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EXPERIMENTAL STUDY OF THE FACTORS EFFECT ON THE S TYPE PITOT TUBE COEFFICIENT

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Abstract:
For the measurement of velocity of gas streams in ducts, the S pitot tube is one of the most widely used velocity measurement devices. Factors as Reynolds number and misalignment can be additional error sources for the S pitot coefficient. The variation of S pitot coefficient is observed on five different manufactures of S pitot through the airs peed standard system. The results of these experiments indicate that the coefficient curve of S pitot tube is fluctuated at small velocities around 0.2 % up to 0.7 %. The coefficient value of S pitot tube has a band from 2 % to 4 %

Keywords: S pitot tube; misalignment; yaw and pitch angle; coefficient.

1. INTRODUCTION

The S pitot tube determines the gas velocity by measuring the pressure difference between the total pressure through the impact orifice and the static pressure in the stack through the wake orifice. Because of certain configuration, the S pitot tube is easy to avoid blockage in the dirty environment

ISO 3966 [1] specifies the S pitot coefficient is calibrated against the Standard Pitot tube and its value is determined by measuring the same velocity in a wind tunnel system. The S pitot coefficient is defined as:

$$C_{p_S} = C_{pstd}\sqrt{\frac{\Delta p_{std}}{\Delta p_S}} \tag{1}$$

where $C_{p_{std}}$ is coefficient of standard Pitot tube (it is practically equal to 1), Δp_{std} is the differential pressure indicated by the standard pitot tube [Pa], Δp_S is the differential pressure indicated by the S pitot tube [Pa].

Vollaro et al. [2] and ISO 10780 [3] have recommended the way to install and calibrate the S pitot but in real condition, the installation is difficult and makes misalignments easily. Leland et al. [4] reported the misalignment effect over a range of velocity from 3 m/s to 24 m/s. The change of coefficient is observed at sixteen regularly spaced yaw and pitch angles, covering the range from -40 degrees to +40 degrees. Pitch angles of up to ±10 degrees and yaw angles of up to ±5 degrees increase or decrease the S pitot coefficient within a range of 2 % and 4 %, respectively. Pitch angles only cause drastic change in the S pitot coefficient with angles larger than 30 degrees while yaw angles greater than ±5 degrees will cause significant change.

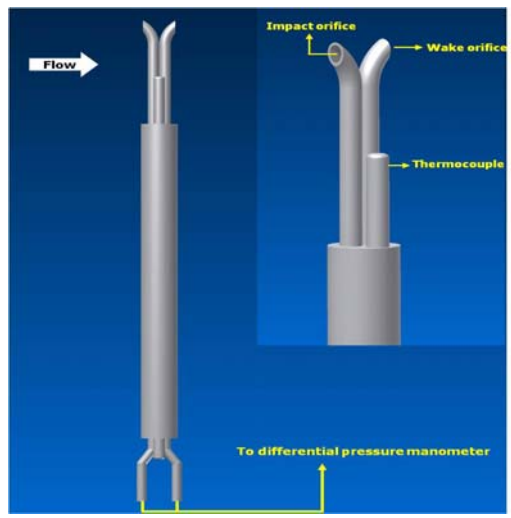

Figure 1. S pitot tube configuration

ISO 10780 [3] estimated a coefficient factor of 0.84 ± 0.01 for S pitot tubes made of metal tubing with an external diameter of 4 mm to 10 mm; the equal distance between the base of each leg of the S pitot tube and its orifice plane and this distance less than 1.05 and not more than 10 times the external diameter of tube. Vollaro et al. [5] presented the baseline coefficient value for 14 S pitot tubes being between 0.84 and 0.85. The data were taken at velocity of 15 m/s.

In the present study, the misalignment effects are surveyed in detail over a smaller range of velocity from 2 m/s to 15 m/s for the first manufacture of S pitot tube. The Reynolds number effect is studied over a range of velocity from 2 m/s to 29 m/s. In other hand, the baseline coefficient value and the shift of coefficient are evaluated on four remaining of S pitot tube at the range of velocity from 3 m/s to 30 m/s.

2. EXPERIMENTAL APPARATUS AND METHODS

These experiments are performed on the Korea Research Institute of Standard and Science (KRISS) and Korea Environment Corporation (KECO) wind tunnel system. The S pitot tube was installed opposite to the standard pitot side. It is connected with a Micromanometer (FC0510-1002178) to measure the differential pressure. The KRISS and KECO wind tunnel can generate velocities which vary from 2 m/s to 16 m/s and 2 m/s to 30 m/s, respectively. Parameters in wind tunnel system as static temperature, pressure and the pressure across the standard Pitot tube were acquired through a computer by LABVIEW program.

The alignment of impact orifice of S pitot tube is accomplished as the following. The first, it ascertains that the S pitot tube openings are perpendicular to the flow direction to specify the standard pressure coefficient. The second, change of the S pitot tube opening aligns out of the perpendicular line to the flow direction. This alignment comprises two types as yaw and pitch angle.

Pitch angle is an angle that rotates around the axis of S pitot tube. The rotational direction of pitch angle is stipulated for negative when it goes up and in turn. Yaw angle moves in the plane that contains the axis of S pitot tube. The moveable direction of yaw angle is specified for plus sign when it moves the same direction with the flow and in turn.

The study about the effect of misalignment was performed at 14 different velocities within the range from 2 m/s to 15 m/s. The change of yaw and pitch angles are performed at ten regularly spaced angles from -10 degrees to +10 degrees. At each velocity and misalignment angle setting, three values of S pitot coefficient are acquired.

Figure 2. S pitot installation in the wind tunnel

The studies about the effect of changing Reynolds number on the S pitot tube coefficient were executed on two ranges of velocity. For the small range velocity from 2 m/s to 15 m/s, experimental data were taken on KRISS and KECO wind tunnel system at 14 testing velocities. For the velocity higher than 15 m/s, experimental data were acquired on the KECO system at three testing velocity points, spaced at approximately equal intervals.

The study about the stabilization of the S pitot tube coefficient was done on the KECO wind tunnel system at the range of testing velocity from 3 m/s to 30 m/s. S pitot tubes in this study were calibrated at five different velocities within this range, spaced at approximately equal intervals.

3. RESULTS AND DISCUSSION

Baseline coefficient value and stabilization of the S pitot tube over the range of velocity from 3 m/s to 30 m/s are presented in Figure 3. For case 1, the coefficient values of 27 S pitot tubes are between 0.789 and 0.830. The ninety nine percent of coefficient values in this set of data are smaller than 0.830. The band of coefficient values is maximum difference interval between obtained coefficient values at each testing velocity. The band of case 1 is from 3 % to 5 %. For case 2, the coefficients of values of 35 S pitot tubes are between 0.803 and 0.844. The fifty two percent of coefficient values in the second set are smaller than 0.830. The band of coefficient values is within 4 % and 5 %. For case 3, the coefficients of values of 28 S pitot tubes are between 0.804 and 0.845. The seventy two percent of coefficient values in the third set are smaller than 0.830.

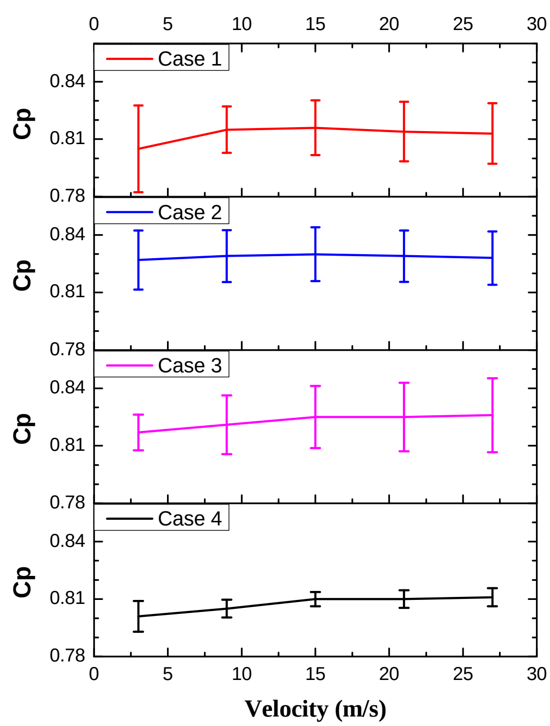

Figure 3. Stabilization of S pitot tube coefficient

The band of coefficient values is from 2 % to 4 %. For case 4, the coefficients of values of 11 S pitot tubes are between 0.793 and 0.816. In the last set, all of the coefficient values are smaller than 0.830. However, the band of coefficient values is smaller than previous sets. The biggest band of this set is only up to 2 %.

Misalignment effect: The S pitot tube coefficient is a function of different pressure. So that the impact and wake orifices of S pitot tube are not perpendicular to the direction of flow, they will change to the pressure distribution around the S pitot tube and the coefficient value will change. The experiment results are expressed below.

For the pitch angle, coefficient values are obtained by this experiment range from 0.807 to 0.824. The variation of ratio of the coefficient value at each pitch angle and at zero degree is demonstrated in Figure 4.These observations show that the pitch angles vary up to ±10 degree over range of Reynolds numbers from 4.3×10^5 to 3.4×10^6, the coefficient of S pitot tube only increases or decreases within ±2 %. This result totally conforms to the data of Leland [4].

For yaw angle, coefficient values from 0.802 to 0.853 are obtained by this experiment range. The variation of ratio of the coefficient value at each yaw angle and at zero degree is shown in Figure 5. In this case, the experiment results are separated into two regions. In the first region, the change of yaw angle within -10 degrees and 4 degrees will make either an increase or a decrease up to ±4 %. Particularly, the negative angles only make the oscillation of coefficient values up to ±2 %. In the second region, the change yaw angle within 4 and 10 degrees will produce the big variation of up to ±8 %. These data also agree with the study of Leland [4].

From the equation (1), the accuracy measurement of the S pitot tube coefficient only depends on the standard air speed system, the instrument indicating the differential pressure of S pitot tube and the measurement data. The measurement error is calculated as follows:

$$\delta C_{pS} = \left[(\delta W_{std})^2 + (\delta \Delta P)^2 + (\delta M_d)^2 \right]^{0.5}$$

where δW_{std} is error of the standard system, $\delta\Delta P$ is error of the different pressure instrument and δM_d is the standard deviation of measured data.

The uncertainty analyses from present experimental data show that the S pitot tube coefficient can be obtained to the accuracy ± 1.3 %.

To understand flow phenomena around the S pitot tube as yaw angle misalignments happen, numerical simulations (computational fluid dynamics) were conducted. A commercial computational code, ADINA was used for solving 3 dimensional Reynolds-Averaged Navier-Stokes (RANS) equations. Computational domain is test section of wind tunnel (30D × 30D × 180D) attached the S pitot tube as shown in Figure 6, where D is distance between impact and wake orifice surface. 875,500 unstructured mesh based tetrahedral elements were applied in the whole of computational domain. Spalart-Allmaras model (DES model) was used to model the turbulence in present simulations. Pressure distributions and velocity vectors around the S pitot tube inside the test section of wind tunnel are shown in Figure 7.

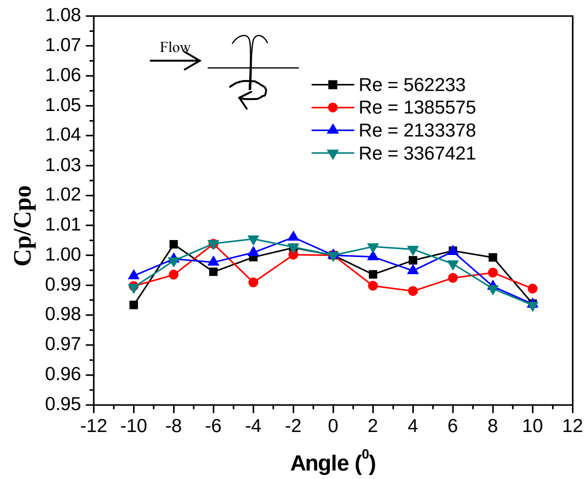

Figure 4. Pitch angle misalignment effect

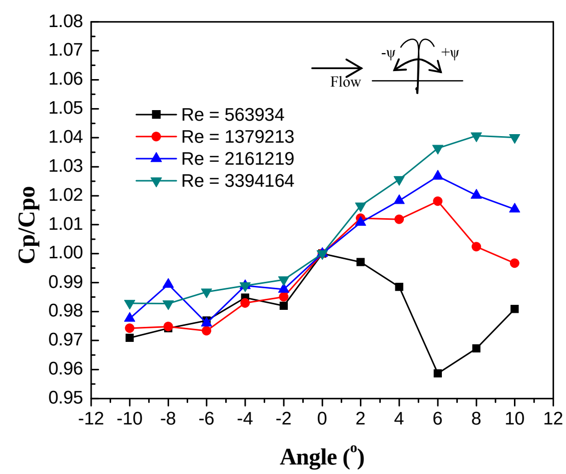

Figure 5. Yaw angle misalignment effect

Pressure distributions are normalized versus the dynamic pressure $(P - P_o)/(\rho U_o^2)$, where P_o is upstream pressure, P is downstream pressure, and U_o is upstream velocity.

The simulation results indicate that high positive pressure appears in the area near impact orifice and negative pressure appears near wake orifice. Vortical structure is generated between impact and wake orifice due to geometrical characteristics.

The pressure distribution and velocity vectors with misalignment installation of S pitot tube at yaw angle of +10 degrees and -10 degrees are illustrated in Figure 8. At yaw angle of -10 degrees, vortex grows up around the wake orifice making a decrease of the pressure around wake orifice and coefficients value.

At yaw angle of +10 degrees, incoming flow separated on the upper edge of impact orifice strongly due to the tilt of S pitot tube. Vortex becomes dramatically large at the region

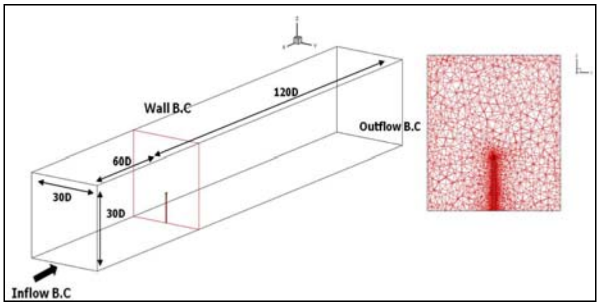

Figure 6. Computation domain and mesh

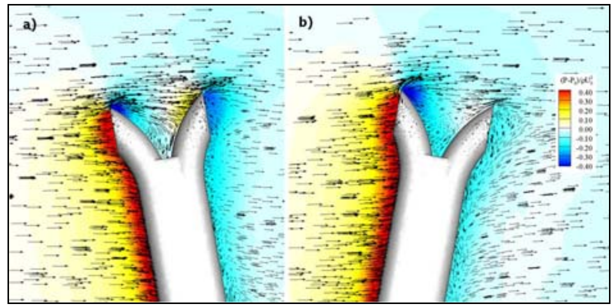

Figure 8. Pressure distribution and velocity vector with misalignment installation, a) yaw angle = -10 degrees b) yaw angle = +10 degrees

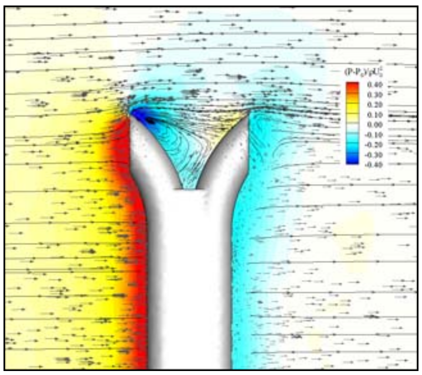

Figure 7. Pressure distribution and velocity vector around S pitot tube at upstream velocity of 7 m/s

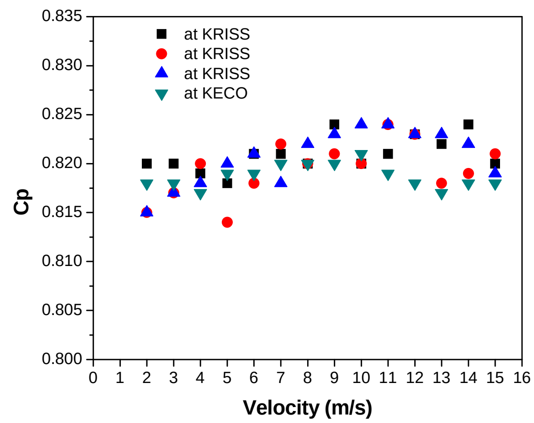

Figure 9. The variation of S pitot tube coefficient curve follows velocity

close to the impact orifice and in inverse relationship to the wake orifice.

Negative pressures near the wake orifice recover more rapidly in comparison with the yaw angle of 0 and –10 degrees. Differential pressures between impact and wake orifice decrease. Consequently, S pitot tube coefficient must have value at yaw angle of +10 degrees larger than at yaw angle of 0 degree and -10 degrees.

Reynolds number effect: Reynolds number is one of factors that characterises the property of the flow stream and the frictional losses in the flow around any obstruction in the flow stream.

When the velocity of the wind tunnel system varies, Reynolds number changes simultaneously. So that, Reynolds number effect can be evaluated indirectly through the variation of velocity.

The variation of coefficient value of the same S pitot tube over two different wind tunnel system is showed in Figure 9. The usage of two separate velocity sources made no longer a big difference in the S pitot tube coefficient.

In the range of velocity from 2 m/s to 15 m/s, it only yields the tolerance of up to ±1 % in coefficient values. However, the change of velocity makes the S pitot coefficient curve fluctuated.

4. CONCLUSIONS

To study factors effect on the S pitot tube, the S pitot tubes manufactured by ISO 10780 [3] were tested in the standard air speed system to study factors that effect on the S pitot tube coefficient. The conclusions are as follows:

1. Misalignment interferences to the S pitot tube coefficient at $4.3 \times 10^5 < Re <$ to 3.4×10^6 are ± 2 % with pitch angles up to ±10 degrees and ± 4 % with yaw angles smaller than 4 degrees. For yaw angles larger than 4 degrees, there are drastic changes in S pitot tube coefficient.
2. The trend of coefficient curve oscillates more strongly at low range of Reynolds number than larger one. The fluctuated modulation is about ± 1 %.
3. Most of the coefficient values for the S pitot tube in this study are 0.81 or 0.82 which is smaller than suggested value of 0.84 ± 0.01 in ISO 10780 [3].
4. Between the S pitot tubes having the same condition; their coefficient values have a tolerant band from 2 % to 4 %.

5. REFERENCE

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