

mercury, and inverted in a cup partially filled with mercury. The height of the mercury column in the tube above the mercury surface in the cup is a measure of the existing atmospheric pressure, except for the slight pressure of the mercury vapor in the space above the mercury in the tube. This can ordinarily be ignored.

Elaborate mercury barometers, fitted with vernier scales, are available. For precise work, corrections must be made for the thermal expansion of the mercury and of the scales.¹⁴ The instruments are usually calibrated for 32 F mercury and 62 F scale temperature, and the correction C to be subtracted from the observed barometer's height is obtained by means of Equation 2.

$$C = \frac{h(t - 28.630)}{(1.11234 - 10978)} \quad (2)$$

where

C = correction to be subtracted, inches of mercury.
 h = observed height, inches of mercury.
 t = observed temperature of the barometer, Fahrenheit degrees.

Standard atmospheric pressure at sea level is 29.921 in. Hg, and since normal atmospheric pressure decreases about 0.01 in. Hg for each 10 ft increase in elevation, it is important to make a correction if the elevation of the barometer is not that of the test apparatus. In many cases the barometric reading may be obtained from a nearby Weather Bureau Station, in which case inquiry should be made as to whether the value is for station or sea level pressure.

Atmospheric pressure may also be measured by an aneroid barometer which is easily portable. In this type, variations in atmospheric pressure deflect the thin surface of a sealed diaphragm capsule. Most commercially available aneroid barometers are not as accurate as the mercurial type, and the best require occasional recalibration. Open-scale aneroid barometers are more expensive than common mercurial barometers.

Most of the pressure gages used in engineering work indicate gage pressures, that is, the difference between the pressure being measured and the atmospheric pressure. Such pressures are called gage pressures. Absolute pressure may be obtained by adding barometric pressure and gage pressure algebraically.

AIR-FLOW MEASUREMENT

The theory of various means for measuring the flow of fluids is discussed in Chapter 4 Fluid Flow. Heating and air-conditioning engineers are called upon to measure the flow of air more often than that of other gases, and usually the air is measured at or near atmospheric pressure. Under this condition, the air can be treated substantially as an incompressible fluid which implies that simplified formulas can be used with sufficient accuracy for the solution of many problems.¹⁵

The Pitot Tube

The Pitot tube, used in conjunction with a suitable manometer, provides a simple method of determining the air velocity in a duct. The construction of a Standard Pitot Tube¹⁶ and the method of connecting it to a draft gage is shown in Fig. 3. The equation for determining the air

velocity from the measured velocity pressure is as follows:

$$V = 1096.5 \sqrt{\frac{h_v}{\rho}} \quad (3)$$

where

V = velocity, feet per minute.
 h_v = velocity pressure (Pitot tube manometer reading), inches of water.
 ρ = density of air, pounds per cubic foot.

Since the velocity in a duct is seldom uniform across any section, and since a Pitot tube reading indicates a velocity at only one location, a traverse is usually made to determine the average velocity so that the flow can be computed. In general, the velocity is lowest near the edges

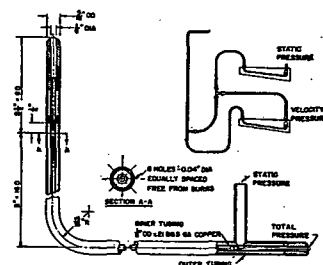


Fig. 3. Standard Pitot Tube

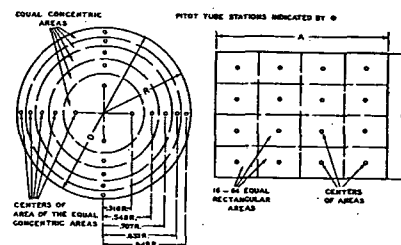


Fig. 4. Pitot Tube Traverse for Round and Rectangular Ducts

or corners, and greatest at or near the center. Suggested Pitot tube locations for traversing round and rectangular ducts are shown in Fig. 4. In round ducts not less than 20 readings should be taken along two diameters at centers of equal areas as shown. In rectangular ducts the readings should be taken in the center of equal areas over the cross-section of the duct. The number of spaces should not be less than 16, and need not be more than 64. When less than 64 are taken, the number of equal spaces should be such

that the centers of the areas are not more than 6 in. apart. In determining the average velocity in the duct from the readings given, the calculated individual velocities or the square roots of the velocity heads must be averaged. It is incorrect to use the average velocity head for this purpose.

Pulsating or disturbed flow will give erroneous results and therefore, if possible, the Pitot tube should be located at least 7½ diameters downstream from a disturbance such as that caused by a turn. Straightening vanes¹⁷ located 1½ duct diameters ahead of the Pitot tube will serve to improve the precision of the measurements.

The type of manometer to be used with a Pitot tube depends upon the magnitude of the velocity pressure being measured and the accuracy desired. At velocities greater than 1500 feet per minute, a draft gage of appropriate range is usually satisfactory. If the Pitot tube is being used to measure low air velocities, a precision manometer of some type is essential.

Many forms of Pitot tubes, other than the one described, have been used and calibrated.¹⁸ A double-ended tube,¹⁹ one end pointing downstream, and one upstream, is sometimes used for low velocities, but it should be carefully calibrated for accurate results. A special form of this tube design consists of two straight ½-in. tubes soldered together, closed at the end, and with a 0.04 in. hole in each tube opposite the line of contact. This tube is useful in exploring velocities in exhaust inlets, such as hoods placed around grinding wheels. To meet special conditions, different sized Pitot tubes which are geometrically similar to the standard tube can be used.

Orifices and Nozzles

Application of the Pitot tube is often inconvenient when velocities are low, because the resultant velocity pressures become so small that extraordinary means are necessary for measuring them. In addition, velocity surveys of the whole cross-sectional area of a duct are inexpedient when numerous test runs are in prospect. Chiefly for these reasons orifices are used in many test and research applications.

Plate or square-edge orifices²⁰ are simple to construct and convenient to use. They may be mounted between flanges, and a set of orifices of different sizes may be made readily interchangeable to measure a wide range of air-flow rates. The proportions of standard orifices and nozzles are given in Chapter 4.

Several standard arrangements of pressure taps for use with orifices are described in Chapter 4. Where velocities are low or where flow is free of large eddies and parallel to the walls of the duct, a drilled hole cleared of burrs and at a right angle to the stream is satisfactory.²¹ For higher velocities it is common practice to provide four or more holes around the periphery of the duct and connect them into a manifold.

To determine air flow by means of an orifice or nozzle, the pressure drop across the device is measured. The flow rate may then be calculated by means of the equation,

$$Q = 1096.5 K A_s \sqrt{\frac{h}{\rho}} \quad (4)$$

where

Q = air flow, cubic feet per minute.
 A_s = area of the orifice or nozzle, square feet.
 h = pressure drop across orifice or nozzle, inches of water.

ρ = density of air, pounds per cubic foot.
 K = orifice or nozzle coefficient.

The discharge coefficient K for an orifice is approximately 0.60, and for a nozzle is approximately 0.95. Correct values of K for various diameter ratios, pressure tap locations, and Reynolds numbers are given in Chapter 4. In some instances nozzles are used in multiple so that the capacity of the testing equipment can be changed by shutting off the flow through one or more nozzles. An apparatus designed for testing the air flow and capacity of air-conditioning equipment is described by Wile²² in an article in which pertinent information on nozzle discharge coefficients, Reynolds numbers, and the resistance of perforated plates is also presented. Such apparatus in some laboratories is commonly referred to as a code tester.

The Venturi meter is like the nozzle, except for the addition of a downstream transition section that reduces the pressure drop through the measuring apparatus.

In some cases air flow through a heater coil or heating unit may be estimated by computation from the heat given up by the coil, and the temperature rise (measured by thermocouples) of the air passing through. It is essential to have a uniform flow over the entire inlet and outlet of the heater at the planes of temperature measurement, and temperatures must be taken at enough points to provide a good average.

Propeller or Revolving Vane Anemometer

The propeller or revolving vane anemometer consists of a light revolving wind-driven wheel connected through a gear train to a set of recording dials that read the linear feet of air passing in a measured length of time. It is made in various sizes, 3 in., 4 in., and 6 in. being most common. Each instrument requires individual calibration. At low velocities the friction drag of the mechanism is considerable. In order to compensate for this, a gear train that overspeeds is commonly used. For this reason the correction is often additive at the lower range and subtractive at the upper range, with the least correction in the middle range of velocities. Most of these are not sensitive enough for use below 200 fpm.

Deflecting Vane Anemometer

The deflecting vane anemometer consists of a pivoted vane enclosed in a case. Air exerts a pressure on the vane as it passes through the instrument from an upstream to a downstream opening. The movement of the vane is resisted by a hair spring and a damping magnet. The instrument gives instantaneous readings of directional velocities on an indicating scale. With fluctuating velocities, it is necessary to average visually the swings of the needle to obtain average velocities. This instrument is very useful for studying motion of the air in a room,²³ and in locating objectionable drafts. Various attachments are available, such as the double tube arrangement for determining velocities in ducts, and a device for measuring static pressures. Each instrument, and the attachments for it, must receive individual calibration. For determining average velocity in a duct, it is necessary to traverse the duct as is done when using the Pitot tube.

Thermal Anemometers

If a suitable sensing element is heated electrically at a fixed rate and exposed to an air stream, the temperature