Flow Measurement in Large Ducts & Pipes

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ABSTRACT

Flow measurements in very large pipes and ducts and the establishment of associated measurement accuracy is a challenging task. Flow meters if any installed in such cases will be very large, complicated and costly. The calibration or verification at their installed condition is even more complex. With the hunger for more power, energy and fluid transportation on the increase, the related cost implications have become substantial. Hence there is ever larger requirement for precise measurement and subsequent verification of the quantity on the move. While quality assurance through Laboratory calibration would be the ideal solution, this is not always possible due to reasons of size, space, set up cost etc.

Among the several methods practiced for onsite flow verification of large ducts and pipes, velocity-area integration method is fairly established. Summing up, of the product of velocities and the applicable areas of its prevalence, over the entire cross section, would give the total flow.

This paper describes some general Industrial practices, their applicability, reliability and related issues. General problems encountered, accuracy, re-calibration methodologies etc. are discussed. Developmental aspects of a new versatile foldable pitot are also described.

Key words: Flow measurement, Large duct, Multipitot.

1. INTRODUCTION

Averaging pitot static tube, Aerofoil, array of pressure / thermal probe etc. are generally employed for flow measurement in large pipes and ducts. Many installations have very short straight lengths prior to the meter and do not satisfy the conditions helpful to offer good and dependable results. Significant flow velocity profile distortions generally occur in these cases. Flow rate variations made for process requirements drastically alter the flow pattern, thereby adding to the uncertainty.

Due to restricted availability of essential straight lengths, absence of periodic maintenance in difficult working environment and significantly because of the lack of calibration at operating conditions, the measurement accuracy is very coarse. The calibration constants that are provided by the device supplier during installation may be far from the true prevailing value due to several factors including the installation conditions. The estimated error in flow can be significant.

The solution is an onsite calibration of these primary sensors at their installed conditions to determine the correct associated constants and its subsequent use. This, though ideal, poses a host of problems of implementation in industrial practice. As a partial solution, attempts made by FCRI in practicing velocity-area integration technique will be described in this paper.

2. SOME COMMON DEVICES

Power plants, chemical industries, Fertilizer plants, Pneumatic conveying system etc. employ different types of flow measurement methods depending on convenience, inherent design availability, constrains etc. Once fitted, they remain without much disturbance and attention and their outputs are taken at face value.

2.1 Aerofoil– This consists of a suitably shaped obstruction in the duct and is mostly employed in Rectangular and Square cross section ducts. Two pressure taps emerge from the unit, which furnish High & Low pressures readings detected from the designated location of the profile as shown in Fig. 1. The high pressure impulse is obtained from the leading tip and low pressure is taken from a point lower down in a low pressure region.

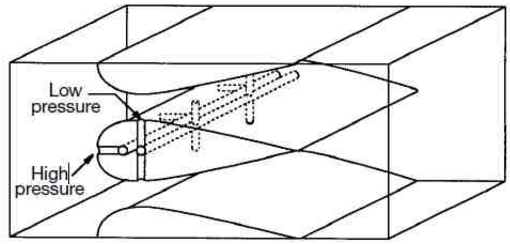


Fig. 1 Aerofoil Pressure ports

Sometimes an array of thinner aerofoils spread across the cross section is used. In some designs, one full and two half sections are attached to the duct section. Some typical commercial configurations are shown in Fig. 2.

When more than one aerofoil are assembled together to a common manifold, they give an average of both high and low pressures together. .

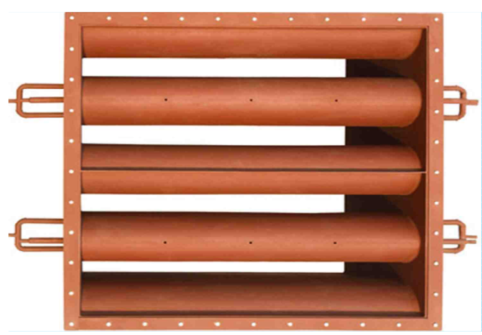


Fig. 2 Some typical designs

In the case of large ducts, several units of aerofoils arrays are used parallel. Each aerofoil section may have several holes at the leading and trailing planes. These will be fed to individual manifolds. Ultimately all the high tappings will be joined together to a common High pressure port and similarly for the case with the low port. These two are connected to a DP measuring instrument to get the differential pressure value. Static pressure is separately measured from the low pressure port along with a temperature sensor in some installations were mass flow rate is important.

2.1.1 Common problems: The flow rate is computed based on the velocity estimated from the DP detected by the aerofoil and the duct cross section area. A single constant in general or multiple constants are included in the flow computation equation by the manufacturer. The most significant of these is the correction factor (flow coefficient) which quantifies the flow rate. The biggest contributor of the estimation of error is in this factor. Accurate assignment of the factor by the manufacturer is of utmost importance.

<u>2.2 Averaging Pitot Tubes, Multiple thermal meters, nozzles, orifices etc.</u> - Some designers of large duct flow metering installation rely on measurement of velocity at a few specific points in the duct. Fig. 3 shows a few of such installations. These are then converted into a summarized flow figure after including the area of cross section.

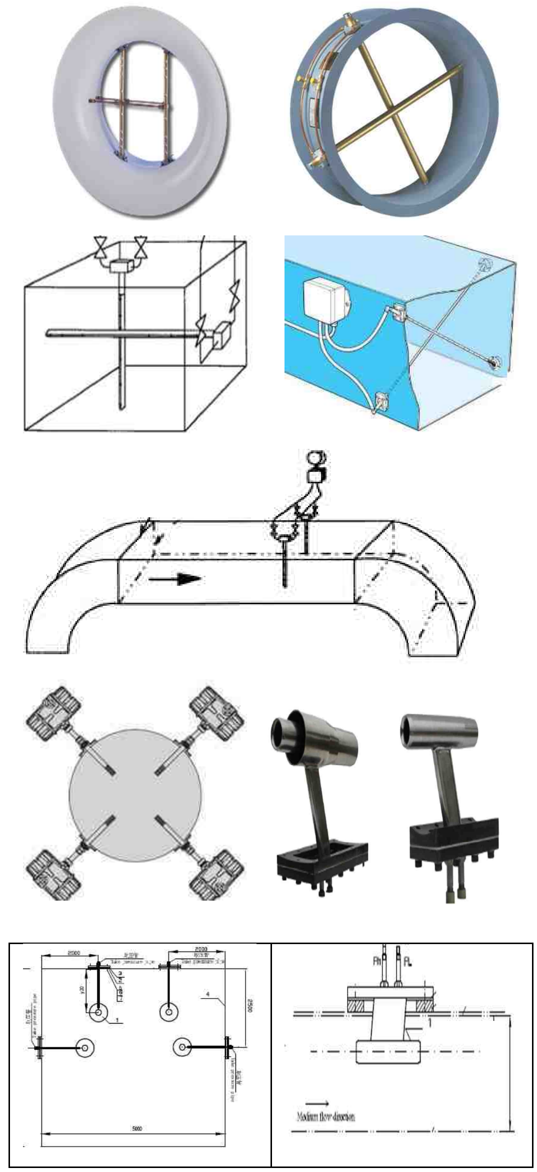


Fig. 3 Industial Installations

Here also a single or several factors (coefficient) are used and mostly a second order equation is used to predict the flow from the measured DP. Field verification of such factor is seldom done and the assigned values are used as such till a problem arises.

2.2.1 Common issues: In reality, the meter factor (coefficient) values are given purely based on theoretical assumptions or from past experience only and not from any real calibration in the field. This is mostly due to the sheer size and absence of facilities and knowhow to obtain reference flow for such large flow conditions. Estimation of flow is complicated by the configuration of the preceding and succeeding pipeline layout, positioning of valves and damper, bends, cross section changes, elevation height etc. In addition, corrosion and erosion alters the shape of the primary element and size of the pressure taping holes. Blockages, dirt, ruptures inside the duct etc. also contribute to wrong DP measurement. The differential pressure is the vital parameter and most essential input for proper flow computation. Correct assessment of the DP is also an instrumentation issue.

3. MEASUREMENT AT SITE

3.1 Reference system

The underlined point is that periodic in situ calibration of such devices are most essential to obtain a credible flow meter reading. This is possible only with use of a portable reference system that generally does not require much straight lengths and whose calibration does not change with duct sizes. 'L' type Pitot Static Tube is a practical and ideal equipment for point velocity measurement and is used in general, but requires a traversing within the measurement plane in order to get the average pipe velocity. ISO 3966 [1] recommends the minimum number of points required for circular and rectangular ducts. With this method, the accuracy of the flow measurement is very dependent on the location of the velocity measurement points in the duct section and the velocity profile. Very reasonable results can be obtained subject to flowing conditions.

3.2 Velocity Integration

This method needs a large number of measurement points to be investigated to get a sufficient accuracy level. Summing up, of the product of velocities and the applicable areas of its prevalence, over the entire cross section, would give the total flow In very large pipes and ducts of size say 1000 mm and more, traversing is tedious and takes prolonged time within which time, flow itself can change significantly there by creating a biased measurement output. Flow induced vibrations, due to cantilever action of the probe, causing heavy fluctuations in differential pressure, is also a big concern. The individual velocity is calculated for each pressure reading and then averaged together to get the mean duct velocity. Incorrect results may be obtained by this way especially when the flow disturbances are very high. For a pitot static tube, velocity is proportional to the square root of differential pressure and hence the significance of accurate DP information. Proper tuning of the DP measuring devices is always emphasized.

3.3 Single point measurement

Laborious velocity integration can be substituted by simpler methods at the cost of accuracy. Several techniques and Methods are available.

3.3.1 Measurement at the point of mean axial velocity[3].

ISO 7145 says – "Wherever possible, and in particular if the indication given by the primary device is unaffected by the transverse gradient of velocities and if the straight length available upstream of the measuring plane is sufficient, the measurement shall be made at a point where the local velocity is assumed to be equal to the mean axial velocity".

For this purpose, the primary device shall be installed at a distance of 0,242 R from the internal wall of the conduit with a tolerance of less than ± 0,01 R, this distance being calculated with respect to the diameter on which the primary device is installed and not with respect to the mean diameter of the conduit.

3.3.2 Measurement on the axis of the conduit[3].

ISO 7145 further says – "If the primary device does not provide the required accuracy in view of the transverse gradient of velocities, or if its dimensions do not satisfy the requirements of 4.3.2 (of the standard) for a measurement at the point of mean axial velocity, or again if the straight length available is between the values appearing respectively in the two columns of the table in 4.1, it is still possible to measure the flow by placing the primary device on the axis of the conduit. However, it is then necessary to carry out calibrations by previously determining the **ratio of the mean axial velocity to the velocity at the Centre**".

"This ratio in principle remains constant throughout the entire area of rough turbulent conditions. It is however recommended, wherever possible, to verify it by carrying out this calibration for two or three conditions that differ as widely as possible and covering the range of flows considered".

Calibration can be obtained either by measuring the velocity at the point of mean axial velocity as indicated in 4.4.1(of the standard) or by using any other standard method of measuring flow rate which has an uncertainty of less than ± 2 %. The accuracy of the subsequent flow measurements will depend directly on the accuracy of the method of flow measurement used for calibration purposes.

3.3.3 Measuring in the center of the duct[4].

Application note AF-106 (A4) explains an other practice to take a single measurement at the center of the duct and multiplying the reading by 0.9 to correct for the higher velocity at the center of the duct. An accuracy of about ±10 percent can be obtained this way. This method is not dependable, but may only be used in small duct size, in a fully developed turbulent velocity profile condition or conditions do not permit a full traverse”.

From the considerations on the methods cited in section 3.3 above we can see that accuracy is compromised if comprehensive velocity area integration is sought to be avoided for the sake of convenience.

4. Velocity Integration &Duct shape

4.1 Traversing in a circular Duct

Isabelle Caréett. et al. 4] have explained elaborately about Measurement of air flow in duct by velocity measurements. In one of the techniques, using the log-Tchebycheff method, the duct measurement section is divided into concentric circles of equal area as shown in Fig. 4.

An equal number of readings is taken from each circular area, thus obtaining the best average. Commonly, three, four and five concentric circles (6, 8 and 10 measuring points per diameter) are used depending on the duct size. Additional points also are considered depending on the velocity profile distortion. Measurements must be made with Pitot tubes with proper calibration and established multiplication factor . Various designs of standard pitot tubes are described in reference 1.

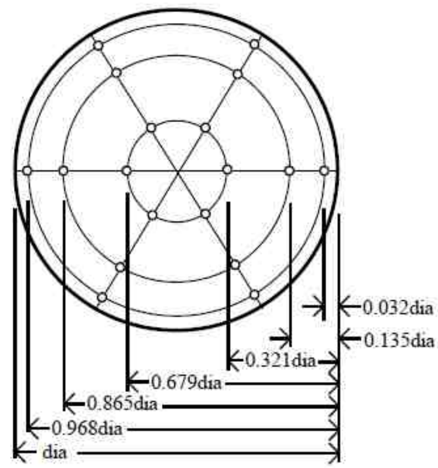


Fig. 4 Circular section

#of Measuring Points Per Diameter	Position Relative to Inner Wall
6	0.032, 0.135, 0.321, 0.679, 0.865, 0.968
8	0.021, 0.117, 0.184, 0.345, 0.655, 0.816, 0.883, 0.979
10	0.019, 0.077, 0.153, 0.217, 0.361, 0.639, 0.783, 0.847, 0.923, 0.981

Table 1

By multiplying with the numbers in the Table 1 with the duct diameter we get the insertion depth for the probe tip center. Inside dimension of the duct shall be considered for all measurement references.

4.2 Traversing in a Rectangular or Square Duct

In case of rectangular or square ducts, the duct is divided into rectangular areas, which are further adjusted in size to account for effects of the duct wall on the airflow. A minimum of 30 points must be measured in order to get a good average. The number of data points to be taken along each side of the duct depends on the duct size. More points need to be considered in the case of higher velocity profile distortion. Fig. 5 shows the locations in a rectangular duct.

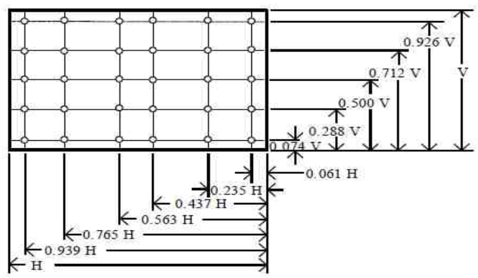


Fig. 5 rectangular section

By multiplying with the numbers in the Table 2 with the duct size provides the insertion depth for the probe tip center.

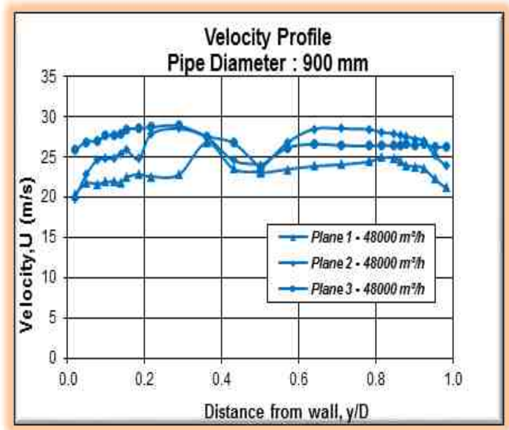
# of Points or Traverse Lines per Side	Position Relative to Inner Wall
5	0.074, 0.288, 0.500, 0.712, 0.926
6	0.061, 0.235, 0.437, 0.563, 0.765, 0.939
7	0.053, 0.203, 0.366, 0.500, 0.634, 0.797, 0.947

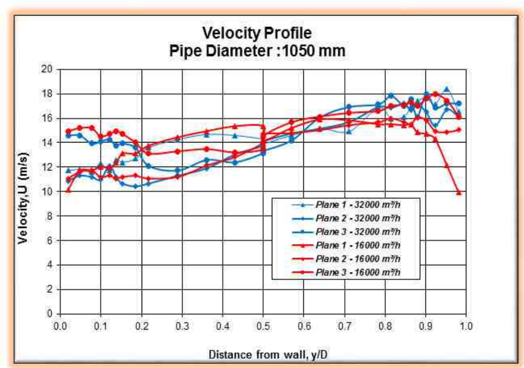
Table 2

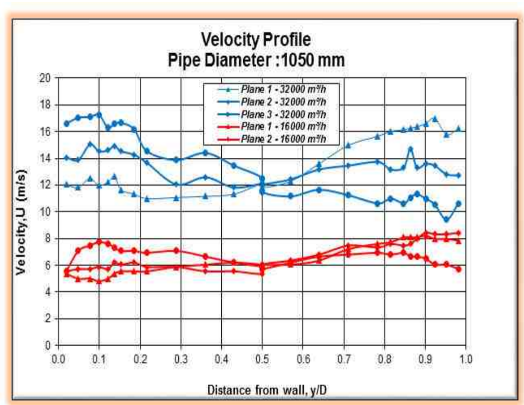
5. FIELD EXPERIANCE.

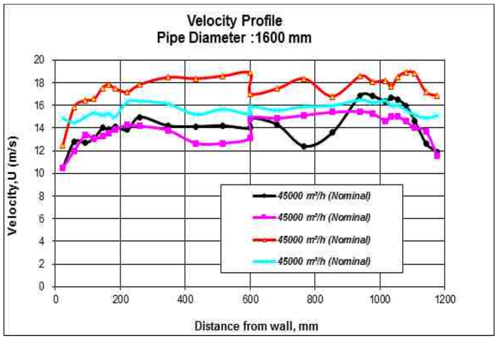
FCRI has encountered several issues with on site calibrations of different installations and sensor types. Self-averaging pitot static tubes, Nozzles, Aerofoils etc. are some among the host of meters calibrated at site by FCRI. A few of them were installed in circular cross sections and Aerofoils were in rectangular cross section. The calibrations were done by traversing of ‘L’ type pitot static tube method. Additional number of points than those mentioned in ISO 3966 were taken to mathematically manage distorted turbulent velocity profile . A few of the velocity profiles in circular cross sections is given in Fig. 6 and in rectangular cross section is given in graphs below..

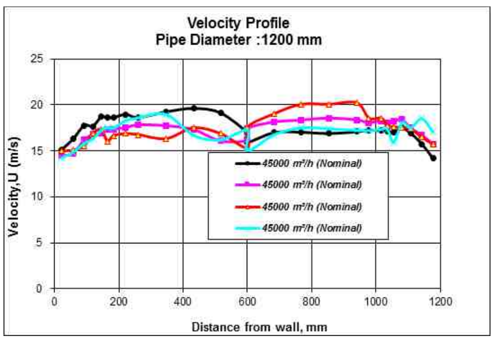
Velocity profiles encountered in a circular cross section.

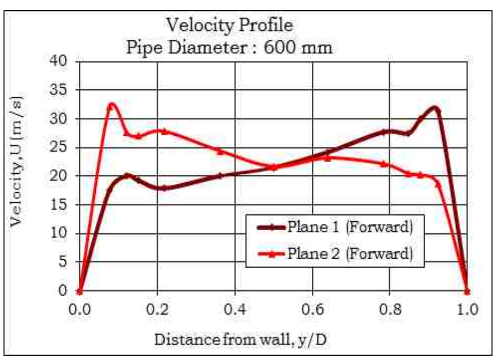


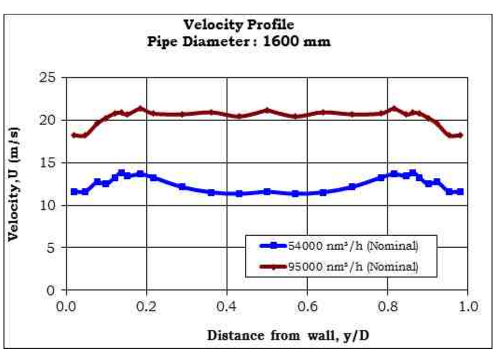




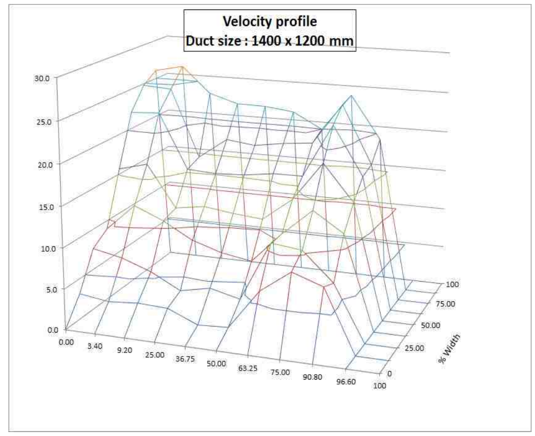


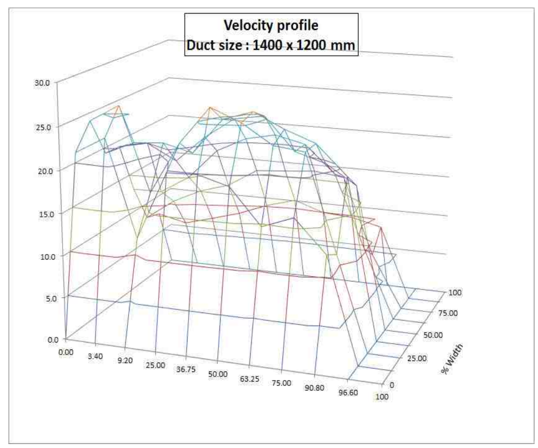


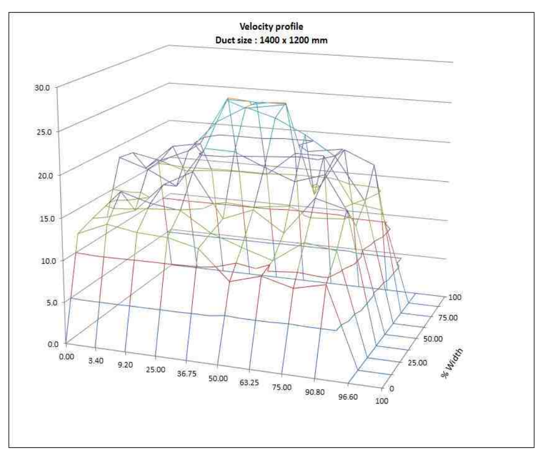


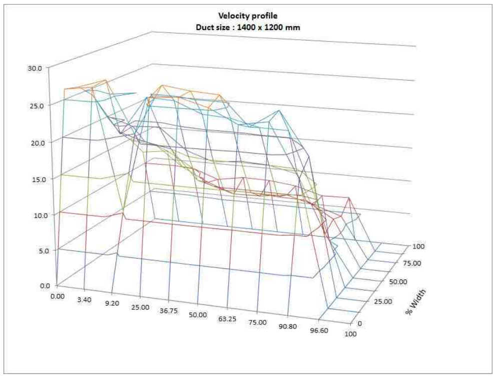


Velocity profiles in a rectangular cross section under different conditions.









6. PRACTICAL ISSUES

The above patterns are a few of the examples for the velocity profile distortions in large size ducts. This only emphasizes the need for proper reference flow estimation in such cases. For a given condition, extensive velocity area integration can give the closest approximation to the actual flow with its associated uncertainty. Depending on the shape and size of the duct the entire measurement could take hours. Though all the associated systems are put under manual control and kept unchanged during the measurement, still some marginal variation in flow condition does occur during measurement process. It is difficult to judge whether the process condition changes or velocity profile distortions have occurred in the period

An alternative method to avoid time consuming and laborious probe traversing is fixing/employing regular pitot static tubes at the specified points as per standard and scanning the pressure signals. This can shorten the overall time required and minimize the total measurement process difficulty. Fig. 8 shows such a probe developed at FCRI and tried in the field successfully. This particular case involved positioning of 9 pitot in a single go.

Another advantage of this Multi pitot is the feasibility to calibrate each probe head independently in a wind tunnel. Al the dimensions can be maintained as per standards except the stem. Performance of laboratory calibration will compensate for the deviations of stem dimensions. Multipitot is a very promising solution in many specific cases. FCRI has carried out several optimized site measurements with Multipitot.

Fig. 8 Multipitot

7. A NEW CONCEPT.

Multiple pitot configuration helps to take a number of measurements in one go with the help of a scanner and a single set of DP sensor. This results in substantial savings of time, effort and revenue. But this method is also has some drawbacks. The multiple pitot need a larger rectangle opening in the duct to permit the entry / exit of the stem and the protruding heads.

A small circular cut or opening is many times more convenient than any large rectangular opening on an industrial scenario. Yawing, blanketing and stuffing of the joint will be a lot simpler with a circular probe. Obviously, Multipitot needs to be improved to make it further more utilitarian. The probe stem has to be circular in cross section and the protruding pitot heads need to be re designed.

A new version of probe is under development in FCRI which comprises a set of standard pitot head fitted to a circular stem pipe. The specialty is that the head can be folded, opened and closed (perpendicular to stem and parallel to stem) as desired. A smaller circular cut in the flowing Duct with a simple gland/stuffing box will assist the entry of the stem with all the pitot heads folded along into the stem pipe. When once fully inserted into the duct, all the pitot can be opened up perpendicular to the flow.

Readings can be taken from all the ports as done in the Multi pitot earlier described. Once readings are taken, the pitots can be folded back into the stem tube in an action similar to a folding pen knife. This can be conveniently retracted through the glands and re-positioned into the next traversing section.

The actuation of the probe tips to the "end – on" position with respect to fluid flow will be effected employing quarter turn actuator or stepper motors. Individual calibration of each of the pitot is possible in a designated wind tunnel which will provide the traceability. Pilot studies are under way at FCRI.

8. CONCLUSIONS

Various systems for flow measurement in large pipes and ducts were discussed. Velocity profiles distortions and methods to get good reference flow were highlighted. Practical issues, use of Pitot tube array and future modifications and developments in Multipitot are also discussed.

9. REFERENCES

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