the flow meter 40 by making the flow tube(s) more robust or thicker tends to compromise the functional accuracy of the flow meter 40. This can make the flow meter capable of high pressure operation functionally impractical for managed pressure drilling applications.

[0016] For high pressure applications, a turbine flow meter instead of the Coriolis flow meter 40 could be used to make the desired measurements, but the accuracy of the turbine flowmeter at measuring a full range of flow rates is inferior to a Coriolis flow meter. In fact, managed pressure drilling requires a high level of flow-measurement accuracy so that use of a turbine flowmeter is not acceptable.

[0017] Furthermore, because the pressure limitation of the Coriolis meter 40 requires it to be downstream of the chokes 32, any gas in the drilling fluid can come out of solution during the pressure drop experienced across the chokes 32. When this occurs, the Coriolis meter 40 may not function properly.

[0018] Keeping the gas in solution for the Coriolis flow meter 40 after the chokes 32 has been partially controlled by adding a valve (not shown), orifice, or the like down-stream of the Coriolis flow meter. The downstream valve or the like can supply adequate back pressure to the meter 40, thereby keeping the gas in solution and allowing the meter 40 to read the fluid flow rate with improved accuracy. Although this arrangement may offer better pressure control to keep the gas in solution, positioning such a valve downstream of the meter 40 does not enable to the Coriolis flow meter 40 to operate at higher pressures, and such a valve downstream of the meter 40 adds complexity to the drilling system.

[0019] The subject matter of the present disclosure is directed to overcoming, or at least reducing the effects of, one or more of the problems set forth above.

SUMMARY OF THE PRESENT DISCLOSURE

[0019A] According to a first aspect, there is provided an apparatus used in a drilling system conducting flow of drilling fluid, the drilling fluid having gas, liquid, and/or solids and being at a first pressure level for drilling the wellbore, the apparatus comprising: a Coriolis flow meter for measuring the flow of the drilling fluid and having an inlet side and an outlet side, the meter comprising at least one flow tube adapted to vibrate and conducting the flow of the drilling fluid at the first pressure level from the inlet side to the outlet side, the at least one flow tube configured to withstand a pressure limit, of internal pressure relative to atmospheric pressure, that is less than the first pressure level of the

drilling fluid to which the at least one flow tube is exposed; and a vessel enclosing the at least one flow tube in a chamber and holding an internal fluid separate from the drilling fluid at a second pressure level in the chamber about the at least one flow tube; and a controller monitoring variation in the first pressure level of the drilling fluid conducted through the at least one flow tube, the controller regulating the second pressure level of the internal pressure relative to the first pressure level and controlling a pressure differential across the at least one flow tube to conduct the drilling fluid at the first pressure level above the pressure limit of the at least one flow tube.

[0019B] According to a second aspect, there is provided a drilling method for a wellbore, the method comprising: conducting flow of drilling fluid in a drilling system, the drilling fluid having gas, liquid, and/or solids and being at a first pressure level for drilling the wellbore; measuring the flow by vibrating at least one flow tube of a Coriolis flow meter conducting the flow from an inlet side to an outlet side, the at least one flow tube configured to withstand a pressure limit, of internal pressure relative to atmospheric pressure, being less than the first pressure level of the drilling fluid to which the at least one flow tube is exposed; and controlling, with a controller, a pressure differential across the at least one flow tube to conduct the drilling fluid at the first pressure level above the pressure limit of the at least one flow tube by monitoring variation in the first pressure level of the drilling fluid conducted through the at least one flow tube and regulating, relative to the first pressure level, a second pressure level of an internal fluid separate from the drilling fluid in a chamber disposed about the at least one flow tube.

[0020] An apparatus according to the present disclosure include a Coriolis flow meter for measuring flow of fluid—*i.e.,* measuring several fluid parameters (*e.g.,* flow, density, temperature). The meter has an inlet side and an outlet side. At least one flow tube is adapted to vibrate and conducts the flow of the fluid at a first pressure level from the inlet side to the outlet side. A vessel encloses the at least one flow tube in a chamber and holds a second pressure level in the chamber about the at least one flow tube. For example, the vessel can hold an internal fluid in the chamber, such as a liquid, a gas, helium, argon, air, nitrogen, an electrically inert fluid, process fluid, hydraulic fluid, transformer oil, silicon oil, mineral oil, fluorocarbon-based fluid, and castor oil.

[0021] The second pressure level is regulated relative to the first pressure level and controls a pressure differential across the at least one flow tube. In one arrangement, the second pressure level is elevated above environmental (*e.g.,* ambient, atmospheric,

etc.) relative to the first pressure level and reduces a pressure differential across the at least one flow tube. The second pressure level can be elevated to a level at, near, above, or below the first pressure level. For instance, the second pressure level can be elevated to above the first pressure level to produce a positive of the pressure differential from the chamber to the at least one flow tube. Alternatively, the second pressure level can be elevated to below the first pressure level to produce a negative of the pressure differential from the chamber to the at least one flow tube.

[0022] In the apparatus, the meter can be disposed in a drilling system upstream of a choke, between at least one pump and a well, downstream from at least one charge pump connected to a mud tank, and/or downstream from at least one mud pump connected to a well.

[0023] For the meter, the at least one flow tube can include first and second flow tubes disposed in parallel to one another, and the at least one flow tube can define a bend. The meter can have at least one exciter and at least first and second sensors. The at least one exciter is disposed adjacent the at least one flow tube and imparts vibration thereto. The first and second sensors are disposed respectively adjacent the inlet and outlet sides and measure response to the imparted vibration.

[0024] A controller of the apparatus can monitor variation in the first pressure level and can adjust the second pressure level in accordance therewith. The apparatus can have a pressure sensor associated with the vessel to measure the second pressure level for comparison to the first pressure level. This can be done to actively control the second pressure level from a source relative to the first pressure level.

[0025] For example, the apparatus can include a source of the second pressure level in communication with the vessel. In one implementation, the source can include an accumulator translating a pressure associated with the first pressure level to the second pressure level of the vessel. Additionally or in the alternative, the source can include a pump producing the second pressure level of the vessel.

[0026] A drilling system according to the present disclosure for a wellbore includes at least one choke, a Coriolis flow meter, and a vessel. The at least one choke is in fluid communication with the wellbore and controls flow of fluid from the wellbore. The meter is disposed in fluid communication upstream of the at least one choke and measures the flow from the wellbore. The meter has at least one flow tube being adapted to vibrate and conducting the flow at a first pressure level from an inlet side to an outlet

side. The vessel encloses the at least one flow tube in a chamber and holds a second pressure level in the chamber about the at least one flow tube. This second pressure level is regulated relative to the first pressure level and controls a pressure differential across the at least one flow tube. For instance, the second pressure level is elevated above environmental relative to the first pressure level and reduces a pressure differential across the at least one flow tube.

[0027] In the system, one or more controllers can be operatively coupled to the at least one choke and/or the meter. For example, the one or more controllers can monitor one or more parameters of the flow and can control operation of the at least one choke in response to the one or more monitored parameters. The one or more controllers can determine a mass flow of the fluid based at least in part on a measurement from the meter and can determine a density of the fluid based at least in part on a measurement from the meter.

[0028] For its part, the at least one choke in the system can be in fluid communication with a rotating control device of the wellbore. The Coriolis flow meter can be disposed in fluid communication between the at least one choke and the rotating control device. Finally, the system can have another Coriolis flow meter disposed in fluid communication downstream of the at least one choke and configured to operate in conjunction with the Coriolis flow meter disposed in fluid communication upstream of the at least one choke.

[0029] In an example, a controlled pressure drilling method for a wellbore involves controlling surface backpressure in the wellbore by controlling flow of fluid at a first pressure level from the wellbore with at least one choke. The method involves measuring the flow from the wellbore upstream of the at least one choke by operating a Coriolis flow meter having at least one flow tube conducting the flow. In the method, a pressure differential across the at least one flow tube is regulated relative to the first pressure level to controls a pressure differential across the at least one flow tube. For instance, the second pressure level is reduced by elevating a second pressure level above environmental in a chamber disposed about the at least one flow tube relative to the first pressure level.

[0030] A drilling system according to the present disclosure for a wellbore includes at least one pump, a Coriolis flow meter, and a vessel. The at least one pump is in fluid communication with the wellbore and delivers flow of fluid to the wellbore. The Coriolis

flow meter is disposed in fluid communication between the at least one pump and the wellbore and measures the flow of fluid to the wellbore. The meter includes at least one flow tube being adapted to vibrate and conducting the flow at a first pressure level from an inlet side to an outlet side. A vessel encloses the at least one flow tube in a chamber and holds a second pressure level in the chamber about the at least one flow tube. The second pressure level is regulated relative to the first pressure level and controls a pressure differential across the at least one flow tube. For instance, the second pressure level is elevated above environmental relative to the first pressure level and reduces a pressure differential across the at least one flow tube.

[0031] In another example of a controlled pressure drilling method, flow of fluid is delivered from at least one pump at a first pressure level to the wellbore, and the flow is measured by operating a Coriolis flow meter having at least one flow tube conducting the flow. The method involves regulating the second pressure level relative to the first pressure level to control a pressure differential across the at least one flow tube. For instance, the method involves reducing a pressure differential across the at least one flow tube by elevating a second pressure level above environmental in the chamber about the at least one flow tube relative to the first pressure level.

[0032] The foregoing summary is not intended to summarize each potential embodiment or every aspect of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] Fig. 1 schematically illustrates a choke manifold according to the prior art.

[0034] Fig. 2 illustrates a Coriolis flow meter according to the prior art.

[0035] Fig. 3 diagrammatically illustrates a managed pressure drilling system having a Coriolis flow meter according to the present disclosure for a choke manifold.

[0036] Figs. 4A-4D diagram several arrangements for a Coriolis flow meter for the system of Fig. 3.

CLAIMS:

1. An apparatus used in a drilling system conducting flow of drilling fluid, the drilling fluid having gas, liquid, and/or solids and being at a first pressure level for drilling the wellbore, the apparatus comprising:

a Coriolis flow meter for measuring the flow of the drilling fluid and having an inlet side and an outlet side, the meter comprising at least one flow tube adapted to vibrate and conducting the flow of the drilling fluid at the first pressure level from the inlet side to the outlet side, the at least one flow tube configured to withstand a pressure limit, of internal pressure relative to atmospheric pressure, that is less than the first pressure level of the drilling fluid to which the at least one flow tube is exposed; and

a vessel enclosing the at least one flow tube in a chamber and holding an internal fluid separate from the drilling fluid at a second pressure level in the chamber about the at least one flow tube; and

a controller monitoring variation in the first pressure level of the drilling fluid conducted through the at least one flow tube, the controller regulating the second pressure level of the internal pressure relative to the first pressure level and controlling a pressure differential across the at least one flow tube to conduct the drilling fluid at the first pressure level above the pressure limit of the at least one flow tube.

2. The apparatus of claim 1, wherein the second pressure level is elevated above environmental relative to the first pressure level and reduces the pressure differential across the at least one flow tube.

3. The apparatus of claim 2, wherein the second pressure level is elevated to above the first pressure level and produces a positive of the pressure differential from the chamber to the at least one flow tube.

4. The apparatus of claim 2, wherein the second pressure level is elevated to below the first pressure level and produces a negative of the pressure differential from the chamber to the at least one flow tube.

5. The apparatus of any one of claims 1 to 4, wherein the meter comprises:

at least one exciter disposed adjacent the at least one flow tube and imparting the vibration thereto; and

at least first and second sensors disposed respectively adjacent the inlet and outlet sides and measuring response to the imparted vibration.

6. The apparatus of any one of claims 1 to 5, wherein the controller comprises a source of the second pressure level in communication with the vessel.

7. The apparatus of claim 6, wherein the source comprises an accumulator translating a pressure associated with the first pressure level of the internal fluid to the second pressure level of the vessel.

8. The apparatus of claim 6 or 7, wherein the source comprises a pump producing the second pressure level of the internal fluid of the vessel.

9. The apparatus of any one of claims 1 to 8, wherein the controller comprises a pressure sensor associated with the vessel and measuring the second pressure level for comparison to the first pressure level.

10. The apparatus of any one of claims 1 to 9, further comprising a choke of the drilling system for the wellbore, the choke in fluid communication downstream of the meter.

11. The apparatus of any one of claims 1 to 10, further comprising at least one pump of the drilling system for the wellbore, the meter in fluid communication between the at least one pump and the wellbore.

12. The apparatus of any one of claims 1 to 11, further comprising at least one charge pump for a mud tank of the drilling system, the meter in fluid communication downstream from the at least one charge pump.

13. The apparatus of any one of claims 1 to 12, further comprising at least one mud pump of the drilling system for the wellbore, the meter in fluid communication downstream from the at least one mud pump connected to the wellbore.

14. The apparatus of any one of claims 1 to 13, wherein the at least one flow tube comprises first and second flow tubes disposed in parallel to one another.

15. The apparatus of any one of claims 1 to 14, wherein the at least one flow tube defines a bend.

16. The apparatus of any one of claims 1 to 15, wherein the vessel holds the internal fluid selected from a group consisting of a liquid, a gas, helium, argon, air, nitrogen, an electrically inert fluid, process fluid, hydraulic fluid, transformer oil, silicon oil, mineral oil, fluorocarbon-based fluid, and castor oil.

17. The apparatus of claim 1, further comprising:

at least one choke in fluid communication with the wellbore and controlling the flow of the drilling fluid at the drilling pressure level from the wellbore;

the Coriolis flow meter disposed in fluid communication upstream of the at least one choke and measuring the flow from the wellbore.

18. The apparatus of claim 17, wherein the controller is at least one of:

operatively coupled to the at least one choke, the controller monitoring one or more parameters of the flow and controlling operation of the at least one choke in response to the one or more monitored parameters;

operatively coupled to the meter, the controller determining a mass flow of the fluid based at least in part on a measurement from the meter; and

operatively coupled to the meter, the controller determining a density of the drilling fluid based at least in part on a measurement from the meter.

19. The apparatus of any one of claims 17 or 18, wherein the at least one choke is in fluid communication with a rotating control device of the wellbore, the meter being disposed in fluid communication between the at least one choke and the rotating control device.

20. The apparatus of any one of claims 17 to 19, further comprising another Coriolis flow meter disposed in fluid communication downstream of the at least one choke and configured to operate in conjunction with the Coriolis flow meter disposed in fluid communication upstream of the at least one choke.

21. The apparatus of any one of claims 17 to 20, wherein the controller comprises at least one of:

a source of the second pressure level in communication with the vessel;

an accumulator translating a pressure associated with the first pressure level to the second pressure level of the vessel;

a pump producing the second pressure level of the vessel; and

a pressure sensor associated with the vessel and measuring the second pressure level for comparison to the first pressure level.

22. The apparatus of claim 1, further comprising:

at least one pump in fluid communication with the wellbore and delivering the flow of the drilling fluid to the wellbore;

the Coriolis flow meter disposed in fluid communication between the at least one pump and the wellbore and measuring the flow of the drilling fluid to the wellbore.

23. The apparatus of claim 22, wherein the controller comprises at least one of:

a source of the second pressure level in communication with the vessel;

an accumulator translating a pressure associated with the first pressure level to the second pressure level of the vessel;

a pump producing the second pressure level of the vessel; and

a pressure sensor associated with the vessel and measuring the second pressure level for comparison to the first pressure level.

24. The apparatus of any one of claims 1 to 23, wherein the controller controls excitation of the vibration of the at least one flow tube to account for at least one operational parameter related to the vibration of the at least one flow tube in the internal fluid at the second pressure level.

25. The apparatus of claim 24, wherein to account for the at least one operational parameter, the controller accounts for at least one of:

a density change of the internal fluid in the chamber;

a viscosity change of the internal fluid in the chamber;

drag force on the at least one flow tube as it vibrates in the internal fluid;

attenuation of the vibration of the at least one flow tube due to the internal fluid in the chamber; and

alteration of a resonant frequency of the at least one flow tube due to the internal fluid in the chamber.

26. The apparatus of any one of claims 1 to 25, wherein the at least one flow tube comprises at least one of a wall thickness, a length, a material, a geometric shape, a foil, a series of concave dimples, and a location of vibration sensor configured to compensate for an operational difference in the vibration of the at least one flow tube caused by the internal fluid at the second pressure level in the chamber surrounding the at least one flow tube.

27. A drilling method for a wellbore, the method comprising:

conducting flow of drilling fluid in a drilling system, the drilling fluid having gas, liquid, and/or solids and being at a first pressure level for drilling the wellbore;

measuring the flow by vibrating at least one flow tube of a Coriolis flow meter conducting the flow from an inlet side to an outlet side, the at least one flow tube configured to withstand a pressure limit, of internal pressure relative to atmospheric pressure, being less than the first pressure level of the drilling fluid to which the at least one flow tube is exposed; and

controlling, with a controller, a pressure differential across the at least one flow tube to conduct the drilling fluid at the first pressure level above the pressure limit of the at least one flow tube by monitoring variation in the first pressure level of the drilling fluid conducted through the at least one flow tube and regulating, relative to the first pressure level, a second pressure level of an internal fluid separate from the drilling fluid in a chamber disposed about the at least one flow tube.

28. The method of claim 27, wherein conducting the flow of the fluid at the first pressure level in the drilling system for the wellbore and measuring the flow for the wellbore comprises:

controlling surface backpressure in the wellbore by controlling the flow of the drilling fluid at the first pressure level from the wellbore with at least one choke;

measuring the flow from the wellbore upstream of the at least one choke by operating the Coriolis flow meter having the at least one flow tube conducting the flow.

29. The method of claim 28, wherein regulating the second pressure level in the chamber comprises translating, with an accumulator, a pressure associated with the first pressure level to the second pressure level of the vessel.

30. The method of claim 28 or 29, wherein regulating the second pressure level in the chamber comprises producing the second pressure level of the vessel by operating a pump.

31. The method of claim 28, 29 or 30, further comprising measuring the second pressure level with a sensor associated with the vessel for comparison to the first pressure level.

32. The method of claim 27, wherein conducting the flow of the fluid at the first pressure level in the drilling system for the wellbore and measuring the flow for the wellbore comprises::

delivering the flow of the drilling fluid from at least one pump at the first pressure level to the wellbore;

measuring the flow of the drilling fluid from the at least one pump to the wellbore by operating the Coriolis flow meter having the at least one flow tube conducting the flow.

33. The method of claim 32, wherein regulating the second pressure level in the chamber comprises translating, with an accumulator, a pressure associated with the first pressure level to the second pressure level of the vessel.

34. The method of claim 32 or 33, wherein regulating the second pressure level in the chamber comprises producing the second pressure level of the vessel by operating a pump.

35. The method of claim 32, 33, or 34, further comprising measuring the second pressure level with a sensor associated with the vessel for comparison to the first pressure level.

36. The method of any one of claims 27 to 35, further comprising accounting for at least one operational parameter related to the vibration of the at least one flow tube in the internal fluid at the second pressure level by controlling, with the controller, excitation of the vibration of the at least one flow tube.

37. The method of claim 36, wherein accounting for the at least one operational parameter comprises accounting for at least one of:

a density change of the internal fluid in the chamber;

a viscosity change of the internal fluid in the chamber;

drag force on the at least one flow tube as it vibrates in the internal fluid;

attenuation of the vibration of the at least one flow tube due to the internal fluid in the chamber; and

alteration of a resonant frequency of the at least one flow tube due to the internal fluid in the chamber.

38. The method of any one of claims 27 to 37, further comprising compensating for an operational difference in the vibration of the at least one flow tube caused by the internal fluid at the second pressure level in the chamber surrounding the at least one flow tube by configuring the at least one flow tube with respect to at least one of a wall thickness, a length, a material, a geometric shape, a foil, a series of concave dimples, and a location of vibration sensor.