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Pitot based on mean square error algorithm for gas-liquid flow gas flow measurement

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Abstract

Pitot tube has the advantages of small pressure loss, cost economical, compact size, easy to cary, install and measure., which make It suitable for the flow measurement of medium and large d ameter pipes, and flow velocity and velocity distribution measurement at any point in air duct, water pipe and mine. However, when measuring the mixed phase fluid of gas and liquid, the pitot tube will have abnormal fluctuations in the flow measurement with the passage of time, and the measurement result would be far from the actual flow rate.

Gas-liquid mixed phase fluid is widely used in industrial production. Because gas phase fluid can be compressed, and there is shifting between gas and liquid phases, and the two-phase interface is complex and variable, the flow measurement of gas-liquid mixed phase flow is very difficult . In actual measurement, there could be condense liquid slowly formed on the inner wall of the pressure tapping hole of the pitot tube. As the amount of the condense water increase, due to the effect of liquid surface tension. attracted by internal molecules, the liquid surface molecules have a tendency to be pulled inside. As time goes by, there will be more and more water drops, and once it reached to a certain amount, the water drops will form a water film. Once the water film is formed, the pressure tapping hole of the pitot tube is divided into the meas ring side and the actual flow side by the water film, and the measuring side cannot correctly respond to the change of the flow rate any more, and therefore cause inaccurate measurement.

Based on the analysis of the feature of the flow profile of gas-liquid mixed-phase fluid and the data of the forming of water film, we propose a method of recognizing the abnormal data caused by the water fluid in a gas-liquid mixed-phase fluid base on the square error algorithm. We add a two-way solenoid valve to the front and rear pressure holes of the pitot tube. Under normal circumstances, the solenoid valve is closed. Once the algorithm recognizes the abnormal data, it opens the pressure-receiving hole by controlling the small solenoid valve built in the pitot tube, and the positive pressure or negative pressure of the gas-liquid mixed phase flow destroys the formation of the water film.

1. Background

In most gas measurement applications, pitot tube flow meters are widely used because its low pressure drop, convenient installation and high accuracy. If there is water vapor contained in the gas to be measured, there will be condensate water in the form of liquid drop generated on the inner wall of the pressure tapping hole of the pitot tube. As the amount of the water increase ,a water diaphragm will be generated on the inner wall. And once the diaphragm generated , the pitot pressure tapping tube will be divided into measurement side and real flow side by the water diaphragm. The measurement side can not measure the real pressure anymore, and the flow meter will measure incorrectly due to this cause

In order to overcome the influence of liquid impurities in gas-liquid mixed phase fluid on gas flow measurement, this paper provides a pitot tube flowmeter based on mean square error algorithm for gas-liquid mixed phase fluid flow measurement.

2. Technical goals

2.1 *Analysis of the influence of gas-liquid mixed phase fluid on measurement*

The pitot tube of this paper uses φ 11 probes. The inner diameter of the two capillaries for measuring total pressure and static pressure in the probe is φ 3. The diameter of the capillary and the probe are thinner and can be used in pipe from DN25 to DN450. It cause less pressure loss in the pipe and can be hot tapping installed.The two capillaries in the pitot tube flowmeter are used to measure the total dynamic pressure and static pressure of the fluid in the pipeline. When measuring the gas-liquid mixed phase fluid, the water vapor will condense into water droplets on the two pressure tapping holes of the pitot tube. Due to the presence of surface tension of liquid, the molecules on the surface of the liquid are pulled towards inside by the gravity of the internal molecules. As time goes by, more and more water droplets will be formed and a water diaphragm will be formed afterwards when there is a certain amount of water droplet. According to the capillary condensation phenomenon, the water diaphragm will be a concave liquid surface in the capillary of the pitot tube. Please reference to the illustration (Figure 1) below about the water diaphragm inside the capillary .

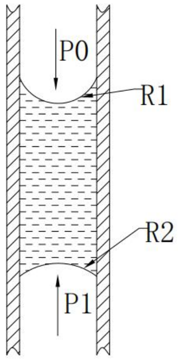


Figure 1: Schematic diagram of water diaphragm in capillary

Due to the surface tension and gravity of liquid, the pressure P_0 at the upper side of the water diaphragm and the pressure P_1 below it must be unequal. If the pressure inside the pipe is in dynamic equilibrium at this time, the relationship between P_0 and P_1 is as follows:

$$P_0 + \rho g h + 2\frac{\alpha}{R_1} = P_1 + 2\frac{\alpha}{R_2} \tag{1}$$

$$\Delta P = P_1 - P_0 = 2\alpha\left({}^{1}\!/_{R_1} - {}^{1}\!/_{R_2} \right) + \rho g h \tag{2}$$

In the formula:

ρ : Air density;

g : Gravitational acceleration;

h : Height of water diaphragm;

α : Water tension coefficient, $7.28\mathrm{e}^{-2} N/m$;

R_1 : Curvature radius of upper side concave surface;

R_2 : Curvature Radius of lower side concave surface;

From Equation 2 we can tell that the pressure difference between the upper and lower side of the water diaphragm is caused by the gravity of water and the additional pressure caused by the different Curvature radius of the upper and lower side of the water diaphragm.

Assuming that a 10 mm thick water diaphragm is produced during the measurement, and the curvature radius of the upper side and lower side of the water diaphragm are 3mm and 5 mm, as illustrated in figure 2:

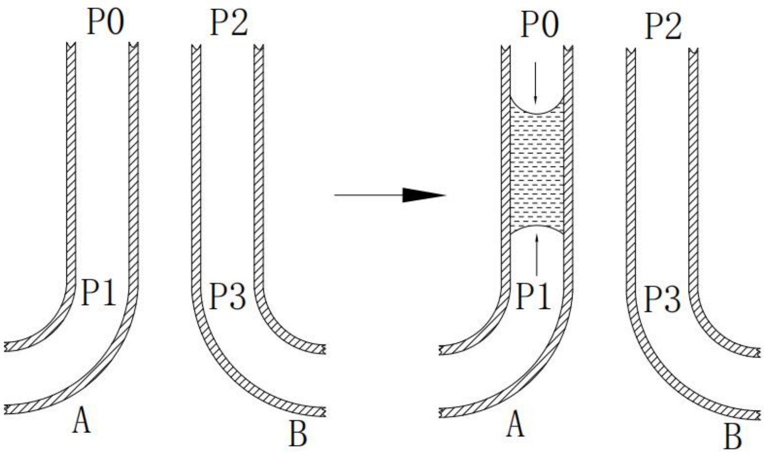


Figure 2: Schematic diagram of the forming of water diaphragm

The delta pressure measured by the differential pressure pitot tube flow meter before the forming of the water diaphragm:

$$P_m = P_0 - P_2 \tag{3}$$

$$P_0 = P_1 \tag{4}$$

$$P_2 = P_3 \tag{5}$$

$$P_m = P_1 - P_3 \tag{6}$$

In the formula：

P_m： Differential pressure value collected by pitot tube；

P_0： Upper side pressure of total pressure capillary；

P_2： Upper side pressure of static pressure capillary；

P_1： Lower side pressure of total pressure capillary；

P_3： Lower side pressure of static pressure capillary；

Since the total pressure and the static pressure capillary are connected：

After the forming of the water diaphragm , the differential pressure value measured by the differential pressure pitot tube flowmeter：

$$P_m^{'} = P_0^{'} - P_2 \quad (7)$$

$$P_m^{'} = P_m - \Delta P \quad (8)$$

In the formula：

$P_m^{'}$ ： The differential pressure value collected by the pitot tube flowmeter after the forming of the water diaphragm；

According to the calculation formula (5), we can tell that the differential pressure value collected by the pitot tube flow meter after the forming of the water diaphragm in the total pressure capillary will be smaller than the value from normal measurement. and will be on the contrary if the water diaphragm formed in the static pressure capillary

The formula of calculating the flow velocity from the differential pressure of a pitot tube flow meter

$$v = K\sqrt{2\Delta P/\rho} \quad (9)$$

In the formula：

v ：Actual velocity in pipeline；

K ：Pitot tube coefficient，0.65；

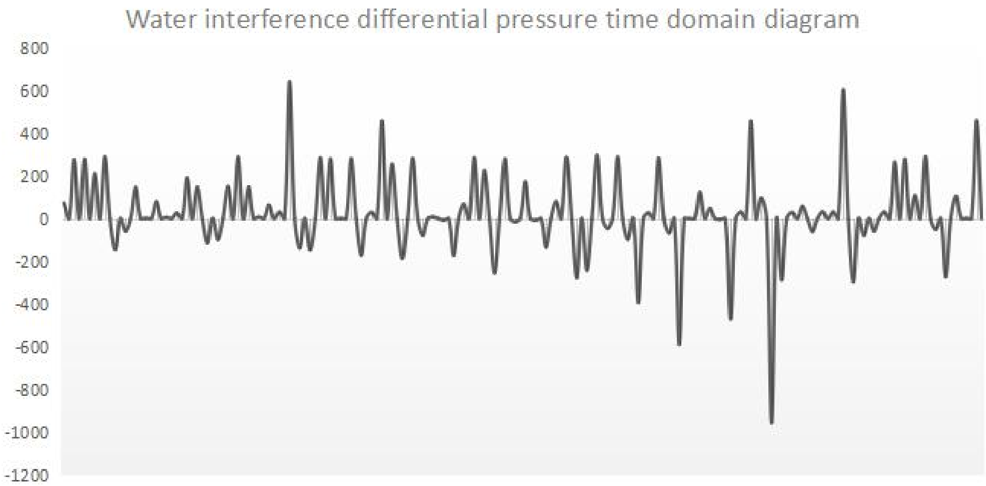
ΔP ：Differential pressure value collected by pitot tube；

ρ ：Actual density value of the air。

If the gas-liquid mixed phase fluid in the pipeline runs at a velocity of 10 m/s, the differential pressure value obtained by the pitot tube calculated according to the calculation formula (6) will be 98.2 Pa. Say the thickness of the total pressure capillary water diaphragm is 10 mm. and the Curvature radius of the lower and upper side of water diaphragm are 5mm and 3mm, ΔP will be about 120Pa according to the calculation formula (2), thus the differential pressure value collected by the pitot tube at this moment is -21.8Pa. If the water diaphragm is in the static pressure capillary, the differential pressure collected by pitot tube will be 218.2 Pa.

Base on these data, we can tell that the water diaphragm cause the pitot flow meter unable to measure the flow rate correctly.

The analysis above is based on the data of a single water diaphragm under a stable condition. But in a real measurement process, multiple of water diaphragms may be generated in the capillary, the thickness of the water diaphragm will be continuously increasing until the equilibrium state is broken, and some of the water diaphragm begins to slide down from the capillary until it reaches to a new balance. The following graphic shows the time-domain diagram of the differential pressure in two experiments on a normal pitot tube flow meter made in a 100mm inner diameter circular pipe with 7.8 barG pressure and 8 Nm3/min flow rate with interference of water.



When there is no water, the data is stable at around 285.7 with less fluctuates. When there is water, the differential pressure data is disorderly without pattern, sometimes even a negative value. After a long period of experiments and analyzing on the formation of water interference and the impact of water interference on differential pressure collection, we reached to a water interference identification algorithm.

Algorithm 1: In normal use, the gas in the pipeline will not flow backward, so there should not be negative differential pressure value. Once the negative differential pressure occurs in the pipeline with a pipe pressure larger than 0.1Mpa, it can be judged as water interference.

Algorithm 2: Calculate the maximum variation threshold of the differential pressure in the pipeline according to the differential pressure value at the moment and the response characteristic of the differential pressure sensing diaphragm. If the variation go beyond threshold, it can be judged as water interference.

Algorithm 3: During a period of operation, although there is no negative differential pressure value, and the variation is within the set threshold, We can calculate the mean square error of the differential pressure value in the period , and check if the mean square error is beyond set threshold to judge if there is water interference.

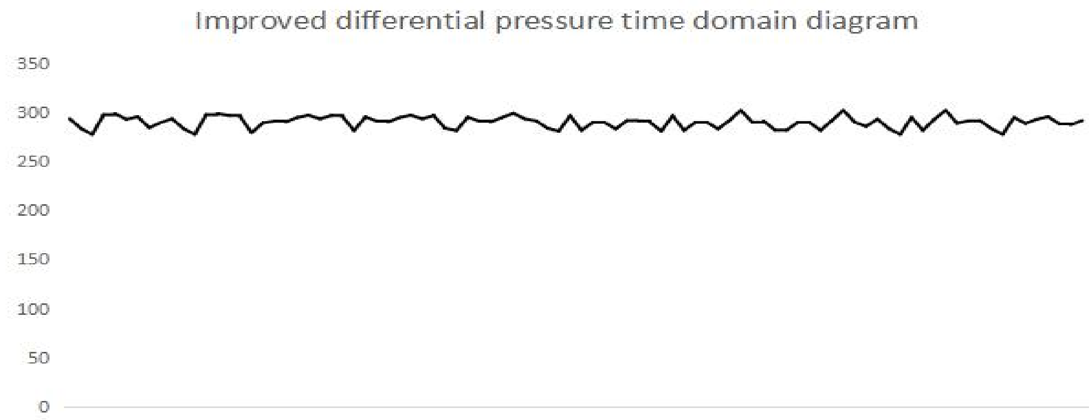
Algorithm 4: In order to ensure the of the reading displayed normally, define a set of damping arrays for flow rate calculation. Only normal differential pressure data determined by Algorithm 1, Algorithm 2, and Algorithm 3 can be put in the damping array and used in the calculation of the displayed flow rate.

2.2 Deal with the interference of gas-liquid mixed phase fluid on the flow rate measurement

The technical solution adopted in this paper is to add dual-pass solenoid valve in both total pressure and static pressure capillary. The solenoid valve is initially and defaulted to be closed, and we know that the total pressure and static pressure capillaries are connected with the differential pressure pizoes. When the solenoid valves are open, the total pressure and static pressure capillaries connect with atmosphere. Control the open/close of the solenoid valve in a pulsing blowing method, to blow the condensate water droplet and water diaphragm in the capillaries. After the blowing process, the solenoid valve will return to initiating status of closed.

Install this kind of pitot tube flow meter in a air flowing pipeline which contains huge amount of water, and once the water diaphragm is formed, the water interference identification algorithms will work. Once a water interference is found according to the algorithms, the solenoid valves in the capillaries will be on and its closing/opening will be controlled under a pulse blowing method. In this method the valves will be opened for 3 seconds and closed for 1 seconds for 5 rounds, so the water diaphragm will be blow away. During the blowing process, the flow rate will be calculated according to historical differential pressure value. The differential pressure value 3 seconds after the blowing will be used in flow rate calculation .

Following charts show the experimental results of using the Pitot flowmeter of the present invention in a circular pipe with a inner diameter of 100 mm, under 0.78MPa, with a flow rate of 8 Nm 3 /min :



From the analysis chart ,we can tell that the differential pressure value fluctuates around 289.9, and the data is stable with no negative value. This invention can ensure a stable measurement with an accuracy of ±1% RD ± 0.5% FS in a tough condition where the normal pitot tube can't measure properly.

This paper present a solution for measuring the gas flow rate in a gas-liquid mixed phase fluid. If the liquid in the fluid gasifies , the density of the gas will change and the flow rate measured by the pitot tube flow meter will differ from the real flow rate a lot. Thus our solution only applies to condition in which the density of the gas in the gas-liquid mixed phase fluid is stable

References

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