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Understanding Airside TAB Measurements

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Testing, adjusting, and balancing (TAB) is a critical component of building HVAC system installation, maintenance and operations. The testing, adjusting, and balancing report is a report card for the system's performance. As engineers, we are required to specify what is required for measurement, testing, adjusting, and balancing and to design HVAC systems that can be measured. We are also required to review and understand the results of the testing and measurement data. In the author's experience, many designers rarely look beyond the measured-to-specified values in the TAB report.

An understanding of TAB measurements allows designers to look deeper into system performance to better understand if the system is operating as designed. This month, I provide guidance to assist engineers and designers to design for measurement and balancing of airside systems, along with tips on how to evaluate airside TAB measurements.

Air Measurements

Primary measurements to verify fan system performance include airflow and pressure. Total pressure, P_t, is the sum of static pressure, P_s, and velocity pressure, P_v, at a specific plane. Static pressure is the portion of the air pressure that exists by the degree of compression only. Velocity pressure is the portion of air pressure that exists by virtue of the rate of motion only.

A tube placed in a duct facing the direction of the flow will measure the total pressure in the duct. If frictional losses are ignored, the mean total pressure at any cross section throughout the duct system is constant. Static pressure can only be determined accurately by measuring it in a manner to ensure the velocity pressure has no influence on the measurement at all.

This is carried out by measuring it through a small hole at the wall of the duct or through a series of holes positioned at right angles to the flow in a surface lying parallel to the lines of flow. The standard pitot tube in *Figure 1* would be used with a manometer while the total pressure port faces the direction of the airflow and the static pressure port is at a right angle to the airflow.

Field volumetric air measurements are typically accomplished with anemometers, pitot duct traverses, and airflow measuring hoods. Thermal and vane anemometers are best suited to low air velocity measurements such as outdoor air intake measurement or fume hood face velocity measurement.

The nonuniform velocity profile in a duct requires a traverse to determine the average velocity. Velocity is generally lower near the edges and corners and greatest near the center of the duct. There are two primary methods of duct traverse, the Log-Tchebycheff (log-T) Method and the Equal Area Method. Both are detailed in ASHRAE Standard 111-2008.[1] The Log-T Method provides the greatest accuracy because its location of traverse points accounts for the effect of wall friction and the falloff of velocity near duct walls. The equation for determining air velocity from measured velocity pressure is:

$$V = 1,096.7\sqrt{\frac{p_v}{\rho}} \quad (1)$$

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Where
V = velocity, fpm
p_v = velocity pressure, in. w.g.
ρ = density of air, lb_m/ft^3

Assuming the density of standard air (air at sea level of 14.7 psi [101.4 kPa] and 70°F [21°C]) is 0.075 lb_m/ft^3 (1.2 kg/m^3), the equation becomes:

$$V = 4,005\sqrt{p_v} \tag{2}$$

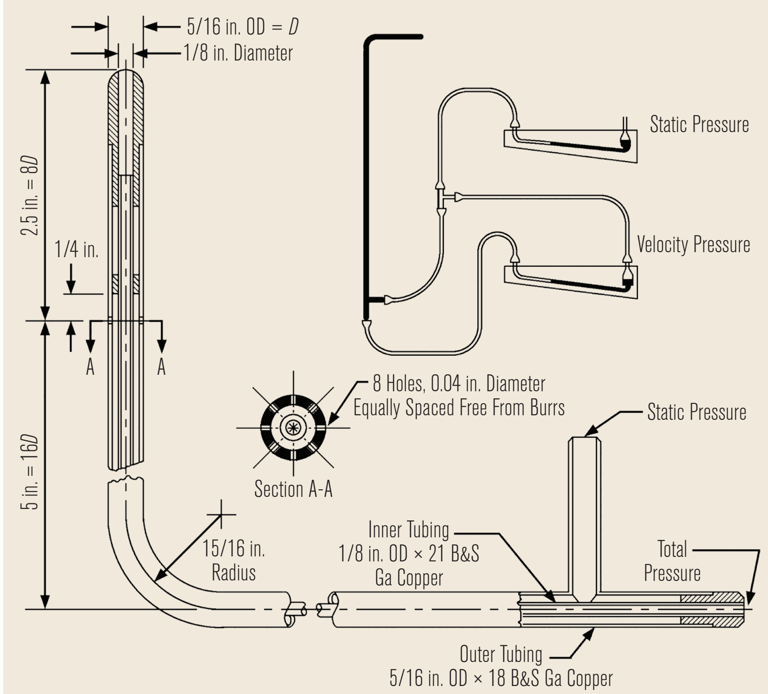
The *2013 ASHRAE Handbook–Fundamentals*[2] indicates that measuring points ideally should be 7.5 equivalent diameters downstream and three equivalent diameters upstream from a disturbance. ASHRAE RP-1245[3] tested traverse locations in rectangular duct with and without fitting disturbances and provides useful error and bias results when duct traverse is made under less than ideal conditions. The upstream locations for all duct sizes are –1 D_e and –3 D_e. The downstream locations for all duct sizes are +1 D_e, +2 D_e, +3 D_e, +5 D_e, and +7.5 D_e. The equivalent diameter for round ducts is the actual diameter. The equivalent diameter for rectangular ducts can be calculated using the inside traverse dimensions as follows:

$$D_e = \sqrt{\frac{4(width)(height)}{\pi}} \tag{3}$$

The location of a useful duct traverse is not necessarily determined by the number of diameters of straight duct, but by the quality of the readings at a given location. The location of the traverse should be taken as far away from the fan inlet and outlet to avoid turbulence. It should also not be taken in a section of duct that is transitioning in size. Judgment in the quality of a traverse should be based on the results of the traverse.

According to ASHRAE Standard 111-2008, which is intended for use with velocity measurement planes in fan-system installations, the velocity pressure region is basically deemed to be satisfactory if more than 75% of the measurements achieve a velocity pressure, *Pv*, greater than one-tenth of the maximum velocity pressure across the measurement plane. RP-1245 determined that negative velocity pressure readings indicate a totally unacceptable traverse location, and corresponding errors in flow value can exceed 50% of the reading if they are used in the volumetric flow rate measurement.

FIGURE 1 Standard pitot tube. (Figure 6 from *2013 ASHRAE Handbook—Fundamentals*, Chap 36).



Flow-measuring hoods are used to measure airflow through diffusers and grilles. The hood is placed over the diffuser or grille, while the hood captures and directs airflow across the flow sensing element at the bottom of the hood that is designed to simultaneously sense and average multiple velocity points. Sensors used by various manufacturers include thermal and vane anemometers, and electronic micromanometers.

Design Considerations

Airside design should give special attention to the balancing and adjusting process so the system can be balanced properly. The balancing capability must be designed into the system by providing the necessary balancing dampers and adequate duct design to allow accurate airflow measurement.

System effect factor is a pressure loss that recognizes the effect of fan inlet restrictions, fan outlet restrictions, or other conditions influencing fan performance in the installed system that are different from the AMCA Publication 210-99[4] fan performance test in the factory. The air performance and sound data based on AMCA Publication 210-99 fan tests can be applied to the fans only if the installed configuration of the fan/ducts is similar to the tested fan/duct configuration.

AMCA Publication 201-02[5] provides system effect factors for a wide variety of obstructions and configurations that may impact a fan's performance and be added to the system pressure drop. System effect is a phenomenon that cannot be measured, but it is real and is one of the reasons many fans cannot develop the required capacity shown in the catalog data.

The "Airside Design TAB Checklist" sidebar can serve as a guide when reviewing airside design for testing and balancing.

Reviewing the TAB Report

The importance of thoroughly reviewing TAB report field measurements should not be overlooked. In the author's experience, most reviews focus too much on whether the measured values are within the allowable ± tolerances to the design values. This is indeed important, but the only way to know if the measurements are valid is to check the various fan measurements to verify that they match the fan curves and anticipated static profiles. *Is the system operating as expected?*

The following will assist in plotting the fan measurements on a fan curve to verify fan performance. Essential fan measurements include inlet static pressure, outlet static pressure, fan rpm, motor voltage, and motor amperage. Fan nameplate data needed includes fan manufacturer and model. Fan motor nameplate data needed includes motor manufacturer, model, frame, size, rpm, phase, efficiency and power factor.

Motor brake horsepower can be calculated from the voltage and current readings:

$$bhp = \frac{I \times E \times pf \times Eff \times \sqrt{Ph}}{746} \qquad (4)$$

Where

bhp = *brake horsepower*

I = *amps*

E = *volts*

pf = *power factor*

Eff = *efficiency*

Ph = *phases*

Most fan manufacturers or selection software can provide a fan performance curve for the measured fan rpm showing airflow, static pressure, and fan energy. Motor manufacturers typically provide motor efficiency and

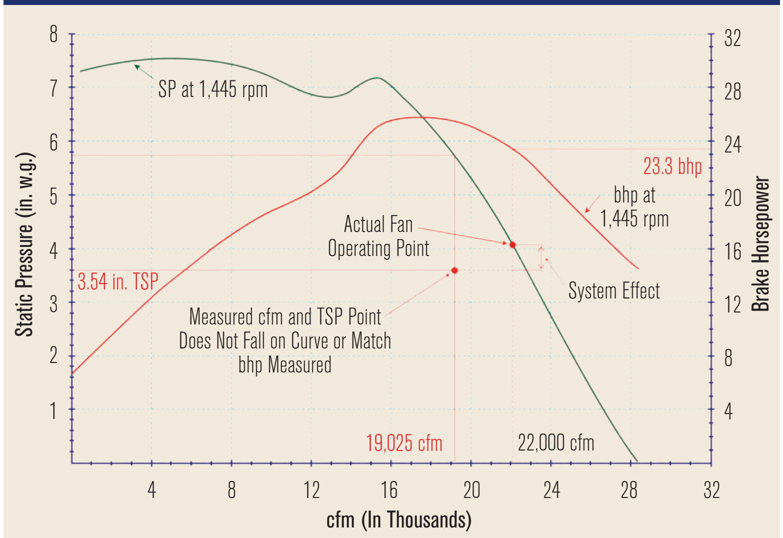
Airside Design TAB Checklist

- ❑ Have all required airflow measurements been identified?
- ❑ Have balancing dampers been specified on all supply branches and return/exhaust branches that are expected to be balanced? (Avoid using dampers in diffusers and grilles to minimize noise.)
- ❑ Have adequate straight lengths of duct been provided for duct traverses to measure supply, return and exhaust airflows? (Field duct traverses from qualified technicians can typically obtain measurement that range within ±5% to 10% accuracy with +7.5 D_e downstream and –3 D_e upstream from a disturbance. Refer to ASHRAE RP-1245 for shorter distances.)
- ❑ When less than +1.0 D_e downstream for a duct traverse, measuring airflow from the face of filters or downstream of coils are considered secondary measurement alternatives that will generally result in lower measurement accuracy than a typical duct traverse measurement.
- ❑ Do fan inlet and outlet conditions differ from AMCA Publication 201-02 performance test condition for the specified fan(s)? If so, system effect factors should be added to fan total static pressure to account for potential system effect.
- ❑ What static pressure profile measurements are expected for AHU/AC units with clean filters? Have the AHU/AC unit internal static pressure drops been documented for coils, clean filters, dampers, etc.?
- ❑ Has variable air volume total air system diversity (fan airflow divided by sum of outlets airflow) been identified? If so, the TAB specification should indicate how to balance the system with diversity.
- ❑ Does the TAB specification indicate what motor nameplate data should be recorded in addition to motor voltage and amperage?
- ❑ Does the TAB specification indicate to what operating condition the system should be measured and balanced?
- ❑ Does the TAB specification require a pre-TAB submittal or meeting with the engineer and commissioning agent to review proposed measurement methods and locations prior to the field measurements?

power factor percent for full load, 75% load, and 50% load. A three-order polynomial can be used to curve fit the efficiency and power factor data to estimate values for the measured load. *Table 1* is an example from a recent TAB report that had two plenum supply fans installed in parallel to illustrate the verification of field measured values.

Fan motor energy of 23.3 bhp (17.4 kW) can be calculated from the measured and motor manufacturer data using the formula above. *Figure 2* shows the airflow, total static pressure and fan motor energy measurements (red values) plotted on the fan curve plotted at the measured rpm. The fan was installed parallel to a second supply fan and some system effect was anticipated.

FIGURE 2 Sample TAB measurements on fan curve.



In the example, none of the three measurements intersect the fan curve at the same location. The brake horsepower measurement intersects the fan curve at 22,000 cfm (10 383 L/s). This would correlate with the measured total static pressure assuming a system effect of roughly 0.5 in. w.g (125 Pa). This shows the measured volumetric value of 19,000 cfm (8967 L/s) from duct traverses in three supply air ducts may have been low since it did not align with the other measurements.

The airflow can also be compared to the cooling coil pressure drop measurement when the cooling coil is dry. Airflow through any system is proportional to the square root of the pressure causing the flow when there is fully developed turbulent flow. This is not the case with cooling coils. If a cooling coil is to be used to cross-check airflow readings, the coil manufacturer's selection software can be used to check corresponding air pressure drop with airflow at 80%, 90%, 100% and 110%. These values can produce a curve to calculate the airflow at various pressure drops while the coil is dry.

It is always worthwhile to understand how various TAB measurements can be used to help better understand system operation. Many field conditions can result in inaccurate measurements.

Concluding Remarks

Air measurement fundamentals provide a basis for the proper selection of measurement methods to be used. Understanding laboratory methods for testing fan performance from AMCA Publication 210-99 provides valuable information on test configurations, uncertainties and tolerances for evaluating the field installed performance of fan systems. Careful consideration of airside measurement and balancing requirements during design can lead to more productive field testing and balancing to allow designers to evaluate system performance. Hopefully, these tips can assist designers in improving airside design and operation.

TABLE 1 Example from recent TAB report that had two plenum supply fans installed in parallel.

SA Duct Traverse cfm	38,050 or 19,025 each
Fan rpm	1,445
Fan TSP	3.54 in. w.g.
Motor hp	25 each
Motor Voltage	485/486/482
Motor Phases	3
Motor Amps	28.2 each, 32 FLA
Motor Efficiency	93%
Motor Power Factor	79%

References

1. ASHRAE Standard 111-2008, *Measurement, Testing, Adjusting, and Balancing of Building HVAC Systems*.

2. *2013 ASHRAE Handbook–Fundamentals*, Chap. 36.

3. Hickman, C., T. Beck, B. Babin. 2012. "Determining the Effects of Duct Fittings on Volumetric Air Measurements." ASHRAE Research Project RP-1245, Final Report.

4. AMCA. 1999. "Publication 210-99, Laboratory Methods of Testing Fans for Aerodynamic Performance Rating." Air Movement and Control Association International.

5. AMCA. 2011. "Publication 201-02 (R2011), Fans and Systems." Air Movement and Control Association International. ■