Fog Monitor

Model FM-100

Operator Manual

DOC-0088 Revision I

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Trademark Information

Warranty

The seller warrants that the equipment supplied will be free from defects in material and workmanship for a period of one year from the confirmed date of purchase of the original buyer. The probe owner will pay for shipping to DMT, while DMT covers 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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1.0 Introduction

DMT's Fog Monitor (FM-100) 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. The Signal Processing Package for the Fog Monitor (SPP-FM) is a flexible set of electronics for the forward-scattering optical system designed specifically for this instrument. The Fog Monitor offers flexibility in how it can be used in specific applications.

Figure 1 depicts the Fog Monitor.

Figure 1: Fog Monitor with Pump

The FM-100 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-100 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.

2.0 Specifications

The FM-100 specifications are listed below.

Technique:	Light-scattering probe with 10, 20, 30 or 40 size bins (DMT exclusively supports 20-bin configuration)
Measured Particle Size Range:	2-50 µm droplet diameters
Typical Sample Area:	0.24 mm^2
Sample Flow Rate:	15m/s, 1m^3/min[i]
Sampling Frequency:	Selectable, 0.1 to 10 Hz[ii]
Refractive Index:	non-absorbing, 1.33[iii]
Light Collection Angles:	4° - 12°
Data System Interface:	RS-232 or RS-422 serial interface; 38,400 baud rate.
Calibration:	Precision glass beads

Table 1: Fog Monitor Specifications

[i] This is the range for which the Pitot is properly calibrated and the electronics can clock appropriately.

[ii] Versions of the Particle Analysis and Display System (PADS) earlier than 3.5 assume a sampling frequency of 1 sec / 1 Hz. As a result, this frequency is recommended if you are using PADS 2.7 or earlier.

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

2.1 Electrical Specifications

- 115VAC or 230VAC (determined at manufacture)
- 50-60Hz
- 200W (instrument), 400W (pump)

2.2 Physical Specifications

Weight: 13kg (instrument), 5kg (pump)
Dimensions: 23 cm high, 28 cm wide, 37 cm long

Figure 2: Fog Monitor Control Panel

3.0 Getting Started

3.1 Instrument Setup

Figure 3 depicts the Fog Monitor (FM-100) components.

Figure 3: FM-100 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.

3.2 Connecting the FM-100 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:

1. Insert the inlet horn (2) into the outer block of the particle sensor (1a) 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.

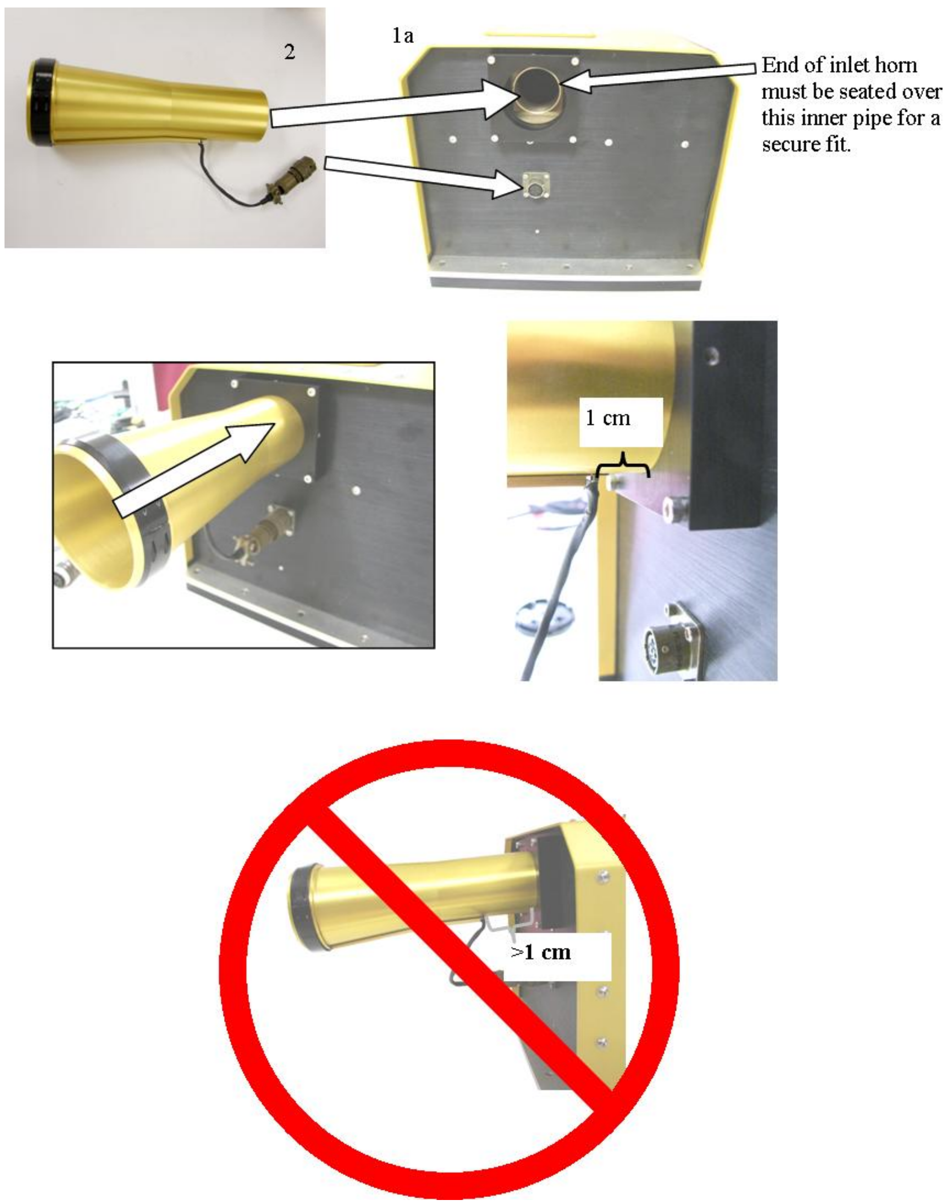


Figure 4: Inserting the Inlet Horn. Push inlet horn in as far as it will go.

2. Connect the pump hose (3) to the pump (4) (Figure 5).

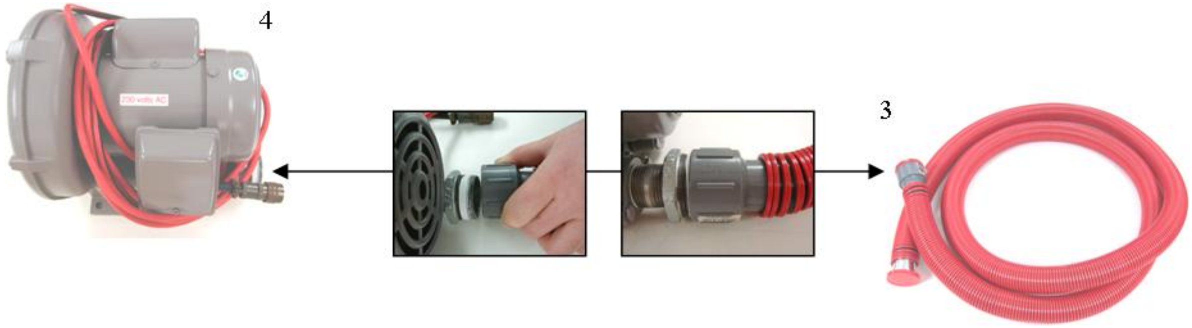


Figure 5: Connecting the Pump to the Pump Hose

3. Connect the FM-100 power cable (8) to the **AC POWER INPUT** on the particle sensor (1b) (Figure 6).

4. Connect the data cable (7) to the **SERIAL DATA** receptacle (1b) (Figure 6).

5. Connect the pump power cable (4) to the **AC POWER TO PUMP** receptacle (1b) (Figure 6).

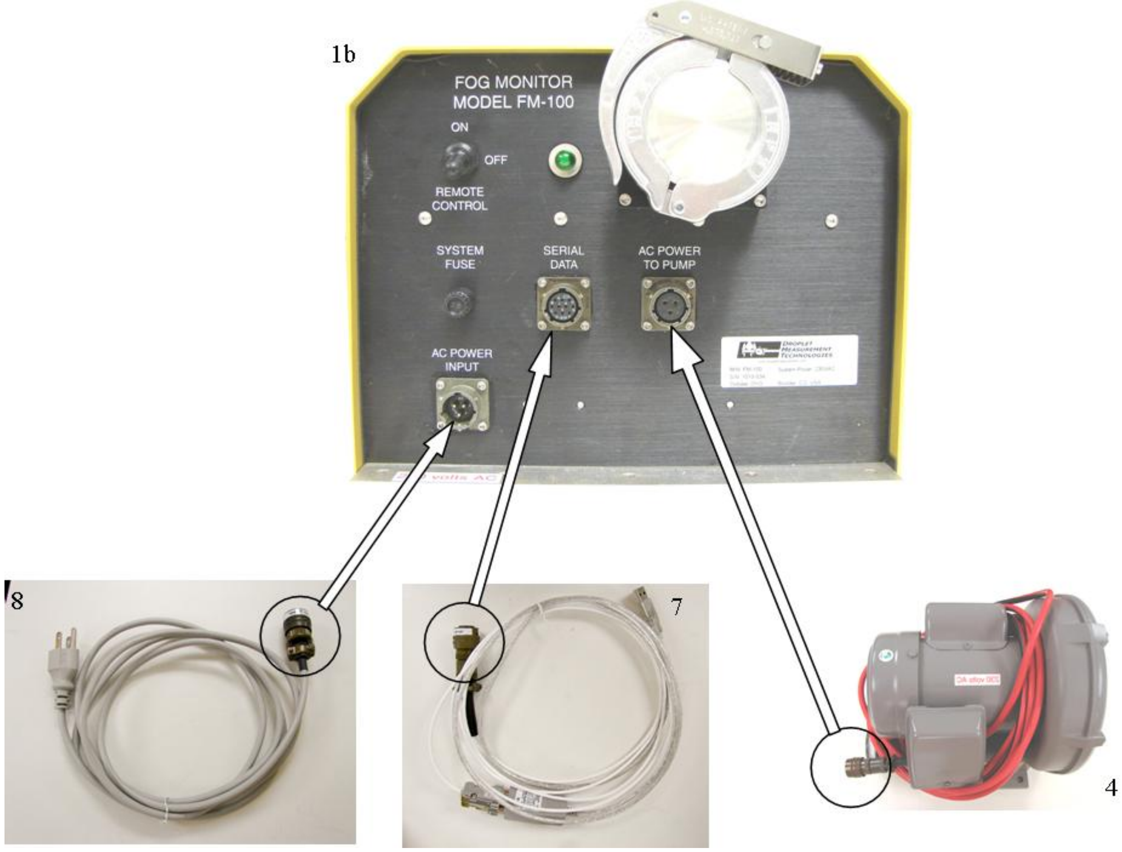


Figure 6: Connecting the Serial Data Cable, Power Cable, and Pump Power Cable to the Particle Sensor

6. Remove the clamp and pump hose connection cover from the particle sensor (1 b). Keep the black O-ring and metal centering ring on the unit.

7. Attach the pump hose (3) to the particle sensor (1b).

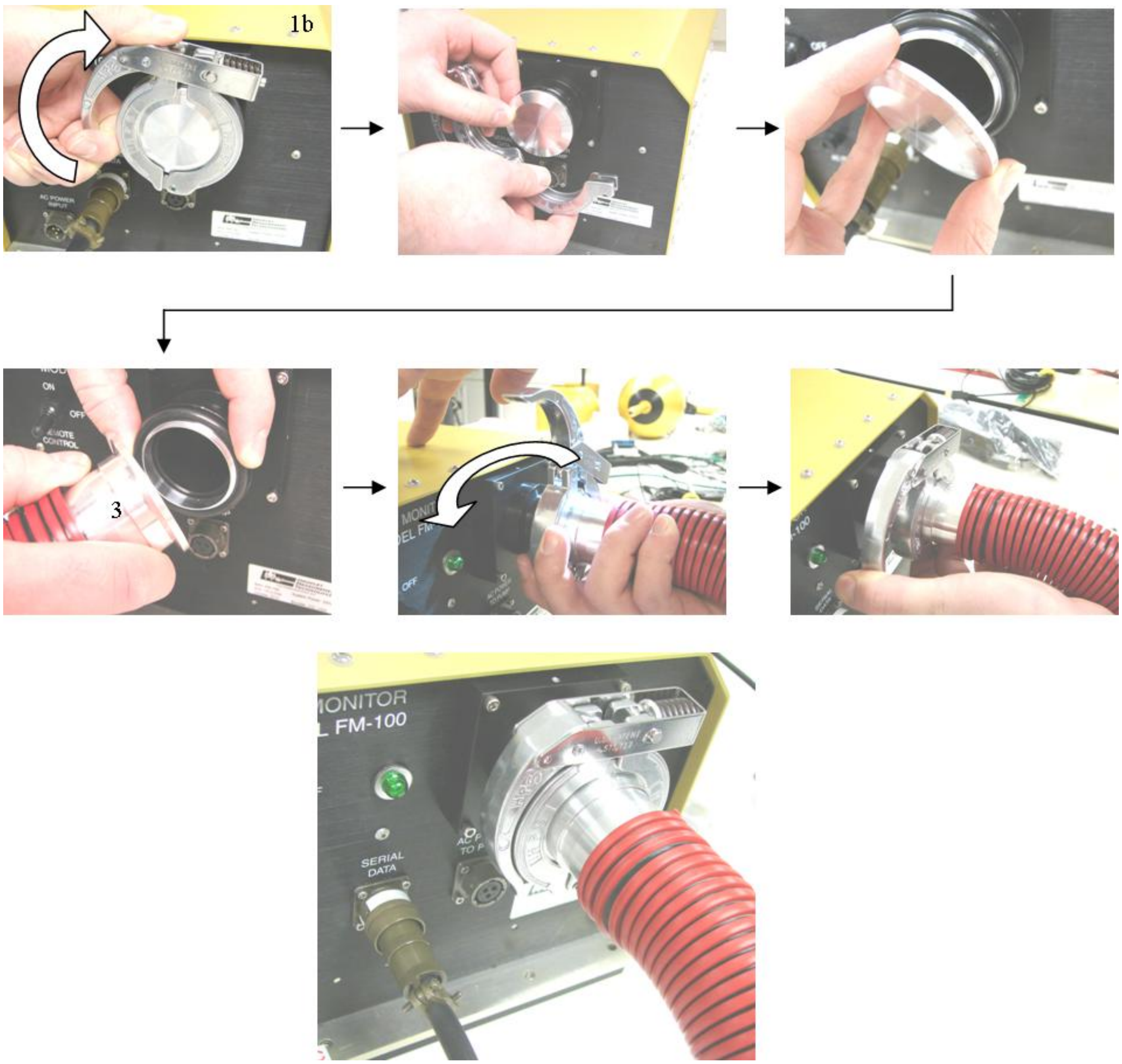


Figure 7: Attaching Pump Hose to Particle Sensor

8. Connect the FM-100 power cable and pump power cable to power sources.

9. Turn on FM-100 power. (Flip the power switch up, so the light turns on.)

10. Insert the green FM-100 PADS software USB key (9, labeled “FM-100 PADS”) into a USB 2.0 port on the computer (5) (Figure 8).

11. Connect the serial data / RS-232 cable (7) to into a USB 2.0 port on the computer (5) (Figure 8).

12. Connect the laptop power supply (6) to the computer (5) (Figure 8).

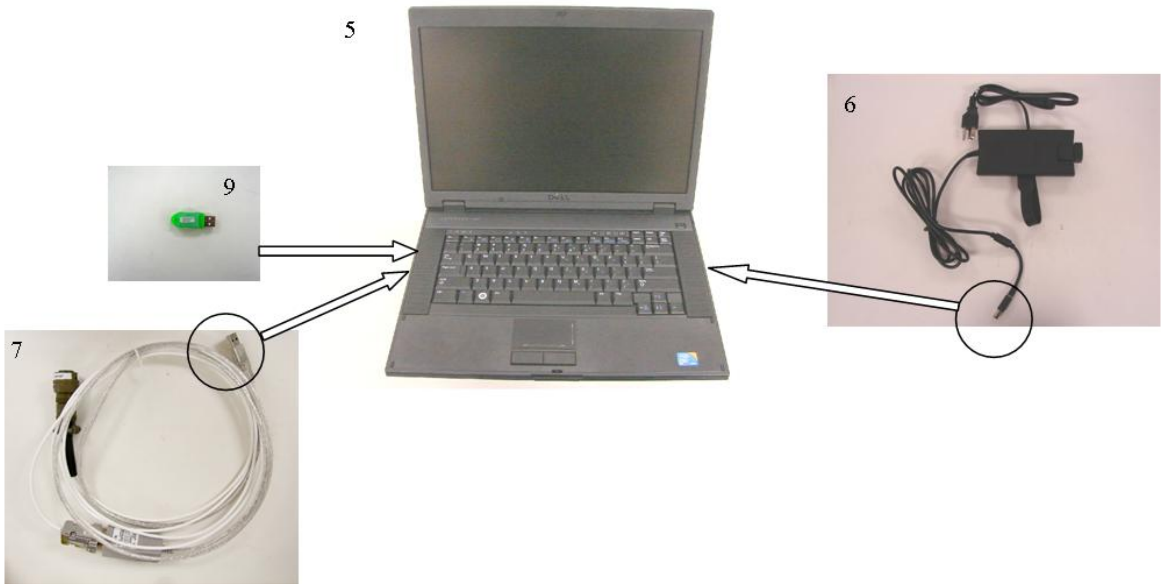


Figure 8: Connecting Computer Components

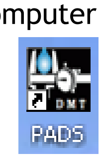
13. Connect the laptop power supply to the power source.

14. Turn on the computer.

3.3 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 XP, double-click on the “PADS” icon on the computer desktop to open the PADS program.



A display will appear similar to that shown in Figure 32.

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_100 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, the instrument will not work properly and it needs to be serviced.

6. Check temperatures. Initially after turn 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.

3.4 Instrument Shutdown

Follow these steps to shutdown the FM-100 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-100 interface.

3. Exit the FM-100 Software Interface via the Program/Exit selection from the menu.

4. Turn off the power switch on the FM-100 front panel.

5. Transfer data files from the laptop as necessary.

6. Turn off the laptop via the Windows XP Start/Shutdown command.

4.0 Cleaning and Routine Maintenance

There are three tasks the user can perform to maintain the FM-100: 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
- Areas with high concentrations of industrial soot

	Normal Conditions	***Severe Conditions***
Basic Health Check (described in section 4.3 of main manual)	Weekly	Daily
Windows Cleaning (described in section 1.1)	Monthly	1 - 3 times a week
Pitot Tube Cleaning (described in section 1.2)	N/A—the yearly calibration and cleaning at DMT should suffice	Twice a week to monthly

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.

4.1 Cleaning the FM-100 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.

To clean the FM-100 windows, remove the access panel shown in Figure 9. Use a 0.05" Allen wrench to remove the screws.

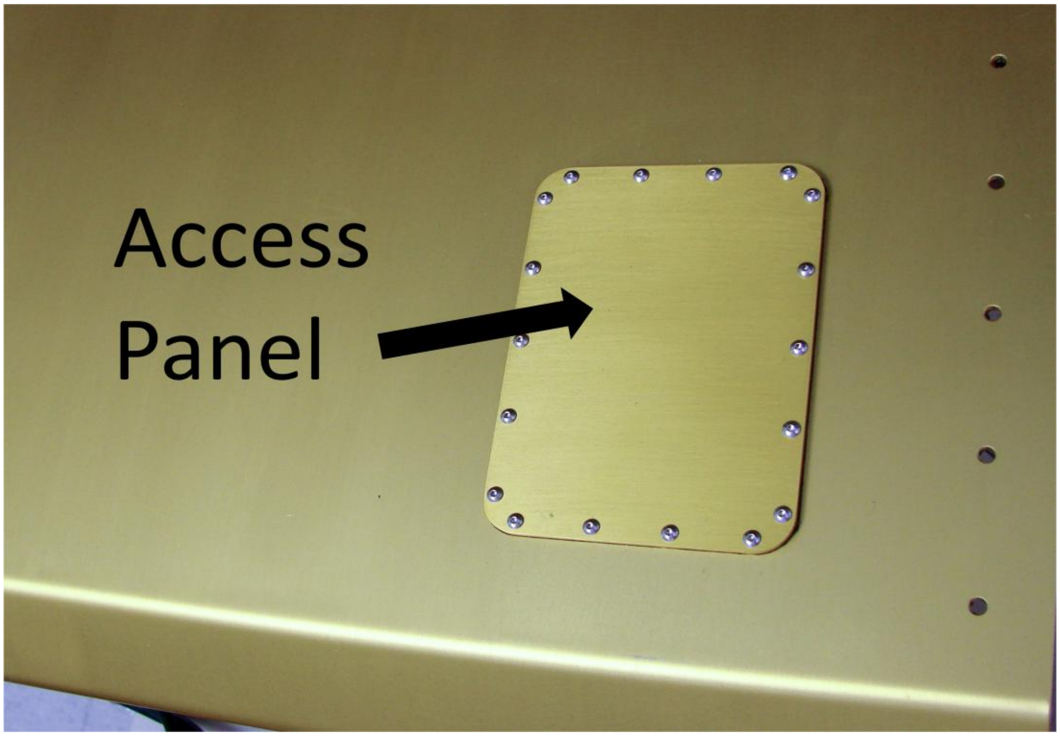


Figure 9: Fog Monitor Access Panel

Next, clean the windows by swabbing them with a Q-tip saturated with a commercial glass cleaner such as Windex, then dry them with another Q-tip. Repeat this procedure using isopropyl alcohol or acetone. The best solvent depends on the nature of the contamination. The windows, being sapphire, can withstand almost any solvent and moderate scrubbing. When cleaning is complete, reinstall the access panel.

4.2 Cleaning the Pitot Tube

To clean the Pitot tube, first unplug the instrument. Then remove the entire instrument cover. Next, unscrew the two sample tube set screws using a 1/16" Allen wrench (Figure 10).

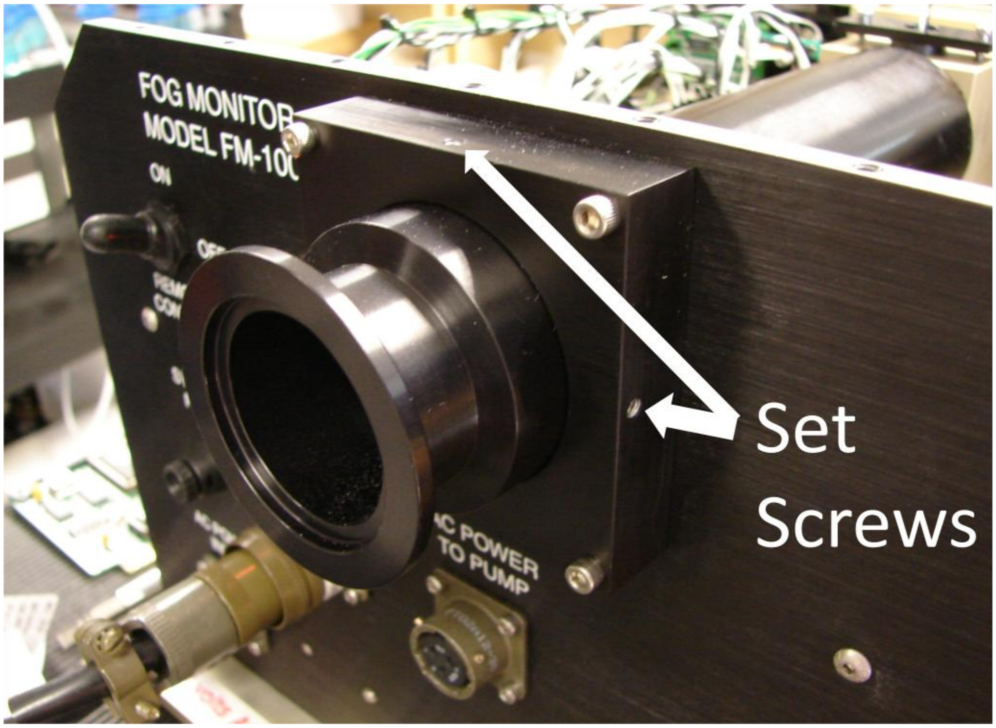


Figure 10: Sample Tube Set Screws

Slide the sample tube out from the instrument (Figure 11).

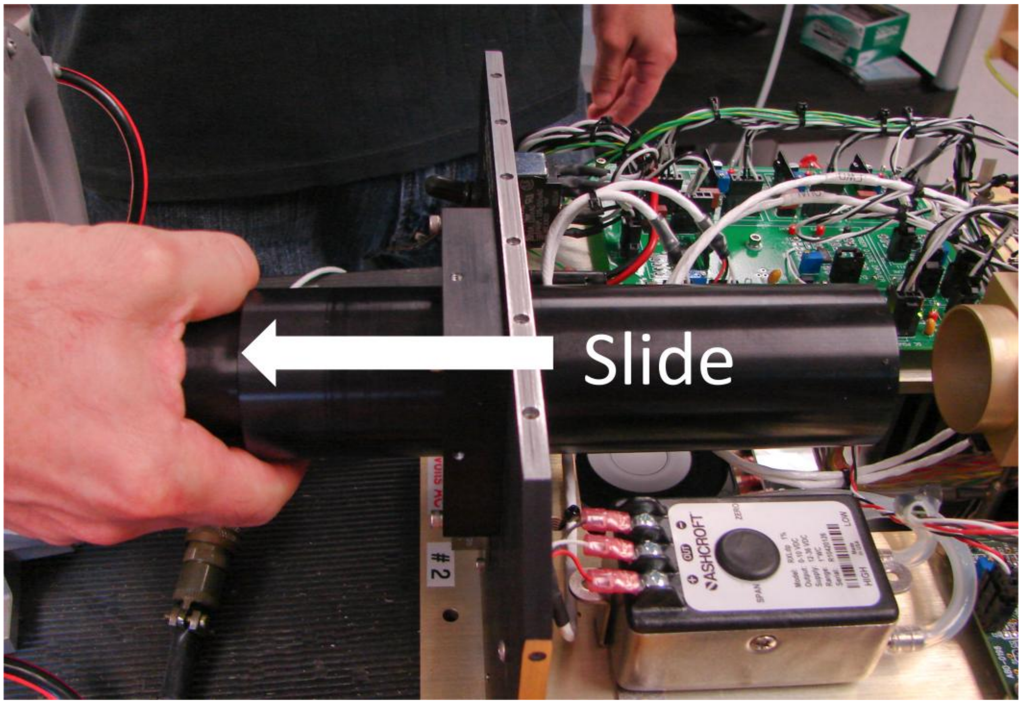


Figure 11: Sliding Sample Tube Out

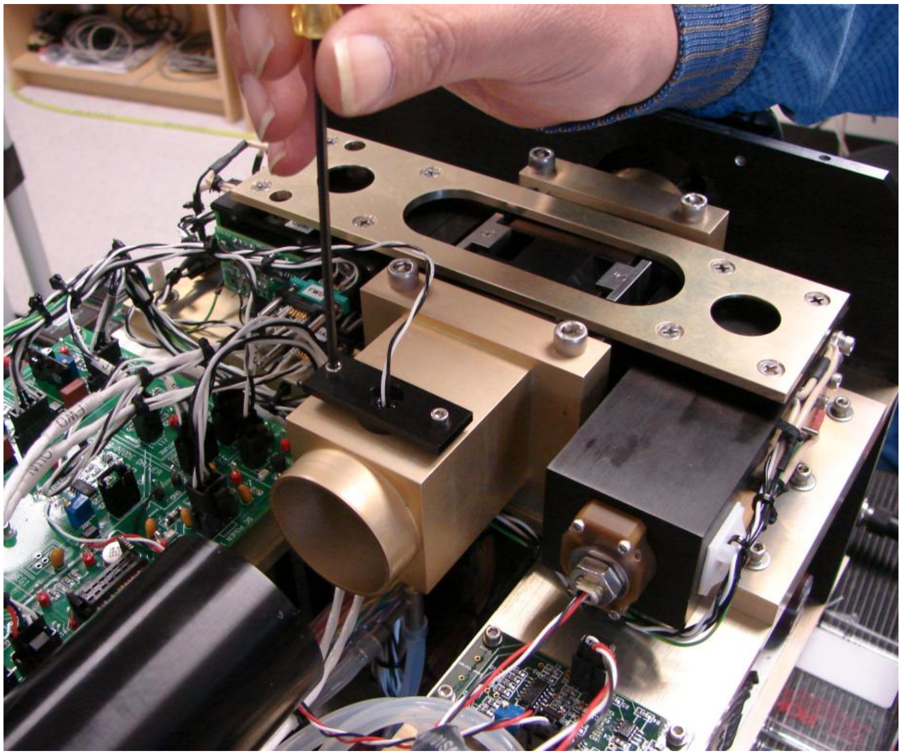


Figure 12: Unscrewing the RH Sensor Screws

Next, unscrew the two RH sensor screws (Figure 12) using a 3/32” Allen wrench. Then remove the sensor (Figure 13).

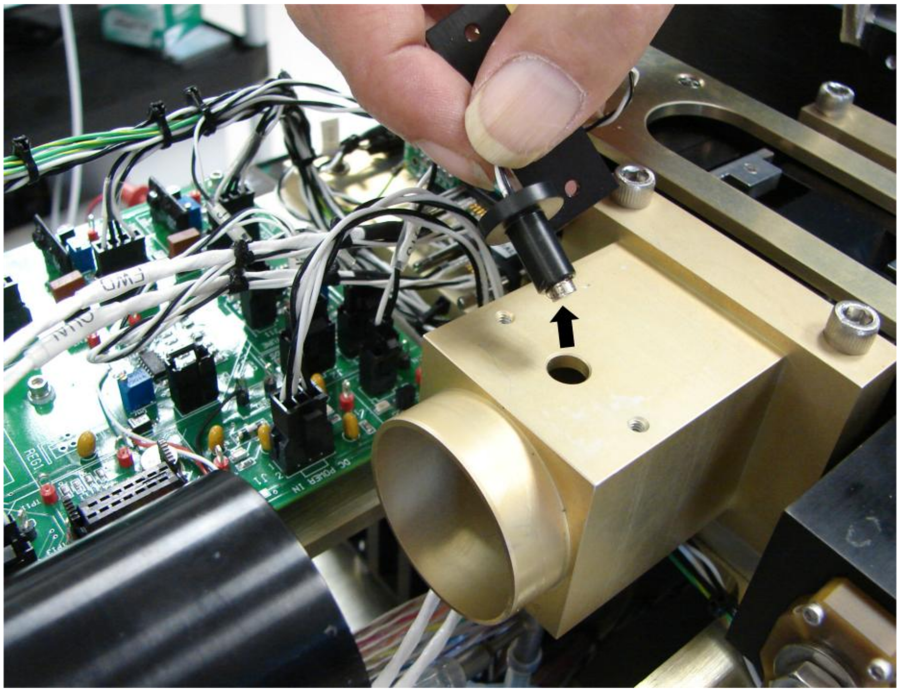


Figure 13: Removing the RH Sensor

Unscrew and remove the large socket head caps (Figure 14).

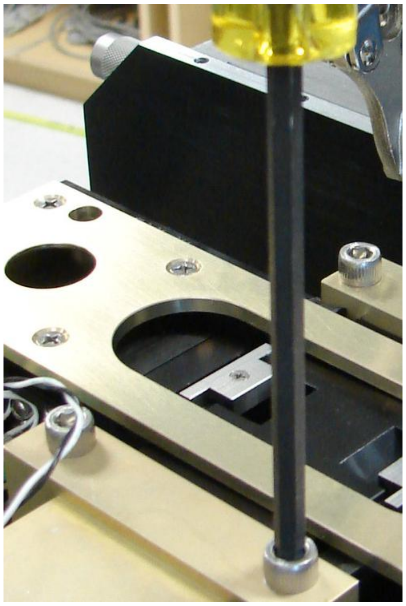


Figure 14: Unscrewing the Socket Head Caps

Then carefully lift up the entire Pitot block (Figure 15).

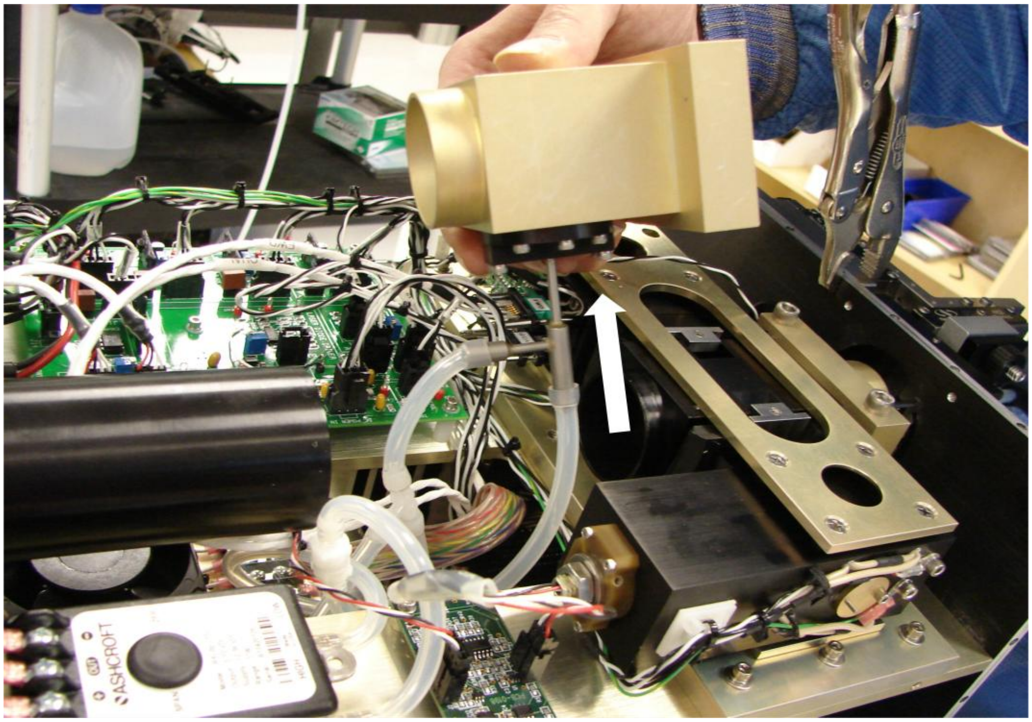


Figure 15: Lifting the Pitot Block

CAREFULLY remove the bottom plastic tube from the metal Pitot port (Figure 16). Removing the tube too violently may cause a sudden pressure shift, which in turn could cause the pressure transducer to fail. With a sticky note or label, label the tube “Bottom” so you remember which Pitot port it attaches to.

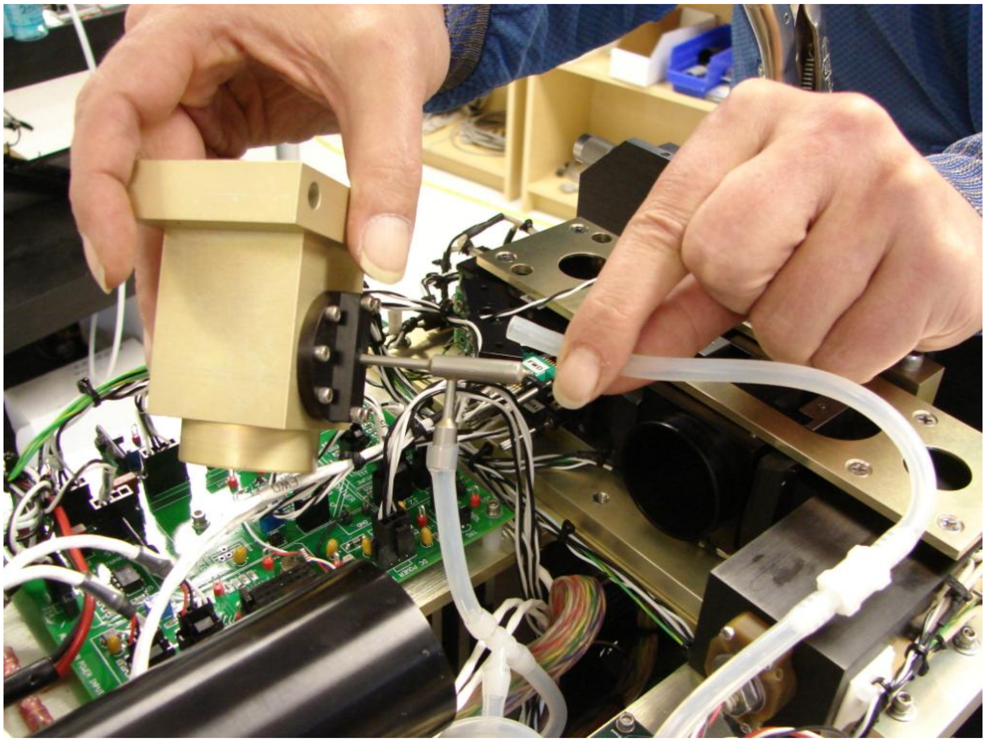


Figure 16: Removing the Bottom Pitot Tube

Next, carefully remove the side Pitot tube (Figure 17) and label it as well.

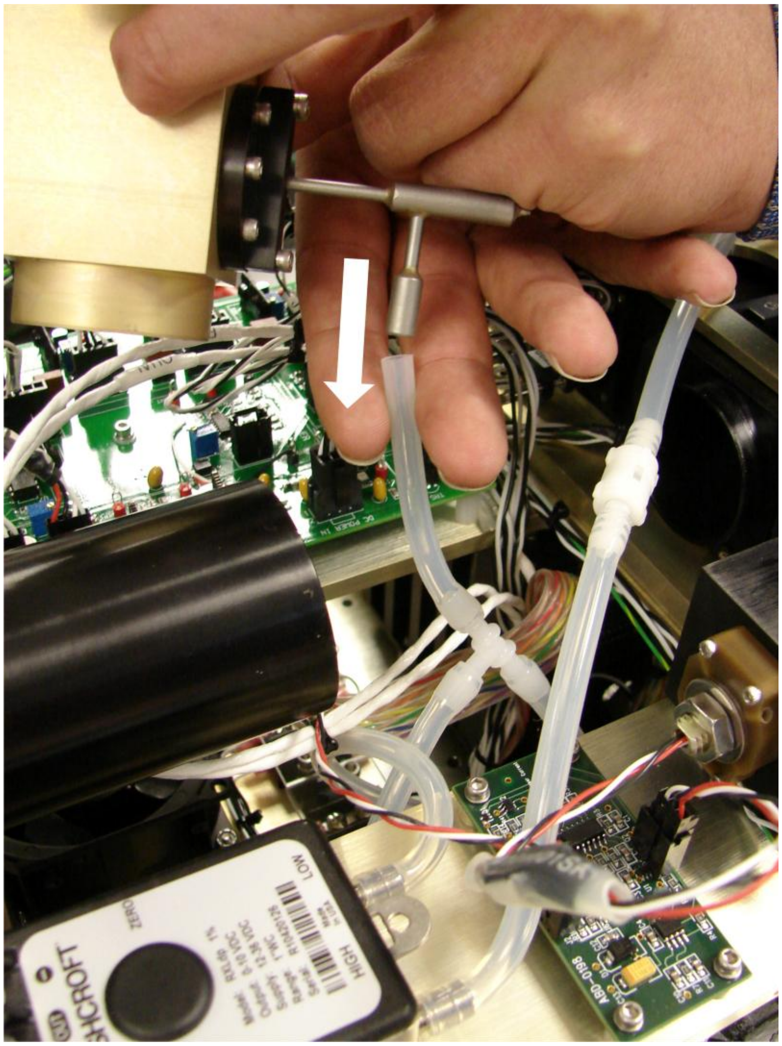


Figure 17: Removing the Side Pitot Tube

The Pitot tube block can then be removed (Figure 18) and set on a separate surface.

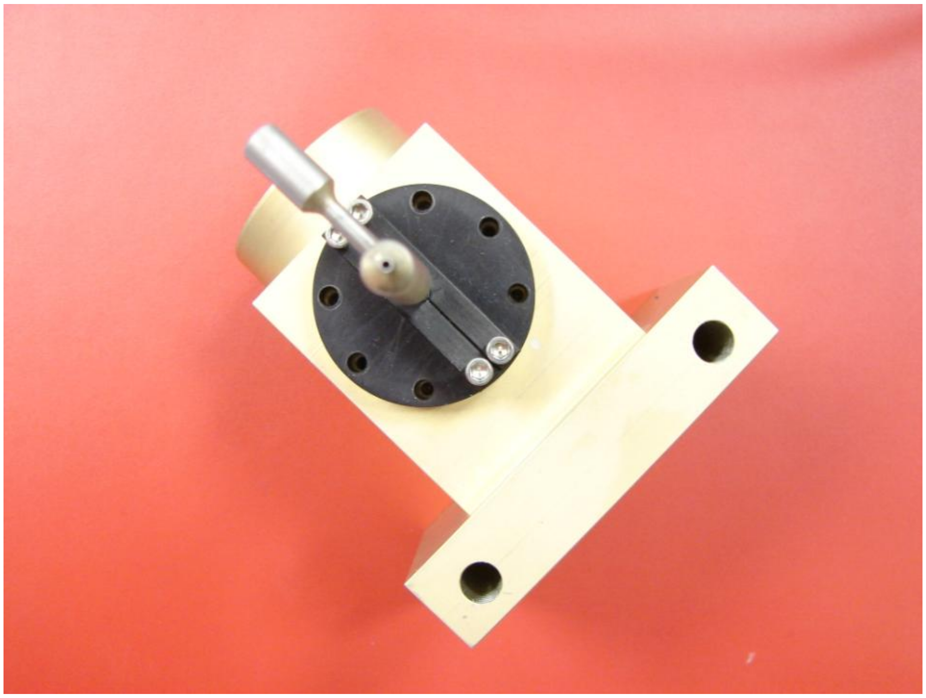


Figure 18: The Pitot block

Use a 3/32” Allen wrench to remove the Pitot assembly from the Pitot block (Figure 19).

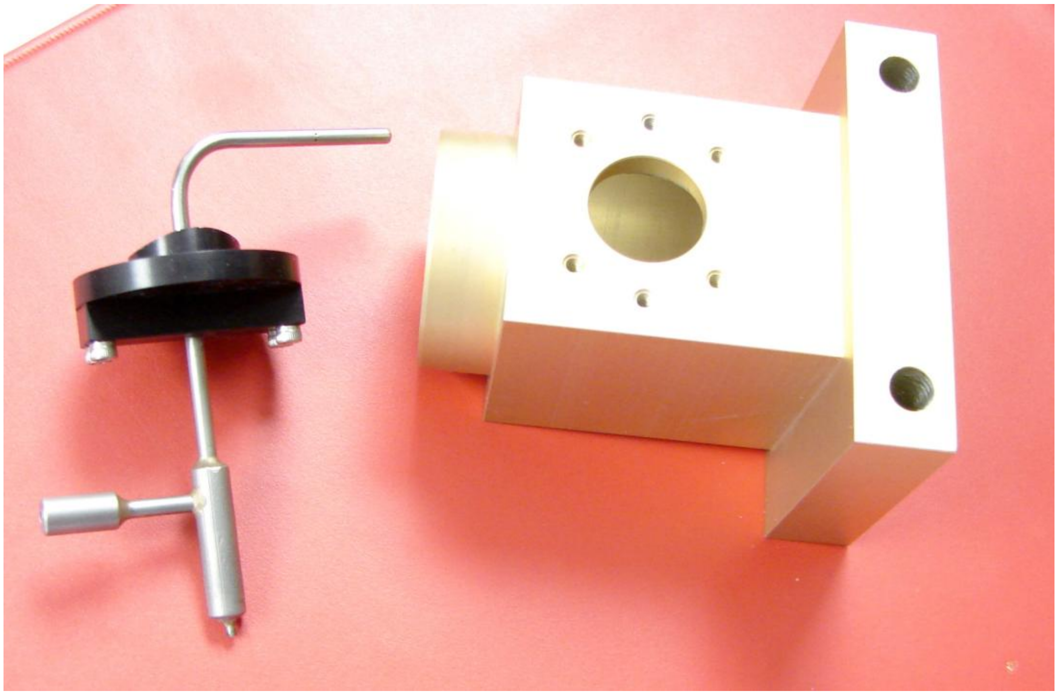


Figure 19: Removing the Pitot assembly (left) from the Pitot Block (right)

Put the Pitot assembly in an ultrasonic bath. Use a 5% solution of EDTA in distilled water or substitute Johnson's Baby Shampoo as the cleaning agent, and keep the water temperature at 80 – 90˚F. After three to five minutes, remove the Pitot assembly. Blow air through it using your mouth or low pressure compressed air. If the unit is clean, the flow should be small but continuous. (The purpose of the bath is to clean the holes in Figure 20; since these holes are very small, the flow will also be small.) If the airflow sputters or the ports remain visibly clogged, immerse the assembly again in the bath, in a different position, and repeat the procedure.

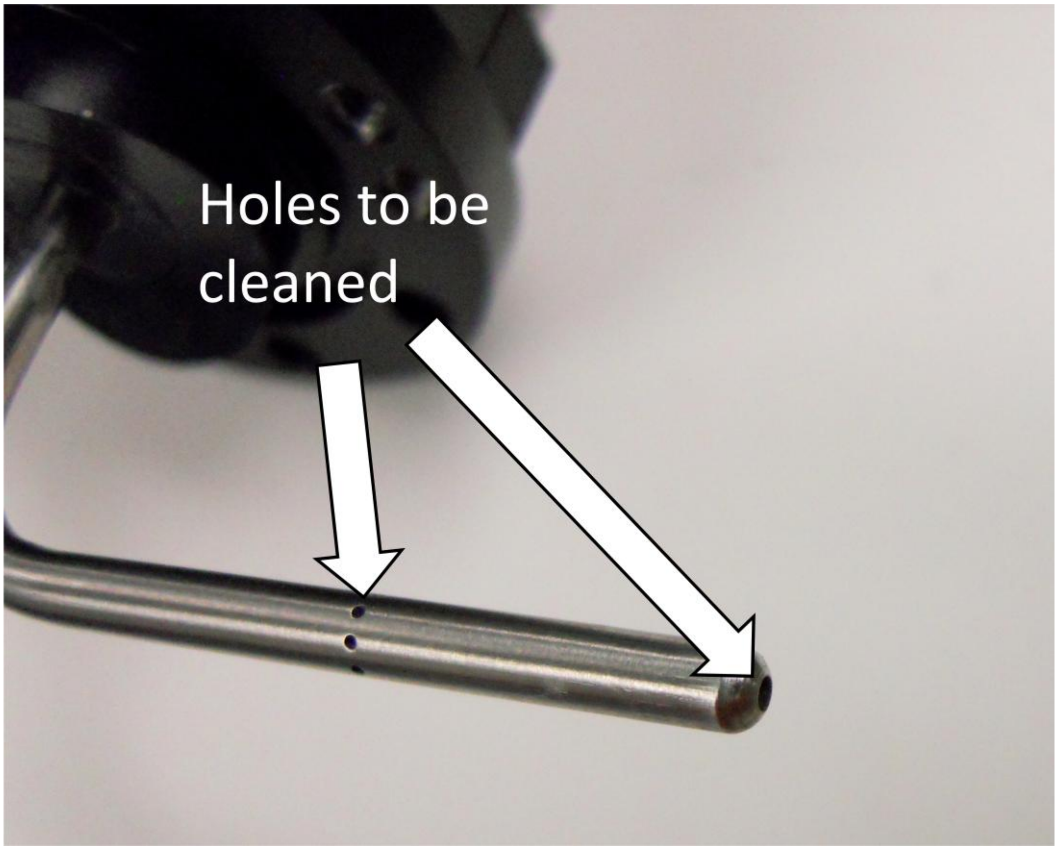


Figure 20: Holes to be Cleaned during Ultrasonic Bath

When the cleaning is complete, reassemble the unit by following the procedures listed above in reverse. Test the cleaning by comparing the TAS to the post-calibration TAS level. These figures should be within 5% of each other.

5.0 Calibration

Precision glass beads can be used to verify the calibration on the FM-100. 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-100 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.

5.1 Required Equipment

To calibrate the FM-100 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 21 for examples of dusters. These are generally available at electronics supply stores or computer stores.
- Bottle of certified glass beads, as shown in Figure 22. These are available from DMT.
- Glass bead dispenser, pictured in Figure 23.
- Calibration fixture for the instrument, designed to keep the glass beads within the appropriate depth of field. Figure 24 shows the calibration fixture for the Fog Monitor.

Figure 21: Compressed Gas Cans or “Dusters”

Figure 22: Bottle of Glass Beads, DMT OP-0591-0020

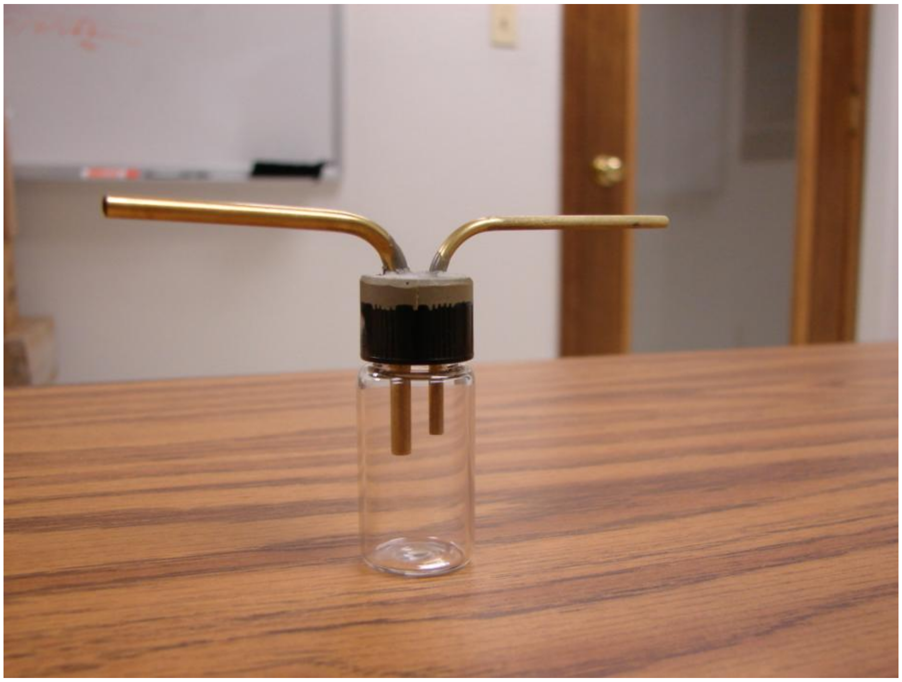


Figure 23: Glass Bead Dispenser, DMT AD-0164

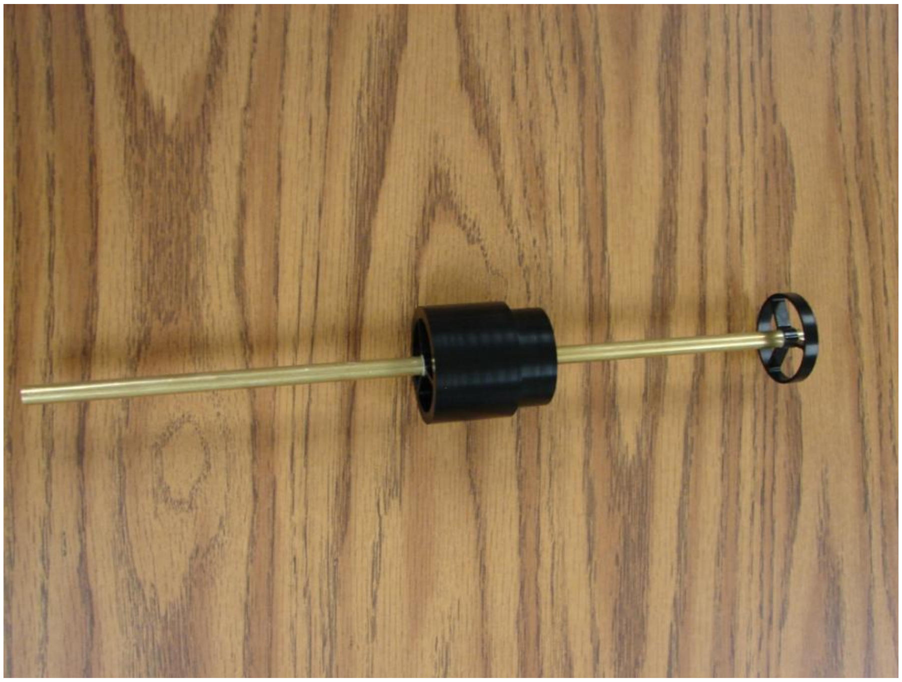


Figure 24: Fog Monitor Calibration Fixture, DMT ASSY-0453

5.2 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 25). Make sure the bottom of the cap and tubes are cleaned as shown on the left in Figure 25. Also clean the dispenser's glass canister as shown on the right.

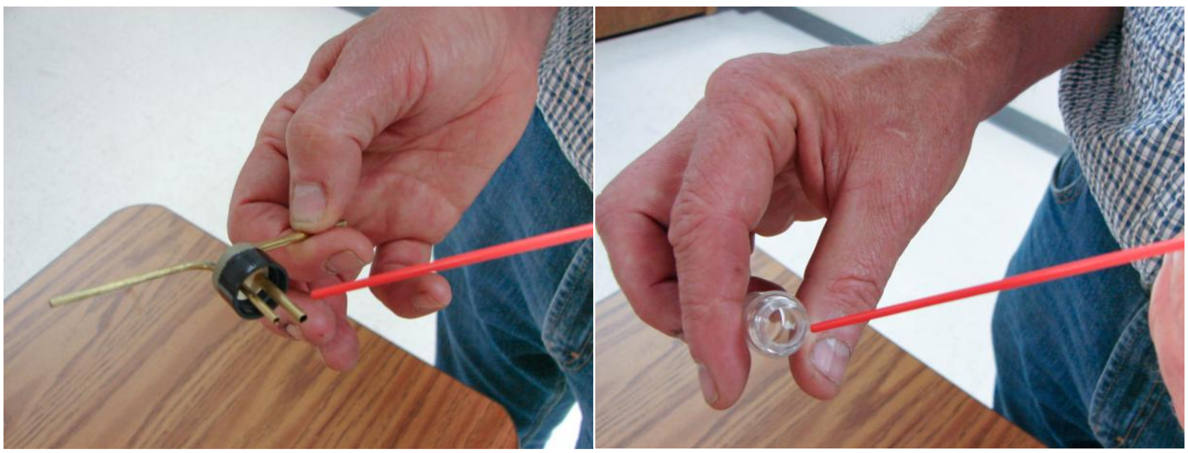


Figure 25: Cleaning the Glass Bead Dispenser

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 26.) A very thin film of beads should appear in the dispenser, as shown in Figure 27.

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 26: Tapping the Bead Dispenser to Dislodge Beads

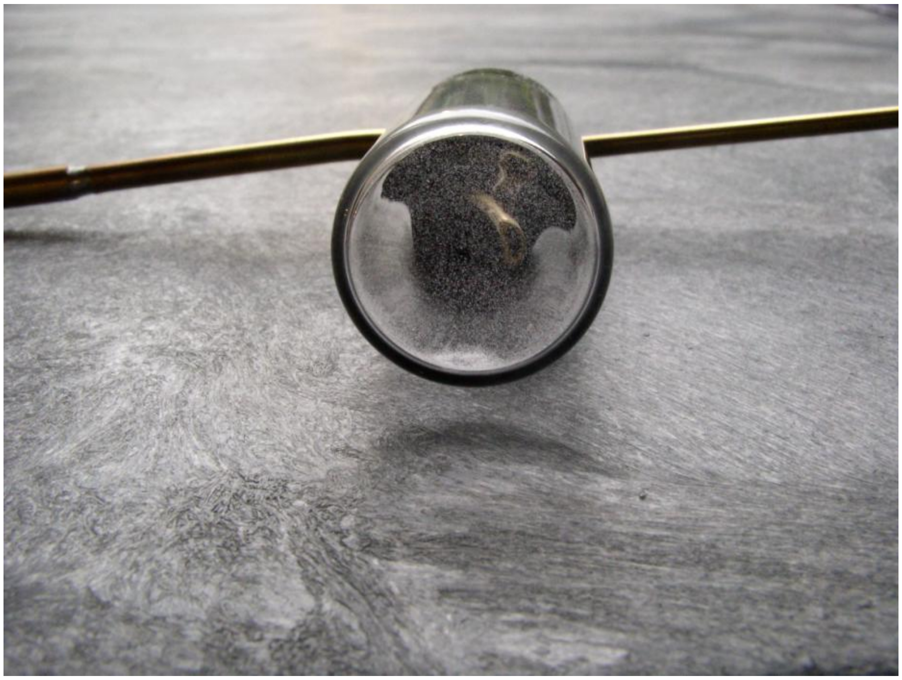


Figure 27: Dispenser with Film of Beads on Bottom

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 28 shows a calibration fixture being inserted into an FM-100.

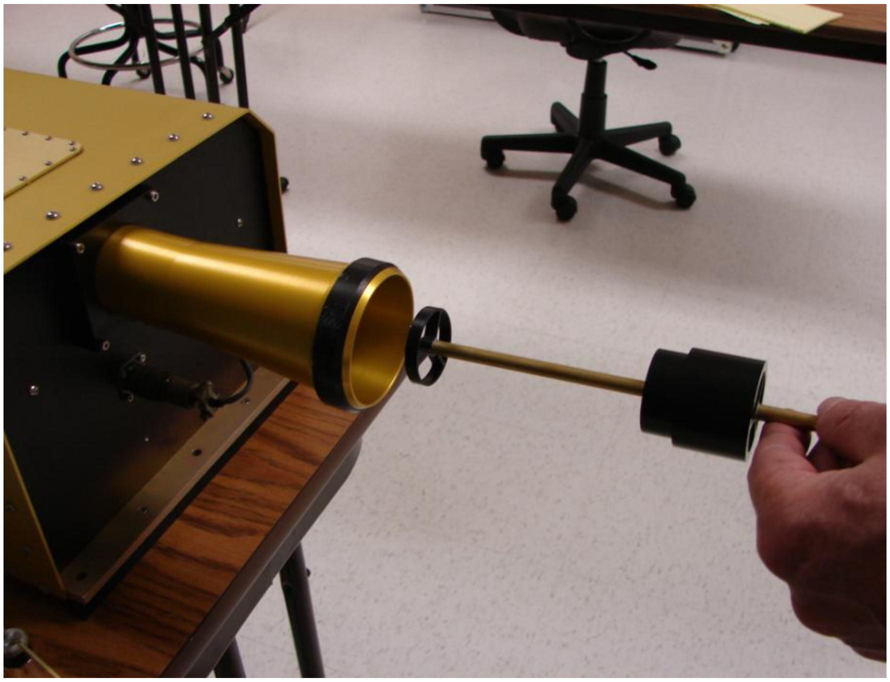


Figure 28: Inserting the Calibration Fixture into the Fog Monitor. The calibration fixture should be placed as far into the instrument's inlet as it will comfortably go.

8.) Connect the tube on the calibration fixture's far end to the dispenser, and connect the dispenser to the duster. (See Figure 29.) *Gently* press the duster so glass beads are released into the instrument. A very small amount of pressure on the trigger of the duster can 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 30.) The total number of particle counts, not concentration, should be 30-200. This is summed across all of the bins.

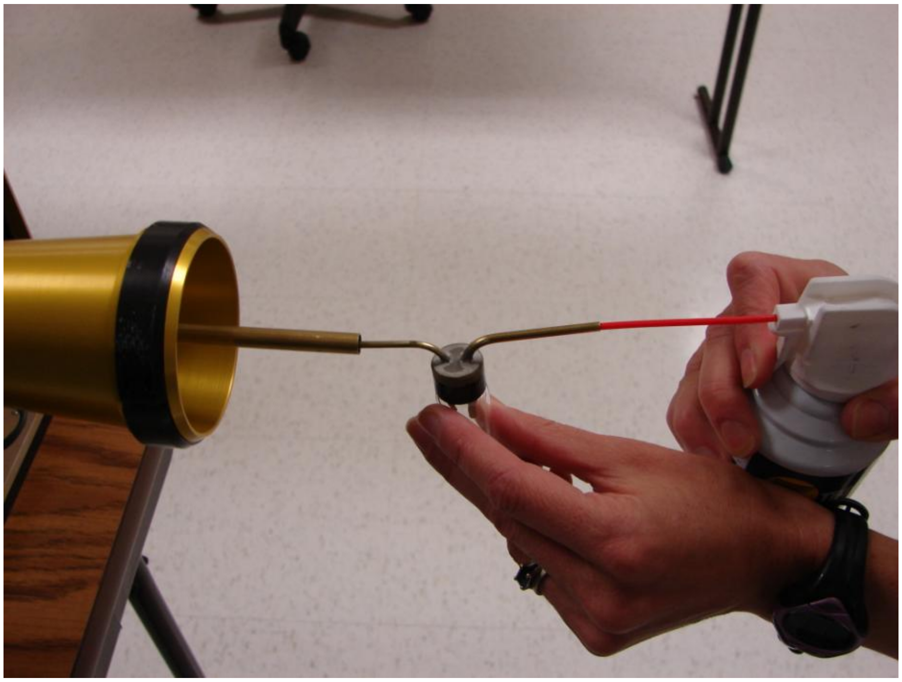


Figure 29: Blowing Glass Beads through the Calibration Device

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 22, 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 30 shows the typical calibration response for the FM-100. 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 A, the equivalent water size is 14.5 μm. In Figure 30, 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*.

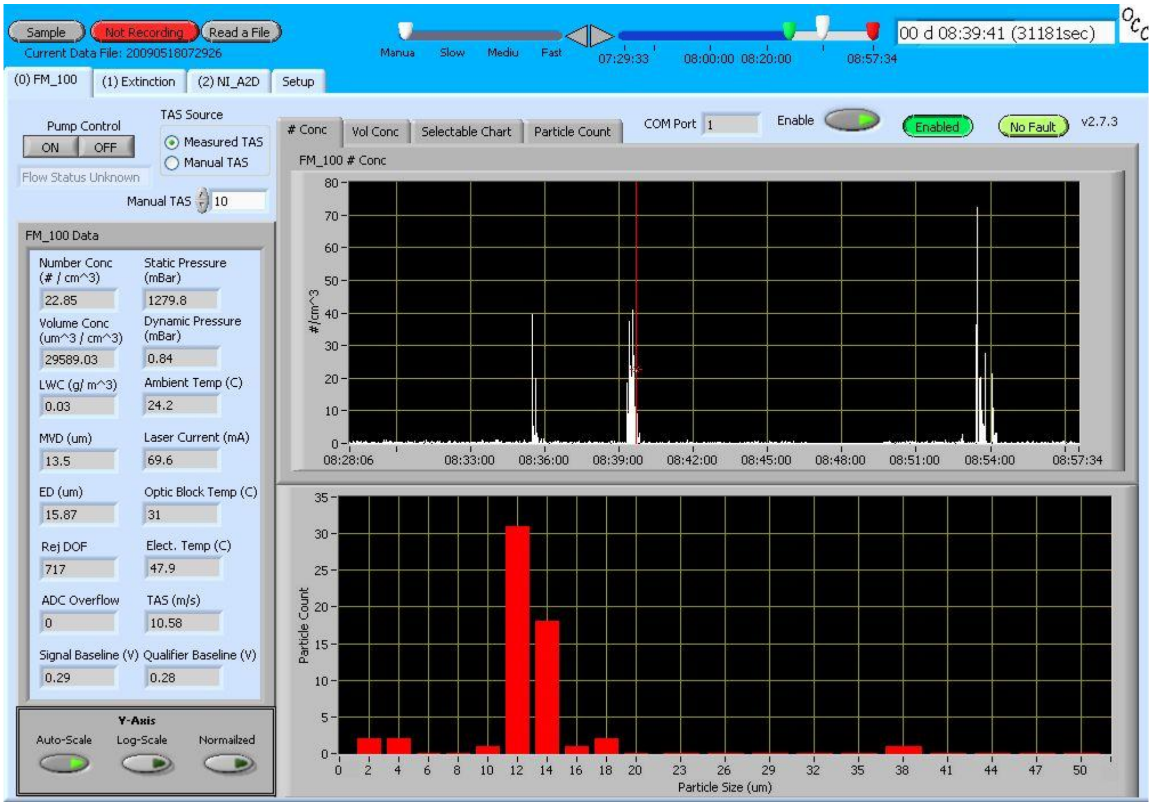


Figure 30: PADS Display of Calibration Test Results. Note the definite peak in the 12-14 µm particle range.

6.0 Particle Analysis and Display Software (PADS)

Figure 31 shows the instrument configuration screen for the FM-100 module in PADS.

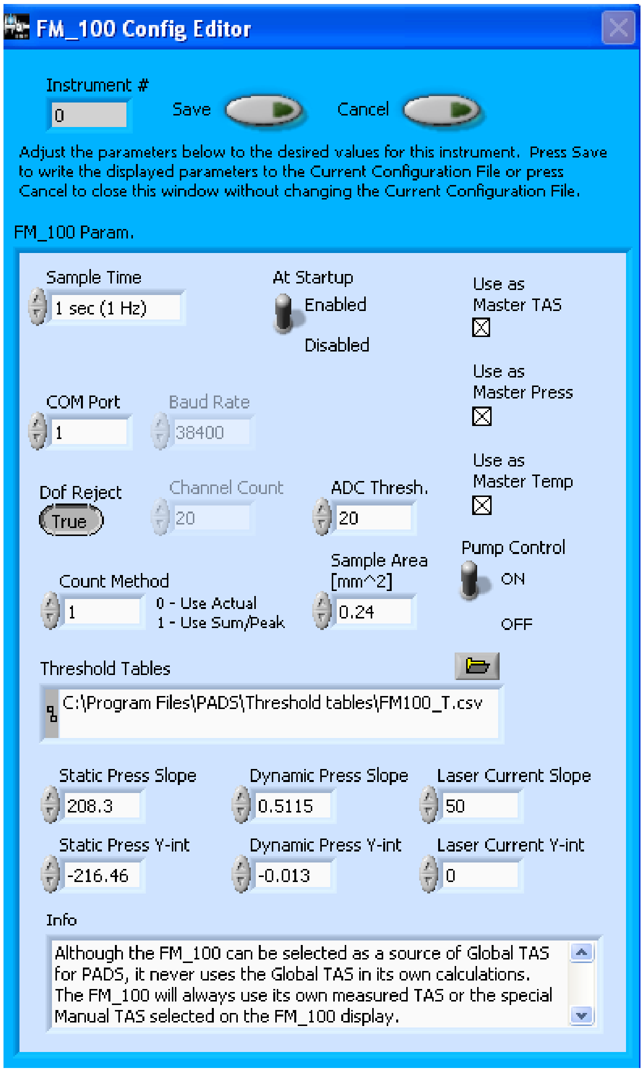


Figure 31: Configuration Editor for FM-100 in PADS

Figure 32 shows a typical PADS histogram display and concentration time plot. Statistical information, including housekeeping parameters, is displayed on the left.

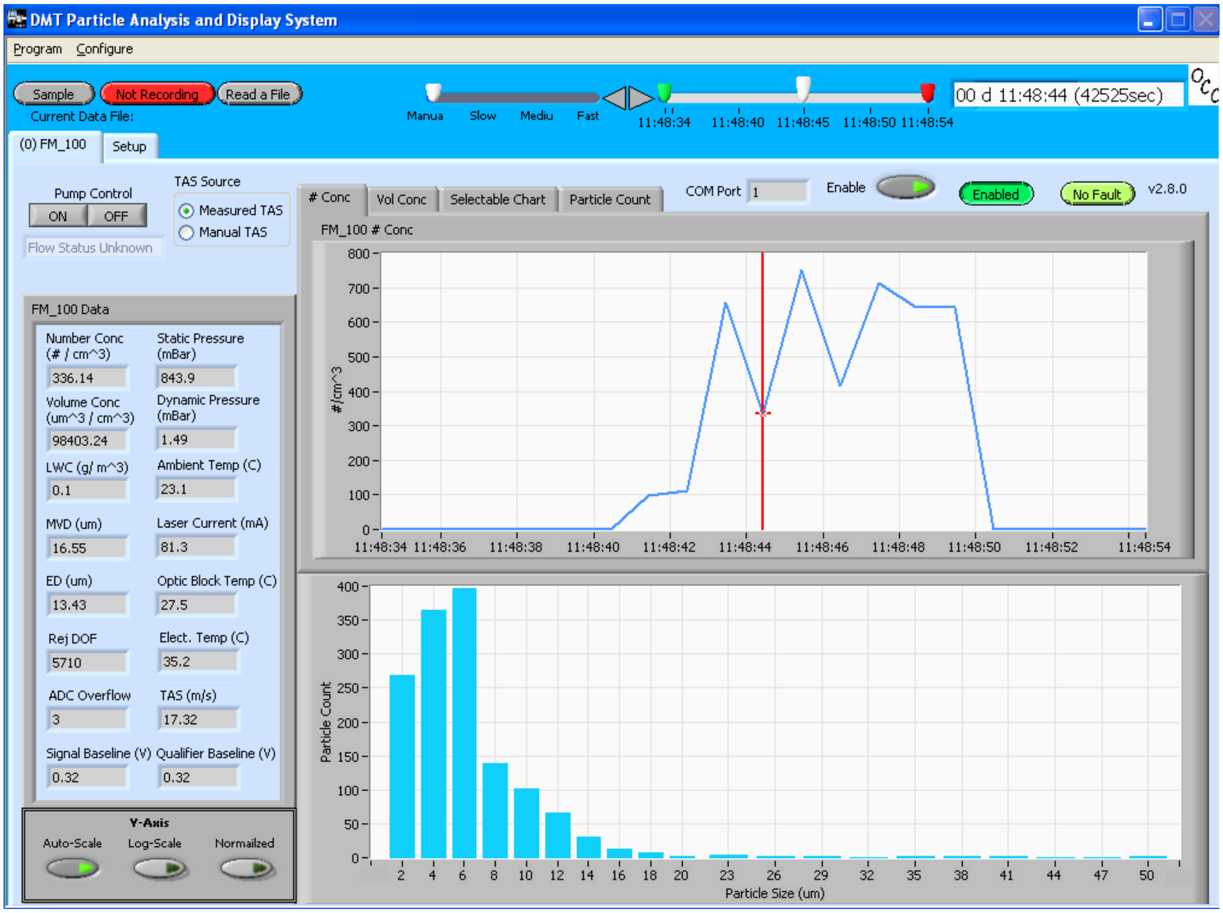


Figure 32: Main Window for FM-100 in PADS

Table 3 describes the FM-100 statistical channels shown on the left side of the window above. For more details, consult the FM-100 Module of the *PADS Operator's Manual*.

1	=	**Number Concentration**	=	This is the number of particles, calculated in this sample period, in a volume of one cm^3.
2	=	**Volume Concentration**	=	This is the ratio of total summed volume of DOF accepted particles in a sample space, to the total volume of that space.
3	=	**LWC (Liquid Water Content)**	=	Also called the liquid water mixing ratio, the LWC is the ratio of the mass of liquid water to the mass of dry air in a unit volume of air. Units are mass of liquid water per mass of dry air, such as gm^{-3} or $g\ kg^{-1}$.
4	=	**MVD (Median Volume Diameter)**	=	A measure of the diameter that contributes most to cloud liquid water or mass. This is the diameter for which the total volume of all drops having greater diameters is just equal to the total volume of all drops having smaller diameters.
5	=	**ED (Effective Diameter)**	=	The ratio of the third moment to the second moment of the size distribution, $\Sigma c_i d_i^3 / \Sigma c_i d_i^2$, where c_i and d_i are the concentration and size of each channel i.
6	=	**Rej DOF (Reject Depth of Field)**	=	The number of particle events that fell outside of the DOF
7	=	**ADC Overflow (Analog to Digital Converter Overflow)**	=	This is the number of particles that saturated the ADC, and are larger than 50µm
8	=	**Signal Baseline**	=	This is the average background baseline voltage from the sizing detector. Monitoring this will show possible problems with stray light or electronics malfunction.
9	=	**Qualifier Baseline**	=	Background baseline for the masked detector.
10	=	**Optic Block Temp**	=	Temperature of the forward scatter optical block.
11	=	**Elect. Temperature**	=	Temperature inside the electronic card cage.
12	=	**Static Pressure**	=	Static Pressure in millibars.
13	=	**Dynamic Pressure**	=	Differential pressure as measured from the Pitot tube.
14	=	**Ambient Temp**	=	As measured by the AD590 located in the sample tube.
15	=	**Laser Current**	=	This is a measurement of the current going to the laser diode
16	=	**TAS (True Air Speed)**	=	Air velocity in the sample tube, as calculated from Static Pressure, Dynamic Pressure and Ambient Temperature.

Table 3: FM-100 Statistical Channels

7.0 Theory of Operation and Firmware

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***.

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***.

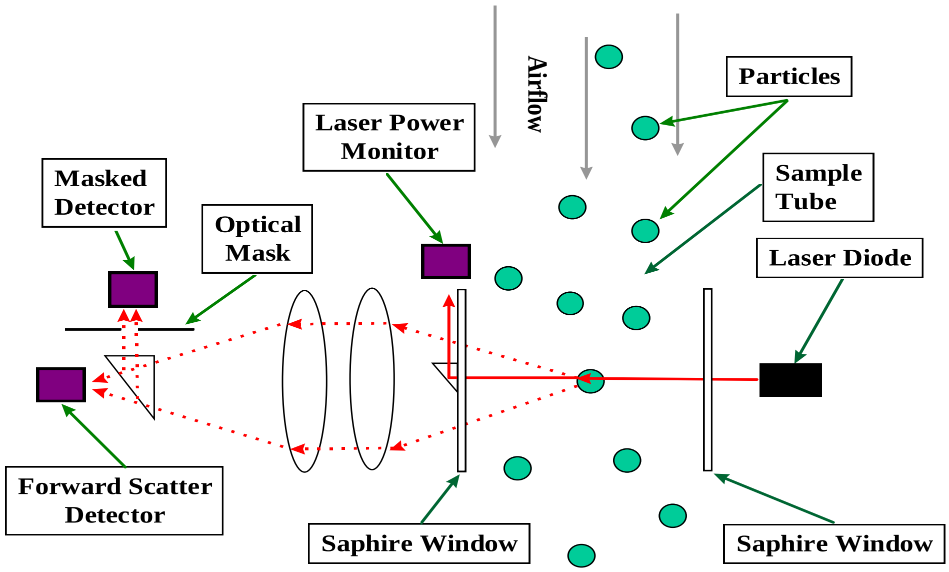


Figure 33: Theory of Operation

7.1 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.

7.2 Remote Control

The FM-100 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.

7.3 Signal Analysis

The SPP-FM consists of signal processing and data acquisition sections. The main sections of the signal processing section are the baseline restoration module (slot #1), the analog multiplexer module (slot #2), and the signal processing module (slot #3). These modules consist of the analog to digital (A/D) conversion, threshold detection, the sample counting, digital peak detection and area accumulation, and the first-in-first-out (FIFO) memories (slot #4 is empty). The data acquisition module (slot #5) consists of a digital processor (DSP) and control sections.

7.4 Pulse Height Analysis Implementation

The six subsections of the DMT Signal Processing Module are the analog to digital (A/D) conversion section, the threshold detector, the sample counter, the digital peak detector, the accumulator, and the first-in-first-out (FIFO) memories. The A/D converter continuously samples the incoming signal pulse at 20 MHZ. After each sample, the threshold detector checks to see if the value of the current sample is greater than a preset threshold (controllable from the data system). If the sample value exceeds the threshold, the processing of the remainder of the signal pulse begins. For each pulse, a counter records the number of samples that occurred while the signal voltage was above the threshold. The digital peak detector saves the largest voltage value that occurred and the accumulator sums all the sample values. After the particle exits the laser beam and the voltage no longer exceeds the threshold, the voltage pulse peak, area, and transit time values are written to the FIFO memories. This buffering of data into a FIFO allows the control processor to access the information when it has time and allows the signal-processing module to immediately process another particle. Thus, there is effectively no "dead time," i.e. no period of time between particles when the probe cannot detect new particles.

7.4.1 A/D Conversion of Signal Pulses

The A/D conversion section consists of a free-running 12 bit A/D converter sampling at 20 MHz. This converter simply samples and latches (holds) the incoming signal voltage from the unmasked detector every 50ns. The value is latched so that the data bus is driven with the value for the next 50ns. The analog input range of the Burr-Brown AD801U is approximately +0.3V to positive 4.3V. The proper gain and offset is adjusted on the Baseline Restoration Module.

7.4.2 Threshold Detection

The threshold detector is clocked at 20 MHz. During each sample of the A/D converter, the threshold detector checks the value latched by the A/D conversion section and sees if it is larger than zero. If the value is less than zero, no action is taken and the threshold detector simply waits for the next value to be latched. If the value is greater than zero, indicating the beginning of a particle's pulse, the threshold detector sends a flag to the other signal processing sections that a particle has been detected in the beam. The threshold detector continues to send the flag for every A/D conversion that exceeds zero. When the sampled value again falls below zero the signal is set false and the threshold detector section initiates the FIFO memory writing process. The count from the sample counter, a value that represents the particle transit time, is placed on FIFO lines 0 to 15. The maximum (peak) value detected during the passage of the particle is placed on FIFO lines 16 through 27. A flag that tells whether or not the depth of field signal was true or false on the first sample after the peak sample is placed on FIFO lines 28 to 31. The threshold detector then signals for this information to be written into the FIFO memories. The accumulator section output is subsequently enabled by the threshold detector and this information is written into the FIFO memories. While this is happening, the threshold detector is clearing the counter and resetting the peak detector to watch for another peak.

7.4.3 Sample Counter Section

The purpose of the counter section is to count the number of 20 MHz samples that occurred while the A/D value stays above the threshold. There are two uses for the value obtained by this counter. Since it is counting 20 MHz samples, the transit time of the particle can be calculated by multiplying the sample count by 50 ns (depending, of course, which sampling clock speed has been selected). This count is also the total of how many samples were summed in the accumulator.

7.4.4 Peak Detection

The peak detector begins looking for the maximum value of the signal pulse as soon as it receives the flag from the threshold detector section. As soon as this flag turns to true, the peak detector latches the current value on the data bus. On each sample clock cycle the detector checks the current sample versus its latched value. If the current value is greater than the latched value, the latched value is replaced with the current value. If the current value is less than the latched value, the latched value is not changed. The first time the current value is less than the latched value, the DOF flag is also latched into the peak detector. This flag is used to indicate whether or not the particle being processed has passed through the Depth of Field of the probe. When the peak detector receives a true signal, it drives FIFO memory lines 16 to 27 with the peak value it has latched, and drives line 28 to 31 with the latched value of the DOF flag.

7.4.5 Accumulator

The accumulator section of the signal processing board consists of an IDT7210 multiply accumulator. This device multiplies two 16-bit integers and adds the result to an ongoing accumulation in a single clock cycle. The output is given in a 35-bit integer number. One of the 16-bit numbers that is used in the multiplication is hardwired to 16384 (4000 hexadecimal) and the 12-bit value that is digitized by the A/D converter is wired to bits 2 through 13 of the other 16-bit number. All other bits (0, 1, 14 and 15) of the second number are tied low. This configuration guarantees that the result of the multiplication will always be 65536 (10000 hexadecimal) or greater. Therefore, only the top 19 bits of the result are actually written to the FIFO memories. This essentially divides the result by 65536 and causes the FIFO word to be the sum of all the values encountered while the particle passed through the beam.

Since the result is held to 19 bits, there are 19 - 12 = 7 bits of headroom for the sum. This means that the sum could overflow if more than 2^7 = 128 samples occur in a single pass of a particle. The sample rate of the A/D converter must be lowered if particles are expected to be processed will have a transit time in the beam that exceeds 128 * 50 = 6400 ns (6.4 microseconds). The ongoing accumulator register is cleared to zero each time the sum is written out to the FIFO memories.

7.4.6 FIFO Operations

The FIFO memory section of the signal processing board consists of four 9-bit wide FIFO memories (IDT7205). Currently these FIFO memories are 4096 words deep, but they can be replaced by deeper memories if overflow becomes a problem. These FIFO memories are attached to a 16-bit bus. The least significant FIFOs (U7 and U10) need to be read first, as reading this data latches the other FIFO outputs for a second read. The FIFOs are read by asserting signals *RF0 or *RF2 true. The Signal Processing Module is selected with "Board Select 0" at address 0. A second Signal Processing Module is used with the FSSP-300 electronics. This would use "Board Select 1" at address 0x100.

The words that are written in the FIFO memories are in the format shown below. Bytes 0 and 1 of the first word contain the count of the number of samples that were taken as the particles passed through the beam. Bits 16 to 27 of the first word contain the maximum value that was digitized during the transit of the particle. Bits 28 to 31 of the first word will be all zeros if the particle passed the depth of field criteria and will be all ones if the particle failed the depth of field test. The second word contains the sum of all values that were digitized as the particle passed through the beam. This sum is in bits 0 to 18. Bits 19 to 31 are not currently being used.

<table>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="8">Byte 3</td><td colspan="8">Byte 2</td><td colspan="8">Byte 1</td><td colspan="8">Byte 0</td></tr>
<tr><td colspan="4">DOF Accepted</td><td colspan="12">Peak Value</td><td colspan="16">Transit Count</td></tr>
</table>

Unused	Sum of All Values

Figure 34: FIFO Memory

The Signal Processing Module writes the first word to the FIFO memories in the middle of the first cycle, after the value has dropped below the threshold. It writes the second word on the next sample of the A/D converter. If that next sample is above the threshold, a new particle will begin to be processed. This means that only a single sample is needed between particles as a demarcation of the end of one particle and the beginning of another. This essentially gives the probe zero wait time between particles.

Overflow occurs if the signal processing electronics totally fill up the FIFO memories (with 4096 particles) before the digital processing module can process a particle. When this overflow occurs, the FIFO full line (*FF) is used to interrupt the DSP on the digital processing board, the DSP immediately clears the FIFO memories with the *CLRFIFO signal, and increments its total count by the 4096 particles that were lost by clearing the FIFO memories. In this manner the electronics at least count every particle, even if not all particles are processed.

7.5 Digital Signal Processing Unit

The DMT Digital Processor and Control Module are built around an Analog Device's ADSP-2181 digital signal processor (DSP). The board consists of the DSP, a ROM memory, a watchdog timer, a universal asynchronous receiver transmitter (UART), and a bus interface. The memory is used to store the program that runs on the DSP. The watchdog timer will reset the DSP if the program ever fails to access the watchdog timer within 1.6 seconds. The UART is the main serial communications chip for passing information to the data system and receiving control commands back. This is where the RS-232 or RS-422 format is selected. The bus interface connects to all of the other boards in the system to which the DSP needs access.

The ADSP-2181 is a 16-bit digital signal processor with 80K bytes of onboard RAM. The DSP is configured in a way that, upon reset (or power on), it loads its internal program memory from the 27C256 ROM, and starts execution of the program out of internal RAM. The processor is a fixed-point device and is rated at 33 MIPS of sustained performance. The processor also contains a programmable timer, extensive interrupt-handling capabilities, and a versatile input/output interface that includes programmable wait states to facilitate maximizing access to external devices. The internal architecture of the DSP provides for a separate program and data bus that allows simultaneous fetching of instructions and data.

The bus interface consists of a 22V10 programmable logic chip, two FCT543 octal bus transceivers, and one FCT541 octal bus driver. The drivers are simply used to provide the drive capabilities for off-board electronics, the 22V10 is used to generate the I/O strobe (*IO_STB) and seven board selects (*BRD_SEL0 to *BRD_SEL6). The I/O strobe has a software-controllable duration as described below. The board selects are generated when the DSP accesses certain locations in its memory. The exact address of these locations is explained below.

The bus consists of five address lines (AB0 to AB4), 16 data lines (DB0 to DB15), seven board select lines (*BRD_SEL0 to *BRD_SEL6), a low true strobe line (*IO_STBB), and two bus direction indicators (*RDB and *WRB). When the DSP accesses the I/O bus, it will set either *RDB or *WRB low to indicate whether the access is a read or a write, respectively. Then, it will place the proper address on the address lines and set one and only one board select low. If the access is a write, data will be placed on the data lines. Only after all of these conditions have been set up will the strobe line go low. The other lines will remain driven until the strobe line goes high. Other boards can latch data from the bus on either edge of the strobe. The DSP will latch the data bus (on a read), on the rising edge of the strobe. Therefore, any boards that are read by the DSP must be driving the data bus when the strobe line comes high.

The UART is a Phillips/Signetics SCC2691 UART. For a complete description of its operation, please refer to the Signetics reference manual. The address at which the UART resides in the DSP's memory map that follows.

0x000-0x01F	:I/O Board 0	**(IOWAIT0)**
0x100-0x11F	:I/O Board 1	**(IOWAIT0)**
0x200-0x21F	:I/O Board 2	**(IOWAIT1)**
0x300-0x31F	:I/O Board 3	**(IOWAIT1)**
0x400-0x41F	:I/O Board 4	**(IOWAIT2)**
0x500-0x51F	:I/O Board 5	**(IOWAIT2)**
0x600-0x61F	:I/O Board 6	**(IOWAIT3)**
0x700-0x71F	:2691 UART	**(IOWAIT3)**

Table 4: The DSP's 2K of 16-bit Addressable Space

IOWAIT0-IOWAIT3 is the programmable 3-bit wait state fields in the Wait State Control Register (wait states are discussed below). I/O Board 0 is the primary signal processor module 0. I/O board 1 is the secondary signal processor module (if needed). Some probes need only one signal-processing module. I/O board 2 is the Analog Multiplexer Module. The remaining four slots are available for future use. Each I/O Board, including the UART, has a maximum of 32, 16-bit locations addressable by the DSP. Each location can be read and/or written to. Note that no hardware protection is provided for undefined addressing. Address aliasing is a consequence of this design.

The UART is assigned 8, 8-bit locations on data bus D8-D15. The I/O data bus maps to D8-D23 in the hardware, so D8-D15 equates to the lower I/O byte. These locations correspond to the 8 internal registers of the UART. The registers are naturally located in the lower address space, 0x700-0x707. The address spaces within each of the three DMT I/O Boards are discussed with each board individually.

The software controls an I/O access by programming the number of wait states in the Wait State Control Register and by setting two general-purpose flag pins, PFI-PFO, before the access takes place. The following combinations are allowed:

I/O Target	R/W	PFI-PFO	IOWAITx	I/O STB Duration	Access Time
Board 0-6	W	N/A	0x4	35 ns	175 ns
Board 0-6	R	0x0	0x4	35 ns	175 ns
Board 0-6	R	0x1	0x5	70 ns	210 ns
Board 0-6	R	0x2	0x6	105 ns	245 ns
Board 0-6	R	0x3	0x7	140 ns	280 ns
UART	R/W	N/A	0x7	175 ns	280 ns

Table 5: I/O Access

Note: **IOWAITx** must always be set to 0x4-0x7 and that “N/A” means don't care in this case. These settings must be adhered to by the software to insure proper operation.

There are three additional software-controlled flag output pins. They are defined as follows:

Output Flag	State	Function	Reset State
FL0	N/A	Toggle within every 1.6 secs. to reset the watchdog timer	N/A
FL1	0	Turn on LED	1
	1	Turn off LED	
FL2	0	Enable UART	1
	1	Hold UART in reset	

Table 6: Three Additional Software-Controlled Flag Output Pins

The remaining flag and interrupt pins on the DSP and UART are connected to the backplane. The FIFO memory empty line (*EF-A) from the Signal Processor Module 0 is connected to the DSP's PF2 line. The software monitors this line. When a particle goes through the beam and the Signal Processor Module places the information about the particle into the FIFO memory, the memory empty signal goes false. This causes the DSP to enter its main processing loop, read the data from the FIFO memory, and process the particle.

The FIFO memory full line (*FF-A), from the Signal Processor Module 0, is connected to the DSP's IRQ0* line. If the Signal Processor Module 0 fills the FIFO memories completely the *FF-A line will go true, causing an interrupt in the DSP. In the DSP's interrupt service routine, the FIFO memories are cleared by asserting the CLRFIFO-A signal, which is connected to the DSP's line PF6. After clearing the FIFO memories, the software increments its counter for the total number of rejected particles by 4096 to account for the 4096 particles that were lost by clearing the FIFO memory.

7.6 Analog Multiplexer Module

The DMT Analog Multiplexer Module, slot #2, is used to monitor various housekeeping voltages in the probe. It consists of signal conditioners, bus interface, so that it can be controlled by the Digital Processor and Control Module, an analog multiplexer, to choose one of 8 different channels to monitor, an analog to digital convertor (A/D), and bus drivers.

The channel of the multiplexer to use is selected by the writing to any address (between 0 and 7) in the board's address space. This will cause the GAL16V8 to latch that address and drive the lines S0, S1 and S2 with the latched address. These lines are fed to the analog multiplexer (mux 08) as its channels selection lines. For example, writing to address 5 on the board will cause S0 to go high, S1 to go low and S3 to go high, selecting channel 5 of the multiplexer. An analog to digital conversion is started by asserting the *ADCS and R/*C lines low. The processor then executes a 10.

Low pass filters are provided for the analog input signals, SIGNAL-1 (sizer) and SIGNAL-2 (qualifier). The photodetector signals from the transimpedance amplifiers are fed to this board to give the ability to monitor baseline changes. These will drift slowly with time, temperature, and optical alignment. These baselines are monitored by the electronics to get an idea of the quality of the optical signals and to tell whether they have drifted. There are provisions on the Analog Multiplexer Module to ground any unused inputs.

Note: Analog inputs should be grounded, and not left floating.

Also, there are provisions to set the A/D to be bipolar, accepting both positive and negative voltages, or unipolar, accepting only positive voltages. The "HI-SPAN" selection allows a 20-volt input range, while "LO-SPAN" accepts a 10-volt range. During the construction of the SPP-FM, The A/D is routinely set for a range of –10V to +10V. See the schematic of this board for details on jumper settings.

Mux Chnl	Parameter	Control Module Connections (Ribbon Cable connections, Control Module to SPP-FM backplane).	Notes
S-0	Signal Baseline	N/C. Signal level is received from the SPP-FM backplane.	The displayed level is RMS, and typically .28V to .31 V
S-1	Qualifier Baseline	N/C. Signal level is received from the SPP-FM backplane.	The displayed level is RMS, and typically .28V to .31 V
S-2	Ambient Temperature	S-18 to S-3, (J12 pin-5 to SPP-FM backplane pin #15)	Analog signal comes from the Control Module. 0V = -50C, +10V = +50C
S-3	Laser Current	S-19 to S-10, (J12 pin-7 to SPP-FM backplane pin #16)	Laser Diode Driver's current monitor: 1V = 50mA
S-4	Laser Power Monitor	S-20 to S-12, (J12 pin-9 to SPP-FM backplane pin #18)	Laser Diode Driver's power monitor: 1mA/V
S-5	Static Pressure Transducer	S-16 to S-1, (J12 pin-1 to SPP-FM backplane pin #13)	Signal comes from Sen-Sym transducer: 142SC15A, 0-15 psia, 1V. to 6V. output.
S-6	Differential Pressure Transducer	S-17 to S-2, (J12 pin-3 to SPP-FM backplane pin #14)	Signal comes from Ashcroft transducer: RX7MB210ST2IW.
S-7	Card Cage Internal Temp.	N/C. This sensor is already on the Analog Mux Module	Analog Device, TMP01EP.

Table 7: Housekeeping Parameters

7.7 Baseline Restoration Module

The Baseline Restoration Module is used to prevent baseline shift due to the AC coupling used in the Photodetector Module. Also, there is a section that will supply the positive offset required for the Signal Processing Module's A/D converter. These offset trim-pots will set the signal and mask levels just below the "0" threshold of the A-D converter, which is about 300mV. Both of the baselines should be adjusted such that the top of the noise level is at 300mV.

This module also has the LM211 comparator for the DOF signal. Monitor the “DOF” test point and adjust the associated offset trim-pot until the signal is just consistently low. Any adjustment of either the Signal or Mask Baselines will affect the output of the DOF comparator. For a “True” level DOF, the Mask pulse will be greater than the Signal pulse.

7.8 Control Module

The Control Module contains several circuits, which are outlined below. See the schematics for more details.

Circuit Description	*Reference Designator*	*Notes*
Heater Control for Inlet Horn	U1	100W (230V), or 50W (115V)
Heater Control for Laser Block	U2	40W
Heater Control for Wetless Windows	U4	40W
Heater Control for Optical Block	U5	40W
Heater Control: Aux Circuit	U7	Not used
Laser Power Monitor	U17, U18	
Buffer amps for the static and differential P. transducers	U21	
Ambient Temperature amplifier	U16	0V = -50C, +10V = +50C
Digital Control buffers	U20	Drives Pump Control relay

Laser Diode Driver	U13	
Laser Diode current and power monitor buffer amp	U15	

Table 8: Control Module Circuits

8.0 Communications between the PC and SPP-FM

Any computer capable of communications over an RS-232 or RS-422 port should be capable of communicating with the SPP-FM. The port parameters for communications should be set to 38400 baud, 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 SPP-FM be programmed at a low level to avoid this problem.

The host computer initiates all communications with the SPP-FM. There are two commands that the SPP-FM responds to: the setup data acquisition parameters command (command = 1) and the send data command (command = 2). Since the SPP-FM only responds with data after it has received a request for data, all of the timing for data acquisition needs to be performed in the host processor. To increase the data rate from the SPP-FM the host only needs to increase the rate at which it makes requests for data. After filing a data request the SPP-FM clears all of its summation and starts taking a new set of data.

The code in both the SPP-FM and the DMT-supplied control software that runs on a PC are written in the "C" programming language. As such, the communications between the two boxes occurs through predefined structures, the format of these structures is given below. In the structures, parameters defined as 'int' and 'unsigned' are 16 bits long, those defined as 'char' and 'unsigned char' are 8 bits long, and those defined as 'unsigned long' are 32 bits long.

The probe uses a 16-bit processor, which requires some data manipulation depending on what type of architecture is used in the host PC system. All data sent and received is in multiples of 16-bit words (an even number of bytes). When using a 'low byte first' architecture, such as the x86 family, the unsigned long fields will need to have the low and high bytes swapped after reception from the probe. When using a 'high byte first' architecture, such as the 68K family, every 16-bit group (integers or byte pairs) will have to be switched, both incoming and outgoing. This can be done using the 'swab()' function in C, or by writing a communications routine which sends and receives the low-order byte first.

8.1 SETUP: DATA ACQUISITION PARAMETERS COMMAND

The structure below contains the format of the packet sent to the SPP-FM probe to setup the data acquisition parameters. The SPP-FM automatically comes up with default parameters at power on, but it should be set up each time it is used by the control software, just to be sure of the setup parameters. These parameters will remain until power is cycled or a new setup data acquisition parameters command is sent.

```
struct
{       char esc;                          // ESC character starts all commands
        char num;                          // command number
        unsigned threshold;                // trigger threshold
        unsigned transRej;                 // Avg. Transit Reject flag (always 0 for FM)
        unsigned chanCnt;                  // 10, 20, 30, or 40
        unsigned dofRej;                   // DOF Reject flag
        unsigned flags;                    // Digital output control, pump control
        unsigned avgTransWeight;           // calc. avg. trans to the -2 power
        unsigned attAccept;                // % of transit time average for acceptance
        unsigned divisor flag;             // 0 = / 2 , 1 = / 4
        unsigned ct_method;                // 0 = actual sample count, 1 = sum/peak
        unsigned OPCthreshold[OPCCHAN];    // 10, 20, 30, or 40
        unsigned cksum;                    // checksum
}
```

The meanings of each of the above declared parameters are:

esc	Is always ASCII 27, the escape character.
num	Is the command number: 1 = setup data acquisition parameters.
threshold	Is the PHA trigger level in clock counts.
transRej	Flags if average transit rejection is enabled. (Not used in Fog Monitor)
chanCnt	Indicates the channel count to use.
dofRej	Flags if DOF rejection is enabled.
flags	Sets the digital output (bit 0) , and Pump Control (bit 1).
avgTransWeight	Sets the number of particles used to determine the average transit.
attAccept	Sets the percent of average transit time for acceptance. (Not used in FM)
divisor flag	Selects the PHA divisor of basic clock speed to determine sampling speed.

ct_method	Derived 'Average Transit Count' uses particle width if zero, or particle area divided by particle peak if one.
OPCthreshold[]	Sets the peak count threshold for the channels.
cksum	Is the 16-bit sum of the characters in the packet.

For command number 1 (setup data acquisition parameters) the SPP-FM probe responds with two ACK characters (ASCII character 6).

8.2 SEND DATA (POLL REQUEST) COMMAND

The structure below shows the packet that is sent to the SPP-FM probe to request a data packet. It simply contains esc, num, and cksum.

```
struct
{
        char esc;               // ESC character starts all commands
        char num;               // command number
        unsigned cksum;         // checksum
}
```

The meanings of each of the above declared parameters are:

esc	Is always ASCII 27, the escape character.
num	Is the command number: 2 = send data (poll request).
cksum	Is the 16-bit sum of the characters in the packet.

For command number 2 (send data / poll request) the SPP-FM probe responds with the structure below.

```
struct
{
        unsigned cabinChan[8];
        unsigned long rejDOF;
        unsigned long rejAvgTrans;
        unsigned AvgTransit;
        unsigned FIFOfull, resetFlag;
        unsigned long ADCoverflow;              // particle ADC overflow
        unsigned long OPCchan[OPCCHAN];         // 10, 20, 30, or 40
        unsigned checksum;                      // will be at end of channels in use
}
```

The meanings of the above declared parameters are:

cabinChan[]	Is an array which holds the most recent Analog-to-Digital conversion raw counts for the eight analog channels.
rejDOF	Holds the number of particles rejected because the signal pulse height is less than the qualifier pulse height (not in Depth-of-field).
rejAvgTransit	(not used for FM)
AvgTransit	(not used in the FM)
FIFOfull	(not used in the FM, for firmware development only)
resetFlag	(not used in the FM, for firmware development only)
ADCoverflow	Holds the count of readings where the Analog to Digital Converter was saturated at its maximum digitized counts and was in overflow/overrange. These particles are not processed into the calculated parameters.
OPCchan[]	Is an array which holds the particle counts for the different peak size channels.
checksum	Is the 16-bit sum of the characters in the packet.

Note: The FM-100 is programmed for 20 bin resolution. Other resolutions are available by special order. Note that the length of the data packet will change based on the number of channels being used. The total length for 10 channels is 76, for 20 channels is 116, for 30 channels is 156, and for 40 channels is 196.

9.0 Modifying the FM-100 Processor when Switching Communications Protocols

If you are switching communications protocols, you may need to make some modifications to the FM-100 processor.[4] The FM-100 processor is labeled "SPP-FM DSP/Control Module."

For RS-232 Protocol:

When using an RS-232 protocol, Resistor 18 *must* be removed (Figure 35). Also, if the jumpers on S1-S5 are on pins 1-2, as shown in , they must be moved to pins 2-3.

For RS-422 Protocol:

The jumpers on S1-S5 should be on pins 1-2, as shown in Figure 35. Resistor 18 can either be installed or removed—the processor will operate correctly either way.

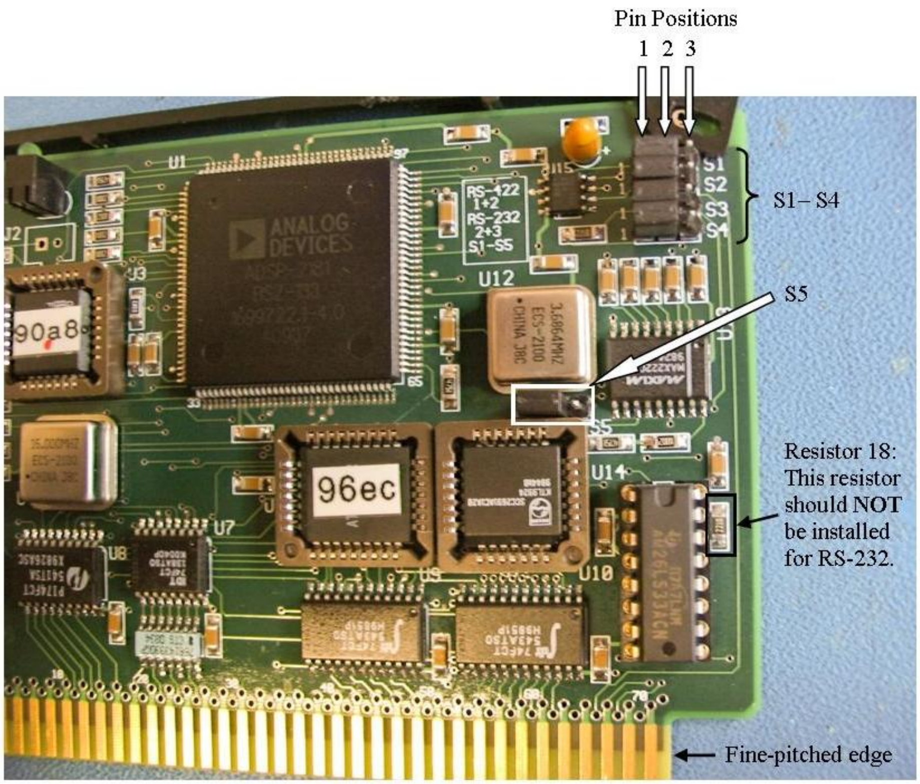


Figure 35: FM-100 Processor

[4] While this document only describes adapting the processor, other tasks (e.g., cable conversion) must be performed to switch communications protocols. Contact DMT for more information.

10.0 Selection of Channel Size Thresholds

The SPP-FM classifies the size of a particle by comparing its digitized 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 4° - 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. Conver 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

Glass Bead to Water Droplet Conversion Table 5 May, 1999

Glass Bead Calibration Size: n=1.51 Water Equivalent Size: n=1.33

Glass Bead Tolerances, and Equivalent, in Microns:

Glass Bead			Range		
2.1	±0.5	=	1.6	to	2.6
8.1	±0.8	=	7.3	to	8.9
15.5	±1.1	=	14.4	to	16.6
19.9	±1.4	=	18.5	to	21.3
20.6	±1.4	=	19.2	to	22.0
40.0	±2.8	=	37.2	to	42.8

Glass	Water	Glass	Water	Glass	Water	Glass	Water
0.5	0.6	13.5	11.6	26.5	21.5	39.5	31.8
1.0	0.9	14.0	12.0	27.0	21.9	40.0	32.5
1.5	1.3	14.5	12.5	27.5	22.3	40.5	32.9
2.0	1.8	15.0	12.8	28.0	22.7	41.0	33.3
2.5	2.3	15.5	13.2	28.5	23.1	41.5	33.7
3.0	2.7	16.0	13.6	29.0	23.4	42.0	34.1
3.5	3.1	16.5	13.9	29.5	23.8	42.5	34.5
4.0	3.5	17.0	14.3	30.0	24.4	43.0	34.9
4.5	4.0	17.5	14.7	30.5	24.8	43.5	35.3
5.0	4.5	18.0	14.9	31.0	25.1	44.0	35.7
5.5	5.0	18.5	15.3	31.5	25.5	44.5	36.1
6.0	5.2	19.0	15.7	32.0	25.9	45.0	36.5
6.5	5.5	19.5	16.1	32.5	26.3	45.5	36.9
7.0	5.8	20.0	16.1	33.0	26.7	46.0	37.3
7.5	1.5	20.5	16.5	33.5	27.1	46.5	37.7
8.0	6.2	21.0	17.0	34.0	27.5	47.0	38.2
8.5	6.6	21.5	17.4	34.5	27.9	47.5	38.6
9.0	7.3	22.0	17.8	35.0	28.3	48.0	39.0
9.5	8.1	22.5	18.2	35.5	28.6	48.5	39.4
10.0	8.9	23.0	18.6	36.0	29.0	49.0	39.8
10.5	9.1	23.5	19.0	36.5	29.4	49.5	40.2
11.0	9.5	24.0	19.4	37.0	29.8	50.0	40.6
11.5	9.9	24.5	20.0	37.5	30.3		
12.0	10.3	25.0	20.4	38.0	30.7		
12.5	10.8	25.5	20.8	38.5	31.1		
13.0	11.2	26.0	21.2	39.0	31.5		

Appendix C: Interpreting Glass Beads Calibration Tests

The FM-100 is typically calibrated with precision glass beads. Figure 36 through Figure 44 show the results of such tests as the FM-100 is progressively moved out of alignment. Figure 36 through Figure 38 are for 8-µm beads, Figure 39 through Figure 41 for 20-µm beads, and Figure 42 through Figure 44 for 40-µm beads.

Figure 36, Figure 39, and Figure 42 show the calibration with a properly aligned FM-100. The FM-100 response to the calibration beads gives a narrow histogram with the bead sizing falling in the proper bin (see note below). As the FM-100 is moved out of alignment, the width of the histogram increases, as shown in Figure 37, Figure 40, and Figure 43. With severe misalignment, as seen in Figure 38, Figure 41, and Figure 44, 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-100, 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.

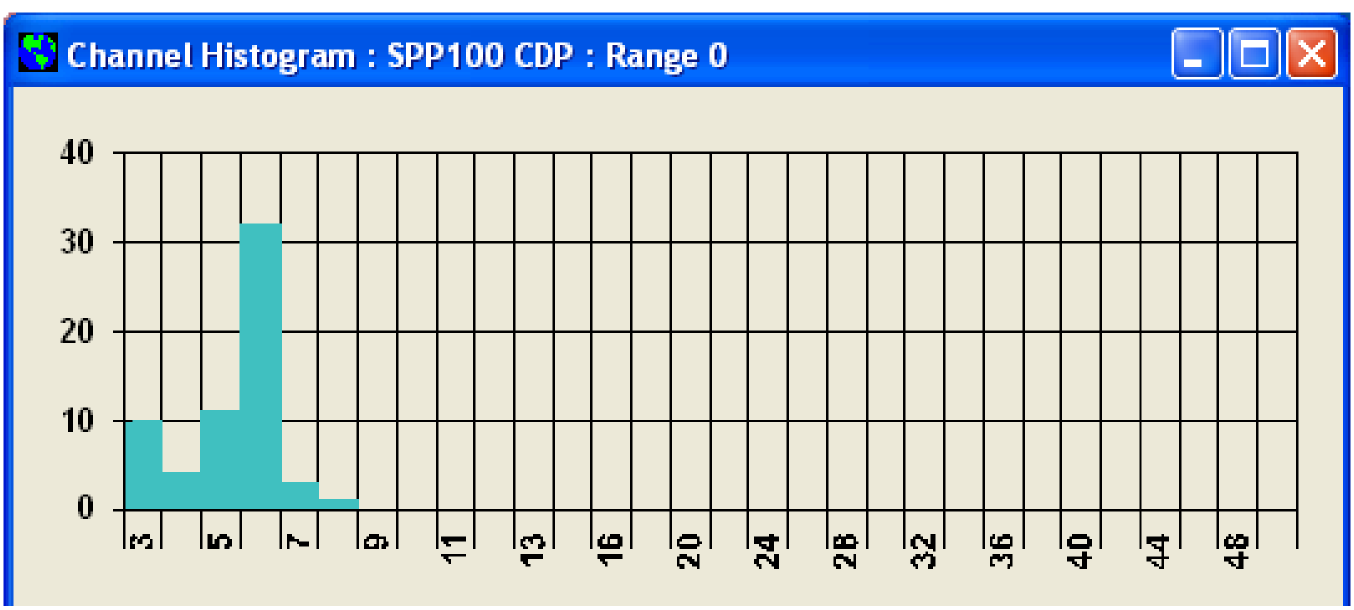


Figure 36: 8-µm glass beads FM-100 aligned

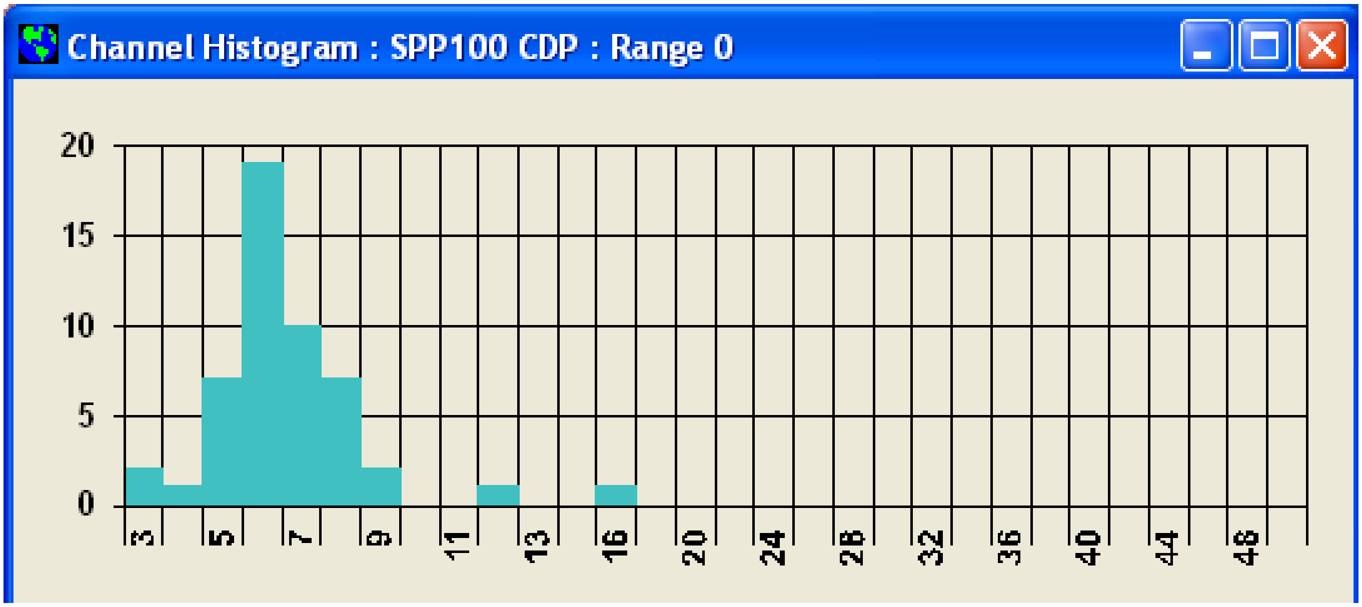


Figure 37: 8-μ glass beads FM-100 moderate misalignment

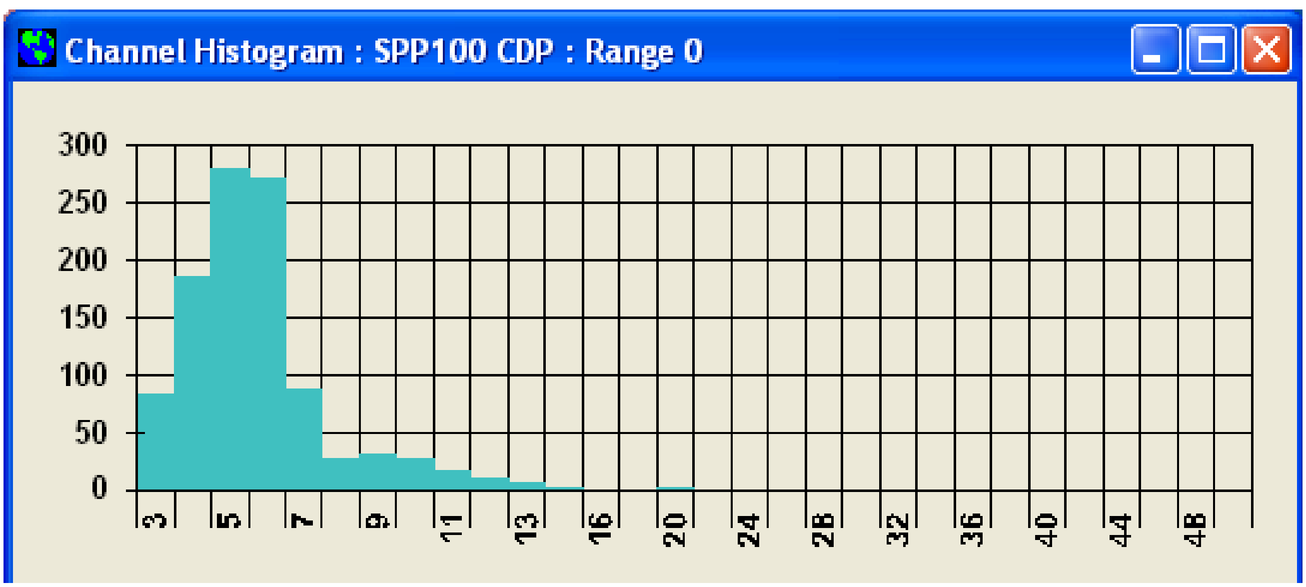


Figure 38: 8-μ glass beads FM-100 severe misalignment

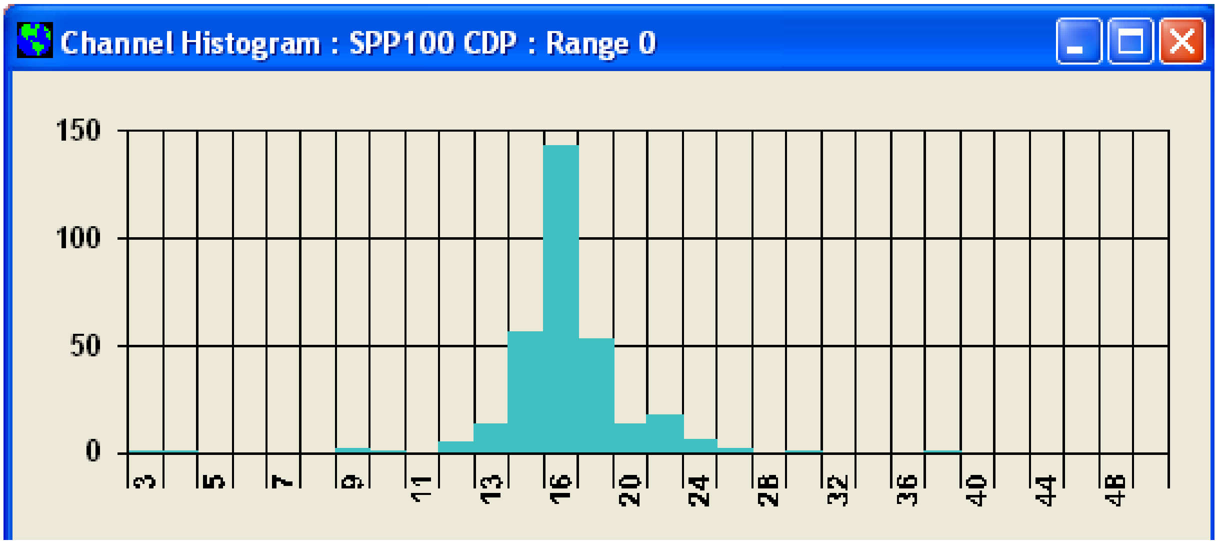


Figure 39: 20-μ glass beads FM-100 aligned

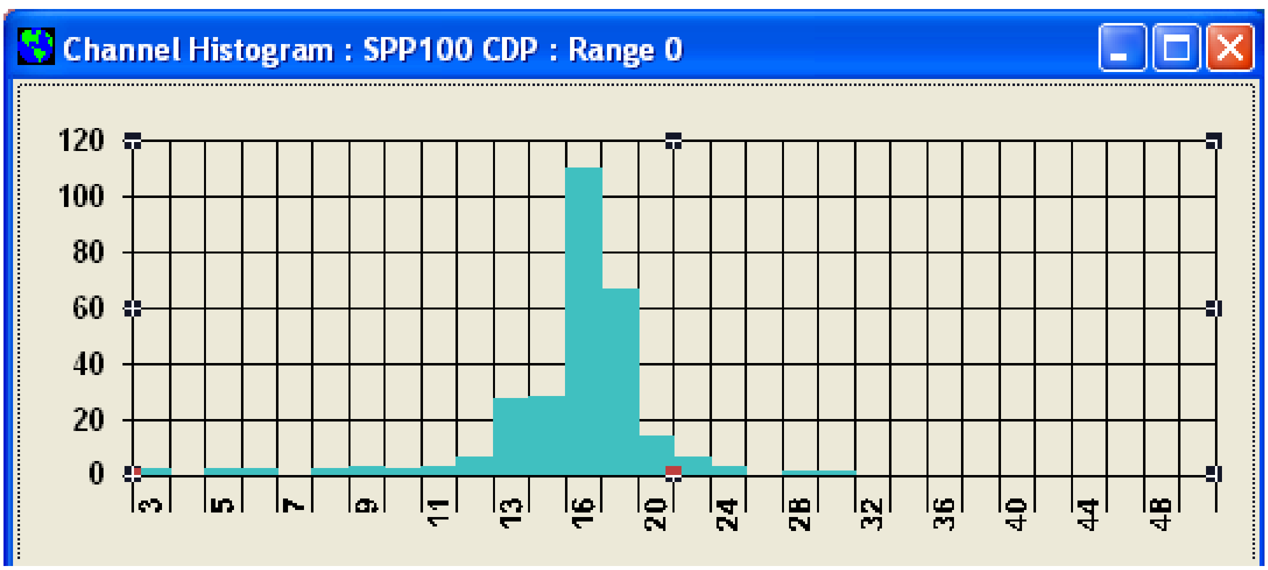


Figure 40: 20-μ glass beads FM-100 moderate misalignment

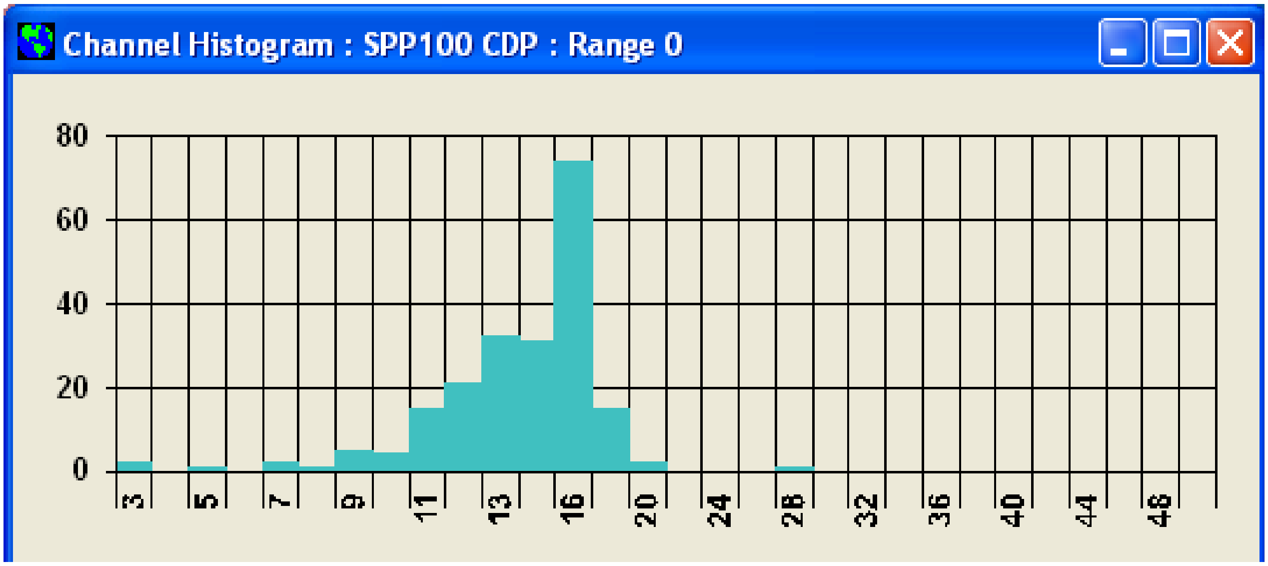


Figure 41: 20-μ glass beads FM-100 severe misalignment

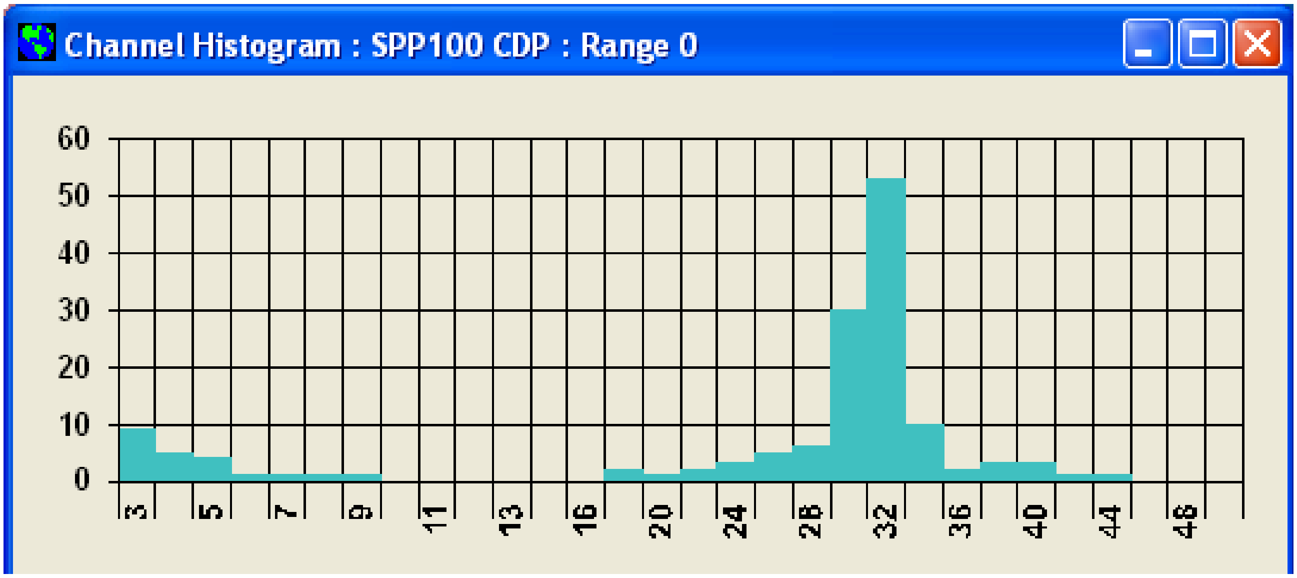


Figure 42: 40-μ glass beads FM-100 aligned

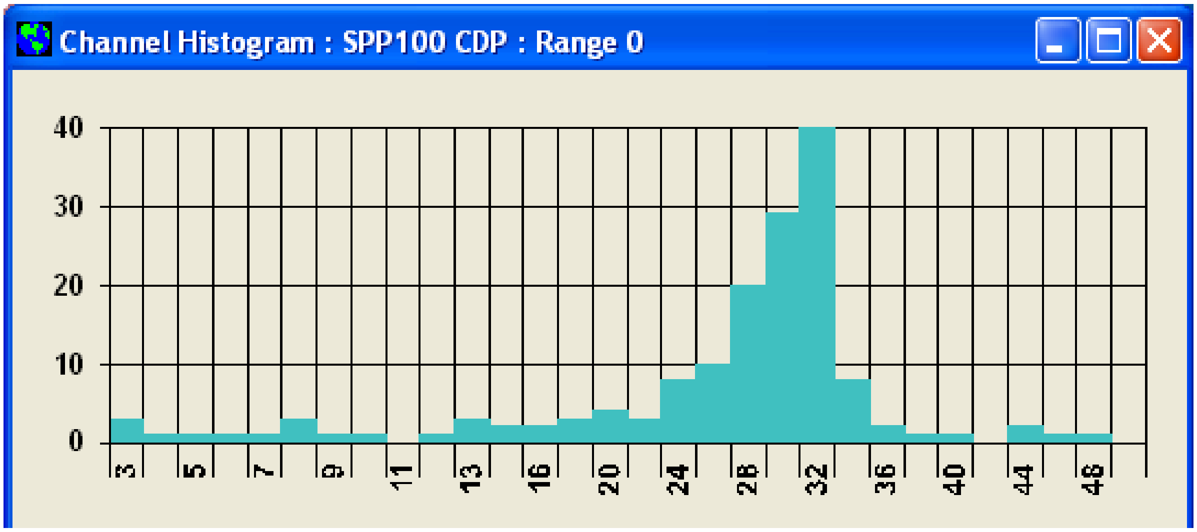


Figure 43: 40-µ glass beads FM-100 moderate misalignment

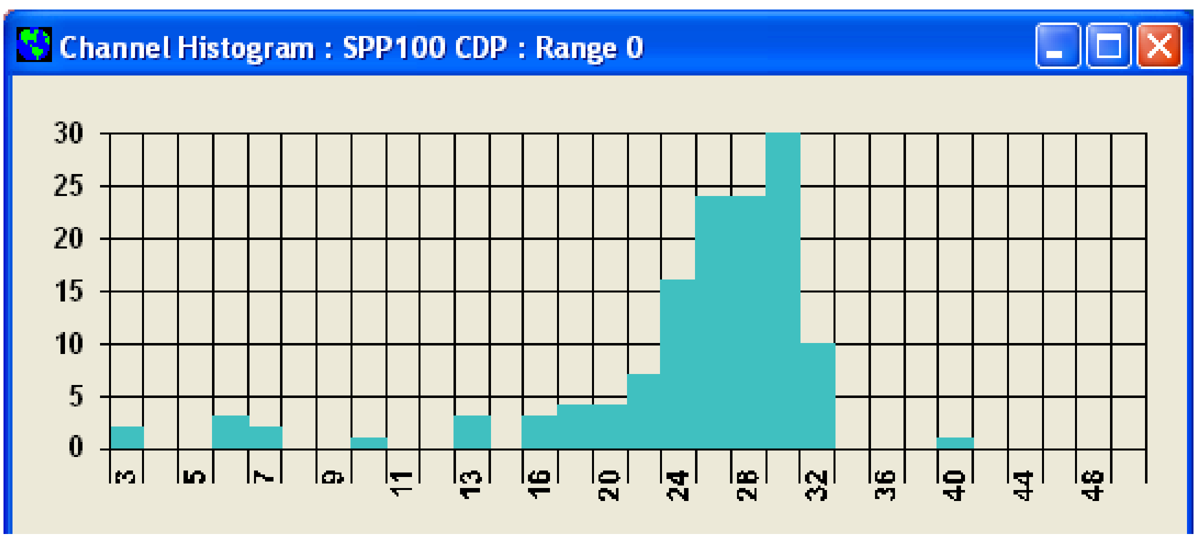


Figure 44: 40-µ glass beads FM-100 severe misalignment

Figure 45 shows the calibration of a FM-100 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.)

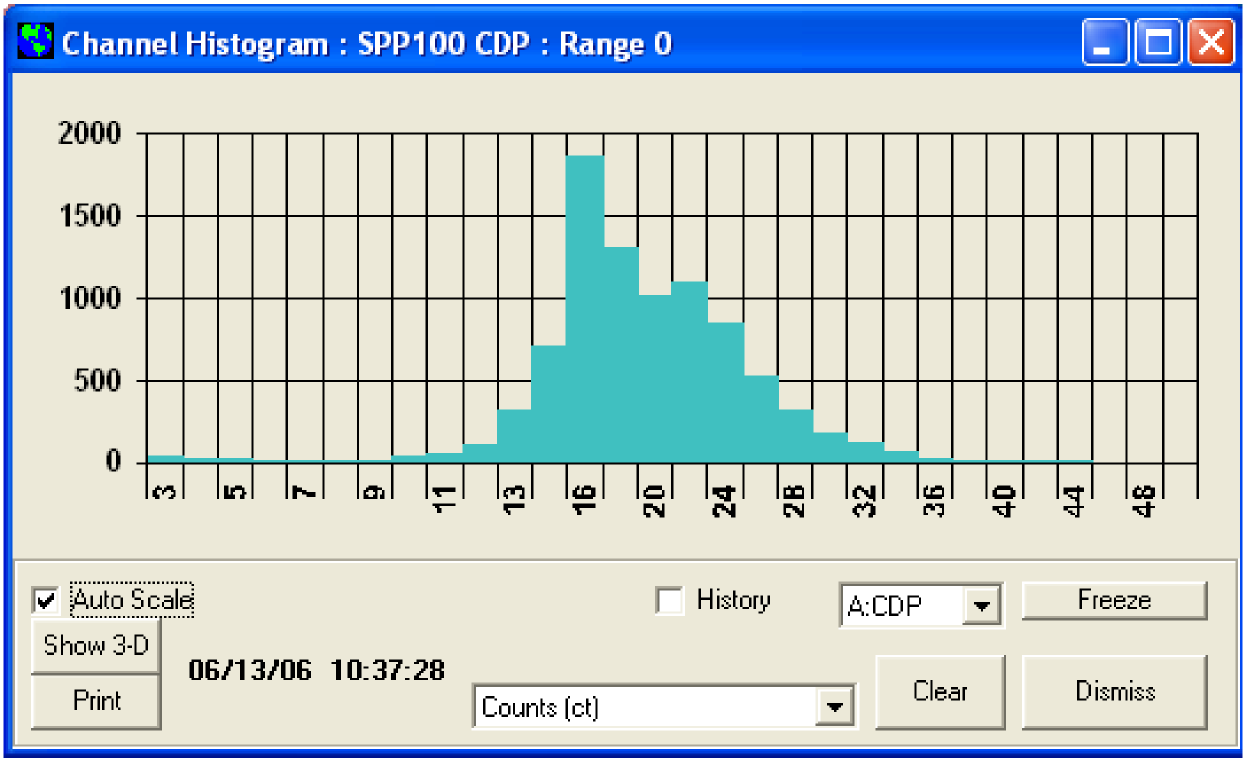


Figure 45: 20-μ glass beads calibration overload

Appendix D: Revisions to Manual

Rev. Date	Rev No.	Summary	Section
8-12-09	E-2	Added Glass Beads Calibration Section	5.0
9-23-09	E-3	Added Getting Started section (from separate Quick-Start Guide)	4.0
7-7-10	F	Added instructions for inserting inlet horn into outer block of instrument	4.2
11-11-10	G	Inserted cleaning and maintenance section	4.0
		Moved Theory of Operation / Firmware section	7.0
12-20-10	H	Expanded setup section	3.1, 3.2
2-14-11	I	Added instructions on modifying the processor when switching communications protocols	9.0

Appendix E: Schematics