

AMCA Standard 803-02 (R2008)

Industrial Process Power Generation Fans: Site Performance Test Standard



**AIR MOVEMENT AND CONTROL
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AMCA STANDARD 803-02 (R2008)

Industrial Process / Power Generation Fans: Site Performance Test Standard



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RELATED AMCA STANDARDS

For Air Performance:

ANSI/AMCA Standard 210 *Laboratory Method of Testing Fans for Aerodynamic Performance Rating*

For Sound:

AMCA Standard 300 *Reverberant Room Method for Sound Testing of Fans*

AMCA Standard 301 *Methods for Calculating Fan Sound Ratings from Laboratory Test Data*

AMCA Standard 320 *Laboratory Methods of Sound Testing of Fans Using Sound Intensity*

For Balance and Vibration:

ANSI/AMCA Standard 204 *Balance Quality and Vibration Levels for Fans*

Industrial Process / Power Generation Series:

AMCA Publication 801 *Industrial Process/Power Generation Fans: Specification Guidelines*

AMCA Publication 802 *Industrial Process/Power Generation Fans: Establishing Performance Using Laboratory Models*

AMCA Standard 803 *Industrial Process/Power Generation Fans: Site Performance Test Standard*

Fan Application Manual:

AMCA Publication 200 *Air Systems*

AMCA Publication 201 *Fans and Systems*

AMCA Publication 202 *Troubleshooting*

AMCA Publication 203 *Field Performance Measurement of Fan Systems*

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Industrial Process / Power Generation Fans: Site Performance Test Standard

1. Purpose

This standard establishes uniform methods to be used in measuring the aerodynamic performance of industrial process or power generation fans under actual operating conditions on the site. The standard also defines rules for converting the measured performance to other specified operating conditions.

This standard is also intended to produce results comparable to those obtained in a laboratory test of a fan in accordance with ANSI/AMCA 210 *Laboratory Methods of Testing Fans for Aerodynamic Performance Rating*. Fans in systems which have unstable operating characteristics or have distorted flow profiles at the inlet of the fan may not be suitable for testing in accordance with this standard.

The object of a performance test on a fan installed in its system generally falls into one of the following categories:

a) General Fan and System Evaluation

The purpose for conducting this type of an on-site test is to evaluate the performance of the fan in its system as a basis for future modifications to the fan or system.

b) Acceptance Tests

An on-site test specified as part of the sales agreement for the purpose of verifying the quoted fan performance.

c) Proof of Performance Test

This type of on-site test is conducted as a result of a complaint that the fan or system is not performing as intended.

This standard defines the quantities which need to be measured to establish fan performance, the personnel, the location of the measurement points, the calculation of results, the degree of uncertainty, the measurement methods and instrumentation which are to be used. Limits on the types of fans and systems which may be regarded as meeting the requirements of this test standard are also defined.

2. Scope

The term **on-site test**, as used in this standard, is a test conducted for the purpose of determining the aerodynamic performance of a fan when operating in the system for which it was intended.

2.1 Acceptable fans

This standard may be used as the basis for testing all types of centrifugal, axial, and mixed flow fans in ducted installations. The ducting may be on either the inlet side of the fan, the outlet side of the fan, or both.

The term **fan** encompasses all types of air or gas moving devices including blowers and exhausters, having one or more stages, but without interstage cooling. Circulating fans such as ceiling fans and desk fans, and positive displacement machines are not within the scope of this standard.

Sound tests, vibration tests, and mechanical tests of all types are not within the scope of this standard.

2.2 Acceptable installations

The performance of a fan when installed in a system is dependent not only on the fan, but also on the system, and on the interaction of one with the other. The effect of the system of the fan performance is known as "System Effect."

Assuming that the fan is rated and manufactured correctly, the three most common causes of deficient performance of the fan and system combination are:

- Improper inlet and/or outlet connections
- Non-uniform inlet flow
- Swirl at the fan inlet

These conditions alter the aerodynamic characteristics of the fan so that its flow potential is not fully realized. The conditions will occur when the connections to the fan inlet and/or outlet are poorly designed or installed. One bad connection can reduce the fan's actual performance to a point far below its rated performance.

This standard defines minimum requirements for flow velocity profiles at the measurement stations and duct geometry requirements which will result in insignificant system effects. Any installation which does not fall within the defined limitations is remarked

as unacceptable for the purposes of on-site testing to this standard.

Full size fan performance is generally calculated by manufacturers based on laboratory model tests in accordance with ANSI/AMCA 210 [1]. Scaling rules are defined in AMCA Publication 802 [2]. Calculated fan performance is therefore based on ideal laboratory flow conditions designed to facilitate accurate measurement.

On site, the magnitude of the System Effect may vary from zero for a well designed system to an amount that makes fan performance appear totally unacceptable. Significant System Effects may render an on-site performance test meaningless.

An unacceptable installation must be altered to bring it within the requirements stated in this standard if an on-site test to this standard is mandatory. In the event that suitable installation modifications cannot be achieved, then a test according to Standard 803 is not possible. In this case, various alternatives to an on-site test according to this standard are outlined in Annex F.

3. Units of Measurement

3.1 System of units. SI units (The International System of Units - Le Système International d'Unités) [3] are the primary units employed in this standard, with I-P units given as the secondary reference. SI units are based on the fundamental values of the International Bureau of Weights and Measures [4], and I-P values are based on the values of the National Institute of Standards and Technology which are, in turn, based on the values of the International Bureau.

3.2 Basic units. The unit of length is the meter (m) or millimeter (mm); I-P units are the foot (ft) or inch (in.). The unit of mass is the kilogram (kg); the I-P unit is the pound-mass (lbm). The unit of time is either the minute (min) or the second (s). The unit of temperature is either the kelvin (K) or the degree Celsius (°C); I-P units are the degree Rankine (°R) or the degree Fahrenheit (°F). The unit of force is the newton (N); the I-P unit is the pound (lb).

3.3 Flow rate and velocity. The unit of flow rate is the cubic meter per second (m³/s); the I-P unit is the cubic foot per minute (cfm). The unit of velocity is the meter per second (m/s); the I-P unit is the foot per minute (fpm).

3.4 Pressure. The unit of pressure is either the pascal (Pa); the I-P unit is either the inch water gauge (in. wg), or the inch mercury column (in. Hg). Values of in. Hg shall be used only for barometric pressure measurements. The in. wg shall be based on a one inch column of distilled water at 68°F under standard gravity and a gas column balancing effect based on standard air. The in. Hg shall be based on a one inch column of mercury at 32°F under standard gravity *in vacuo*.

3.5 Power, energy, and torque. The unit of power is the watt (W); the I-P unit is the horsepower (hp). The unit of energy is the joule (J); the I-P unit is the foot pound (ft-lb). The unit of torque is the Newton-meter (N•m); the I-P unit is the pound inch (lb-in.).

3.6 Efficiency. Efficiencies are expressed on a per unit basis. Percentage values can be obtained by multiplying by 100.

3.7 Speed. There is no unit of rotational speed as such in the SI system of units. The commonly used unit in both systems is the revolution per minute (rpm).

3.8 Gas properties. The unit of density is the kilogram per cubic meter; the I-P unit is the pound-mass per cubic foot. The unit of viscosity is the pascal second (Pa•s); the I-P unit is the pound-mass per foot-second (lbm/ft•s). The unit of gas constant is the joule per kilogram kelvin (J/kg•K); the I-P unit is the foot pound per pound mass degree Rankine (ft-lb/lbm•°R).

3.9 Dimensionless groups. Various dimensionless quantities appear in the text. Any consistent system of units may be employed to evaluate these quantities unless a numerical factor is included, in which case units must be as specified.

3.10 Physical constants. The value of standard gravitational acceleration shall be taken as 9.80665 m/s² at mean sea level at 45° latitude; the I-P value is 32.1740 ft/s² at mean sea level at 45° latitude [4]. The density of distilled water at saturation pressure shall be taken as 998.278 kg/m³ at 20°C; the I-P value is 62.3205 lbm/ft³ at 68°F [5]. The density of mercury at saturation pressure shall be taken as 13595.1 kg/m³ at 0°C; the I-P value is 848.714 lbm/ft³ at 32°F [5]. The specific weights in kg/m³ (lbm/ft³) of these fluids in vacuum under standard gravity are numerically equal to their densities at corresponding temperatures.

4. Symbols and Subscripts

4.1 Symbols and subscripted symbols

Symbol	Description	SI Units	I-P Units
A	Area of cross-section	m^2	ft^2
C_p	Specific heat at constant pressure	J/kg K	BTU/lbm°F
C_v	Specific heat at constant volume	J/kg K	BTU/lbm°F
D	Diameter and equivalent diameter	m	ft
D_h	Hydraulic diameter	m	ft
e	Base of natural logarithm (2.718...)	Dimensionless	
E	Energy factor	Dimensionless	
f	Coefficient of friction	Dimensionless	
H	Fan power input	kW	hp
H_o	Fan power output	kW	hp
K_p	Compressibility coefficient	Dimensionless	
$L_{x,x'}$	Length of duct between planes x and x'	m	ft
$\ln$	Natural logarithm	--	--
N	Speed of rotation	rpm	rpm
n	Number of readings	Dimensionless	
P_s	Fan static pressure	Pa	in. wg
P_{sx}	Static pressure at plane x	Pa	in. wg
P_t	Fan total pressure	Pa	in. wg
P_{tx}	Total pressure at plane x	Pa	in. wg
P_v	Fan velocity pressure	Pa	in. wg
P_{vx}	Velocity pressure at plane x	Pa	in. wg
p_b	Corrected barometric pressure	kPa	in. Hg
p_e	Saturated vapor pressure at t_w	kPa	in. Hg
p_p	Partial vapor pressure	kPa	in. Hg
Q	Fan flow rate	m^3/s	cfm
Q_x	Flow rate at plane x	m^3/s	cfm
R	Gas constant	J/kg K	ft-lb/lbm-°R
Re	Reynolds number	Dimensionless	
S	Aspect parameter	Dimensionless	
t_d	Dry-bulb temperature	°C	°F
t_t	Total temperature	°C	°F
t_w	Wet-bulb temperature	°C	°F
u_x	Uncertainty for Parameter x	Per Unit	
V	Velocity	m/s	fpm
$\bar{V}$	Mean velocity at Plane 1	m/s	fpm
$\hat{V}_a$	Velocity distortion parameter (axial):	%	%
$\hat{V}_t$	Velocity distortion parameter (transverse):	%	%
$\hat{V}_r$	Velocity distortion parameter (radial):	%	%
$\hat{V}_\theta$	Velocity distortion parameter (circumferential):	%	%

**Square or Rectangular Flow Passage,
re: Velocity Distortion**

T	Number of traverse grid velocity measurements in transverse direction	--	--
U	Number of transverse grid velocity measurements in axial direction	--	--
i	Index in transverse direction for velocity matrix	--	--
j	Index in axial direction for velocity matrix	--	--
$\bar{V}_i$	Mean velocity for each of the T traverses	m/s	fpm
$\bar{V}_j$	Mean velocity along each of the U grid stations	m/s	fpm

**Circular Flow Passage,
re: Velocity Distortion**

r	Index in the radial direction in the measuring plane	--	--
θ	Index in the circumferential direction in the measuring plane	--	--
t	Number of velocity measurements at a given radius, r , taken in circumferential increments	--	--
u	Number of velocity measurements at a given angle, θ , taken at radial increments	--	--
$\bar{V}_\theta$	Mean velocity at a given angle, θ , in the measuring plane	m/s	fpm
$\bar{V}_r$	Mean velocity at a given radius, r , from duct center	m/s	fpm
W	Power input to motor	kW	W
x	Function used to determine K_p	Dimensionless	
y	Thickness of straightener element	m	ft
z	Function used to determine K_p	Dimensionless	
γ	Ratio of specific heats	Dimensionless	
ΔP	Pressure differential	Pa	in. wg
η	Motor efficiency	Per unit	
η_s	Fan static efficiency	Per unit	
η_t	Fan total efficiency	Per unit	
μ	Gas viscosity	Pa•s	lbm/ft-s
ρ	Fan gas density	kg/m ³	lbm/ft ³
ρ_x	Gas density at plane x	kg/m ³	lbm/ft ³
Σ	Summation sign	--	--

4.2 Additional subscripts

Subscript	Description
c	Converted value
r	Reading
x	Plane 0, 1, 2, ... as appropriate
0	Plane 0 (general test area)
1	Plane 1 (fan inlet)
2	Plane 2 (fan outlet)
3	Plane 3 (Pitot traverse station)
4	Plane 4 (downstream static pressure)

5. Definitions

This section is excerpted from the AMCA Standards handbook [6].

5.1 Shall and should

The word **shall** is to be understood as mandatory, the word **should** as advisory.

5.2 Fan

(1) A device which utilizes a power-driven rotating impeller for moving air or gases and which has at least one inlet opening and one outlet opening. The openings may or may not have elements for connection to ductwork. The internal energy (enthalpy) increase imparted by a fan to a gas does not exceed 25 kJ/kg (10.75 BTU/lbm). (2) A device having a power-driven rotating impeller without a housing for circulating air in a room. (AMCA 99)

In many instances, a customer lists the system requirements and requests that the fan manufacturer supply additional accessories such as silencers or dampers. The pressure losses for accessories must be accounted for if the system is to operate properly.

If the fan manufacturer supplies these items, then the appropriate accessory losses are added to the system requirements and a fan is selected for the sum of the overall pressure losses.

5.3 Equivalent diameter

The equivalent diameter, D , of a rectangular cross-section duct with inside traverse dimensions a and b is:

$$D = \sqrt{\frac{4ab}{\pi}}$$

5.4 Fan inlet

The fan inlet is defined as the plane perpendicular to the airstream where it first meets the inlet cone or the inlet box furnished by the fan manufacturer. In this publication, the fan inlet is indicated by **Plane 1** (see Figure 5.1).

5.5 Inlet flow profile

The shape of the flow field just upstream of the fan inlet. It is an indicator of the varying flow in a plane extending across the flow passage.

5.6 Velocity distortion parameter - inlet flow

An indicator of the variation of the flow field at the inlet plane of a fan. It is calculated by applying the principle of standard deviation using velocity measurements taken in a matrix form in a transverse plane across the flow field and is expressed as percent distortion.

5.6.1 Velocity distortion parameter, axial, ($\hat{V}_a$).

The distortion of the inlet flow which is parallel to the fan shaft centerline in a rectangular inlet plane (see Figure 7.1)

5.6.2 Velocity distortion parameter, transverse, ($\hat{V}_t$).

The distortion of the inlet airflow perpendicular to the fan shaft. It is expressed as a percentage of the mean velocity (see Figure 7.1). (AMCA 99)

5.6.3 Velocity distortion parameter, radial ($\hat{V}_r$).

The distortion of the inlet flow relative to the radial position of a circular inlet plane (see Figure 7.1).

5.6.4 Velocity distortion parameter, circumferential ($\hat{V}_\theta$).

The distortion of the inlet flow relative to the circumferential position in a circular inlet plane (see Figure 7.1).

5.7 Fan outlet

The fan outlet is defined as the plane perpendicular to the gas stream at the outlet opening of the fan or the outlet opening of the evasé or diffuser. In this publication, the fan outlet is indicated by **Plane 2** (see Figure 5.1).

5.8 Flow

5.8.1 Flow rate. The flow rate is the volumetric flow rate at a specific gas density.

5.8.2 Mass flow rate. Mass flow rate is the volumetric flow rate multiplied by the gas density.

5.8.3 Fan flow rate. Fan flow rate is the volumetric flow rate at fan gas density at the fan inlet.

5.9 Pressure

5.9.1 Absolute pressure. Pressure above a perfect vacuum; the sum of gauge pressure and atmospheric pressure. The value is always positive. (AMCA 99)

5.9.2 Barometric pressure. The absolute pressure exerted by atmosphere at a location of measurement. (AMCA 99)

5.9.3 Gauge pressure. Gauge pressure is the value of a pressure when the reference pressure is the barometric pressure at the point of measurement. It may be negative or positive.

5.9.4 Total pressure. The air pressure which exists by virtue of the degree of compression and the rate of motion. It is the algebraic sum of the velocity pressure and the static pressure at a point. Thus, if the air is at rest, the total pressure will equal the static pressure. (AMCA 99)

5.9.5 Velocity pressure. Velocity pressure is that portion of the pressure that exists by virtue of the rate of motion only. It is always positive.

5.9.6 Static pressure. Static pressure is that portion of the pressure that exists by virtue of the degree of compression only. It may be positive or negative relative to the ambient atmospheric pressure.

5.9.7 Fan total pressure (P_t). Fan total pressure is the difference between the total pressure at the fan outlet and the total pressure at the fan inlet.

$$P_t = P_{t2} - P_{t1}$$

5.9.8 Fan velocity pressure (P_v). Fan velocity pressure is the pressure corresponding to the average velocity at the specified fan outlet area.

$$P_v = P_{v2}$$

5.9.9 Fan static pressure (P_s). Fan static pressure is the difference between the fan total pressure and the fan velocity pressure. Therefore, the fan static pressure is the difference between the static pressure at the fan outlet and the total pressure at the fan inlet (See Figure 5.2).

$$P_s = P_t - P_v = P_{t2} - P_{t1} - P_{v2}$$

$$P_s = (P_{s2} + P_{v2}) - P_{t1} - P_{v2}$$

$$P_s = P_{s2} - P_{t1}$$

5.9.10 Fan static pressure rise (ΔP_s). The increase in static pressure between fan outlet and fan inlet. (AMCA 99)

Fan static pressure rise is often mistaken for fan static pressure. The value of fan static pressure rise is the static pressure at the fan outlet minus the static pressure at the fan inlet (See Figure 5.2).

$$\Delta P_s = P_{s2} - P_{s1}$$

It can be shown that the difference between fan static pressure and fan static pressure rise is the inlet

velocity pressure.

$$\begin{aligned}\Delta P_s - P_s &= (P_{s2} - P_{s1}) - (P_{s2} - P_{t1}) \\ &= P_{s2} - P_{s1} - P_{s2} + P_{t1} + P_{v1} \\ &= P_{v1}\end{aligned}$$

5.10 Compressibility

Compressibility is the characteristic of a gas to change its density as a function of pressure.

5.10.1 Compressibility coefficient. A thermodynamic coefficient used to correct the perfect gas equation when applied to real gases, in determining fan total efficiency (AMCA 99). It is the ratio of the mean flow rate through the fan to the flow rate at the fan gas density. It is also the ratio of the fan total pressure that would be developed with an incompressible fluid to the fan total pressure that is developed with a compressible fluid.

5.11 Density

5.11.1 Gas density. Gas density is the mass per unit volume of the gas.

5.11.2 Fan gas density. Fan gas density is the density of the gas corresponding to the total pressure and total temperature at the fan inlet.

5.11.3 Duct gas density. Duct gas density is the density of the gas corresponding to the total pressure and total temperature at a specific plane in the duct.

5.12 Viscosity

5.12.1 Fluid viscosity. Viscosity is the characteristic of all fluids to resist flow.

5.12.2 Absolute viscosity. Absolute viscosity is the proportionality factor relating shearing stress (force per unit area) and rate of shear (incremental velocity per incremental distance).

5.12.3 Kinematic viscosity. The kinematic viscosity is the absolute viscosity divided by mass density.

5.13 Reynolds number

The Reynolds number is a dimensionless number representing the ratio of inertial forces to viscous forces at a particular point of a fluid in motion. Its value is calculated as the flow velocity at the point of interest multiplied by a characteristic linear dimension and divided by the fluid's kinematic viscosity.

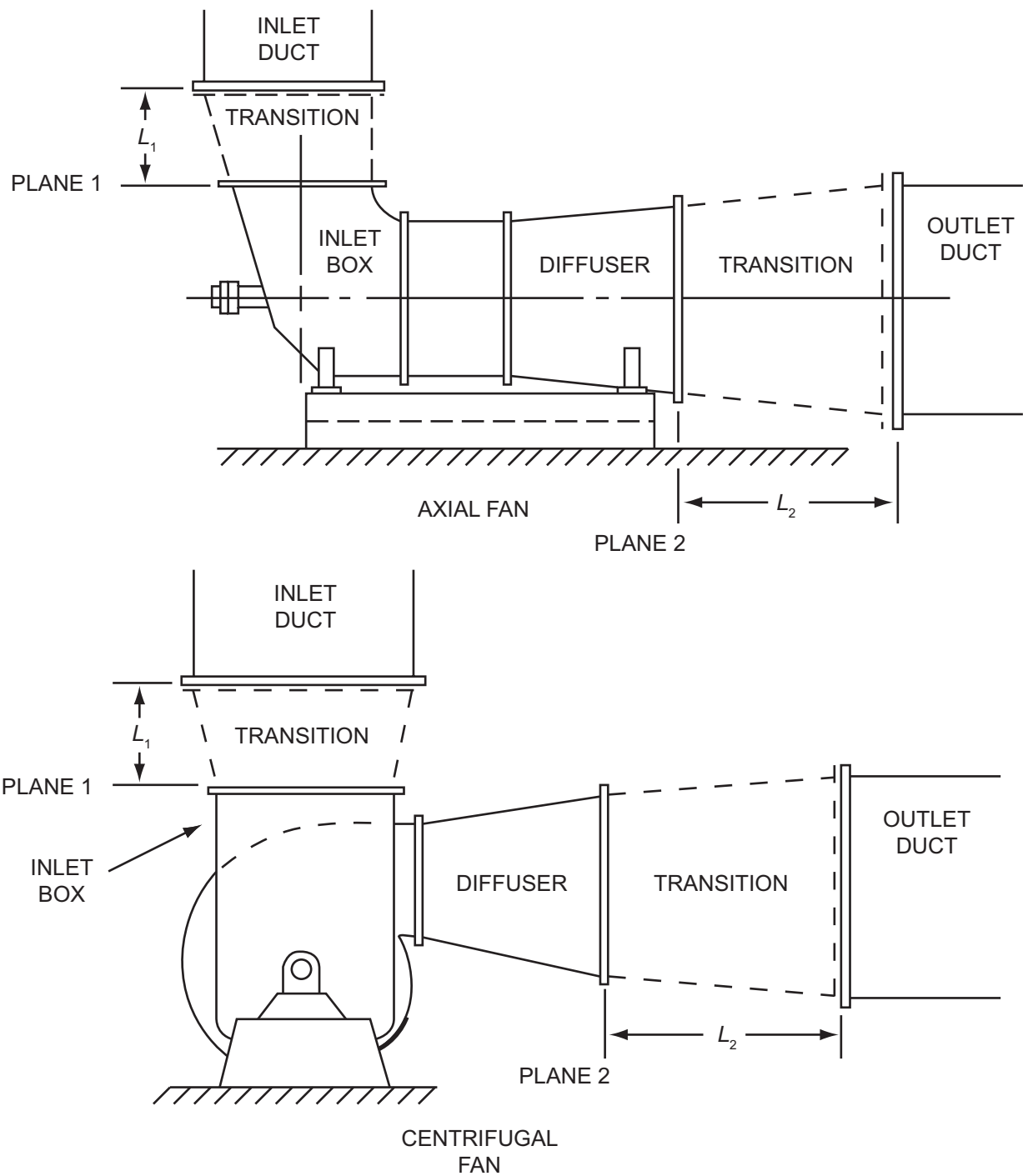


Figure 5.1

5.14 Temperature

5.14.1 Total temperature. Total temperature is the temperature which exists by virtue of the internal and kinetic energy of the gas. If the gas is at rest, the total temperature will equal the static temperature.

5.14.2 Static temperature. Static temperature is the temperature which exists by virtue of the internal energy of the gas only.

5.15 Specific heat

5.15.1 Specific heat at constant pressure. Specific heat at constant pressure is the quantity of heat required to increase the temperature of a unit mass of substance one degree at constant pressure.

5.15.2 Specific heat at constant volume. Specific heat at constant volume is the quantity of heat required to increase the temperature of a unit mass of substance one degree at constant volume.

5.15.3 Specific heat ratio. Specific heat ratio is the numerical ratio of the specific heat of a gas at constant pressure to that of the same gas at constant volume.

5.16 Standard air

Standard air is air with a density of 1.2 kg/m^3 , a ratio of specific heats of 1.4, a viscosity of $1.819 \times 10^{-5} \text{ Pa}\cdot\text{s}$, and an absolute pressure of 101.325 kPa. Air at 20°C, 50% relative humidity, and 101.325 kPa has these properties, approximately.

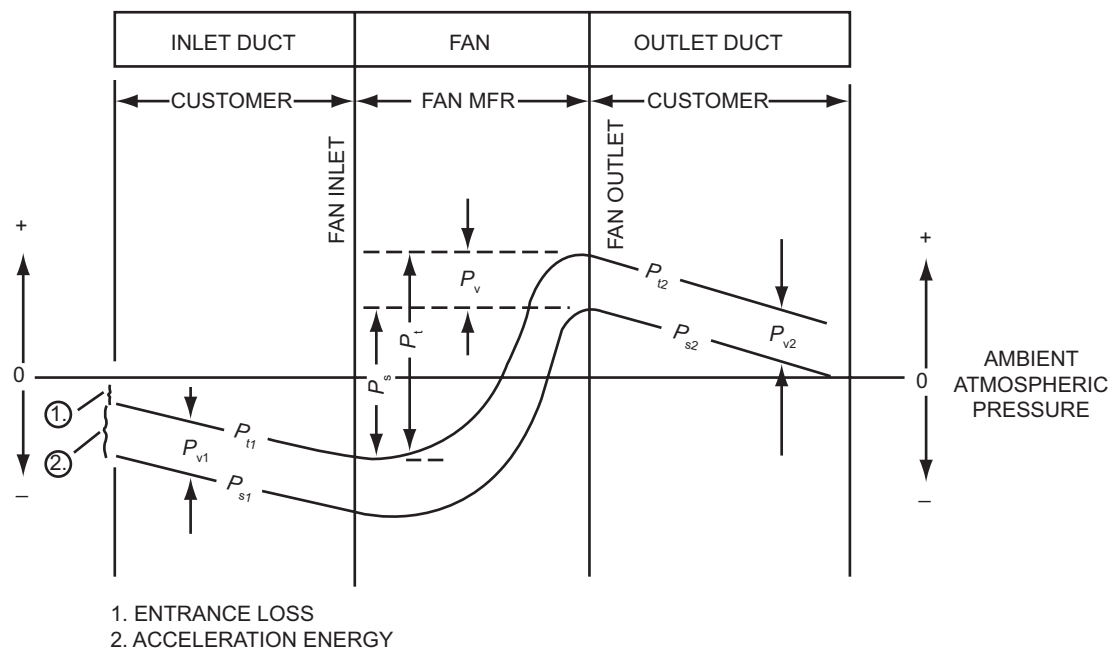
In the I-P system, standard air is air with a density of 0.075 lbm/ft^3 , a ratio of specific heats of 1.4, a viscosity of $1.2 \times 10^{-5} \text{ lbm/ft}\cdot\text{s}$. Air at 68°F, 50% humidity, and 29.92 in. Hg has these properties, approximately.

5.17 Power

5.17.1 Motor power. Motor power is the power delivered from the output shaft of the motor.

5.17.2 Fan shaft power (fan power input). The fan shaft power is the power delivered to the input end of the fan shaft and does not include any drive losses (e.g. belts and sheaves, etc.) other than the fan bearings, fan shaft seal and fan shaft cooler (heat flinger).

5.17.3 Fan impeller power. This is the power delivered to the fan impeller, specifically, the fan shaft power minus the fan shaft losses.



There is a distinct difference between an entrance loss and the acceleration energy when using static pressure nomenclature. Total pressure nomenclature should be used when discussing fan performance, however, from past practice, static pressure terminology is still used. It is most important to recognize the interdependence between total and static pressure in a typical system.

Figure 5.2 - Fan Pressure Interpretation

5.17.4 Fan shaft losses. Fan shaft losses are the power losses resulting from friction in the main bearings of the fan, the shaft seal, and/or the aerodynamic losses from the shaft cooler (heat flinger).

5.17.5 Fan power output. The fan power output is the useful power delivered to the fluid being handled. This output is proportional to the product of the fan flow rate, the fan total pressure, and the compressibility coefficient (K_p).

5.18 Efficiency

5.18.1 Efficiency-total. Ratio of fan output power divided by the fan input power.

5.18.2 Efficiency-static. Total efficiency times fan static pressure divided by fan total pressure.

5.19 Performance points

5.19.1 Maximum continuous rating (MCR). The maximum continuous rating point at which the fan is expected to operate.

5.19.2 Test block (TB). That point above and beyond the MCR demonstrating the fan margin to the customer.

5.19.3 Design point. That rating point which establishes the size and speed of the fan. In power generation, this would normally be the Test Block condition.

5.19.4 Point of rating. Point of rating is a specified operating point on the fan characteristic curve.

5.19.5 Point of operation. Point of operation is the relative position on the fan characteristic curve corresponding to a particular flow rate.

5.19.6 Determination. A determination is a complete set of measurements for a particular point of operation of a fan. The measurements must be sufficient to determine all fan performance variables as defined in Section 8.

6. Instruments and Methods of Measurement

6.1 General

Fan performance shall be defined by the accurate determination of flow rate, fan static or total pressure, speed, input power, and inlet density of the gas being handled. This section describes the minimum

requirements for determining each of these parameters.

Instruments used in making measurements shall be in good condition and possess the capability of performing their intended function for the complete duration of the test. Portable instruments shall not require changes in batteries, and fragile, sensitive instrumentation shall not be located where it can be subjected to the influences of inclement weather, temperature, or vibration. This may require special protective enclosures such as vans, tents, etc. The instruments shall be calibrated for the environment in which they will be used, and shall be used in accordance with the manufacturer's recommendations.

Personnel operating instruments shall be familiar with the instruments and shall possess enough experience to detect a possible malfunction or degradation of instrument performance. When instruments require corrective measures, personnel shall make an immediate evaluation as to the impact of the corrective action upon the parameter being measured and determine whether to void the test data or substitute alternate replacement equipment. Suspect instruments shall be removed from service until calibrated.

6.2 Instrument calibration

All instrumentation used in the test shall have a calibration against a known standard. The complexity of the calibration may vary from a minimum of a physical inspection, such as for a Pitot tube to ensure it does not leak and dimensionally agrees with appropriate standards, to a complete calibration which can be traced to the National Institute of Standards and Technology (NIST) if necessary. Specific calibration requirements are defined for each instrument in the appropriate sections which follow, however, the following calibration requirements apply to all instrumentation used in the test:

- a) All parties shall agree with the method of calibration, the calibration results, and the interval between the test and the last calibration
- b) Any calibration shall cover the range of readings to be encountered during the test
- c) The instrument shall not be used in any environment which violates its calibration
- d) Each instrument shall have a current calibration tag. The calibration period should be that recommended by the instrument manufacturer. If operational data can demonstrate that a longer period can be maintained between calibrations,

the interval can be increased. Portable equipment should have a maximum calibration period of six months. Self-calibrating equipment is exempt from the above requirements, but shall be identified on the report document by make and serial number. A calibration which is not in general agreement with historical data for the same instrument may indicate a malfunction, or indicates physical damage may have occurred.

- e) Each instrument shall be verified as operational prior to and after the test. If there are any irregularities such as a meter not returning to zero in the operational verification after the test, the test data may be inaccurate and unusable.
- f) Instrumentation used as individual components shall have individual calibrations. If the instrument is used as part of a measurement system or data acquisition system, the entire system shall be calibrated.
- g) Instruments which have a discontinuity or readability (resolution) not commensurate with the accuracy required for the test shall not be used.
- h) Calibration data may be curve-fit for use in computerized data acquisition systems, however, the curve fit must accurately represent the data so that no errors are introduced into the final results. All parties shall agree to the method of curve fit, and to the verification that it indeed does accurately reflect the data.

6.3 Instrument accuracy

Instrument accuracy forms a very important part of the overall consideration involved in test error analysis. Individual instrument accuracies or measured system accuracies listed in the appropriate sections represent maximum levels consistent with obtaining accurate results. All parties to the test shall agree prior to the test on the allowable measurement errors.

6.4 Measurement concepts

This standard utilizes the traverse method for determining average values of test data in which a duct cross-sectional area is divided into many smaller elemental areas dimensionally proportional to the original duct dimensions. A measurement of the desired parameter is then obtained at the center of each elemental area. These measurements are then combined to yield an average value of that test data parameter.

The measurement may be made using four general approaches as follows:

6.4.1 Manual recording of data. Using a grid pattern as defined in Section 7.7, an estimate of each parameter is obtained by observing and hand recording data from manometers or other instruments for several seconds while a sensor is located at the center of each elemental area. Once an average is obtained at one location, the sensor is sequentially moved to the centers of other areas where other average values are obtained.

6.4.2 Automatic recording of data. This technique is similar to the manual method, however, the sensor is connected to a transducer which is then connected to an automatic recording instrument such as a strip chart recorder. While holding the sensor steady at the center of each elemental area, the output is recorded for a specified time interval on the recording instrument. This provides a time history of the data at each location which is then analyzed at a later time to obtain the average value along with maximum and minimum values and any trends which were present. The strip chart recorder provides a copy of the data which is independent of mental averaging.

6.4.3 Continuous trace with automatic recording of data (See Figure 6.5A). This method uses the previously defined grid pattern, but instead of obtaining individual mental estimates (manual method) or time histories (automatic recording method), the sensor is moved very slowly and at a constant rate as agreed to by the participants (See Figure 6.5A) across the grid pattern while recording the output from the transducers on a strip chart recorder or other recording instrument. After the test, the area under the data on the strip chart can be integrated using many hundreds of readings to provide an average value of the parameter. This method has the advantage of providing not only a hard copy of the data and its fluctuations, but also a profile of the data across the duct as the sensor is moved. It can provide an evaluation of possible system effects and may become a criterion for acceptability of the test itself.

6.4.4 Automatic data acquisition systems with multiple point recording (See Figure 6.5B). This method uses multiple stationary sensors instead of one sensor that is systematically moved from one location to another. As an example, the sensors may be a Pitot tube array within a duct such that a Pitot tube is located at the center of each previously defined elemental area of the grid pattern. The output from each sensor is either manually or electronically sampled usually under a controlled data acquisition system. The data can be automatically stored and analyzed with the results being immediately available.

Use of this approach requires detailed considerations

of sampling rates, durations, and numbers of samples in order to achieve representative test results. The entire data acquisition system shall be calibrated and if a computer is employed, the computer program and calibration corrections verified as being correct.

6.5 Determination of measured parameters

6.5.1 Flow rate. Flow rate is based upon the measurement of velocity pressure and gas density at Plane 1 or 3. The instrumentation used to measure velocity pressure is discussed in Section 6.5.2. The velocity pressure at Plane 1 or 3 is defined as the squared mean root of all of the individual velocity pressure measurements at the center of the elemental areas. The flow rate at Plane 1 or 3 is calculated by converting the velocity pressure to its equivalent velocity and multiplying by the area of the traverse plane.

6.5.2 Pressure measurements. This section applies to the measurement of velocity pressure and static pressure at any of the measurement planes. Instruments used for pressure measurement include a sensor and an output device, or indicator, and may or may not include a recording instrument. Sensors include Pitot-static tubes and double reverse tubes. Output or indicating devices include manometers, slack tubes, water filled U-tubes, or pressure transducers and digital readout. Recording devices include strip chart or magnetic tape recorders.

The accuracy of the pressure measuring system shall be $\pm 1\%$ of the reading. Corrections shall be made for differences between calibration conditions and actual usage, such as manometer fluid specific weight, gas column balancing effect, or the expansion/contraction of scales due to differences in temperature.

Calibration of the system shall be against a water filled hook gauge, micro manometer, or other commercially available pressure standard device. The number of calibration points shall include the extremes of the anticipated pressures for the test and about nine essentially equally spaced intermediate points.

6.5.2.1 Instrumentation

Pitot-static tube. The Pitot-static tube of the proportions shown in Figure 6.1 is the primary sensing instrument for this standard. It is connected as shown in Figure 6.2 to an inclined manometer or pressure transducer for measurements of static pressure and velocity pressure.

The Pitot-static tube is considered to be a primary

instrument and need not be calibrated if maintained in the specified condition. It is suited for use in relatively clean gases. It may be used in gases that contain moderate levels of particulate matter such as dust, water or dirt, providing certain precautions are employed.

Pitot-static tubes shall be used subject to the following conditions:

- The Pitot-static tube shall be manufactured in conformity with the dimensional specifications stipulated in Figure 6.1 and shall be in good condition.
- The axis of the head of the Pitot-static tube shall be parallel to the axis of the duct within $\pm 7.5^\circ$. Appropriate devices shall be provided for this purpose (see Figure 6.3). [7]
- The Pitot-static tube shall be kept firmly in place during the measurements.
- The distance between the axis of the Pitot-static tube and the wall shall be greater than the diameter of the head of the tube.
- The local Reynolds number, related to the diameter of the head of the tube, shall be greater than 500. Where a Pitot-static tube is used to determine the Reynolds number, Reynolds number shall be determined by:

$$Re = \frac{\rho d_t V}{\mu}$$

Where:

ρ = density of gas, kg/m³ (lbm/ft³)

μ = absolute viscosity of gas, Pa·s (lbm/ft·s)

d_t = as given below

For tests with atmospheric air, the velocity shall not be less than:

$$v = \frac{B}{d_t}$$

Where:

	SI Units	I-P Units
v is the minimum velocity in:	m/s	fpm
d_t is the diameter of the head of the tube in:	mm	in.
B is equal to:	7.5	58

For additional information on Reynolds number calculations, see ANSI/AMCA 210.

Double reverse (Stauscheibe or S-Tube). The double reverse tube is intended for use in those instances in which the amount of particulate matter in the gas stream impairs the function of the Pitot-static tube. The double reverse tube shall be calibrated in a laboratory immediately before and after the test. It is important that the tube be used in the same orientation as used during calibration. The tube shall be marked to indicate the direction of the gas flow used in its calibration. The double reverse tube is connected to the inclined manometer as shown in Figure 6.4.

The tube upstream senses a true total pressure and the downstream tube a pseudo static pressure. A calibration factor is applied to each individual velocity pressure reading in order to determine true values of velocity pressure. The true static pressure is calculated by subtracting the true velocity pressure from the true total pressure.

Static Pressure Wall Taps. A tap can be used to sense static pressure at the surface of a duct. The tap needs no calibration. It shall conform to certain minimum requirements as illustrated in Figure 6.6. No fewer than four taps shall be used at a single measurement plane, and the tap shall be located near the center of each wall. The inner surfaces of the duct in the vicinity of the taps shall be smooth and free from irregularities. The tap shall be perpendicular to the direction of flow so that the velocity of the gas stream does not influence the pressure measurements by impinging upon the hole.

Whereas in an ideal flow situation the static pressure at a duct surface is usually identical to that obtained in a Pitot tube traverse taken across a duct, this is not always true when changes in duct area, or elbows or bends are present. Care should be exercised in this regard.

Before the commencement of any series of observations, the pressure at the four side taps should be individually measured at a flow rate towards the maximum of the series. If any one of the four readings lies outside a range equal to 5% of the rated fan pressure, the taps and manometer connections should be examined for defects, and if none are found, the flow shall be examined for uniformity. In the event that the flow is found to be non-uniform, pressure measurement should be performed by Pitot traverse.

The individual static pressure readings may be arithmetically averaged or the wall taps may be

manifolded as shown in Figure 6.6C. Care shall be taken to ensure that all tubing and connections are free from blockage and leakage.

Manometers. Manometers are available in both fixed and adjustable range types. Both types require calibration. The adjustable range type is convenient in that it may be adjusted at the test site to the range appropriate to the pressures which are to be measured. It is adjusted by changing the slope to any of the various fixed settings and by changing the range scale accordingly. Each setting provides a different ratio of the length of the indicating column to its indicated height. Adjustable range type manometers in which the slope may be fixed at 1:1, 20:1, and intermediate ratios are available.

The accuracy of the manometer used in the measurement of velocity pressures is of prime importance. The considerations involved in selecting a manometer that will provide an acceptable degree of accuracy include the range, slope, quality, scale graduations and indicating fluid of the instrument and the range of the pressures to be measured. Due to practical limitations in length, the manometer use is restricted to instances where the measured velocity pressures are very low. Recommended minimum value is 10 Pa (0.023 in. wg) at standard gas density.

Slack-Tubes. A slack-tube or water filled U-tube may be used for pressures above 2.5 kPa (10 in. wg) without calibration. This instrument shall not be used for velocity pressure measurement.

Pressure Transducers. A pressure transducer is a pressure sensing device whose voltage output is proportional to the pressure applied. A typical system is shown in Figure 6.5. The pressure measurement system shall be calibrated by a hook gauge, a micro manometer, or another pressure standard. The transducer shall be sized such that the pressures measured are within its linear range so that no over range condition can occur. The transducer shall not be subjected to vibration or heat beyond vendor specifications, and shall have a sufficient warm-up period prior to its use to eliminate the possibility of drift.

Readout Devices. Devices such as strip chart recorders, digital readouts, and magnetic tape recorder shall be calibrated as part of the system or have a reference calibration signal applied as in the case of magnetic tape. The resolution of the instrument shall be consistent with the overall system accuracy requirements.

6.5.3 Barometric pressure measurements. A Fortin type or a portable aneroid barometer is

recommended for determinations of barometric pressure. The barometer shall be accurate within 0.05 in. Hg (170 Pa) of the measured value and readable to (35 Pa) 0.01 in. Hg. The test value of barometric pressure shall be determined by averaging measurements made at the beginning of the test and at specified time intervals not to exceed 20 minutes for the duration of the test.

Barometers shall be calibrated against a mercury column barometer with a calibration that is traceable to the National Institute of Standards and Technology or other national physical measures recognized as equivalent by NIST. A convenient method of doing this is to use an aneroid barometer as a transfer instrument and carry it back and forth to the Weather Bureau Station for comparison [8]. A permanently mounted mercury column barometer should hold its calibration well enough so that comparisons every three months should be sufficient. Transducer type barometers shall be calibrated for each test. Barometers shall be maintained in good condition.

6.5.4 Temperature measurements. Temperature measurements are necessary in order to calculate the gas density in the duct as well as at ambient conditions. A duct temperature measurement must be obtained for each pressure measurement obtained in the center of each elemental area. A wet bulb duct gas temperature may be required to calculate the duct gas density. Duct gas temperatures are normally obtained using thermocouples or thermistors in conjunction with a readout device. A continuous temperature trace may be obtained providing the system reaction time is commensurate with the rate of temperature change across the duct. Temperatures shall be accurate within 1°C (2°F) of the measured value using instruments with a resolution of 0.5°C (1°F). The instruments must be calibrated as a system, taking care to correct for reference junctions or other conditions which might influence the reading.

Ambient temperatures should be obtained using a thermometer or other calibrated instrument. Obtain readings at the beginning of the test and at specified time intervals not to exceed 20 minutes for the duration of the test. Wet-bulb temperature should be obtained with a psychrometer or thermometer with a wick. The wet-bulb thermometer wick should be clean, closely fitted, and wetted with fresh water. The velocity of the air over the wick shall be between 3.5 and 10.2 m/s (700 and 2000 fpm).

A sling psychrometer is recommended for use in obtaining dry and wet-bulb air temperature measurements at the fan inlet for fans with nonducted inlets.

6.5.5 Gas stream composition measurements.

Gas stream density can be established when the pressure, temperature, and composition of the gas (including moisture) is known. Pressure and temperature measurements are discussed in Sections 6.5.2 and 6.5.4 respectively.

If the gas being handled has a composition other than air, each constituent must be identified whether by weight or volume. Gas analysis by electronic means, by chemical composition analysis, or other analysis system should be used. The system used must have a demonstrated accuracy of 1.0% by volume. This should be verified using commercial gas samples.

Gas composition measurements need to be obtained at only one measurement plane providing the gas stream does not change composition or undergo a change of state between planes. Calculations of density between planes is based on the density being directly proportional to the absolute pressure and inversely proportional to the absolute temperature. Measurements necessary to determine gas composition need to be obtained at the center of every other elemental area of every other traverse. The number of measurements can be reduced if all parties to the test agree that no stratification is present and that the composition does not change with time.

Moisture in the gas stream at elevated temperatures is sometimes very difficult to determine accurately. It is possible to withdraw a sample of gas into a desiccation sampling system or other measuring system. A system using condensation or desiccant method which has a demonstrated accuracy of 0.001 mass units of water vapor per mass unit of dry gas is required. Calibration of the system should be in accordance with the appropriate sections of ASME PTC 19 [9].

6.5.6 Speed measurements. Fan performance is a function of speed. This relationship is expressed by the compressible fan laws. It is important that during a test the fan speed be held constant. If a fan is direct connected to a motor, this may not be a problem. However, if the fan has a variable speed drive in the driveline, this is a very important consideration.

Speed shall be recorded at the beginning of the test and at specified time intervals not to exceed 20 minutes for the duration of the test. Readings should not vary by more than 1% for the total duration of the test. Acceptable instruments include a tachometer-generator system, an electronic counter timer initiated by a positive trigger such as a 60 tooth gear or shaft key, and a photoelectric triggered counter. A

stroboscopic device triggered by the line frequency of a public utility is considered a primary instrument and need not be calibrated if it is maintained in good condition. Speed measurement systems shall have a demonstrated accuracy of 0.5% of the measured value and shall be calibrated against a line-frequency oscillator which has previously been calibrated, or other frequency standard.

6.5.7 Input power measurement. Fan input power shall be determined through the use of torque meters or calibrated electric motors in conjunction with electric line measurements. When intending to use this method, it is usually necessary to specify in the motor purchase arrangements that the motor be calibrated since an additional cost is normally involved. Calibration data are similar to typical motor performance data with the exception that, instead of being merely typical, the calibration data represent the performance of a specific motor based on a test of that motor. The motor is calibrated over a range of operation. Electrical input data and other data sufficient for the determination of power output are obtained in the calibration.

Only with prior agreement between all parties can typical motor performance data be used in the determination of fan power input. These data, which are referred to as typical in that the data and the actual performance of the motor are expected to correspond closely, can usually be obtained from the motor manufacturer.

If the fan is supplied with bearings, it is assumed that any quoted fan power includes bearing friction losses, fan shaft seal friction losses, etc. It is only necessary to establish the motor output power to determine the fan power input since the coupling losses are assumed to be negligible for direct driven fans.

In the case of belt driven fans, the fan shaft power has to be established by deducting any drive loss from the calculated motor output power. The value of the drive losses must be determined by agreement between the parties if not included in the original performance quoted.

The data provided can be in a variety of forms, but must be sufficient to determine motor power output based on electrical input measurements. It is important that the power supplied to the motor during an on-site test be consistent with that used as the basis for the motor performance data. The phase voltage should be stable and balanced, and the average should be within 2% of the voltage indicated in the performance data.

Measurements of current, voltage, watts and power factor can be obtained by using an industrial type power analyzer of good quality. This type of instrument is available with accuracies of 1% of full scale for volts, amps, and power factor and 2% of full scale for watts.

On motors controlled by variable frequency AC controllers, electric line measurements cannot be used to determine fan input power. The data would be erroneous due to voltage variations and the nonsinusoidal wave shape of the current.

Calibration of power using instrumentation shall be based upon appropriate documents as follows:

Direct current machines IEEE 113-1999 [10]

Gas turbines ASME PTC 22 1997 [11]

Hydraulic prime movers . . .ASME PTC 18 1992 [12]

Induction Motors/Generators . . .IEEE 112 1996 [13]

Measurement of
shaft power ASME PTC 19.2 1987 R1998 [9]

Steam turbines ASME PTC 6S 1988 R1995 [13]

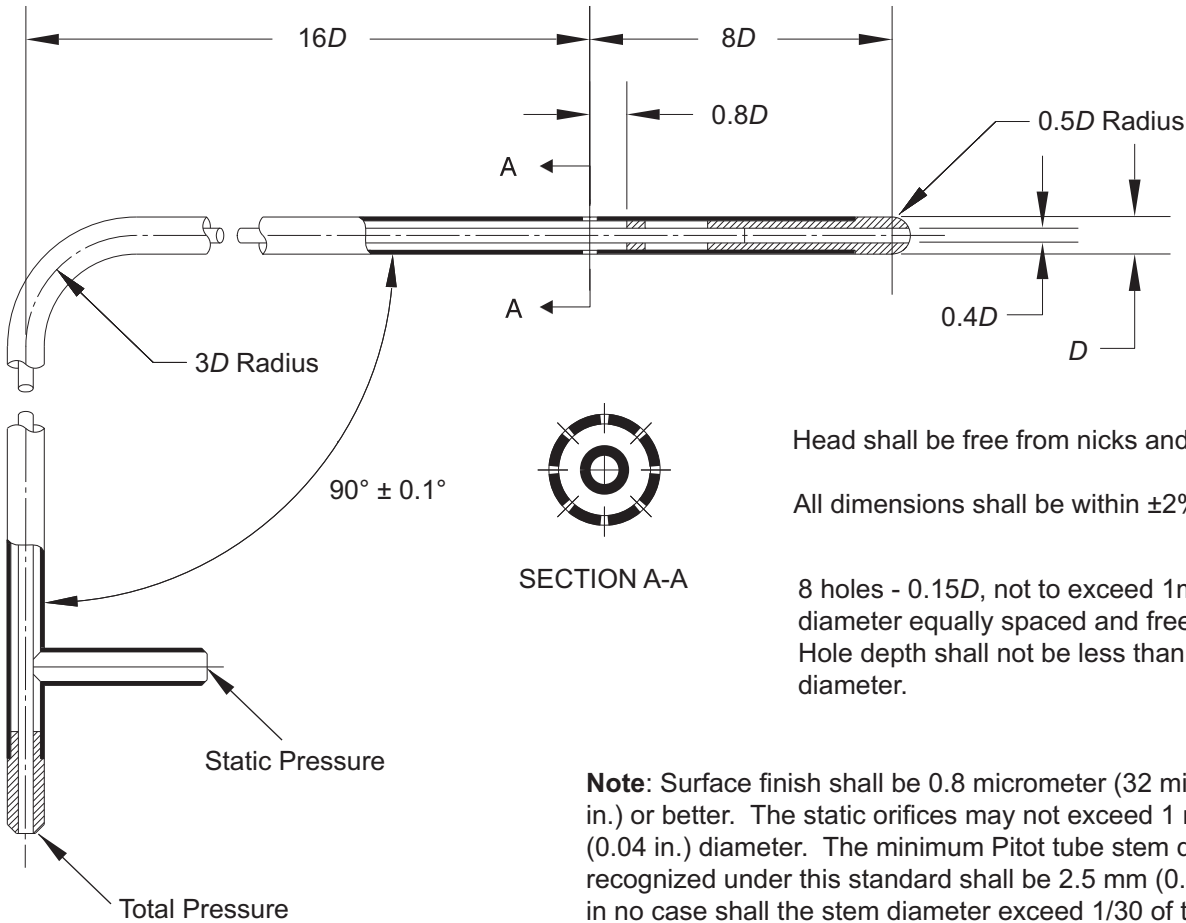
Synchronous machines IEEE 115 1995 [14]

Torque meters ASME PTC 19.2 1987 R1998 [9]

For other types of power transmission equipment it is suggested that the fan manufacturer be consulted to establish whether transmission losses are included in the fan ratings, and, if so, the magnitudes of the losses allowed in the ratings.

Otherwise, it will be necessary to consult the manufacturer of the power transmission equipment for the information regarding transmission losses.

Measurement of power shall be obtained at the beginning of the test and at specified time intervals not to exceed 20 minutes for the duration of the test.



Head shall be free from nicks and burrs.

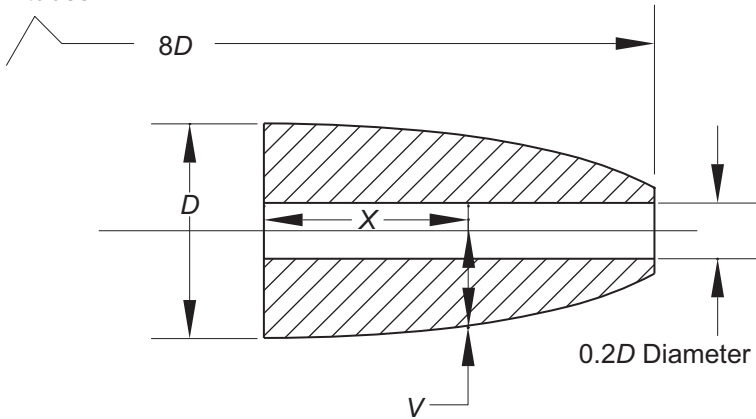
All dimensions shall be within ±2%.

8 holes - 0.15D, not to exceed 1mm (0.04 in.), diameter equally spaced and free from burrs. Hole depth shall not be less than the hole diameter.

Note: Surface finish shall be 0.8 micrometer (32 micro-in.) or better. The static orifices may not exceed 1 mm (0.04 in.) diameter. The minimum Pitot tube stem diameter recognized under this standard shall be 2.5 mm (0.10 in.) in no case shall the stem diameter exceed 1/30 of the test duct diameter.

PITOT-STATIC TUBE WITH SPHERICAL HEAD

All other dimensions are the same as for spherical head pitot-static tubes.



X/D	V/D	X/D	V/D
0.000	0.500	1.602	0.314
0.237	0.496	1.657	0.295
0.336	0.494	1.698	0.279
0.474	0.487	1.730	0.266
0.622	0.477	1.762	0.250
0.741	0.468	1.796	0.231
0.936	0.449	1.830	0.211
1.025	0.436	1.858	0.192
1.134	0.420	1.875	0.176
1.228	0.404	1.888	0.163
1.313	0.388	1.900	0.147
1.390	0.371	1.910	0.131
1.442	0.357	1.918	0.118
1.506	0.343	1.920	0.109
1.538	0.333	1.921	0.100
1.570	0.323		

ALTERNATE PITOT-STATIC TUBE WITH ELLIPSOIDAL HEAD

Figure 6.1 - Pitot-Static Tubes (From ANSI/AMCA 210-99)

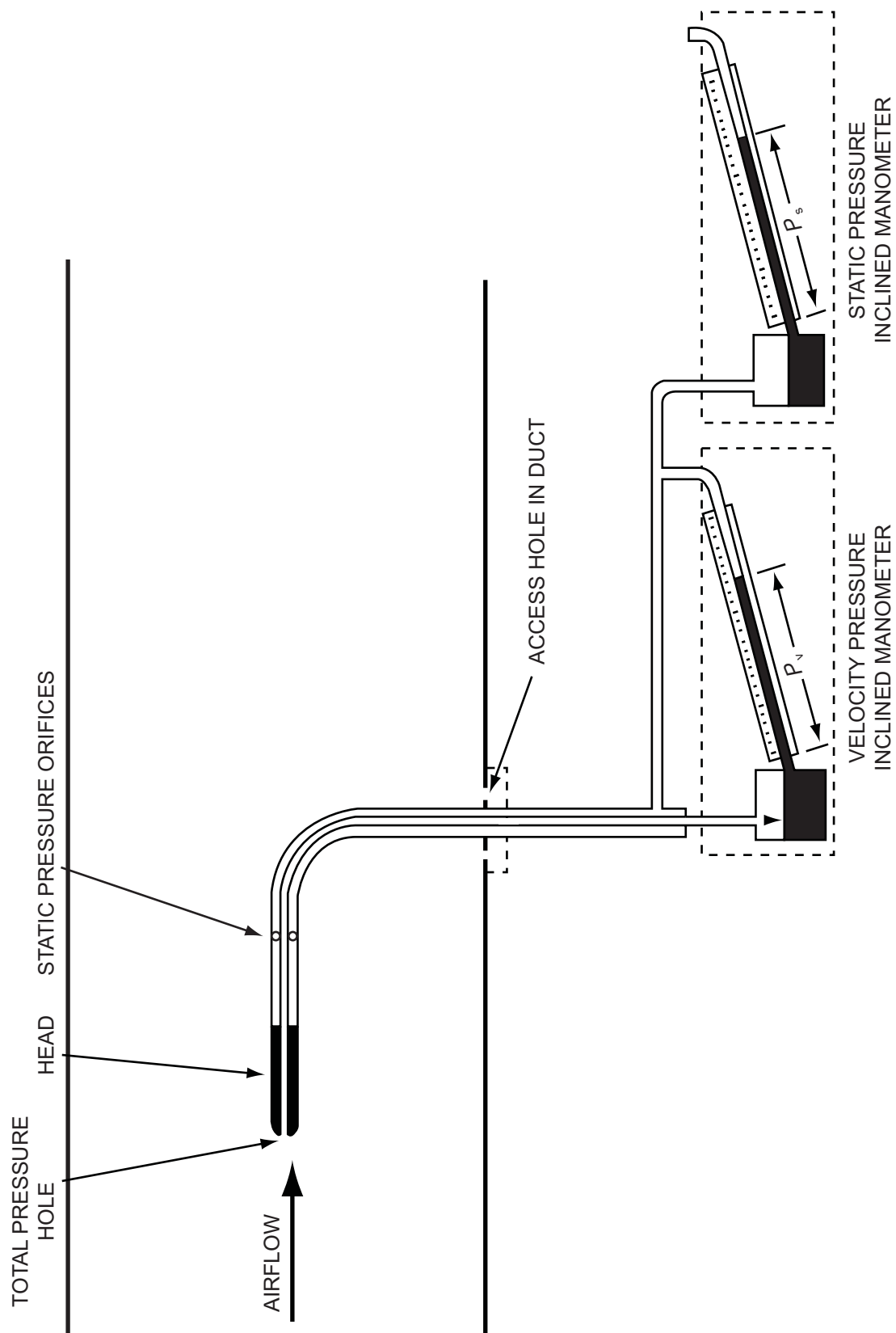


Figure 6.2 - The Pitot-Static Tube Connection

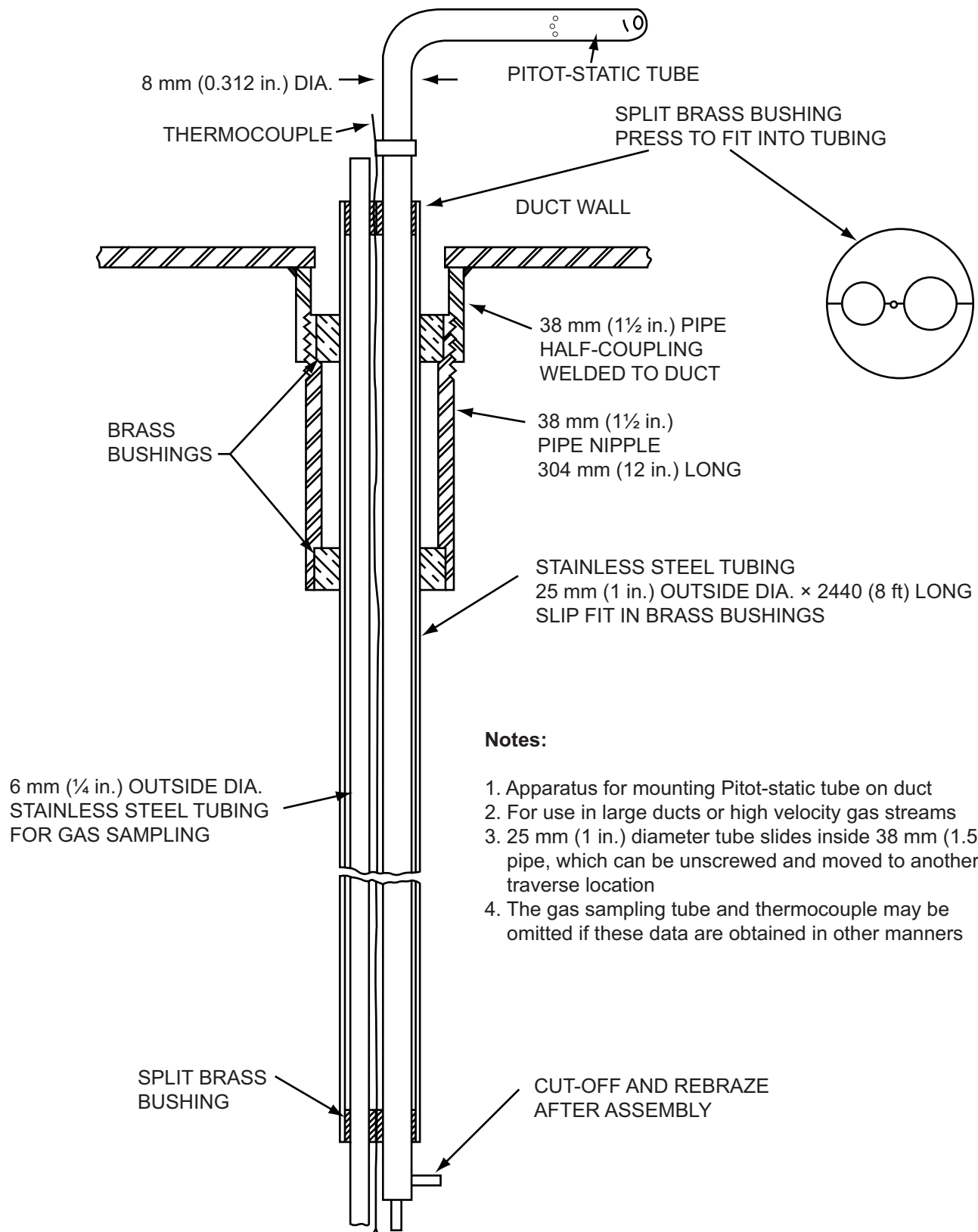
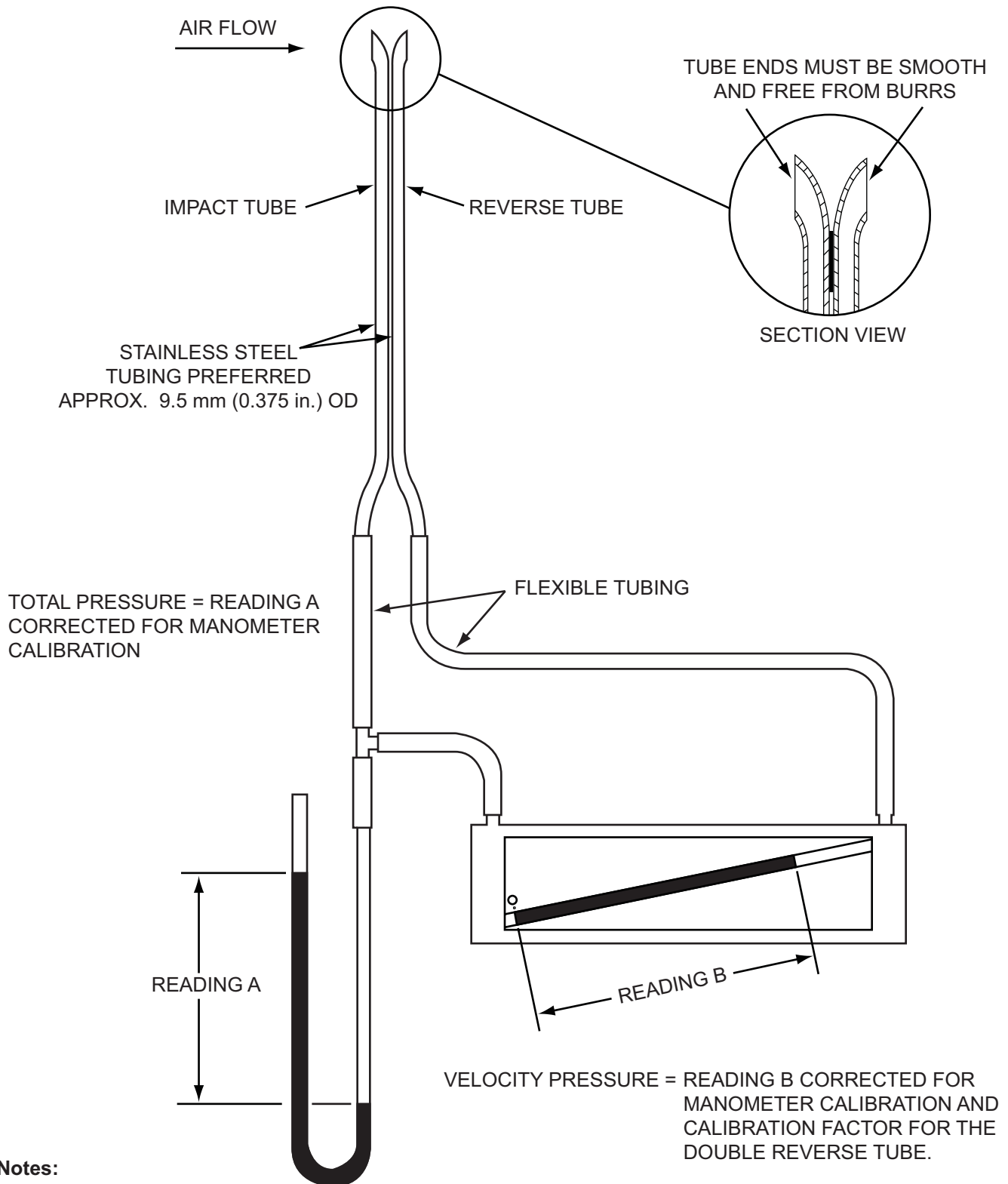


Figure 6.3 - Example Pitot-Static Tube Holder



Notes:

1. For use in dirty or wet gas streams.
2. The double reverse tube must be calibrated and used in the same orientation as used in its calibration
3. Also referred to as impact reverse tube, combined reverse tube, and type S tube.

Figure 6.4 - Double Reverse Tube (Stauschiebe or S-Tube)



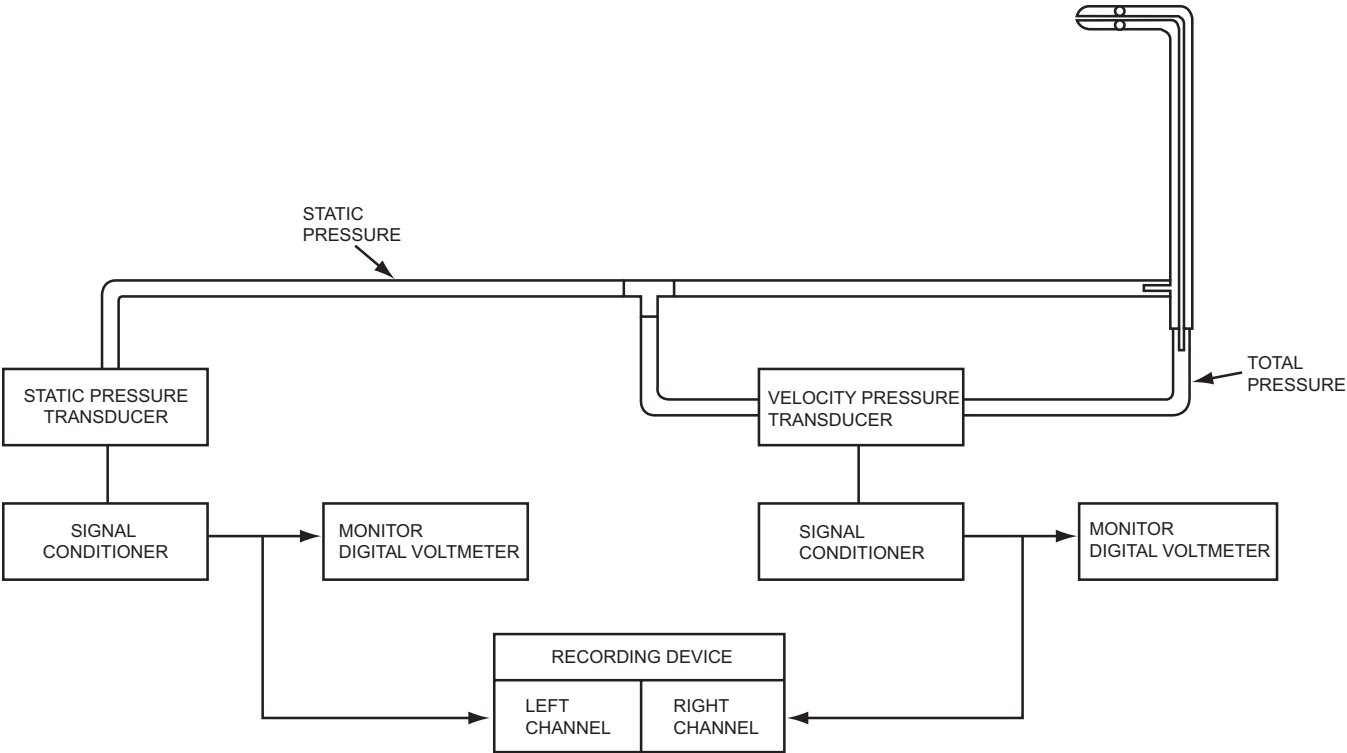


Figure 6.5A - Typical Continuous Trace System Instrumentation Schematic

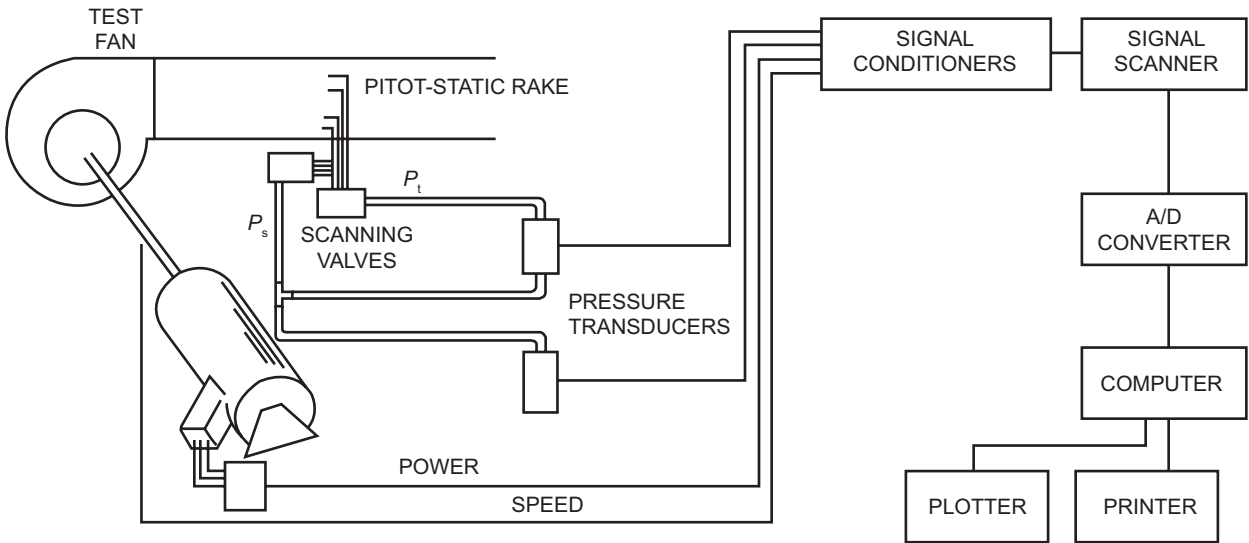


Figure 6.5B - Typical Automatic Data Acquisition System Instrumentation Schematic

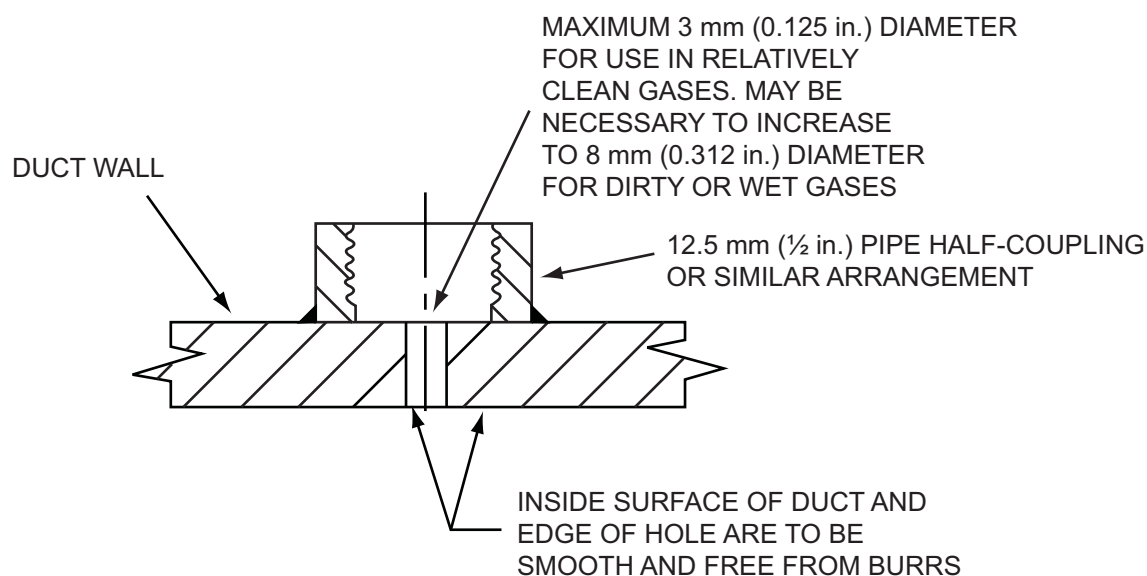


Figure 6.6A - Static Pressure Tap

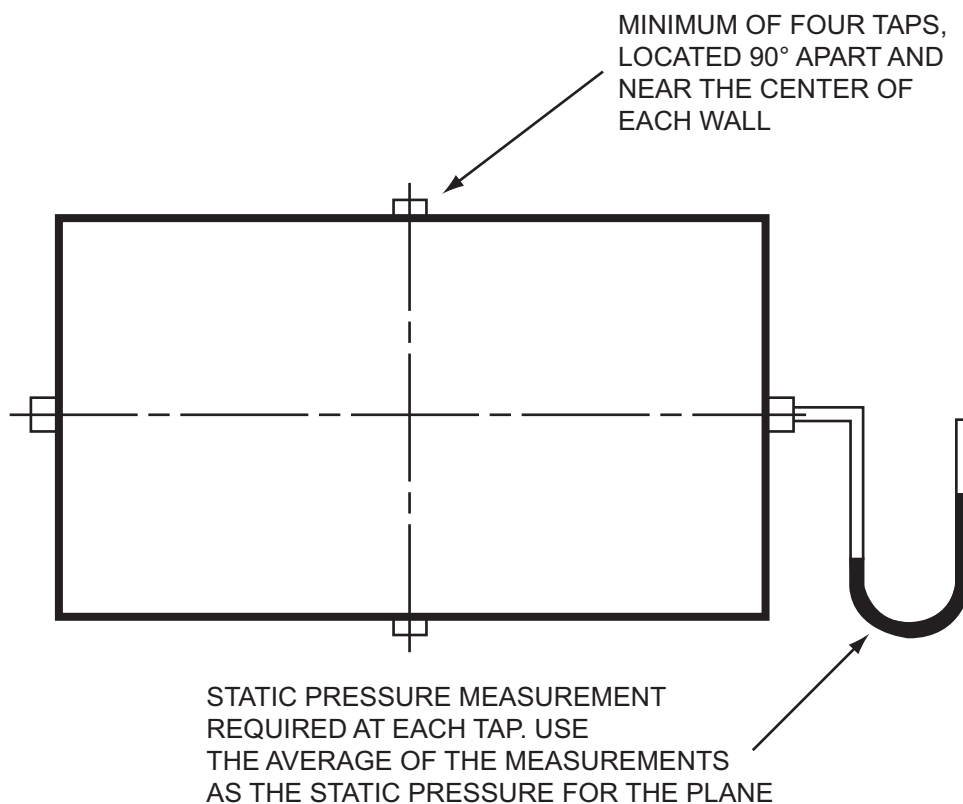
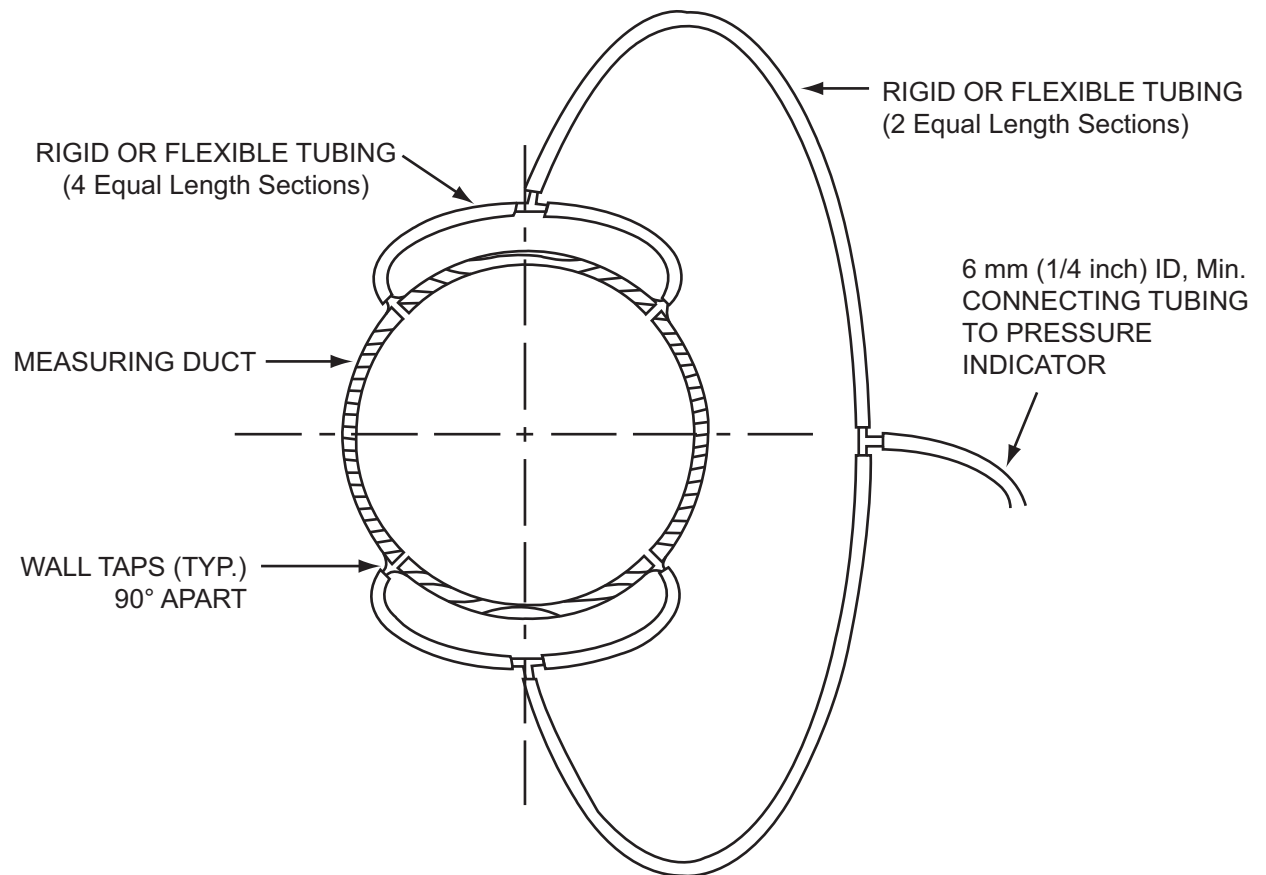


Figure 6.6B - Locations of Static Pressure Taps

Figure 6.6 - Static Pressure Wall Taps



Notes:

1. Manifold tubing internal area shall be at least 4 times that of a wall tap.
2. Connecting tubing to pressure indicator shall be 6 mm (1/4 in.) or larger in ID.
3. Taps shall be within ± 13 mm (1/2 in.) in the longitudinal direction.

Figure 6.6C - Piezometer Ring Manifolding