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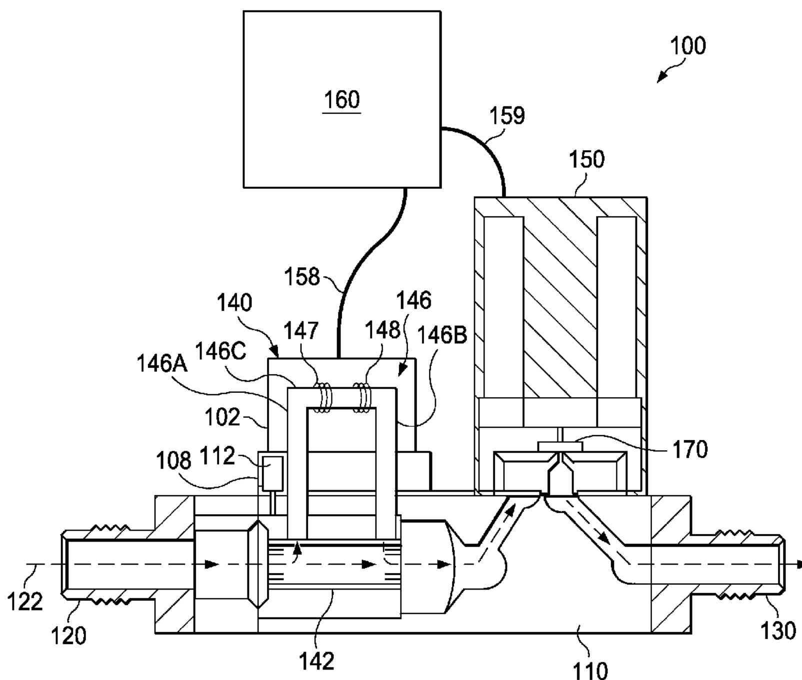
(54) **Title**: HIGH FLOW PIEZO TYPE VALVE



(57) **Abstract**: The disclosed embodiments include a piezo valve for both high and low flow mass flow controllers. This style valve utilizes a piezo stack for controlling flow by deflecting a valve seat upwards from its sealed seated position over an orifice of known diameter in a controlled fashion. Due to its inherent limitations, a piezo stack can generate a large force, but with a small displacement. In order to develop high flows within the valve, the disclosed embodiments include a stroke multiplier or amplifier for increasing a displacement of the valve seat to increase flow through the valve assembly by increasing the ratio of movement of the piezo stack to a deflection of the valve seat.

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HIGH FLOW PIEZO TYPE VALVE

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates generally to methods and systems for controlling fluid flow, and more particularly to a high flow piezo type valve.

[0003] 2. Discussion of the Related Art

[0004] Many industrial processes require precise control of various process fluids. For example, in the semiconductor industries, mass flow controllers are used to precisely measure and control the amount of a process fluid that is introduced to a process chamber. The term fluid is used herein to describe any type of matter in any state that is capable of flow.

[0005] An integral part of the mass flow controller is the valve, which regulates, directs or controls the flow of a fluid by opening, closing, or partially obstructing various passageways.

SUMMARY

[0006] The disclosed embodiments include a piezo valve for both high and low flow mass flow controllers. This style valve utilizes a piezo stack for controlling flow by deflecting a valve seat upwards from its sealed seated position over an orifice of known diameter in a controlled fashion. The maximum flow possible through the valve for a given set of fluid conditions is governed by the diameter of the orifice and the maximum displacement of the valve seat. Due to its inherent limitations, a piezo stack can generate a large force but with a small displacement. For example, a typical 2.5" long piezo actuator has a maximum displacement of only about 0.0022". This is not adequate displacement to allow the desired amount of flow using an orifice of practical size. Thus, in order to develop high flows within the valve, the disclosed embodiments include a stroke multiplier or amplifier for increasing a displacement of the valve seat to increase flow through the valve assembly by increasing the ratio of movement of the piezo stack to a deflection of the valve seat.

[0007] For instance, one embodiment disclosed herein is a valve assembly that includes a piezo stack; a valve seat configured to be moved in a vertical direction using the piezo stack; and a stroke amplifier for increasing a displacement of the valve seat to increase flow through the valve assembly by increasing the ratio of movement of the piezo stack to a deflection of the valve seat. In certain embodiments, the stroke amplifier is a spring pivoted on a fulcrum. In

one embodiment, the fulcrum is a multiplier pin, whereas in other embodiments the fulcrum is a pivot nut. Still, in other embodiments, the stroke amplifier is a single piece flexure component as disclosed herein. Further, in certain embodiments, the valve assembly may also include a sensor to determine a position of a valve seat relative to an orifice for enhancing control of the
5 flow through the valve assembly. The disclosed valve assembly may be incorporated in a mass flow controller as described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Illustrative embodiments of the present invention are described in detail below with
10 reference to the attached drawing figures, which are incorporated by reference herein and wherein:

[0009] Figure 1 illustrates an example of a mass flow controller in which embodiments of a high flow piezo type valve disclosed herein may be incorporated;

[0010] Figure 2 illustrates an example of a high flow piezo type valve in accordance with a
15 disclosed embodiment;

[0011] Figure 3 illustrates an example of a high flow piezo type valve in accordance with another disclosed embodiment;

[0012] Figure 4 illustrates an example of a pivot nut in accordance with a disclosed embodiment;

20 **[0013]** Figure 5 illustrates the top view of two examples of a pressure plate spring in accordance with the disclosed embodiments;

[0014] Figure 6 illustrates another example of a high flow piezo type valve that uses a single monolithic flexure component to provide valve stroke multiplication or amplifier in accordance with the disclosed embodiments;

25 **[0015]** Figure 7 illustrates a variant of a flexure for use in a valve in accordance with the disclosed embodiments;

[0016] Figures 7A and 7B illustrate the movement of a flexure in accordance with a disclosed embodiment;

[0017] Figures 8-13 illustrates various non-limiting examples of flexure designs in accordance
30 with the disclosed embodiments; and

[0018] Figure 14 illustrates an example of a sensor to determine position of a valve seat relative to an orifice in accordance with the disclosed embodiments.

DETAILED DESCRIPTION

5 [0019] The disclosed embodiments and advantages thereof are best understood by referring to Figures 1-14 of the drawings, like numerals being used for like and corresponding parts of the various drawings. Other features and advantages of the disclosed embodiments will be or will become apparent to one of ordinary skill in the art upon examination of the following figures and detailed description. It is intended that all such additional features and advantages be
10 included within the scope of the disclosed embodiments. Further, the illustrated figures are only exemplary and are not intended to assert or imply any limitation with regard to the environment, architecture, design, or process in which different embodiments may be implemented.

[0020] FIG. 1 shows schematically a typical mass flow controller 100 that includes a block 110, which is the platform on which the components of the MFC are mounted. A thermal mass flow
15 meter 140 and a valve assembly 150 containing a valve 170 are mounted on the block 110 between a fluid inlet 120 and a fluid outlet 130. The thermal mass flow meter 140 includes a bypass 142 through which typically a majority of fluid flows and a thermal flow sensor 146 through which a smaller portion of the fluid flows.

[0021] Thermal flow sensor 146 is contained within a sensor housing 102 mounted on a
20 mounting plate or base 108. In the depicted embodiment, thermal flow sensor 146 comprises a small diameter tube, typically referred to as a capillary tube, having a sensor inlet portion 146A, a sensor outlet portion 146B, and a sensor measuring portion 146C about which two resistive coils or windings 147 and 148 are disposed. In operation, electrical current is provided to the two resistive windings 147 and 148, which are in thermal contact with the sensor measuring
25 portion 146C. The current in the resistive windings 147 and 148 heats the fluid flowing in measuring portion 146C to a temperature above that of the fluid flowing through the bypass 142. The resistance of windings 147 and 148 varies with temperature. As fluid flows through the sensor conduit, heat is carried from the upstream resistive winding 147 toward the downstream resistive winding 148, with the temperature difference being proportional to the
30 mass flow rate through the sensor.

[0022] An electrical signal related to the fluid flow through the thermal flow sensor 146 is derived from the two resistive windings 147 and 148. The electrical signal may be derived in a

number of different ways, such as from the difference in the resistance of the resistive windings or from a difference in the amount of energy provided to each resistive winding to maintain each winding at a particular temperature. The electrical signals derived from the resistive windings 147 and 148 after signal processing comprise a sensor output signal. The sensor output signal is correlated to mass flow in the mass flow meter 140 so that the fluid flow can be determined when the electrical signal is measured. The sensor output signal is typically first correlated to the flow in thermal flow sensor 146, which is then correlated to the mass flow in the bypass 142, so that the total flow through the flow meter can be determined and the valve 170 can be controlled accordingly.

[0023] The bypass 142 is coupled to the thermal flow sensor 146 and is characterized with a known fluid to determine an appropriate relationship between fluid flowing in the mass flow sensor 146 and the fluid flowing in the bypass 142 at various known flow rates, so that the total flow through the mass flow meter 140 can be determined from the sensor output signal. In certain embodiments, the mass flow controller 100 may not utilize a bypass 142 and the entire flow passes through the thermal flow sensor 146.

[0024] In addition, the mass flow controller 100 may include a pressure transducer 112 coupled to a flow path 122, typically, but not limited to, upstream of the bypass 142 to measure pressure in the flow path 122. Pressure transducer 112 provides an electrical signal indicative of the pressure.

[0025] Control electronics 160 control the position of the valve 170 in accordance with a set point indicating the desired mass flow rate, and an electrical flow signal from the thermal flow sensor 146 indicative of the actual mass flow rate of the fluid flowing in the sensor conduit. In one embodiment, traditional feedback control methods such as proportional control, integral control, proportional-integral (PI) control, derivative control, proportional-derivative (PD) control, integral-derivative (ID) control, and proportional-integral-derivative (PID) control are then used to control the flow of fluid in the mass flow controller 100. A control signal (e.g., a control valve drive signal) is generated based upon an error signal that is the difference between a set point signal indicative of the desired mass flow rate of the fluid and a feedback signal that is related to the actual mass flow rate sensed by the thermal flow sensor 146. The valve 170 is positioned in the fluid flow path 122 (typically downstream of the bypass 142 and the thermal flow sensor 146) and can be controlled (e.g., opened or closed) to vary the mass flow rate of fluid flowing through the main fluid flow path 122, the control being provided by the control electronics 160.

[0026] In the illustrated example, the flow rate is supplied by electrical conductors 158 to the control electronics 160 as a voltage signal. The signal is amplified, processed and supplied to the control valve assembly 150 to modify the flow. To this end, the control electronics 160 compares the signal from the mass flow meter 140 to predetermined values and adjusts the
5 valve 170 accordingly to achieve the desired flow.

[0027] Figure 2 illustrates an example of a high flow piezo type valve 200 in accordance with a disclosed embodiment. In the depicted embodiment, the high flow piezo type valve 200 includes a diaphragm assembly 202 that contains a diaphragm and a valve seat 204. In one embodiment, the outer part of the diaphragm is rigid while the inner part of the diaphragm and
10 the valve seat 204 is moveable along a vertical axis. Attached to the outer part of the diaphragm assembly 202 are an outer housing 206 and a top cap 208 that hold a piezo stack 210 in place. In the illustrated embodiment, the piezo stack 210 is shown in its relaxed state, or its shortest length.

[0028] By applying voltage to the piezo stack 210, its overall length increases, which in turn
15 generates a downward force on a ball 218. In the disclosed embodiment, the ball 218 pushes against a multiplier plate 214 that pivots against a set of multiplier pins 216 that are coupled to a multiplier body 220 for increasing the diaphragm stroke. The downward force on the multiplier plate 214 and the set of multiplier pins 216 causes the outer portion of the multiplier body 220 to be deflected upwards lifting the base of the multiplier body 220 and a valve stem 222. The
20 inner part of the diaphragm and the valve seat 204 is then in turn deflected upwards allowing flow between the bottom of the diaphragm and the top of the orifice (not shown).

[0029] As stated above, the spring is pivoted on a fulcrum, which in this embodiment is a multiplier pin that allows a configurable motion ratio to increase the diaphragm stroke. For example, assume in one embodiment that the orifice is .250" and we desire the diaphragm
25 assemble to have a stroke of approximately .011". Assuming that the stroke from the stack is .0019", then a 5.2:1 multiplier is needed. In this example, if a spring having a diameter approximately equal to .650" (radius = .325") and a ball having a diameter approximately equal to .062" is used, then the effective arm length would equal .293", thus, providing a 6:1 multiplier ratio.

30 **[0030]** Figure 3 illustrates another example of a high flow piezo type valve 300 in accordance with the disclosed embodiments. The high flow piezo type valve 300 includes a piezo stack 316 located within an outer housing 318 and covered by a top cap 320. In some embodiments, the

top cap 320 can also be manufactured into the outer housing 316 to reduce the total parts required in the valve 300. The housing 318 is coupled to a diaphragm assembly 326. In one embodiment, the housing 318 employs a threaded design 322 that enables a locking nut 324 to be used in the assembling of the valve 300 such that a proper preload can be applied to the piezo
5 stack 316.

[0031] Similar to the valve in Figure 2, the piezo stack 316 when extended contacts a ball 330, which causes a downward force onto a transfer device 334. In this embodiment, the high flow piezo type valve 300 uses a pivot plate 310 for providing a fulcrum on which a pressure plate spring 314 pivots, which allows a configurable motion ratio to increase the diaphragm stroke.
10 Here, the downward force on the transfer device 334 causes the pressure plate spring 314 to pivot against the pivot plate 310, thereby causing the inner portion of the pressure plate spring 314 to elevate. The inner portion of the pressure plate spring 314 pushes upwards against a nut 336 that is coupled to a valve stem 340 causing the valve stem 340 to rise resulting in the inner part of a diaphragm and a valve seat 342 to deflect upwards allowing flow between the bottom
15 of the diaphragm and a top of an orifice.

[0032] Figure 4 illustrates an example of a pivot plate 400 in accordance with a disclosed embodiment. In some embodiments, to provide a larger diaphragm stroke, the ratio of the stroke may be modified by changing the diameter of the ring of the pivot plate (i.e., the smaller the diameter of the ring, the bigger the ratio). For example, in the depicted embodiment, the
20 illustrated diameter of the pivot plate has pivot points 404A and 404B that provide a 1:1 ratio. However, the diameter of the pivot plate 400 may be reduced to provide bigger ratios. For example, the diameter of the pivot plate may be decreased to where the pivot point moves from the pivot points 404A and 404B locations to a 6:1 ratio pivot point location as illustrated by pivot points 402A and 402B in the diagram. Of course, the pivot point/diameter of the pivot
25 plate 400 may be modified to any ratio in between the depicted pivot points. Additionally, in certain embodiments, the pivot plate may provide ratios greater than 6:1 by decreasing the diameter even further.

[0033] Figure 5 illustrates the top view of two examples of a pressure plate spring 500A and 500B in accordance with the disclosed embodiments. By using a spring that has only a thin
30 band connecting the fingers 510A and 510B, the transfer device is easily able to move the outer diameter of the spring downwards while the inner diameter of the spring moves upwards against the nut. Reducing the width of the band connecting the fingers 510A and 510B allow for reduced stress within the spring as well as reduced force within the entire system since it is

mechanically easier to pivot a single beam on a fulcrum as compared to a disc on a fulcrum. The number of fingers 510A and 510B required may vary as well as their configuration depending on the motion ratio and force required to meet the valve stroke.

[0034] Figure 6 illustrates another example of a high flow piezo type valve 600 that uses a single monolithic flexure component 650 to provide valve stroke multiplication or amplifier in accordance with the disclosed embodiments. The valve 600 includes a piezo stack 618 located and covered within an outer housing 616. In the depicted embodiment, the housing 616 is coupled to a diaphragm assembly 626 using a housing coupler 602. In one embodiment, the housing 616 employs a threaded design 622 that enables a locking nut 624 to be used in securing the outer housing 616 to the housing coupler 602 allowing preload adjustment on the piezo stack 618. Use of shims 664 underneath the flexure 650 allows the contact point 656 to not engage the flexure support 660 until the piezo stack 618 is preloaded to deflect the flexure 650. This flexure deflection allows optimum preload on the piezo stack 618 while not disrupting the valve shutoff thereby decoupling the valve shutoff from the piezo stack 618 preload. This is a significant benefit as the piezo stack 618 has an optimum preload and the valve shutoff has an optimum value. Assembly is drastically more difficult if these two settings are interdependent.

[0035] In this embodiment, the piezo stack 618 when extended contacts a ball 630, which causes a downward force onto a center 652 of the flexure 650. The center 652 of the flexure 650 translates down. This causes arms 654 of the flexure 650 to pivot about a contact point 656 between the flexure 650 and a flexure support 660. This motion lifts the base of the flexure 650, allowing the diaphragm and a valve seat 640 to move upwards opening the valve 600. Multiplication ratio is controlled by changing the location of the contact point 656 with respect to the center 652 of the flexure 650. In this particular embodiment, as the flexure component is just a single part, changing of the stroke multiplier can easily be done by swapping out the flexure component with a different flexure component that has a different location for contact points 656.

[0036] In some embodiments, different thickness therefore different spring rate preload springs 632 can be used to increase valve shutoff if required.

[0037] Figure 7 illustrates a variant of a flexure 700 for use in a valve in accordance with the disclosed embodiments. In the depicted embodiment, the flexure 700 differs from flexure 650 depicted in Figure 6 in that it has more of a rectangular center 702 and arm 704 components.

The arm 704 components are connected to the center 702 using straight flexible joints 706. An advantage of this design is that it easier to fabricate and thus, likely to reduce cost.

[0038] As illustrated in Figure 7A, when the piezo stack is extended, a downward force will be exerted onto the center 702 of the flexure 700. The arm 704 of the flexure 700 will pivot about
5 a contact point 710 against a support structure 712 and lift the outer portion of arm 704 up as illustrated in Figure 7B. Thus, lifting a base 708 of the flexure 700, allowing the inner part of a diaphragm to move upwards opening the valve.

[0039] Figures 8-13 illustrates various non-limiting examples of flexure designs in accordance with the disclosed embodiments. For instance, Figure 8 illustrates an embodiment of a flexure
10 in which the arm portions are connected to a bottom portion of the center portion of the flexure using a curved s-shaped flexible joint. In contrast, Figure 9 illustrates an embodiment of a flexure in which the arm portions are connected to a top portion of the center portion of the flexure using a curved s-shaped flexible joint.

[0040] Still, other embodiments within the scope of the claims may have the arm and contact
15 points located on the bottom portion of the flexure component as illustrated in Figure 10. Further, as depicted in Figure 10, in certain embodiments, the contact points may be located on either the top or bottom side of the arm portion of the flexure. For instance, one such example is illustrated in Figure 11 in which the center portion is located on a top tier level above the arms and contact points.

20 **[0041]** It is also contemplated that the center portion of the flexure that contact the ball may be located on a bottom tier level as illustrated in Figure 12. Still, Figure 13 illustrates another embodiment of a flexure in which the center portion of a flexure is slightly elevated from the two arm portions and contact points.

[0042] Additionally, in certain embodiments, the disclosed valve assemblies may also include a
25 sensor, as illustrated in Figure 14, to determine position of the valve seat relative to the orifice. For instance, in one embodiment, a laminated etch foil sensor may be incorporated directly to a valve diaphragm. Alternatively, a foil sensor may be laminated to a metal disk that is packaged separate from the diaphragm between the seat and piezo actuator for use in any piezo valve. In another embodiment, a silicon sensor may be used. For example, in one embodiment, four
30 silicon strain gauges may be epoxied or bonded to a diaphragm. In other embodiments, the silicon sensor may be bonded to a separate disk instead of directly to the diaphragm. By placing the sensor(s) on a separate disk, the sensor is isolated thermally from gas path and gas pressure.

Another advantage of placing the sensor on a separate disk is that it decreases the cost to produce the sensors.

[0043] Accordingly, the disclosed embodiments provide a high flow piezo type valve that eliminates the problems associated with existing designs by including a stroke multiplier component(s) as disclosed herein. The disclosed high flow piezo type valve may be incorporated within a mass flow controller, such as, but not limited to, the mass flow controller 100 illustrated in Figure 1, for controlling the flow of fluid. Further, the disclosed embodiments may incorporate the use of a sensor to determine position of the valve seat relative to the orifice for enabling better control of the valve.

[0044] Advantages of the disclosed embodiments include, but are not limited to, amplifying the stroke of a piezo stack to change the motion ratio of the stack with regard to seat deflection in order to develop high flows within the valve. For example, by changing the diameter of the pivot nut ring or the diameter of the multiplier pin locations, the ratio between piezo stroke to diaphragm stroke is changed. This allows the valve to amplify the stroke (e.g., up to a 6:1 ratio) thereby allowing greater flow beneath the valve seat. In turn, one top level assembly can handle both low flow and high flow ranges with the change of a few parts. This provides the opportunity for a highly configurable valve with only a small range of orifice sizes.

[0045] Those skilled in the art will recognize that the present teachings are amenable to a variety of modifications and/or enhancements. While the foregoing has described what is considered to be the best mode and/or other examples, it is understood that various modifications and/or enhancements may be made and that the subject matter disclosed herein may be implemented in various forms and examples, and that the teachings may be applied in numerous applications, only some of which have been described herein. Such modifications are intended to be covered within the scope of the present teachings and appended claims.

CLAIMS

What is claimed:

Claim 1. A valve assembly comprising:

a piezo stack;

5 a valve seat configured to be moved in a vertical direction using the piezo stack; and

a stroke amplifier for increasing a displacement of the valve seat to increase flow through the valve assembly by increasing a ratio of a movement of the piezo stack to a displacement of the valve seat, wherein the stroke
10 amplifier is a beam pivoted on a fulcrum.

Claim 2. The valve assembly according to Claim 1, wherein the fulcrum is a multiplier pin.

Claim 3. The valve assembly according to Claim 1, wherein the fulcrum is a pivot plate.

Claim 4. The valve assembly of Claim 1, further comprising a sensor to determine a position of a valve seat relative to an orifice for enhancing control of the flow through the
15 valve assembly.

Claim 5. A valve assembly comprising:

a piezo stack;

a valve seat configured to be moved in a vertical direction using the piezo stack; and

20 a stroke amplifier for increasing a displacement of the valve seat to increase flow through the valve assembly by increasing a ratio of a movement of the piezo stack to a displacement of the valve seat, wherein the stroke amplifier is a single monolithic flexure component comprising a center portion, a first arm component and a second arm component attached to
25 the center portion using flexible joints, and a first pivot contact point coupled to the first arm component about which the first arm component pivots, and a second pivot contact point coupled to the second arm component about which the second arm component pivots.

Claim 6. The valve assembly of Claim 5, wherein a placement of the first pivot contact point and the second pivot contact point determines the ratio of the movement of the piezo stack to the displacement of the valve seat.

Claim 7. The valve assembly of Claim 5, wherein the single monolithic flexure component applies a preload to the piezo stack and wherein the valve assembly further comprises a preload spring that provides flow shutoff.

Claim 8. The valve assembly of Claim 5, further comprising a sensor to determine a position of a valve seat relative to an orifice for enhancing control of the flow through the valve assembly.

Claim 9. The valve assembly of Claim 5, wherein the flexible joints are curved s-shaped flexible joints.

Claim 10. The valve assembly of Claim 5, further comprising a ball that is in contact with the center portion of the stroke amplifier.

Claim 11. The valve assembly of Claim 10, wherein the valve assembly is configured such that when the piezo stack is extended, the piezo stack contacts the ball, which causes a downward force on the center portion of the stroke amplifier.

Claim 12. The valve assembly of Claim 11, wherein the downward force on the center portion of the stroke amplifier causes the center portion to translate down, which causes the first arm component and the second arm component to respectively pivot about the first pivot contact point and the second pivot contact point to lift a base portion of the stroke amplifier to move the valve seat.

Claim 13. A mass flow controller comprising:

a flow sensor assembly for sensing flow through a flow path;

a control device programmed to receive a desired flow rate from a user input device, receive an indication of flow from the flow sensor assembly, determine an actual flow rate through the flow path, and control a valve assembly to regulate fluid flow; and

wherein the valve assembly comprises:

a piezo stack;

a valve seat configured to be moved in a vertical direction using the piezo stack; and

a stroke amplifier for increasing a displacement of the valve seat to increase flow through the valve assembly by increasing a ratio of movement of the piezo stack to a displacement of the valve seat, wherein the stroke amplifier is a single monolithic flexure component comprising a center portion, a first arm component and a second arm component attached to the center portion using flexible joints, and a first pivot contact point coupled to the first arm component about which the first arm component pivots, and a second pivot contact point coupled to the second arm component about which the second arm component pivots.

Claim 14. The mass flow controller of Claim 13, wherein a placement of the first pivot contact point and the second pivot contact point determines the ratio of the movement of the piezo stack to the displacement of the valve seat.

Claim 15. The mass flow controller of Claim 13, wherein the single monolithic flexure component applies a preload to the piezo stack and wherein the mass flow controller further comprises a preload spring that provides flow shutoff.

Claim 16. The mass flow controller of Claim 13, wherein the valve assembly further comprises a sensor to determine a position of a valve seat relative to an orifice for enhancing control of the flow through the valve assembly.

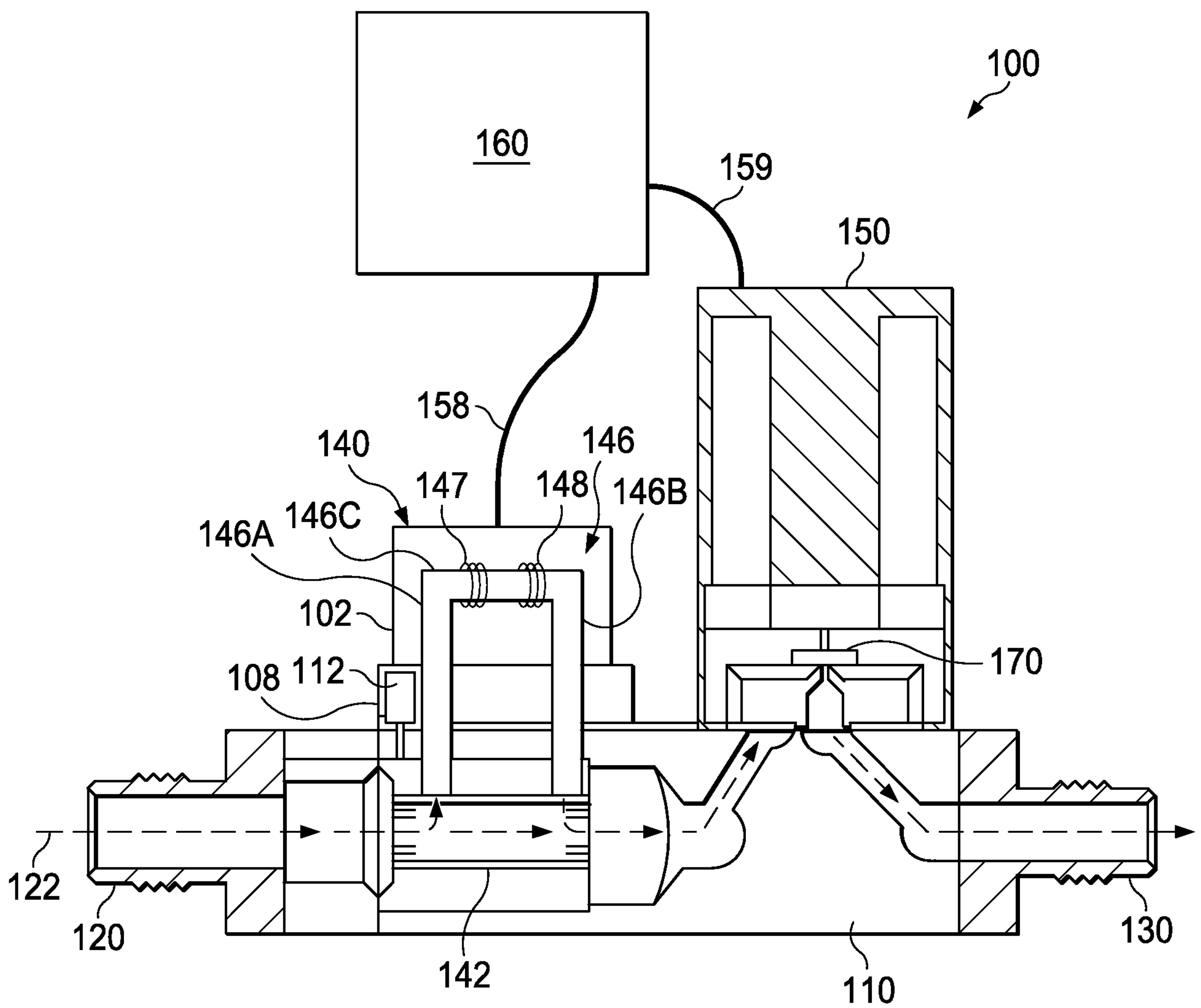
Claim 17. The mass flow controller of Claim 13, wherein the flexible joints are curved s-shaped flexible joints.

Claim 18. The mass flow controller of Claim 13, wherein the valve assembly further comprises a ball that is in contact with the center portion of the stroke amplifier.

Claim 19. The mass flow controller of Claim 18, wherein the valve assembly is configured such that when the piezo stack is extended, the piezo stack contacts the ball, which causes a downward force on the center portion of the stroke amplifier.

Claim 20. The mass flow controller of Claim 19, wherein the downward force on the center portion of the stroke amplifier causes the center portion to translate down, which causes the first arm component and the second arm component to respectively pivot about the first pivot contact point and the second pivot contact point to lift a base
5 portion of the stroke amplifier to move the valve seat.

FIG. 1



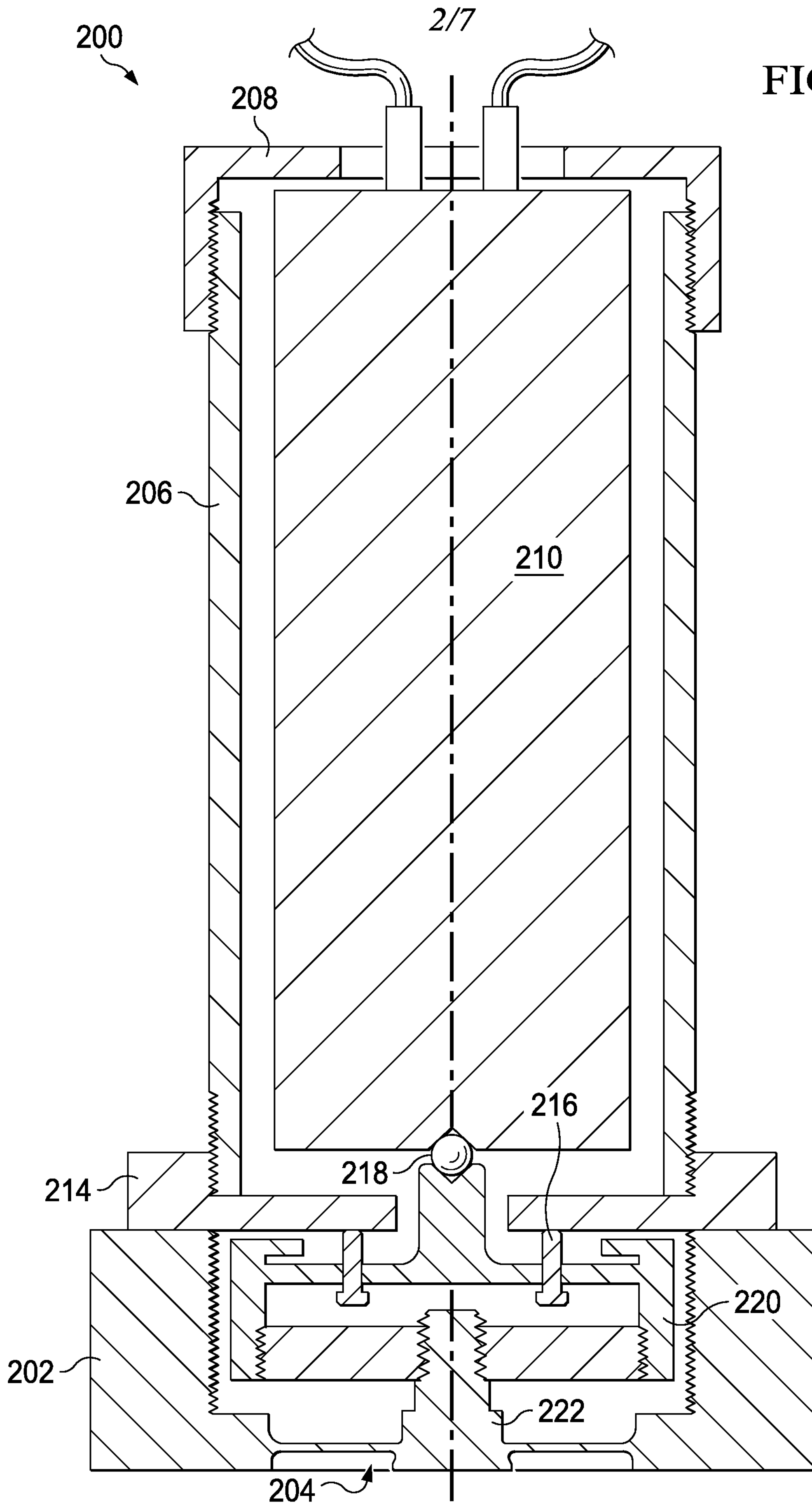


FIG. 2

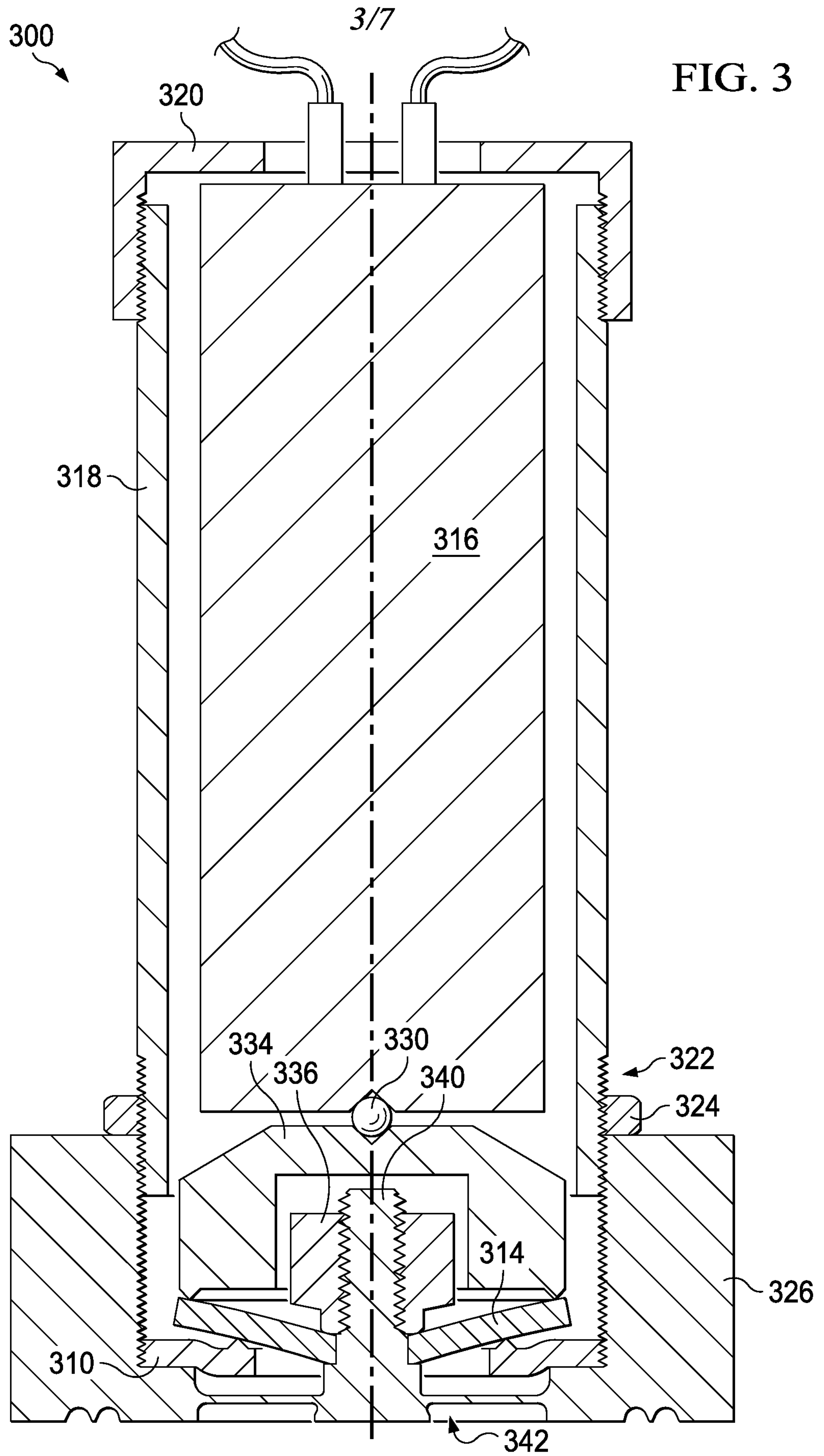


FIG. 3

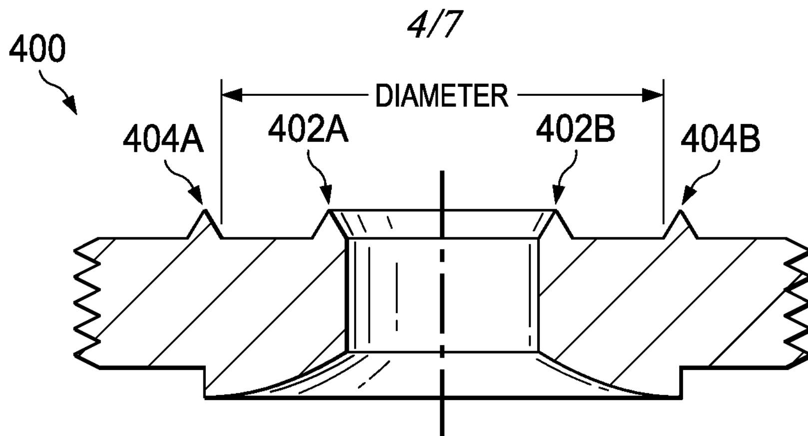


FIG. 4

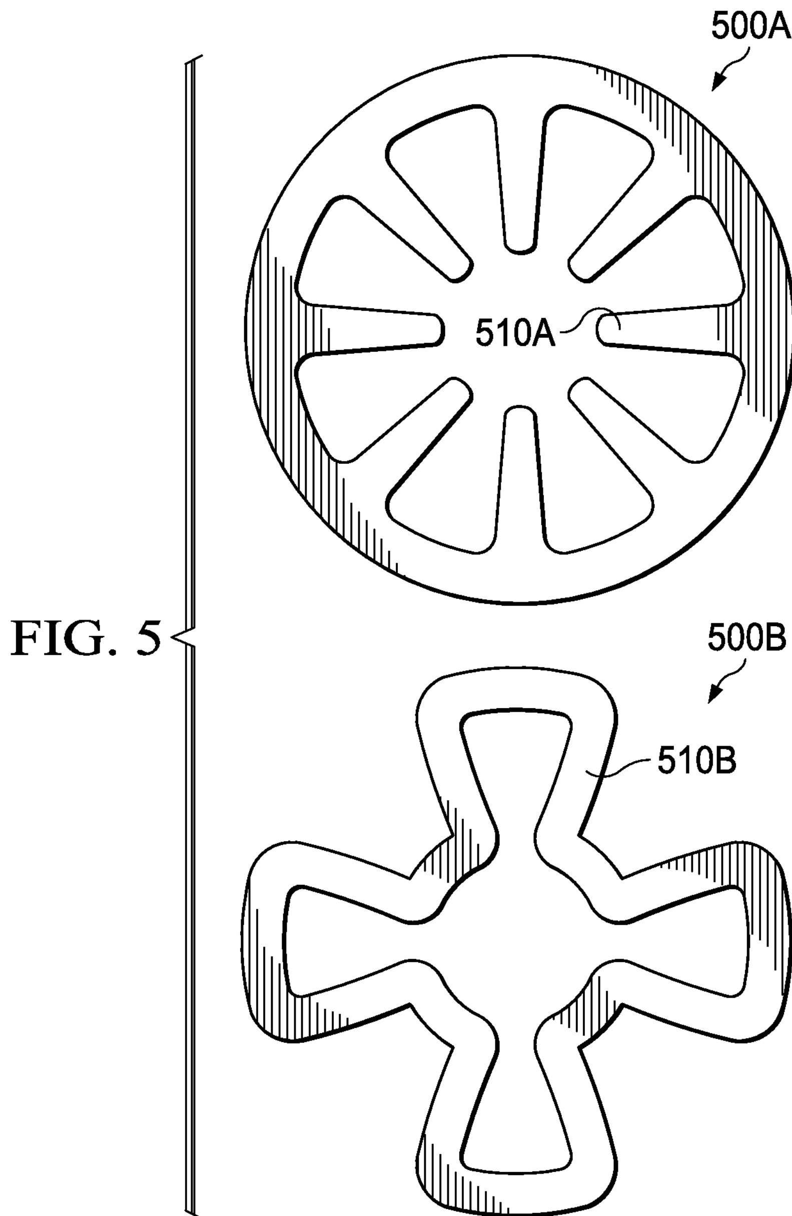


FIG. 5

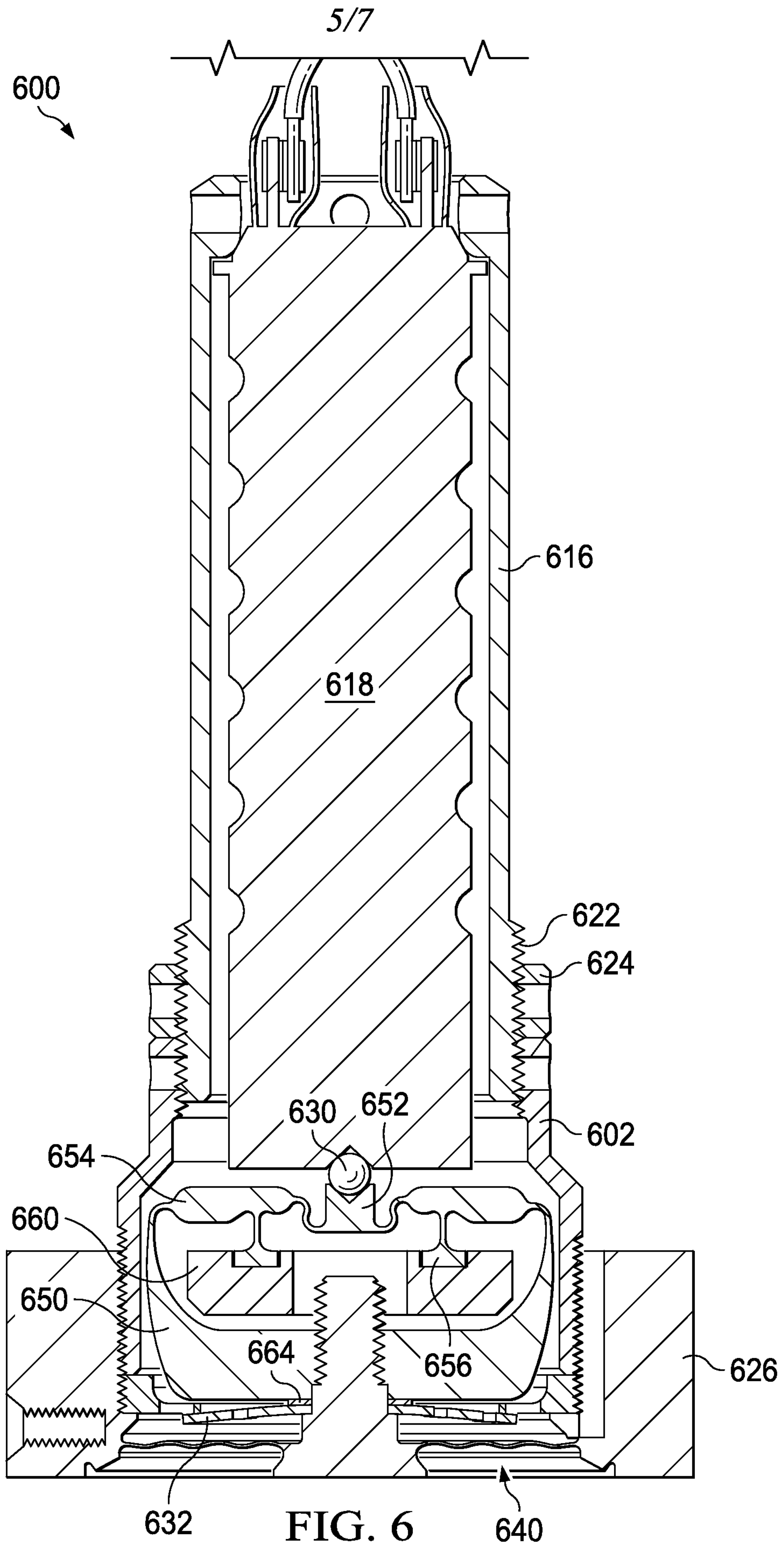


FIG. 6

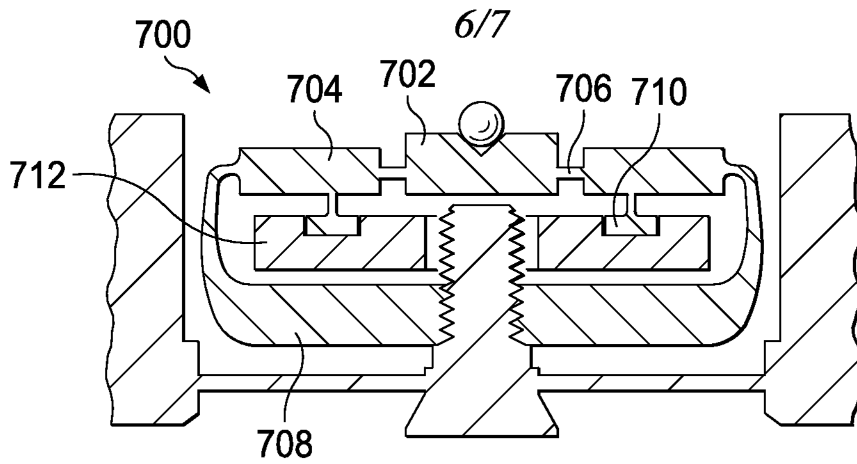


FIG. 7

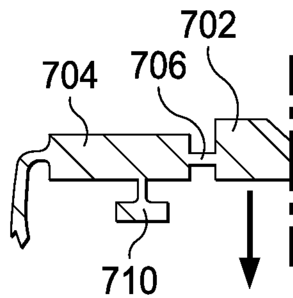


FIG. 7A

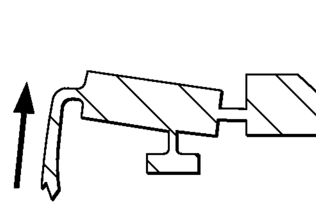


FIG. 7B

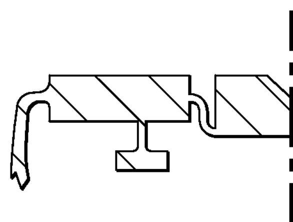


FIG. 8

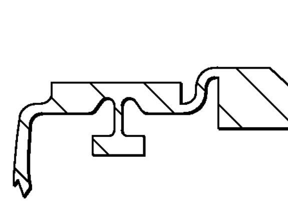


FIG. 9

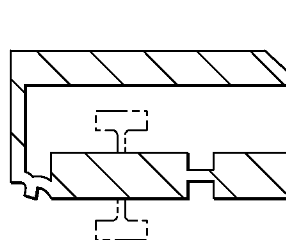


FIG. 10

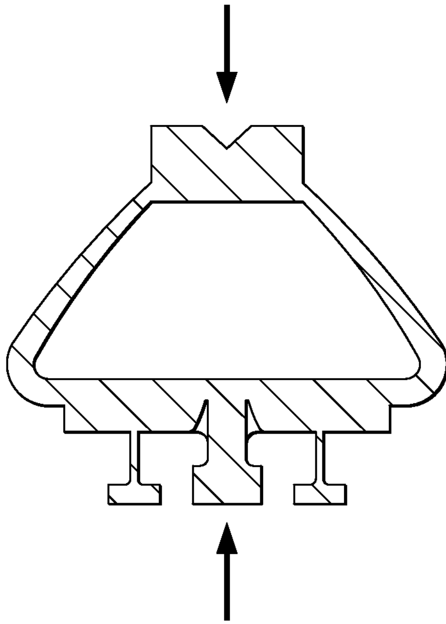


FIG. 11

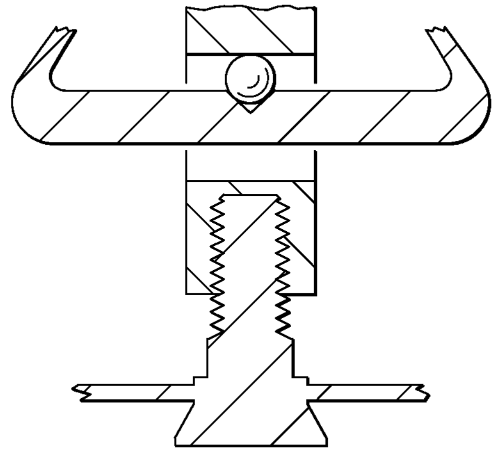


FIG. 12

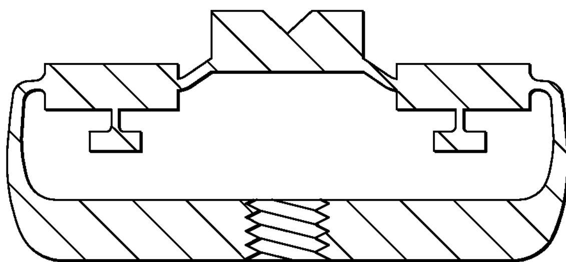


FIG. 13

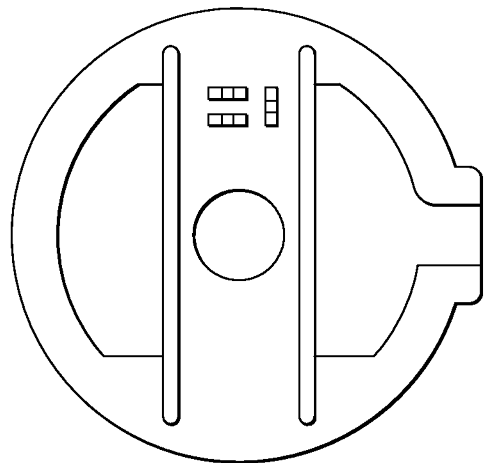


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/041762

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H01L 41/00 (2014.01)
CPC - H01L 41/00 (2014.09)
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - F15B 13/00; F16K 11/00, 11/10, 31/00, 31/02; H01L 41/00, 41/04, 41/08 (2014.01)
CPC - F15B 13/00; F16K 11/00, 11/10, 31/00, 31/02; H01L 41/00, 41/04, 41/08 (2014.09)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 137/271, 596.2, 831; 251/129.01, 129.06; 310/323.08, 323.17, 328

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Orbit, Google Patents, Google, Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2011/144642 A1 (CEWERS) 24 November 2011 (24.11.2011) entire document	1-20
A	US 2005/0199301 A1 (FRISCH) 15 September 2005 (15.09.2005) entire document	1-20
A	US 7,360,750 B2 (YANO et al) 22 April 2008 (22.04.2008) entire document	1-20

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 September 2014	16 OCT 2014

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774