ORIFICE METER TUBE DIMENSIONAL TOLERANCES
Class # 7020.1

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Introduction

The orifice meter is the most predominantly utilized device for measurement of natural gas. It's dominant presence in the natural gas industry stems from many years of acceptance as the primary means for accurate measurement. In 2000, revised manufacturing and inspection standards, along with new technology for flow enhancement have improved the overall accuracy of orifice metering. Though other measurement devices and technologies have made significant impact, the orifice meter offers stands as the dominant device for several reasons:

- Rugged construction that stands up to many applications
- No moving parts involved in the measuring process
- Relatively inexpensive to manufacture and maintain
- Proven and accepted technology
- Dimensional calibration is accepted in lieu of flow calibration

Proper design / testing procedures and accurate determination the actual dimensions of an orifice meter is key to ensuring that the device performs with minimum uncertainty.

The American Gas Association and American Petroleum Institute have developed the criteria for design, testing and inspection of orifice meters as provided in the AGA Report No. 3, Part 2 and API 14.3.2, Specification and Installation Requirements. This paper will address the design, testing and calibration procedures in compliance with these standards, herein referred to as AGA / API standards.

The Primary Device

The orifice meter includes the primary device that consists of the orifice fitting, adjacent piping and the flow conditioning device, if used, otherwise know as the meter tube. The secondary device(s) is the associated measurement instrumentation used in conjunction with the meter tube. This paper will address the primary device.

The AGA / API Standards allow a range of dimensions and tolerances for many aspects of the meter tube and are a function of Beta Ratio. This being the ratio of the orifice plate bore diameter to the diameter of the meter tube, or may be express as the percentage of the meter tube diameter. The meter tube criteria should be based on .75 Beta Ratio which involves the longest meter tube lengths, most stringent tolerances and allows a design that can be utilized for the maximum throughput capacity of the meter tube. Effectively, the largest orifice plate bore size should be limited to 75% of the diameter of the meter tube. This will be the basis for the dimensional tolerances discussed below.

Orifice Fittings

The orifice fitting is the heart of the meter tube. It provides two or more sets of pressure taps for instrumentation installation and measurement of the line pressure and differential pressure created by the orifice plate. The orifice fitting provides the means to center the orifice plate in the flow stream while allowing efficient installation and inspection the orifice plate. The orifice fitting is the location where the meter tube diameter is determined which will be discussed further below.

Due to the geometry of the orifice fitting body, it is normally manufactured using a sand molded steel casting. Before the orifice fitting becomes part of the meter tube, it is subjected tests to check for the integrity of the casting and manufacturing / assembly process.

Upon completion of the machining process, the body is to be hydrostatically tested to 1.5 x maximum working pressure. This first test is conducted as the most practical method to verify that the body is sound and is suitable for meter tube manufacture. The second reason the body is tested to induce any stress that could change dimensions within the orifice fitting body as a result of the pressure testing. This means that any inspection or other testing will take place after stress is applied to the body and provides for more accurate dimensions.

Upon completion of the hydrostatic testing, the orifice fitting pressure taps are inspected for integrity. The tap hole is sealed on the interior of the orifice fitting and a vacuum is applied form the exterior of the body. If the vacuum test holds without leaking, the tap hole is considered sound. These tests should be applied to all tap holes to ensure that there is no porosity between the high and low pressure taps and no communication exists between these critical pressure measuring points.

<u>Orifice Fitting Tolerances and Inspection</u>
The tap holes described above, known as “Flange Taps” are to be located 1” from the respective upstream and downstream face of the orifice plate. This measurement is the centerline of the tap hole to the orifice plate face. As stated above, the tolerance is provided in a range based on meter tube size and Beta Ratio. Using the .75 Beta criteria, the maximum deviation from 1” location is:

2” – 3” meter tubes = +/- .015”
4” and larger meter tubes = +/- .035”

There are a various inspection methods that include direct reading, specialty tap hole gauges, go-no go gauges and comparison bars.

<u>Eccentricity</u>

The orifice plate bore must be centered concentrically within the orifice fitting or meter tube. Special care is taken to ensure that the alignment process and repeatability occurs when installing an orifice plate. There is little margin for error using the 0.75 Beta tolerances provided in Table 2-6 of the AGA / API Standards. Below is the example based on the .75 Beta tolerances from the AGA / API Standards:

Maximum Tolerance of Orifice Plate Bore Eccentricity

		Internal Diameter					
	Bm	2.067	3.068	4.026	6.065	7.981	10.020
Eccentricy Tolerance	0.75	0.006”	0.009”	0.012”	0.018”	0.024”	0.030”

$$\text{Basis (Bm 0.75):} \quad E \leq \frac{0.0025\ Dm}{0.1 + Bm^4}$$

Another consideration in the orifice fitting is the orifice plate sealing mechanism. There are specifications detailed in the AGA / API Standards that define the tolerances and restrictions for orifice plate seals. There are orifice fittings available that are not designed in compliance with the current edition of the AGA / API Standards. The seal design is the primary reason for non-compliance and it is specifically the responsibility of the orifice fitting manufacturer to comply, or not. This paper will only address the seal testing requirements in the Meter Tube section.

<u>Meter Tubes</u>
The purpose of a meter tube is to determine the primary meter tube diameter. This will be used in determining flow rate and to provide adequate length, along with conditioning devices, to correct undesired flow conditions and to provide a flow profile conducive to accurate measurement. The design and construction of the meter tube involves applying the proper meter tube length requirements, selecting meter tube pipe that will comply with the roundness tolerances and surface finish requirements, removal of any abrupt changes due to welding, seams or inconsistencies, and performing diameter inspection (calibration).

<u>Meter Tube Pipe</u>

The AGA / API Standards have stringent requirements for surface finish and roundness tolerances. Typical pipe found in pipe supplier's inventory generally will not meet both of these requirements on a consistent basis. Therefore, a select group of suppliers make a specialty, cold drawn tubing or provide pipe that is produced to tighter specifications or is conditioned to improve these tolerances. Which is normally achieved by honing the pipe to final dimension. The honing process also provides a very smooth finish.

<u>Meter Tube Lengths</u>

Selecting the proper meter tube length is key to minimizing the adverse flow conditions that are caused by elbows, fittings and valves upstream of the meter tubes. As gas passes through these bends and restrictions, the flow is turbulent, has a swirling effect resulting in an undesirable flow profile. The objective of the meter tube is to reduce these adverse conditions and to attain a fully developed flow profile that resembles the form of a bullet, as it approaches the orifice plate. In order to achieve the flow profile objective, the AGA / API standards provide recommended meter tube minimum lengths. These are the upstream and downstream length of meter tube preceding the orifice plate and following the orifice plate. Within this area, there should be no branch connections or devices installed other than flow straightening vanes or flow conditioners. Table 2-7, below is an example of the minimum meter tube lengths without the use of flow conditioners.

Table 2-7—Orifice Meter Installation Requirements Without a Flow Conditioner

	Minimum Straight Unobstructed Meter Tube Length from the Upstream Side of the Orifice Plate (in multiples of published internal pipe diameter, D_i)										
Diameter ratio β	a. Single 90° elbow. b. Two 90° elbows in the same plane with $S > 30D_i$. c. Two 90° elbows in perpendicular planes with $S > 15D_i$.	Two 90° elbows in the same plane "S" configuration spacer $S \leq 10D_i$	Two 90° elbows in the same plane, "S" configuration $10D_i < S \leq 30D_i$	Two 90° elbows in perpendicular planes, $S < 5D_i$*	Two 90° elbows in perpendicular planes, $5D_i \leq S \leq 15D_i$	Single 90° Tee used as an elbow but not as a header element	a. Single 45° elbow. b. Two 45° elbows in the same plane "S" configuration $S \geq 22D_i$	Gate valve at least 50% open	Concentric reducer	Any other configuration (catch all category)*	Downstream meter tube length
	UL	UL	UL	UL	UL	UL	UL	UL	UL	UL	DL
≤ 0.20	6	10	10	50	19	9	30	17	6	70	2.8
0.30	11	10	12	50	32	9	30	19	6	108	3.0
0.40	16	10	13	50	44	9	30	21	6	145	3.2
0.50	30	30	18	95	44	19	30	25	7	145	3.5
0.60	44	44	30	95	44	29	30	30	9	145	3.9
0.67	44	44	44	95	44	36	44	35	11	145	4.2
0.75	44	44	44	95	44	44	44	44	13	145	4.5
Recommended length for maximum range β ≤ 0.75	44	44	44	95	44	44	44	44	13	145	4.5

UL = Minimum meter tube length upstream of the orifice plate in internal pipe diameter (D_i)(see Figure 2-6). Straight length shall be measured from the downstream end of the curved portion of the nearest (or only) elbow or of the tee or the downstream end of the conical portion of reducer or expander.

DL = Minimum downstream meter tube length in internal pipe diameters (D_i)(see Figure 2-6).

S = Separation distance between piping elements in internal pipe diameter (D_i) measured from the downstream end of the curved portion of the upstream elbow to the upstream end of the curved portion of the downstream elbow.

* These installations exhibit the strong effect of Reynolds number and pipe roughness on the recommended length due to the rate of swirl decay. The present recommendations have been developed for high Reynolds numbers and smooth pipes to capture the worst case.

Note: The tolerance on specified lengths for UL and DL is ± $0.25D_i$.

<u>Meter Tube Calibration / Tolerances</u>

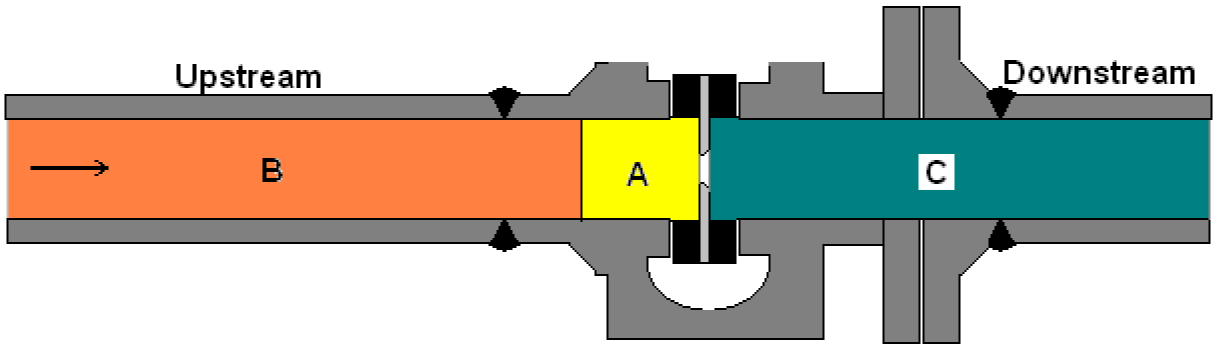
After the meter tube pipe is welded to the orifice fitting, all welds are ground and/or honed to eliminate abrupt changes in diameter and create a uniform transition between the pipe and fittings. Upon completion of the manufacturing process, a hydrostatic pressure test is performed to verify the integrity of the welds. This is done prior to dimensional checks or calibration to account for any expansion resulting from the testing process, as done during the manufacturing of the orifice fitting.

Calibration

The first step in the calibration process is to establish the reference dimension or mean meter tube diameter. The meter tube diameter is determined by taking a minimum of four (4) (or more) measurements. These (4) measurements, spaced at equal points around the perimeter of the orifice fitting, are located at the upstream pressure taps, or 1” upstream of the orifice plate. The average of these four or more measurements (Dm) become the **Measured Meter Tube Diameter**, and is the reference diameter for all other measurements of the meter tube. The temperature of the meter tube at the time of calibration is recorded and corrected to referenced temperature, generally accepted as 68 Deg F, where no thermal expansion occurs (Dr). This final dimension will be utilized in the secondary instrumentation to determine flow rate.

FIGURE 1

METER TUBE DIAMETER TOLERANCES



A - First Upstream Pipe Diameter = Any Diameter ≤ 0.25% Dm
B - Upstream of 1D = Max - Minimum = ≤ 0.50% Dm
C - Downstream = ± 0.50% Dm

Uniformity

First Diameter Tolerances:
Within the first diameter preceding the orifice plate (Figure 1-Section A), the maximum and minimum measured dimensions must all be within 0.25% of the mean diameter. In many cases, this area is within the orifice fitting and is easily attained in the machining process. However, in larger sized meter tubes, this first diameter may include the upstream section where the meter tube pipe is welded to the orifice fitting. For these larger sizes, the grinding or honing process is critical to attain this level of uniformity.

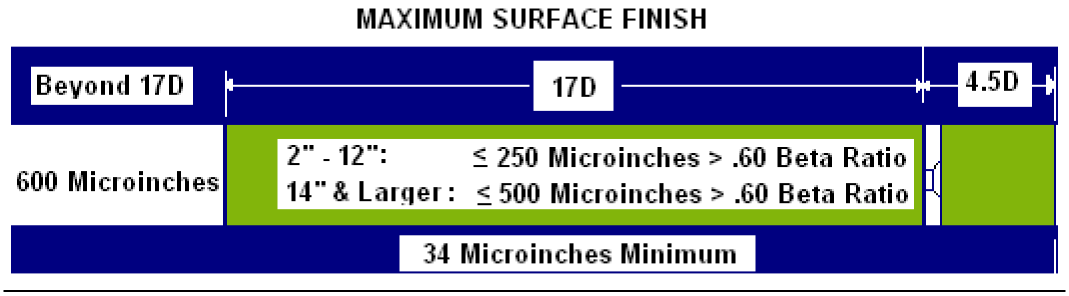
Upstream Tolerances, Beyond First Diameter:
The remaining upstream meter tube beyond the first diameter (Figure 1-Section B), the difference between the maximum – minimum shall agree with the mean diameter (Dm) within +/- 0.50%. This is a total tolerance allowed for the largest – smallest measurement taken in any plane over the entire length of the upstream meter tube section.

Downstream Tolerances
Within the downstream section following the orifice plate (Figure 1-Section C), the maximum and minimum measured dimensions must all be within 0.50% of the mean diameter.

The Figure 1, B & C dimensions are made to verify uniformity of the entire length of meter tube but do not become part of the mean meter tube diameter.

Surface Finish

The surface finish requirements are listed in the sketch below and are a function of meter tube diameter and based on beta ratios above 0.60 to satisfy our design criteria of B= .75.
It is not practical to visually determine the surface profile of a surface. Therefore, the use of an electronic surface profile instrument is used to make the determination of the actual finish.



Documentation

The results of the dimensional and surface measurements are logged onto a calibration report and are provided with the meter tube for determination of mean meter tube diameter, verification of uniformity and compliance with the AGA / API Standards.

Conclusion

The intent of the properly designed and manufactured meter tube is to provide a primary device that is dimensionally consistent throughout and is accurately defined relative to the actual dimensions manufactured. Adhering to the tolerances discussed herein is critical to accurate measurement with minimal uncertainty.

References:

AGA Report No 3, Part 2 – Specifications and Installation Requirements, Fourth Edition, 2000

American Petroleum Institute - API 14.3.2, 2000