models. The current model has a 2 & 3 arrangement whereas the old model has a 1 & 4 arrangement. Each model only works on a head with the corresponding design.

WARNING!!
Using a cantilever holder model on a non-compatible head
causes serious damage to the head.

Cantilever Holder Diagram



Top of Cantilever Holder



Bottom of Cantilever Holder

Chemical Compatibility

The parts of the cantilever that are exposed to liquid during fluid experiments are:

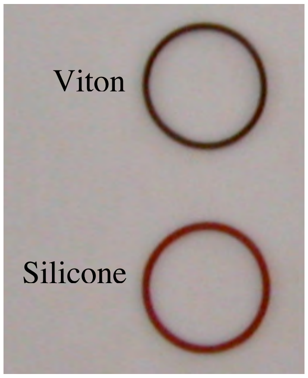
- kel-f (the plastic body)
- fused silica glass (the glass insert)
- stainless steel (the cantilever clip and mounting screws)
- silicone or Viton (depending on the type of o-ring used, see below)

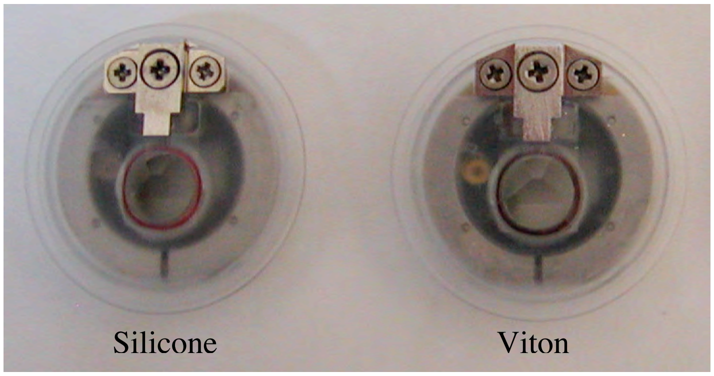
It is the customer's responsibility to use only liquids that are compatible with these materials. Cole-Parmer has a useful website on chemical compatibility (http://www.coleparmer.com/techinfo/chemcomp.asp).

Important Design Changes

O-Ring

The o-ring seals the glass insert and the surrounding kel-f body and is critical in preventing leaks during fluid experiments. The original o-ring was silicone. The currently shipping o-ring is Viton because it is more chemically inert. It is only important to have the Viton o-ring if you are doing fluid experiments with liquids that can degrade silicone. The two materials can be distinguished by their colors. The silicone o-ring is red; Viton is dark brown.





When you are performing a rigorous cleaning it is worth changing the o-ring (regardless of the material) as they can degrade over time. Several o-rings are provided with each cantilever holder.

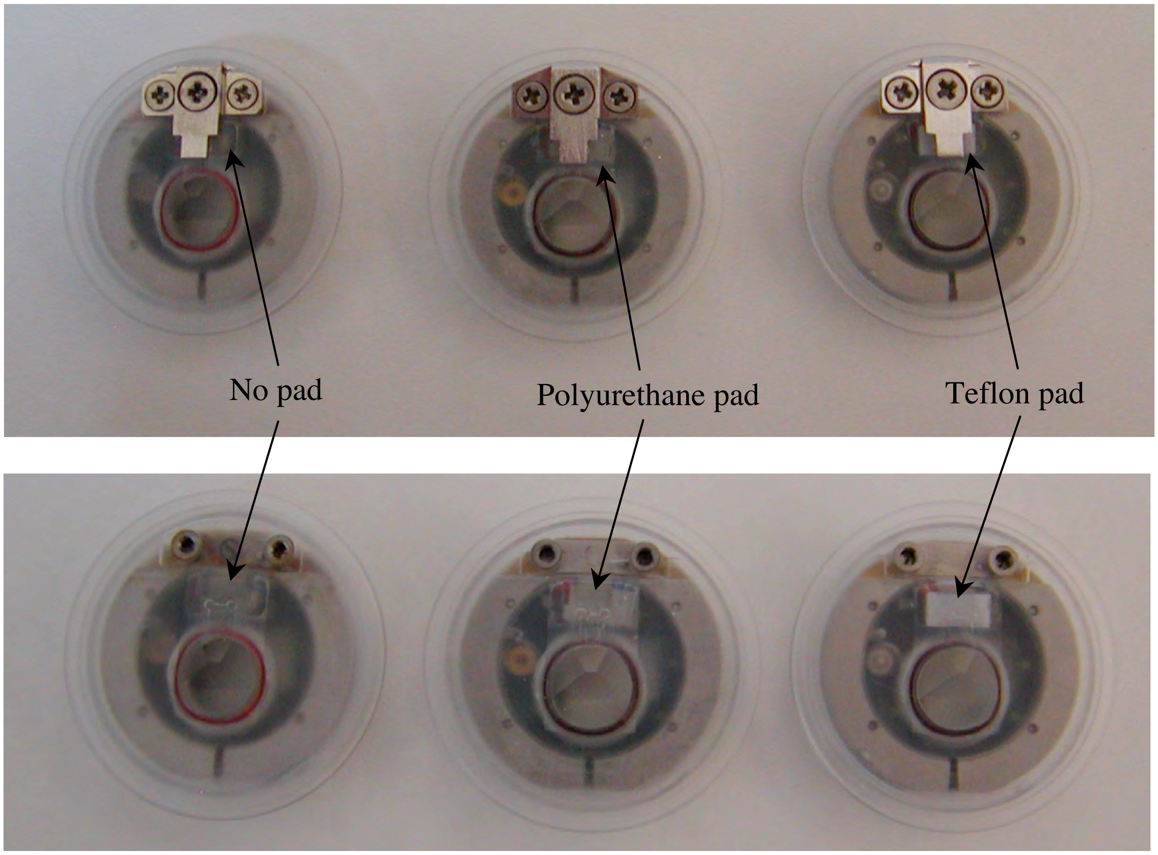
Instructions on how to change the o-ring in your cantilever holder are contained in the disassembly procedure.

Drive-Coupling Pad

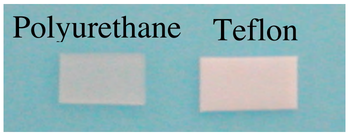
In the latest revision of the current cantilever holder model, a small plastic pad is pressed between the drive piezo and the kel-f body. The pad was added to improve the mechanical coupling of the drive piezo to the cantilever. This makes the drive more efficient (less drive amplitude produces more cantilever motion). If your holder does not have a pad it is recommended that it be added, especially if you are having difficulty tuning standard levers.

With a pad installed, the typical drive amplitude needed to get 1 V of free amplitude on a 300 kHz lever is between 20 and 200 mV. Without a pad the needed drive amplitude will be larger. If the drive amplitude exceeds 1 V it puts significant load on the driving electronics and often results in a “Cantilever tune failed” message.

First, identify whether or not there is a pad in your cantilever holder. The pad is rectangular and located beneath the kel-f under the cantilever clip. If you are not sure if you see a pad, it may help to take the cantilever clip off for a better view (see instructions in the Routine Cleaning section).



Second, make sure your cantilever holder has the appropriate type of pad. The most common pad is polyurethane, which looks milky white through the kel-f. Polyurethane is appropriate for all applications except for the Polymer Heater. A Teflon pad is needed to withstand the high temperatures of the Polymer Heater. The Teflon pad is more opaque than the polyurethane and looks more distinctly white through the kel-f.



If you need to add or change the drive-coupling pad in your cantilever holder, instructions are contained in the disassembly procedure.

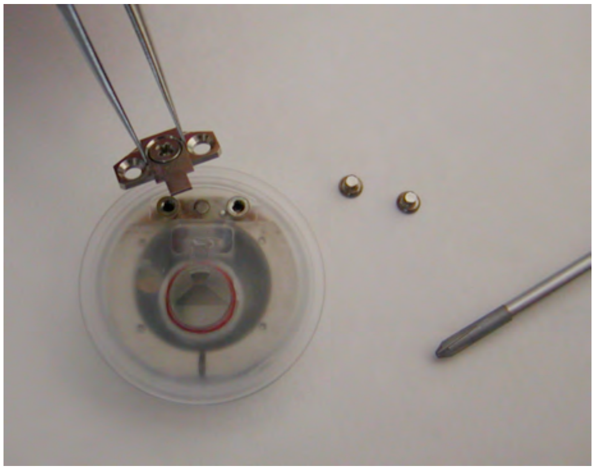
Maintenance

Routine Cleaning

For the most basic level of cleaning, no disassembly of the cantilever holder is required. Clean the entire topside of the cantilever holder, including all parts exposed to the liquid during fluid experiments (the kel-f, glass, and clip). Use camera lens paper and alcohol. Cotton swabs and tissues such as Kimwipes are too coarse and can scratch the glass surface.

This basic cleaning should be done after each fluid experiment.

For more careful cleaning, you can remove the cantilever clip and clean the underside of the clip and the kel-f below. Using a small jewelers screwdriver, remove the 2 cantilever clip mounting screws and lift off the clip.



If the **sum signal is low** or you have consistent **difficulty tuning standard levers** (very high drive amplitudes are required or the peaks are ugly), it is likely that the optics in the cantilever holder are dirty. Start by cleaning the top of glass insert as described above. If this does not solve the problem, then clean the backside of the glass. To do this the mounting ring must first be removed (follow disassembly procedure below).

Rigorous Cleaning

For more rigorous cleaning, take apart the cantilever holder following the disassembly procedure. Then immerse the cantilever clip, 2 cantilever clip mounting screws, kel-f body, glass insert, and o-ring in a container of ethanol and sonicate. It may be more appropriate to replace the o-ring rather than clean it (several o-rings are provided with each cantilever holder). All parts need to be completely dry before reassembling the holder.

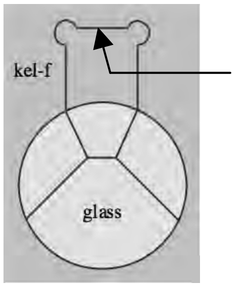
Rigorous cleaning does not need to be done regularly unless you suspect that your fluid experiments are contaminating the holder.

Inspection

Periodically inspect the cantilever holder for the following issues:

1) Damaged Cantilever Slot

Because kel-f is soft relative to silicon and silicon nitride, cantilever substrates can damage the cantilever slot in the kel-f body. The problem primarily occurs along the back wall of the slot as the cantilevers are loaded. Remove the cantilever clip (see Routine Cleaning above for instructions) and use an optical microscope to inspect the slot.

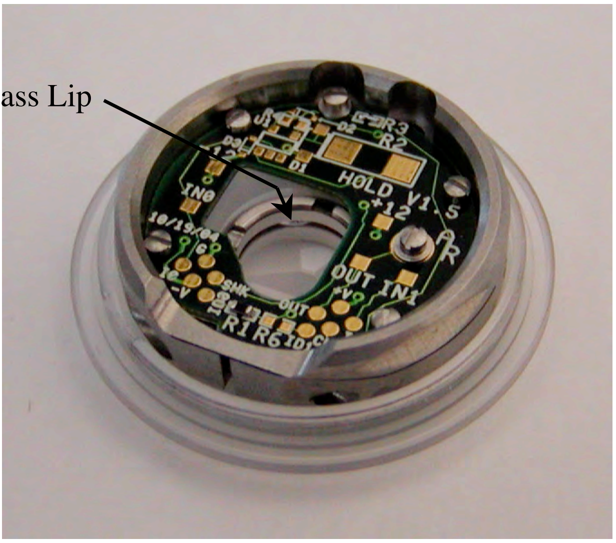


Back Wall of Cantilever Slot

Damaged walls make it difficult to properly install substrates and thus to align the light source on the cantilever. The kel-f body is meant to be disposable, so it is recommended to replace the body if there is any damage; call the factory for pricing. To help avoid this problem read the Installing Cantilevers section.

2) Broken Glass Lip

From the backside of the cantilever holder, inspect the glass insert just above the o-ring. If the glass lip is broken it looks like a bubble or imperfection in the glass.



Broken Glass Lip

The o-ring seats on the lip, so if the glass is broken the seal is compromised. This creates a potential leak point for fluid experiments. If the glass appears to have a break, contact the factory.

3) Corrosion

Inspect the cantilever holder for any rust, deposits, or corrosion. If any of these occur somewhere not exposed to liquid during fluid work (examples: under the kel-f, on the circuit board, or on the mounting ring) it indicates that the cantilever holder is no longer leak proof.

Depending on the degree of damage, the o-ring, the kel-f body, or the entire holder may need replacement. A damaged cantilever holder can result in system wide instrument failure.

4) Cracks in Kel-f

Minute cracks in the kel-f emanating from the clip area are normal. The posts for the cantilever clip mounting screws are interference press fit into the kel-f to form a waterproof seal. This process can leave tiny cracks in the surrounding kel-f. Before shipping, each holder is tested for leaks under 6 feet of water. Occasionally larger cracks appear over time. The holder is generally still waterproof but it is possible to create a leak point, so it is prudent to replace the kel-f body if the cracks get too large. The holder pictured below has clearly visible cracks though it was still waterproof.

To help avoid cracking, be careful not to over-tighten the cantilever clip mounting screws.

Disassembly Procedure

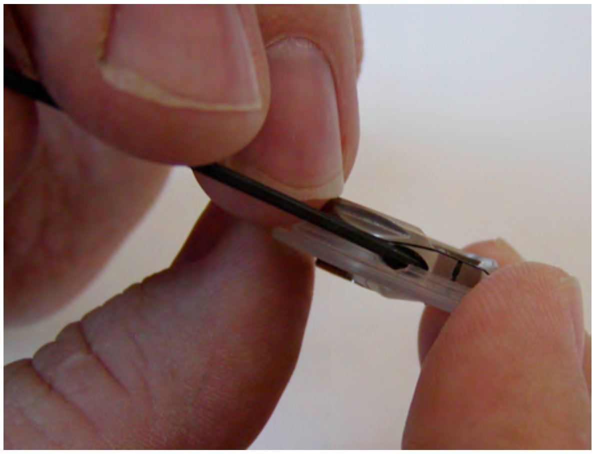
Various stages of disassembly of the cantilever holder are needed for:

- Routine cleaning
- Rigorous cleaning
- Adding/Changing the drive-coupling pad
- Changing the o-ring

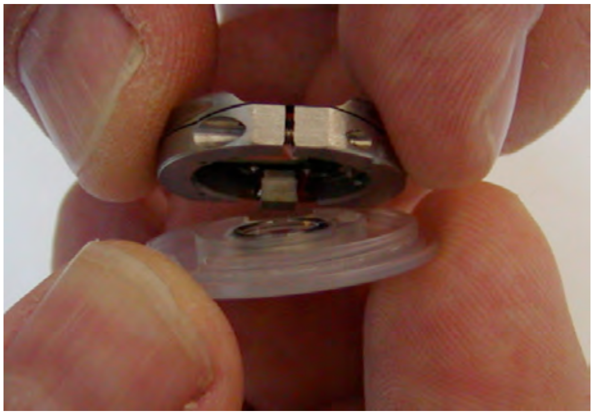
This procedure is a guide for the complete disassembly and reassembly of the cantilever holder. Instructions for each of the above topics are contained within the procedure. Refer to the cantilever holder diagram for identifying the components.

Disassembly Procedure

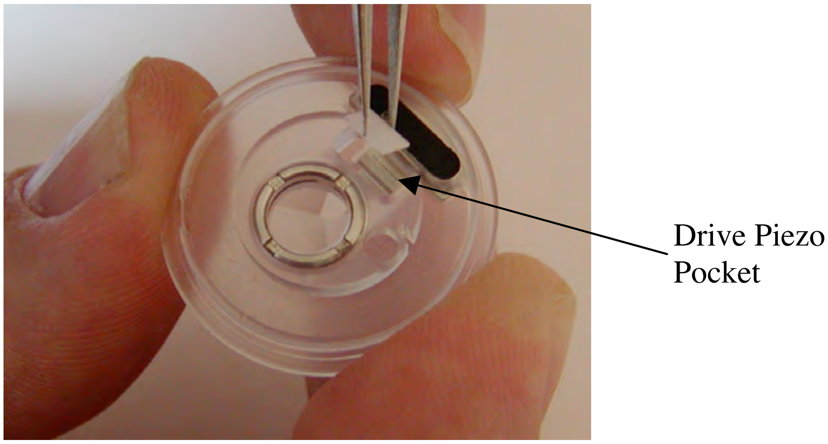
1. Using a small jewelers screwdriver, loosen the 2 board mounting screws that are closest to the tension screw (rotate CCW 1/2 turn).
2. Remove the tip bias screw.
3. Using a 0.050” hex wrench, loosen the tension screw on the side of the ring (rotate CCW 1/2 – 1 turn as needed).



4. Separate the kel-f body from the mounting ring by gently pulling apart.
If only cleaning the backside of the glass, skip to step 12.

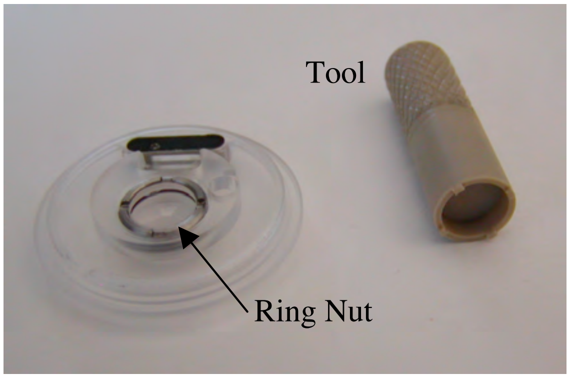


5. Remove the drive coupling pad with tweezers from the drive piezo pocket.
If only changing/adding the drive coupling pad, skip to step 12.

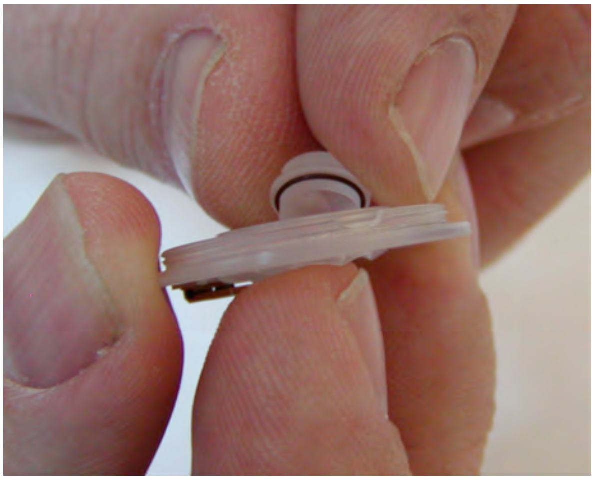


6. Remove the glass insert:

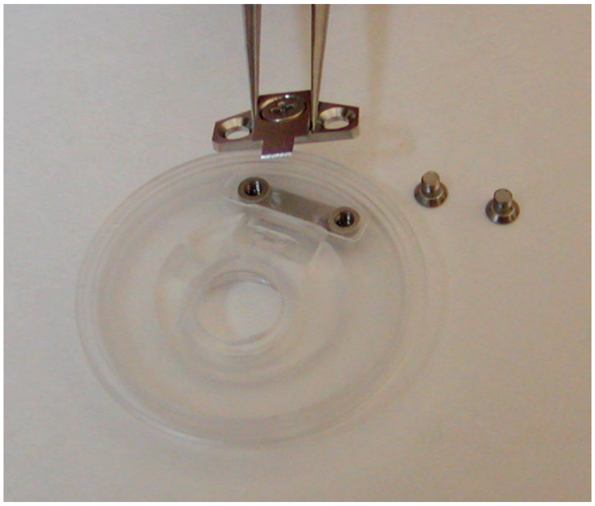
a. Line up the 4 tabs on the rim of the supplied tool with the 4 notches in the ring nut. Use the tool to unscrew the ring nut from the kel-f body.



b. From the top side of the cantilever holder (clip side), push the glass insert through with your finger.



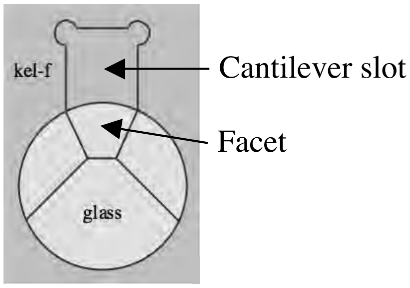
7. Remove the o-ring with tweezers.
   If only changing the o-ring, skip to step 9.
8. Unscrew the two cantilever clip mounting screws and remove the cantilever clip.



The holder is now completely disassembled and ready for rigorous cleaning (see details in the Maintenance section).

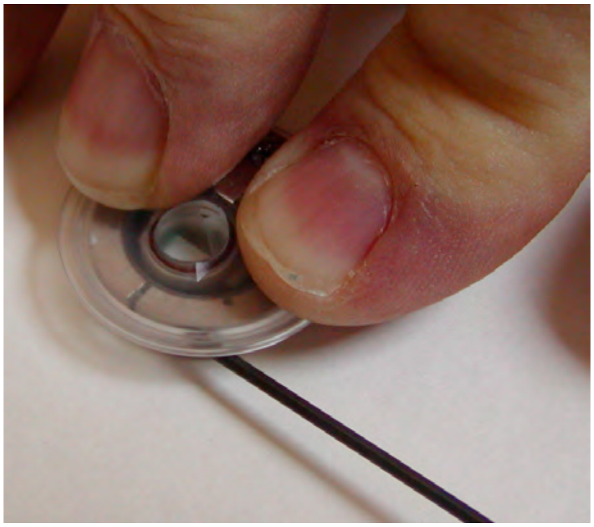
Reassembly:

9. Put the o-ring on the glass insert. The o-ring seats against the glass lip toward the faceted side of the insert.
10. Reinstall the glass insert:
    a. Push the glass insert into the body from the underside of the cantilever holder.
    b. Place the ring nut in the groove around the glass insert. Use the tool to thread the ring nut onto the body but do not fully tighten it.
    c. Rotate the glass insert with your fingers to align the small facet of the glass with the cantilever slot in the kel-f body. Screw the ring on a little more. Tightening the ring rotates the facet. Realign the facet and slot. Tighten the ring a little more. It is an iterative process of aligning the facet and tightening the ring until both are accomplished. Only tighten the ring nut until just snug; Do not over-tighten.



11. Put the cantilever clip back on. Do not over-tighten the two cantilever clip mounting screws; this can create small cracks in the kel-f that may cause fluid leaks.

12. Clean the underside of the glass insert from the bottom side of the cantilever holder using camera lens paper and alcohol. Cotton swabs and tissues such as Kimwipes are too coarse and can scratch the glass surface.
13. Drop the drive coupling pad (either polyurethane of Teflon as appropriate) into the pocket in the kel-f.
14. Reinstall the mounting ring:
    a. Place the mounting ring onto the body, lining up the drive piezo cube with the pocket in the kel-f.
    b. Place the cantilever holder onto a flat working surface so that the top (kel-f) is facing upward.
    c. Place a finger on each side of the body and press downward (to compress the drive coupling pad) while using the hex wrench to tighten the tension screw.



15. Tighten the 2 board mounting screws that are closest to the tension screw.
16. Reinstall the tip bias screw until just snug. Do not over-tighten; this can crush the circuit board. Note that the tip bias screw serves no mechanical purpose, only electrical.
17. Clean the top of the glass insert from the upper side of the cantilever holder to remove any fingerprints from the reassembly. Use camera lens paper and alcohol.

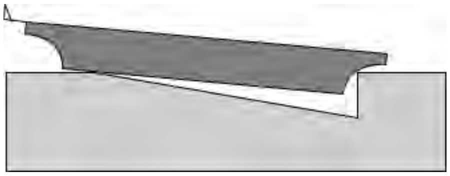
Troubleshooting

Installing Cantilevers

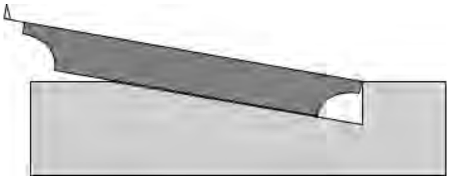
The angle of the cantilever is critical in an optical lever detection scheme like that used in the MFP-3D, so installing the cantilever correctly is a key part of running the AFM. Many people find it useful to install cantilevers while looking at the holder through a low power optical microscope.

Make sure that the cantilever substrate is squarely up against the back wall of the slot and not up over the edge putting the cantilever at incorrect angle. Be especially careful with Olympus SiN chips. The curved beveled edge of these substrates can easily jump the back edge of the slot.

Bad Cantilever Position



Good Cantilever Position



Indications that the cantilever may be positioned incorrectly:

- Difficult or impossible to align the light source.
- Large lateral signal after light source is aligned and deflection is zeroed (greater than +/-1V).
- Does not engage. (The substrate or cantilever clip can touch the surface before the probe does.)
- Vertical deflection drifts over time. (Pressure from the incorrectly seated cantilever substrate slowly compresses the kel-f.)

Also, be gentle when installing cantilevers to avoid damaging the kel-f. Do not jam the cantilever substrate into the back end of the slot. The hard Si/SiN can easily tear up the softer plastic. Once the slot walls are disfigured it is very difficult to correctly position any cantilever and the kel-f body will need replacement.

Installing the Cantilever Holder

When installing the cantilever holder onto the head, be careful not to drag the metal mounting ring of the holder across the gold pogo pins on the head. Doing this can short the chip pin on the pogo pin board to either +/-15 V. The system will survive a brief short circuit but multiple or extended shorts will cause resistors to fail and damage the instrument.

Fluid Spills

Use care when scanning in a Petri dish. If the fluid level is too high, the fluid will go up over the top of the cantilever holder body. If fluid gets inside the cantilever holder the circuit board can short which can result in further damage to the instrument. If fluid gets onto the gold mating pins on the head ("pogo pins") causing shorts, this can also result in damage to the instrument.

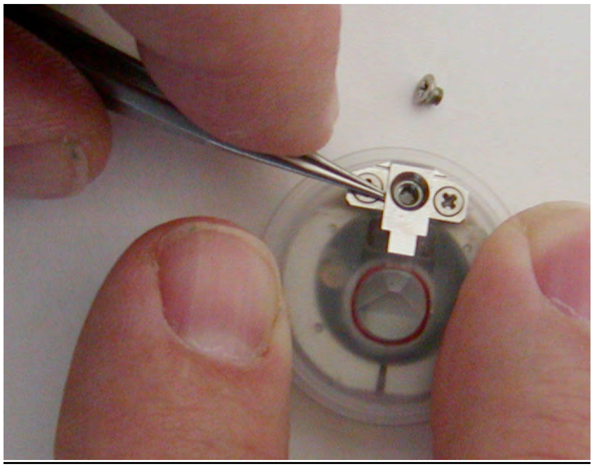
If you suspect that a fluid spill has taken place, inspect the holder and the pogo pins on the head for signs of corrosion.

Tight Spring Clip

If Si cantilevers are used exclusively for a significant period of time, it is common that SiN substrates will no longer fit under the cantilever clip. The clip does not spring back up far enough to accommodate the thicker SiN substrates.

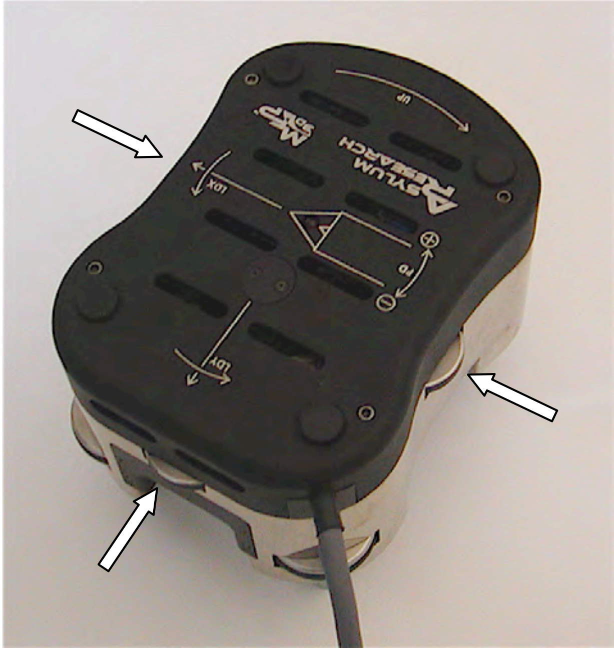
To refresh the spring:

- Remove the cantilever clip screw.
- Slide tweezers (or another appropriately sized tool) under the clip from the side, just in front of the screw hole. This will push up on the clip and refresh the spring.



- Replace the cantilever clip screw.

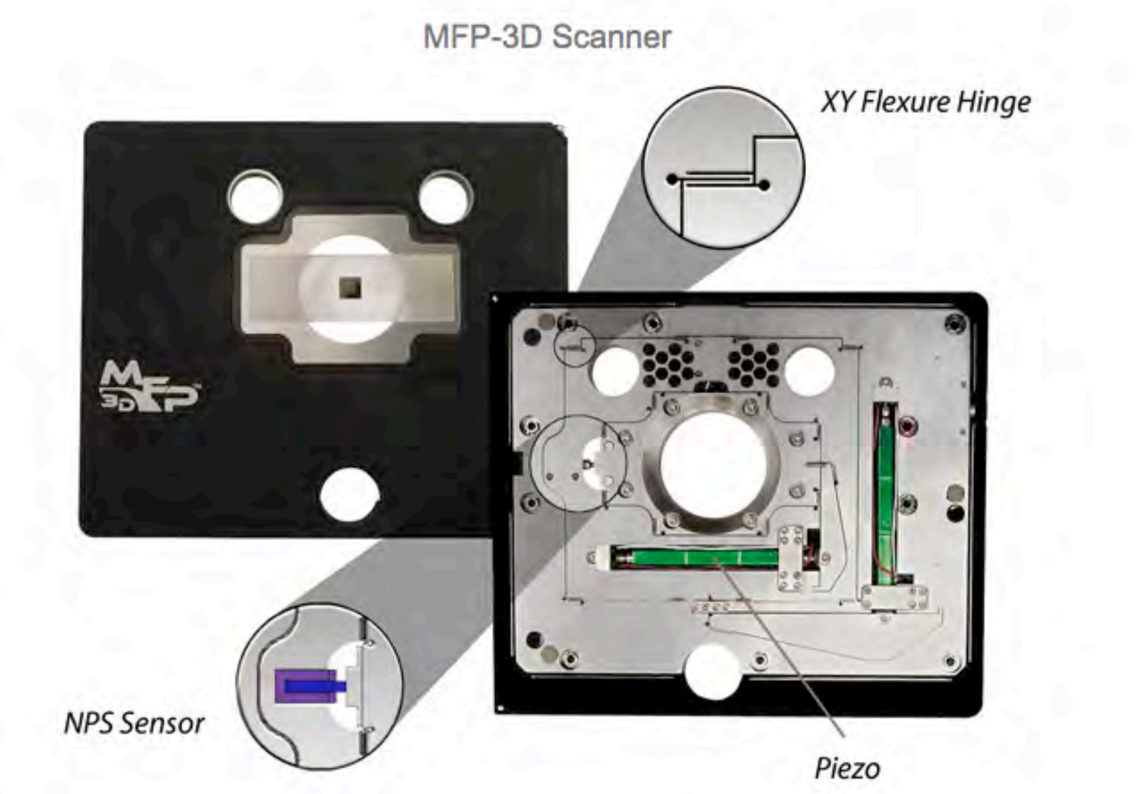
IV. Thumbwheels



There are 2 thumbwheels (LDX and LDY) on the head used to position the light source onto the cantilever. A third thumbwheel (PD) is used to move the photo diode to adjust the deflection signal.

Each thumbwheel turns a belt inside the head. As the thumbwheel turns, it is possible for the belt to slip and not rotate with the wheel. It feels like the thumbwheel stutters or slips as you rotate it. If this happens frequently enough either the light source cannot be moved in range of the cantilever or the photodiode cannot be aligned. If you think this has happened, call the factory for assistance.

The Scanner



I. Introduction

The scanner is responsible for moving the stage and sample in x and y (in-plane with the sample). Applying voltage to two piezo stacks inside the scanner, one for x and one for y, generates the motion. NPS LVDT sensors measure the resulting x and y position and feedback that information to more accurately move the piezos. Thus the scan motion and the xy data in any image rely on the proper functioning and accurate calibration of the sensors, piezos, and their assemblies. Checking the performance and updating the calibration of the sensors and piezos are the predominant maintenance/troubleshooting done on the scanner. The scanner houses sensitive electronics, so it is important that fluid spills are dealt with appropriately and fluid does not make it inside the scanner causing a piezo short. Finally, the stage plate on which the sample sits can be changed for application specific models.

II. Performance and Calibration

The performance and calibration of the xy scanner is set at the factory and checked again at installation. The sensitivities of the xy sensors (also called LVDT) rarely change over time. The sensitivities of the piezos do change with time, but as the system runs in xy closed loop the piezo calibration does not need to be very accurate to achieve accurate scanning. If you do however experience scan related problems or need to verify scanner performance/calibration, this section serves as a guide. Further troubleshooting should be done with support from the factory.

Possible scan related problems:

- No visible signs of scanning in the video system after engage
- Distorted/elongated features along edge of scan on a known sample
- Asymmetric scan range

The scanner and the XY LVDT board are calibrated together as a matched set. The scanner should only be used on the MFP-3D system for which it is calibrated.
The XY LVDT board is located in the base where the scanner and controller cables connect. If it is necessary to send the scanner to the factory, the XY LVDT board must accompany it (see Removing XY LVDT Board in the Base section of this chapter).

<u>How to check and maintain the performance of the xy scanner:</u>

Recommended every 6 months or if you have any scan movement problems.

1. Check xy sensor range.
    b. If does not pass, contact factory.
2. Check scanner hysteresis.
    c. If does not pass, check xy sensor calibration then contact the factory.
3. Check xy sensor calibration.
    d. If needed, calibrate xy sensors.
4. Check scan range.
    e. If needed, set xy sensor offsets.
5. If desired, calibrate xy piezos.
6. Check xy sensor noise.

f. If does not pass, contact factory.

For all procedures, first read through the relevant Test Panel section to become familiar with the parameters and functions used in the instructions.

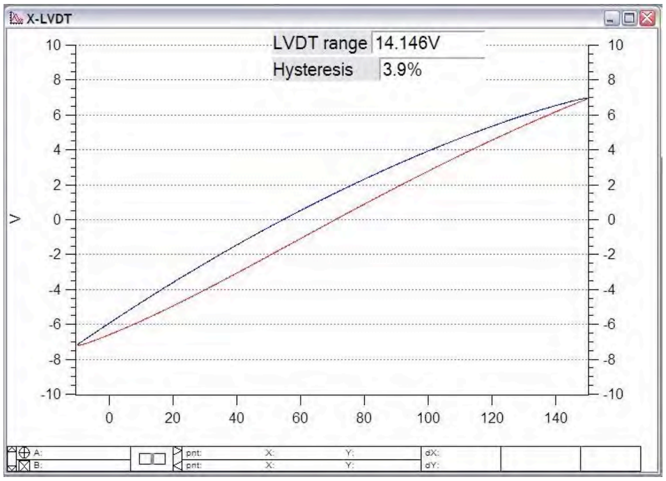
XY Sensor Range

This procedure measures the voltage of the x and y sensors while the piezos are exercised in open loop through their full range. The measurement is done off the surface; no tip or sample is required. The range and endpoints of the sensor data are verified.

- Open the Test Panel and select the Calibrate tab.

Channel: X-axis
Action: Drive
X Start: -10.0V
Range: 160.0V
Freq: 1.0Hz
Y Start: 70.0V
Diff A: 0
Phase: 180.00°

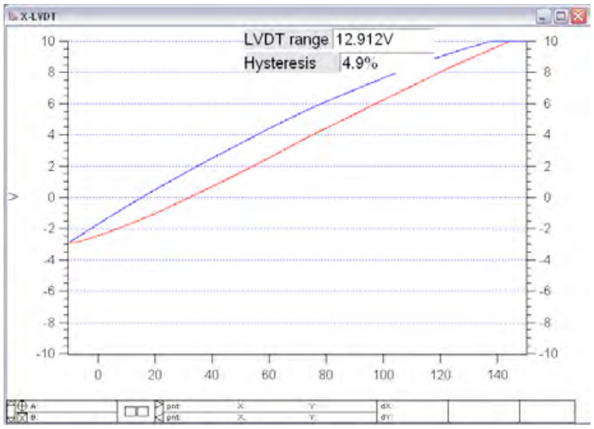
- Set the parameters as follows:
    - Channel = X-axis
    - Action = Drive
    - X Start = -10 V
    - Range = 160 V
    - Frequency = 1 Hz
    - Y Start = 70 V
    - ***Do not change Diff A and Phase!*** They are set at the factory and should not to be changed by the customer.
- Click Start.
- A graph of the sensor (LVDT) voltage vs. piezo drive voltage appears.



LVDT range 14.146V

Hysteresis 3.9%

- Results:
  - The LVDT range is ideally 14 V. If not between 13 and 15 V contact the factory.
  - The endpoints of the sensor range are ideally at +/- 7 V with the center at 0 V. It is common for the center to be off by a volt. If either endpoint is outside of +/-9 V, contact the factory.
    - Example of bad sensor range. The positive end is clipping at 10 V.



LVDT range 12.912V

Hysteresis 4.9%

  - The Hysteresis should be 5% or less (a full hysteresis check, covered in its own section, is the best measure of scanner hysteresis).
- Repeat for the Y-axis (set Y Start = -10 V and X Start = 70 V).

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. 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.

- Open the Test Panel and select the Calibrate tab.

LVDT/ Piezo Calibration

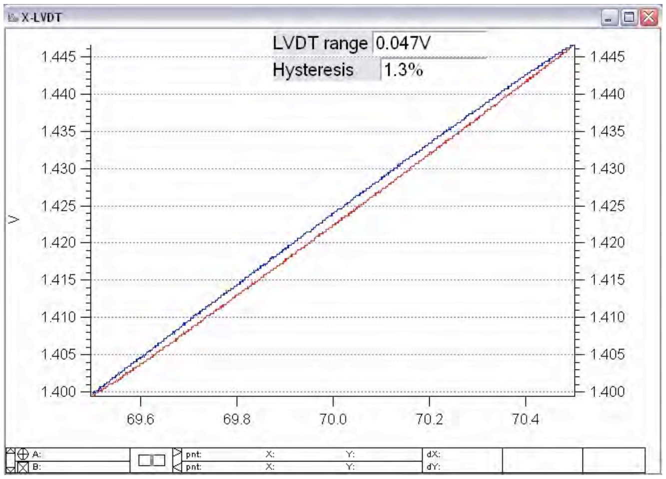
Channel X-axis

Action Measure Hyst.

Freq 1.0Hz Cycles 50

	160V	10V	1V
Hyst.	4.25%	3.66%	1.30%

- Set Channel to X-axis.
- Set Action to Measure Hysteresis.
- Set Frequency to 1 Hz.
- Set Cycles to 50.
- 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.



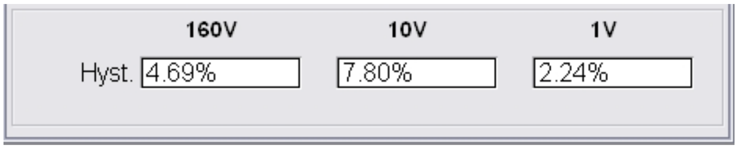
LVDT range 0.047V

Hysteresis 1.3%

- 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 turns back into Start. Note the three hysteresis values.
- Repeat for the Y-axis.

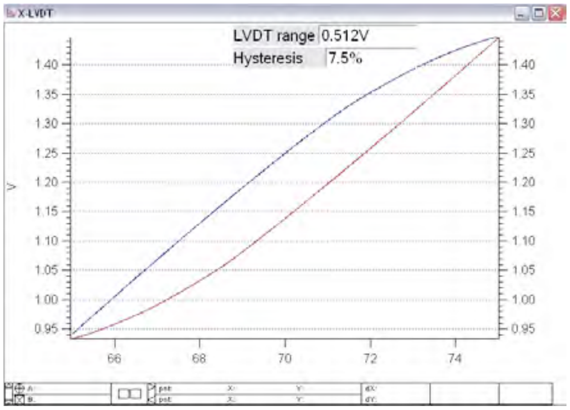
The hysteresis should be less than or equal to 5% for 160 V, 4% for 10 V, and 3% for 1 V for both x and y. It is typical for y to have larger hysteresis than x due to the greater mass the y scanner moves.

The most common result for a bad scanner is that the 160 V range is acceptable while the 10 V range, and sometimes the 1 V, are much higher than spec.



	160V	10V	1V
Hyst.	4.69%	7.80%	2.24%

Example of bad hysteresis values.



LVDT range 0.512V

Hysteresis 7.5%

Example of bad hysteresis plot for the 10 V range.

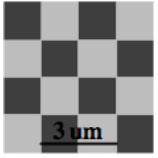
If the hysteresis is above spec, the moving component of the scanner is likely rubbing against the housing or has some other mechanical restriction. Contact the factory for assistance.

XY Sensor Calibration

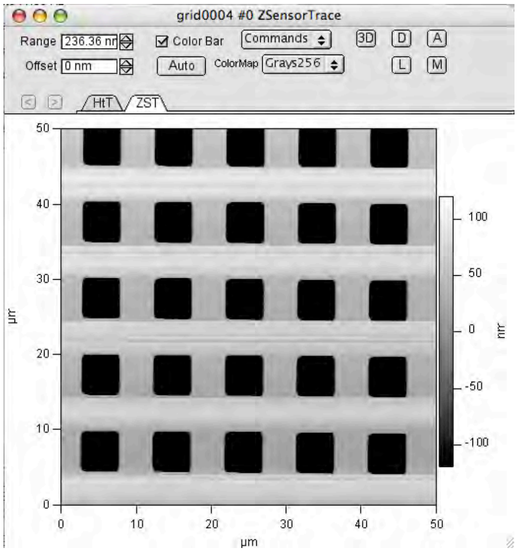
1) Check the XY Sensor Calibration

This procedure checks the calibration of the X and Y Sensors (LVDT) to within the accuracy of the standard calibration sample. The calibration sample is scanned in contact mode. The pitch of the grid is measured on sections through the Z Sensor data.

- Align the 10 x 10 um calibration sample on the stage plate so the grid is orthogonal with the scan axes.
    - Note: Early systems shipped with a 3 x 3 um standard. Under an optical microscope or in the AFM scan it has a checkerboard pattern.



  - If you have the 3 x 3 standard, it is recommended that a new 10 x 10 um standard be purchased.
- Engage in contact mode.
- Set Scan Size to 50 um.
- Set Scan Angle to 0°.
- Set Scan Rate to 1 Hz.
- Set Scan Points and Lines to 512.
- Monitor the Z Sensor signal on one of the channels.
- Adjust feedback (Set Point, Gains) as needed to get good tracking of the sample.



grid0004 #0 ZSensorTrace

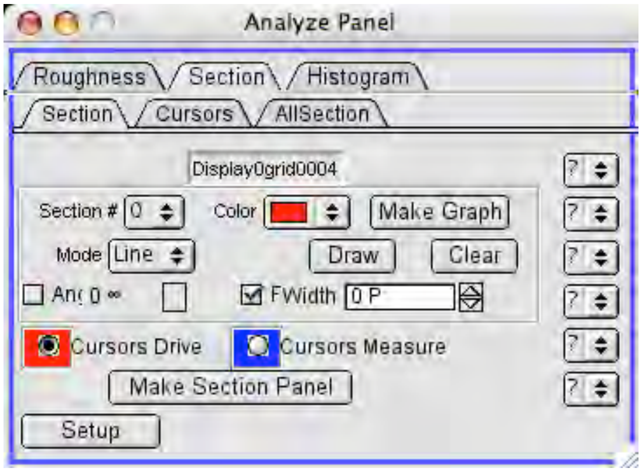
Range 236.36 nm

Offset 0 nm

☑ Color Bar

ColorMap Grays256

- Save an image.
- Make pitch measurement:
  - Open the saved image.
  - (Optional) Flatten image. This is helpful but not necessary for the analysis.
  - From the MFP IP menu select Analyze Panel or click on the ‘A’ above the image.
  - Select the Section tab.



Display0grid0004

Section # 0

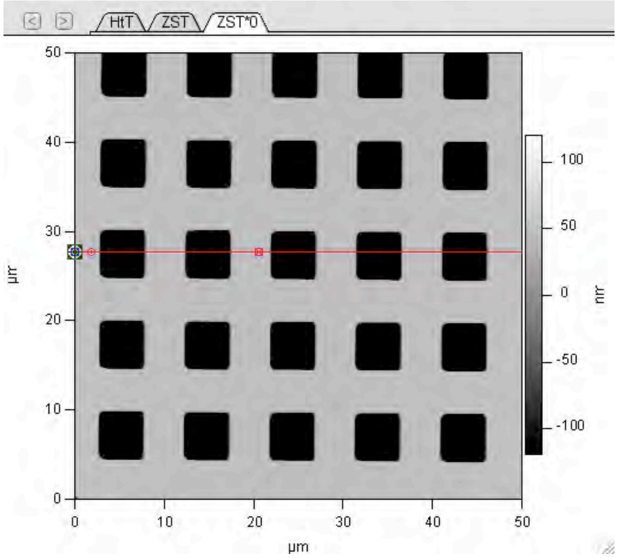
Color

Mode Line

☐ Ang 0 ∞

☑ FWidth 0 P

- ○ Select Cursors Measure button.
- ○ Click the Draw button.
- ○ Draw a horizontal line through the center of a row of pits:
  - ▪ On image, click and hold on the first point to define line.
  - ▪ Drag and release on second point to define line.



  - ▪ To redo the line, click the Clear button and then the Draw button to start over.
  - ▪ To adjust the line, select the Cursors Drive button. On the image, drag either cursor on the line (circle or square) to adjust that defining point. When finished, select Cursors Measure button.
- ○ On the Section graph that appears, click & drag on cursors A and B to move them onto two leading (or falling) edges of the pits furthest apart. Make sure *not* to use one leading and one falling edge. Put the cursors as close to the same height, relative to the top of the step, as possible.

Set Cursors grid0004_ZSTm0000
RotateSection _error_

A : grid0004_ZSTm0000 pnt : 29 X : 2.8376e-06 Y : -1.1771e-08 ΔX : 3.8356e-05
B : grid0004_ZSTm0000 pnt : 421 X : 4.1194e-05 Y : -3.262e-08 ΔY : -2.085e-08

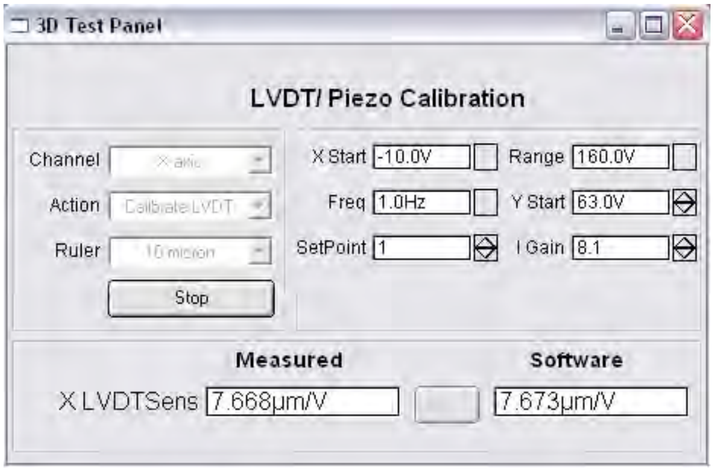
- Result: The x pitch is ΔX/(# of pits). In this in this example:

  x pitch = 38.356 um/4 = 9.59 um
- Repeat the analysis for the y pitch by drawing a vertical line through the center of a column of pits. The y pitch is ΔX/(# of pits).
- If either the x or y pitch of the grid is not within +/-1% of 10 um follow the sensor calibration procedure below.

2) Calibrate the XY Sensors

This procedure calibrates the X and Y Sensors using the standard calibration sample. The tip is engaged in contact mode and an automated routine performs the measurement.

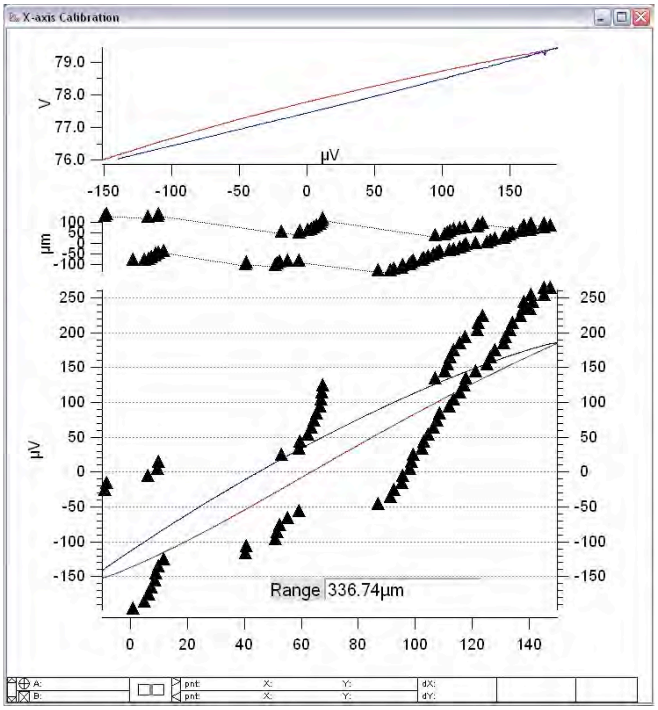
- Align the 10 x 10 um calibration sample on the stage plate so the grid is orthogonal with the scan axes.
- Engage in contact mode.
- Open the 3D Test Panel and select the Calibrate tab.



Channel X-axis
Action Calibrate LVDT
Ruler 10 micron
X Start -10.0V
Range 160.0V
Freq 1.0Hz
Y Start 63.0V
SetPoint 1
I Gain 8.1
X LVDTSens Measured 7.668µm/V Software 7.673µm/V

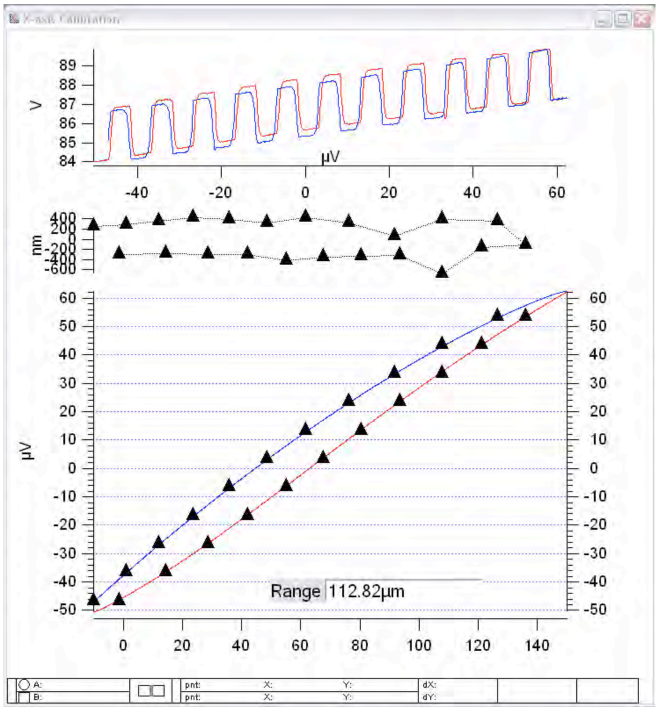
- Set the parameters as follows:
  - Channel to X-axis
  - Action to Calibrate LVDT

    - Ruler to 10 micron
    - X Start = -10 V
    - Range = 160 V
    - Frequency = 1 Hz
    - Y Start = 70 V
- Click Start.
- A window with three plots appears.



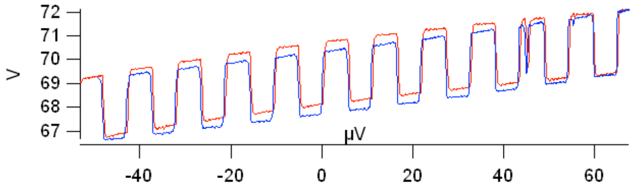
Range 336.74µm

- Adjust Y Start until the scan line (top plot) occurs over a row of pits, if it is not already.
- Adjust the SetPoint and I Gain as needed to get good tracking of the pits.



Range 112.82µm

- Once you are successfully scanning over a row of pits, the measured X sensor sensitivity in the test panel should be correct.
  - The calibration of the sensors changes very little over time so the new Measured sensitivity should be very close to the old Software value. If the values are not within 2% contact the factory.
  - Be careful to avoid dirty or scratched/deformed pits. Any irregularity in the pits will throw the measurement off. If in doubt, move to a cleaner area of the sample. For example, the scratch below changed the measured sensitivity by 8%.

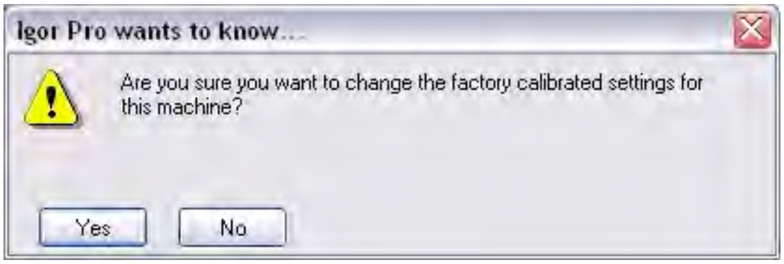


- Click Stop.
- Click the arrow button to move the measured sensitivity into software memory.
  -->
- Change the channel to Y-axis and repeat the measurement.
  - Make sure to change Y Start to –10 V and X Start to 70 V.

WARNING!!

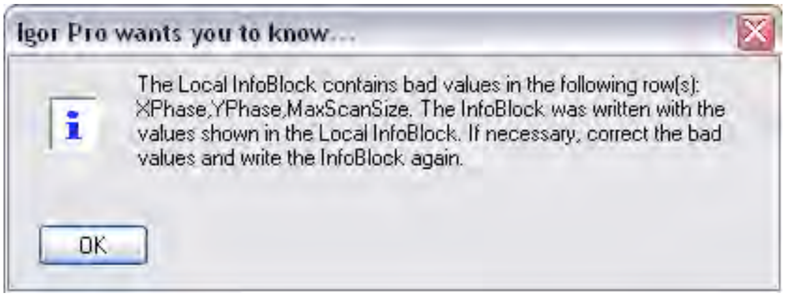
Changing values in Info Block causes permanent changes to the hardware calibration. Only make changes specifically detailed here and only do so once you are confident of your work. Other changes can cause physical damage to the system.

- To write the new sensitivities to the Scanner hardware:
  - Select the Info Blocks tab.
  - Set Device to Scanner.
  - For Action, select Local <- Software. If Action is already set to Local <- Software, you must reselect it. Confirm that the X and Y LVDT Sensitivity values are now the same for both Local InfoBlock and Software.
  - Change Action to Write InfoBlock.
    - Select Yes on the warning dialog to continue.



Are you sure you want to change the factory calibrated settings for this machine?

    - Select OK on the error dialog to continue.



The Local InfoBlock contains bad values in the following row(s): XPhase,YPhase,MaxScanSize. The InfoBlock was written with the values shown in the Local InfoBlock. If necessary, correct the bad values and write the InfoBlock again.

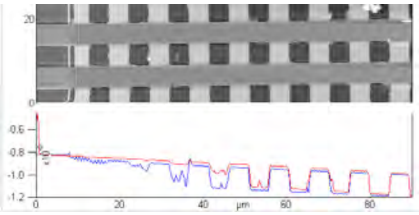
  - Reselect Action to Write InfoBlock
    - Select Yes on the warning dialog (same as above) to make the change final.
    - A success dialog will appear.
    - Verify the change by checking the new sensitivities appear in both Local InfoBlock and Software.

Scan Range

This procedure checks that the scanner is functioning across 90 um of range. The calibration sample is scanned in contact mode. The image is evaluated for correct scan behavior.

- Align the 10 x 10 um calibration sample on the stage plate so the grid is orthogonal with the scan axes.

- Engage in contact mode.
- Set Scan Size to 90 um.
- Set Scan Angle to 0°.
- Set Scan Rate to 1 Hz.
- Set Scan Points and Lines to 512.
- Monitor the Z Sensor signal on one of the channels.
- Adjust feedback (Set Point, Gains) as needed to get good tracking of the sample.
- Collect a full image.
- Evaluate the image for correct scanning over the full 90 um range in both x and y.
    - Pits should be square and evenly spaced across the entire image.
    - If the pits or the spaces in between are elongated near the edge of the image, then the scan range is limited in that direction. The scan pictured here has a problem in the X direction along the left edge.

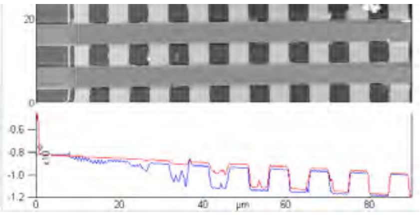


    - If the scan does not have full range in any direction, follow the procedure to set the xy sensor offsets.
        - If this does not solve the issue, contact the factory.

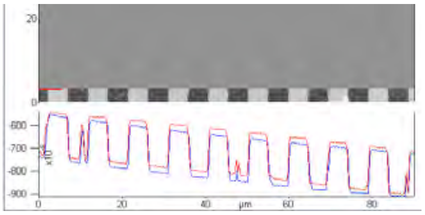
XY Sensor (LVDT) Offsets

This routine finds the x and y sensor voltages (offsets) that correspond to the center position of the xy piezo range. Over time the mechanical center position of the piezos shifts due to stresses in the system. If the mismatch between the centers of the piezo and sensor ranges becomes too large, the feedback loop will not work correctly near the edge of the range and large scan sizes will be clipped. To correct this, an offset is applied to the set point of the xy position feedback loop corresponding to the x and y sensor offsets. These offsets need to be periodically updated.

Example: Before updating the xy sensor offsets, the scan range was clipped along the left edge.

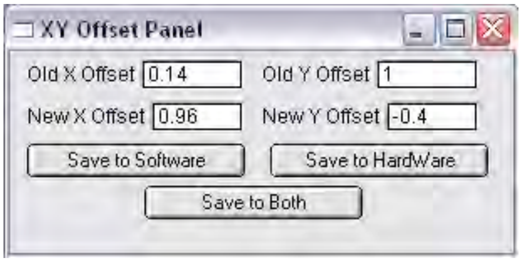


Before offset calibration



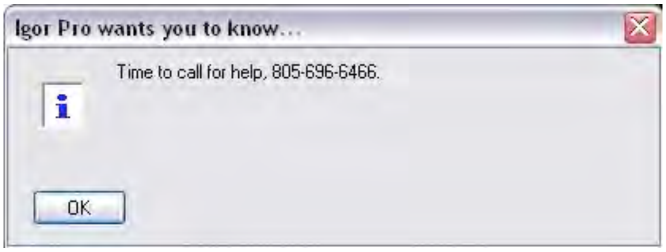
After offset calibration

- From the Programming menu, select Calibrate XY LVDT Offsets.
    - The scanner moves in circles at the edge of its range (the x and y piezos are ramped through their full range, -10 to 150 V) while the LVDT sensors are monitored. This takes about twenty seconds. From this motion, the center of the x and y piezo range is deduced and the sensor offset is determined.
- When the routine is complete, a window appears with the old and new offset values.



Old X Offset 0.14
Old Y Offset 1
New X Offset 0.96
New Y Offset -0.4

- Hit the Save to Both button and close the window.
    - Occasionally an error message may appear when saving the new Offsets.



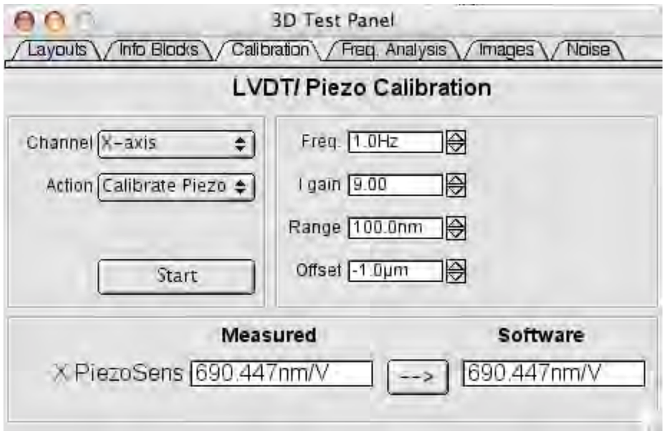
Time to call for help, 805-696-6466.

-
    - If you get this message, it is not necessary to call the factory. Open the Info Blocks panel in the Test Panel. Set Device to Scanner. Select Action to Write InfoBlock (if it is already set to Write InfoBlock you must reselect it). Now the new Offsets should be saved.

XY Piezo Calibration

Since the MFP-3D runs in xy closed loop, it is not necessary to have an accurate xy piezo calibration and this is not a required procedure.

This procedure calibrates the xy piezos relative to the xy sensors. The measurement is done off the surface; no tip or sample is required. The piezo is in closed loop feedback from the sensor. The piezo is extended to the middle of its range and driven through 100 nm of motion as seen by the sensor. The piezo sensitivy is calculated from the drive voltage required for the excursion.

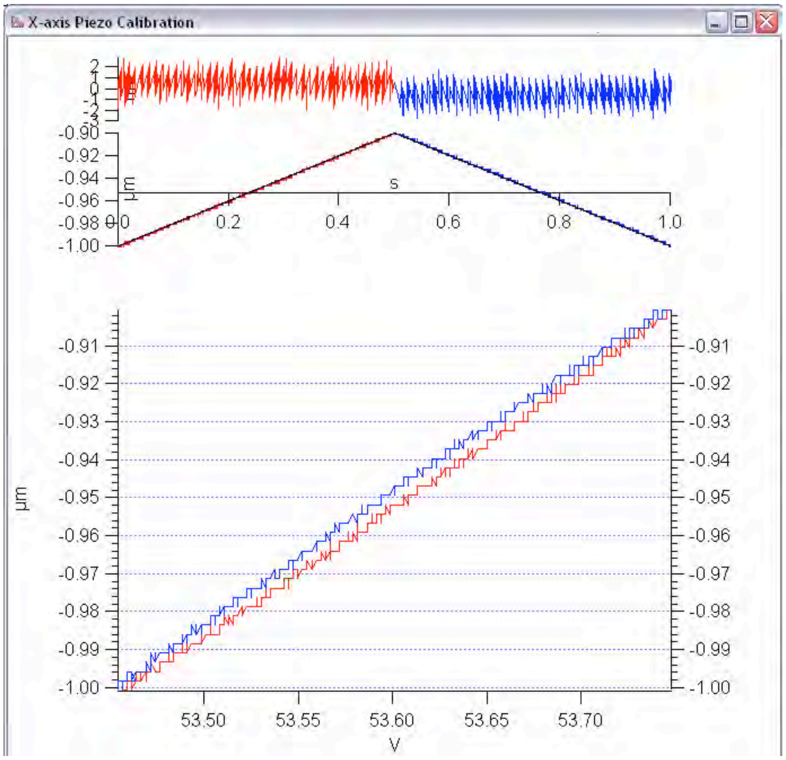


LVDT/ Piezo Calibration

Channel X-axis
Action Calibrate Piezo
Freq. 1.0Hz
I gain 9.00
Range 100.0nm
Offset -1.0μm

	Measured	Software
X PiezoSens	690.447nm/V	690.447nm/V

- Open the Test Panel and select the Calibration tab.
- Set parameters:
  - Channel to X-axis
  - Action to Calibrate Piezo
  - Frequency to 1 Hz
  - I gain is set at factory during full calibration. ***Do not change***!
  - Range to 100 nm
  - Offset to –1.0 um
- Click Start.
  - The piezo cycles through 100 nm excursions. A new X Piezo Sensitivity is measured each cycle. Allow the software to cycle the X piezo several times until the measured sensitivity stabilizes (~10 cycles).
- A graph window opens with 3 plots.
  - Top plot is the error signal.
  - Middle plot is X sensor vs. time.
  - Bottom plot is X Sensor vs. X Piezo voltage.
    - The X Piezo Sensitivity is the slope of this line.

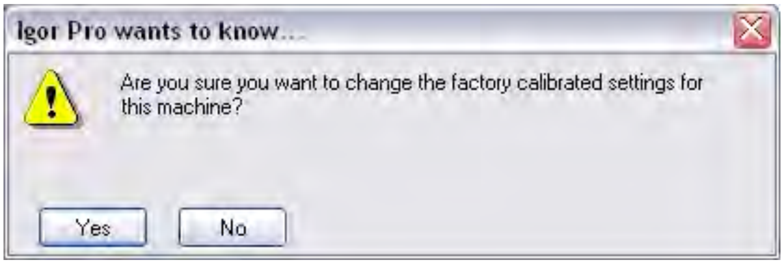


- Click Stop.
- Click the arrow button to move the measured sensitivity into software memory.
  -->
- Change Channel to Y-axis.
- Click Start.
  - Allow the software to cycle the Y piezo several times until the measured sensitivity stabilizes.
- Click Stop.
- Click the arrow button to move the measured sensitivity into software memory.

WARNING!!

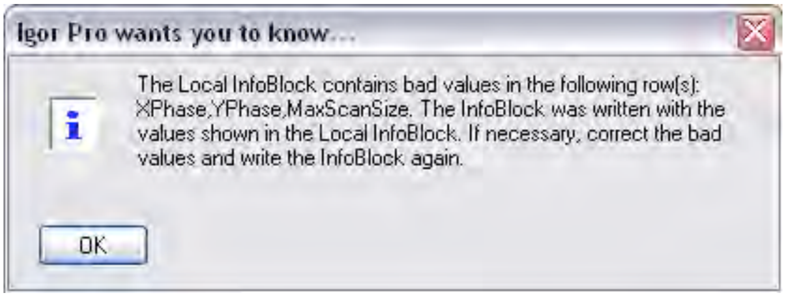
Changing values in Info Block causes permanent changes to the hardware calibration. Only make changes specifically detailed here and only do so once you are confident of your work. Other changes can cause physical damage to the system.

- To write the new sensitivities to the Scanner hardware:
  - Select the Info Blocks tab.
  - Set Device to Scanner.
  - For Action, select Local <- Software. If Action is already set to Local <- Software, you must reselect it. Confirm that the X and Y Piezo Sensitivity values are now the same for both Local InfoBlock and Software.
  - Change Action to Write InfoBlock.
    - Select Yes on the warning dialog to continue.



Are you sure you want to change the factory calibrated settings for this machine?

    - Select OK on the error dialog to continue.

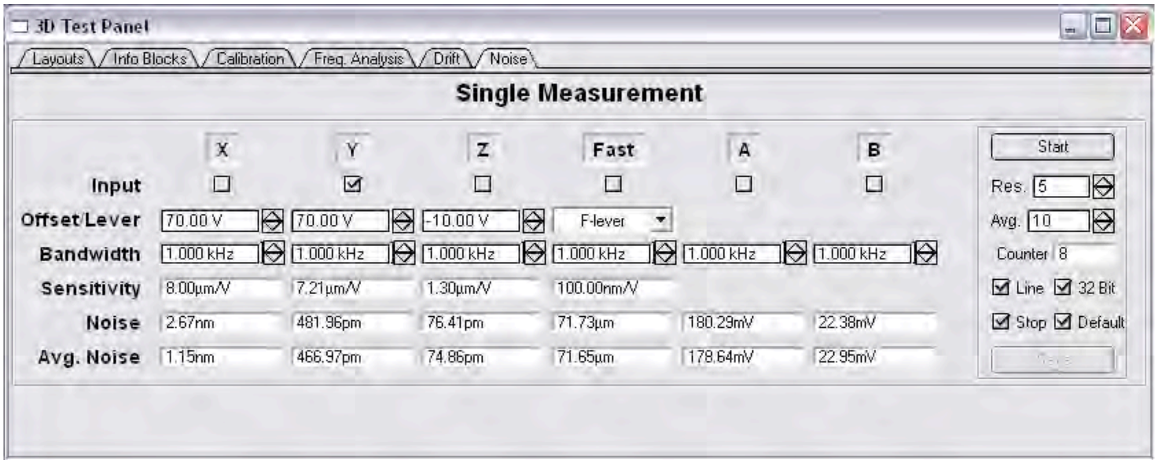


The Local InfoBlock contains bad values in the following row(s): XPhase,YPhase,MaxScanSize. The InfoBlock was written with the values shown in the Local InfoBlock. If necessary, correct the bad values and write the InfoBlock again.

  - Reselect Action to Write InfoBlock
    - Select Yes on the warning dialog (same as above) to make the change final.
    - A success dialog will appear.
    - Verify the change by checking the new sensitivities appear in both Local InfoBlock and Software.

XY Sensor Noise

This procedure measures the noise of the x and y sensors. The measurement is done off the surface; no tip or sample is required. The x or y piezo is held still near the middle of its range (by applying a constant 70 V) while the sensor data is monitored. The piezo is in open loop (no feedback from the sensor).

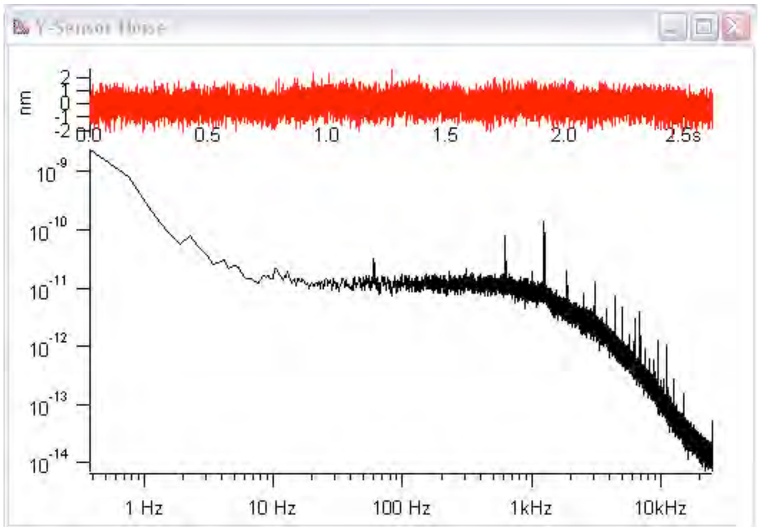


Single Measurement

	X	Y	Z	Fast	A	B
Input	☐	☑	☐	☐	☐	☐
Offset/Lever	70.00 V	70.00 V	-10.00 V	F-lever		
Bandwidth	1.000 kHz	1.000 kHz	1.000 kHz	1.000 kHz	1.000 kHz	1.000 kHz
Sensitivity	8.00µm/V	7.21µm/V	1.30µm/V	100.00nm/V		
Noise	2.67nm	481.96pm	76.41pm	71.73µm	180.29mV	22.38mV
Avg. Noise	1.15nm	466.97pm	74.86pm	71.65µm	178.64mV	22.95mV

Res. 5
Avg. 10
Counter 8
☑ Line ☑ 32 Bit
☑ Stop ☑ Default

- Open the Test Panel and select the Noise tab.
- Set the parameters up as follows:
  - Input to Y
  - Y Offset to 70V
  - Y Bandwidth to 1.0 kHz
  - Res. to 5
  - Avg. to 10
  - Verify Line, 32 Bit, Stop, and Default options are selected
- Click Start.
- A window with 2 graphs will appear.



The top red plot is the Y sensor signal versus time for the last data set.

The bottom black plot is the average PSD of all the Y sensor data collected so far in the experiment.

- Watch the Noise value for Y. Once it stabilizes, restart the measurement (Hit Stop and then Start)
  - When the 70 V offset is applied, the piezo position can creep for a short time. The creep will be seen as a bow or overall curve in the top plot and as a low frequency component in the PSD. This creep will throw the noise

measurement off and you must wait for it to settle out (~ 1 minute) before collecting the noise data.

- Once 10 data sets are complete, the experiment will automatically stop.
- The Average Noise for Y should be 600 pm or less (for this bandwidth of 0.1 Hz to 1 kHz).
- Repeat for X (set X offset to 70 V and Bandwidth to 1 kHz). The Average Noise for X should also be 600 pm or less.
- If either noise level is above spec, make sure that the isolation table is floating and the scanner is well insulated from other vibrations. If this does not bring the sensor noise below spec, contact the factory.

III. Fluid Spills

It is important to be careful when using fluids with the MFP-3D. The scanner houses sensitive electronics and is only water resistant, not waterproof, so fluid spills can short scanner circuitry. Spills can also contaminate internal scanner parts, building deposits or eroding components.

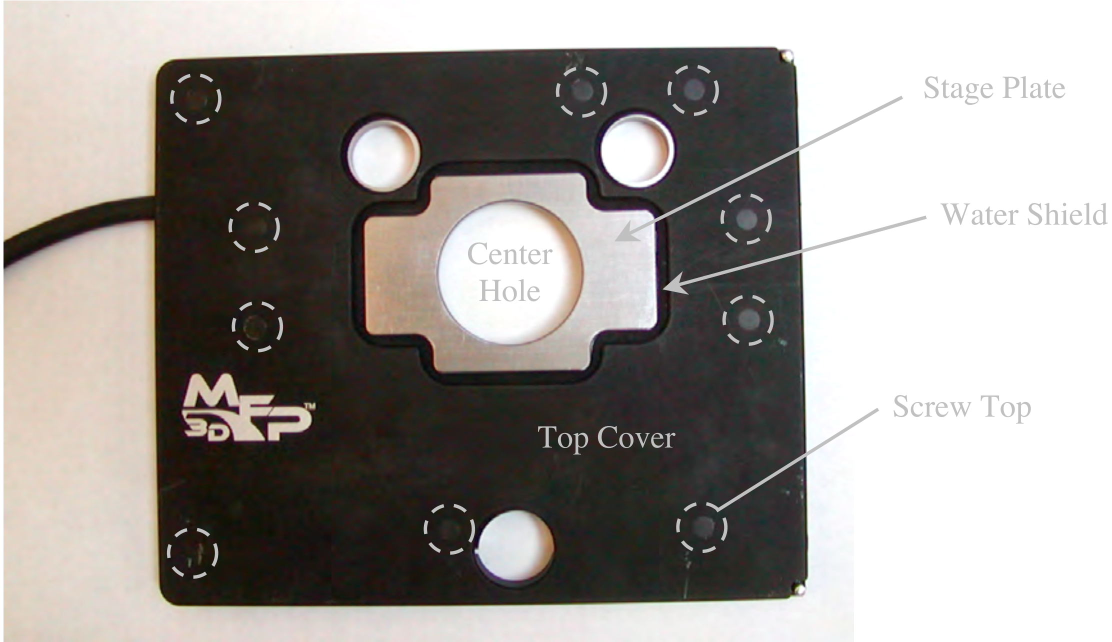
If a fluid spill does occur it should be dealt with immediately by blotting away all accessible fluid. The stage plate can be removed for cleaning (see Changing Stage Plate in Scanner section of this chapter). Do not disassemble the scanner. If further action is needed, contact the factory for support.

To avoid fluid leaks it is useful to understand what places on the scanner are most vulnerable.

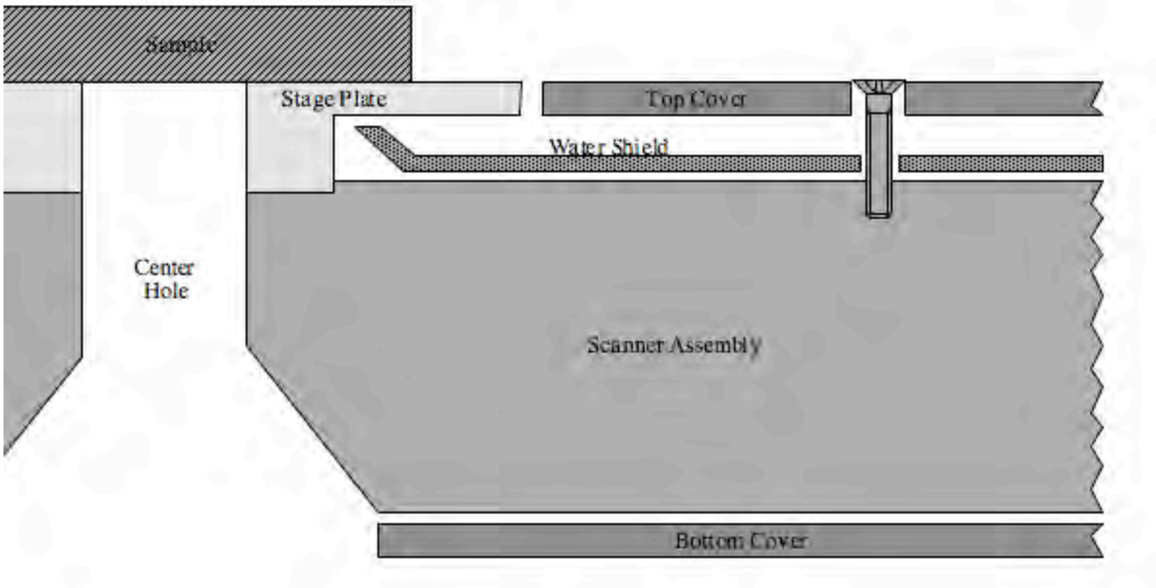
Common leak points:

- Gap between stage plate and top cover
- Around screw tops
- Through center hole

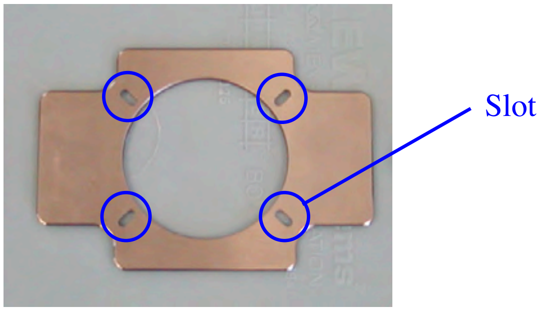
Scanner: Top View



Scanner: Side View Diagram (not to scale)

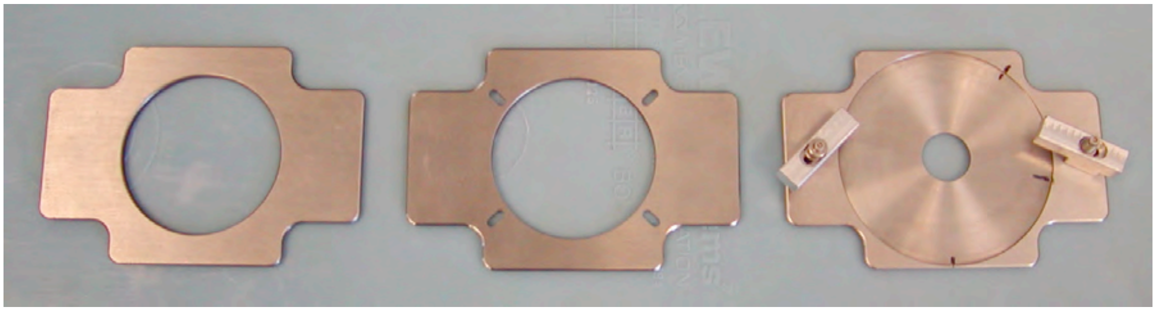


- The water shield provides a barrier for leak protection for the gap between the stage plate and top cover, but is not waterproof. The shield can only deal successfully with very small amounts of water.
- The tops of screws are common places for water to leak.
- Water can travel along the center hole walls and short the piezos. When blotting spills, get down into the hole alongside the objective. Do not remove the objective until you blot all accessible fluid.
- The special stage plate for the variable field magnet has slots in it that are also vulnerable to fluid spills.



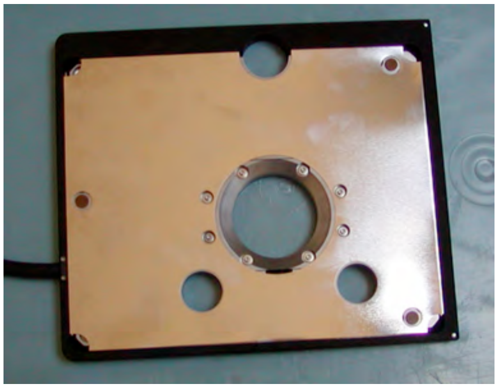
IV. Changing the Stage Plate

The stage plate may be removed for cleaning purposes (after a fluid spill or extended fluid use) or to change to another style of plate. There are currently 3 stage plates available - the standard, variable field magnet accessory, and Petri dish holder.


Standard Variable field magnet Petri dish holder


Top of scanner

These instructions are only good for the current model scanner. For the older model, call the factory for instructions. The four additional screws around the center hole on the new design distinguish the models.



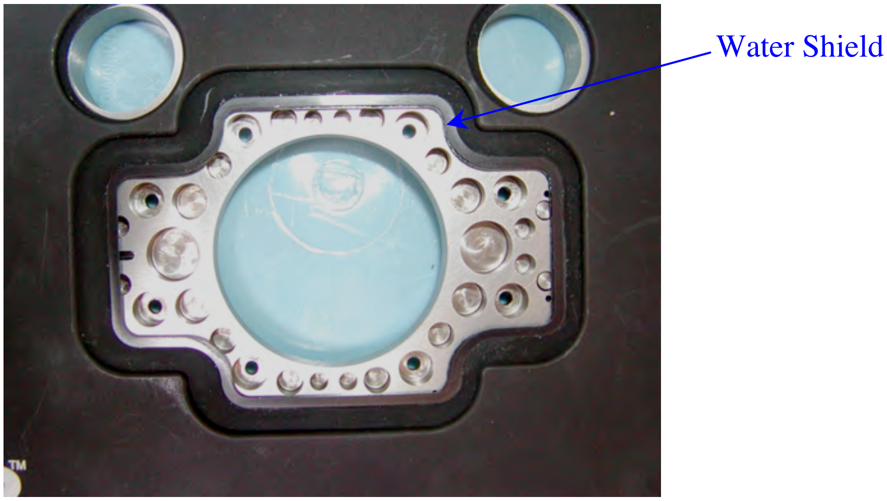
Bottom of current model scanner

Bottom of original model scanner

1. Run hysteresis tests for both x and y before changing anything! (See the Scanner Performance and Calibration section) Make note of the results.
2. Using 0.05" hex wrench, remove 8 screws from bottom plate: 4 in the chamfered wall of the center hole, 4 on the flat just outside the hole. Be careful not to lose screws and washers. Use tweezers to handle parts.

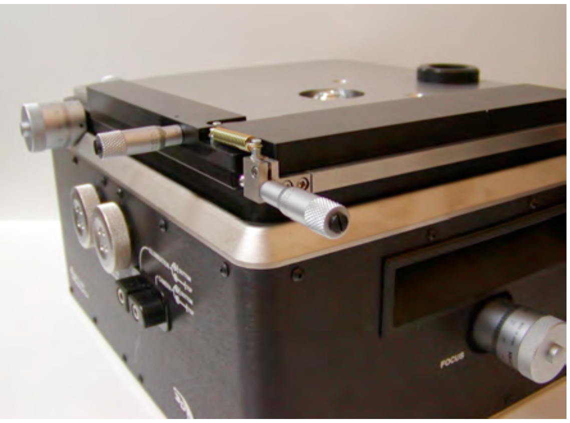
3. Flip scanner over and lift off stage plate.

4. Clean water shield and exposed stage part with cotton swab and alcohol as needed.



5. Place new stage plate upside down on working surface. Place scanner on top of stage plate (bottom of scanner facing upward) and slide around to visually center the 8 screw holes.
6. Reinstall screws. Start all 8 screws before tightening. Be careful not to over torque screws when tightening.
7. Run x and y hysteresis tests. If results have changed significantly from original values the stage plate is likely rubbing the water shield. If any of the three hysteresis values are higher by more than 5% of the original measured value then reposition the plate (repeat steps 2 – 6) and re-run hysteresis tests.

The Base



I. Introduction

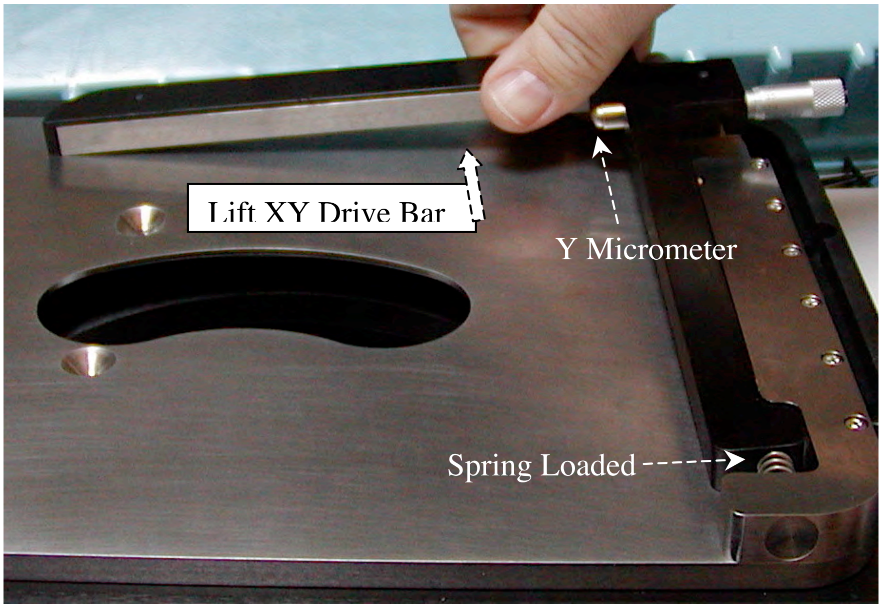
The base provides the physical platform for the AFM; both the scanner and head sit directly on it. The base mounts onto an inverted optical microscope (IO) or stands alone (SA), depending on your model. There are generally few things to maintain and troubleshoot in the base as it has only a small number of functions. It has a micrometer driven sample stage that allows for coarse adjustment of the sample relative to the head in x and y. If the sample translation becomes jerky parts may need cleaning or adjustment. Some SA bases have bottom view optics which require a special tool for changing the objective. Fluid spills should be dealt with appropriately if they occur. All bases contain the XY LVDT board, which must be removed and sent back with the scanner if the scanner needs repair.

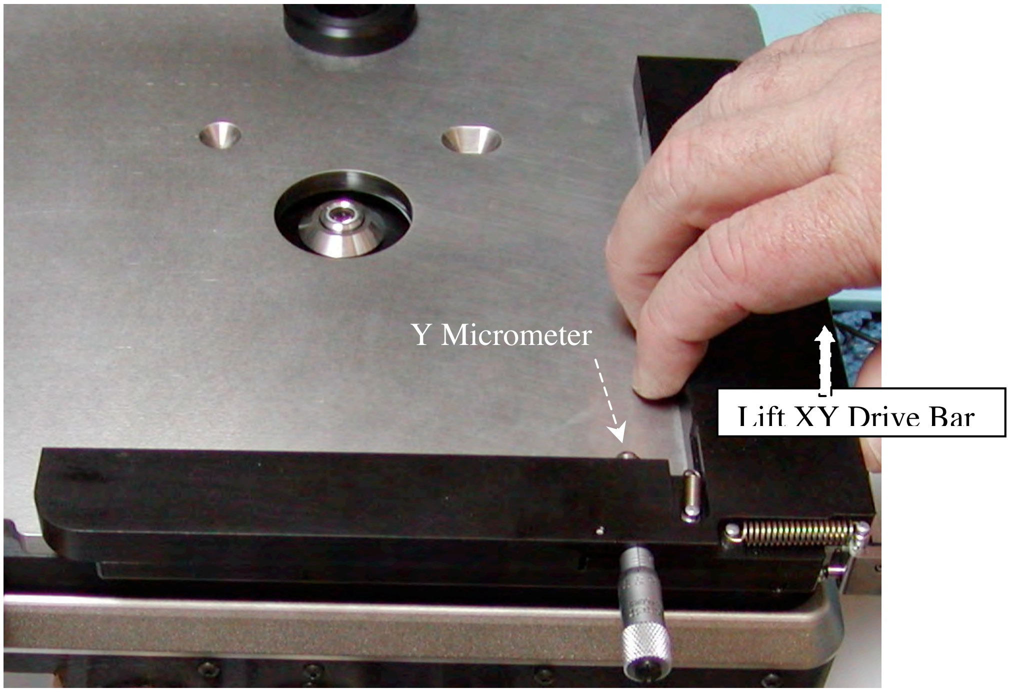
II. Jerky XY Sample Stage

If the XY sample stage has jerky motion, there are several possible causes. Start with the first action below and check to see if that solves the problem. If not, move on to the next possible solution in the list.

1. Lift off the scanner and clean the 3 brown Rulon (plastic) feet on the bottom of the scanner with alcohol. Clean the top of the base with alcohol.

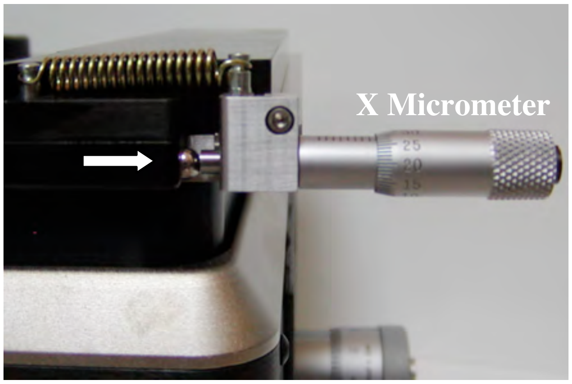
2. Remove the XY Drive Bar. It is held magnetically to the base and just lifts off. There are several models of drive bars; the two most common are shown below.

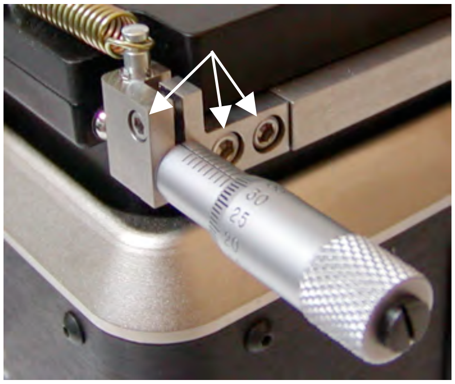




Clean all the brown Rulon (plastic) feet on the drive bar and the mating surfaces on the base with alcohol. Clean the end of the Y micrometer that pushes on the scanner.

3. Check the alignment of the X micrometer on the side of the base. The micrometer axis needs to line up with the centerline of the ball it is pushing on. Move the micrometer through its full range and make sure the ball stays lined up with the micrometer bar throughout. To adjust the alignment, loosen the three screws (do not remove) on the brackets, change the angle of the micrometer, and tighten screws.





4. Clean the mating surfaces of the ball and X micrometer driving bar. To access these surfaces, remove the xy driver bar (the ball is attached to the xy driver bar).

III. Changing the Objective

A special tool is supplied for changing the objective in stand alone bases with bottom view capability. The open end of the tool is tapered. Push it onto the objective until snug and then unscrew the lens.

IV. Fluid Spills

It is important to be careful when using fluids with the MFP-3D. Fluid spills on the base can allow liquid to get onto and around the objective of the bottom view optics in the SA model or onto the microscope lens in the IO model.

If a fluid spill does occur blot it immediately, getting paper towels down in alongside the objective. Do not remove the lens for cleaning until all accessible fluid has been blotted away.

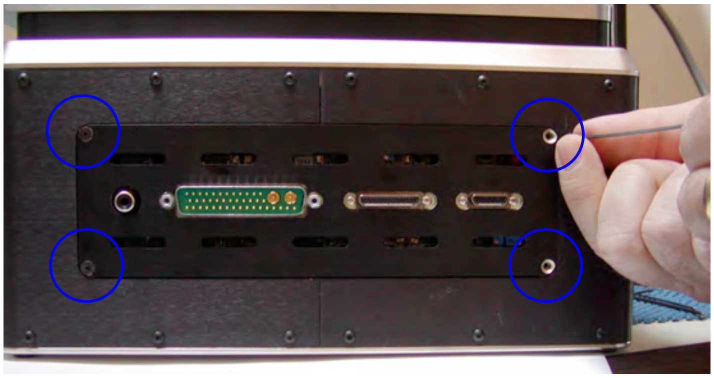
V. Removing the XY LVDT Board

The XY LVDT board routes signals to the head and scanner from the controller and vice versa. It is located in the base of the microscope. The board is calibrated to your specific scanner. If you need to send your scanner in for repair it is necessary to send the LVDT board with it. Following are instructions for disconnecting the LVDT board from the base.

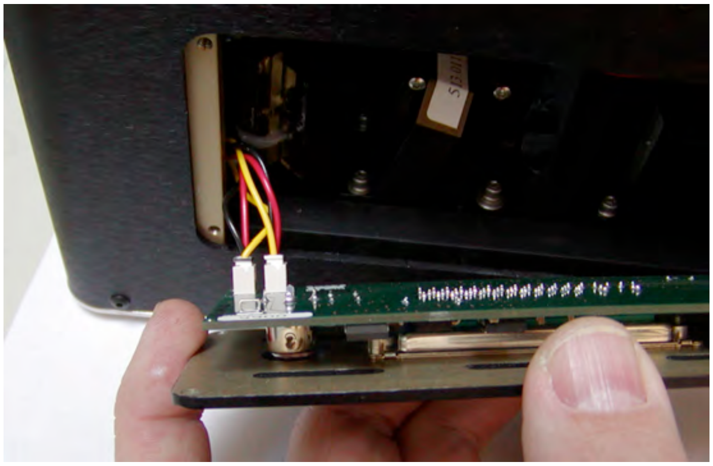
A. Unplug all external cables connected to the LVDT plate in microscope base.
B. Follow the instructions below for your model base to remove the LVDT plate/housing from the base.
C. Send back the plate/housing and LVDT board together; do not separate.

<u>Stand Alone Bases</u>:

1. Remove the 4 screws mounting the LVDT plate to base.



2. Gently pull the plate away from the base until you see the two video connectors plugged into the LVDT board.



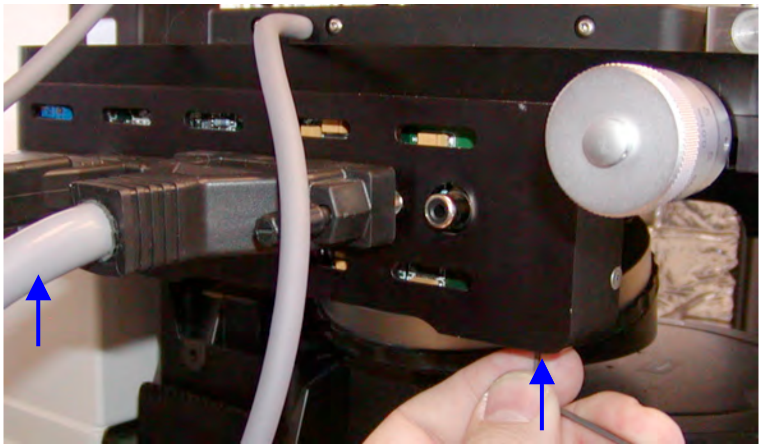
3. The high-mag optics plug has a black pen mark from assembly at the factory and the socket is labeled “high mag” on the board. If the mark is not visible or might rub off, color-code the connectors and sockets by marking with felt tip pens.
4. Unplug the connectors. They are snap-lock connectors so it takes significant force to unplug.

<u>Olympus IO Bases</u>:

1. Remove the 4 screws mounting the LVDT plate to base.

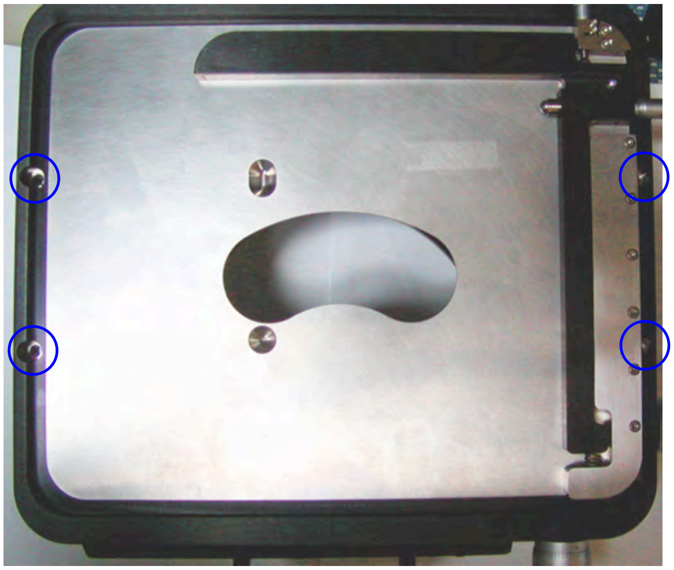
<u>Early Nikon or Zeiss IO Bases</u>:

1. Rubber feet cover the 2 screws mounting the LVDT housing to the base. Remove the rubber feet and then the screws. Pull the housing down away from base.

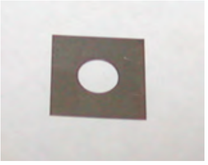


Current Nikon IO Bases:

1. Take the base off of the Nikon optical microscope.
    a. Unplug and remove the scanner and head.
    b. Remove 4 screws on top of base.

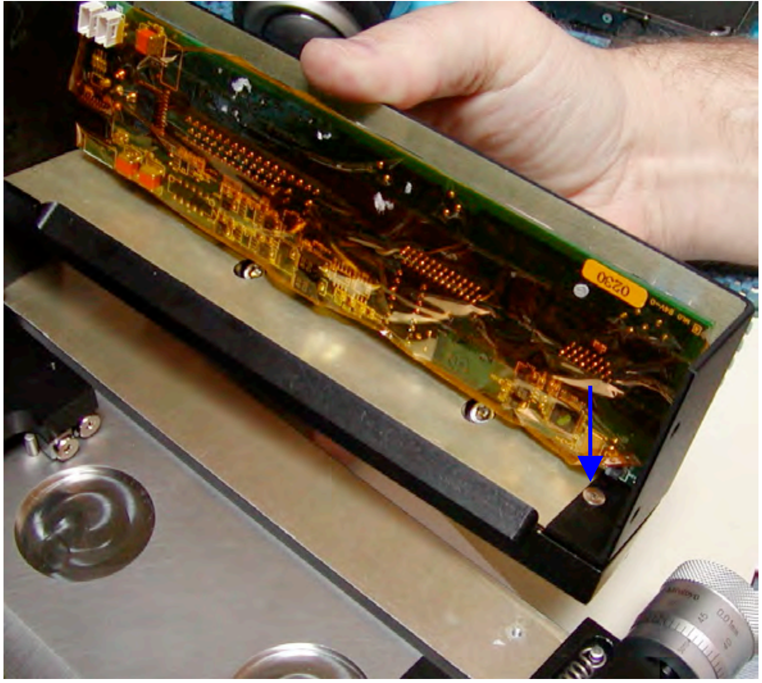


    c. Make sure to keep track of the shims around the screws on the underside of the base so they can be replaced upon reassembly.



2. Flip the base over.
3. Remove the 4 screws from the backside of the LVDT housing and lift off the housing cover plate.

4. Remove the screw inside the LVDT housing that attaches it to the base. Lift off the housing from base.

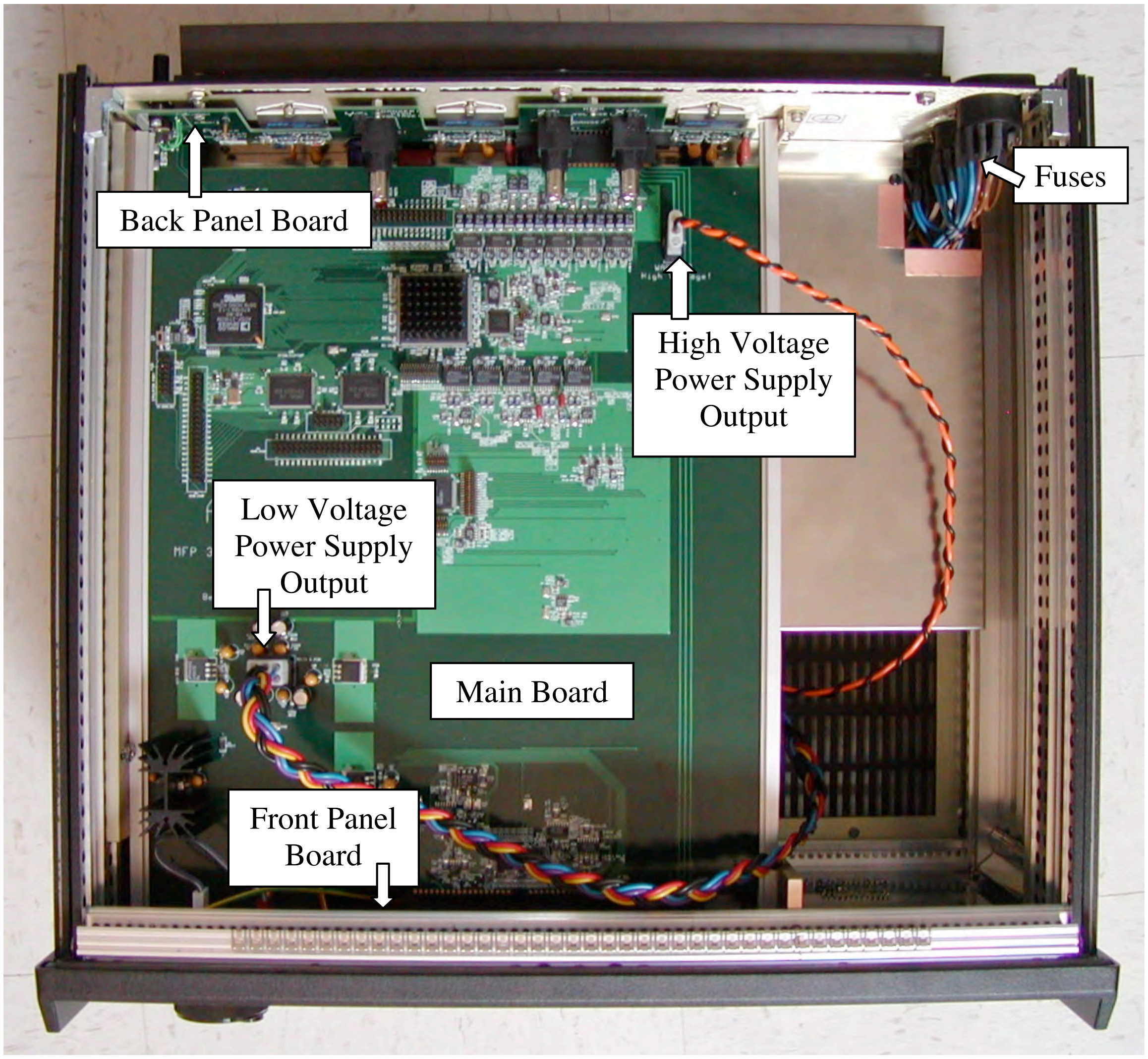


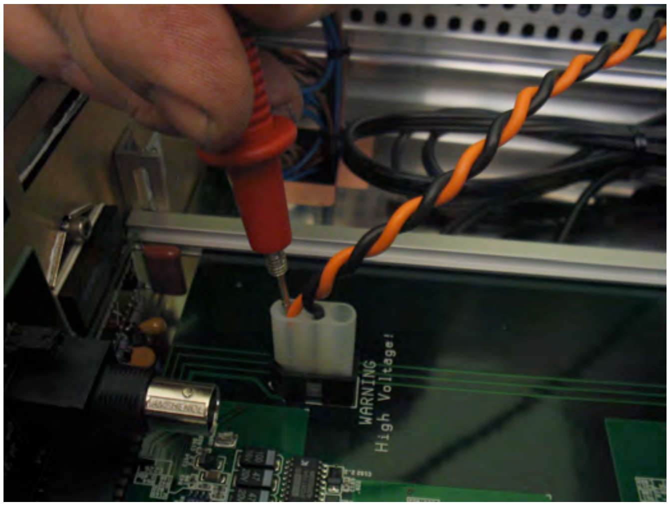
The Controller

MFP-3D Controller

I. Inside the Controller

The location of the boards, power supply outputs, and fuses in the controller are identified on the photo below.





To measure the power outputs, the probe from a voltmeter can be inserted into the plug at the base of the wire. Put the ground probe somewhere on the chassis with bare metal. *Do not put the ground probe into the plug!* It is easy to cross the probes and short the power to ground.

Use appropriate caution when measuring high voltage!

Low Voltage Lines:

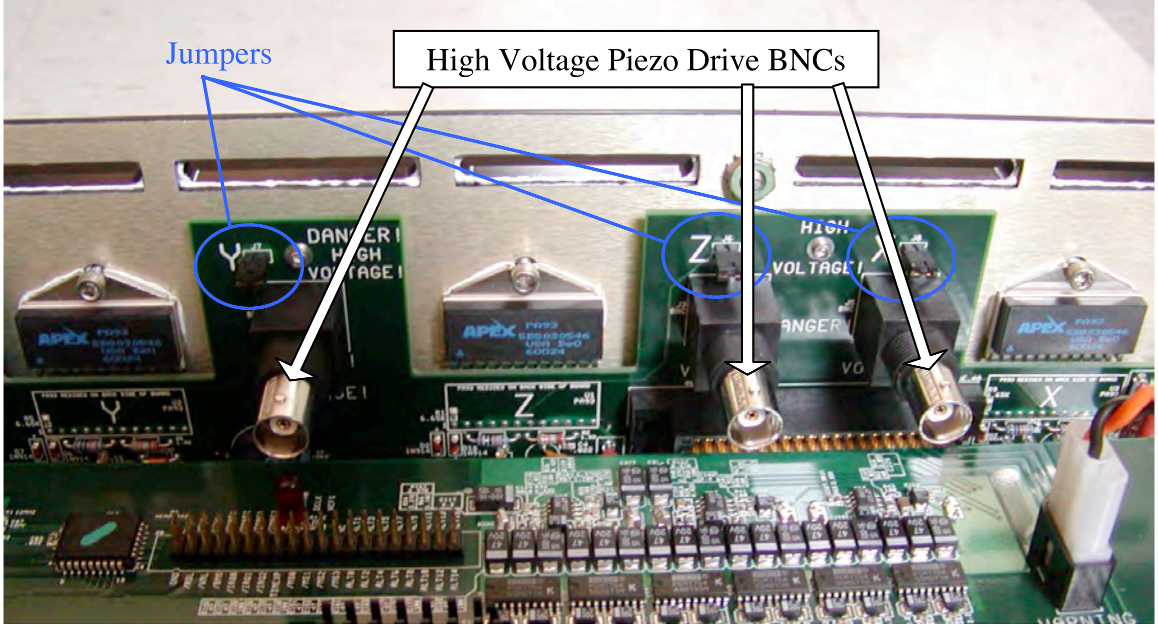
High Voltage Lines:

Yellow	+15VDC
Blue	–15 VDC
Red	+7VDC
Violet	–7 VDC
Blacks	ground

Orange	+165 VDC
Black	ground

There are three BNC connectors on the back panel board that allow the user to either measure or input to the high voltage piezo drives depending on the configuration of three jumpers (one for each axis).
With the jumpers installed (as shipped from the factory and shown below in the photo), the BNCs are outputs. If the jumpers are removed, the BNCs are inputs to the piezos.

Back Panel Board

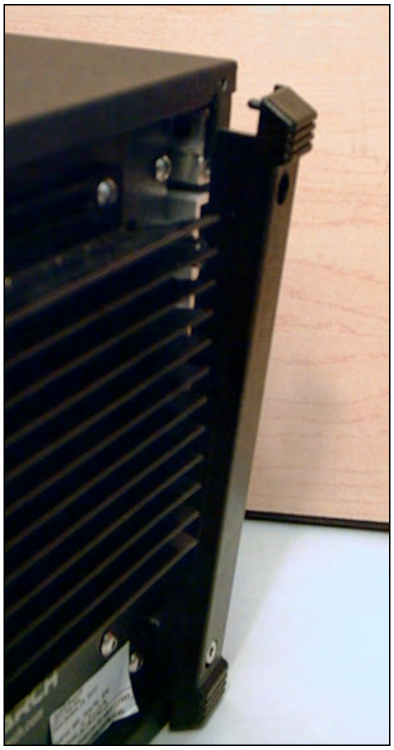


II. Removing the Top

Instructions for removing the top of the controller:

1. Locate the four screws on the back of the controller, as shown below. These are socket head cap screws which require a 3mm hex wrench.

2. Remove the two top screws.
3. Loosen, but do not fully remove the two bottom screws.
4. Tilt the tops of the plastic bezels away from the controller, as shown below.
5. Lift the lid of the controller from the back, as shown.

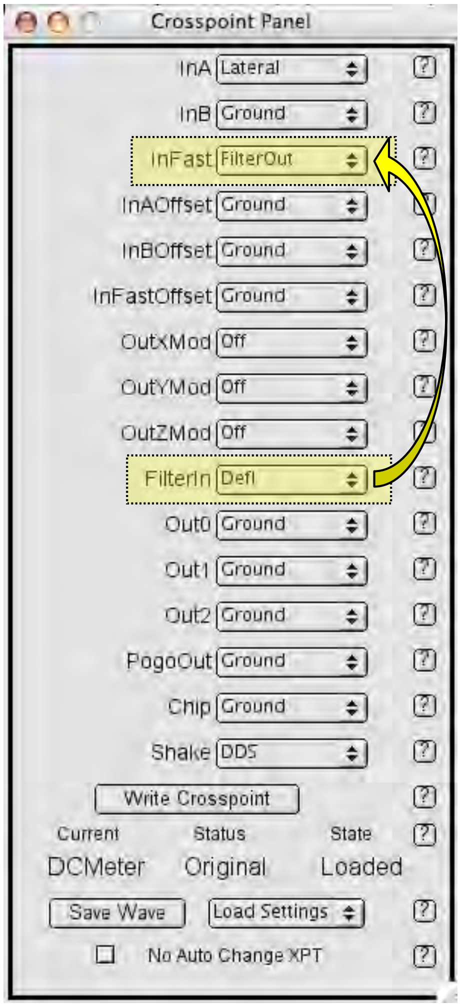


III. Audio Jack

The set of headphones that ship with the system can be plugged into the audio jack of the controller to listen to noise on a signal line. This tool is primarily used to for tuning the system at installation, particularly to help isolate the source of any deflection noise (either optical lever noise or system noise, *see System/Performance and Calibration section*).

To use the audio jack, plug in the headphones and rotate the knob to control the volume. The audio monitors whichever signal is routed to the “InFast” ADC. This is the deflection signal for the default configurations of both contact and AC mode. To see which signal is currently routed to InFast open the Crosspoint Panel from the Programming menu.

Defaults for Contact Mode

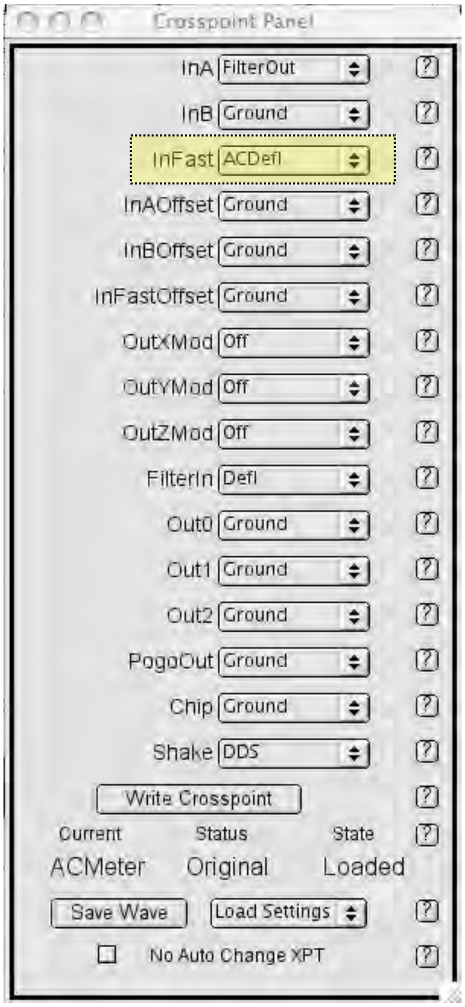


InA	Lateral
InB	Ground
InFast	FilterOut
InAOffset	Ground
InBOffset	Ground
InFastOffset	Ground
OutXMod	Off
OutYMod	Off
OutZMod	Off
FilterIn	Defl
Out0	Ground
Out1	Ground
Out2	Ground
PogoOut	Ground
Chip	Ground
Shake	DDS

Current	Status	State
DCMeter	Original	Loaded

☐ No Auto Change XPT

Defaults for AC Mode



InA	FilterOut
InB	Ground
InFast	ACDefl
InAOffset	Ground
InBOffset	Ground
InFastOffset	Ground
OutXMod	Off
OutYMod	Off
OutZMod	Off
FilterIn	Defl
Out0	Ground
Out1	Ground
Out2	Ground
PogoOut	Ground
Chip	Ground
Shake	DDS

Current	Status	State
ACMeter	Original	Loaded

☐ No Auto Change XPT

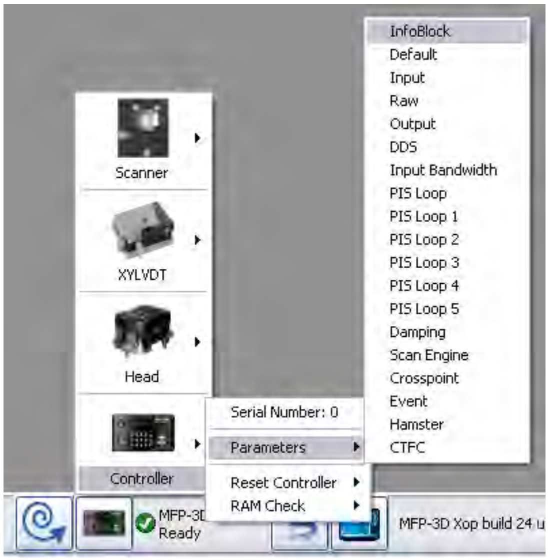
To monitor a different signal with the audio, use the Crosspoint Panel to route the desired signal to InFast. For example, to listen to the noise on the X Sensor:

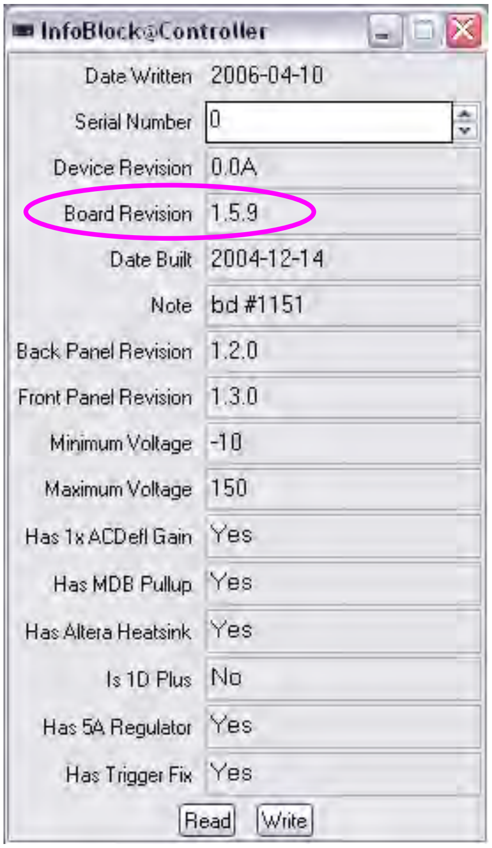
- In the Crosspoint Panel,
    - Set InFast to In0 (In0 is a user input BNC on the front of the controller).
    - Select the Write Crosspoint button. The State goes to Loaded.
- Use a BNC cable to connect X Sensor to In0 on the front of the controller.

Changing the signal routed to InFast affects the height feedback loop so be sure the system is not engaged!

- When the noise testing is done, return InFast to its original routing. An easy way to get back to the default settings is to change the Imaging Mode in the Master Panel (this works only if the "No Auto Change XPT" option is unselected in the Crosspoint Panel).

Note: On version 1.2.** main boards, the audio jack is permanently wired to the deflection signal; you cannot change the monitored signal by using the crosspoint switch as described above. Check the board revision by clicking on the device icon next to the Rescan button on the bottom toolbar. Select the controller InfoBlock.





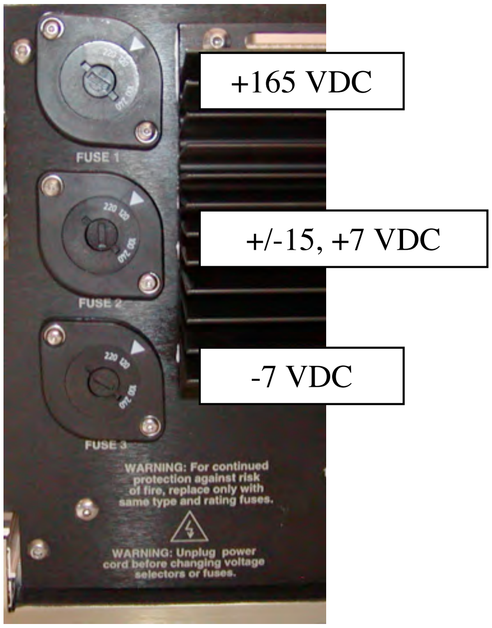
Date Written	2006-04-10
Serial Number	0
Device Revision	0.0A
Board Revision	1.5.9
Date Built	2004-12-14
Note	bd #1151
Back Panel Revision	1.2.0
Front Panel Revision	1.3.0
Minimum Voltage	-10
Maximum Voltage	150
Has 1x ACDefl Gain	Yes
Has MDB Pullup	Yes
Has Altera Heatsink	Yes
Is 10 Plus	No
Has 5A Regulator	Yes
Has Trigger Fix	Yes

IV. Troubleshooting

<u>Fuses</u>

Three fuses can be accessed from the back of the controller.
If you suspect a fuse is blown, use a screwdriver to remove the center portion and examine the fuse.

Fuse 1 controls the +165 VDC power.
Fuse 2 controls the +/-15 and +7 VDC powers.
Fuse 3 controls the -7 VDC power.



If you need to replace a fuse, it must be of the same type and rating. There is a chart printed on the back of the controller that lists the correct amperage for your specific line voltage. All the fuses are slow-blow or time-delayed type.

Checking U29

This procedure allows you to perform a diagnostic test to determine the condition of U29 on the controller's main electronics board. U29 is the chip that provides output for the tip bias, the sample bias, and the AC oscillator (shake piezo in the cantilever holder). There are two scenarios that can cause U29 to fail. Both of them send + or -15V to the chip pin on the pogo pin board in the head. This causes a large current to flow through resistors R114 and R115 and also U29. Usually R114 or R115 blows depending on the polarity of the voltage and U29 stops working but is saved from damage.

Symptoms of failure:

If U29 fails, the controller will send incorrect or **no drive amplitude** to the shake pin for AC mode operation. U29 also sends voltage to the chip and pogo out line and will prevent the correct bias voltage from going to the tip or sample.

Causes:

Fluid leaks inside the cantilever holder

A fluid spill inside the cantilever holder from improper sealing of the top membrane of the fluid cell can cause this problem. Additionally, any fluid spill that allows the gold pins on the pogo pin board to get wet for extended time can cause the damage.

Shorting +/-15v to the Chip pin when installing the cantilever holder

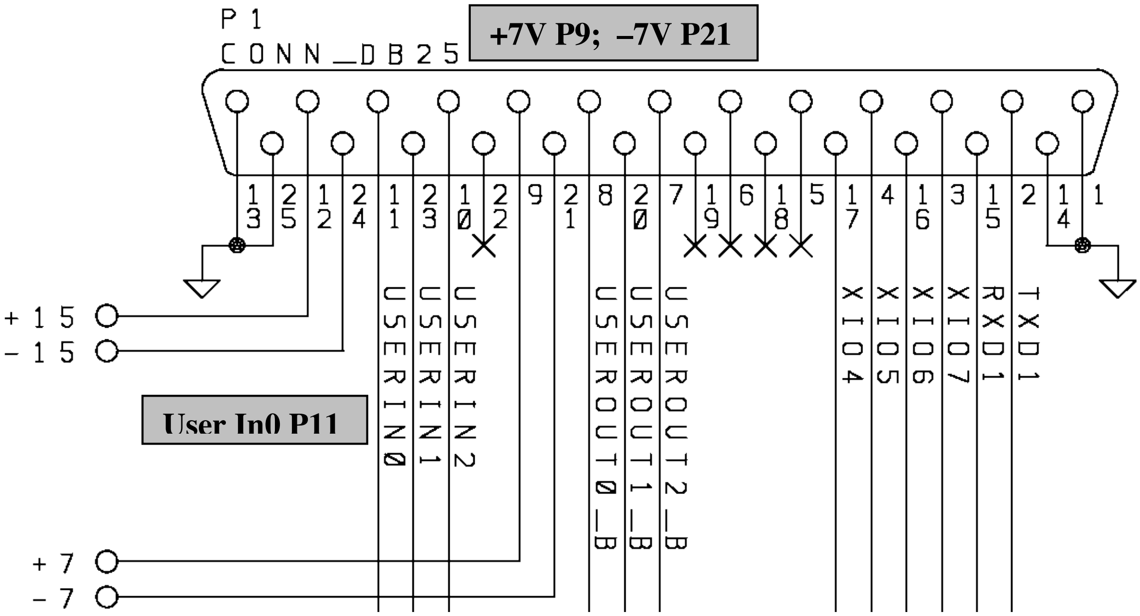
It is possible to short the Chip pin on the pogo pin board to either +/-15 V by dragging the metal ring of the cantilever holder across the pins as it is installed in the head. The system will survive a brief short circuit but multiple or extended shorts will cause the resistors to fail.

Performing the test:

The test consists of using the DDS set to 1 Hz @ 5 V as a signal source, connecting various signal lines to the User In0 and monitoring the response in the software.

You will need a small length of wire to stick into the socketed pins on the front panel connectors of the controller. Refer to the following connector diagrams as you follow the instructions. Note that there is a possibility to connect +150 V to the user input by accident. *Double check the pin positions before making any connections.*

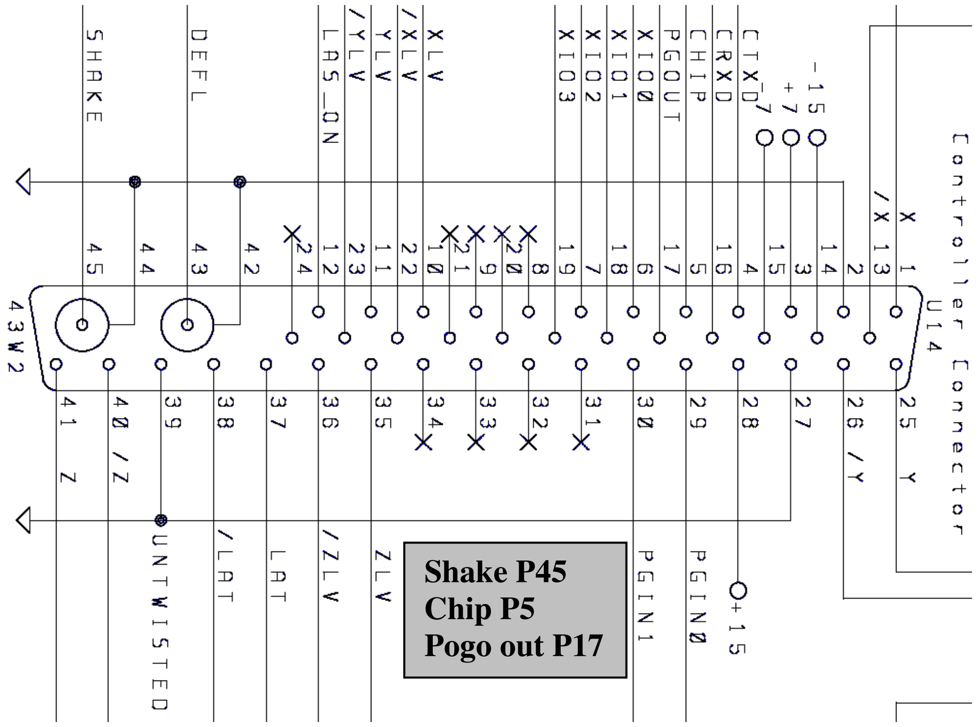
25 pin expansion connector



+7V P9; –7V P21

User In0 P11

45 pin microscope connector



Shake P45
Chip P5
Pogo out P17

1. Disconnect the main AFM microscope cable from the front of the control box.
2. Turn the controller power ON and start a fresh experiment.

3. Click on the setup button on the SUM/Deflection meter.
4. Set the User In0 meter from Auto to ON. Click on Done when set.

5. In the Main Controls window, set the operating mode to AC.
6. Set the Drive frequency to 1 Hz. (Not 1 kHz)
7. Set the Drive amplitude to 5 V.

8. Go to Programming-Crosspoint panel and display the crosspoint switch panel.
9. Set Pogo out, Chip, Shake to DDS. Press the "Write Crosspoint" button to activate the change.

10. Insert one end of the wire into pin 11 (User In0) of the 25 pin expansion connector on the front of the controller.
11. Test to make sure that the software is set up correctly by plugging the other end of the wire to pins 9 first and then 21 second of the expansion connector. You should read +7 V and –7 V respectively on the User In0 display.
12. Connect the wire from the User In0 pin (p11) to the shake line (the center conductor on the leftmost coax connector on the front panel connector, P45). You should see the User In0 bar graph move back and fourth between +/-5 V.

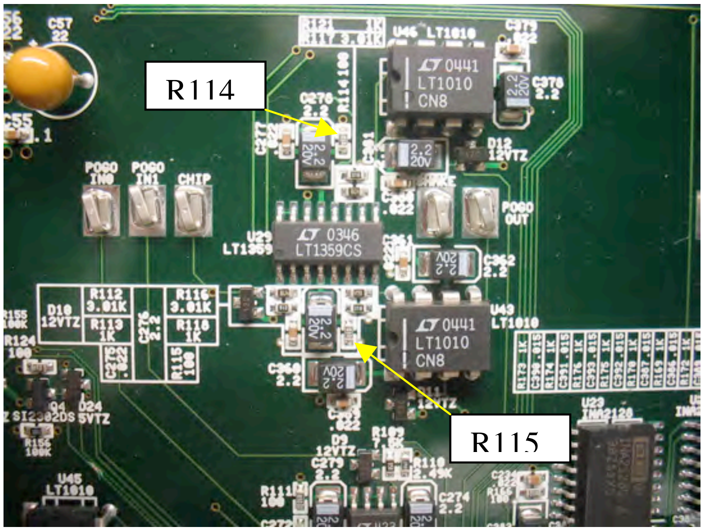
13. Move the wire from the Shake pin to the Pogo Out (P17) and the Chip (P5) pins. Verify that both of those pins cause User In0 to sweep +/-5 V.

If this all works then the controller is okay.

If you are not able to read the signal coming out of the shake or Pogo out pins then U29 or one of the surrounding resistors R114 or R115 are probably damaged.

Inspecting R114 and R115 on the controller main electronics board:

1. Remove the top cover of the microscope controller. Follow the instructions in the Controller/Remove the Top section. Disconnect the power from the controller before removing the cover.
2. Locate R114 and R115 located near U29 toward the front center of the main circuit board.



3. Measure the resistance of R114 and R115. They should be 100 Ohms.

If you find that one or both of the resistors are damaged, replace them with equivalent type 100 Ohm, 1%, 0603 SMD resistors.

Software

I. Test Panel

The Test Panel contains routines for making noise, hysteresis, and calibration measurements for the nanopositioning system sensors, piezos, and other signals. The Noise function is commonly used for troubleshooting problems with the instrument. The Calibration functions are used for maintaining the accuracy of instrument.

The Noise and Calibration panels may be used with caution by customers with a clear understanding of their purpose. Other panels are not appropriate for customer use without specific factory guidance.

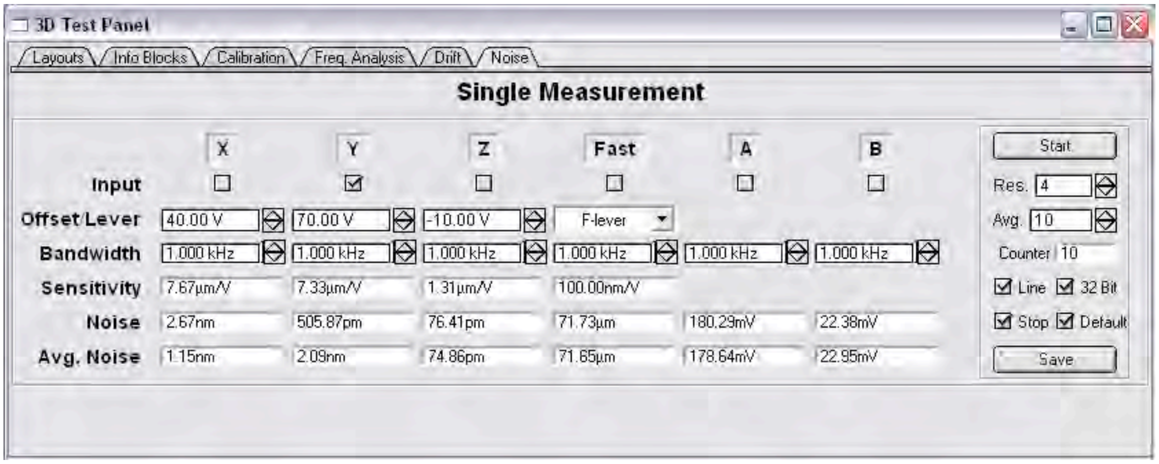
Step-by-step instructions for procedures (such as calibrating piezos or measuring sensor noise) are in the appropriate hardware sections. This section gives definitions of the parameters and functions.

To access the Test Panel, select Load Test Procs from the Programming menu. Then select Test Panel from the MFP Controls menu.

Noise Panel

The Noise panel is used to measure the noise of the X, Y, and Z sensors (also called LVDT). It can also be used to measure the noise on whichever signal is on the Fast, A, or B ADC.

To view which signals are currently assigned to the Fast, A, and B ADCs, go to Programming>Crosspoint Panel. In the Crosspoint Panel they are called InFast, InA, and InB. By default, InFast is used for the feedback signal (ACDefl in AC mode and Defl in contact mode).



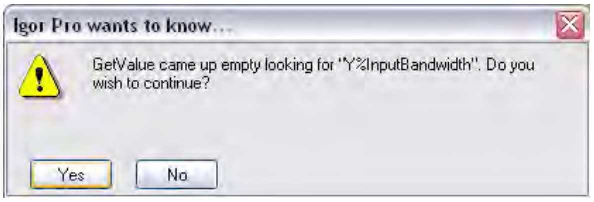
Single Measurement

	X	Y	Z	Fast	A	B
Input	☐	☑	☐	☐	☐	☐
Offset/Lever	40.00 V	70.00 V	-10.00 V	F-lever		
Bandwidth	1.000 kHz	1.000 kHz	1.000 kHz	1.000 kHz	1.000 kHz	1.000 kHz
Sensitivity	7.67µm/V	7.33µm/V	1.31µm/V	100.00nm/V		
Noise	2.67nm	505.87pm	76.41pm	71.73µm	180.29mV	22.38mV
Avg. Noise	1.15nm	2.09nm	74.86pm	71.65µm	178.64mV	22.95mV

Res. 4
Avg. 10
Counter 10
☑ Line ☑ 32 Bit
☑ Stop ☑ Default

Noise Panel Inputs:

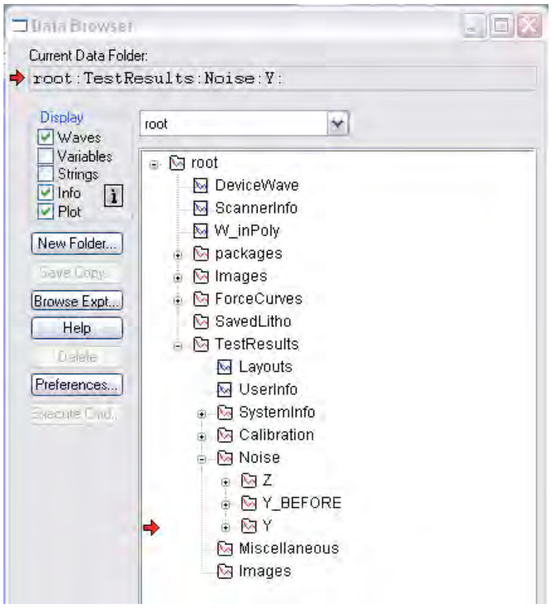
- Input selects which signal will be used for the noise measurement.
- Offset/Lever:
  - For X, Y, or Z, Offset is the voltage applied to the corresponding piezo stack.
  - For the Fast ADC, Lever is a drop down list of common cantilever types. It is only a label, useful for reference in a saved experiment; the setting does not effect the measurement.
- Bandwidth sets the upper end of the bandwidth.
- Resolution sets the lower end of the bandwidth.
  - Res=5 corresponds to a low frequency of 0.1 Hz.
  - Res=4 is 0.4 Hz
  - Res=3 is 1.5 Hz
  - Res=2 is 6 Hz
  - Res=1 is 24 Hz
  - Because it takes more time to gather data for low frequencies, the experiment time will be longer for higher Resolutions. Generally a Resolution of 3 or 4 is sufficient for troubleshooting. The NPS noise specs are done at full bandwidth (Res=5).
- Sensitivity (not user editable in Noise panel)
  - For X, Y, or Z, Sensitivity is taken from the info block of the appropriate component.
  - For the Fast ADC, Sensitivity is the detector InVols (deflection in contact mode or amplitude or AC mode).
- Start/Stop button begins/ends the measurement.
- Average is the number of data sets collected in an experiment if the Stop option is selected. The data are averaged together for the average noise value and for the PSD plot. If Stop is not selected, Average has no effect on the experiment or results.
- Save button allows experiment data to be saved.
  - Save is only available once a full experiment is complete (Counter=Average) using the Stop option.
  - When Save is selected you must accept the warning(s) to save the data set.



Igor Pro wants to know...

GetValue came up empty looking for "Y%InputBandwidth". Do you wish to continue?

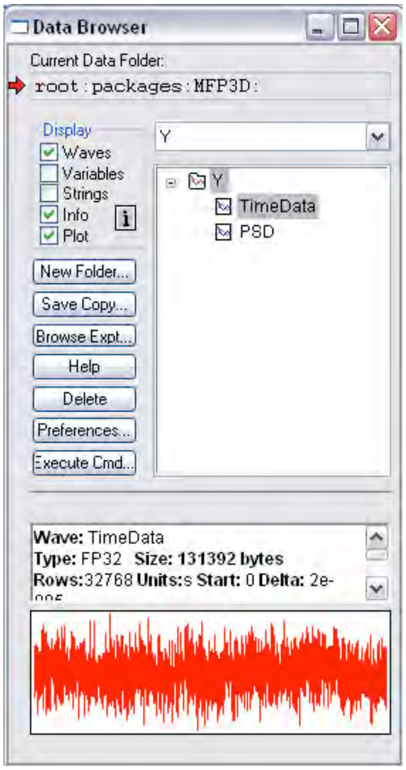
- To view the saved data go to Data>Data Browser. Open Root>Test Results>Noise>…



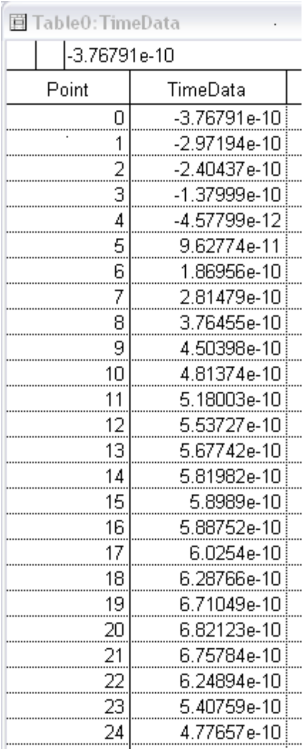
Current Data Folder: root:TestResults:Noise:Y:

- The file is automatically saved with the Input as the name (Ex. Y). A new experiment with the same Input will override a previously saved file. To avoid this, rename the file from the Data Browser (Ex. Y_BEFORE).

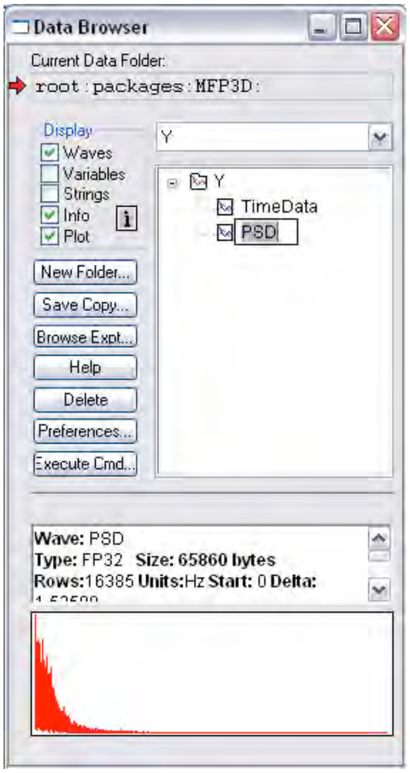
Example of saved data



Wave: TimeData
Type: FP32 **Size:** 131392 bytes
Rows:32768 **Units:**s **Start:** 0 **Delta:** 2e-

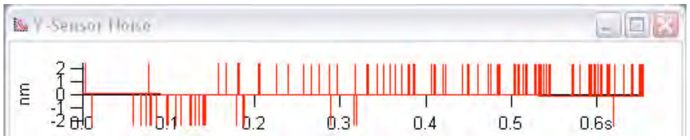


Point	TimeData
0	-3.76791e-10
1	-2.97194e-10
2	-2.40437e-10
3	-1.37999e-10
4	-4.57799e-12
5	9.62774e-11
6	1.86956e-10
7	2.81479e-10
8	3.76455e-10
9	4.50398e-10
10	4.81374e-10
11	5.18003e-10
12	5.53727e-10
13	5.67742e-10
14	5.81982e-10
15	5.8989e-10
16	5.88752e-10
17	6.0254e-10
18	6.28766e-10
19	6.71049e-10
20	6.82123e-10
21	6.75784e-10
22	6.24894e-10
23	5.40759e-10
24	4.77657e-10



Wave: PSD
Type: FP32 **Size:** 65860 bytes
Rows:16385 **Units:**Hz **Start:** 0 **Delta:**

- Options (recommended to have all options selected)
  - Line: If selected, a line fit is applied to the Input vs. Time plot. The noise and average noise values are lower (RMS is relative to line fit instead of overall average). The low frequency end of the PSD plot is reduced.
  - 32 bit: If selected, data resolution is 32 bits. If unselected, data resolution is16 bits. Be aware of possible bit noise at the lower setting.

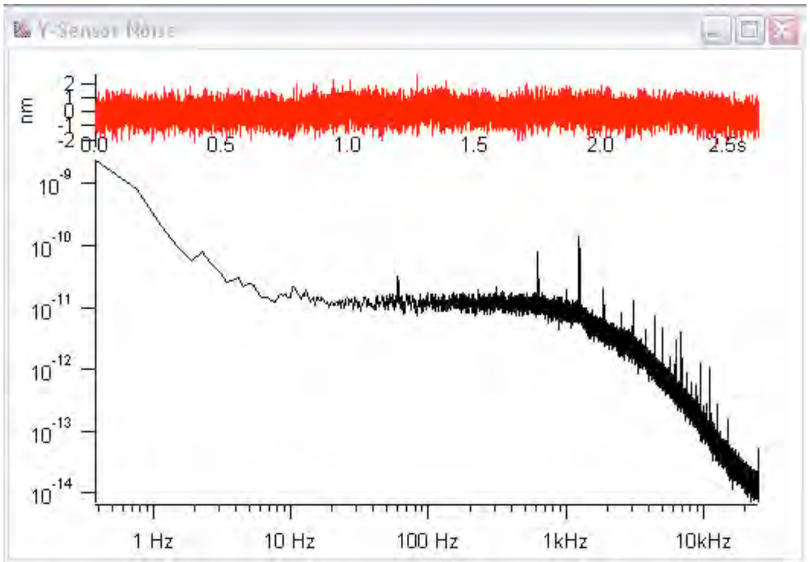


  - Stop: If selected, the experiment will automatically stop once the defined number of data sets (Average) has been collected (as indicated by the Counter).
  - Default?

Noise Panel Outputs:

- Noise is the RMS (root mean square) of the most recent data set.
- Average Noise is the average of the all the Noise values since the Start button was selected.
- Counter displays how many data sets have been collected since the Start button was selected.
- Once a measurement is started, a window with 2 plots will appear.
  - The top red plot is the Input signal vs. time for the most recent data set.

- The bottom black plot is the average Power Spectral Density (PSD). It includes all data sets collected since the Start button was selected.



Calibration Panel

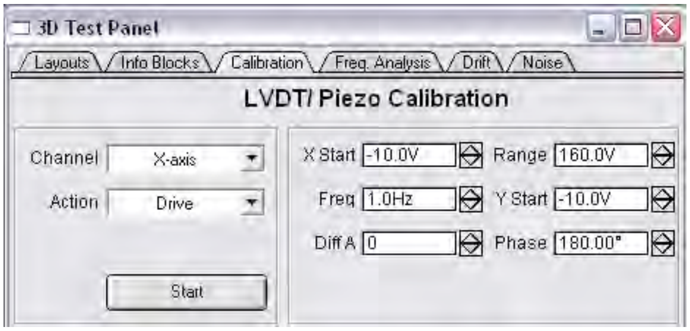
The Calibration panel contains routines important for maintaining the accuracy of your instrument. Some functions can also be helpful for troubleshooting.

The various routines available in the calibration panel are selected by the Action. Each action can be performed on any of the 3 axes (X, Y, or Z) as selected by the Channel.

This section is organized by the Actions:

- Drive
- Calibrate LVDT
- Set Phase/Amp – not used.
- Measure Hysteresis
- Calibrate Piezo

Drive – Drives the x/y/z piezo repeatedly through the specified range while recording the corresponding sensor signal. It is commonly used to check the state of the piezo assemblies (see Testing for Bad Piezo Assemblies)



LVDT/ Piezo Calibration

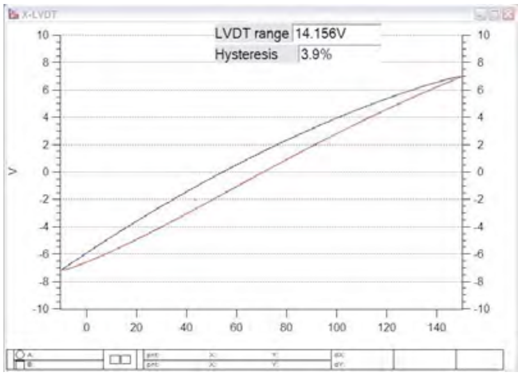
Channel X-axis
Action Drive
X Start -10.0V
Range 160.0V
Freq 1.0Hz
Y Start -10.0V
Diff A 0
Phase 180.00°

Drive Inputs:

- X/Y/Z Start: Starting voltage for the x/y/z piezo drive (range is –10 to 150 V)
- Range: Voltage range for the x/y/z piezo drive (max is 160 V).
- Frequency: Frequency of the piezo drive (cycles/second). A cycle is one round-trip excursion.
- X/Y Start: When the x or y piezo is being driven, this specifies the voltage the other axis is held at during the experiment.
- *Diff A and Phase* are related to tuning the lock-in and *should not to be changed by the customer*.
- Start/Stop button begins/ends the measurement.

Drive Outputs:

- Once a measurement is started, a graph of the sensor (LVDT) voltage vs. piezo drive voltage appears.



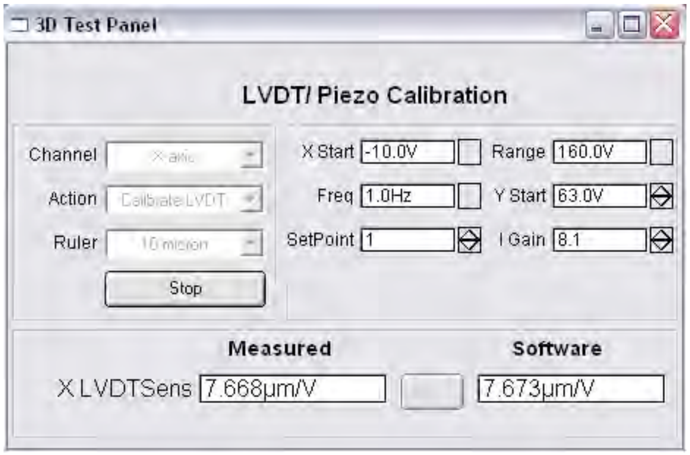
LVDT range 14.156V
Hysteresis 3.9%

- LVDT range is the measured sensor voltage range for the specified piezo drive.

- Hysteresis % = max LVDT error/LVDT range x 100.

Calibrate LVDT – Routine used to calibrate the sensors (LVDT) after engaging on a calibration sample. Customers should use only X and Y; Z must be calibrated at the factory.

The x/y piezo is cycled through the specified range while recording the height and corresponding sensor signal. The piezo is in open loop during the measurement. The analysis routine locates the pit walls in the height data and measures the pitch of the calibration grid to calculate a new sensor sensitivity.



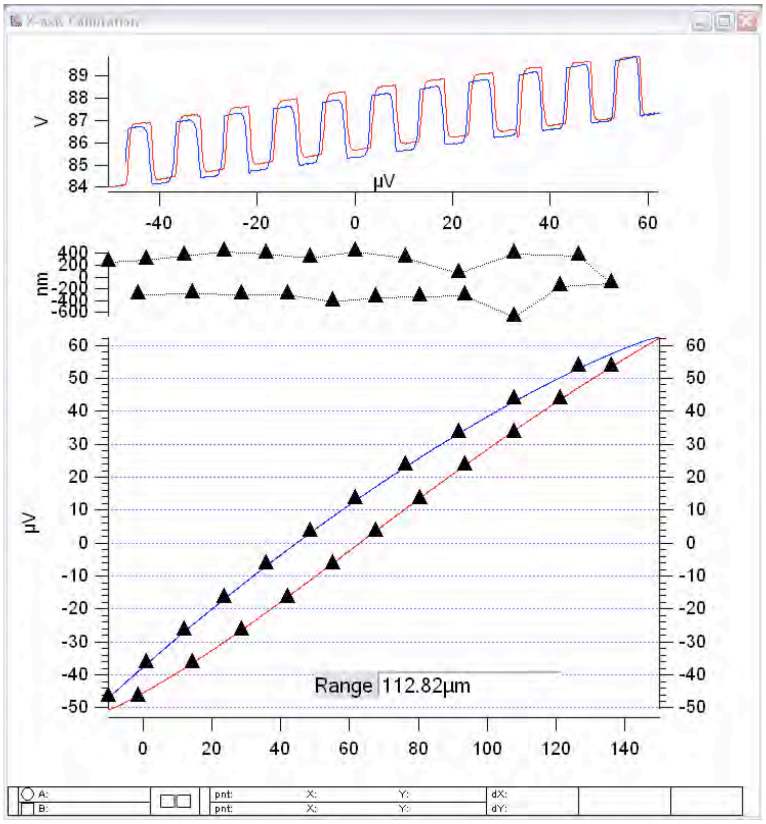
Channel: X-axis
Action: Calibrate LVDT
Ruler: 10 micron
X Start: -10.0V
Range: 160.0V
Freq: 1.0Hz
Y Start: 63.0V
SetPoint: 1
I Gain: 8.1
X LVDTSens: 7.668µm/V (Measured), 7.673µm/V (Software)

Calibrate LVDT Inputs:

- Ruler: Specifies the calibration grating being imaged. The 10 um standard should be used for x and y calibration.
- X/Y Start: Starting voltage for the x/y piezo drive.
- Range: Voltage range for the x/y piezo drive.
- Frequency: Frequency of the piezo drive (cycles/second). A cycle is one round-trip excursion.
- Y/X Start: When the x or y piezo is being driven, this specifies the voltage that the other axis is held at during the experiment. For calibration, the opposite axis is held at the center of its range, 70 V.
- SetPoint: Same as Set Point in main panel; used to control height feedback loop.
- I Gain: Same as Integral Gain in main panel; used to control height feedback loop.
- Start/Stop button begins/ends the measurement.

Calibrate LVDT Outputs:

- X/Y LVDT Sens:
    - “Measured” is the sensor sensitivity calculated each cycle of the experiment.
    - “Software” is the currently saved sensitivity value being used by the software.
- Once a measurement is started, a graph window with 3 plots appears.



Range 112.82µm

The top plot is the Z piezo voltage (height) vs. X/Y Sensor voltage.

The middle plot is the “residuals” Average height of trace and retrace vs. X/Y piezo drive voltage).

The bottom plot is the X/Y Sensor voltage vs. X/Y piezo drive voltage.

Range is the total scanner range.

- Pit walls are identified when the height signal crosses though zero. Zero is defined as the average height for trace and retrace Black triangles on the graphs mark the locations of ever other transitionthrough zero on the piezo drive voltage in trace and retrace. The software has a preprogrammed value of 10 um/triangle. Using a 10 um pitch calibration standard, the software can calculate the sensitivity of the X/Y position sensors.

Measure Hysteresis – A routine that measures the hysteresis of the x, y, or z scanner (piezos and mechanical assembly). The x/y/z piezo is cycled in open loop (no feedback from sensors) through three voltage ranges, 160, 10, and 1 V. The hysteresis of the corresponding sensor data is measured for each range.

LVDT/ Piezo Calibration

Channel X-axis

Action Measure Hyst.

Freq 1.0Hz

Cycles 50

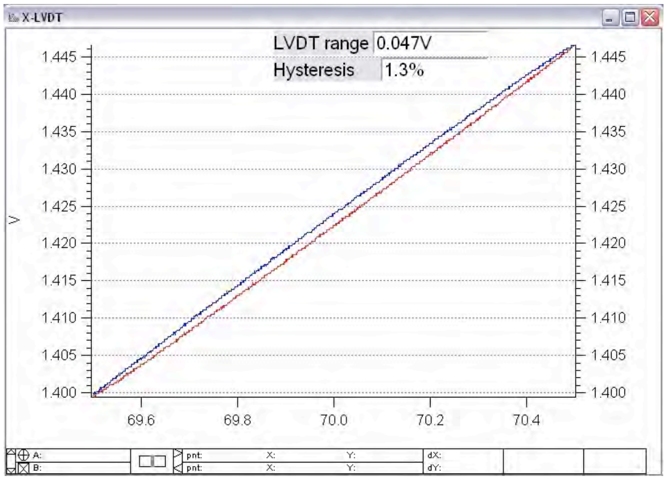
	160V	10V	1V
Hyst.	4.25%	3.66%	1.30%

Measure Hysteresis Inputs:

- Frequency: Frequency of the piezo drive (cycles/second). A cycle is one round-trip excursion.
- Cycles: Number of piezo excursions done at each of the three voltage ranges.
- Start/Stop button begins/ends the measurement.

Measure Hysteresis Outputs:

- Hyst. = max LVDT error/LVDT range x 100. The hysteresis values in the calibrate panel shows the most recent hysteresis measurement done at the specified voltage range.
- Once a measurement is started, a graph of the sensor (LVDT) signal vs. piezo drive voltage appears.



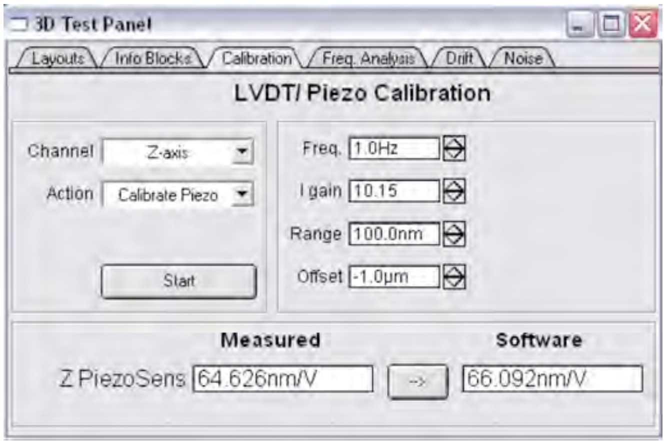
LVDT range 0.047V

Hysteresis 1.3%

- LVDT range is the measured sensor voltage range for the specified piezo drive.

- The hysteresis on the graph is updated for each data set.

Calibrate Piezo – Routine used to calibrate the x, y, or z piezo relative to its corresponding sensor. The x/y/z piezo is cycled in closed loop through the specified sensor range and offset. The piezo sensitivity is calculated from the drive voltage required for the excursion.



LVDT/ Piezo Calibration

Channel: Z-axis
Action: Calibrate Piezo
Freq. 1.0Hz
I gain 10.15
Range 100.0nm
Offset -1.0µm

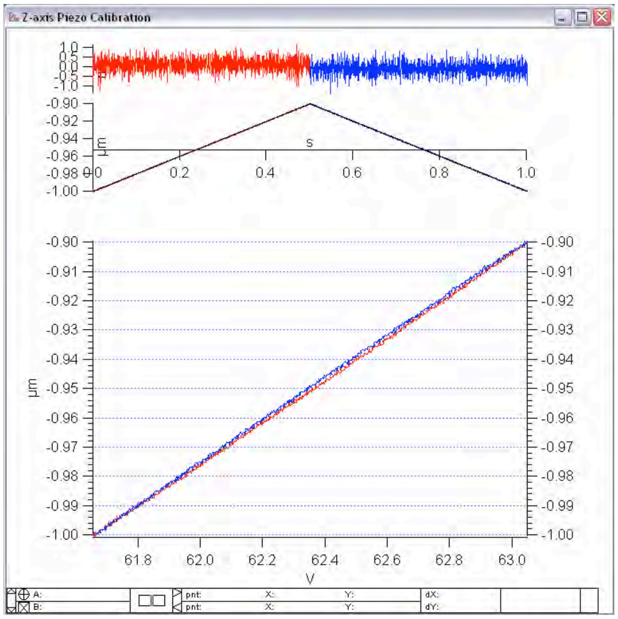
	Measured	Software
Z PiezoSens	64.626nm/V	66.092nm/V

Calibrate Piezo Inputs:

- Freq: Frequency of the piezo drive (cycles/second). A cycle is one round-trip excursion.
- I gain: Gain of the piezo-sensor feedback loop. *Do not change. Set at factory during full calibration.*
- Range: Sensor range for the x/y/z piezo excursion.
- Offset: Center of the excursion relative to the middle of the sensor range.
- Start/Stop button begins/ends the measurement.

Calibrate Piezo Outputs:

- X/Y/Z Piezo Sens:
  - "Measured" is the piezo sensitivity calculated each cycle of the experiment
  - "Software" is the currently saved sensitivity value being used by the software.
- Once a measurement is started, a graph window with 3 plots appears.



The top plot is the residual difference between the set point position and the measured sensor position vs. time.

The middle plot is the sensor signal vs. time.

The bottom plot is the sensor signal vs. the piezo drive voltage. The piezo sensitivity is the slope of this line.

II. Remote Operation

Asylum Research subscribes to a service that gives us the ability to remotely operate your MFP-3D system over the internet. This tool is useful to help diagnose instrument problems or to help answer operational questions in realtime. All you need to do is contact Asylum Research to schedule a session and have your instrument's computer connected to the internet.

To start an online session:

- Contact Asylum and ask to start a session.
- An engineer will activate the session.
- Once the session is initiated on our end, go to help->AR-webcontrol support from with top command line from the 3D software. Your internet browser will go to the the web control site, http://www.citrixonline.com/partners/asylumSmartButton.html
- A window with a blue "Start" button will appear. Click on the button to start the session.
- You will be asked to down load chatlink.exe. Click the 'Run' button to down load the software.
- A window warning you to close any sensitive documents will appear. Click O.K. to allow the session to begin.
- A window will appear saying that "Your representative has arrived" indicating that the session has begun.

III. Web Addresses

Asylum Research's website http://www.asylumresearch.com/ has a button at the top for the support area of the site. There are many links to pages of answers to FAQs.

Email support should go to support@asylumresearch.com

Instructions for uploading files to Asylum's FTP site can be found at http://www.asylumresearch.com/Support/FAQ3D.shtml#FTP

We have a Customer Forum at http://www.asylumforum.com/forum/index.php
You have to register before posting questions.

On the forum, click on "IGOR Software" to get to links for *updating the MFP-3D software*. Many of the software links on the main company website are also found here along with threads to customer discussions.