Measurement Methodology

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Airflow Measurement

Standard Design Pitot Tube

This device consists of a probe placed in the moving airstream that provides two different pressure components as its output. One component, sensed by ports parallel to airflow, is the total pressure. Total pressure is the combination of the impact pressure of the airstream hitting the part of the probe facing into the stream and the static pressure in the duct that impacts all surfaces, including the entire surface of the probe. The second component is the static pressure in the duct system— which is measured by sensing ports perpendicular to the airflow stream. These two pressure components are transmitted to a differential pressure transducer via pneumatic air lines.

The differential pressure transducer accepts the total pressure at its high sense port and the static pressure at its low sense port. The transducer takes the low value and subtracts it from the high value to leave a pressure component that represents just velocity pressure. The velocity pressure is then converted into a flow rate in CFM through the following equation:

$$\text{CFM} = \sqrt{\text{Velocity Pressure}} \times 4005 \times \text{A}$$

where A is the cross-sectional area, in square feet, of the duct where the probe is located and 4005 represents a constant for air at standard pressure and density.

For example, a 12-inch round duct's cross-sectional area in square feet is determined by the equation

$$\text{A} = \Pi \times r^2$$

where $\Pi = 3.14159265$ and
$r = 0.5$ ft. (6 inches)

hence the area is 0.7853982 square feet. Assuming a velocity pressure of 0.25" w.c., flow rate is determined by the previous equation:

$$\text{CFM} = \sqrt{0.25} \times 4005 \times 0.7853982$$

This equation results in a flow rate of 1572.7599 CFM.

Most often this sensing method is accomplished using an array or cross configuration consisting of multiple ports for each pressure component in order to achieve a good average of the airflow in the duct. Single point sensing elements are too susceptible to turbulence and stratification of airflow.

This sensor transducer combination is only adequate for flow measurement in the higher flow rate ranges, due to the fact that the square root function amplifies errors as flow is reduced. In addition, the standard functional design of pitot tubes creates vortices around the static pressure ports at low velocities, resulting in erroneous pressure readings to the transducer which are then *amplified* by the square root function. This sensing method also requires adequate straight duct runs before and after transitions, elbows, or control elements in order to achieve straight airflow. To achieve maximum accuracy ten duct-diameter runs are required upstream while five are required downstream.

Orifice Plate

This device usually consists of a round flat plate with an orifice of a specific size located in the center. The plate is mounted perpendicular to the airflow so that all air passes through the orifice. Pressure sensing taps are placed in the duct upstream and downstream of the orifice. The differential pressure drop across the orifice is measured in a manner similar to that used in the pitot tube sensor. The equation used to calculate flow from the differential pressure is similar to that used for the pitot tube:

$$\text{CFM} = \sqrt{\Delta P} \times 4005 \times C \times A$$

where C is a specific coefficient for the orifice and A is the duct cross-sectional area.

Since the orifice plate provides for a narrower range of differential pressure drops the transducer can operate higher up on the square root curve to deliver better accuracy at low flows. However, the orifice plate causes pressure drops in the duct system and usually requires air straightening or long straight duct runs; twenty diameters upstream and ten downstream.

Thermal Anemometer

This device is inserted in the duct perpendicular to the airstream and uses a thermal compensation circuit to determine airflow speed. The sensing basis for this device is a pair of temperature elements, either thermistors or RTDs, that are located in the probe. One temperature element is exposed to the airflow stream and the other measures ambient temperature within the duct. Current is driven through the element in the airstream until a resistive bridge is balanced. The amount of current required to balance this bridge is directly related to airflow speed in FPM. This value can then be converted to flow by multiplying the result by the duct cross-sectional area.

These devices display good accuracy throughout the entire airflow range, typically ±3% of the sensor range. However, they present several disadvantages: since they rely on heat transfer to accurately sense airflow their accuracy can be affected by debris that accumulates on the sensor surface; they are expensive to apply in a multipoint averaging application and require air straightening and precise placement for use as a single point sensor. Additionally, the heat generated by the current flowing through the sensor may may reach temperatures high enough to ignite some low flash point chemical vapors.

Linear Air Valve

This device combines the control function with the flow sensing function. The device is basically linear in operation between the pressure drop range of 0.6” w.c. to 3.0" w.c.. The valve is calibrated for a specific flow range and flow rate is accurately (±5%) determined from valve position, thus eliminating the need for flow measuring as long as the device stays calibrated and the pressure drop is within the correct range.

However, this device has some major disadvantages in that it requires a fairly high minimum pressure drop of 0.6" w.c. Such a minimum requires the mechanical systems to be larger than what would normally be required, which uses additional energy. In addition, since the accuracy and correct function of this device are based on the spring-loaded cone being able to move freely, it is susceptible to any condensable material which may adhere to the shaft on which the cone floats. Also, this device is normally about five to seven times the cost of a standard control device that includes flow sensing instrumentation.

Parallel Plate Pitot

This device is a recent development in pitot technology. It incorporates new computer design criteria which result in a device that is specifically suited to a wide range of velocities from 50 to 5000 FPM. It is unique in that the static ports (the most crucial component of the reading at lower velocities) are located on the side of parallel plates in order to allow time for a smooth boundary layer to form prior to static pressure measurement. This arrangement allows for accurate readings to be made at much lower velocities than can be achieved with standard pitot technology. Additionally, this design minimizes the need for straightening vanes in the duct and only requires five duct diameters of straight duct upstream and two downstream.

Space Pressure Measurement

Static Pressure Differential

A common means of determining the space pressure relationship of a laboratory to its surroundings is to measure the static pressure differential between the two spaces. This measurement is accomplished by placing static probes in the ceiling surfaces of both spaces and connecting them to a differential pressure transducer. The resultant pressure is usually readable in the 0.01" w.c. to 0.05" w.c. range. This reading is very susceptible to airflow currents within the space that impact on the sensor. In addition, this type of pressure reading cannot usually be measured when the door to the space is open.

Through the Wall Infiltration Velocity using Thermal Anemometry

This method of determining space pressure differential is accomplished by boring a hole through the boundary wall between the two spaces and inserting a thermal anemometer in the hole to sense the velocity of the air passing through. The measured velocity is in the 50 to 100 FPM range. This sensing method is capable of measuring differentials when the door is open. However, this technology is typically bidirectional and can sense air flowing in the wrong direction without the ability to determine the difference. It is also very susceptible to air currents within the space generated by diffusers and/or grills, and by personnel traffic. The device also suffers from the same drawbacks as thermal anemometers in duct work.

Total Pressure Differential across Boundary Wall

This method employs a sensor located on the surface of the boundary wall in the higher pressure space and a sensor located on the opposite side of the same wall in the lower pressure space. These sensors are then connected to an ultra low range differential pressure transmitter to provide readings in the 0.002" w.c. to 0.008" w.c. range. The range of measurement is maintained even when the door to the space is open. Such a method effectively measures the impact pressure of the air on the outside of the boundary wall, ensuring measurement of the actual relationship between the spaces. Total pressure differential methodology is uni-directional and cannot return false measurements when flow is in the wrong direction.

Face Velocity Measurement

Sidewall Infiltration Velocity Using Thermal Anemometry

This method consists of a single thermal anemometer mounted in an orifice which penetrates the sidewall of the fume hood interior shell to provide an air path from the exterior. The theory behind this method of measurement is that the fume hood interior is operating at a negative pressure in relation to the surrounding space so air always flows from the exterior of the hood, through the orifice, into the interior. The thermal anemometer senses the speed of the air flowing through the orifice. With correct placement of the orifice this air speed is equal to the speed of the air entering the face opening of the hood.

Such a method is very dependent upon the correct placement of the orifice in the hood sidewall because there is a restricted amount of area available to provide a pressure relationship corresponding to that of the fume hood face opening. This relationship is also easily upset when large pieces of equipment are placed near the sidewall of the hood interior.

Thermal anemometers are bidirectional measuring devices that provide readings of velocity regardless of whether or not the air is flowing in the right direction. Also, the internal design of a thermal anemometer is based on temperature compensation which adds heat to the sensing element as airflow increases to balance a temperature bridge. Flow is calculated by determining how much energy must be added to maintain the balance.

The process basically involves adding energy as flow increases and dissipating energy as flow decreases. Of course this method results in a different time response function between the two cases. Energy can be added quickly by increasing the flow of current through the device, but as the airflow decreases the dissipation of energy is dependent on the cooling effect of the airstream. Since the cooling effect takes more time the result is a slower time response function when going from high to low flow as compared to going from low to high flow.

In practice this method of measurement provides a velocity reading which, under the right conditions, is indicative of the average face velocity. This method responds to the effect of external changes in sash area, including someone working at the hood, that effectively change the open sash area. It also responds to competing air velocities caused by operators walking past the fume hood or by air currents within the space itself. However this method is not the most desirable due to:

- the changes in velocity readings caused by apparatus within the hood,
- the unequal time response function of increase vs. decrease airflow,
- the possibility of measuring flow in the wrong direction.

Sash Position Based

Face velocity measurement based on sash position methods is related to sensing two different elements, the position of the sash and the volume of air flowing through the hood.

There are three basic styles of sash that need to have their position measured.

1. The first of these is the simplest and most common and is called the vertical rising sash.The position of vertical rising sashes is determined by one of two prevalent methods. The most common method is to attach a spring-wound potentiometer to the top of the sash and measure the vertical displacement as a resistance range. Sash area is then determined by multiplying this value by the fixed sash width. The other prevalent method is to attach an ultrasonic transmitter to the top of the hood above the sash and measure the displacement by the time differential of the returning pulse. Sash area is then determined by multiplying this value by the fixed sash width.

2. The second type of sash is the horizontal sliding pane type. The position of these sashes is commonly determined by one of two different methods. The first is a combination of magnetic bars and magnetically activated reed relays located within a bar. These bars are mounted on the top edge of the horizontal panels, alternating between a magnet bar and a relay bar from one panel to the next. As a magnetic bar passes a relay bar the relays activate, giving a displacement which is multiplied by the fixed horizontal pane height to determine sash area. The other prevalent method is to attach a strip of resistive tape and a pressure impact device to the top of alternating horizontal panels. As a panel slides its pressure impact device presses on the tape and gives a displacement reading.This reading is then multiplied by the fixed horizontal pane height to determine sash area.

3. The third type of sash is the combination vertical rising and horizontal sliding assembly. This type of sash requires a combination of the previously described position sensors.

Sash Position Using Measured Airflow

This method consists some resistive or electronic means of measuring the open area of the hood face based on the position of its sash(es) and a means of measuring the current hood exhaust flow rate in cubic feet per minute (CFM). The face velocity, in FPM, is then calculated by dividing the flow rate, in CFM, by the sash open area in square feet. The resulting velocity value is then used as a representation of average face velocity. This method effectively relies on a *calculated prime control variable* instead of a measured one. Also, any error in the exhaust flow reading will result in an errant calculated face velocity.

While this method provides a means of fast response to sash changes, since it directly measures the sash area, it cannot compensate for changes in sash area affected by operators working at the hood or changes in face velocity affected by competing air currents. Also multiple or combination sashes will require expensive or complex configurations of sash sensors in order to accurately determine sash area.

It is critical to consider the effects on this technology caused by operators using the hood. In the case of a 4 foot fume hood the typical inside width of the sash is about 38 inches. A large person standing in front of the hood effectively cuts the sash width in half, resulting in twice the desired face velocity. At these high face velocities a vortex develops on either side of the operator’s body creating an area where contaminants can be trapped and possibly introduced to the operator’s breathing area. Additionally, when a person walks at a normal speed of 3 to 5 feet per second he creates a draft of air currents behind his body at speeds up to 300 FPM. If these currents are not sensed, which a sash position-based system cannot do, they can draw air and airborne contaminants out of the hood.

Sash Position Using Linear Air Valve with Calibrated Position

Some types of the sash position-based systems do not measure actual flow rate for use in calculating face velocity. These systems depend on a somewhat pressure independent airflow valve (usually independent between 0.6" w.c. and 3.0" w.c.) from which a position feedback is used to derive expected airflow rate. These valves by their nature are very dependent upon smooth repeatable operation in order to function properly. They rely on a system with a cone assembly that floats upon a stainless steel shaft with Teflon bearings. This design is very susceptible to condensable materials that adhere to the shaft and cause loss of pressure independence. This device has an additional disadvantage in that it requires a fairly high minimum pressure drop of 0.6" w.c. which requires the mechanical systems to be larger than what would normally be required, which uses additional energy.

This device is also normally about five to seven times the cost of a standard control device even with flow sensing instrumentation included.

Airfoil Pitot Measurement in the Sash Plane

This method comprises a new technology in pitot design called a parallel plate pitot array (see earlier description). This measurement takes place under the bypass deflector vane airfoil in the hood's face entrance at bench level. The pitot is combined with a new type of ultra low range (0.0” to 0.0015" w.c. full scale) high volume differential pressure transducer. Since the transducer is based on a high volume design the characteristic noise of low range pressure transducers is eliminated. Eliminating the noise makes the readings much smoother.

This velocity reading is an average of the flow across the width of the hood in the plane of the fume hood face. This location is the optimum one for face velocity measurement as it is the best representation of the desired prime control variable. The velocity under the airfoil has a fairly linear relationship to the velocity through the open face of the hood, regardless of sash position. This relationship is represented by an entrance coefficient associated with the particular manufacturer's fume hood design. The coefficient is a representation of the efficiency of the hood baffle design and the hood airfoils, both the bypass airfoil and the side airfoils.

This methodology has definite advantages over the previous ones because it can compensate for both external competing airflows and external effects on sash area. Both are *directly* sensed by this technology. Additionally, since the transducer has a response time of 100 milliseconds it can produce changes in signal output 10 times per second resulting in fast representation of changes in face velocity.

Total Pressure Differential in the Sash Plane

This methodology comprises a new sensor design called a space pressure primary. This sensing technology is based on a combination of sensors, multiple space pressure elements located in the face of the hood lintel, and a hood pressure probe mounted in the hood. The pressure probe extends across the width of the hood interior in the plane of the sash just above its top when fully closed. The system works by measuring the total pressure loss, not the static pressure, across the hood opening. Primarily intended for use on walk-in fume hoods, the system works equally well on bench style fume hoods that are not equipped with a bypass airfoil.

This sensor configuration is combined with a new type of ultra low range (0.0 to 0.003 " w.c. full scale) high volume differential pressure transducer. Since the transducer is based on a high volume design the characteristic noise of low range pressure transducers is eliminated. Eliminating the noise makes the readings much smoother.

The velocity reading is an average of the flow across the width of the hood in the plane of the fume hood face. This location is optimum for face velocity measurement as it is the best representation of the desired prime control variable. The total pressure loss across the hood opening has a fairly linear relationship to the velocity through the open face of the hood regardless of sash position. This relationship is represented by an entrance coefficient associated with the particular manufacturer's fume hood design. This coefficient is a representation of the efficiency of the hood side airfoils and the hood baffle design.

This type of measurement presents the same kind of advantages over the sidewall velocity and sash position-based methods as stated for the airfoil pitot method.