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BAY AREA
AIR QUALITY
MANAGEMENT
DISTRICT

TECHNICAL SERVICES DIVISION

QUALITY ASSURANCE PROJECT PLAN

MET SOP 501

WIND SPEED

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STANDARD OPERATING PROCEDURE
BAAQMD TECHNICAL SERVICES DIVISION

WIND SPEED AUDIT PROCEDURES

AUGUST 2007

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INTRODUCTION

Horizontal wind speed sensors commonly utilize a cup or propeller assembly turning on either a vertical or horizontal axis. The aerodynamic shapes of the cups convert the wind pressure into torque. This will turn a shaft which is supported by low friction, precision bearings. The shaft rate of rotation is converted to wind speed by the use of an infrared emitter, receiver, and slotted wheel. A performance audit on this sensor provides physical verification that: 1) the sensor's starting threshold is below the allowed tolerance and 2) the transducer is properly converting cup rate of rotation (rpm) to wind speed. The audit procedures described herein address BAAQMD sensors utilizing cups assemblies.

GENERAL OPERATING PROCEDURES

The cups are removed from the sensor and the variable speed motor is attached with a coupling to the sensor shaft. The motor will provide energy to rotate the wind speed shaft. This will challenge the relationship between rate of rotation and output wind speed. An R.M. Young 18801 anemometer drive control unit with motor and clamp and bar assembly (Figure 1) is used to verify this. The rotation rate provided by the motor is verified by a large 4 digit Liquid Crystal Display (LCD) on the drive unit. The motor rotation and time base for display are referenced to an internal crystal oscillator, which provides 0.1 (rpm) accuracy. The rpm applied to the sensor is converted to wind speed by using the transfer function provided by the sensor manufacturer (see equation 1). This transfer function is calculated when the manufacturer has an example of the wind speed sensor calibrated by the National Institute of Standards and Technology (NIST). This calibration provides the relationship between wind speed and rate of rotation, measured by counting pulses, frequencies, or voltage. The transfer function defines what the signal conditioning electronics require to express the measured rotation rate in wind speed units. Following *PAMS Meteorological Monitoring Guidance*[2], the accuracy of the wind speed sensor should be within 0.2 meters per second (m/s) plus 5% of the observed speed from 0.5 to 50 m/s, with a resolution of 0.1 m/s. EPA *Ambient Monitoring Guidelines For Prevention of Significant Deterioration (PSD)*[3] cites an accuracy of within 0.25 m/s for speeds less than or equal to 5 m/s and 5% of observed speed above 5 m/s, not to exceed 2.5 m/s.

The starting threshold of a sensor is a function of torque. The sensor is removed From its location on the tower and the cups are removed. It is then positioned horizontally on a level surface. The R.M. Young torque disc 18312 (Figure 2) is attached to the shaft. The disc has a number of concentric circles etched on its face, with holes drilled at various points along each circle. These holes are used to screw in weights, which at some point will provide sufficient torque to turn the anemometer shaft. The force of gravity provides gram-centimeters (gm-cm) torque at the center of rotation. This gram-centimeters torque applied equals the weights and distances when the weights are in the same horizontal plane as the shaft. EPA *PAMS Meteorological Monitoring Guidance*[2], *Ambient Monitoring Guidelines For Prevention of Significant Deterioration (PSD)*[3], and *Meteorological Monitoring Guidance for Regulatory Modeling Application*[4] all cite a starting torque threshold of less than or equal to 0.5 m/s.

Data recording should be disabled during an audit to prevent audit data from being recorded into memory. EPA *Meteorological Monitoring Guidance for Regulatory Modeling Application*[4] states that at least two 15-minute averaged periods of valid data are required to represent an hourly period. The Campbell Scientific CR10 datalogger is programmed to average all data recorded to memory within a given hour with as little as one data point (one data point is recorded per second). If there is not enough valid data

for two 15-minute averaged periods, the data for the averaged hourly period must be deleted from the data bank.

Figure 1
R.M. Young Anemometer Drive, Motors, and Clamp Bar

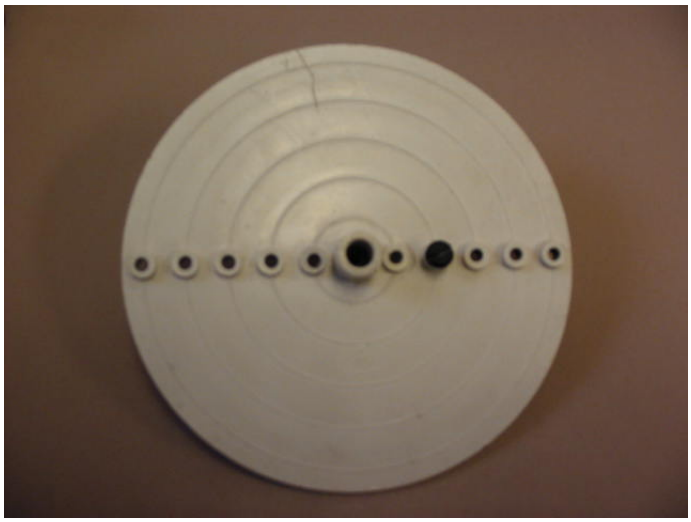

Figure 2
R.M. Young 18312 Torque Disc

AUDIT EQUIPMENT

1. We use two R.M. Young 18801 variable speed anemometer drives. One is labeled “Audit” and the other is labeled “Calibration.”

2. We use two R.M. Young 18801 100-10,000 rpm range high-speed motors with ~1 inch flexible tubing at the end of the shafts. One is labeled "Audit" and the other is labeled "Calibration."

3. R.M. Young 18810 10-1,000 rpm range low-speed motor assembly (with 10:1 gear reduction) with ~1 inch of flexible tubing at the end of the shaft

4. R.M. Young 18850 Clamp and Bar Assembly

5. R.M. Young 18312 torque disc with black 0.1 g·cm screw

6. BAAQMD Wind Audit Worksheet (Appendix A)

NOTES

1. During the audit, inspect the condition of the wind speed sensor, cups, and associated cables. Record any pertinent information on the worksheet.

2. During spring/fall audits, use the anemometer drive and high-speed motor labeled "Audit." During summer/winter calibrations, use the anemometer drive and high-speed motor labeled "Calibration."

AUDIT PROCEDURES

WIND SPEED TEST

The actual wind speed in meters per second (m/s) is calculated by applying the manufacturer's slope and intercept to the rpm of the audit device:

$$Wind\ Speed = rpm * Slope + Intercept$$

The Climatronics F460 Wind Speed Sensor and Heavy Duty Anemometer Cup Assembly parameters in m/s are:

$$Slope = 1/42.55$$
$$Intercept = 0.2235$$

The transfer functions for wind speed *ws* given rpm is:

$$ws = \frac{rpm}{42.55} + 0.2235 \qquad [1]$$

A comparison of seven points (0, 30, 100, 200, 300, 600, 1200 rpm) is performed during the test. The expected wind speed shown in the audit worksheet (Appendix A) associated

with each rpm is derived from *equation 1*. *Table 2* shows error tolerances at each rpm. Despite these tolerances, it is extremely unusual for readings to deviate by even .01 m/s. As a preventive measure, replace wind direction sensors that show an error of .01 m/s or greater.
NOTE: Flag 1 – a software flag – is set *high* during audits to disable audit data from recording to memory. To prevent data loss when a tower operator forgets to re-enable data recording, the program automatically does so after 3 hours. A program timer in input location 10 keeps track of the time by incrementing once per second. When the timer reaches 10800 (the number of seconds in 3 hours), flag 1 is set *low*. Tower operators should always (1) check that the timer is zeroed before disabling data recording and (2) clear the timer after enabling data recording. Failure to do so may cause the timer to reach 10800 before the full 3 hours and, as a result, enable audit data to be recorded to memory.

Wind speed audit procedures are as follows:

1. Attach the CR10KD Keyboard Display to the CR10 datalogger (a CR10X may also be used). Unplug the communications device attached to the logger and plug in the 9-pin I/O cable from the logger to the CR10KD.

2. On the CR10KD, press *C1955A to disable the program security.

3. View the program timer by pressing *6, and then A repeatedly to input location 10. If the program timer is not zero, clear it by pressing C0A.

4. Access software flags by pressing *6AD. You may need to disable security again (step 2). The first digit from the left represents the state of flag 1, the second from the left – the state of flag 2, etc.

5. Set flag 1 high to disable data recording to memory. – 0 is *low*, 1 is *high*. If flag 1 is *low*, then press 1 to toggle it to *high*.

6. Set the CR10KD to display wind speed (input location 1). Press *6, then (pressing "A" repeatedly will scroll through the channels).

7. With the sensor attached to the crossarm, remove the anemometer cups from the shaft. Record the reading on the worksheet. This will be the zero rpm value.

8. Attach the clamp bar assembly, then slide the low speed motor down the clamp bar, fitting the flexible tubing securely over the sensor shaft. Secure the motor to the clamp bar.

9. On the control unit, set the rotation direction to clockwise (CW). Plug the motor into the control unit.

10. The low speed motor has a 10:1 reduction gear set. Therefore, the rpm setting on the anemometer drive will be ten times the motor speed (rpm). Select a rotation rate of 30 rpm by setting the rpm switch to read *03 (x 100)*. Turn the power switch on. The motor will start turning and the control unit should display 0*300* – ten times the motor speed. If the anemometer does not display *0300* and the CR10KD does not output exactly *0.93* – the equivalent speed in m/s 0 - check for proper alignment of the connection between the motor and sensor shaft. Correct the alignment if necessary.

11. Leave the motor at the specified speed until a constant reading is displayed on the control unit and keypad. Usually, 10 seconds is adequate. Record the sensor output speed in the appropriate row on the audit worksheet.

12. Repeat steps 10 and 11 at 100, 200, 300, and 600 rpm.

13. Replace the low-speed motor with the high-speed motor. The number displayed on the rpm switch *(x 100)* is the true rpm. Set the rpm switch to *12* and repeat steps 6 and 7 at 1200 rpm (**NOTE**: The high-speed motor can also be used to test the sensor at 600 rpm).

14. Determine if the sensor is within tolerance at each rpm (*see Table 2*). However, if the *measured* wind speed deviates from the *reference* wind speed by more than 0.01 m/s, replace the sensor as a precautionary measure.

15. The seven point wind speed comparison is now complete. Turn off the power switch and disconnect the motor from the sensor. Disconnect the motor from the console. The sensor can now be removed from the tower to perform the torque threshold check.

16. Set flag 1 *low* if data recording no longer needs to be disabled (e.g. the audit is complete). Disable security (step 2), display flags in the CR10KD (step 4), then press 1 to toggle flag 1 *low* to resume data recording.

17. Clear the program timer (step 3). You may have to first disable the program security (step 2) depending on how much time has elapsed since it was last disabled.

<u>STARTING TORQUE TEST</u>

The starting threshold is calculated using the measured torque (gm-cm) and the manufacturer's K factor:

$$\textit{Starting Threshold} = (\textit{Measured Torque/K Factor})^{1/2}$$

The K-Factor of the Climatronics F460 wind speed sensor is 1.4. Therefore, the transfer function for starting threshold *st* given measured torque *tq* is:

$$st = \left(\frac{tq}{1.4}\right)^{1/2} \qquad [2]$$

The maximum starting threshold is 0.5 m/s. This is equivalent to a maximum starting torque of 0.4 g-cm. As a preventive measure, sensors with a starting torque greater than 0.1 g-cm should be replaced. Starting torque test procedures are as follows:

1. With the anemometer cups removed, remove the wind speed sensor from the crossarm on the tower.

2. Go to an area free of wind or excess air movement (usually inside the vehicle). Rotate or spin the shaft while listening to the sound of the bearings. Note any sounds of abrasion or scraping.

3. The maximum wind speed threshold is 0.5 m/s. Using the transfer function provided (see worksheet), this equates to a maximum threshold torque of 0.4 g·cm.

4. The "Rotation" torque test method should suffice if the sensor bearings are in good condition. Hold the sensor so that its body is level and parallel to the ground with the top of the sensor (shaft end) facing furthest away and the bottom (connector end) closest to you. Slowly rotate the sensor body clockwise through one full revolution (looking at the sensor body from the top, rotate the sensor towards the right side) and observe the movement of the sensor cap. It has been empirically shown that the starting torque is within 0.1 g·cm if the cap is able to remain at a single angular position through the rotation.

5. If the cap remains in a single position, the sensor has passed the "Rotation" torque test with a threshold torque of less than 0.1 g-cm. Check the box in the worksheet indicating that a passing torque threshold was measured by way of a "Rotation" test. Record 0.1 g·cm as the starting torque on the worksheet, calculate and record the starting threshold, then skip steps 6 through 10 and proceed to step 11.

6. Attach the torque disc to the sensor by sliding the disc all the way into the shaft so that the mating surface at the center of the disc is flush with the surface of the sensor cap. Make sure that the fit is secure without excess slippage. Remove any screws from the torque disc and place the sensor on its side on a flat, level surface.

7. Balance the torque disc on the sensor by orienting the disc so that the screw holes are horizontally positioned from the shaft. If the screw holes do not stay horizontally aligned after letting go of the disc, carefully rotate the sensor in small angular increments until an equilibrium is found where the screw holes are horizontally aligned with the shaft (this may sometimes not be possible due to a slightly bent shaft).

8. There are a total of 10 holes on the disc, but only 5 holes on one side of the main center hole are used for a torque test on a wind speed sensor. Attach the 0.1g nylon screw onto the side that would cause the disc to rotate clockwise. The weight of the screw times the distance from center determines the gram-centimeters torque. Ideally, you are looking for the minimum weight at the minimum distance from the center. When the disc makes the slightest movement (i.e. moves 5 degrees downwards from horizontal), the torque has been measured at that position.

9. Measure the maximum starting torque over the entire 360 degree rotation. Slowly and carefully rotate the sensor in the direction that moves the weight higher than at equilibrium. If the weight goes above the height of the shaft at any position, the torque indicated by the position of the weight has been exceeded and the weight will have to be moved closer towards the outer edge of the torque disc. Repeat this process until the minimum torque threshold is found throughout the entire 360 degree range.

10. Record the threshold torque on the worksheet. Check the box in the worksheet indicating that a passing torque threshold was measured by a torque disc. Calculate and record the starting threshold according to the given transfer function.

11. If the measured starting torque is equal to or greater than 0.5 g-cm, replace the sensor as a precautionary measure.

12. Remove the torque disc from the sensor (**NOTE**: Be sure to lift the disc off the sensor shaft by pulling from close to the center of the disc or else the disc may bend and/or crack). Install the sensor with the cups back onto the crossarm.

PREVENTATIVE MAINTENANCE

R.M. YOUNG ANEMOMETER DRIVE UNIT

1. Periodic battery replacement is required (AA alkaline batteries). The decimal points on the console display will blink when battery voltage is low.

2. Perform wind speed sensor audits in an efficient manner. Turn the power off when the unit is not in use.

3. Be careful not to drop the control unit or motors.

R.M. YOUNG TORQUE DISC

1. Keep the disc and weights clean. Dirt, lint, etc. may add weight and effect the balance of the wheel.

2. Periodically inspect the center hole of the disc for excessive wear to ensure that the disc continues to fit properly onto the anemometer shaft. If the center hole is too large or abraded, the disc should not be used.

CALIBRATION AND CERTIFICATION PROCEDURES

R.M. YOUNG 18801 ANEMOMETER DRIVE UNIT

1. The anemometer drive unit and motors should be checked before each quarterly audit or calibration. The pulsed output of the integral high resolution optical encoder can be measured from a jack on the side of the console case. Connect this output to an external frequency counter (i.e. Fluke 8020A multimeter) to confirm the motor speed. If there is any discrepancy between the selected rpm rate and the measured rpm rate, the manufacturer will be contacted to initiate a troubleshooting/repair sequence which may entail returning the defective unit to the factory.

Output from the encoder should be steady (zero pulse rate) at 0 rpm so no pulse rate error should be expected. Thus, wind speed error at zero rpm should also be zero.

When using a frequency counter, the expected pulse rates and R.M. Young pulse rate and error tolerances (from Appendix B, equations [4] and [8]) are:

RPM	Pulse Rate (Hz)	Tolerance (Hz)
0	0.00	0.00
30	16.00	± 0.50
100	53.33	± 1.67
200	106.67	± 3.33
300	160.00	± 5.00
600	320.00	± 10.00
1200	640.00	± 20.00

Table 1: Calibration Tolerance

R.M. YOUNG TORQUE DISC

The 0.1g nylon screws should be weighed quarterly with a precision scale. The tolerance is ±0.1g.

AUTHORS, REVISIONS, AND APPROVALS

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APPENDIX A

BAAQMD CALIBRATION RECORD

BAAQMD CALIBRATION RECORD

Site Name _____ Start Time _____(pst) Finish Time _____(pst)

Auditor _____ Logger Clock Diff: _____ Logger Model No **CR10**

Date __/__/__ Logger Serial No _____ Last Audit Date _____

WIND SPEED & DIRECTION SENSOR:

Sensor Mfg	**Climatronics**	Old WD SN	
Model No	**F460**	Old WS SN	
Sensor Ht		New WD SN	
		New WS SN	

EPA PASSING CRITERIA[1]:

WS Max Difference:	**0.22 m/s**
WS Starting Threshold:	**0.5 m/s**
WD Total Error:	**5 deg**
WD Starting Threshold:	**0.5 m/s**

[1] *EPA-454/R-99-005 Meteorological Guidance for Regulatory Modeling Applications Table 5-1*

WIND SPEED TEST:

No.	rpm's	Reference	Measured	Difference
1	0	0.0	_____	_____
2	30	0.93	_____	_____
3	100	2.57	_____	_____
4	200	4.92	_____	_____
5	300	7.27	_____	_____
6	600	14.32	_____	_____
7	1200	28.42	_____	_____

WS Max Difference: _____

Results: Pass/Fail

Torque Test: Rotation ☐ Disk☐ _____ g-cm

WS Starting Threshold: $(T/1.4)^{½}$ _____ m/s

Results: Pass/Fail

Transfer Function (rpm to m/s): (rpm)/42.55+0.2235

WIND DIRECTION TEST:

2. Calculate from Wddiff.exe program total error.

3. Average Error column value that results in highest total error.

Object	Reference	Measured (Adjust if diff. > 1 deg.)	Difference	Corrected Difference[2]	Highest Linearity[3]	WD Total Error
Old Along	_____	_____	_____	_____°	_____°	_____°
Old Opposite	_____	_____	_____			
New Along	_____	_____	_____			
New Opposite	_____	_____	_____			

Results: Pass/Fail

WD Torque Disk Test: _____ g-cm

WD Starting Threshold: $(T/29.8)^{½}$ _____ m/s

Results: Pass/Fail

CROSSARM REFERENCE CALCULATION: (re-shoot if >15 deg diff. front/back)

Along: Mag.=	_____	Dec.=	_____	True=	_____	Az.=	_____	Time=	_____
Opposite: Mag.=	_____	Dec.=	_____	True=	_____	Az.=	_____	Time=	_____

COMMENTS:

Auditor: _____

APPENDIX B

VERIFICATION OF R.M. YOUNG TOLERANCE

The pulsed output of the integral high resolution optical encoder can be measured from a jack on the side of the R.M. Young anemometer drive console case. The output has a rate of 32 pulses/sec. The factory tolerance is ±1 pulse/rev throughout the entire rpm range. EPA *PAMS Meteorological Monitoring Guidance*[2] cites an accuracy threshold of 0.2 meters per second (m/s) plus 5% of the observed speed from 0.5 to 50 m/s while *Ambient Monitoring Guidelines For Prevention of Significant Deterioration (PSD)*[3] cite an accuracy of within 0.25 m/s for speeds less than or equal to 5 m/s and 5% of observed speed above 5 m/s, not to exceed 2.5 m/s. In order to determine if the R.M. Young factory tolerance meets these two specifications (results are in "Calibration and Certification Procedures"), we can derive the transfer function relating wind speed error in m/s to rpm at an error of 1 pulse/rev.

For a given rpm and pulse/rev error *err*, the pulse rate output is:

$$Pulse\ Rate\ (p/s) = (32 + err)\frac{pulse}{rev}\ X\ RPM\left(\frac{rev}{\min}\right) X\ \frac{1\min}{60\sec}$$

Thus, for pulse rate *pr*, we have

$$pr = \frac{32 + err}{60}\ rpm \qquad [3]$$

At a nominal 32 pulse/rev factor, we have *err = 0*:

$$rpm = \frac{60}{32}\ pr \qquad [4]$$

It is clear that rpm varies in direct proportion to pulse rate:

$$\Delta rpm = \frac{60}{32}\Delta pr \qquad [5]$$

Now recall equation [1] in *Audit Data Calculations* (p. 7): if $\Delta ws = ws_1 - ws_2$ and $\Delta rpm = rpm_1 - rpm_2$, we have

$$\Delta ws = ws_1 - ws_2 = \left(\frac{rpm_1}{42.55} + 0.2235\right) - \left(\frac{rpm_2}{42.55} + 0.2235\right) = \frac{rpm_1 - rpm_2}{42.55} = \frac{\Delta rpm}{42.55} \quad [6]$$

This implies (as expected) that the change in wind speed varies in proportion to the change in rpm. By [5] and [6]we have

$$\Delta ws = \frac{\Delta rpm}{42.55} = \frac{60 \cdot \Delta pr}{32 \cdot 42.55} = \frac{60}{1361.6} \Delta pr \qquad [7]$$

We wish to find what the wind speed error tolerance is given the factory tolerance of 1 pulse/rev. Recall equation [3] which gives the relationship between pulse rate, error, and rpm. Note that if we set the pulse/rev error *err* to the maximum factory tolerance of 1 pulse/rev, the change in pulse rate with respect to the nominal pulse rate (32 pulse/sec) is the difference between the pulse rate with 1 pulse/rev error and the nominal pulse rate:

$$\Delta pr = \frac{32+1}{60} rpm - \frac{32}{60} rpm = \frac{rpm}{60} \qquad [8]$$

By (7) and (8), we have

$$\Delta ws = \frac{rpm}{1361.6} \qquad [9]$$

The following table shows that R.M. Young factory tolerances (calculated using equation [9]) exceeds tolerances recommended by both EPA sources cited at the six non-zero test points. Therefore, the R.M. Young factory tolerance of 1 pulse/rev may be used (see "Calibration and Certification Procedures").

RPM	Speed (m/s)	R.M. Young	EPA PAMS	EPA PSD
30	0.93	± 0.02	± 0.25	± 0.25
100	2.57	± 0.07	± 0.33	± 0.25
200	4.92	± 0.15	± 0.45	± 0.25
300	7.27	± 0.22	± 0.56	± 0.36
600	14.32	± 0.44	± 0.92	± 0.72
1200	28.43	± 0.88	± 1.62	± 1.42

Table 2: Wind Speed Error Tolerance