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NOISE REDUCING DIFFERENTIAL PRESSURE MEASUREMENT PROBE

BACKGROUND OF THE INVENTION

The process industry employs process variable transmitters to monitor process variables associated with substances such as solids, slurries, liquids, vapors, and gases in chemical, pulp, petroleum, pharmaceutical, food and other processing plants. Process variables include pressure, temperature, flow, level, turbidity, density, concentration, chemical composition and other properties. A process fluid flow transmitter provides an output related to a sensed process fluid flow. The flow transmitter output can be communicated over a process control loop to a control room, or the output can be communicated to another process device such that the process can be monitored and controlled.

Measuring the rate of fluid flow in a confined conduit by modifying the internal geometry of the conduit and applying an algorithm to the measured differential pressure in the flowing fluid, is known. The geometry of the conduit is traditionally changed by altering the cross section of the conduit, such as with a venturi meter, or by the insertion into the conduit of a flow altering device such as a orifice plate, or an averaging pitot tube or the like.

An averaging pitot tube generally includes a shaped bluff body that slightly impedes fluid flow within the conduit. One limitation of some averaging pitot tubes is a relatively lower signal to noise ratio in the differential pressure data being sensed. "Noise" in the context of a differential pressure measuring device, such as a flow transmitter, is the instantaneous

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deviation from an average pressure reading from one data point to another. The noise generated in a pitot tube type of differential pressure sensor originates in the impact pressure sensors on the upstream facing side of the pitot tube and in the low pressure ports on the downstream side of the pitot tube.

As differential pressure transmitters and data acquisition systems have become more sophisticated and responsive, they have also become more sensitive to and are increasingly influenced by the noise generated by the pressure sensing unit. Accordingly, the noise characteristics of differential pressure sensing devices, such as flow transmitters, have become a more important factor in their selection and operation. Thus, there is a need to provide an improved differential pressure sensing device having an improved signal to noise ratio.

SUMMARY OF THE INVENTION

A differential pressure measuring probe with an improved signal to noise ratio is provided. The probe includes a substantially flat longitudinally extending impact surface that is configured to create a dome of relatively high pressure in the impacting fluid proximate one or more impact apertures. The dome of high pressure provides an increased stagnation area on the impact surface to quickly provide a more accurate measurement of pressure. A non-impact surface is provided with non-impact apertures to measure a non-impact pressure at a stagnation point such that differential pressure between the impact surface and the non-impact surface can be calculated.

BRIEF DESCRIPTION OF THE DRAWINGS

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Figs. 1 and 2 are diagrammatic views of a process measurement system illustrating the environment of embodiments of the invention.

5 Figs. 3a and 3b are system block diagrams of process measurement system 12 and differential pressure measurement probe 20, respectively.

10 Fig. 4 is a fragmentary perspective view of a "T" shaped form bluff body of an embodiment of the invention with a portion cut away to better reveal the total construction.

Fig. 5 is a cross sectional view taken along lines 3-3 of Fig. 4. The curved arrows show the general direction of fluid flow around the body.

15 Fig. 6 is a fragmentary perspective of another embodiment showing a form of the flat-face bluff body.

Fig. 7 is a fragmentary perspective view of another embodiment illustrating a substantially "V" shaped cross section for the flat-face bluff body.

20 Fig. 8 is a fragmentary perspective view of another embodiment, illustrating a substantially "U" shaped cross section for the flat-face bluff body.

Fig. 9 is a diagrammatic view of fluid flowing around the differential pressure measurement probe shape of Fig. 4.

25 Figs. 10 - 12 are charts of pressure versus time illustrating the noise reduction of embodiments of the invention.

DETAILED DESCRIPTION

30 Although the invention will be described with reference to specific embodiments of differential pressure measuring probes, workers skilled in the art will recognize that changes can be made in form and detail without departing from the spirit and scope of the invention, which are defined by the appended claims.

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Fig. 1 is a diagrammatic view of process control system 10 illustrating one example of an environment of embodiments of the invention. Pressure measurement system 12 is coupled to control room 14 (modelled as a voltage source and resistance) through process control loop 16. Loop 16 can utilize any appropriate protocol to communicate flow information between measurement system 12 and control room 14. For example, process control loop 16 operates in accordance with a process industry standard protocol such as Highway Addressable Remote Transducer (HART®), FOUNDATION™ Fieldbus or any other appropriate protocol.

Fig. 2, shows a cut away portion of a process fluid container such as a pipe, or closed conduit, 18 into which is installed a differential pressure measuring probe 20 of the averaging pitot tube type. The bluff body 22 of probe 20 is constructed in accordance with an embodiment of the invention that will be described in greater detail later in the specification. Bluff body 22 diametrically spans the inside of pipe 18. The directional arrow 24 in Fig. 2 indicates the direction of fluid flow in pipe 18. A fluid manifold 26 and flow transmitter 13 are shown mounted on the exterior end of pitot tube 20. Transmitter 13 includes a pressure sensor 28 that is fluidically coupled to probe 20 through passageways 30 (shown in phantom in Fig. 2).

Figs. 3a and 3b are system block diagrams of differential pressure measurement system 12 and differential pressure measurement probe 20, respectively. System 12 includes flow transmitter 13 and differential pressure measurement probe 20. System 12 is coupleable to a process control loop such as loop 16 and is adapted to communicate a process variable

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output related to a differential pressure of fluid flow within pipe 18. Transmitter 13 of system 12 includes a loop communicator 32, pressure sensor 28, measurement circuitry 34, and controller 36.

5 Loop communicator 32 is coupleable to a process control loop, such as loop 16, and is adapted to communicate upon the process control loop. Such communication can be in accordance with any appropriate process industry standard protocol such as the protocols
10 discussed above.

 Pressure sensor 28 includes first and second inlets 38, 40 which are coupled to first and second plenums 42, 44 respectively through passageways 30. Sensor 28 can be any device that has an electrical
15 characteristic that changes in response to changes in applied pressure. For example, sensor 28 can be a capacitive pressure sensor the capacitance of which changes in response to the differential pressure applied between ports 38, and 40. If desired, sensor 28 can
20 include a pair of pressure sensitive elements such that each plenum is coupled to its own pressure sensitive element.

 Measurement circuitry 34 is coupled to sensor 28 and is configured to provide a sensor output related
25 to differential pressure between ports 38 and 40. Measurement circuitry 34 can be any electronic circuitry that can provide a suitable signal related to differential pressure. For example, measurement circuitry can be an analog-to-digital converter, a
30 capacitance-to-digital converter or any other appropriate circuitry.

 Controller 36 is coupled to measurement circuitry 34 and loop communicator 32. Controller 36 is adapted to provide a process variable output to loop

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communicator 32, which output is related to the sensor output provided by measurement circuitry 34. Controller 36 can be a Programmable Gate Array device, microprocessor, or any other appropriate device.

5 Although loop communicator 32, measurement circuitry 34 and controller 36 have been described with respect to individual modules, it is contemplated that they can be combined such as on an Application Specific Integrated Circuit (ASIC).

10 Differential pressure measurement probe 20 is coupled to transmitter 13 by passageways 30. Thus, port 38 of sensor 28 is coupled to first plenum 42, while port 40 of sensor 28 is coupled to second plenum 44. A "plenum" is a passageway, a channel, a tube or the like
15 into which fluid of a particular character or pressure is directed or admitted and through which the fluid is conducted or conveyed.

 First plenum 42 includes a longitudinally extending impact surface 46 with at least one impact
20 aperture 48 disposed to communicate pressure from impact surface 46 to port 38 of sensor 28. In some embodiments, surface 46 has a width ranging between about 12.7 millimeters (0.50 inches) to about 50.8 millimeters (2.00 inches). As shown in Figs. 2, 4, and
25 5, substantially all of impact surface 46 is normal to the upstream direction of fluid flow which is indicated by arrow 24. As can be seen from Figs. 2 and 4 - 8, the at least one impact aperture 48 can have any appropriate width. For example, aperture 48 can have a width
30 between about 0.762 millimeters (0.030 inches) and about 6.35 millimeters (0.250 inches). Thus, a ratio of plenum width to aperture width greater than about 8:1 appears to provide beneficial results. Additionally aperture 42 can take the form of a longitudinally

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extending slit. Such slit provides enhanced noise reduction in the pressure signal, and thus increases the signal to noise ratio of the measurement system. When a slit is used, it is important for the width of the slit to be less than an interior width of the plenum to which it is connected. Additionally, a plurality of slits can be used which can be spaced from one another laterally, or longitudinally. Further still, slits can be used for the downstream aperture as well.

Second plenum 44 includes a non-impact surface 50 spaced from impact surface 46. Surface 50 includes at least one non-impact aperture 52 disposed to communicate pressure from the non-impact surface to port 40 of sensor 28. As can be seen in Figs. 2, and 4 - 8, a variety of geometries can be used with embodiments of the invention. Generally, with each embodiment at least one of the first and second plenums 42, 44 is shaped to create a fluid stagnation point at the at least one non-impact aperture 52. If a second plenum is not needed, a pressure tap can be provided in the wall of pipe 18 such that non-impact aperture 52 is disposed within pipe 18 to communicate a non-impact pressure to port 40. For example, aperture 52 can be disposed proximate an inside wall of pipe 18. Additionally, flow transmitter 13 and probe 20 can be factory matched to provide enhanced accuracy, longevity and diagnostics for a particular differential flow measurement application.

Figs. 4 and 5 show fragmentary and cross sectional views of the bluff body portion 22 of the pitot tube 20, respectively. As illustrated, a cross section of the bluff body resembles the letter "T", including a bar portion 54 having a blunt, substantially flat face impact surface 46 on the "top" of the letter "T". The cross section of the body also illustrates the

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stem portion 56 of letter "T," depending from the center of the bar 54 and disposed generally perpendicularly. In a perspective or in a side view of the bluff body the so-called "stem" of the "T" is seen to be a
5 longitudinally extending rib 56 that projects in a downstream direction from the back side of the flat faced bar.

In order to increase the signal-to-noise ratio of the low pressure measurement, the ratio of length to
10 width (L/W) of bluff body 22, as shown in Fig. 4, should be greater than about one half ($1/2$) and less than about one and one half ($1\ 1/2$). A ratio of one (1) appears to provide advantageous results.

First and second plenums 42 and 44 are
15 disposed along the length of and within the bluff body and extend into the portion of the pitot tube 20 that projects outside of fluid-carrying conduit 18 to flow transmitter 13.

Fig. 2 shows the bluff body 22 oriented within
20 fluid-carrying conduit 18 so that the blunt, flat impact surface 46 proximate bar 54 faces the flow front and is perpendicular to the direction of fluid flow 24. Such orientation provides a relatively large dome of high pressure extending across surface 46, and thus creates
25 a more effective impact stagnation zone. The projecting rib 56 is generally parallel to the direction of fluid flow in the conduit 18.

The normal plurality of high pressure sensing apertures in the upstream surface of a bluff body of a
30 traditional averaging pitot tube can be replaced, in one embodiment of the invention, with one or more narrow slit openings, each positioned laterally centrally of bar portion 54 and extending longitudinally substantially the entire length of bluff body 22. The

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slits provide communication between the high pressure (impact) fluid in conduit 18 and plenum 42 thus conducting the impact pressure of the flowing fluid into plenum 42 and to port 38 of pressure sensor 28 within flow transmitter 13. As opposed to a plurality of spaced apart circular apertures, the slit configuration provides a further reduction in the noise associated with the measurement of the high fluid pressure, provided that the narrow slit serves as the entry to a wider and larger plenum. In order to achieve the noise reduction, the slit should not act as the plenum itself. For example, if the slit in the bar face is 0.762 millimeters (0.030 inches) wide and plenum 42 is 3.2 millimeters (0.125) inches wide, a satisfactory ratio would exist. These dimensions and the ratio are exemplary only and should not be taken as restrictive or limiting.

The non-impact fluid is directed into second plenum 44 in pitot tube 20 through one or more downstream apertures 52, or alternatively, a longitudinally extending slit, located behind bar 54 of the bluff body 22. As shown in Fig. 5, bar portion 54 of bluff body 22 creates shedding vortices in the fluid flowing around edges 58 and 60 of the lateral extremities of bar 54, producing stagnation of the fluid in the area adjacent the back side 50 of the bar 54 and around the lateral sides of projecting rib 56. The main function of the rib 56 of the "T" shaped embodiment is to extend in a downstream direction, the point of reattachment of the fluid vortices that are created by the lateral edges 58 and 60 of the flat faced bar 54. Deferring reattachment of the vortices increases the size of stagnation zone, thus reducing the residual

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noise in the low pressure component of the differential pressure measurement.

Sharp corners on the upstream lateral edges 58 and 60 of the bar 54 will produce shedding vortices around the bar, however violent or abrupt vortices are less desirable for production of fluid stagnation resulting quiescence than vortices produced by smoother rounded lateral edges of the bluff body's fluid profile. While specific roundness specifications must depend on the size of the bluff body which, in turn depends on the size of the fluid carrying conduit, it may be said that for a bluff body sized for a 25.4 cm (ten inch) diameter pipe, leading edge corners having a radius of about .4 to .8 millimeters (1/64 to 1/32 of an inch) can be suitable.

The blunt impact face of the bluff body, together with the lateral edges, produce enhanced fluid flow characteristics and shedding vortices that provide the noise reducing quiescence in the flowing fluid. Although one embodiment of the invention utilizes an impact surface that would, in ordinary parlance, be considered "flat," it is apparent that an impact face that departs somewhat from the nominal "flat" surface can also be used. For example, a slightly convex surface would suffice as well as a moderately undulating, roughened or scalloped surface. A concave surface would preserve the fluid flow characteristics and its lateral edges would provide the requisite flow separation. Accordingly, for purposes of the description of the invention and the accompanying claims, "flat" means a surface having a convex, or upstream facing, deviation from a nominal flat surface of not more than 0.134 times the width of the bluff body

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(0.134 x W) or having an unlimited concave deviation from a nominal flat surface.

Additional embodiments of the invention are shown in Figs. 6 - 8. In each, the blunt, flat impact face having one or more narrow high pressure fluid admitting slit openings is a common feature. The primary difference between the alternative embodiments and embodiment described above is the shape and position of the downstream depending extensions of the bar that provide delay in the reattachment of the vortices. Different designs of the downstream extension result in variation of the shape and size of the fluid stagnation zones. Selection of the particular form or design of the bluff body's extension member may depend on several factors incident to the measuring environment, such as, for example, cost, the character of the fluid, the range of fluid flow rates of the size of the conduit carrying the fluid, among others.

Fig. 6 depicts a basic form of a bluff body 22a, one having no reattachment extension or projecting rib. A body 70 is provided with a flat impact facing surface 72 having at least one narrow slit 48a that conducts the high pressure fluid into first plenum 42a, through the bluff body, and into the exterior portion of the pitot tube and on into flow transmitter 13. Confined spaces 44a in the interior of the body communicate with non-impact apertures 52a and conduct the low pressure fluid through the body, into the exterior part of the pitot tube, and into flow transmitter 13. The stagnation zone created by the shedding vortices is smaller than that created by the "T" shaped embodiment shown in Figs. 2 and 4 - 5, but nevertheless provides improvement in the reduction of residual noise in the low pressure measurement. The

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provision of impact slits 48a in the face of the bluff body achieves a similar increase in signal-to-noise ratio in the high pressure measurement as found in the "T" shaped embodiment.

5 Fig. 7 illustrates a "V" shaped form of a bluff body 22b having a flat faced bar portion 54b that faces upstream and is provided with the same plurality of longitudinally extending impact slits 48b and a first plenum 42b, as in the previously discussed embodiments.

10 The downstream extension for deferring reattachment of fluid vortices takes the form of a pair of projecting ribs or legs 74 and 76, depending from the lateral extremities of the back side of the bar 54b and diverging outwardly into the stream of flowing fluid.

15 As between the bar edges 78 and 80 and the outside edges 82 and 84 of the legs 74 and 76, the lateral edges 86 of the legs (the lateral edges of the fluid profile of the body) create the greatest amount of separation of the fluid boundary layer, producing a zone of fluid

20 quiescence between the legs. The width L_1 of the bar 54b should be less than or equal to total width L_2 of the total bluff body. A plurality of longitudinally spaced apart non-impact apertures 52b are located on the interior sides of the legs 74, 76 and communicate with

25 second plenums 44b in the body of the legs to convey the low pressure fluid to the pressure transducer.

 Another embodiment of a bluff body 22c of the present invention is shown in Fig. 8. The primary difference between this form of the bluff body and that

30 of Fig. 7 is that legs 74c and 76c are positioned perpendicularly to the back side of the bar 54c, forming a structure having a lateral cross section that resembles the letter "U." Vortices are shed from the upstream edges 78c and 80c of the bar 54c, similarly to

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the action seen in the embodiment shown in Figs. 2 and 4 - 5. The stagnation zone is created between the legs 74c and 76c of the bluff body 22c. A plurality of longitudinally spaced apart non-impact apertures 52c are located on the back side of the bar 54c, interiorly of the legs 74c and 76c and communicate with interior spaces or plenums 44c in the body of the legs to convey the low pressure fluid to port 40 of pressure sensor 28 in flow transmitter 13.

Fig. 9 is a diagrammatic view of fluid flowing around the differential pressure measurement probe shape of Fig. 4. As shown in Fig. 9, the substantially flat impact surface creates a dome of high pressure in the fluid proximate the impact surface.

Figs. 10 - 12 are charts of pressure versus time illustrating the noise reduction of embodiments of the invention. Fig. 10 illustrates a sample pressure chart of a differential pressure measurement probe in accordance with the prior art. Fig. 11 illustrates a sample pressure chart measured from a probe incorporating an impact slit as shown in Figs. 2 and 4 - 8. Fig. 12 illustrates a sample pressure chart measured from a probe incorporating both the substantially flat impact surface, and the longitudinally extending slit shown in Figs. 2 and 4 - 8. As shown in Figs. 10 - 12, appreciable noise reduction in a differential pressure measurement system can be achieved. Such noise reduction provides for quicker calculation of an accurate indication of differential pressure, thus potentially providing more effective process control.



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WHAT IS CLAIMED IS:

1. A differential pressure measurement probe adapted for placement within a fluid-carrying conduit, the probe comprising:

a first plenum configured to couple to a first pressure sensor port, the first plenum including an impact surface with at least one impact aperture disposed therein to communicate pressure from the impact surface to the first pressure sensor port;

a non-impact surface spaced from the impact surface, the non-impact surface having at least one non-impact aperture disposed therein to communicate pressure from the non-impact surface to a second pressure sensor port; and

wherein the impact surface extends longitudinally and is substantially flat, such that fluid within the conduit impinges upon the substantially flat impact surface.

2. The probe of claim 1, and further comprising a second plenum, and wherein the non-impact surface is disposed on the second plenum.

3. The probe of claim 2, wherein the first and second plenums are spaced by a longitudinal rib configured to extend downstream.

4. The probe of claim 3, wherein the rib is disposed perpendicular to the impact surface.



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5. The probe of claim 2, wherein the second plenum is shaped to include a longitudinally extending rib portion coupled to the first plenum.
6. The probe of claim 5, wherein the at least one non-impact aperture is disposed in the rib portion.
7. The probe of claim 2, wherein the non-impact surface is substantially flat.
8. The probe of claim 7, wherein the non-impact surface is substantially parallel to the impact surface.
9. The probe of claim 2, wherein the second plenum is shaped to include a pair of longitudinally extending rib portions diverging angularly with respect to the impact surface.
10. The probe of claim 9, wherein the non-impact surface is disposed on a portion of one of the laterally extending rib portions that faces the other of the laterally extending rib portions.
11. The probe of claim 2, wherein the second plenum is shaped to include a pair of spaced apart longitudinally extending rib portions each disposed perpendicular to the impact surface.
12. The probe of claim 1, wherein the first plenum has a plenum width and the impact surface is shaped to create a localized region of relatively high pressure across substantially the entire plenum width.



13. The probe of claim 12 wherein the plenum width ranges from about 1.27 centimeters to about 5.08 centimeters.

14. The probe of claim 1, wherein the at least one impact aperture has an aperture width ranging from about 0.0762 centimeters to about 0.635 centimeters.

15. The probe of claim 1, wherein the first plenum has a plenum width, the at least one impact aperture has an aperture width, and wherein the ratio of plenum width to aperture width is greater than about 8:1.

16. A differential pressure measurement probe adapted for placement within a fluid-carrying conduit, the probe comprising:

means for sensing impact fluid pressure through at least one impact aperture;
and

means for sensing non-impact fluid pressure through at least one non-impact aperture.

17. A method of measuring differential pressure in a fluid-carrying conduit comprising:

generating an upstream pressure with a longitudinally extending substantially flat impact surface;

communicating the upstream pressure from an impact aperture disposed on the impact surface to a first pressure sensor port;

generating a non-impact pressure;

communicating the non-impact pressure from a non-impact aperture to a second pressure



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sensor port, the non-impact aperture being spaced from the impact aperture.

18. A differential pressure measurement system coupleable to a process control loop and adapted to communicate a process variable output related to a differential pressure of a fluid flow within a fluid-carrying conduit, the system comprising:

- a process pressure transmitter including:

- a loop communicator coupleable to the process control loop and adapted for communication upon the process control loop;

- at least one pressure sensor having first and second pressure inlets;

- measurement circuitry coupled to the at least one pressure sensor and configured to provide a sensor output related to differential pressure between the first and second pressure inlets; and

- a controller coupled to the measurement circuitry and the loop communicator, the controller adapted to provide a process variable output to the loop communicator, the process variable output related to the sensor output; and

- a differential pressure measurement probe adapted for placement within the fluid-carrying conduit, the probe including:

- a first plenum coupled to the first pressure inlet, the first plenum



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including a longitudinally extending impact surface with at least one impact aperture disposed to communicate pressure from the impact surface to the first pressure inlet;

a non-impact surface spaced from the impact surface, the non-impact surface having a non-impact aperture disposed to communicate pressure from the non-impact surface to the second pressure inlet.

19. The system of claim 18, wherein the transmitter and probe are matched for a specific application.