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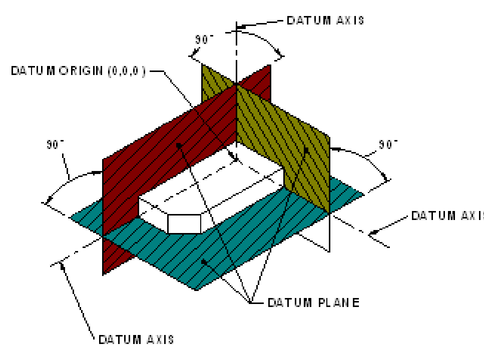

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Flow Measurement in Pipes and Ducts

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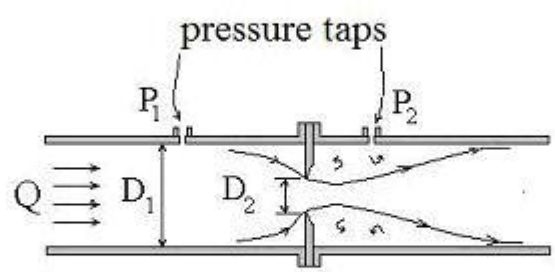
COURSE CONTENT

1. Introduction

This course is about measurement of the flow rate of a fluid flowing under pressure in a closed conduit. The closed conduit is often circular, but also may be square or rectangular (such as a heating duct) or any other shape. The other major category of flow is open channel flow, which is the flow of a liquid with a free surface open to atmospheric pressure. Measurement of the flow rate of a fluid flowing under pressure, is carried out for a variety of purposes, such as billing for water supply to homes or businesses or, for monitoring or process control of a wide variety of industrial processes, which involve flowing fluids. Several categories of pipe flow measurement devices will be described and discussed, including some associated calculations.



Orifice Meter Parameters

2. Learning Objectives

At the conclusion of this course, the student will

- Be able to calculate flow rate from measured pressure difference, fluid properties, and meter parameters, using the provided equations for venturi, orifice, and flow nozzle meters.

- Be able to determine which type of ISO standard pressure tap locations are being used for a given orifice meter.

- Be able to calculate the orifice coefficient, C_o, for specified orifice and pipe diameters, pressure tap locations and fluid properties.

- Be able to estimate the density of a specified gas at specified temperature and pressure using the Ideal Gas Equation.

- Be able to calculate the velocity of a fluid for given pitot tube reading and fluid density.

- Know the general configuration and principle of operation of rotameters and positive displacement, electromagnetic, target, turbine, vortex, and ultrasonic meters.

- Know recommended applications for each of the type of flow meter discussed in this course.

- Be familiar with the general characteristics of the types of flow meters discussed in this course, as summarized in Table 2 in the course content.

3. Types of Pipe Flow Measurement Devices

The types of pipe flow measuring devices to be discussed in this course are as follows:

i) Differential pressure flow meters

a) Venturi meter
b) Orifice meter
c) Flow nozzle meter

ii) Velocity flow meters – pitot / pitot-static tubes

iii) Variable area flow meters - rotameters

iv) Positive displacement flow meters

v) Miscellaneous

a) Electromagnetic flow meters
b) Target flow meters
d) Turbine flow meters
e) Vortex flow meters
f) Ultrasonic flow meters

4. Differential Pressure Flow meters

Three types of commonly used differential pressure flow meters are the orifice meter, the venturi meter, and the flow nozzle meter. These three all function by introducing a reduced area through which the fluid must flow. The decrease in area causes an increase in velocity, which in turn results in a decrease of pressure. With these flow meters, the pressure difference between the point of maximum velocity (minimum pressure) and the undisturbed upstream flow is measured and can be correlated with flow rate.

Using the principles of conservation of mass (the continuity equation) and the conservation of energy (the energy equation without friction or Bernoulli equation), the following equation can be derived for ideal flow between the upstream, undisturbed flow (subscript 1) and the downstream conditions where the flow area is constricted (subscript 2):

$$Q_{ideal} = A_2 \sqrt{\frac{2(P_1 - P_2)}{\rho(1 - \beta^4)}} \qquad (1)$$

Where: Q_{ideal} = ideal flow rate (neglecting viscosity and other friction effects), cfs

A_2 = constricted cross-sectional area normal to flow, ft^2

P_1 = upstream (undisturbed) pressure in pipe, lb/ft^2

P_2 = pressure in pipe where flow area is constricted to A_2, lb/ft^2

$\beta = D_2/D_1 = $ (diam. at A_2)/(pipe diam.)

$\rho = $ fluid density, slugs/ft^3

A discharge coefficient, C, is typically put into equation (1) to account for friction and any other non-ideal factors, giving the following general equation for differential pressure meters:

$$Q = C A_2 \sqrt{\frac{2(P_1 - P_2)}{\rho(1 - \beta^4)}} \quad (2)$$

Where: Q = flow rate through the pipe and meter, cfs

C = discharge coefficient, dimensionless

All other parameters are as defined above

Each of the three types of differential pressure flow meters will now be considered separately.

Venturi Meter: Fluid enters a venturi meter through a converging cone of angle 15^o to 20^o. It then passes through the throat, which has the minimum cross-sectional area, maximum velocity, and minimum pressure in the meter. The fluid then slows down through a diverging cone of angle 5^o to 7^o, for the transition back to the full pipe diameter. Figure 1 shows the shape of a typical venturi meter and the parameters defined above as applied to this type of meter. D_2 is the diameter of the throat and P_2 is the pressure at the throat. D_1 and P_1 are in the pipe before entering the converging portion of the meter.

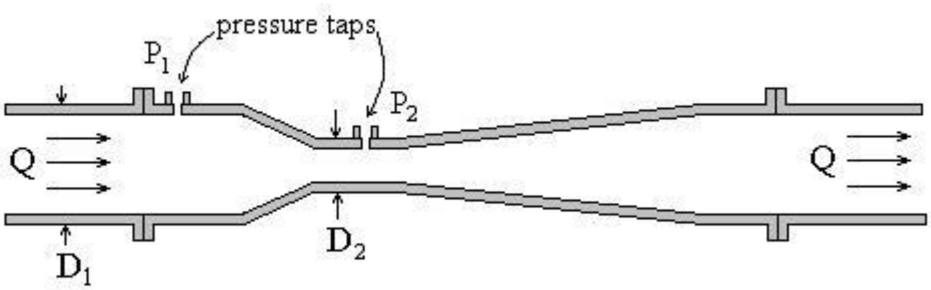


Figure 1. Venturi Meter Parameters

Due to the smooth transition to the throat and gradual transition back to full pipe diameter, the head loss through a venturi meter is quite low and the discharge coefficient is quite high. For a venturi meter the discharge coefficient is typically called the venturi coefficient, C_v, giving the following equation for a venturi meter:

$$Q = C_v A_2 \sqrt{\frac{2(P_1 - P_2)}{\rho(1 - \beta^4)}} \quad (3)$$

The value of the venturi coefficient, C_v, will typically range from 0.95 to nearly one. In ISO 5167 (ISO 5167-1:2003 – see reference #2 for this course), C_v is given as 0.995 for cast iron or machined venturi meters and 0.985 for welded sheet metal venturi meters meeting ISO specifications, all for Reynold's Number between 2×10^5 and 10^6. Information on the venturi coefficient will typically be provided by venturi meter manufacturers.

Example #1: Water at 50° F is flowing through a venturi meter with a 2 inch throat diameter, in a 4 inch diameter pipe. Per manufacturer's information, Cv = 0.99 for this meter under these flow conditions. What is the flow rate through the meter if the p

Solution: Tl 1.94 slugs/ft^3, to tl

$\pi D_2^2/4 = \pi(2$ e

difference to

Substituting

Q =

Orifice Met ssure

flow meters.

held in place