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Advances in Thermal Dispersion Mass Flow Meters

Part 2: Installation and Flow Calibration

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Abstract

Part 1 of this two-part series describes the principle of operation of a new microprocessor-based thermal dispersion mass flow meter that uses four temperature sensing elements in its flow sensor and has a dry velocity sensor. Part 1 shows how this unique system provides automatic management of changes in gas selection, gas temperature, gas pressure, and outside temperature. This Part 2 describes advances in the installation and flow calibration of thermal dispersion mass flow meters, including a built-in flow conditioner for in-line flow meters that greatly reduces upstream straight-pipe requirements and a high-performance flow calibration facility that accommodates a range of gases, temperatures, and pressures.

Introduction

For over forty years industrial-grade thermal dispersion mass flow meters have solved the wide range of general industry's needs for directly measuring the mass flow rate of air, natural gas, and other gases in pipes and ducts in rugged industrial applications. Thermal dispersion mass flow meters measure the heat convected into the boundary layer of the gas flowing over the surface of a heated velocity sensor immersed in the flow. Since it is the mass-bearing molecules of the gas that carry away the heat, thermal dispersion mass flow meters directly measure mass flow rate. In acknowledgement of the wide acceptance of thermal dispersion mass flow meters for industrial applications, the American Society of Mechanical Engineers (ASME) has published a new national standard for this kind of flow meter [1].

Figure 1 shows the two primary configurations of thermal dispersion mass flow meters: in-line and insertion. The flow sensor of both configurations has a heated velocity sensor and a separate temperature sensor that are mounted side-by-side in rugged stainless-steel tubular sheaths and immersed in the flow stream. This kind of robust construction is responsible for transforming the predecessor light-duty thermal anemometer [2] into an industrial-grade flow meter.

Traditional thermal dispersion mass flow meters have two temperature sensing platinum RTD elements, one electrically self-heated element in the tip of the velocity sensor and one in the tip of the temperature sensor that measures the gas temperature T. Typically both elements are potted into their sheaths with a potting compound, such as ceramic cement or epoxy. The sensor drive in the transmitter electronics delivers an electrical current I_1 to the velocity sensor such that it is self-heated to an average temperature T_1 that is elevated above the gas temperature. In the constant temperature differential mode of operation, the flow sensor drive maintains at a constant value the temperature difference $\Delta T = T_1 - T$. The output signal is the electrical power W supplied to the heated velocity sensor that is required to keep ΔT constant.

Stem conduction and skin resistance are the two phenomena in traditional thermal dispersion mass flow meters most responsible for degrading accuracy and stability. Part 1 of this two-part series describes an advanced flow sensor that facilitates solving these two problems. This new flow sensor employs a total of four platinum RTD temperature sensing elements, instead of the traditional two. The velocity sensor in this “four-temperature” flow sensor has the heated T_1 temperature sensing element in its tip as before, but now has a second element in its stem. The temperature sensor has the temperature sensing element in its tip as before, but now also has a second element in its stem. The T_1 element is a wire-wound platinum RTD and the remaining three elements are thin-film platinum RTDs.

The two temperature sensing elements in the velocity sensor together act as a heat flux gauge that measures the fraction of heat conducted down the stem of the velocity sensor. The two elements in the temperature sensor perform the same function for the temperature sensor. This is how the four-temperature flow sensor facilitates correction for stem conduction. Additionally, the construction of the velocity sensor avoids altogether the use of any potting materials between the T_1 element and the internal surface of the sheath by means of tightly fitting, as in swaging or press fitting, the cylindrical wire-wound T_1 element into the sheath. Such velocity sensors are known as “dry” sensors. Because it has no potting materials and because the mating parts have the same coefficient of thermal expansion, the skin resistance of the velocity sensor is minimized and is stable. This is how the four-temperature flow sensor facilitates solving the skin resistance problem.

Part 1 describes the principles of operation embedded in the microprocessor-based electronics that operates the physical layer with the four-temperature flow sensor incorporating a dry velocity sensor. This advanced system provides automatic management of changes in gas selection, gas temperature, gas pressure, and outside temperature, as well as automatic correction for stem conduction and skin resistance. This Part 2 describes some advances in the installation and flow calibration of this four-temperature microprocessor-based system, but has general applicability to all thermal dispersion mass flow meters.

Installation

In all cases, specifications and instructions provided by the manufacturer should be followed in sizing and installing in-line and insertion thermal dispersion mass flow meters. Reference 1 is an excellent source for details regarding sizing, installation, safety, and flow calibration.

Figure 2 is helpful in the flow meter selection process for in-line thermal dispersion mass flow meters. The permanent pressure loss shown in Figure 2 applies to an in-line meter with a built-in flow conditioner consisting of two upstream separated perforated plates. In sizing thermal dispersion mass flow meters, as with all flow meters used for gas flow applications, the Mach number of the gas flow should be kept under approximately 0.3 to avoid compressibility effects. At an absolute gas pressure of 1 bara (approximately 1 atmosphere), the permanent pressure loss is about 0.1 bar (approximately 2 psi) at all full scale mass flow rates. This is one or two orders of magnitude less than that required by Coriolis mass flow meters for gas flow applications. Almost all of the permanent pressure loss shown in Figure 2 is due to the built-in flow conditioner.

Insertion flow meters have very low permanent pressure loss, especially for larger line sizes. In-line flow meters without a built-in flow conditioner and no shield on the flow sensor likewise have low pressure drops. These two configurations are why thermal dispersion mass flow meters are considered to be in the class of flow meters with low pressure drops.

As with most kinds of flow meters, the performance of thermal dispersion mass flow meters can be degraded if the flow meter is installed where flow conditions are different than those for which it was flow calibrated. Improper installation is the single biggest cause of measurement inaccuracy for any kind of flow meter.

Components in the piping system upstream and, to a far lesser extent, downstream of the flow meter can create non-uniformities in the flow profile, swirls, and turbulence. All of these phenomena degrade performance. Such flow-disturbing components include single and multiple elbows, expansions, contractions, tees, valves, and pumps. Fortunately, viscous forces in a sufficiently long length of straight pipe upstream and downstream of the flow meter reduce swirl and drive the flow towards a fully developed velocity profile.

Table 1 shows the straight pipe length requirements for both in-line and insertion thermal dispersion mass flow meters and, for purposes of comparison, an orifice-plate flow meter with a 0.7 beta ratio (orifice diameter: pipe internal diameter). The in-line flow meter in Table 1 has a built-in flow conditioner consisting of two upstream separated perforated plates. Figure 3 shows the upstream straight pipe requirements downstream of a single elbow for three kinds of flow meters. This shows the marked contrast between the one diameter length required for the thermal dispersion mass flow meter with the built-in flow conditioner versus the ten and twenty-eight diameter lengths required for typical vortex and orifice-plate flow meters, respectively. Since piping systems in the industrial process control field seldom have suitably long straight piping runs preceding the desired location for flow meter installation, Table 1 and Figure 3 reveal the installation advantage in-line thermal dispersion mass flow meters with the built-in flow conditioner have over alternative flow meters. In essence, in-line flow meters with the built-in flow conditioner trade the advantage of greater accuracy for a small amount of pressure drop.

Normally, the transmitter is mounted directly on the flow body or probe. In cases where the ambient temperature at the pipe line exceeds the specified limit for the transmitter (usually, approximately 60℃), then the transmitter must be located remotely. Additionally, in some cases the application requires that the transmitter be located remotely for easier access. Since the wires leading to the sensors are part of each sensor's electrical circuit, remote location can cause measurement errors if the cable length is altered in the field from that for which it was flow calibrated. The advanced four-temperature microprocessor-based system avoids this problem by incorporating high-impedance voltage sensing wires in the flow meter's cable that essentially make remote transmitter location independent of cable length.

Some applications require that the flow in the process line not be interrupted. This case is solved by employing an insertion flow meter installed in the pipe with hot-tap hardware. The hot-tap method and assembly provides an isolation valve facilitating installation, insertion, retraction, and removal of the insertion flow meter from an active process pipe line without interruption of the flow or the leakage of process gas. The retraction mechanism provides operator safety for pressurized process lines.

Flow Calibration

Because the critical dimensions of the flow sensor of thermal dispersion mass flow meters are so small, manufacturing technology is generally incapable of maintaining sufficiently small tolerances to ensure a high degree of reproducibility from flow sensor to flow sensor. Additionally, the internal diameters of the pipes used in in-line flow bodies have substantial variations. For these reasons, every general-purpose thermal dispersion mass flow meter is flow calibrated by the manufacturer, just like most other kinds of flow meters. Exceptions may include flow switches and low-accuracy flow meters.

The gas flow calibration facilities of manufacturers, flow calibration laboratories, and users should be capable of: (1) generating a stable, steady-state, reproducible gas mass flow rate; (2) accommodating the entire mass flow rate range specified; (3) having a flow calibration standard that has an accuracy at least three times better than the flow meter under test; and (4) reproducing the gas composition, temperature, and pressure to be encountered in the actual application. Gas flow calibration facilities are of two types: open loop and closed loop.

Closed-loop facilities are recommended because they allow flow calibration at elevated pressures and temperatures and with gases other than air. The preferred pressurized closed-loop system for high-accuracy applications has the following major components, listed in flow sequence: (1) a gas charging source, such as a compressed gas tank; (2) a flow source, such as a high pressure axial or centrifugal in-line pump ; (3) a flow controller, such as a precision flow control valve or variable speed motor drive; (4) flow-conditioning section(s) upstream of the flow calibration standard(s); (5) the in-line flow calibration standard (more than one may be needed to cover the mass flow rate range); (6) a heating section, such as an in-line electric heater; (7) a flow-conditioning section upstream of the flow meter under test; and (8) the flow meter under test. Additionally, the facility should have: accurate gas temperature and pressure instrumentation at both the flow calibration standard and the flow meter under test; pressure relief and venting components; a vacuum pump for evacuating the system prior to charging; and, optionally, a cooling section downstream of the flow meter under test. High accuracy in-line flow calibration standards include custody-transfer grade multi-path ultrasonic flow meters; turbine flow meters; flow nozzles; and positive-displacement flow meters.

Conclusion

In-line thermal mass flow meters with the built-in flow conditioner consisting of two upstream separated perforated plates allows users to install their flow meter at a convenient location in the process line without loss of specified accuracy. Flow calibration in the preferred pressurized closed-loop flow calibration facility provides high accuracy for a wide range of gases, pressures, and temperatures that match those encountered in the field application. The advanced four-temperature microprocessor-based system makes remote transmitter location independent of cable length.

References

1. ASME MFC-21.2-2010. Measurement of fluid flow by means of thermal dispersion mass flowmeters.

2. Olin, J. G. 1999. Thermal anemometry. In *The Measurements, Instrumentation, and Sensors Handbook*, ed. Webster, J. G., 29-18 to 29-37. Boca Raton: CRC Press

3. Miller, R. W. 1996. *Flow Measurement Engineering Handbook. 3rd Ed.* McGraw-Hill.

Table 1 Straight pipe length requirements for thermal dispersion mass flow meters in multiples of pipe diameter[a]

Flow disturbance	**Thermal dispersion mass flow meters**				**Orifice plate, β = 0.7[c]**	
	In-line[b]		**Insertion**			
	Upstream	**Dnstream**	**Upstream**	**Dnstream**	**Upstream**	**Dnstream**
Single elbow	1	0	15	5	28	7
4:1 Reduction	3	0	15	5	14	7
4:1 Expansion	3	0	30	10	30	7
Control valve[d] or pressure regltr.	3	0	40	5	32	7
Two elbows in the same plane	3	0	20	5	36	7
Two elbows in different planes[e]	5	0	40	10	62	7

Notes to Table 1: (a) Requirements for the length of intervening straight pipe in multiples of pipe diameter at 1 bara pressure; consult manufacturer for pressure effects; specifications may vary from manufacturer to manufacturer. (b) For an in-line meter with a built-in flow conditioner consisting of two upstream separated perforated plates. (c) For comparison purposes only; based on ISO standard 5167 [3]. (d) If the control valve is always wide open, base the length requirement on the valve's inlet or outlet fitting size. (e) For three elbows, the required length is doubled.

Figure Captions

Figure 1 In-line and insertion meter configurations of the advanced thermal dispersion mass flow meter. These microprocessor-based flow meters have the four-temperature flow sensor with a dry velocity sensor.

Figure 2 Permanent pressure loss for in-line flow meters with a built-in flow conditioner consisting of two upsteam separated perforated plates. Notes: (a) for air and nitrogen at 21.1 ℃ and 1 atmosphere; (b) 1 inch of water = 0.0361 psi; (c) at standard conditions of 21.1 ℃ and 1 atmosphere; and (d) at standard (normal) conditions of 0 ℃ and 1 atmosphere.

Figure 3 Upstream straight pipe requirements for three kinds of flow meters located downstream of a single elbow. The thermal dispersion mass flow meter has a built-in flow conditioner consisting of two separated perforated plates.

Figure 4 Pressurized closed-loop gas flow calibration system. 1 is the gas charging source; 2 is the flow source; 3 is the flow control element; 4 is a flow-conditioning section for a flow calibration standard (two shown); 5 is an in-line flow calibration standard (two shown); 6 is the pressure relief element; 7 is the vent to the outside environment or to a scrubber or other gas purifying device; 8 is the vacuum pump for evacuating the gas charge; 9 is the heating section; 10 is the flow-conditioning section for the flow meter under test; and 11 is the flow meter under test.

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About the Author

John G. Olin, Ph.D., is the founder and chairman of Sierra Instruments, Inc., located in Monterey, Calif. Dr. Olin received his bachelor's degree from Illinois Institute of Technology and his master's and Ph.D. from Stanford University, all in Mechanical Engineering. At Stanford, Dr. Olin specialized in fluid mechanics and heat transfer and used thermal flow meters in research pursuant to his doctoral dissertation. He founded Sierra Instruments in 1973 with the purpose of offering thermal mass flowmeters to solve industry's need for accurate, reliable flowmeters based on the thermal principle. Dr. Olin has a dozen patents and over 60 papers in the field.