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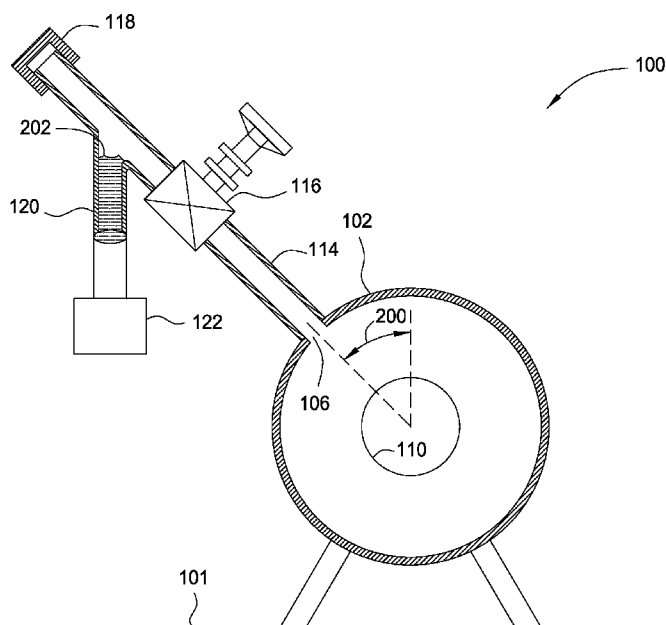
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(54) Title: STEAM METER

FIG. 2



(57) Abstract: A flowmeter detects a differential pressure of steam as the steam passes through a conduit with a feature shaped to produce changes in velocity and pressure of the steam. Taps used to enable detection of the differential pressure extend from a wall of the conduit upward toward vertical (defined as parallel to the direction of gravitational force) in order to drain liquid water into the conduit from the tap. The differential pressure measured enables calculation of flow rate of the steam.

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STEAM METER

5 Cross-Reference to Related Applications

This application claims the benefit under 35 U.S.C. § 119(e) to provisional application No. 60/971,700, filed September 12, 2007, the entire contents of which are incorporated herein by reference.

10 **Background**

Conduits in many applications carry steam utilized for its heat or its ability to be converted to mechanical work. These applications often require measuring flow of the steam through the conduits. In one example, such measurements enable determining quantity of the steam purchased. The quantity and cost to generate the steam can make annual value of the steam worth substantial sums of money. Accordingly, proper accounting for these purchases relies on accuracy of metering.

One prior meter design utilizes a differential pressure measured across a restriction in the conduit. However, configurations for such previous steam meters produce results subject to errors. Further, difficult calibration procedures for these meters add to inaccuracy of the results.

Therefore, a need exists for improved meters to measure flow of steam.

25 **Summary**

In one embodiment, a steam meter includes a steam-conveying conduit defining a fluid-flow-pressure-change-inducing-section. First and second ports through a wall of the conduit are spaced apart across the section. First and second tap ducts coupled respectively to the first and second ports extend from the wall of the conduit at an angle less than 90° from vertical, which is defined as parallel to gravitational force, such that orientation of the tap ducts drains liquid into the conduit from the tap ducts. First and second sensing ducts couple respectively to the first and second tap ducts and are filled with liquid up to levels limited by communication with

the tap ducts. At least one pressure sensor couples to at least one of the sensing ducts.

According to one embodiment, a method of measuring a flow rate of steam includes conveying the steam through a conduit. First and second tap ducts are coupled respectively to first and second ports through a wall of the conduit along part of the conduit that defines a fluid-flow-pressure-change-inducing section. The method further includes draining liquid from the tap ducts into the conduit by orienting the tap ducts to extend from the wall of the conduit at an angle less than 90° from vertical, which is defined as parallel to gravitational force. In addition, the method includes detecting a differential pressure across the section, wherein the differential pressure is established through the ports and tap ducts to first and second sensing ducts filled with liquid up to levels limited by communication with the tap ducts. The differential pressure detected enables calculating the flow rate of the steam.

In one embodiment, a method of measuring flow rate of steam includes conveying the steam through a conduit. First and second tap ducts are coupled respectively to first and second ports through a wall of the conduit along part of the conduit that defines a fluid-flow-pressure-change-inducing section. The method includes closing first and second valves disposed respectively along the first and second tap ducts, introducing liquid into ends of the tap ducts distal relative to the conduit such that the liquid fills first and second sensing ducts, and opening the valves to drain liquid from the tap ducts oriented to extend from the wall of the conduit at an angle less than 90° from vertical, which is defined as parallel to gravitational force. Further, the method includes detecting a differential pressure across the section, wherein the differential pressure is established through the ports and tap ducts. The differential pressure detected enables calculating the flow rate of the steam.

30 Brief Description of the Drawings

For a further understanding of the nature and objects of the present invention, reference should be made to the following detailed description, taken in conjunction with the accompanying drawings, in which like elements are given the same or analogous reference numbers and wherein:

Figure 1 illustrates a cross-sectional side view of a steam meter, according to one embodiment of the invention; and

5 Figure 2 illustrates a cross-sectional end view of the steam meter taken across line 2-2 in Figure 1, according to one embodiment of the invention.

Description of Preferred Embodiments

Embodiments of the invention generally relate to flowmeters. In one
10 embodiment, the flowmeter detects a differential pressure of steam as the steam passes through a conduit with a feature shaped to produce changes in velocity and pressure of the steam. Taps used to enable detection of the differential pressure extend from a wall of the conduit at an angle less than 90° from vertical (defined herein as parallel to gravitational force). Orientation of the taps drains liquid water
15 into the conduit from the taps. Since the taps extend from the wall upward in the vertical direction, this draining mitigates or avoids errors from condensation in the taps and improper calibration. The differential pressure measured enables calculation of flow rate of the steam.

20 Exemplary applications for the flowmeters include conduits within steam distribution networks or at a power plant. The conduit may couple to a turbine for electric generation at the power plant. For some embodiments, the size of the conduit may be between 30 centimeter (cm) and 100 cm in diameter.

25 Figure 1 shows a side view of a steam meter **100** disposed along a conduit **102**. The conduit **102** as depicted runs parallel to a ground surface **101** of earth and is supported above the surface **101**. While reference to this orientation is described herein, other orientations may incorporate aspects disclosed and achieve like benefits. The side view illustrates the steam meter **100** in cross section taken
30 longitudinally down a bore of the conduit **102**. In operation, the steam meter **100** measures flow rate of a fluid **104** (depicted by an arrow) flowing through the conduit **102**.

For some embodiments, a condensable gas such as steam forms the fluid **104**, which is in a gaseous phase and may contain only pure vaporized water or vaporized water mixed with one or more other gasses (e.g., air). The fluid **104** may be at a temperature and pressure such that the fluid is superheated and contains no liquid phase. If small amounts of the liquid phase relative to volume of the fluid **104** are reintroduced to the fluid **104**, the liquid phase returns to the gaseous phase due to the superheating of the fluid **104**.

A fluid-flow-pressure-change-inducing-section of the conduit **102** defines part of the steam meter **100** and has a feature such as a flow nozzle, an orifice plate, or V-cone that produces changes in velocity and pressure of the fluid **104** according to conservation of energy and mass as the fluid **104** passes through the feature. As shown, the feature defines a Venturi with a first inner diameter **112** that converges to a smaller second inner diameter **110** at a throat of the Venturi. The conduit **102** defines both an entry frustoconical shape converging to the throat and an exit frustoconical shape diverging from the throat. The throat may maintain the second inner diameter **110** and spaces apart this convergence and divergence along the conduit **102**.

First and second ports **106**, **108** through a wall of the conduit **102** enable measuring pressure of the fluid **104** at locations of the ports **106**, **108**. As a result of the locations for the ports **106**, **108**, the first port **106** provides fluid communication with the fluid **104** at the first inner diameter **112** while the second port **108** is in fluid communication with the fluid **104** at the second inner diameter **110**. Restriction caused by the second inner diameter **110** creates a differential pressure that can be detected between the ports **106**, **108** and used in flow rate calculations regardless of whether the first port **106** is upstream or downstream of the second port **108**.

The steam meter **100** further includes first and second tap ducts **114**, **124** that are each coupled to an outside surface of the conduit **102**. The first and second tap ducts **114**, **124** respectively align with the first and second ports **106**, **108**. First and second sensor ducts **120**, **130** respectively couple the first and second tap ducts **114**, **124** to at least one pressure sensor, such as a differential pressure sensor **122**. In some embodiments, discrete absolute pressure sensors may replace the differential

pressure sensor **122** such that pressure transmitted by each of the ports **106**, **108** is detected. Calculation of differences in readings of the absolute pressure sensors thus also enables determination of the differential pressure.

5 Signal line **132** couples the pressure sensor **122** to processing equipment **134** configured with logic to calculate the flow rate of the fluid **104** based on detection of the differential pressure by the pressure sensor **122**. While such signal processing is conventional, physical configuration of components forming the steam meter **100** provides accurate detection of the differential pressure relied on to achieve accurate
10 results with the signal processing. The following describes embodiments for this physical configuration.

 In some embodiments, the tap ducts **114**, **124** and sensor ducts **120**, **130** have an inner diameter that is between 0.5 cm and 5.0 cm. As the diameter increases,
15 tendency for siphoning decreases. Further, the inner diameter of the tap ducts **114**, **124** may or may not match the inner diameter of the sensor ducts **120**, **130**. While shown as circular in cross section, the tap ducts **114**, **124** and sensor ducts **120**, **130** may define other shapes such as polygonal.

20 The tap ducts **114**, **124** extend from the wall of the conduit **102** and may be substantially straight. First and second caps **118**, **128** seal respective ends of the tap ducts **114**, **124** distal to the conduit **102**. First and second valves **116**, **126** disposed respectively along the first and second tap ducts **114**, **124** enable fluid isolation of the pressure sensor **122** from the conduit **102**.

25

 Figure 2 illustrates the steam meter **100** in cross section taken transverse to the length of the conduit **102** as shown by line 2-2 in Figure 1. The second tap duct **124**, which is hidden behind the first tap duct **114**, is analogous to the first tap duct **114** in function and interrelations and thus not described separately. The first tap duct
30 **114** extends from the wall of the conduit **102** at an angle **200** (depicted by an arrow) that is less than 90° relative to vertical and that is selected to drain into the conduit **102** liquid from the first tap duct **114**. For some embodiments, the angle **200** permits draining and avoids siphoning as discussed herein by being between 15° and 75° or between 45° and 75°.

In operation, the fluid **104** enters the first tap duct **114** where temperature of the fluid **104** falls as a function of distance from the conduit **102**. The fluid becomes liquid once the temperature of the fluid **104** reaches condensing temperature. Any liquid condensate however falls back into the conduit **102** and is not retained in the first tap duct **114**. Retention of liquid condensate in the first tap duct **114** influences pressure readings and is thus avoided with sufficient slope provided by the angle **200**. In particular, the angle **200** prevents influence of any possible liquid condensate in the first tap duct **114** on calibration that is based on a preset amount of liquid **202** (e.g., water) that fills the first sensing duct **120**.

For some embodiments, the first tap duct **114** couples in a perpendicular relation to the wall of the conduit **102**. As such, the angle **200** further corresponds to the location of the first port **106** around a circumference of the conduit **102**. In these situations, values for the angle **200** approaching zero (*i.e.*, the first tap duct **114** directly on top of the conduit **102**) tend to increase potential for the first tap duct **114** to hold liquid due to a siphoning phenomena. Offsetting the first tap duct **114** from directly on top of the conduit **102** ensures proper functioning of the steam meter **100** and transmission of pressure through the first tap duct **114**. Regardless of circumferential position, the angle **200** that the first tap duct **114** extends from the conduit **102** supports draining of the first tap duct **114** making it also possible to have the first tap duct **114** tangential to the conduit **102**.

The first sensing duct **120** extends from the first tap duct **114** at a location between the first valve **116** and the first cap **118** and in a direction toward the ground surface **101**. The liquid **202** thereby stays in the first sensing duct **120** up to where the first sensing duct **120** and the first tap duct **114** intersect. The first sensing duct **120** bends toward the pressure meter **122**, which is located between the first and second tap ducts **114**, **124**. In operation, pressure from the fluid **104** is established through the first tap duct **114** and acts on the liquid **202** contained in the first sensing duct **120**. The pressure sensor **122** thereby detects pressure of the fluid **104** as transmitted to the pressure sensor **122** via the liquid **202**.

Calibrating of the pressure sensor **122** requires the water **202** to be in the first sensing duct **120**. A set-up procedure for the calibration includes closing the first valve **116** and introducing the liquid **202** into the end of the first tap duct **114** while the first cap **118** is removed from the end. This filling may occur prior to securing the first cap **118** to the first tap duct **114** and continues until the liquid **202** overfills the first sensing duct **120**. Thereafter, the first cap **118** is secured to the first tap duct **114** by threads and/or welding, and the first valve **116** is opened to let excess of the liquid **202** flow into the conduit **102**. Once both the first and second sensing ducts **120**, **130** have been accordingly filled, the calibration of the pressure sensor **122** accounts for the liquid **202**.

A comparison was performed between an embodiment of the present invention (steam meter **100**) and a comparison device. The comparison device had tap ducts extending horizontal with respect to vertical. The steam meter **100** according to an embodiment of the present invention had orientation of the tap ducts **114**, **124** arranged at 45° relative to the vertical direction and provided improved results relative to the comparison device. In a test setup, water was vaporized and passed through the steam meter **100** and the comparison device. Actual volume of the steam passing through the meter **100** or the comparison device was determined by measuring the water that was converted to the steam. The steam meter **100** yielded accurate results. However, the comparison device obtained a false result with about a 5 % error.

It will be understood that many additional changes in the details, materials, steps, and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims. Thus, the present invention is not intended to be limited to the specific embodiments in the examples given above and/or the attached drawings.

What is claimed is:

1. A steam meter, comprising:
a steam-conveying conduit defining a fluid-flow-pressure-change-inducing-
5 section;
first and second ports through a wall of the conduit, wherein the ports are
spaced apart across the section;
first and second tap ducts coupled respectively to the first and second ports
and extending from the wall of the conduit at an angle less than 90° from vertical,
10 which is defined as parallel to gravitational force, wherein orientation of the tap ducts
drains liquid into the conduit from the tap ducts;
first and second sensing ducts coupled respectively to the first and second tap
ducts, wherein the sensing ducts are filled with liquid up to levels limited by
communication with the tap ducts; and
15 at least one pressure sensor coupled to at least one of the sensing ducts.
2. The steam meter of claim 1, wherein the angle is between 15° and 75°.
3. The steam meter of claim 1, wherein the at least one pressure sensor
20 comprises a differential pressure sensor in fluid communication with both the first and
second sensing ducts.
4. The steam meter of claim 1, further comprising signal processing equipment
coupled to the at least one pressure sensor, wherein the signal processing equipment
25 is configured to calculate a flow rate of steam flowing through the steam-conveying
conduit based on a differential pressure transmitted through the first and second
ports.
5. The steam meter of claim 1, wherein the fluid flow pressure change inducing
30 section comprises a Venturi.
6. The steam meter of claim 1, wherein the first port is located in a larger inner
diameter of the conduit than the second port.

7. The steam meter of claim 1, wherein the first and second ports are located around a circumference of the conduit corresponding with the angle.

8. The steam meter of claim 1, wherein the liquid comprises water.

5

9. A method of measuring a flow rate of steam, comprising:

conveying the steam through a conduit, wherein first and second tap ducts are coupled respectively to first and second ports through a wall of the conduit along part of the conduit that defines a fluid-flow-pressure-change-inducing section;

10 draining liquid from the tap ducts into the conduit by orienting the tap ducts to extend from the wall of the conduit at an angle less than 90° from vertical, which is defined as parallel to gravitational force; and

detecting a differential pressure across the section, wherein the differential pressure is established through the ports and tap ducts to first and second sensing
15 ducts filled with liquid up to levels limited by communication with the tap ducts; and
calculating the flow rate of the steam based on the differential pressure detected.

10. The method of claim 9, wherein the angle is between 15° and 75°.

20

11. The method of claim 9, wherein the fluid flow pressure change inducing section comprises a Venturi.

12. The method of claim 9, wherein the first port is located in a larger inner
25 diameter of the conduit than the second port.

13. The method of claim 9, wherein the first and second ports are located around a circumference of the conduit corresponding with the angle.

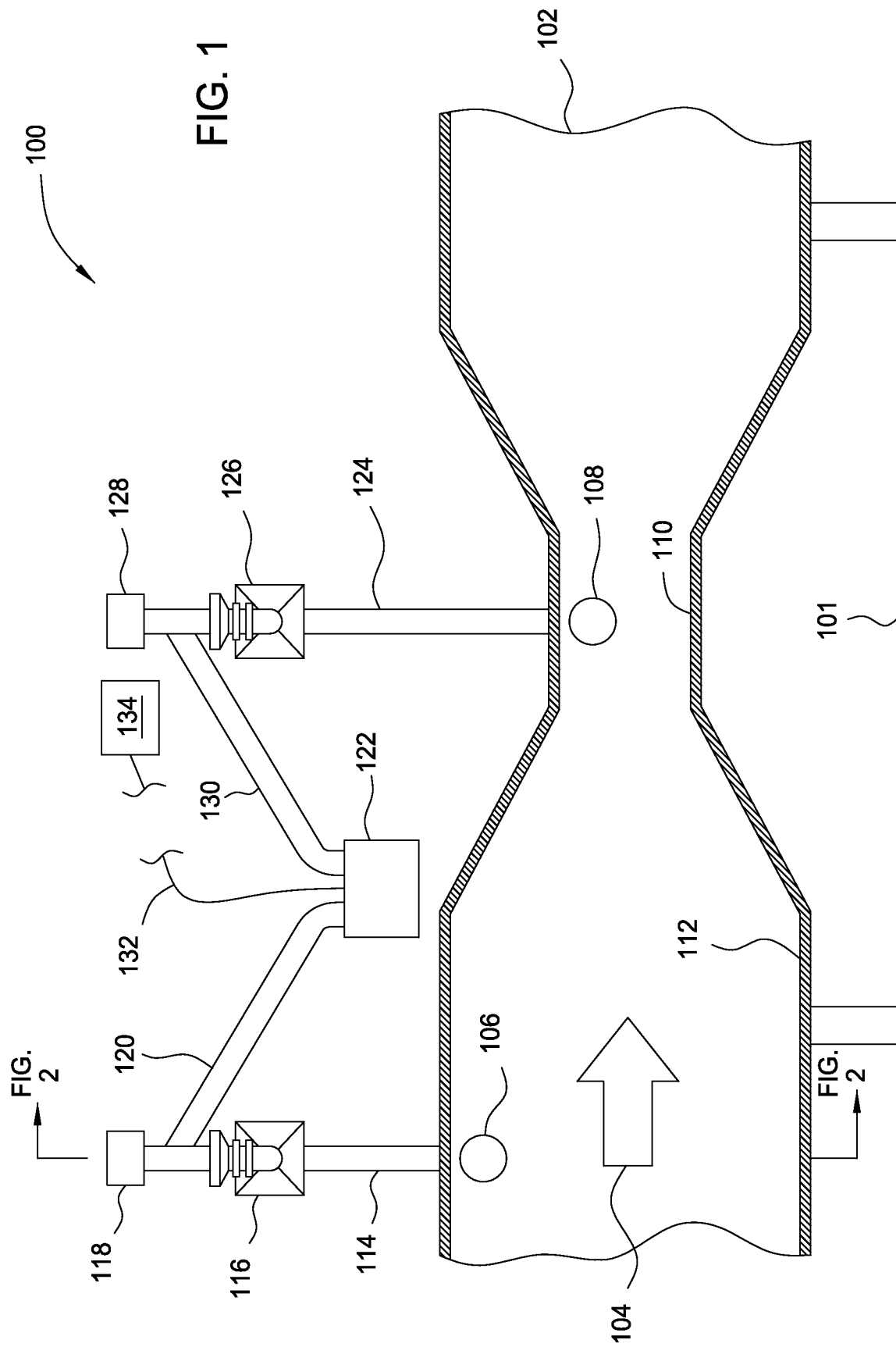
30 14. The method of claim 9, further comprising:

closing first and second valves disposed respectively along the first and second tap ducts;

introducing the liquid into ends of the tap ducts distal to the conduit, wherein the liquid fills the first and second sensing ducts; and

opening the valves to drain liquid from the tap ducts.

15. A method of measuring a flow rate of steam, comprising:
conveying the steam through a conduit, wherein first and second tap ducts are
5 coupled respectively to first and second ports through a wall of the conduit along part
of the conduit that defines a fluid-flow-pressure-change-inducing section;
closing first and second valves disposed respectively along the first and
second tap ducts;
introducing liquid into ends of the tap ducts distal relative to the conduit,
10 wherein the liquid fills first and second sensing ducts;
opening the valves to drain liquid from the tap ducts oriented to extend from
the wall of the conduit at an angle less than 90° from vertical, which is defined as
parallel to gravitational force;
detecting a differential pressure across the section, wherein the differential
15 pressure is established through the ports and tap ducts; and
calculating the flow rate of the steam based on the differential pressure
detected.
16. The method of claim 15, wherein the angle is between 15° and 75°.
- 20 17. The method of claim 15, wherein the fluid flow pressure change inducing
section comprises a Venturi.
18. The method of claim 15, wherein the first port is located in a larger inner
25 diameter of the conduit than the second port.
19. The method of claim 15, wherein the first and second ports are located around
a circumference of the conduit corresponding with the angle.
- 30 20. The method of claim 15, further comprising calibrating a differential pressure
sensor based on the liquid filling the first and second sensing ducts.



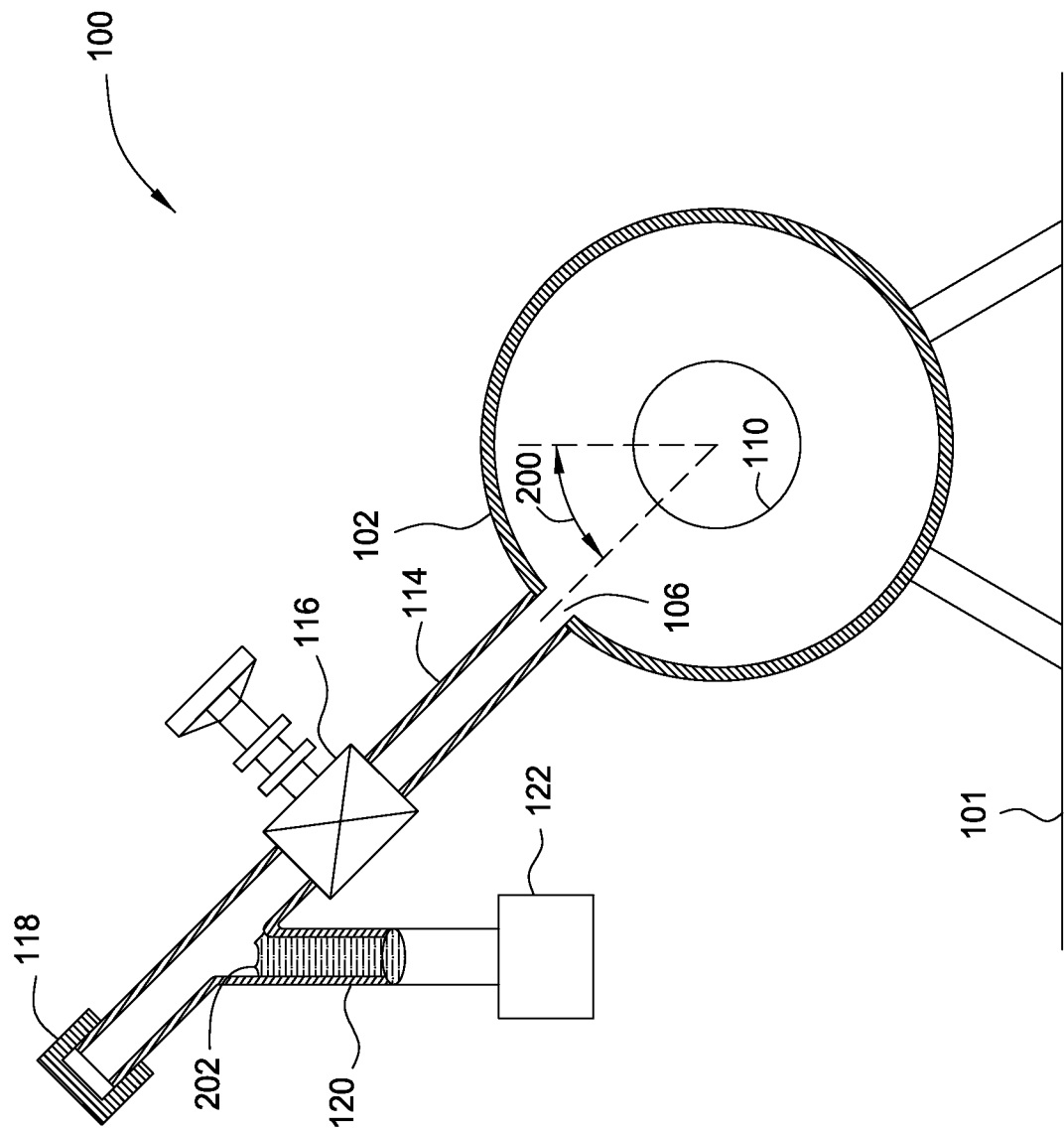


FIG. 2