Fog Monitor
Model FM-120

Operator Manual

DOC-0339 Revision B-1

DROPLET MEASUREMENT TECHNOLOGIES

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Warranty

The seller warrants that the equipment supplied will be free from defects in material and workmanship for a period of eighteen months from date of shipment <u>or</u> 12 months from the date of either installation or first use whichever comes first. When returning the equipment to DMT for warranty or service procedures, the equipment owner will pay for shipping to DMT, while DMT will pay the return shipping expense. Consumable components, such as tubing, filters, pump diaphragms, and Nafion humidifiers and dehumidifiers are not covered by this warranty.

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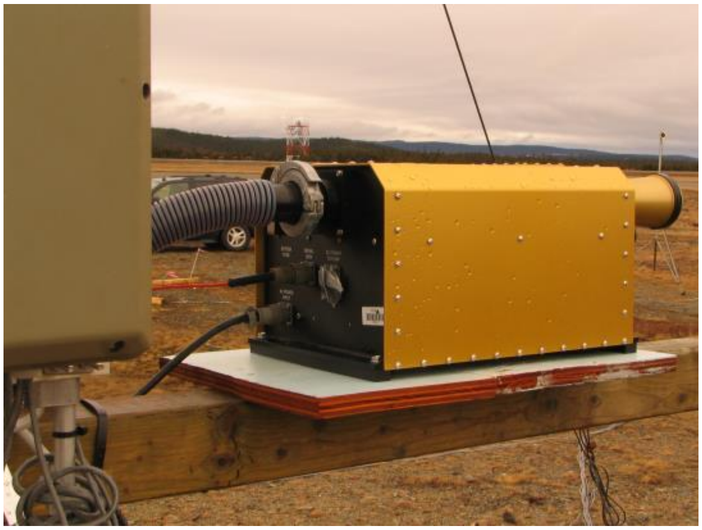
Introduction

DMT's Fog Monitor (FM-120) is a cloud-particle spectrometer designed for use during ground-based or tower-based studies. This robust and weather-resistant instrument has been designed with a solid-state laser diode and compact surface-mount electronic technology. Figure 1 depicts the Fog Monitor.



The FM-120 allows for computation and real-time display of particle concentration, median volume diameter (MVD), equivalent diameter (ED), and liquid water content (LWC).

In addition, the FM-120 monitors multiple housekeeping variables: the number of DOF rejected particles, baseline voltages, static pressure, differential pressure (to determine True Air Speed (TAS) rate in the sample tube), ambient temperature, laser diode current, and laser diode monitor.

Caution: While the FM-120 has universal input, the pump does not. The pump will arrive configured for either 115V or 230V depending on the user's location. Users can change this input by rewiring the pump. (See section 1.5.) Note the actual input voltage must match the pump's electrical input configuration to avoid damage to the pump and/or probe.

Specifications

1.1 General Specifications

The FM-120 specifications are listed below.

Technique:	Light-scattering probe with 30 size bins
Measured Particle Size Range:	2-50 µm droplet diameters
Typical Sample Area:	0.24 mm^2
Sample Flow Rate:	1 m^3/minute
Sampling Frequency:	Selectable, 0.04 to 20 seconds
Refractive Index:	non-absorbing, 1.33[1]
Light Collection Angles:	3.5° - 12°
Data System Interface:	RS-422 serial interface;[2] 460 kB rate.
Calibration:	Precision glass beads

Table 1: Fog Monitor Specifications

1.2 Electrical Specifications

- Universal voltage input for analyzer head
- 50-60Hz
- 200W (instrument), 400W (pump)
- 115V or 230V pump input, user-configurable

1.3 Physical Specifications

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[1] A refractive index of 1.33 for water is the industry standard. Contact DMT for support for measuring particles with other refractive indexes.

[2] The FM-120 is configured for RS-422 serial communication. If you wish to use an RS-232 configuration, contact DMT.

Weight: 13kg (instrument), 5kg (pump)

Dimensions: 23 cm high, 28 cm wide, 37 cm long

Figure 2: Fog Monitor Control Panel

1.4 Environmental Operating Conditions

- Temperature: -20 to 40 ˚C
- Relative Humidity: 0 - 100%, non-condensing
- Altitude: 0 - 4,000 meters

Getting Started

1.5 Power Requirements and Changing the Pump Power

While the FM-120 instrument features universal power input, the pump (Figure 3) does not. The pre-set pump power must match the input power. If it does not, the pump and the instrument itself may be damaged.

Users can rewire the pump to accommodate different input voltages. To rewire the pump, first unscrew the pump lid.

Instructions for rewiring the pump appear under the lid of the pump (see arrow in Figure 3).

Figure 3: Unscrewing Pump Lid

Instructions for wiring the pump appear on the inside of the lid (Figure 3).

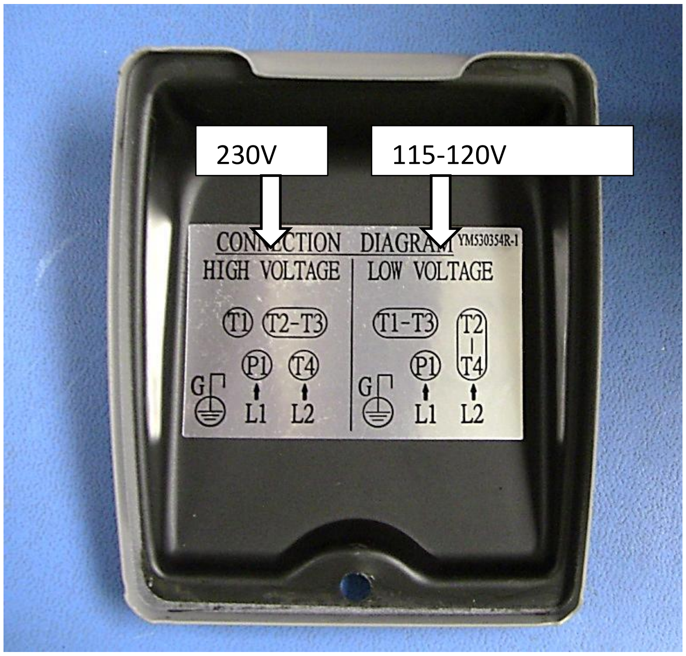


Figure 4: Instructions for Wiring Pump

“L1” refers to the black wire, and “L2” to the white. The wires are labeled.

The pump has ring terminal connections that set the voltage input. To access the ring terminals, first cut off and remove their protective sleeve.

Figure 5: Removing Protective Sleeves

Users can rewire these ring terminals using a screwdriver and small wrench.

Figure 6 shows the how the terminals are configured for a low voltage input.

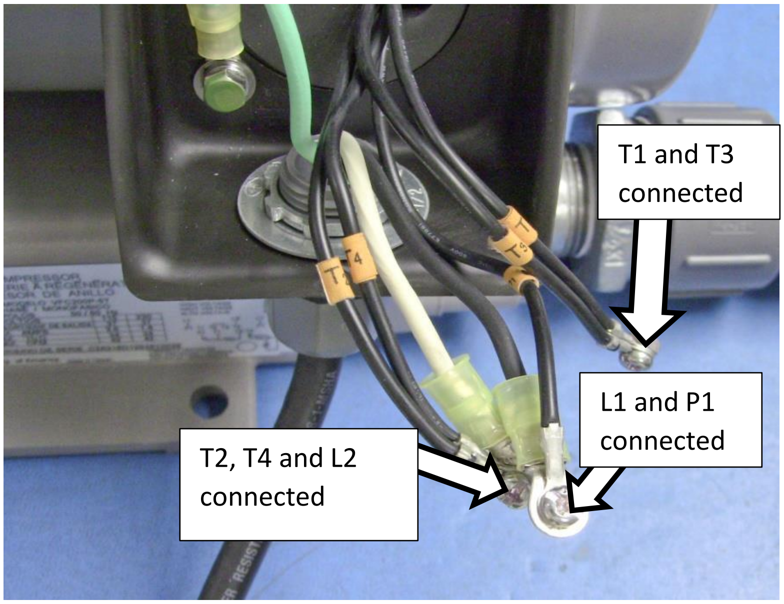


Figure 6: Example Wiring for Low Voltage (115 VAC)

1.6 Instrument Setup

Figure 7 depicts the Fog Monitor (FM-120) components.

FM-120 Components:

1a	Particle sensor front panel	8a	Glass beads for calibration
1b	Particle sensor back panel, with clamp and sealing ring attached	8b	Glass beads dispenser
2	Inlet horn	9	Calibration fixture
3	Laptop	10	Serial data cable
4	Pump hose	11	Probe power cable
5	Pump	12	Manuals
6	Computer accessories	13	Bench-test serial data cable
7	Clip and sealing ring to attach pump to hose	14	Bench-test probe power cable

Figure 7: FM-120 Components

The particle sensor is shipped and stored in a reusable prefabricated shipping case with the inlet horn detached. The computer, pump and associated hardware are shipped in separate containers.

1.7 Connecting the FM-120 Components

Please carefully open the instrument shipping boxes, take out the components and place them on a sturdy surface. Then follow the steps below to set up the system. (Note: customers who wish to mount the optional swivel-head inlet should consult Appendix D.)

1. Insert the inlet horn into the outer block of the particle sensor as far in as it will go. ***Note:*** Make sure that the horn is seated tightly. It can be pushed approximately 4 cm (1.5”) into the block. There should be no visible gap between the horn and block when you look down the horn. Once the horn is properly seated, screw in the set screws to secure it to the block.

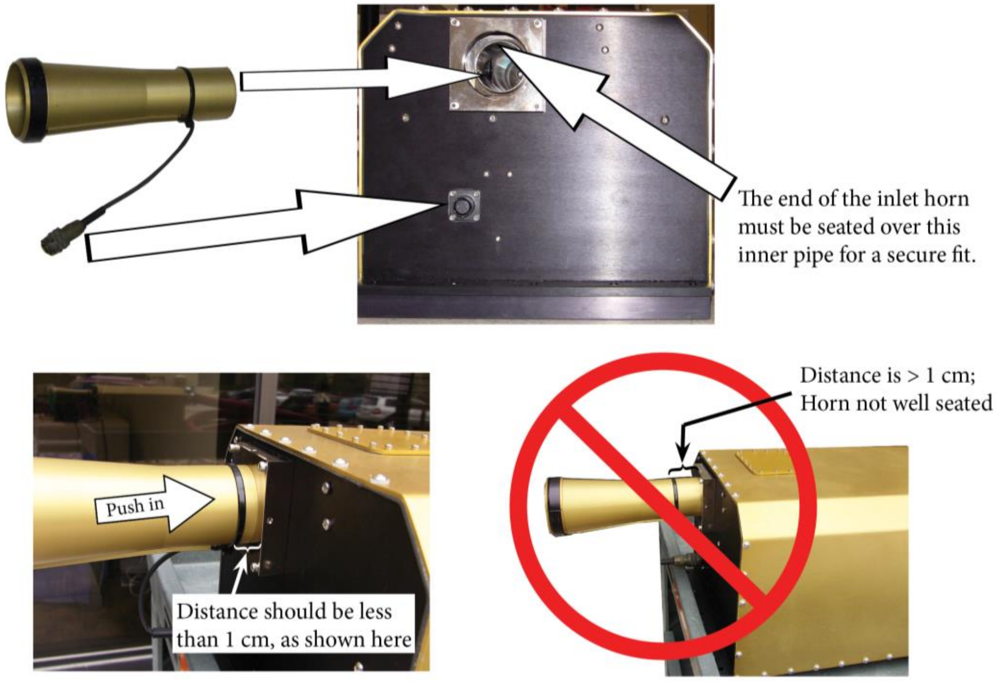


Figure 8: Inserting the Inlet Horn. Push inlet horn in as far as it will go.

2. Connect the pump hose to the pump (Figure 9).

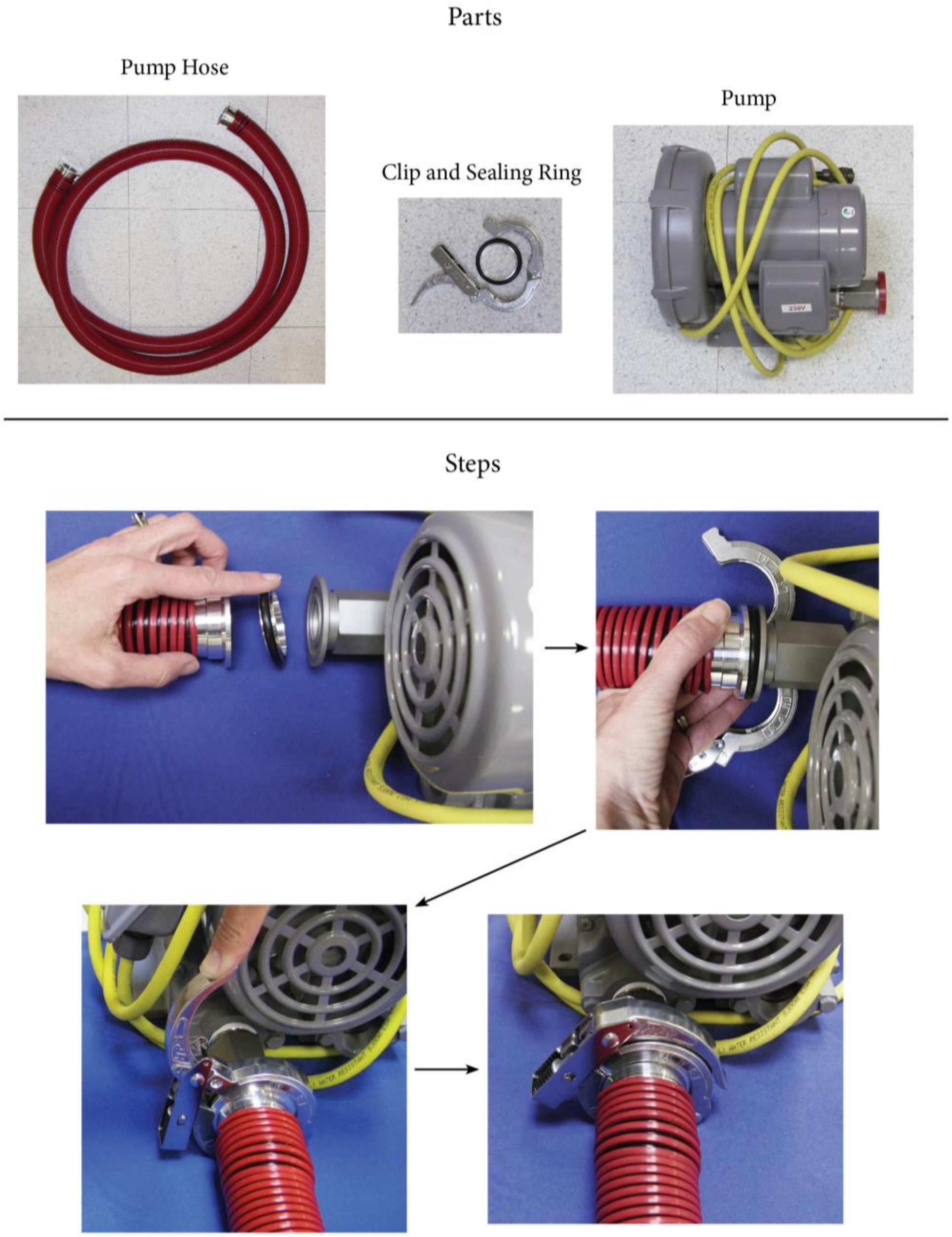


Figure 9: Attaching the Pump to the Pump Hose

3. Connect the FM-120 power cable to the **AC POWER INPUT** on the particle sensor (Figure 10).

4. Connect the data cable to the **SERIAL DATA** receptacle (Figure 10).

5. Connect the pump power cable to the **AC POWER TO PUMP** receptacle (Figure 10). Caution: pump power ***must*** match input power. See section 1.5.

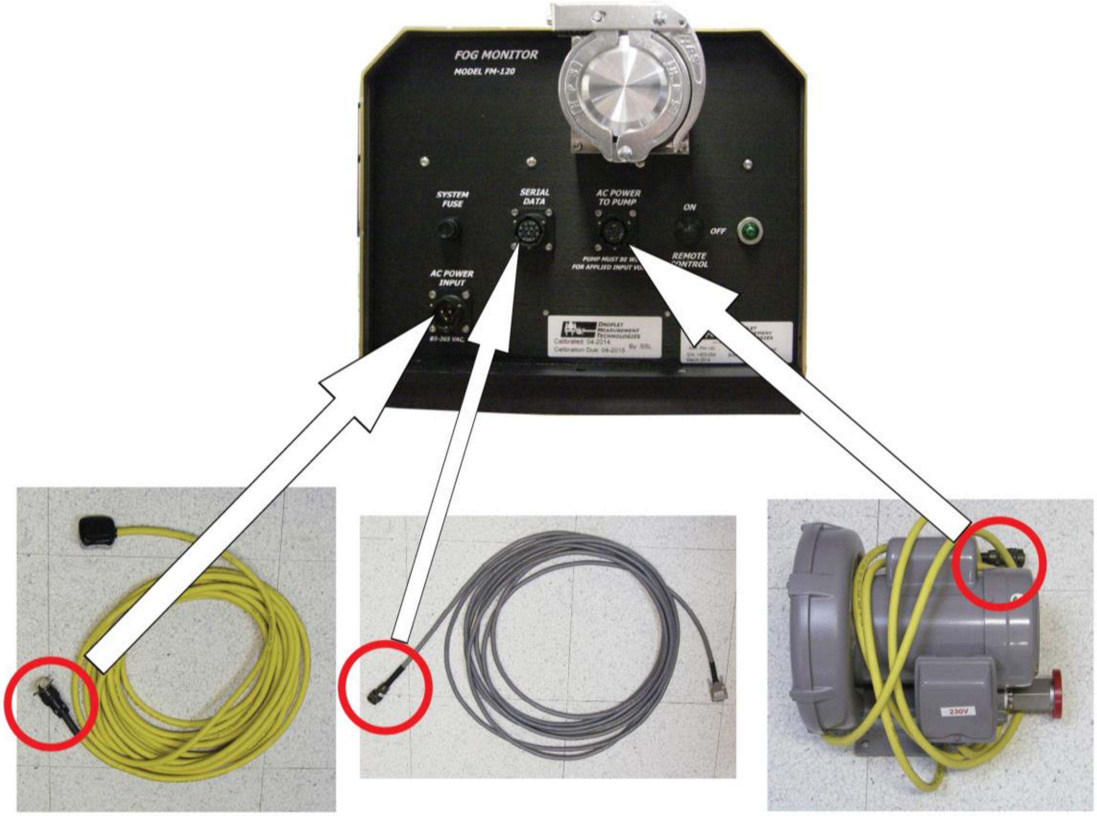
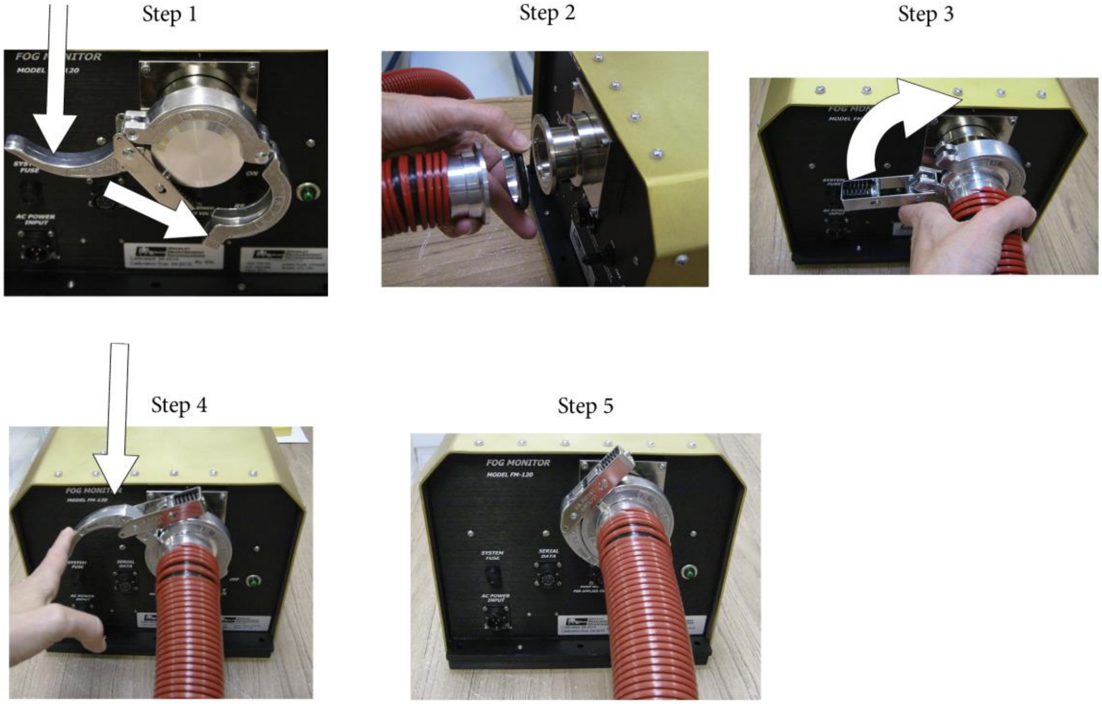


Figure 10: Connecting the Serial Data Cable, Power Cable, and Pump Power Cable to the Particle Sensor

6. Remove the clamp and pump hose connection cover from the particle sensor. Keep the black O-ring and metal centering ring on the unit.

7. Attach the pump hose to the particle sensor.



Step 1

Step 2

Step 3

Step 4

Step 5

Figure 11: Attaching Pump Hose to Particle Sensor

8. Connect the FM-120 power cable and pump power cable to power sources.
9. Turn on FM-120 power. (Flip the power switch up, so the light turns on.)
10. Insert the green FM-120 PADS software USB key (labeled “FM-120 PADS”) into a USB 2.0 port on the computer (Figure 12).
11. Connect the serial data cable to into a USB 2.0 port on the computer (Figure 12).
12. Connect the laptop power supply to the computer (Figure 12).

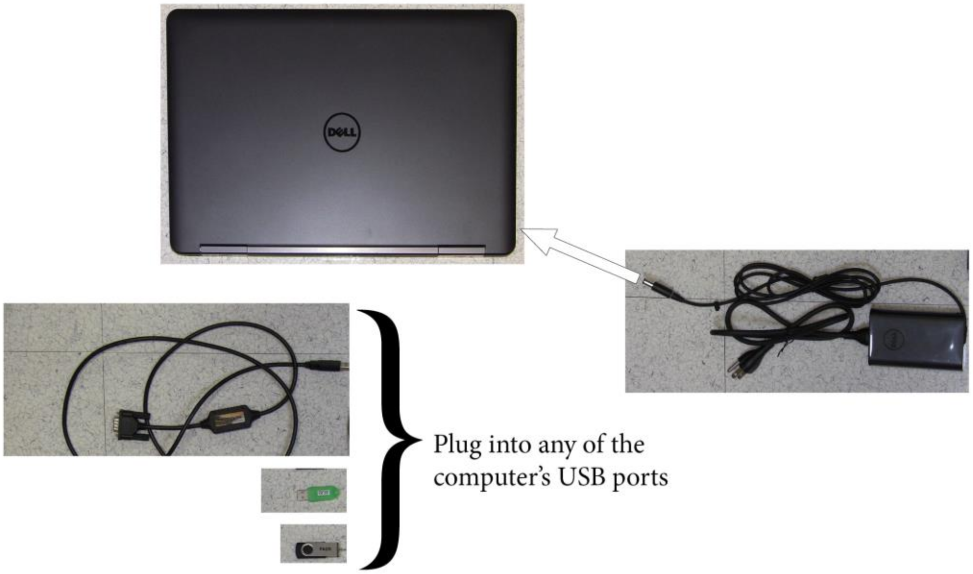


Figure 12: Connecting Computer Components

13. Connect the laptop power supply to the power source.
14. Turn on the computer.

1.8 Basic Health Check

PADS users can follow the steps below to perform a basic health check of the system:

1. After the computer boots into Windows, double-click on the "PADS" icon on the computer desktop to open the PADS program.

   A display will appear.

2. Click on the **Sample** button in the upper left of the window. The button is originally gray. Upon clicking, it will turn green, and the label changes to **Sampling**.

3. The pump is automatically turned on when sampling is started. The "Pump Control" button located towards the upper left of FM_120 instrument panel can be used to turn off the pump if desired.

4. Check the **FM_100 Data** housekeeping data in the leftmost panel of the interface.

5. Check the **Laser Current**. If the laser is operating correctly, the value should be in the 50-100 mA range. If the value is significantly below 50mA, or if it varies by tens of mA over the course of a few minutes, the instrument will not work properly and needs to be serviced.
6. Check temperatures. Initially after turning on, these should be close to ambient temp.
7. Check **Static** and **Dynamic Pressure**. The **Static Pressure** will reflect the local ambient pressure. The **Dynamic Pressure** should read a few millibars, or zero if the pump is turned off.

The response of the instrument to particles can be verified by sampling the output of a fog generator or by passing calibration spheres through the instrument.

1.9 Instrument Shutdown

Follow these steps to shut down the FM-120 system:

1. Stop data recording by pushing the green “Recording” button.
2. Turn off the sample pump by pushing the green “Sampling” button located in the upper left of the FM-120 interface.
3. Exit the FM-120 Software Interface via the Program/Exit selection from the menu.
4. Turn off the power switch on the FM-120 front panel.
5. Transfer data files from the laptop as necessary.
6. Turn off the laptop via the Windows Start/Shutdown command.

Cleaning and Routine Maintenance

1.10 Yearly Maintenance at DMT

DMT recommends returning your FM-120 to the factory for an annual cleaning and calibration. This will ensure your instrument is working properly and prolong its lifetime.

1.11 Maintenance Performed by User

There are three tasks the user can perform to maintain the FM-120: conducting a basic health check, cleaning the instrument windows, and cleaning the Pitot tube. Table 1 gives the recommended frequency for these tasks. This frequency will increase under severe conditions, such as when the instrument is operating in the following types of locations:

- Within five miles of the ocean
- Sandy areas

- Polluted areas with high concentrations of particulate matter

	Normal Conditions	***Severe Conditions***
Basic Health Check (described in section 3.3)	Weekly	Daily
Windows Cleaning (described in section 4.2.1)	Monthly	1 - 3 times a week
Pitot Tube Cleaning (described in section 4.2.2)	N/A—the yearly calibration and cleaning at DMT should suffice	Once every month to two months

Table 2: Frequency of Routine Cleaning and Maintenance Procedures

A good indication that the Pitot tube requires cleaning is if the air speed (the **Calculated TAS** channel in PADS software) differs by more than 5% from its recorded post-calibration value.

1.11.1 Cleaning the FM-120 Windows

Looking in at an angle towards the ends of the sample tube inlet, you should see two windows. When the instrument is on and the windows are clean, only a faint red spot will be visible where the laser beam passes through the center of the window. Dirt on the window will scatter laser light, causing the spot to be much brighter. This scattered light will be collected by the detectors, increasing the noise on the signals. If severe enough, it will cause false counts. Dirt on the windows will also block some of the light scattered by particles, causing them to be undersized.

The frequency of cleaning depends on the environment in which the FM-120 is operated. In urban environments, windows may need to be cleaned as often as once a week.

1.11.1.1 Required Materials for Cleaning

- Q-tips (make sure the Q-tip brand does not contain any lotions or softeners)
- High-purity acetone, methyl alcohol or isopropyl alcohol.
- 1/16” Allen wrench
- Small Phillips-head screwdriver
- Can of compressed air

1.11.1.2 Cleaning Procedure

Note: A video of this cleaning procedure is available on the DMT YouTube channel, https://www.youtube.com/user/dropletmeasurement. See the “FM120 Cleaning” video.

1. To clean the FM-120 windows, remove the access panel shown in Figure 13. Use the Allen wrench to remove the #4 screws.

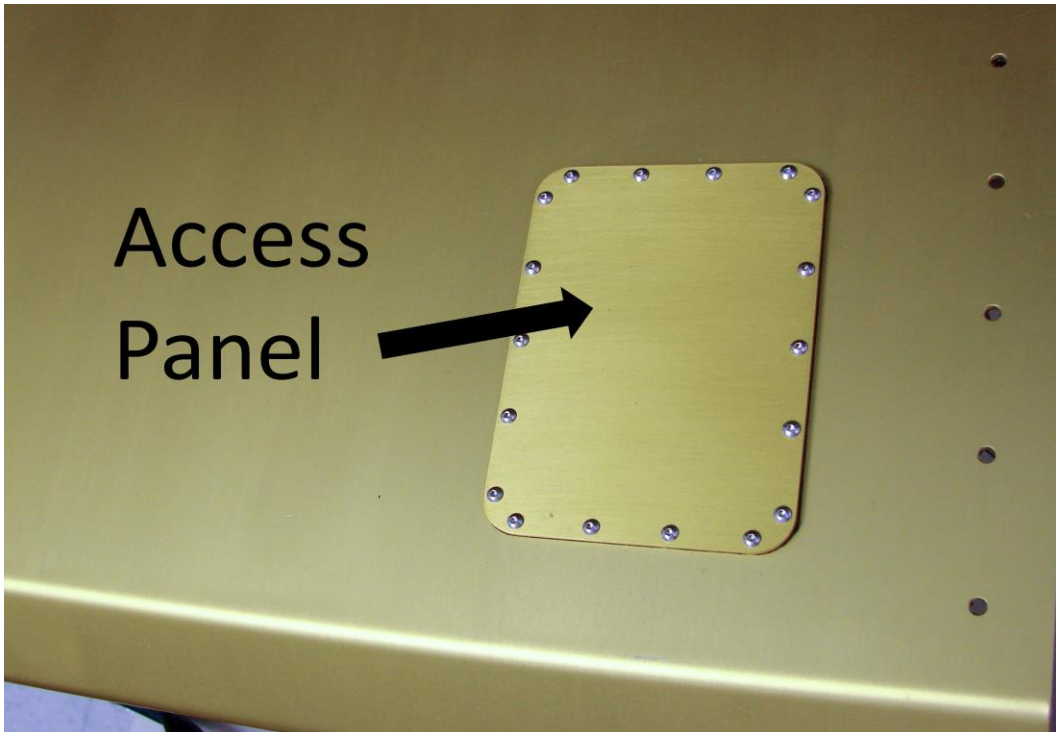


Figure 13: Fog Monitor Access Panel

2. Using the Phillips-head screwdriver, remove the two small screws visible once the access panel has been removed (Figure 14).

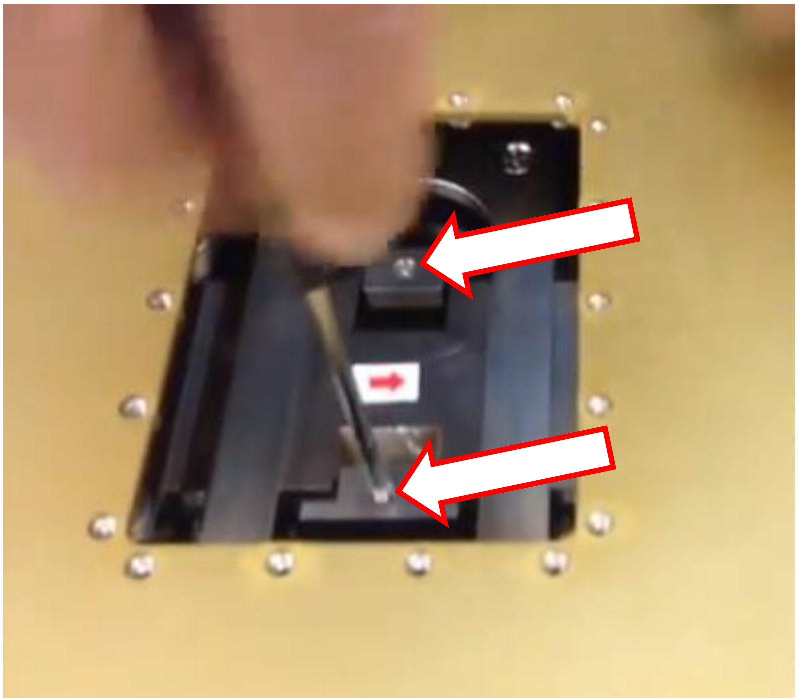


Figure 14: Removing Screws Underneath Access Panel

3. Use the screwdriver as a lever to lift the window gently out. Do not lift it fully out at this point; simply loosen it.

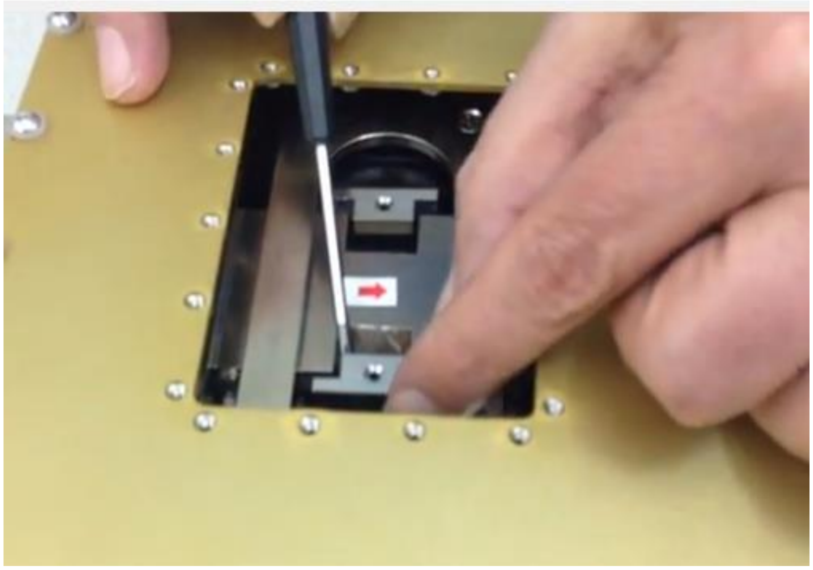


Figure 15: Gently Lifting the Window

4. Next, gently push the window with your finger as shown in Figure 16.

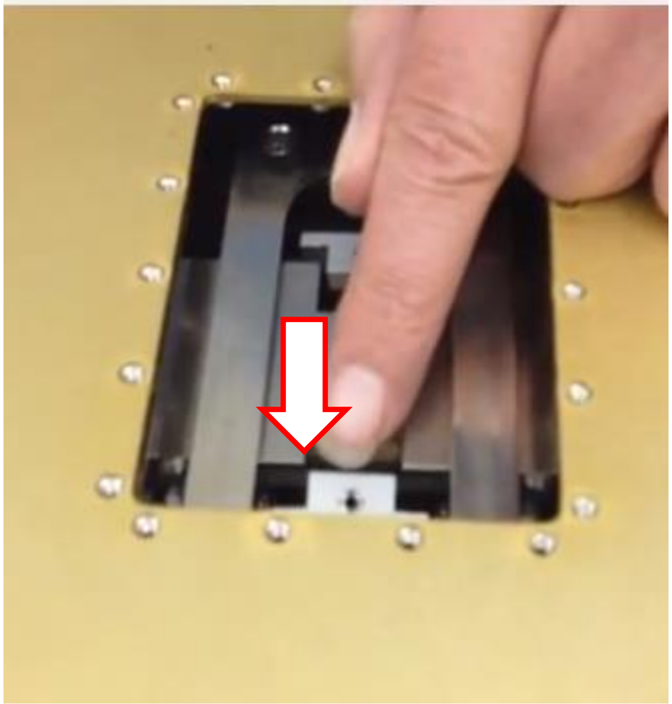


Figure 16: Pushing the Window

5. Now the window is ready to be lifted completely out (Figure 17).

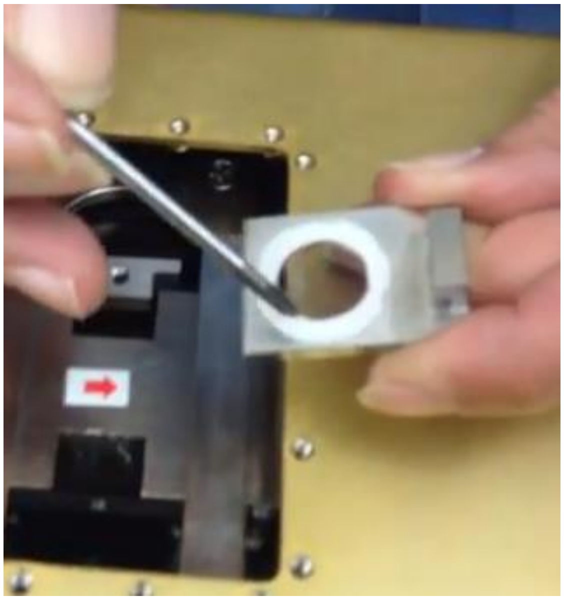


Figure 17: Removed Window with O-Ring

6. Using canned air, first blow off any large chunks of dirt.
7. Take the acetone and pour a few drops onto the Q-tip. (Avoid dipping the Q-tip in acetone, as this can contaminate the acetone.) Shake off the excess liquid.
8. Swipe the Q-tip across the glass, rotating the Q-tip so that the used portion turns up toward you. Rotating the Q-tip prevents the windows from getting scratched by grit.

Figure 18: Swiping Glass

9. Dispose of the Q-tip.
10. Continue swiping window until the window looks clean. Use a new Q-tip and fresh acetone for each swipe. You may need to tilt the window in different directions to see if it is clean.

Note: In some cases, you may have a residual spot around the window that the acetone cannot clean. In this case, you can use white vinegar. Vinegar is not recommended for mundane cleaning purposes, however.

11. Reinsert the window into the FM-120. Insert the window at an angle (Figure 19) to keep the glass off the O-ring until the last moment.

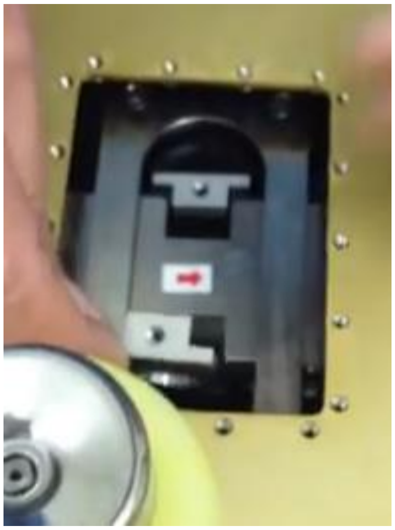


Figure 19: Reinserting Window

12. Push the window forward and then down.

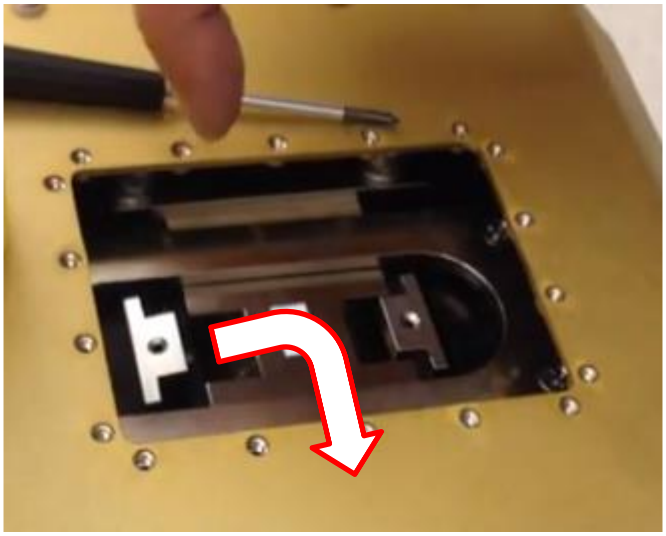


Figure 20: Securing the Window

13. Repeat the cleaning process for the second window.

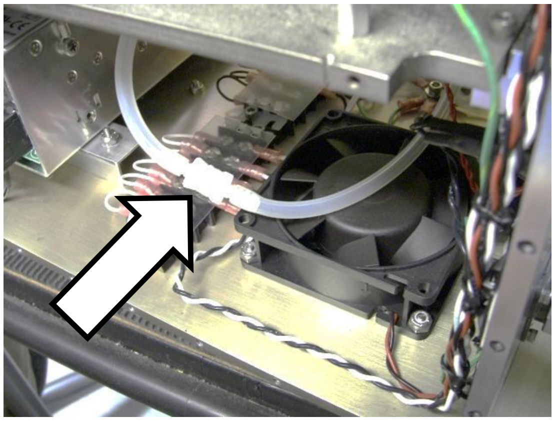
14. Reinstall the two screws that secure the two windows. You may need to shift the window slightly to align the screw-hole properly.

15. When cleaning is complete, reinstall the access panel.

1.11.2 Cleaning the Pitot Tube

To drain the Pitot tube line, first unplug the instrument. Then remove the entire instrument cover.

Next, rotate and pull apart the tips of the Pitot tube line (Figure 3) to drain excess water.



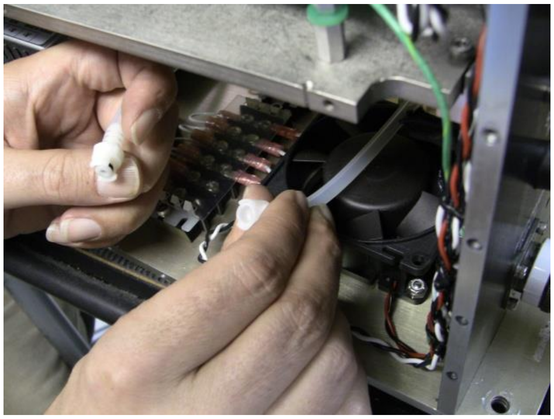


Figure 21: Draining Pitot Tube Line

Calibration

Precision glass beads can be used to verify the calibration on the FM-120. Glass beads of a known size are injected into the sample area, and the instrument sizes them. The resulting particle-size histogram should show a definite peak at a size slightly smaller than the size of the glass beads (see next paragraph).

The FM-120 is calibrated to measure water particles, and water and glass have different refractive indexes. As a result, the particle sizes measured by the instrument will be about 80% of the actual size of the glass beads. The conversion table in *Appendix B* provides corresponding water droplet sizes for given glass bead sizes. The water-droplet size indicates where the number of particles detected during calibration testing should peak. For instance, if 17-µm glass beads are used for testing, the particles detected by the instrument should peak at about 14 µm.

1.12 Required Equipment

To calibrate the FM-120 with glass beads, the following equipment is needed:

- Can of compressed gas (also called a "duster") to clean the bead dispenser and calibration device. See Figure 22 for examples of dusters. These are generally available at electronics supply stores or computer stores.
- Bottle of certified glass beads, as shown in Figure 23. These are available from DMT.
- Glass bead dispenser, pictured in Figure 24.
- Calibration fixture for the instrument, designed to keep the glass beads within the appropriate depth of field. Figure 25 shows the calibration fixture for the Fog Monitor.

Figure 22: Compressed Gas Cans or "Dusters"

Figure 23: Bottle of Glass Beads, DMT OP-0591-0020

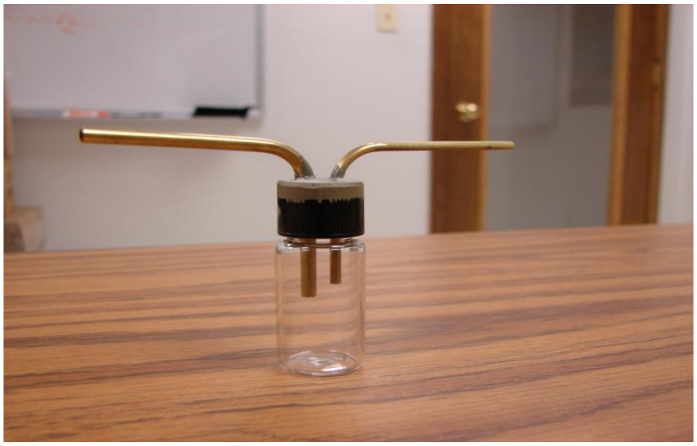


Figure 24: Glass Bead Dispenser, DMT AD-0164

Figure 25: Fog Monitor Calibration Fixture, DMT ASSY-0453

1.13 Instructions

1.) Turn on the instrument system power, turn on the pump, and start the data acquisition system.
2.) Using the duster, clean the glass bead dispenser by blowing air through it (Figure 26). Make sure the bottom of the cap and tubes are cleaned as shown on the left in Figure 26. Also clean the dispenser’s glass canister as shown on the right.

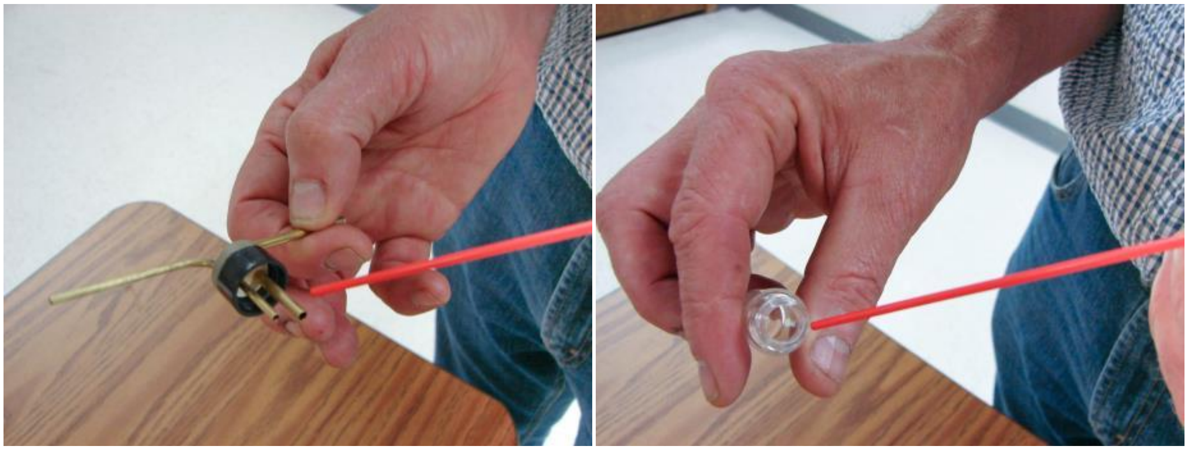


Figure 26: Cleaning the Glass Bead Dispenser

3.) Clean the calibration device with the duster by blowing air down the tube.

Note: Steps 2 and 3 should be performed at the start of each calibration test session and whenever a new size of glass beads is being used. Steps 2 and 3 may be bypassed for repeated tests with the same size of glass beads.

4.) Turn the bottle of glass beads upside down and then right side up. This will leave a thin film of beads on the lid of the bottle.

5.) Place the lid of the bottle over the bead dispenser. Tap the dispenser lightly against a table to dislodge the beads on the lid. (See Figure 27.) A very thin film of beads should appear in the dispenser, as shown in Figure 28.

Warning: Do not pour glass beads directly into the dispenser. Doing so will result in too many beads entering the sample space, which may compromise sizing.

Figure 27: Tapping the Bead Dispenser to Dislodge Beads

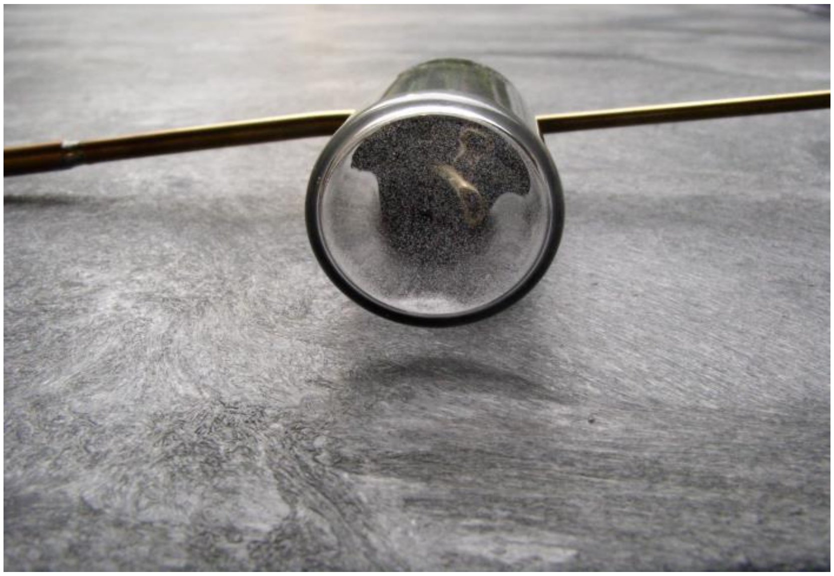


Figure 28: Dispenser with Film of Beads on Bottom

6.) Replace the lid on the glass bead bottle. This prevents water infiltrating the beads, which can cause clumping.
7.) Place the calibration fixture in the instrument. Figure 29 shows a calibration fixture being inserted into an FM-120.

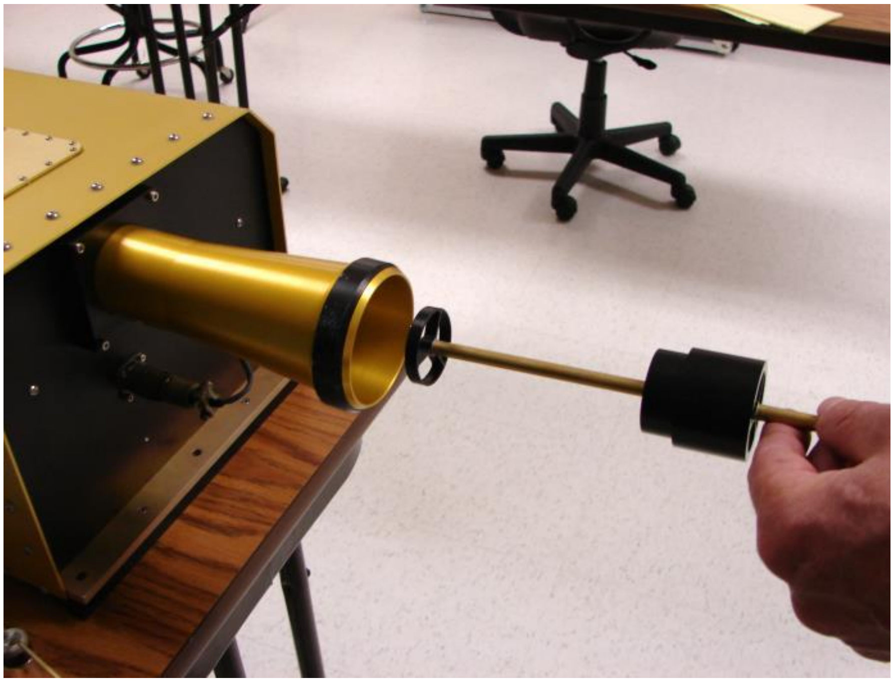


Figure 29: Inserting the Calibration Fixture into the Fog Monitor. The calibration fixture should be placed as far into the instrument's inlet as it will comfortably go.

8.) Connect the tube on the calibration fixture's far end to the dispenser and connect the dispenser to the duster. (See Figure 30.) *Gently* press the duster so glass beads are released into the instrument. A very small amount of pressure on the trigger of the duster will suffice. The calibration should be done in a short burst about 1 second or less. There will be a delay of 1-3 seconds before the data shows on the computer screen. (See Figure 31.) The total number of particle counts, not concentration, should be 30-200. This is summed across all of the bins.

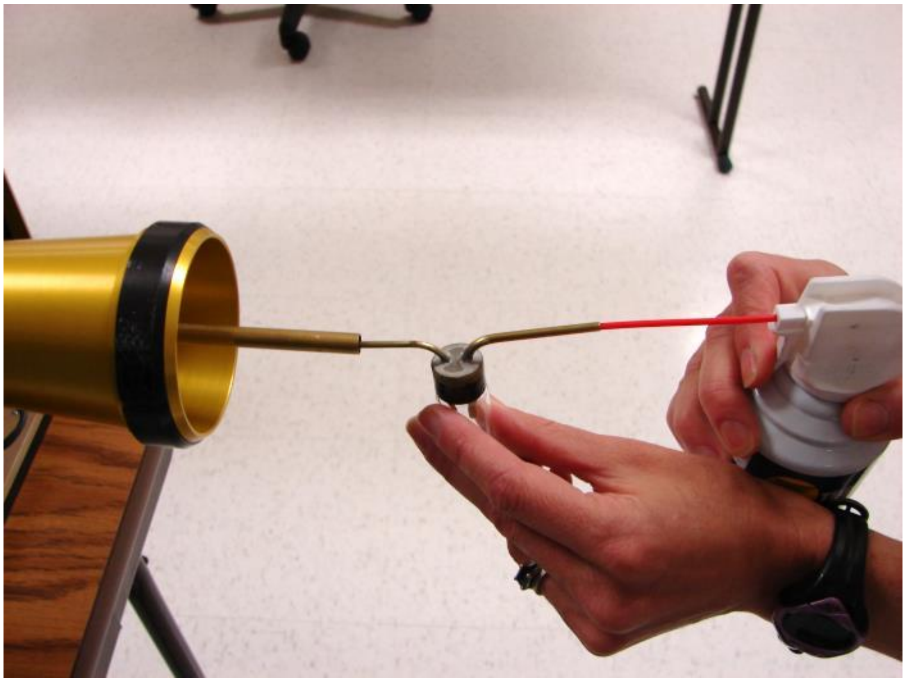


Figure 30: Blowing Glass Beads through the Calibration Device

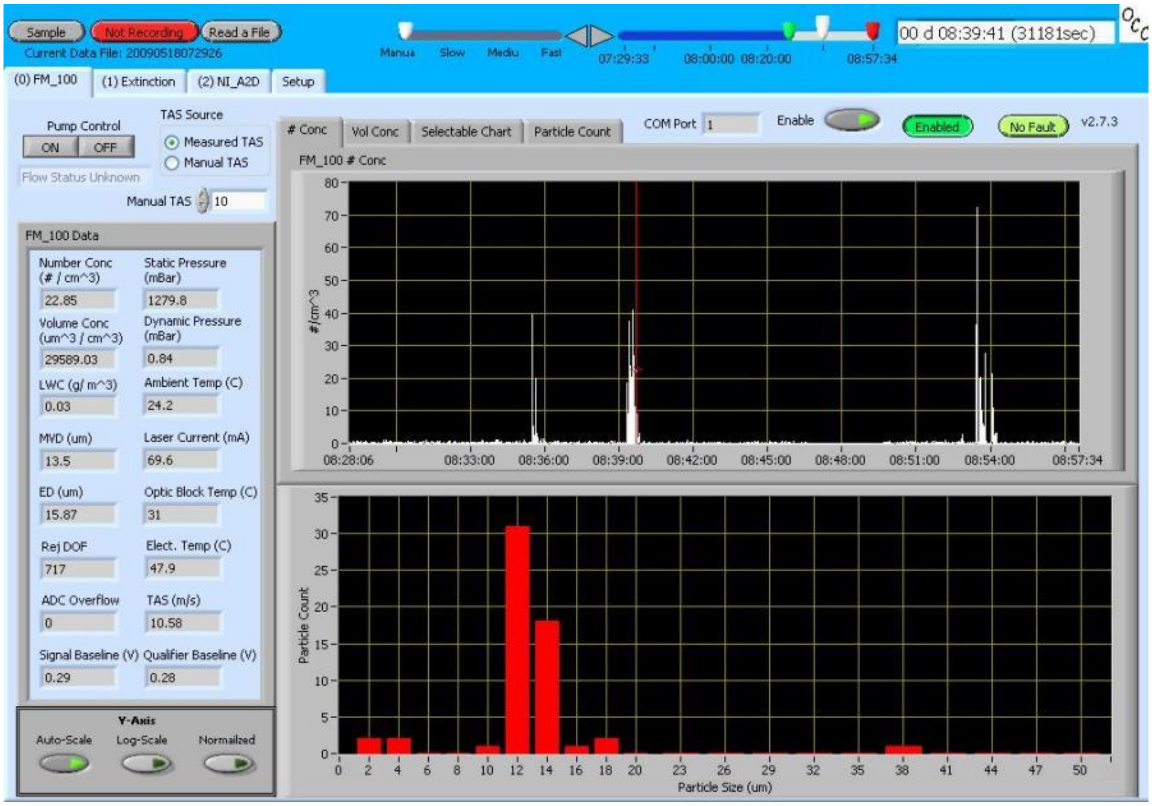
9.) Keep pressing the duster as necessary, checking the data system display to see if the instrument is detecting the glass beads. Ideally, the histogram display should peak at the water droplet size that corresponds to the size of the glass beads being testing. See *Appendix B* for exact glass-to-water conversion values.

    Warning: Make sure to read the label on the bottle of glass beads carefully when determining bead size. Often the size listed most prominently is not the most exact size. The label on the bottle in Figure 23, for instance, lists the beads as size 20 µm, but further down the size is clarified as being 17.3 ± 1.4 µm.

10.) When calibration testing is complete, remove the calibration fixture from the instrument.

Figure 31 shows the typical calibration response for the FM-120. Note that the total number of particle counts is about 50 particles, which is an acceptable concentration. The nominal size of the glass beads is 17.3 µm. In consulting Appendix B, the equivalent water size is 14.5 µm. In Figure 31, there are two predominate peaks, one at 12 µm and the other at 14 µm. The designations are the upper boundaries of bins, so the major peak is 10-12 µm and the other peak is 12-14 µm sizing. While these peaks occur at particle sizes slightly smaller than one might expect, they are acceptable given the +/- 1.4 µm variation in glass bead size and a 12% coefficient of variation.

For more information on interpreting glass beads test results, see *Appendix C.*



Current Data File: 20090518072926

00 d 08:39:41 (31181sec)

COM Port: 1

TAS Source: ● Measured TAS ○ Manual TAS

Manual TAS: 10

Number Conc (# / cm^3): 22.85
Static Pressure (mBar): 1279.8
Volume Conc (um^3 / cm^3): 29589.03
Dynamic Pressure (mBar): 0.84
LWC (g/ m^3): 0.03
Ambient Temp (C): 24.2
MVD (um): 13.5
Laser Current (mA): 69.6
ED (um): 15.87
Optic Block Temp (C): 31
Rej DOF: 717
Elect. Temp (C): 47.9
ADC Overflow: 0
TAS (m/s): 10.58
Signal Baseline (V): 0.29
Qualifier Baseline (V): 0.28

Figure 31: PADS Display of Calibration Test Results. Note the definite peak in the 14 µm range for 17 µm glass beads.

Particle Analysis and Display Software (PADS)

For details on the PADS FM-120 module, consult the *PADS Fog Monitor Manual*, DOC-0285.

Dynamic Threshold Feature

The FM-120's dynamic threshold feature automatically adjusts the instrument's sizer and qualifier signals to account for drifts due to temperature changes.

1.14 Dynamic Threshold for Sizer Signal

The dynamic threshold feature works as follows. The instrument's sizer signal voltage is digitized with a 12-bit ADC, which yields a 0 to 4095 count. A histogram is created of all counts between 0 and 512. (Signals above 512 are assumed to be responses to particles, and thus not relevant to establishing the baseline.) The system then identifies the narrowest band that contains at least 75% of counts in the histogram. This band, referred to as the "noise band," is the system's attempt to identify a range for baseline noise when no particles are present.

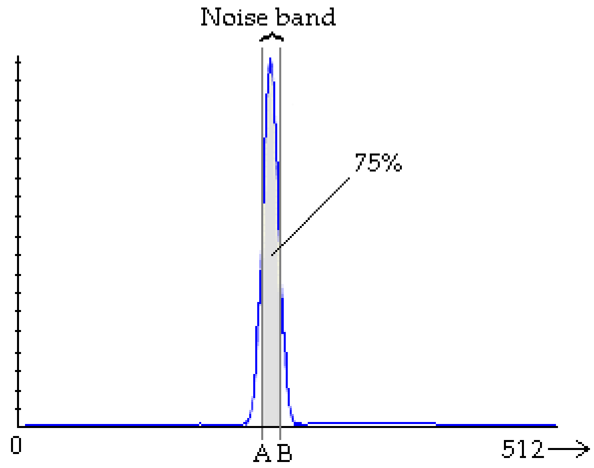


Figure 32: Identifying a Noise Band

If the noise band exceeds 20 counts (i.e., the width is too wide), or if no noise band was identified, the previous noise band is used. These qualifications are imposed in order to distinguish the noise from actual particle events. The instrument then uses the noise band to adjust the sizer baseline and identify particles. The noise band updates at a rate of 10 Hz.

There are two FM-120 output channels related to dynamic thresholding for the sizer signal. **Sizer Noise Bandwidth** is the width of the noise band—that is, [B – A] in Figure 4. **Sizer Baseline Threshold** is the upper boundary of the noise band, i.e. B in Figure 4. Both of these channels are given in digital counts.

1.15 Dynamic Threshold for Qualifier Signal

Dynamic thresholding for the qualifier signal works exactly as it does for the sizer signal, except that the qualifier signal is used to determine the noise band and the qualifier signal is subsequently adjusted. **Qualifier Noise Bandwidth** is the width of the noise band—that is, [B – A] in Figure 4. **Qualifier Baseline Threshold** is the upper boundary of the noise band, i.e. B in Figure 4. Both of these channels are given in digital counts.

Theory of Operation and Firmware

1.16 Overview

As particles pass through the laser beam, photons are scattered in all directions. The cone of photons that is forward scattered in the 4° to 12° range is collected and directed onto a 33%/67% optical beam splitter, and then to a pair of photodetectors. The photodetectors convert the photon pulses into electrical pulses. One photodetector sees 33% of the collected light and one photodetector sees the 67% of the light collected from the particles that pass through the laser beam if, and only if, the scattered light is collected and focused through the optical mask. This area of the laser beam, where scattered light is focused through the optical mask, is called the *Depth of Field* (DOF). The outputs from these two detectors are referred to as ***Sizer*** and ***Qualifier***.

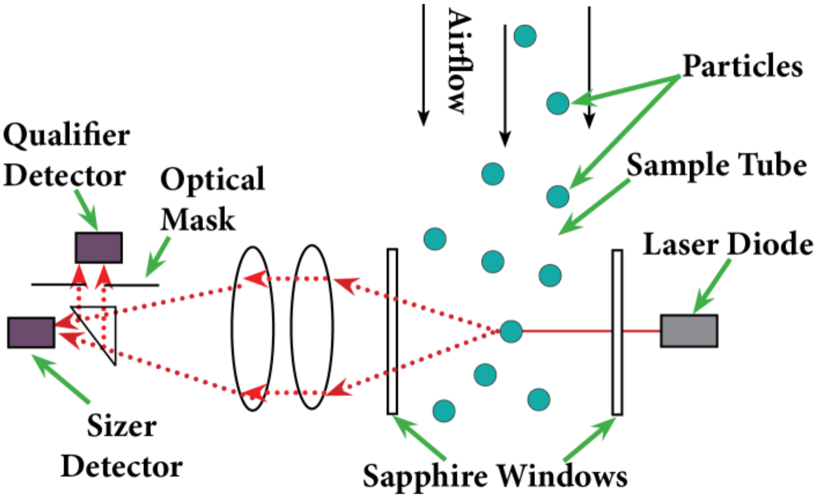


Figure 33: Theory of Operation

The location of the particle in the beam is a critical piece of information needed to interpret the measurement. The intensity of the scattered light will depend upon the size, composition, shape of the particle, and the intensity and wavelength of the incident laser light. The amount of light collected will depend upon how far the particle is from the collecting optics when it passes through the beam. For accurate sizing, the Fog Monitor must accept and size only particles that pass through a uniform power region of the laser beam, creating the need for the “qualified” particle. The voltage pulse from the ***Sizing*** detector is compared with the voltage pulse from the ***Qualifying*** detector, and a digital flag is raised if the masked detector’s output exceeds that of the signal to be sized. This indicates if light scattered from a particular particle is within the DOF. Particles that do not raise the DOF flag are ***DOF Rejected***.

1.17 Interpreting Sizer and Qualifier Channels in the Fog Monitor’s PBP File

The FM-120 can generate particle-by-particle files that contain detailed information about particular particles. Several data channels are recorded for each PBP particle, including **Sizer Peak** and **Sizer Transit Time**, **Qualifier Peak** and **Qualifier Transit Time**, and **Delta Peak Time (S-Q)**. The example below explains these channels in more detail.

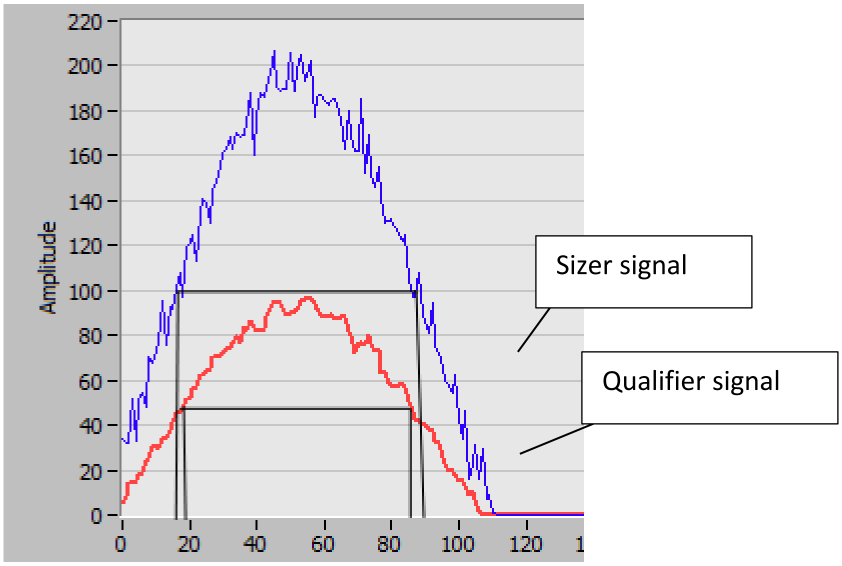


Figure 34: Raw Data Plot of the Sizer and Qualifier Signals

Figure 34 shows sample data from one particle. The peak signals are the maximum values of the samples taken. The maximum possible value is 4095. For this example, **Sizer Peak** would be ~205 and **Qualifier Peak** would be ~95.

To calculate **Transit Time** for either signal, first divide the signal's peak value by two. The time at which the signal first reached this half-peak point is then subtracted from the time of the second half-peak point. The transit time is thus the full width of half max. In this example, the S peak is 205 so half is about 102; the time at the first point is 15 and the time at the second point is 90, so the full width half max is 90-15 = 75. Each sample point is 25 nano-seconds, so a Transit Time of 75 is equal to 25 * 75 = 1875 ns.

Delta Peak Time (S-Q) equals the Sizer peak minus the time at the Qualifier peak. In the example above, **Sizer Peak** is about 45 and **Qualifier Peak** is about 55, so **Delta Peak Time (S-Q)** would be approximately -10.

1.18 System Vacuum Source

The sample needs to be pulled through the optical system. This is accomplished with a regenerative pump. The air flow rate is measured with a Pitot tube located just behind the sample area. Static pressure, differential pressure, and ambient temperature are measured, as these are required to determine air density. Finally, airflow is calculated in meters per second.

1.19 Remote Control

The FM-120 can be turned on and off by remote control through the “SERIAL DATA” connector. To utilize this feature, place the main power switch in the “REMOTE CONTROL” position, and apply +12 VDC to pin A of the “SERIAL DATA” connector and connect pin B to the return. Placing the power switch in the “REMOTE CONTROL” position, place a solid state relay in control of the system power which will then be activated via the external input.

Communications between the PC and FM-120 Firmware

Any computer capable of communications over an RS-232 or RS-422 port should be capable of communicating with the FM-120. The port parameters for communications should be set to the Baud rate specified in PADS, 8 data bits, and one stop bit with no parity checking. Since binary data are sent across the interface it is possible that some systems will react to the non-ASCII characters that are sent as control characters. It is recommended that all communications with the FM-120 electronics be programmed at a low level to avoid this problem.

The host computer initiates all communications with the firmware electronics. There are several commands that the firmware responds to, which are listed in the table below. Each command is preceded by an ESC character (“1B”). The command number (e.g., “01”) follows.

1B01	Initialize
1B02	get normal data, no PbP and no Raw PbP
1B03	get normal data and PbP data
1B04	get normal data and PbP data and Raw PbP data
1B05	get firmware version

The firmware only responds with data after it has received a request for data, so all of the timing for data acquisition needs to be performed in the host processor. To increase the data rate from the probe, the host only needs to increase the rate at which it makes requests for data. After filing a data request, the firmware clears all of its summation and starts taking a new set of data.

1.20 SETUP DATA ACQUISITION PARAMETERS COMMAND

The table below shows the format of the packet PADS sends to the firmware to set up the data acquisition parameters. These parameters will remain until power is cycled or a new setup data acquisition parameters command is sent.

Start Byte	Length in Bytes	Parameter Name

0	2	ESC and command number (1B01)
2	2	ADC Lower Thresh
4	2	# of PbP packets
6	2	Channel Count
8	2	# of bytes of raw data per channel
10	2	Pump Control
12	2	DOF Reject
14	80	Thresholds (40 bins)
94	2	Checksum

For command number 01 (setup data acquisition parameters) the probe responds with two ACK characters (ASCII character 6).

1.21 SEND DATA (POLL REQUEST) COMMAND

PADS sends the firmware one of the following commands to get data:

1B02	get normal data, no PbP and no Raw PbP
1B03	get normal data and PbP data
1B04	get normal data and PbP data and Raw PbP data

1.22 Response to SEND DATA COMMAND

The FM 120 responds with the following data when polled. Note that the data in italics is only sent if it was requested. PbP data is sent in the event of a 03 or 04 command, while raw data is only sent with an 04 command.

Start Byte	# of Bytes	Name	
0	2	HK 1	Laser Current
2	2	HK 2	Laser Power
4	2	HK 3	Laser Block Temperature
6	2	HK 4	Window Temperature
8	2	HK 5	Spare

10	2	HK 6	Static Pressure
12	2	HK 7	Pitot Pressure
14	2	HK 8	Electronics Temperature
16	2	HK 9	Power Supply Temperature
18	2	HK 10	Top Plate Temperature
20	2	HK 11	Recovery Temperature
22	2	HK 12	Detector Temperature
24	2	HK 13	Inlet Horn Temperature
26	2	HK 14	Spare
28	2	HK 15	NA
30	2	HK 16	NA
32	4	DOF Reject	
36	2	unused	
38	2	Sizer Baseline Threshold	
40	2	Sizer Noise Bandwith	
42	2	Qualifier Baseline Threshold	
44	2	Qualifier Noise Bandwidth	
46	4	Oversize Reject	
50	120	Histogram/Bin Data (4 bytes per bin, 30 bins)	
170	6	Timer response header	
176	*	*PbP Data (12 bytes per PBP particle)*	
*	*2080*	*Raw Data*	
*	2	CheckSum	

* These numbers depend on the amount of PbP data sent.

1.22.1 Definitions of the *Send Data* Response Parameters

Table 3 provides definition for the channels in the FM-120 data packet. For housekeeping channels, shaded in gray, the appropriate conversion equation is also provided. This conversion equation allows the user to calculate meaningful values (i.e., values in volts or degrees Celsius) from the original analog reading, *x*.

Channel	***Definition***	***Conversion Equation***
Housekeeping [1-16]	An array which holds the most recent Analog-to-Digital conversion values for the 16 analog housekeeping channels.	Varies

Laser Current (mA)	The electrical current flowing through the instrument's laser diode. A sudden change could reflect a problem with the instrument. A reading of zero indicates a failure.	$0.061x$
Laser Power (V)	The relative laser power as measured by the onboard laser power monitor. This channel is useful for observing general trends, but currently it does not accurately indicate absolute laser power. Laser power should stay stable ±20%. Vacillation beyond this boundary indicates a problem with the laser.	$0.00122x$
Laser Block Temp (C)	The temperature at the laser block. The laser temperature is controlled, so this channel should be relatively stable. Healthy readings are 20 – 30°C.	Thermistor D*
Window Temp (C)	The temperature at one of the Fog Monitor windows. This temperature reading should be at or above ambient. If the windows get too cold, they may fog over.	Thermistor D*
Static Pressure (mBar)	The static pressure as measured by the Pitot-Static tube system.	$-210.546 + 0.328318x$
Dynamic Pressure (mBar)	The static pressure minus the stagnation pressure, as measured by the Pitot-Static Tube system.	$-0.002435 + 0.000609x$
Electronics Temp	The electronics temperature, which should stay under 45° C.	$153.973 - 0.04819x - 8.60917\text{x}10^{-7}$
Power Supply (V)	The temperature at the power supply.	Thermistor D*
Top Plate Temp (C)	The temperature on the FM-120's top aluminum plate.	Thermistor D*
Recovery Temp (C)	The measured temperature of the air immediately in contact with the probe. used in calculating ambient temperature and probe air speed.	$-50 + 0.02442x$
Detector Temp (C)	The temperature at the detector block that houses the sizer and qualifier photodetectors.	Thermistor D*

Inlet Horn Temp (C)	The temperature at the FM-120 inlet horn. This temperature is controlled so that the inlet horn does not ice over. It should stay at 25 ± 2 ° C.	Thermistor D*
S Noise Bandwidth	The width of the S detector’s noise band in digital counts. See section 0 for more information.	
S Baseline Threshold	The upper boundary of the S detector’s noise band in digital counts. See section 0 for more information.	
P Noise Bandwidth	The width of the P detector’s noise band in digital counts. See section 0 for more information.	
P Baseline Threshold	The upper boundary of the P detector’s noise band in digital counts. See section 0 for more information.	
Oversize Reject	A counter for how many times that the Analog to Digital Converter was at its maximum digitized count (4096). These particles are not processed into the calculated parameters and only reported as “over-range particles”.	
Bin Counts	An array which holds the digital thresholds for the different peak size channels which are defined in the Setup command.	
Checksum	The 16-bit sum of the characters in the packet.	

Table 3: Definitions and Conversion Equations for Channels in the FM-120 Data Packet

* Thermistor D refers to the following equation:

$$\left\{ln\left[\frac{5}{x \times \left(\frac{5}{4095}\right)} - 1\right]\left(\frac{1}{3750}\right) + \left(\frac{1}{298}\right)\right\}^{-1} - 273$$

1.22.2 PBP Data

Fourteen bytes of PBP data are sent for each PBP particle. These bytes break down as follows, with each datum taking up two bytes:

- Arrival time in one-microsecond resolution
- Sizer peak (0 to 4095)
- Qualifier peak (0 to 4095)
- Sizer transit time (full width of half max)
- Qualifier transit time (full width of half max)
- Sizer peak address (0 to 511)
- Qualifier peak address (0 to 511)

1.22.3 Raw Data

The FM-120 electronics capture one raw waveform of sizer and qualifier signals during each sampling period. The sample resolution is 25 nanoseconds, and each sample is 12 bits (0 – 4095 counts). The sizer and qualifier samples are concatenated to give 24 bits, or 3 bytes. There are 512 samples of interweaved sizer and qualifier samples sent to PADS. The total sample size is thus 512 * 3 = 1536 bytes.

The two waveforms can be displayed in PADS. See Figure 34. The ideal waveform will look like a Gaussian curve.

Selection of Channel Size Thresholds

The FM-120 classifies the size of a particle by comparing its digital peak value with a table of values set to represent a functional relationship between Mie scattering intensities and particle size. These values can be determined by generating the appropriate list of scattering cross-sections as a function of particle size using the wavelength of the Fog Monitor’s laser diode (0.658 μm), its collection angles (nominally 3.5° - 12°), and the refractive index of the particles that are likely to be measured. In the case of water, this is 1.33 -0.0000i.

Appendix A: Fog Monitor True Air Speed Calculation for PADS

Sensor Conversions

Note: channel numbers begin with 0, as per C array convention.

Sensor #1: Ashcroft RxLdp 0 to 2” Water differential (dynamic / pitot) pressure, channel 6:

This sensor puts out 0 to 10 volts, corresponding to 0 to 2” of Water Column. Convert the analog to digital value (A/D) read to pressure via the following equation:

$Qc = 2.4884 * (((20* (A/D)/4095) - 10) / 5)$ in millibars

PADS Gain = 2.43067155e-3

PADS Offset = -2047.5

Sensor #2: Sensym 142SC15A 0 to 15 PSI static pressure, channel 5:

This sensor puts out 1 to 6 volts, corresponding to 0 to 15 PSI. Convert the A/D value read to static pressure via the following equation:

$Ps = (((20*(A/D)/4095) – 10) - 1) * 3) * 68.9476$ in millibars

PADS Gain = 1.01022

PADS Offset = -2252.25

Sensor #3: AD590 ambient temperature sensor, channel 2:

This sensor puts out 0 to 10 volts over the range of temperatures –50 to +50 degrees C. Convert the A/D value read to temperature via the following equation:

$Tm = (((20*(A/D)/4095) –15) * 10)$

PADS Gain = 48.84004884 e-3

PADS Offset = -3071.25

Assign the following variables, using the derived values from the equations above:

Tm = Measured (recovered) Ambient Temperature (housekeeping value number 2)

Qc = Dynamic (Pitot) Pressure (housekeeping value number 6)

Ps = Static Pressure (housekeeping value number 5)

Cp = Specific heat at constant pressure: 0.24 cal g^{-1} K^{-1}

Cv = specific heat at constant volume: 0.171 cal g^{-1} K^{-1}

R = gas constant for dry air: $6.8557*10^{-2}$ cal g^{-1} K^{-1}

B = Boltzmann's Constant (gas constant per molecule)= $1.38*10^{-23}$ joule $molecule^{-1}$ K^{-1})

Γ **=** Cp / Cv = 1.4

r = 1. Recovery coefficient of our temperature sensor. $r = (1 - f^2)$, where f is the fraction of true air speed, TAS, that the air around the sensor is flowing. Currently, r should be assumed to have value unity, and this is sent in the CIP setup command (see setup command for details)

First, the Mach number, M, must be calculated:

M = Mach number = $\{2(cv/R)[(Qc/Ps +1)^{R/cp} -1]\}^{0.5}$

Note: the speed of sound $S = [\Gamma * B * Ta / m]^{0.5}$
$= 20.06 * Ta^{0.5}$
where m is the mass of one molecule of air, $4.8 * 10^{-26}$ Kg

Next, the recovered temperature is corrected to the actual ambient temperature:

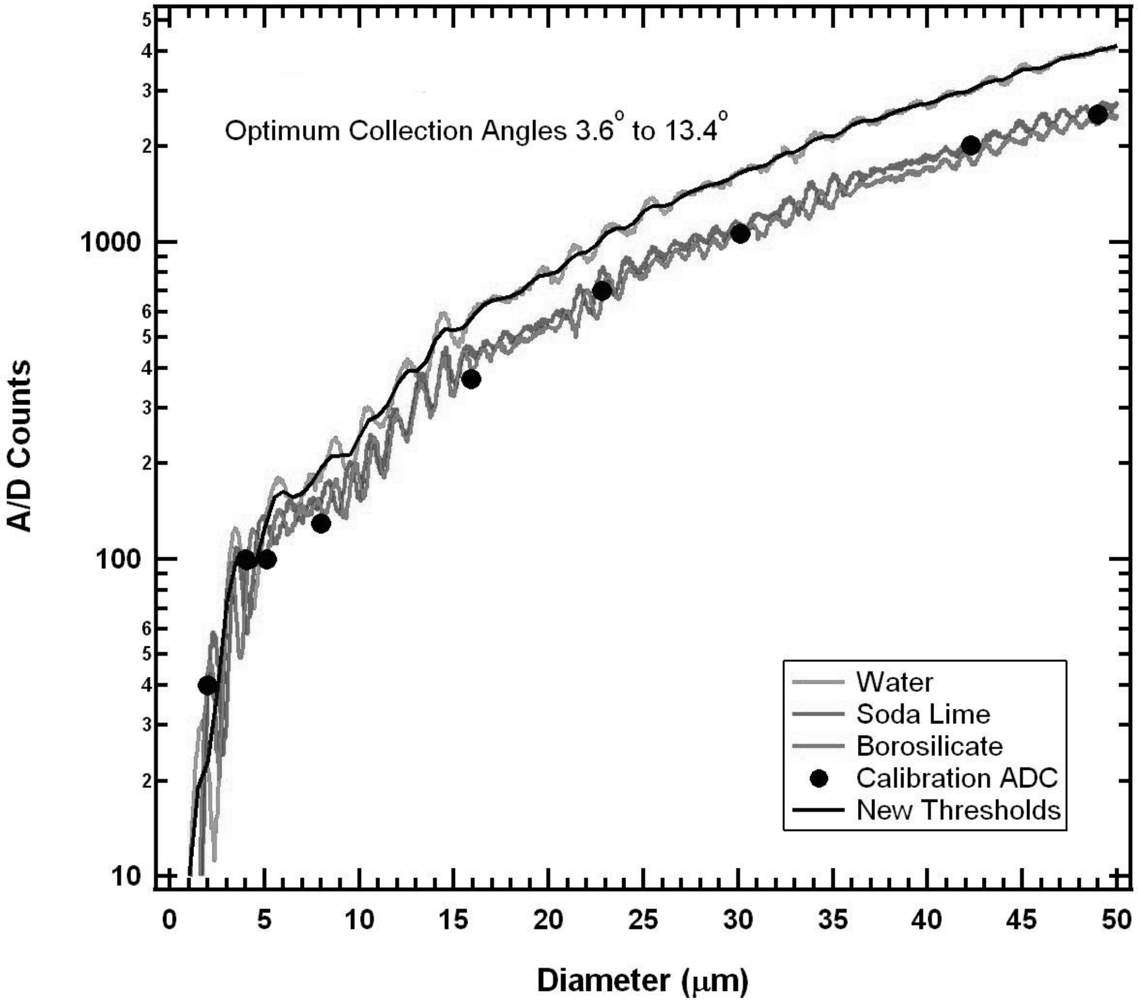
$Ta = Tm / [1 + r M^2 (\Gamma - 1)/2]$

From these, the true air speed is calculated:

TAS = M * 20.06 *

Appendix B: Glass Bead to Water Droplet Conversion

The following graph shows the refractive indices for water and three materials often used to calibrate the FM-120: soda lime glass, borosilicate glass, and PolyStyrene Latex (PSL). The FM-120 typically ships with 30 µm soda lime beads. Check your bottle if you are not sure whether your glass beads are soda lime or borosilicate.



The table on the following pages shows exact glass and PSL bead to water conversion values. Thus a Soda Lime particle with diameter 49µm will display as a 40.5µm particle on a properly calibrated FM-120, since the instrument is calibrated with a water standard. Note that this table is specific to the FM-120. Do not use a generic conversion table for calibration bead to water droplet conversions.

Water	Soda Lime	Borosilicate	PSL
2	1.75	1.8	1.7
2.5	2.3	2.35	1.95
3	3.3	3.35	2.85
3.5	4.05	4	3.9
4	4.1	4.1	3.9
4.5	4.35	4.3	4
5	5.2	5.25	5.1
5.5	6.1	6.15	6.15
6	6.35	6.4	6.25
6.5	6.55	6.6	6.3
7	7.35	7.45	7.3
7.5	8.2	8.35	8.3
8	8.4	8.6	8.35
8.5	8.85	8.95	8.45
9	9.85	10.05	9.6
9.5	10.9	11.15	10.7
10	10.95	11.2	10.7
10.5	11.15	11.45	10.8
11	12.65	13.05	12.9
11.5	14.45	15.2	15.15
12	14.55	15.35	15.15
12.5	14.7	15.55	15.3
13	16.2	17.35	16.45
13.5	17.7	18.65	18.1
14	18.15	19.2	18.95
14.5	18.75	19.6	19.1
15	19.35	20.15	19.1
15.5	19.95	20.75	20.15
16	20.3	21.1	21.2
16.5	20.7	21.55	21.3
17	21.15	22	21.6
17.5	21.6	22.3	22.35
18	22.05	22.7	22.5
18.5	22.35	23	22.5
22	25.45	26	25.75
22.5	26.05	26.75	26.8
23	26.15	26.85	26.8
23.5	26.5	27.1	26.9
24	27.35	28.1	27.95
24.5	28.15	28.85	28.1
25	28.3	29	29
25.5	28.65	29.45	29
26	29.85	30.7	31.2
26.5	30.7	31.7	31.35
27	30.7	31.7	31.35
27.5	31.1	32.2	31.5
28	32.65	33.95	33.55
28.5	33.85	35.6	35.9
29	33.9	35.7	35.9
29.5	34.45	36.2	36.85
30	36.2	38.55	38.75
30.5	37.75	40.05	40.65
31	38	40.25	40.65
31.5	38.75	40.9	40.8
32	40.4	42.6	43.15
32.5	41.4	43.3	43.3
33	41.65	43.5	43.3
33.5	42.2	44.05	44.15
34	43.35	45.15	45.2
34.5	44.1	45.85	45.35
35	44.2	45.9	45.35
35.5	44.5	46.2	46.4
36	45.3	46.9	47.4
36.5	45.8	47.4	47.55
37	46.15	47.7	47.55
37.5	46.55	48.05	47.7
38	46.85	48.45	48.6
38.5	47.25	48.9	48.6

19	22.5	23.15	22.65
19.5	22.95	23.55	23.5
20	23.7	24.35	23.65
20.5	24.25	24.85	24.55
21	24.25	24.9	24.55
21.5	24.45	25.1	24.55

39	47.8	49.45	48.75
39.5	48.25	49.85	49.75
40	48.5	50.15	50.65
40.5	48.8	50.45	50.7
41	49.4	51	50.8
41.5	49.85	51.55	51.85

Water	Soda Lime	Borosilicate	PSL
42	50.1	51.9	52
42.5	50.6	52.45	53
43	51.35	53.3	53.15
43.5	51.9	53.8	54.05
44	52.05	54	54.05
44.5	52.55	54.6	54.2

Water	Soda Lime	Borosilicate	PSL
49	60.35	63.85	63.95
49.5	61.4	64.75	65.75
50	61.6	64.9	65.85
50.5	62.6	65.9	66
51	64.2	67.25	68.1

Appendix C: Interpreting Glass Beads Calibration Tests

The FM-120 is typically calibrated with precision glass beads. Figure 35 through Figure 43 show the results of such tests as the FM-120 is progressively moved out of alignment. Figure 35 through Figure 37 are for 8-µm beads, Figure 38 through Figure 40 for 20-µm beads, and Figure 41 through Figure 43 for 40-µm beads. *Note: While these screenshots are of old software, the histogram displays look similar to those in the current version of PADS.*

Figure 35, Figure 38, and Figure 41 show the calibration with a properly aligned FM-120. The FM-120 response to the calibration beads gives a narrow histogram with the bead sizing falling in the proper bin (see note below). As the FM-120 is moved out of alignment, the width of the histogram increases, as shown in Figure 36, Figure 39, and Figure 42. With severe misalignment, as seen in Figure 37, Figure 40, and Figure 43, the width of the histogram increases even more, and for the 40-µm beads, the sizing of the beads is one bin low. In addition to the increased width of the histogram and the incorrect sizing of the beads, the misalignment will change the sample volume of the FM-120, resulting in incorrect concentration measurements.

Note: Due to the fact glass beads and water droplets have different refractive indexes (see Appendix B), a correctly aligned probe will size glass beads at approximately 80% of their size.

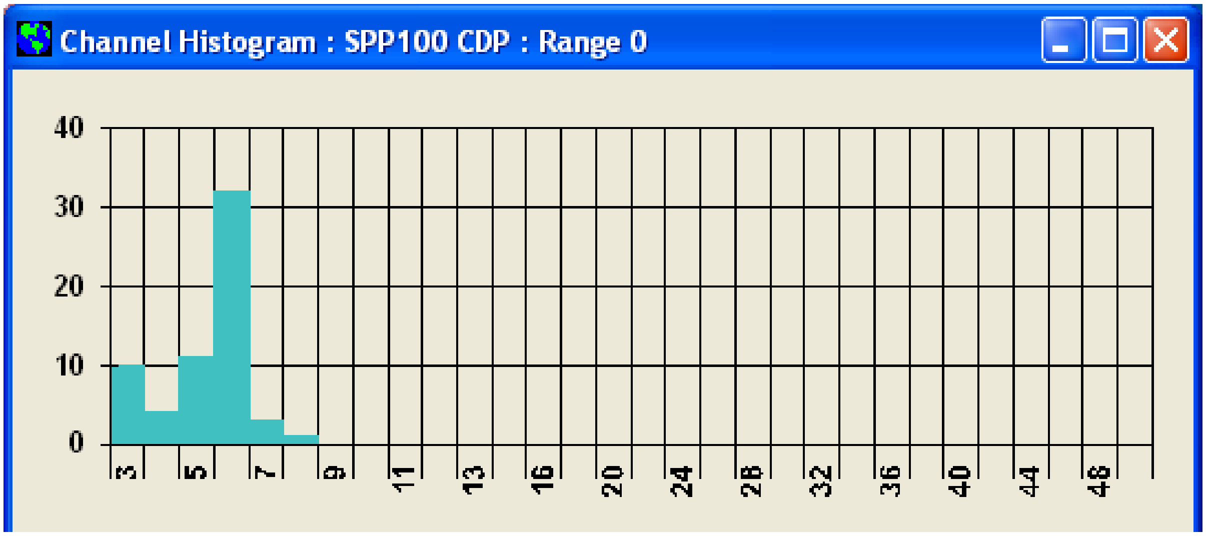


Figure 35: 8-µm glass beads FM-120 aligned

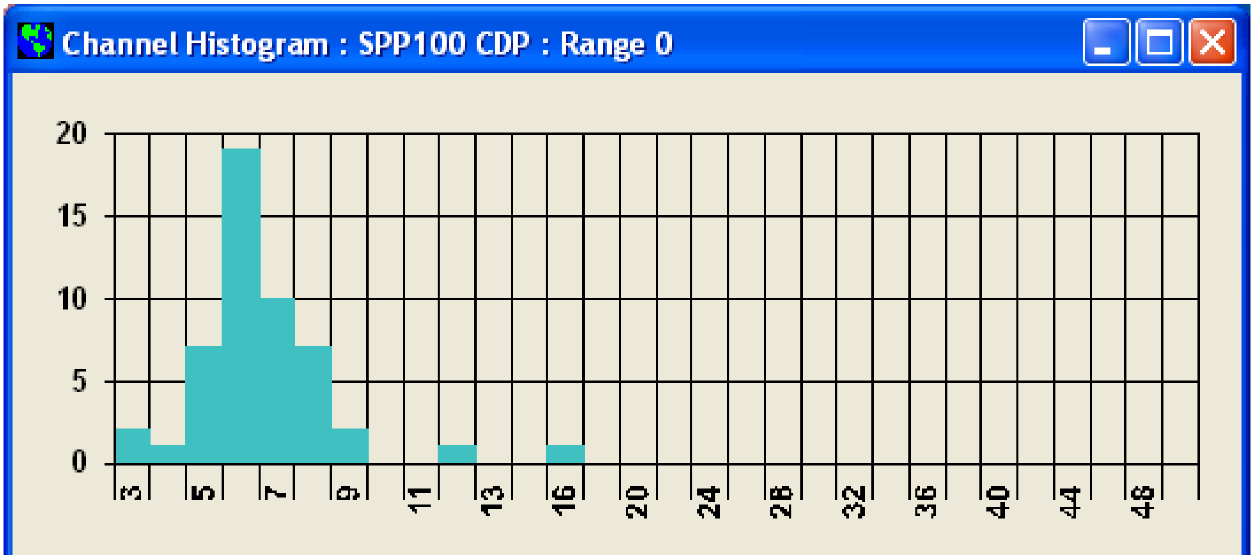


Figure 36: 8-μ glass beads FM-120 moderate misalignment

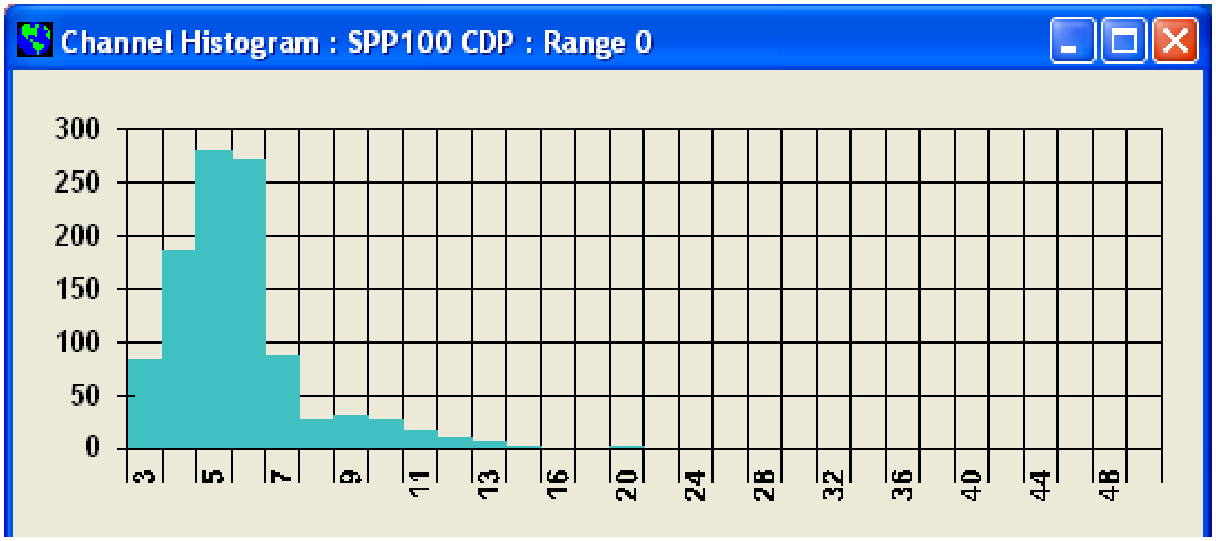


Figure 37: 8-μ glass beads FM-120 severe misalignment

Figure 38: 20-µ glass beads FM-120 aligned

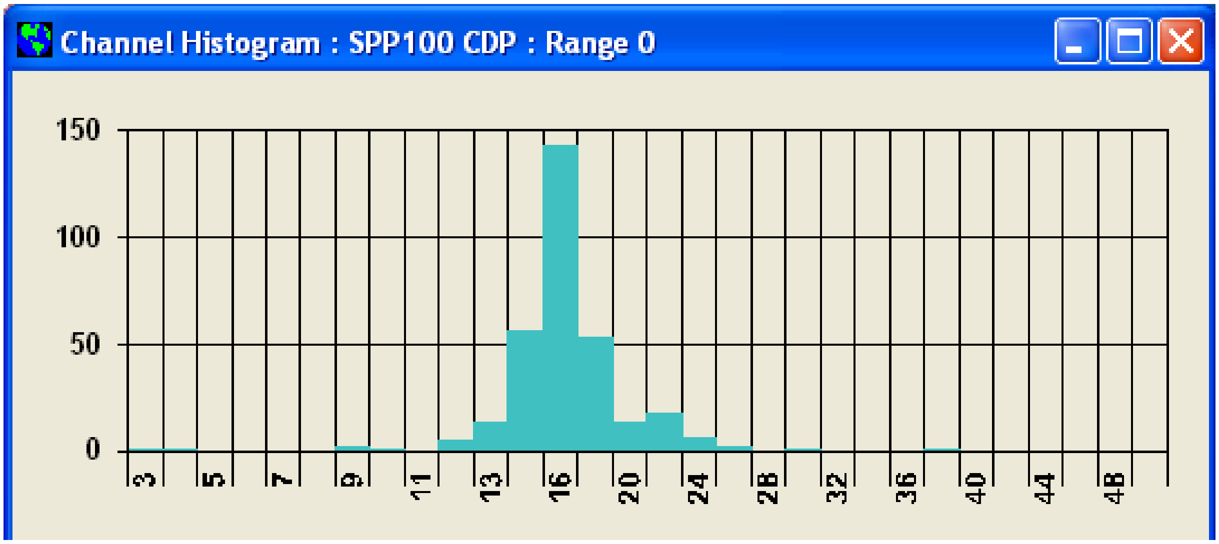
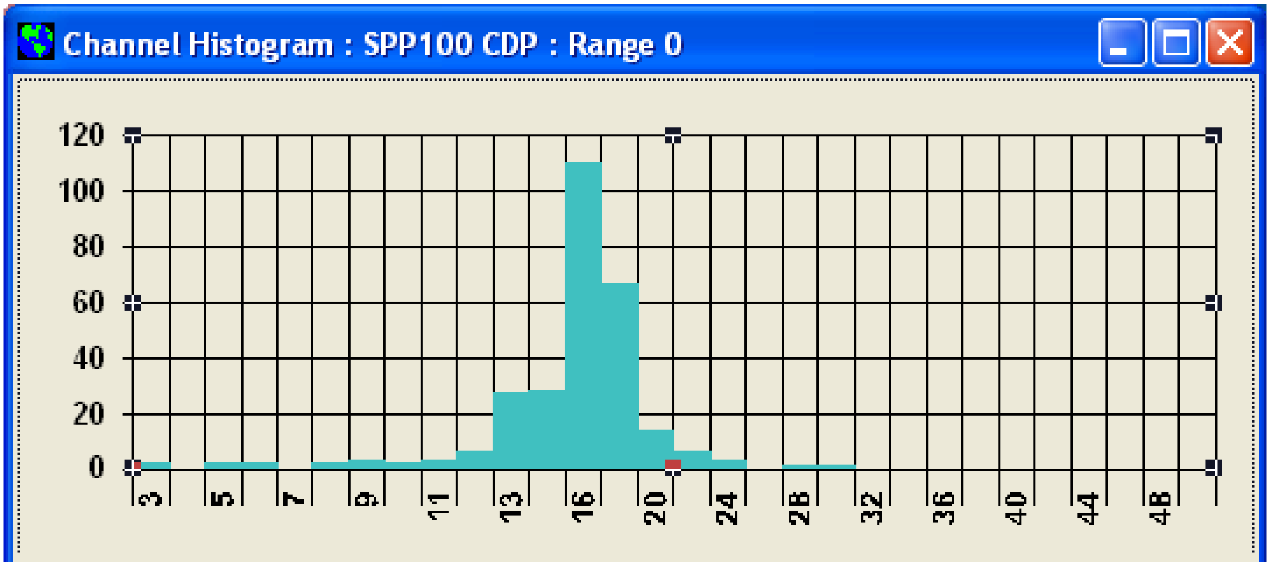


Figure 39: 20-µ glass beads FM-120 moderate misalignment



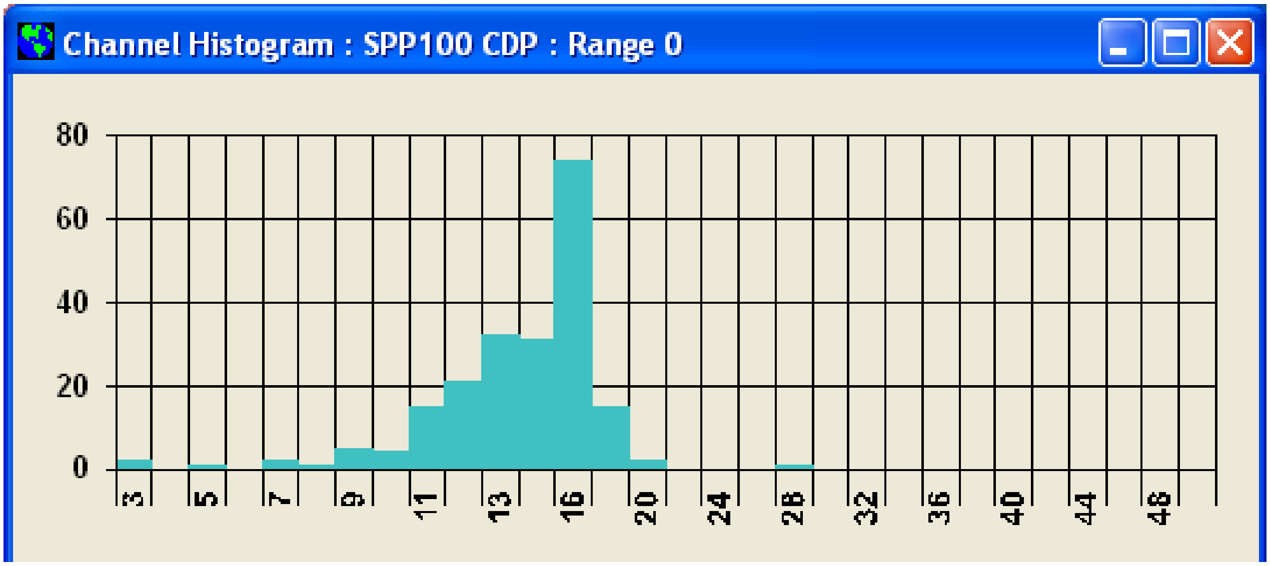


Figure 40: 20-µ glass beads FM-120 severe misalignment

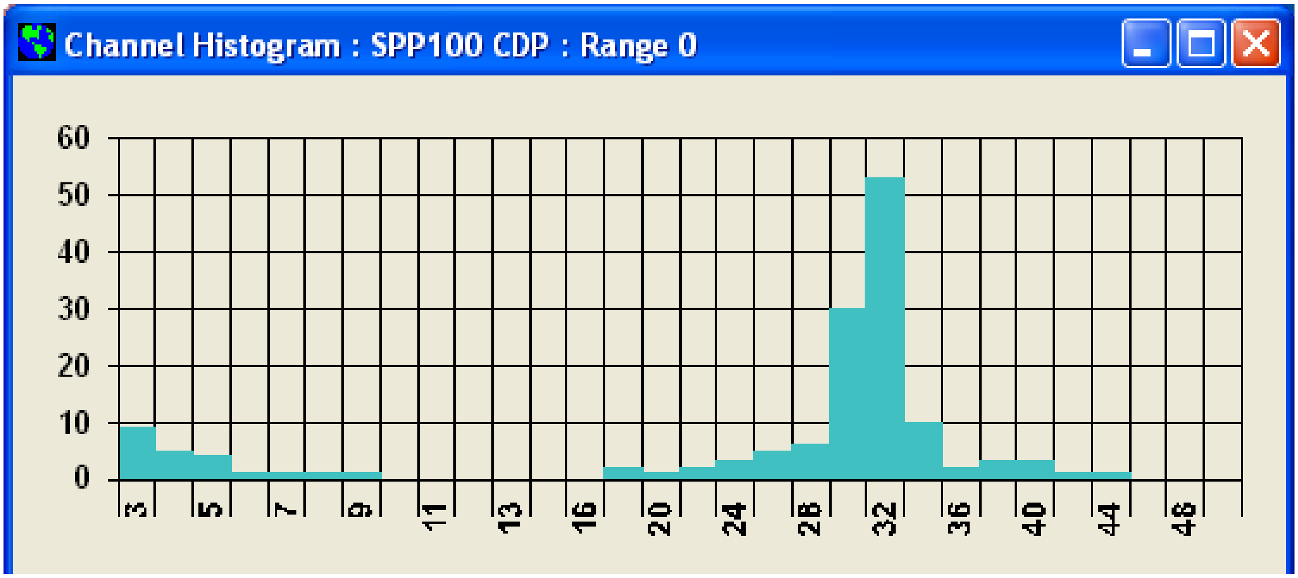


Figure 41: 40-µ glass beads FM-120 aligned

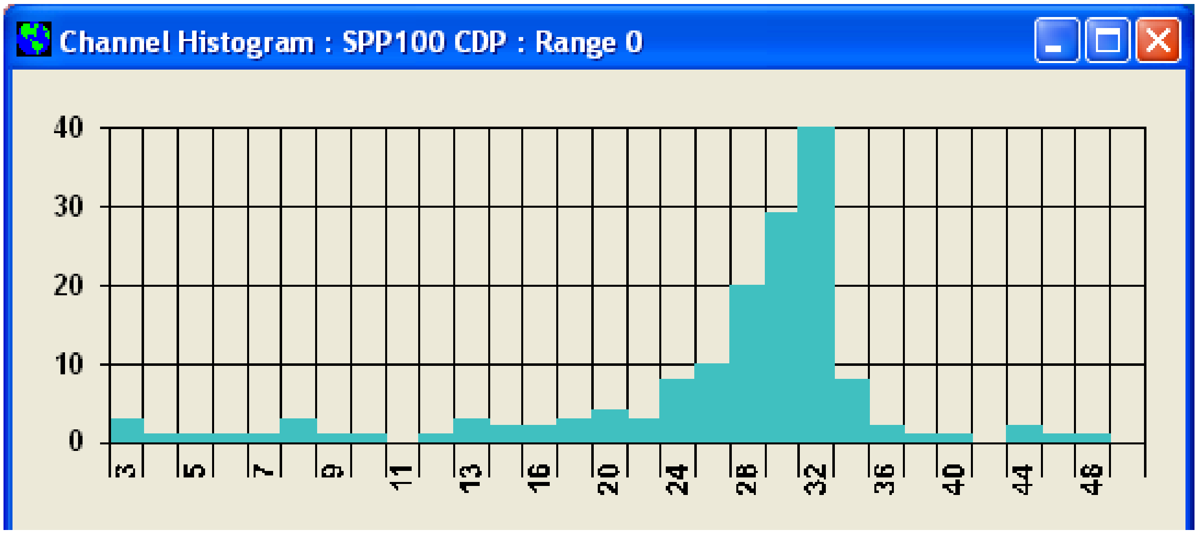


Figure 42: 40-μ glass beads FM-120 moderate misalignment

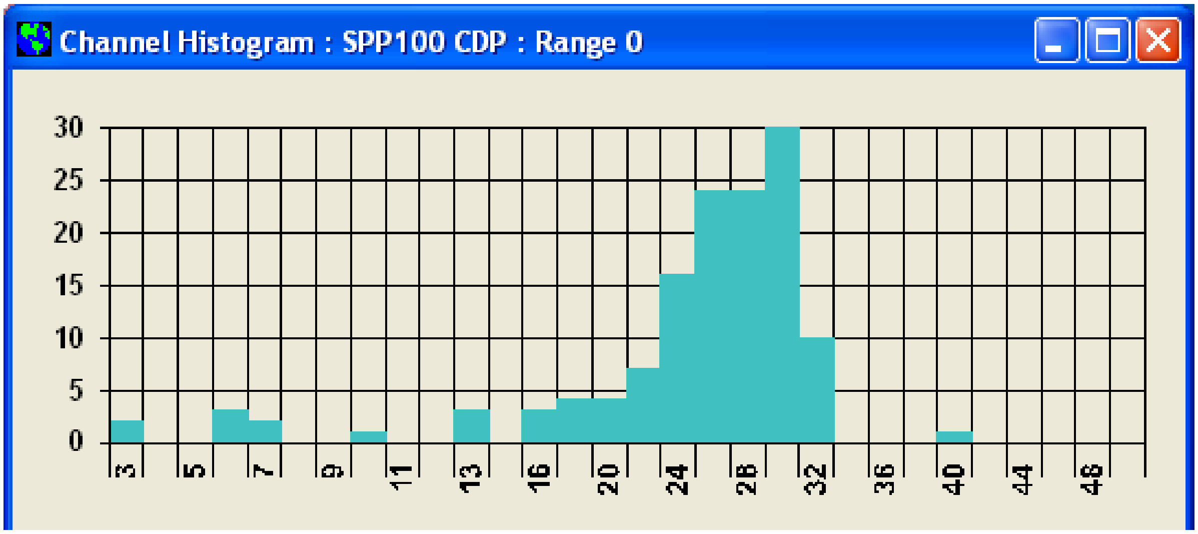
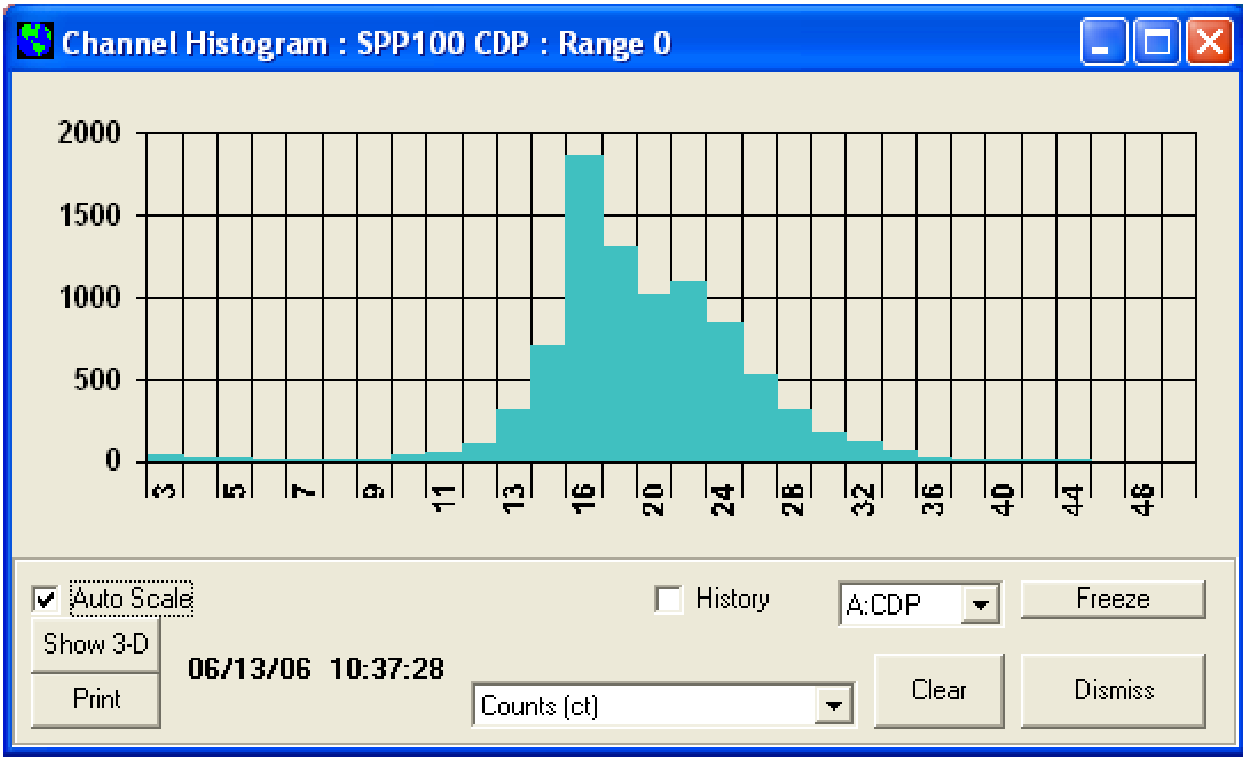


Figure 43: 40-μ glass beads FM-120 severe misalignment

Figure 44 shows the calibration of a FM-120 in good alignment with an excess concentration of calibration beads. Under these conditions, there will be coincidence of the beads in the beam and over-sizing will occur. A major peak can be seen in the 16-micron bin, where the beads are correctly sized. The large numbers of beads shown at the larger sizes are the result of coincidence. If possible, the bead counts should be kept to less than 100 in the calibration bin of the proper size for minimal coincidence. (This is more difficult with the beads of 10 microns and below, as they tend to come out in a cloud from the bead dispenser.)



☑ Auto Scale

☐ History

A:CDP

06/13/06 10:37:28

Counts (ct)

Figure 44: 20-μ glass beads calibration overload

Appendix D: Mounting Optional Swivel-head Inlet

To mount the FM-120's optional swivel-head inlet, follow the instructions below.

Figure 45: FM-120 Optional Swivel-head Mount

1. Locate the six M3 x 12 mm sealing screws that accompanied the instrument.
2. Ensure the instrument is aligned on the vertical axis. If the instrument is tilted, the swivel-head inlet will not achieve optimal performance.
3. Ensure six O-rings (OR-008) are installed under the FM-120's three legs (two apiece; see Figure 46). If any O-rings have fallen off, replace them with the extras provided.

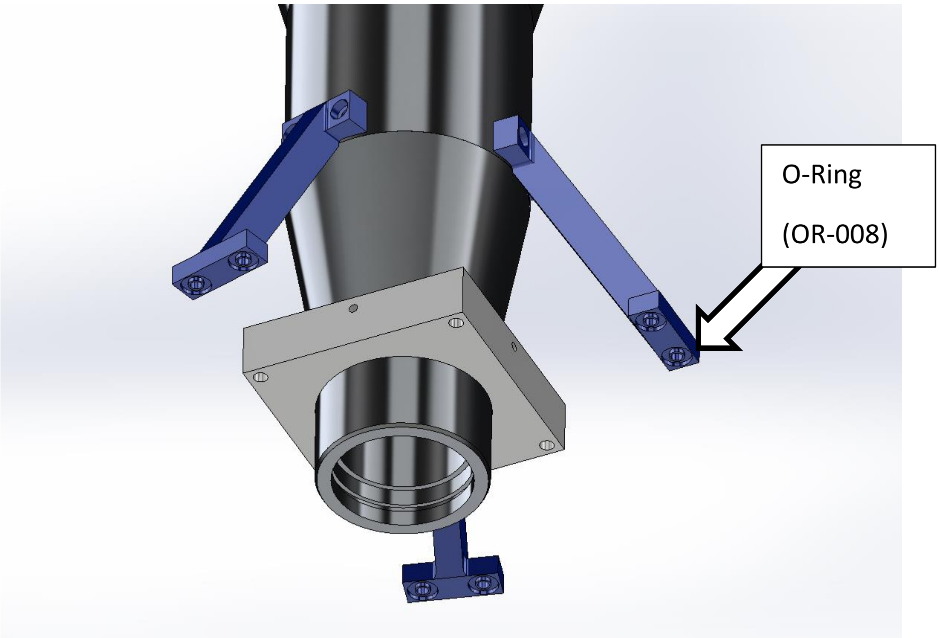


Figure 46: O-ring underneath Screw hole. There are six O-rings in total.

4. Tighten the six sealing screws from above (Figure 47). Each of the instrument's three legs has two screws to secure it. The screws must be installed tightly so that the bottom of the panel flange is seated securely against the instrument cover. This prevents water from entering the FM-120.

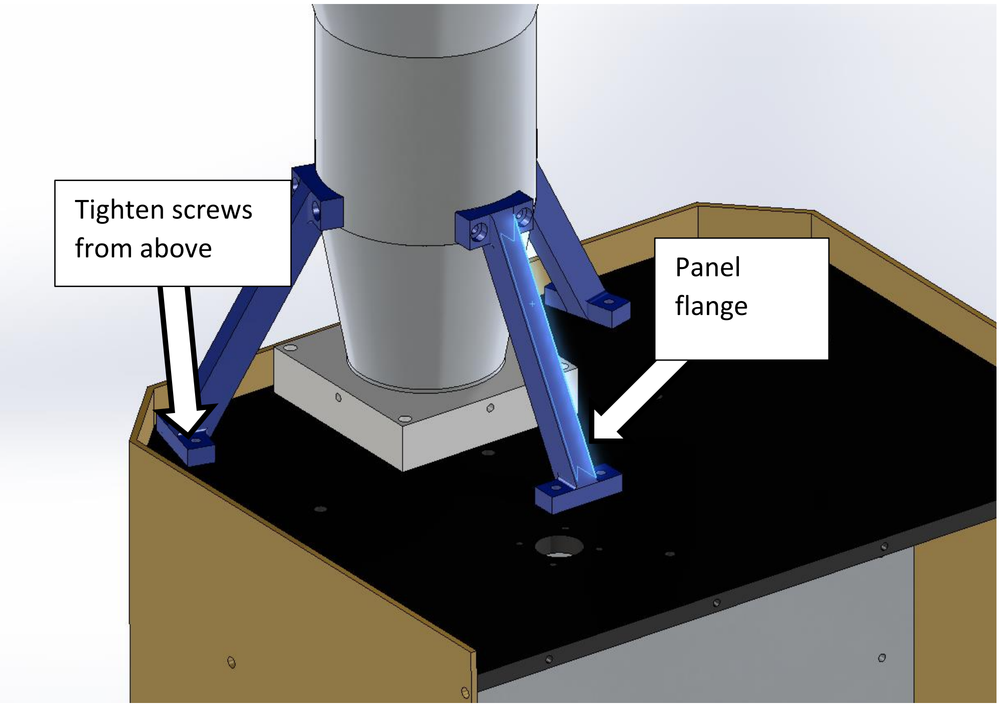


Figure 47: Mounting Swivel-head Inlet

Appendix E: DMT Instrument Locator—Operator Guide

Purpose

The Droplet Measurement Technologies (DMT) Instrument Locator tests whether a DMT instrument is responsive to an initialization command. This can be useful in determining if an instrument is powered on and has functional communications lines, or in verifying the serial port number that each instrument is connected to. Beyond this, the software does not ensure that the instrument is functioning properly.

This document describes version 1.0.1 of the Instrument Locator. This version of the program supports the following DMT instruments:

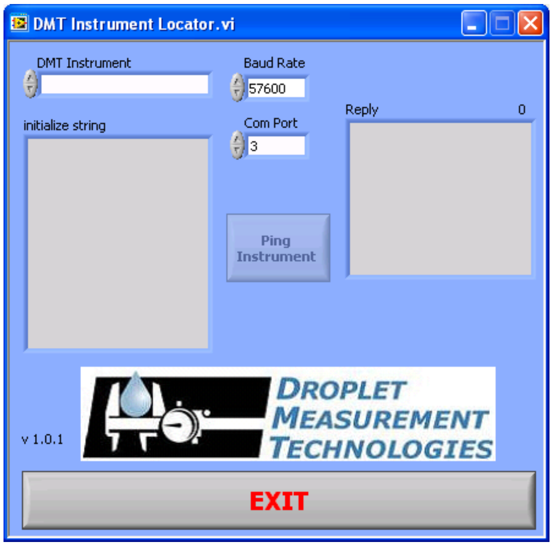
- APSD
- BCP
- CAS and CAS-DPOL
- CDP and CDP-PBP
- CIP and CIP-GS
- CPSD
- FM-100
- FSSP
- MPS
- PCASP-100X
- PCASP-X2
- PIP

Installation

The DMT Instrument Locator is on a USB stick included in a sealed plastic bag. To install the software, follow the instructions on the small card also included in the bag.

Operation

1. To open the Instrument Locator, navigate to `C:\Program Files\PADS 3` and double-click on `DMT Instrument Locator.exe`. You will see the window in Figure 1.



Baud Rate 57600

Com Port 3

Reply 0

Figure 48: Instrument Locator

2. Click on the **DMT Instrument** field to bring up a list of available instruments. (Grayed-out instruments have not yet been tested with the Instrument Locator.) Select your instrument from the list. The **Baud Rate** will auto-populate, though in some special cases you may need to adjust the baud rate for your specific instrument.

3. Select the COM port for the instrument you want to test.

4. Click on **Ping Instrument.**

5. The Instrument Locator will display the initialization string sent to the instrument and the instrument's reply. All instruments reply with "0606" when sent a valid initialization command. If there is no reply, the Instrument Locator will indicate this with a **No Reply** indicator. The Instrument Locator also displays a possible reason for the communication failure in the **Reply** box.

6. To quit the Instrument Locator, click on **Exit.**

Note: Several DMT instruments—the CDP, CDP-PbP, BCP, FSSP, and FM-100—all respond to the same initialization string. The instrument locator simply sends this string to the instrument. The program has no way of knowing if the instrument connected to the COM port is actually of the correct type. Thus, if you have multiple instruments in your system, it is important to specify the correct COM port for the instrument you wish to test.

Appendix F: Dimensions and Mounting Diagram

See the following pages for the FM-120 dimensions and mounting diagram.

Appendix G: Revisions to Manual

Rev. Date	Rev. No.	Summary	Section
10/25/12	A-1	Added instructions on mounting swivel-head inlet	Appendix D
12/5/12	A-2	Removed Dump Spot Monitor from data packet	9.3
		Increased size of each PbP particle data packet from 10 to 12 bytes	9.3
		Added sections on raw data, pbp data, and conversion equations	9.3.1 – 9.3.3
4/7/14	B	Updated photos to show FM-120	Throughout
		Expanded section on FM-120 window cleaning	4.2.1
		Added explanatory information and graph to Glass-beads-to-water conversion information	Appendix B
		Added FM-120 dimensions and mounting diagram	Appendix F
4/28/2014	B-1	Added bench-test cables to components diagram	Figure 7