PROPORTIONAL FLOW CONTROL VALVE POPPET WITH FLOW CONTROL NEEDLE

FIELD

[0001] The present disclosure relates to flow control valves operated by a stepper motor and more particularly to flow control valves that are sealed by a diaphragm and include a flow control needle.

BACKGROUND

[0002] This section provides background information related to the present disclosure which is not necessarily prior art.

[0003] Flow control valves can be operated by a stepper motor to improve repeatability of valve member positions for valves requiring increased accuracy in controlling flow variability between a fully open and a fully closed position. Applications requiring an accurate delivery of fluid volume or fluid pressure to a working device can benefit from the accuracy provided by a stepper motor compared to other known valve actuators. However, known stepper motor actuated flow control valves typically require a gear system or a multi-directional drive system to change the rotational force of the stepper motor to a longitudinal force used to translate a valve member in a reciprocating manner between open and closed valve positions. Common drive systems therefore lose operating force in order to drive multiple moving parts. The complexity, power loss, and tolerance of the multiple moving parts of known systems also decreases position accuracy and repeatability of the valve positions, which are some of the primary reasons for using a stepper motor for valve actuation in the first place.

[0004] The valve member used in typical stepper motor actuated flow control valves, such as a poppet valve, controls the flow of fluid, such as pressurized air, through a manifold. Such manifolds may be part of equipment such as sorters, packaging machines, food processors, paper-making machines, and the like. The valve member typically includes a rubber overmold and/or the valve member closes against a rubber valve seat to create a fluid-tight seal. Such flow control valves may be operated for millions of cycles. Overtime, the rubber overmold on the valve member and/or the rubber valve seat can wear or permanently deform, reducing the accuracy (i.e., flow resolution) of the flow control valve.

[0005] In typical flow control valves, the valve member is slidingly arranged within a valve body. In the closed position, a valve member is generally held in contact with a valve seat of the valve body. In the open position, the stepper motor generally moves the valve member away from the valve seat forming a clearance gap therebetween. As disclosed in United States Patent No. 3,985,333 to Paulsen, a bellows shaped diaphragm can be used to provide a seal between the valve body and the valve member. Such diaphragms can prevent contaminants from working their way into the motor housing while permitting longitudinal movement of the valve member.

[0006] The valve body is designed to be received in a bore provided in the manifold. The manifold usually includes multiple passageways that are arranged in fluid communication with the manifold bore. In operation, the flow control valve controls fluid flow between these multiple passageways. O-ring seals are typically provided on the outside of the valve body to seal the valve body within the manifold bore.

[0007] Although stepper motor actuated flow control valves increase the accuracy of the fluid volume or fluid pressure that can be delivered to a working device, flow control valves within improved accuracy are still needed. Particularly, there remains a need for flow control valves that can provide better flow resolution at low fluid flowrates.

SUMMARY

[0008] This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

[0009] The subject disclosure provides for an improved flow control valve that includes a valve body and a stepper motor that is connected to the valve body. The valve body has a distal valve body end and a proximal valve body end. A poppet bore extends through the valve body along a longitudinal axis. The distal valve body end includes a valve seat. A valve member is disposed within the poppet bore. The valve member includes a poppet and a drive head. The poppet is connected to the drive head and can slide within the poppet bore between open and closed positions. The poppet includes a distal poppet end and a proximal poppet end.

[0010] The drive head includes a threaded bore and the stepper motor has a shaft that is threadably engaged with the threaded bore in the drive head. The stepper motor operates to longitudinally displace the valve member in a longitudinal direction, parallel to the longitudinal axis, between the open and closed positions. The valve member includes a seat engagement surface that contacts the valve seat in the closed position and that is displaced away from the valve seat in the open position.

[0011] A diaphragm extends inwardly from the valve body to the valve member. The diaphragm is connected to the valve body and the valve member and deflects in response to movement of the valve member along the longitudinal axis. The flow control valve includes an inlet port and an outlet port. The inlet and outlet ports each extend through the valve body to the poppet bore.

[0012] A flow control needle is mounted to the poppet of the valve member. The flow control needle protrudes from the distal poppet end and is at least partially received in the outlet port when the valve member is in the closed position. The flow control needle cooperates with an inner surface of the outlet port to define an outlet flow orifice that varies in size when the valve member moves between the open and closed positions. In accordance with this design, the interface between the flow control needle and the inner surface of the outlet port controls the flowrate instead of the interface between the seat engagement surface of the valve member and the valve seat of the valve body. In other words, the interface between the flow control needle and the inner surface of the outlet port controls the flowrate and the interface between the seat engagement surface of the valve member and the valve seat of the valve body creates a fluid-tight seal when the valve member is in the closed (i.e., zero flow) position. Because the sealing interface is separate from the flow control interface, variations and deformation in the vicinity of the sealing interface does not affect the flow control interface, resulting in improved accuracy (i.e., flow resolution).

[0013] Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

[0014] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure, where:

[0015] Figure 1 is a side perspective view of an exemplary flow control valve constructed in accordance with the present disclosure;

[0016] Figure 2 is a partial side cross-sectional view of the exemplary flow control valve illustrated in Figure 1;

[0017] Figure 3 is an enlarged partial side cross-sectional view of the exemplary flow control valve illustrated in Figure 1 where the flow control valve is shown in a closed position;

[0018] Figure 4 is another enlarged partial side cross-sectional view of the exemplary flow control valve illustrated in Figure 1 where the flow control valve is shown in an open position;

[0019] Figure 5 is a side perspective view of another exemplary flow control valve constructed in accordance with the present disclosure;

[0020] Figure 6 is a partial side cross-sectional view of the exemplary flow control valve illustrated in Figure 5;

[0021] Figure 7 is an enlarged partial side cross-sectional view of the exemplary flow control valve illustrated in Figure 5 where the flow control valve is shown in a closed position;

[0022] Figure 8 is another enlarged partial side cross-sectional view of the exemplary flow control valve illustrated in Figure 5 where the flow control valve is shown in an open position; and

[0023] Figure 9 is a partial side cross-sectional view of the exemplary flow control valve of Figure 5 shown installed in a manifold.

[0024] Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION

[0025] Example embodiments will now be described more fully with reference to the accompanying drawings. These example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

[0026] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms “a,” “an,” and “the” may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms “comprises,” “comprising,” “including,” and “having,” are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[0027] When an element or layer is referred to as being “on,” engaged to, “connected to,” or “coupled to” another element or layer, it may be directly on, engaged, connected or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being “directly on,” directly engaged to, “directly connected to,” or “directly coupled to” another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., “between” versus “directly between,” “adjacent” versus “directly adjacent,” etc.). As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0028] Although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as "first," "second," and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

[0029] Spatially relative terms, such as "inner," "outer," "beneath," "below," "lower," "above," "upper," and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the example term "below" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

[0030] Referring to Figures 1-4, a flow control valve **10** constructed in accordance with the present disclosure is shown. The flow control valve **10** includes a valve body **11** that extends along a longitudinal axis **12**. It should be appreciated that the terms “longitudinal,” “longitudinally,” “axial,” and “axially,” when used herein, mean along or parallel to the longitudinal axis **12**. The valve body **11** has a first valve body portion **13** defining a distal valve body end **14** and a second valve body portion **15** defining a proximal valve body end **16**. In the illustrated example, the first and second valve body portions **13, 15** are connected to each other by a first threaded connection **17**. The first valve body portion **13** includes a valve seat **18** that is positioned at the distal valve body end **14**. The valve body **11** includes a poppet bore **19** that extends through the first and second valve body portions **13, 15** and coaxially along the longitudinal axis **12**. The poppet bore **19** has a bore diameter **20**. The valve body **11** can be made from various materials, including without limitation, stainless steel or nickel-plated brass.

[0031] An inlet port **21** extends through the first valve body portion **13** from the poppet bore **19** to a ported face **22** of the valve body **11**. An outlet port **23** extends through the first valve body portion **13** from the poppet bore **19** to an end face **24** of the valve body **11**. Although other configurations are possible, in the example shown in Figures 1-4, the inlet port **21** and the outlet port **23** have inner surfaces **25a, 25b**. The outlet port **23** is co-axially aligned with the longitudinal axis **12** and the inlet port **21** is arranged perpendicular to the longitudinal axis **12**. The valve seat **18** is positioned between the inlet port **21** and the outlet port **23**. Optionally, one or more seal members **26**, such as O-rings, may be positioned in one or more circumferential slots **27** created in the first valve body portion **13** on opposing sides of the inlet port **21**.

[0032] A valve member **28** is slidably disposed in the poppet bore **19** and is oriented coaxially with the longitudinal axis **12**. The valve member **28** includes a poppet

30. The poppet **30** extends between a distal poppet end **31** and a proximal poppet end **32**. In the illustrated example, the poppet **30** includes a first poppet segment **33** that defines the distal poppet end **31** and a second poppet segment **34** that defines the proximal poppet end **32**. The first poppet segment **33** is slidingly received in the first valve body portion **13** and the second poppet segment **34** is slidingly received in the second valve body portion **15**. The second poppet segment **34** extends longitudinally between the first poppet segment **33** and the drive head **29**. The first and second poppet segments **33, 34** are connected by a second threaded connection **35**. The drive head **29** has a female threaded bore **36**. The poppet **30** can be made from various materials, including without limitation, aluminum, stainless steel, or plastic.

[0033] A drive adapter **37** is connected to the proximal valve body end **16** by a third threaded connection **38**. The drive adapter **37** includes a head receiving cavity **39** that receives at least part of drive head **29**. As will be explained in greater detail below, the drive adapter **37** may optionally have external threads **40** for installation purposes. A stepper motor **41** is connected to the drive adapter **37**. The stepper motor **41** operates to rotate a shaft **42** that is threadably engaged with the threaded bore **36** in the drive head **29** to longitudinally displace the valve member **28** in a longitudinal direction over a range of longitudinal positions between a closed position (Figure 3) and an open position (Figure 4).

[0034] The male threaded shaft **42** is connected to and extends from the stepper motor **41**. The male threaded shaft **42** of the stepper motor **41** is threadably received in the female threaded bore **36** created in the drive head **29**. The male threaded shaft **42** can be directly or indirectly connected to and rotatably driven by stepper motor **41**. The male threaded shaft **42** is directly threadably received in female threaded bore **36** and is coaxially aligned with respect to the longitudinal axis **12**. Rotation of male threaded shaft **42** therefore directly axially moves the drive head **29** based on complete or partial revolutions of the male threaded shaft **42**, to move the valve member **28** between the open and closed positions. The shape of the head receiving cavity **39** prevents rotation of the drive head **29** so that rotation of the male threaded shaft **42** is converted into axial displacement of the drive head **29**. The pitch of the threads on the male threaded shaft **42** and the female threaded bore **36** can vary and can be selected to provide different stroke lengths and actuation speeds. By way of example and without limitation, the stroke length of the valve member **28** in the illustrated embodiment is approximately 0.35 millimeters.

[0035] Rotation of the male threaded shaft **42** of the stepper motor **41** in a first rotational direction longitudinally displaces the valve member **28** in the poppet bore **19** from the closed position (Figure 3) to the open position (Figure 4) and rotation of the male threaded shaft **42** in an opposite second rotational direction returns the valve member **28** from the open position (Figure 4) to the closed position (Figure 3), and vice versa. Incremental rotation of the stepper motor **41** in the first and second rotational directions rotates the male threaded shaft **42** within the threaded bore **36** of the drive head **29**, which incrementally translates (i.e., moves) the valve member **28** in first and second longitudinal directions.

[0036] The drive head **29** is detached (i.e. separate) from the second poppet segment **34** of the valve member **28**. Notwithstanding, the drive head **29** abuts the proximal poppet end **32** of the valve member **28** such that the drive head **29** drives the valve member **28** between the closed position (Figure 3) and the open position (Figure 4). The proximal poppet end **32** is held in contact with the drive head **29** by a biasing member **43** that biases the poppet **30** towards the drive head **29**. In the illustrated example, the biasing member **43** is a coil spring that is disposed between a shoulder **44** of the valve body **11**, which extends radially inwardly into the poppet bore **19** and a flange **45** that extends radially outwardly from the proximal poppet end **32**. As a result, the biasing member **43** extends helically about a portion of the second poppet segment **34** and presses against the shoulder **44** of the valve body **11** and the flange **45** of the second poppet segment **34** to help maintain contact between the proximal poppet end **32** and the drive head **29**. The biasing member **43** applies a biasing force to the poppet **30** that acts to bias the poppet **30** towards the drive head **29**.

[0037] The longitudinal position of the valve member **28** is repeatable based in part on the limited slip between the threads of male threaded shaft **42** and the female threaded bore **36**. The biasing force that the biasing member **43** applies to the poppet **30** and thus the drive head **29** mitigates axial dimensional changes resulting from thread clearances and/or wear to further enhance the repeatability of the longitudinal position of the valve member **28**. The valve member **28** includes a seat engagement member **46** that defines a seat engagement surface **47**. The seat engagement surface **47** of the seat engagement member **46** contacts the valve seat **18** when the valve member **28** is in the closed position. The seat engagement surface **47** of the seat engagement member **46** is spaced away from the valve seat **18** when the valve member **28** is in the open position. Although other configurations are possible, in the illustrated example, the seat engagement member **46** is made of a resilient material such as rubber that is overmolded on the first poppet segment **33** at the distal poppet end **31**. Alternatively, the valve seat **18** may be made of a resilient material. The interface between the seat engagement surface **47** of the seat engagement member **46** and the valve seat **18** functions as a sealing interface that stops fluid flow from the inlet port **21** to the outlet port **23** (i.e., creates a zero flow condition through the flow control valve **10**) when the valve member **28** is in the closed position.

[0038] The flow control valve **10** includes a diaphragm **48** that extends radially inwardly from the valve body **11** to the valve member **28**. In the illustrated example, an outer circular portion of the diaphragm **48** is received between the proximal and distal valve body portions **13, 15** and an inner circular portion of the diaphragm **48** is received between the first and second poppet segments **33, 34**. More specifically, the first threaded connection **17** between the proximal and distal valve body portions **13, 15** permits the outer circular portion of the diaphragm **48** to be clamped between the proximal and distal valve body portions **13, 15** and the second threaded connection **35** between the first and second poppet segments **33, 34** permits the inner circular portion of the diaphragm **48** to be clamped between the first and second poppet segments **33, 34**.

[0039] The diaphragm **48** deflects in response to movement of the valve member **28** along the longitudinal axis **12**. The diaphragm **48** provides an atmospheric seal for the flow control valve **10** to prevent a fluid, such as pressurized air or water, and contaminants from entering the head receiving cavity **39** in the drive adapter **37** and the stepper motor **41**. Although other configurations are possible, the diaphragm **48** shown in the illustrated embodiment has a bellows-like portion with a U-shaped cross-section that increases the flexibility of the diaphragm **48**.

[0040] A flow control needle **49**, mounted to the first poppet segment **33**, protrudes from the distal poppet end **31** of the valve member **28**. At least part of the flow control needle **49** is received in the outlet port **23** when the valve member **28** is in the closed position (Figure 3). The flow control needle **49** extends along the longitudinal axis **12** between a distal flow control needle end **50** and a proximal flow control needle end **51**. Although other arrangements are possible depending on the stroke of the valve member **28**, in the illustrated example, the distal flow control needle end **50** remains concentrically aligned inside the outlet port **23** of the valve body **11** in both the open and closed positions of the flow control valve **10**.

[0041] The flow control needle **49** has a needle diameter **52** that varies at the distal flow control needle end **50**. More particularly, the distal flow control needle end **50** has a tapered surface **53** that cooperates with the inner surface **25b** of the outlet port **23** to define an outlet flow orifice **54** that is created by the gap between the tapered surface **53** of the distal flow control needle end **50** and the inner surface **25b** of the outlet port **23** when the flow control valve **10** is in the open position (Figure 4). Due to the tapered shape of the distal flow control needle end **50**, the outlet flow orifice **54** varies in size when the valve member **28** moves between the closed and open positions. More particularly, the outlet flow orifice **54** has a cross-sectional area in the shape of a circular ring that varies in size depending on the longitudinal position of the valve member **28**. By way of example and without limitation, in the illustrated embodiment the maximum cross-sectional area of the outlet flow orifice **54** is approximately 2 square millimeters when the valve member **28** is in the open position.

[0042] The tapered surface **53** of the flow control needle **49** gives the distal flow control needle end **50** a frusto-conical shape. Although other arrangements are possible, in the example illustrated in Figures 2-4, the flow control needle **49** includes a radial step **55** that is positioned longitudinally between the distal and proximal flow control needle ends **50, 51** where the diameter of the flow control needle **49** transitions from a larger diameter to a smaller diameter barrel portion **56** at the proximal flow control needle end **51**. The radial step **55** extends radially inwardly such that the radial step **55** is transverse to the longitudinal axis **12**. The first poppet segment **33** of the valve member **28** has a poppet bore **57** that extends along the longitudinal axis **12** to the distal poppet end **31**. The barrel portion **56** of flow control needle **49** is received in a press-fit within the poppet bore **57**. The flow control needle **49** can be made from various materials, including, without limitation, stainless steel when the fluid passing through the flow control valve **10** is a liquid and aluminum when the fluid passing through the flow control valve **10** is air.

[0043] In the valve closed position shown in Figure 3, the valve seat **18** engagement face on the distal poppet end **31** is held in contact with the valve seat **18** on the first valve body portion **13**. Accordingly, the flow control valve **10** prevents fluid flow between the inlet and outlet ports **21, 23** when flow control valve **10** is in the valve closed position. In the valve open position shown in Figure 4, the seat engagement surface **47** on the distal poppet end **31** moves away from the valve seat **18** on the first valve body portion **13**, thereby providing a flow path from the inlet port **21** to the outlet port **23**. As the stepper motor **41** drives the valve member **28** between the closed position (Figure 3) and the open position (Figure 4), the diaphragm **48** flexes to accommodate the translation of the valve member **28**.

[0044] With reference to Figures 5-8, another flow control valve **100** is illustrated. Many of the elements of the flow control valve **100** shown in Figures 5-8 are the same or substantially the same as the elements of the control valve shown in Figures 2-4, except as noted below. Equivalent elements shared between the embodiments have corresponding reference numbers where 100s have been used to label the equivalent elements in Figures 5-8.

[0045] The flow control valve **100** illustrated in Figures 5-8 includes an adjustable flow control needle **149**. More specifically, the poppet bore **157** includes internal threads **158** and the barrel portion **156** of the flow control needle **149** includes barrel threads **159** that thread into and engage the internal threads **158** in the poppet bore **157**. An O-ring seal **160** is optionally provided on the barrel portion **156** of the flow control needle **149** near the radial step **155** to provide a fluid-tight seal between the barrel portion **156** of the flow control needle **149** and the poppet bore **157**. The distal flow control needle end **150** includes a tool interface **161** permitting rotational adjustment of the flow control needle **149** within the poppet bore **157**. Rotation of the flow control needle **149** within the poppet bore **157** changes the longitudinal position of the flow control needle **149** relative to the distal poppet **130** segment and thus a longitudinal distance measured between the distal flow control needle end **150** and the distal poppet end **131**. By adjusting the longitudinal position of the flow control needle **149** relative to the poppet **130**, the size of the cross-sectional area of the outlet flow orifice **154** can be adjusted to fine tune the fluid flowrate through the flow control valve **100**. This adjustability also accommodates variances due to manufacturing tolerances. For example, the flow control valve **100** can be easily tuned during the manufacturing process, where the flow control needle **149** is backed-out (i.e., unthreaded) until the tapered surface **153** at the distal flow control needle end **150** makes initial contact with the inner surface **125b** of the outlet port **123** when the valve member **28** is in the closed position. If wear occurs, this process can be repeated to re-established proper tolerances between the flow control needle **149** and the outlet port **123**.

[0046] In the embodiment shown in Figures 5-8, the inner surface **125b** of the outlet port **123** in the first valve body portion **113** has a sloped, funnel-like shape. At least part of the tapered surface **153** on the distal flow control needle end **150** contacts the inner surface **125b** of the outlet port **123** when the valve member **128** is in the closed position (Figure 7). The tapered surface **153** of the distal flow control needle end **150** is arranged at a first angle **162** relative to the longitudinal axis **112**. The inner surface **125b** of the outlet port **123** is arranged at a second angle **163** relative to the longitudinal axis **112**. The first angle **162** is different from the second angle **163** by at least one degree. This arrangement helps prevent the distal poppet end **131** from binding in the outlet port **123** when the valve member **128** is in the closed position.

[0047] Referring to Figure 9, flow control valve **100** is shown installed in a manifold **264**. The manifold **264** includes a manifold bore **265**. The valve body **111** of the flow control valve **100** is slidably inserted into the manifold bore **265** and the external threads **140** on the drive adapter **137** threadingly engage a threaded portion **266** of the manifold bore **265**. The seal members **126**, such as O-rings, positioned in the circumferential slots **127** created in valve body **111** contact the manifold bore **265** and create a fluid seal. When the valve body **111** is installed in the manifold bore **265**, the inlet and outlet ports **121, 123** are positioned in fluid communication with inlet and outlet passageways **267, 268** of the manifold **264**, respectively. In operation, the flow control valve **100** controls the flow of fluid, such as pressurized air, between the inlet and outlet passageways **267, 268** in the manifold **264**.

[0048] Each of the flow control valves **10, 100** of the present disclosure provides variable flow control by incremental rotation of the stepper motor **41, 141**. Incremental rotation of the stepper motor **41, 141** is translated into longitudinal translation of the valve member **28, 128**. Also, as the valve member **28, 128** moves toward an open position, a pressure drop is created across the inlet and outlet ports **21, 23, 121, 123**. Because the poppet bore **19, 119** in which the valve member **28, 128** is slidably received has equal diameters at the contact points of the valve member **28, 128** and valve body **11, 111**, each port section balances forces acting on the valve member **28, 128**.

[0049] The flow control valves **10, 100** of the present disclosure offer several advantages. The accuracy (i.e., flow resolution) through the flow control valves **10, 100** disclosed herein is significantly improved because the outlet flow orifice **54, 154** is defined by the interface (i.e., gap) between the tapered surface **53, 153** of the flow control needle **49, 149** and the inner surface **25b, 125b** of the outlet port **23, 123** instead of the interface (i.e., gap) between the valve seat **18, 118** and the seat engagement member **46, 146**. In typical valves, the seat engagement member **46, 146** and/or the valve seat **18, 118** deflect and rebound small amounts when the valve member **28, 128** moves between the open and closed positions, which results in small changes in the gap between these two components. In addition, the seat engagement member **46, 146** and/or the valve seat **18, 118** can become worn and/or can permanently deform over time due to repeated valve cycles. These variations limit the accuracy of typical valves, particularly at lower fluid flowrates. The flow control valves **10, 100** disclosed herein have an outlet flow orifice **54, 154** (i.e., flow control interface) that is separate from the sealing interface between the valve seat **18, 118** and seat engagement member **46, 146**. As a result, deflection, rebound, wear, and deformation in the valve seat **18, 118** and/or seat engagement member **46, 146** do not affect the interface between the flow control needle **49, 149** and the outlet port **23, 123**, increasing the accuracy of the flow control valves **10, 110**. For example, the flow control valves **10, 110** disclosed herein have been found to have improved resolution at flowrates of 670 milliliters per minute down to 30 milliliters per minute at a pressure of 29 pounds per square inch.

[0050] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the present disclosure, and all such modifications are intended to be included within the scope of the present disclosure.

CLAIMS

What is claimed is:

1. A flow control valve comprising:

a valve body having a distal valve body end, a proximal valve body end, a poppet bore extending along a longitudinal axis, and a valve seat positioned at said distal valve body end;

an inlet port and an outlet port each extending through said valve body to said poppet bore, said outlet port having an inner surface;

a valve member slidably disposed in said poppet bore, said valve member including a drive head and a poppet, said poppet including a distal poppet end and a proximal poppet end, and said drive head having a threaded bore;

a stepper motor having a shaft that is threadably engaged with said threaded bore in said drive head, said stepper motor operating to longitudinally displace said valve member in a longitudinal direction, parallel to said longitudinal axis, between a closed position and an open position;

said valve member including a seat engagement surface that contacts said valve seat in said closed position and that is displaced away from said valve seat in said open position;

a diaphragm extending between and connected to said valve body and said valve member such that said diaphragm deflects in response to movement of said valve member along said longitudinal axis; and

a flow control needle mounted to said poppet that protrudes from said distal poppet end and is at least partially received in said outlet port when said valve member is in said closed position, said flow control needle cooperating with said inner surface of said outlet port to define an outlet flow orifice that varies in size when said valve member moves between said closed and open positions.

2. The flow control valve as set forth in Claim 1, wherein said flow control needle extends between a distal flow control needle end and a proximal flow control needle end.

3. The flow control valve as set forth in Claim 2, wherein said distal flow control needle end includes a tapered surface that cooperates with said inner surface of said outlet port to define a cross-sectional area of said outlet flow orifice that varies in size depending on the longitudinal position of said valve member.

4. The flow control valve as set forth in Claim 3, wherein said tapered surface gives said distal flow control needle end a frusto-conical shape.

5. The flow control valve as set forth in Claim 4, wherein said inner surface of said outlet port has a sloped, funnel-like shape.

6. The flow control valve as set forth in Claim 5, wherein at least part of said tapered surface of said distal flow control needle end contacts said inner surface of said outlet port when said valve member is in said closed position and wherein said tapered surface of said distal flow control needle end is arranged at a first angle relative to said

longitudinal axis and said inner surface of said outlet port is arranged at a second angle relative to said longitudinal axis.

7. The flow control valve as set forth in Claim 6, wherein said first angle is different from said second angle by at least one degree so as to prevent binding when said valve member is in said closed position.

8. The flow control valve as set forth in Claim 4, wherein said flow control needle includes a radial step that is positioned longitudinally between said distal and proximal flow control needle ends where said flow control needle transitions from a larger diameter to a smaller diameter.

9. The flow control valve as set forth in Claim 4, wherein said inner surface of said outlet port has a cylindrical shape.

10. The flow control valve as set forth in Claim 2, wherein said poppet includes a poppet bore that extends along said longitudinal axis to said distal poppet end.

11. The flow control valve as set forth in Claim 10, wherein said poppet bore has internal threads and wherein said proximal flow control needle end is received in said poppet bore in threaded engagement with said internal threads.

12. The flow control valve as set forth in Claim 11, wherein said distal flow control needle end includes a tool interface permitting rotational adjustment of said flow control needle within said poppet bore such that rotation of said flow control needle within said poppet bore changes a longitudinal distance measured between said distal flow control needle end and said distal poppet end.

13. The flow control valve as set forth in Claim 10, wherein said proximal flow control needle end is received in a press-fit within said poppet bore.

14. The flow control valve as set forth in Claim 2, wherein said flow control needle has a diameter that varies at said distal flow control needle end.

15. The flow control valve as set forth in Claim 1, wherein said seat engagement surface is positioned at said distal poppet end and is radially outward of said flow control needle.

16. The flow control valve as set forth in Claim 1, wherein at least one of said valve seat and said seat engagement surface is made of a resilient material.

17. The flow control valve as set forth in Claim 1, wherein said poppet includes a first poppet segment defining said distal poppet end and a second poppet segment that extends between said first poppet segment and said drive head and

wherein a portion of said diaphragm is clamped between said first and second poppet segments.

18. The flow control valve as set forth in Claim 1, wherein said poppet is detached from said drive head and said proximal poppet end is held in contact with said drive head by a biasing member that biases said poppet toward said drive head.

19. A flow control valve comprising:

a valve body defining a longitudinal axis;

said valve body having a first valve body portion defining a distal valve body end and a second valve body portion defining a proximal valve body end;

said valve body including a poppet bore that extends through said first and second valve body portions and coaxially along said longitudinal axis;

said first valve body portion including a valve seat positioned at said distal valve body end;

said poppet bore having a bore diameter;

a valve member slidably disposed in said poppet bore and oriented coaxially with said longitudinal axis;

said valve member including a drive head and a poppet;

said poppet including a first poppet segment defining a distal poppet end and a second poppet segment defining a proximal poppet end;

said first poppet segment slidingly received in said first valve body portion;

said second poppet segment slidingly received in said second valve body portion and extending longitudinally between said first poppet segment and said drive head;

said drive head having a threaded bore;

a drive adapter connected to said proximal valve body end;

said drive adapter including a head receiving cavity that receives at least part of said drive head;

a stepper motor connected to said drive adapter;

said stepper motor operating to rotate a shaft that is threadably engaged with said threaded bore in said drive head to longitudinally displace said valve member in a longitudinal direction, parallel to said longitudinal axis, over a range of longitudinal positions between a closed position and an open position;

an inlet port extending through said valve body from said poppet bore to a ported face of said valve body;

an outlet port extending through said valve body from said poppet bore to an end face of said valve body;

said outlet port being co-axially aligned with said longitudinal axis;

said valve member including a seat engagement member at said distal poppet end that defines a seat engagement surface that contacts said valve seat in said closed position and that is displaced away from said valve seat in said open position;

said seat engagement member being made of a resilient material;

wherein rotation of said shaft of said stepper motor in a first rotational direction longitudinally displaces said valve member in said poppet bore from said closed position to said open position and rotation of said shaft in an opposite second rotational direction returns said valve member from said open position to said closed position,

wherein said shaft of said stepper motor is a threaded shaft that is connected to and extends from said stepper motor such that incremental rotation of said stepper motor rotates said threaded shaft within said threaded bore of said drive head to incrementally translate said valve member in said longitudinal direction;

wherein said valve member is detached from said drive head and said proximal poppet end is held in contact with said drive head by a biasing member that biases said valve member toward said drive head,

wherein said biasing member is a spring disposed between a shoulder of said valve body in said poppet bore and a flange on said second poppet segment;

a diaphragm extending inwardly from said valve body that is received between said first and second poppet segments of said valve member such that said diaphragm deflects in response to movement of said valve member along said longitudinal axis;

a threaded connection between said first and second poppet segments that permits said diaphragm to be clamped between said first and second poppet segments;

said first poppet segment of said valve member including a poppet bore that extends along said longitudinal axis to said distal poppet end;

said outlet port having an inner surface;

a flow control needle mounted to said first poppet segment that protrudes from said distal poppet end and is at least partially received in said outlet port when said valve member is in said closed position;

said flow control needle extending along said longitudinal axis between a distal flow control needle end and a proximal flow control needle end;

said distal flow control needle end being concentrically aligned inside said outlet port;

said distal flow control needle end including a tapered surface that cooperates with said inner surface of said outlet port to define an outlet flow orifice that varies in size when said valve member moves between said closed and open positions;

said outlet flow orifice having a cross-sectional area that varies in size depending on said longitudinal position of said valve member;

said flow control needle having a diameter that varies at said distal flow control needle end;

said tapered surface giving said distal flow control needle end a frusto-conical shape and creating a radial step positioned longitudinally between said distal and proximal flow control needle ends where said diameter of said flow control needle transitions from a larger diameter to a smaller diameter;

said inner surface of said outlet port having a cylindrical shape;

said proximal flow control needle end received in a press-fit within said poppet bore; and at least part of said tapered surface of said distal flow control needle end contacting said inner surface of said outlet port when said valve member is in said closed position.

20. A flow control valve comprising:

a valve body defining a longitudinal axis;

said valve body having a first valve body portion defining a distal valve body end and a second valve body portion defining a proximal valve body end;

said valve body including a poppet bore that extends through said first and second valve body portions and coaxially along said longitudinal axis;

said first valve body portion including a valve seat positioned at said distal valve body end;

said poppet bore having a bore diameter;

a valve member slidably disposed in said poppet bore and oriented coaxially with said longitudinal axis;

said valve member including a drive head and a poppet;

said poppet including a first poppet segment defining a distal poppet end and a second poppet segment defining a proximal poppet end;

said first poppet segment slidingly received in said first valve body portion;

said second poppet segment slidingly received in said second valve body portion and extending longitudinally between said first poppet segment and said drive head;

said drive head having a threaded bore;

a drive adapter connected to said proximal valve body end;

said drive adapter including a head receiving cavity that receives at least part of said drive head;

a stepper motor connected to said drive adapter;

said stepper motor operating to rotate a shaft that is threadably engaged with said threaded bore in said drive head to longitudinally displace said valve member in a longitudinal direction, parallel to said longitudinal axis, over a range of longitudinal positions between a closed position and an open position;

an inlet port extending through said valve body from said poppet bore to a ported face of said valve body;

an outlet port extending through said valve body from said poppet bore to an end face of said valve body;

said outlet port being co-axially aligned with said longitudinal axis;

said valve member including a seat engagement member at said distal poppet end that defines a seat engagement surface that contacts said valve seat in said closed position and that is displaced away from said valve seat in said open position;

said seat engagement member being made of a resilient material;

wherein rotation of said shaft of said stepper motor in a first rotational direction longitudinally displaces said valve member in said poppet bore from said closed position to said open position and rotation of said shaft in an opposite second rotational direction returns said valve member from said open position to said closed position, wherein said shaft of said stepper motor is a threaded shaft that is connected to and extends from said stepper motor such that incremental rotation of said stepper motor rotates said threaded shaft within said threaded bore of said drive head to incrementally translate said valve member in said longitudinal direction;

wherein said valve member is detached from said drive head and said proximal poppet end is held in contact with said drive head by a biasing member that biases said valve member toward said drive head,

wherein said biasing member is a spring disposed between a shoulder of said valve body in said poppet bore and a flange on said second poppet segment;

a diaphragm extending inwardly from said valve body that is received between said first and second poppet segments of said valve member such that said diaphragm deflects in response to movement of said valve member along said longitudinal axis;

a threaded connection between said first and second poppet segments that permits the diaphragm to be clamped between said first and second valve poppet segments;

said first poppet segment of said valve member including a poppet bore that extends along said longitudinal axis to said distal poppet end;

said outlet port having an inner surface;

a flow control needle mounted to said first poppet segment that protrudes from said distal poppet end and is at least partially received in said outlet port when said valve member is in said closed position;

said flow control needle extending along said longitudinal axis between a distal flow control needle end and a proximal flow control needle end;

said distal flow control needle end being concentrically aligned inside said outlet port;

said distal flow control needle end including a tapered surface that cooperates with said inner surface of said outlet port to define an outlet flow orifice that varies in size when said valve member moves between said closed and open positions;

said outlet flow orifice having a cross-sectional area that varies in size depending on said longitudinal position of said valve member;

said flow control needle having a diameter that varies at said distal flow control needle end;

said tapered surface giving said distal flow control needle end a frusto-conical shape and creating a radial step positioned longitudinally between said distal and proximal flow control needle ends where said diameter of said flow control needle transitions from a larger diameter to a smaller diameter;

said inner surface of said outlet port having a sloped, funnel-like shape;

at least part of said tapered surface of said distal flow control needle end contacting said inner surface of said outlet port when said valve member is in said closed position;

said tapered surface of said distal flow control needle end being arranged at a first angle relative to said longitudinal axis and said inner surface of said outlet port being arranged at a second angle relative to said longitudinal axis;

said first angle being different from said second angle by at least one degree to avoid binding when said valve member is in said closed position;

said poppet bore having internal threads;

said proximal flow control needle end received in said poppet bore in threaded engagement with said internal threads; and

said distal flow control needle end including a tool interface permitting rotational adjustment of said flow control needle within said poppet bore such that rotation of said flow control needle within said poppet bore changes a longitudinal distance measured between said distal flow control needle end and said distal poppet end.

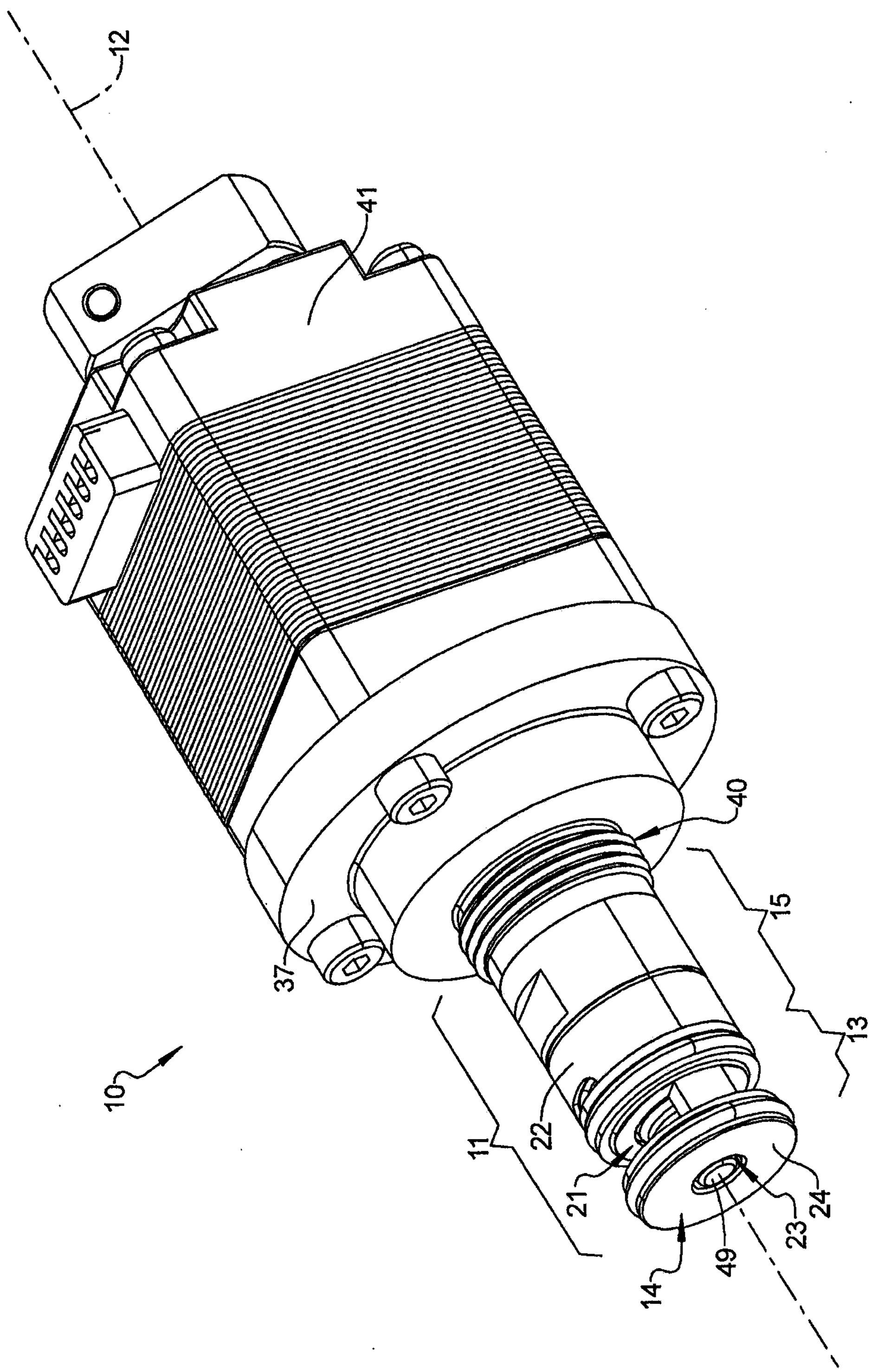

FIG. 1

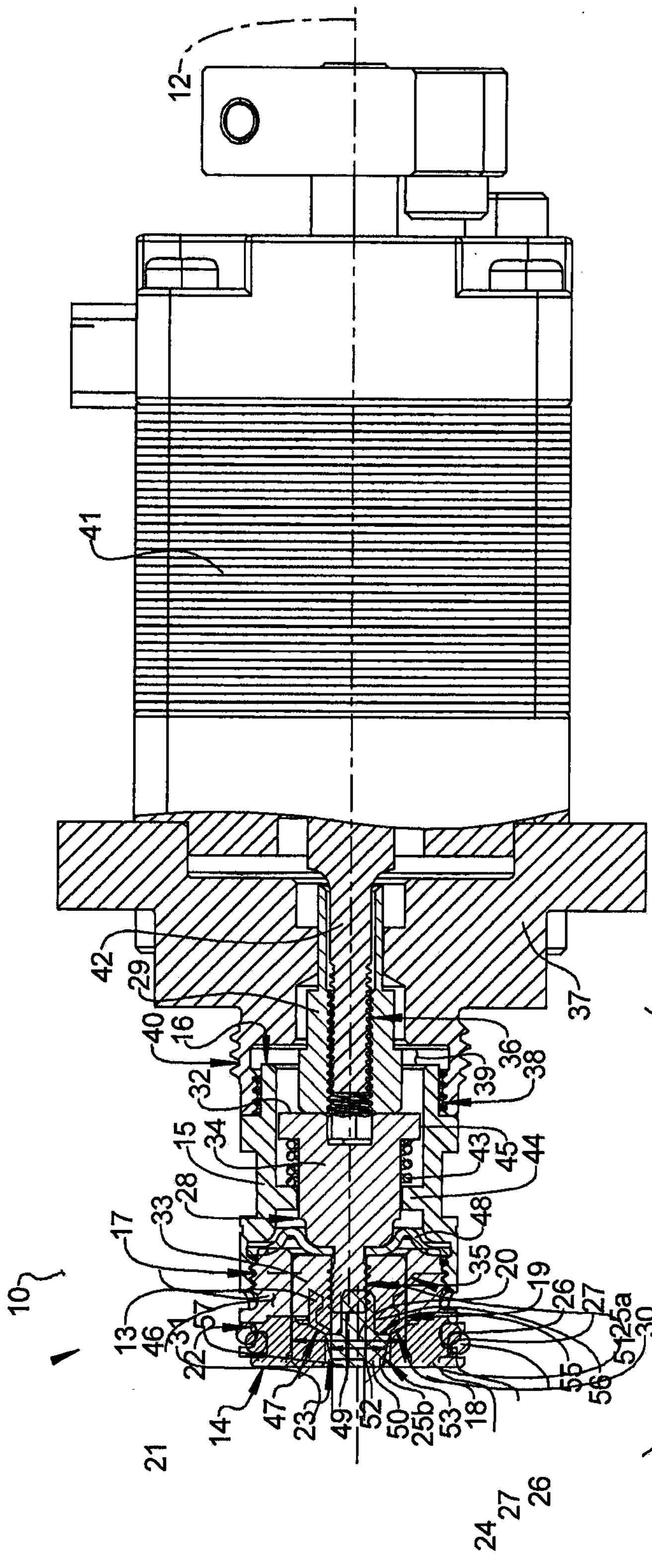
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FIG. 2

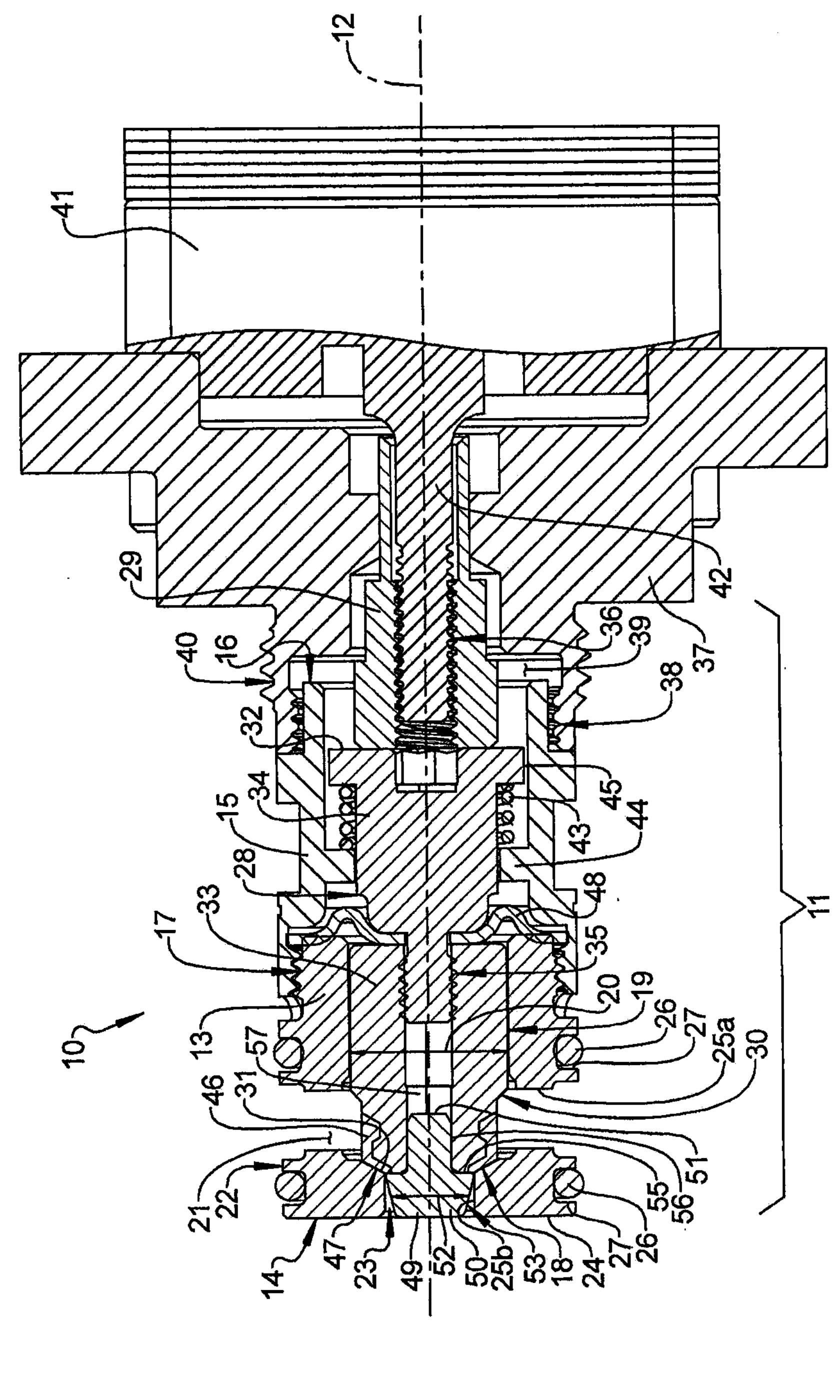

FIG. 3

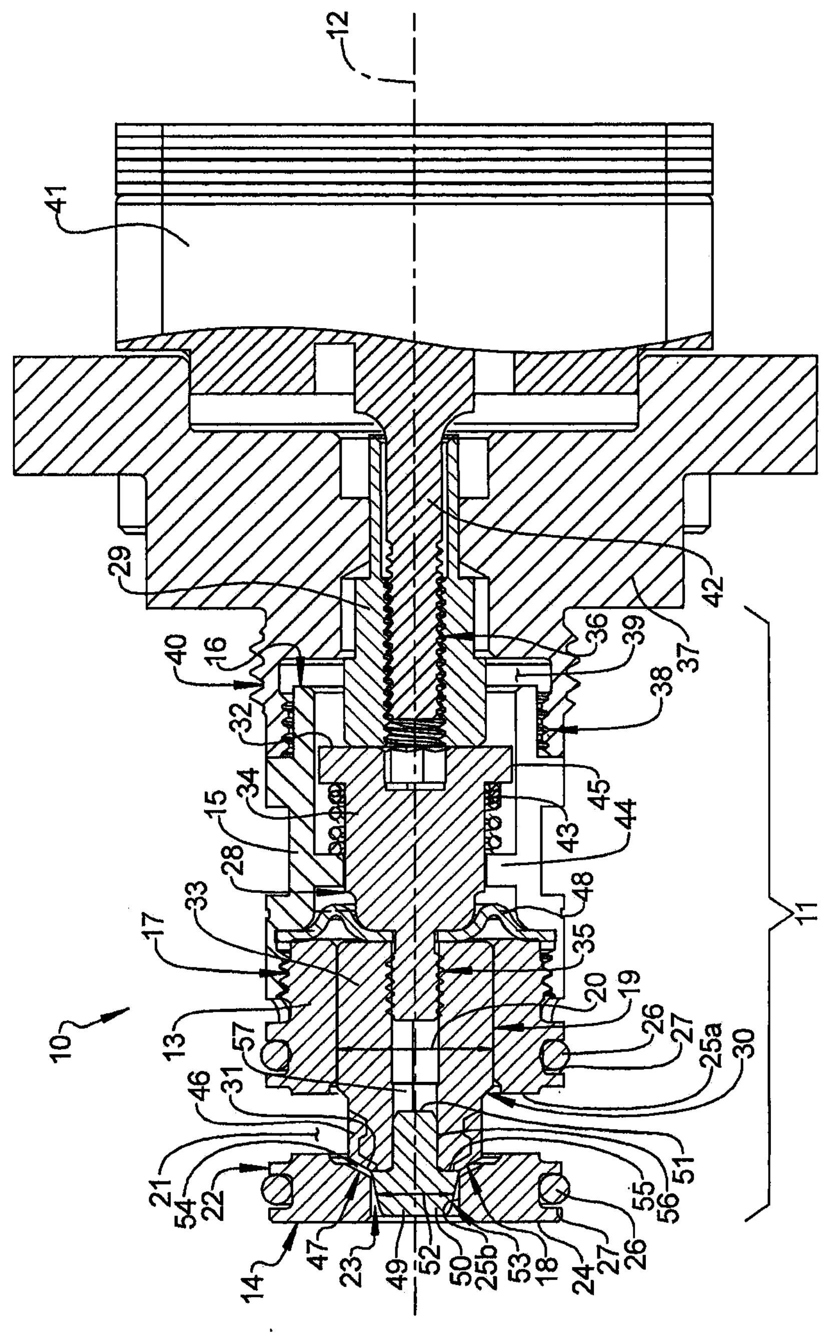
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FIG. 4

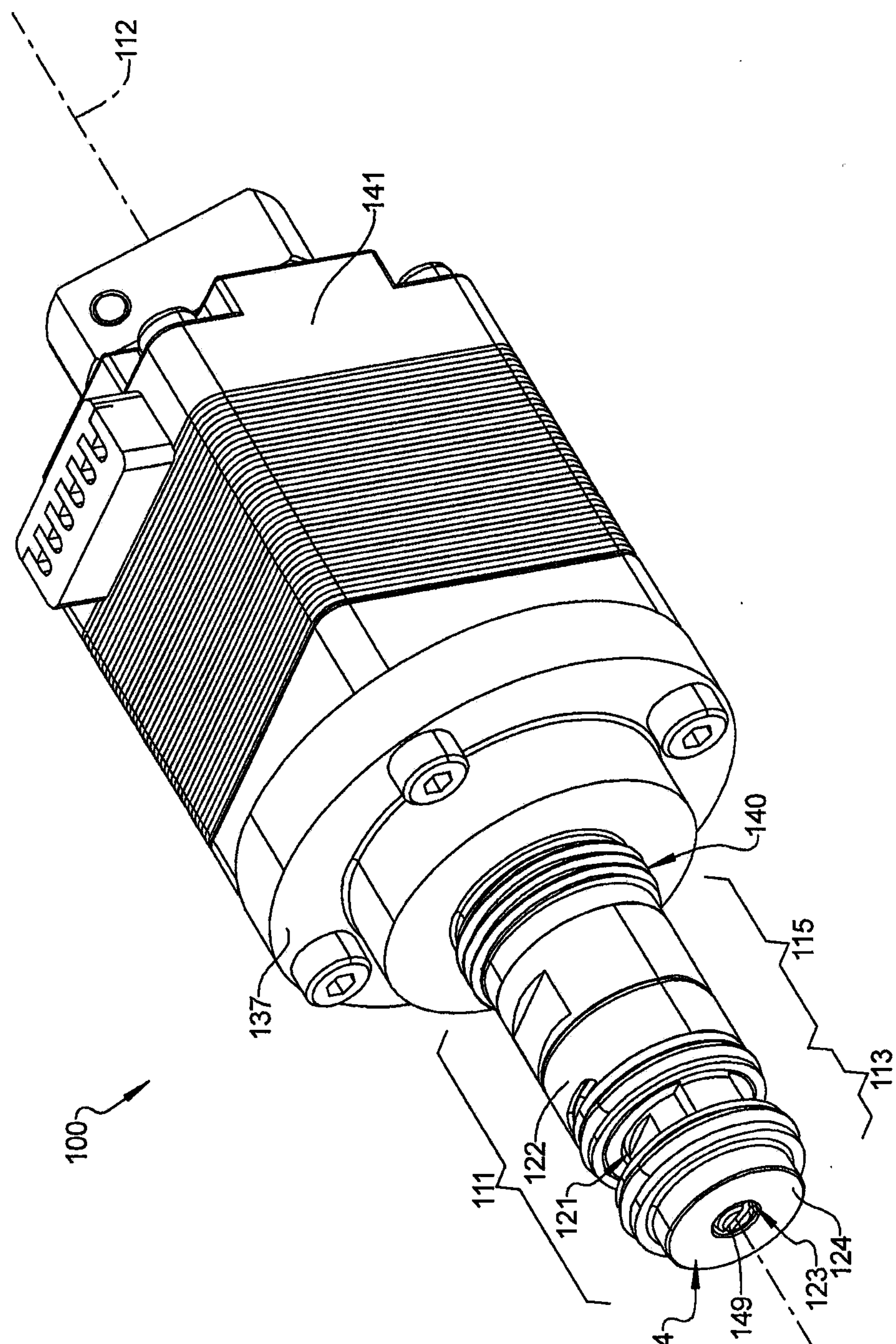

FIG. 5

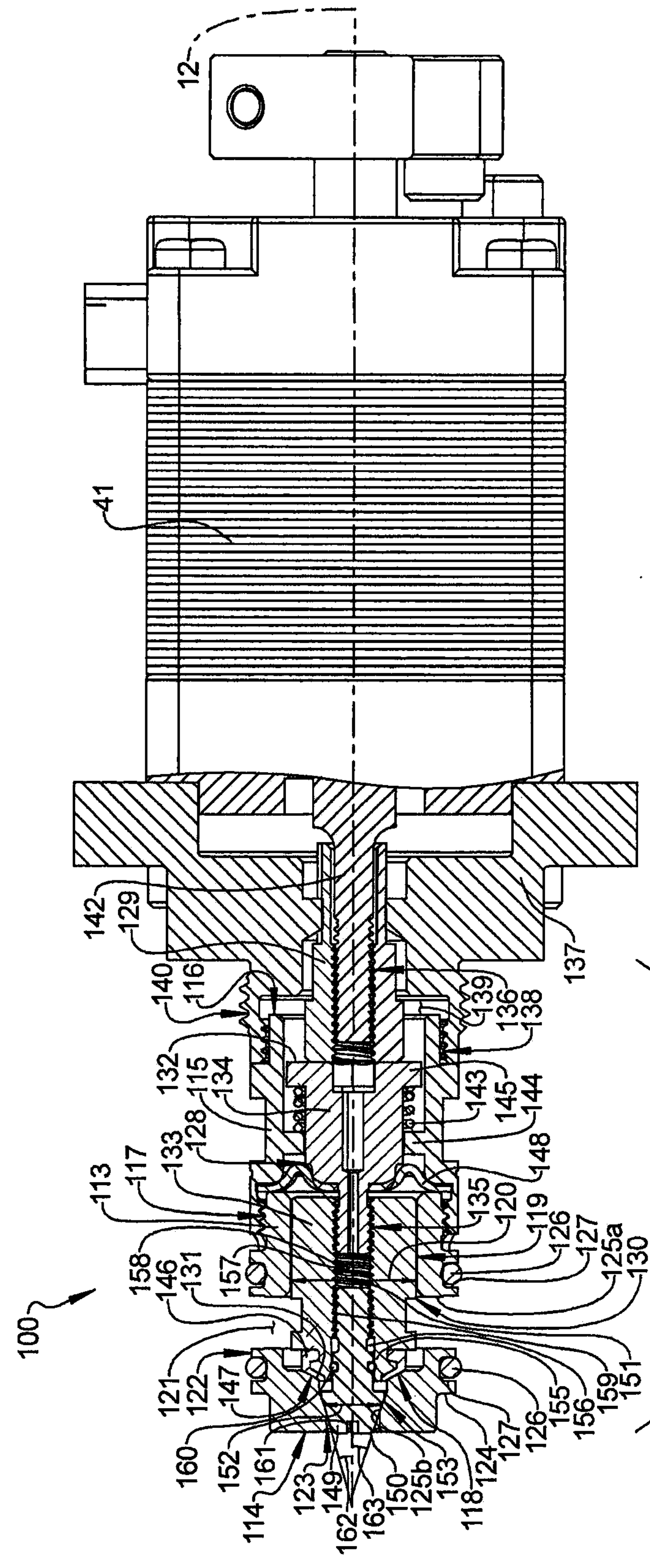
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FIG. 6

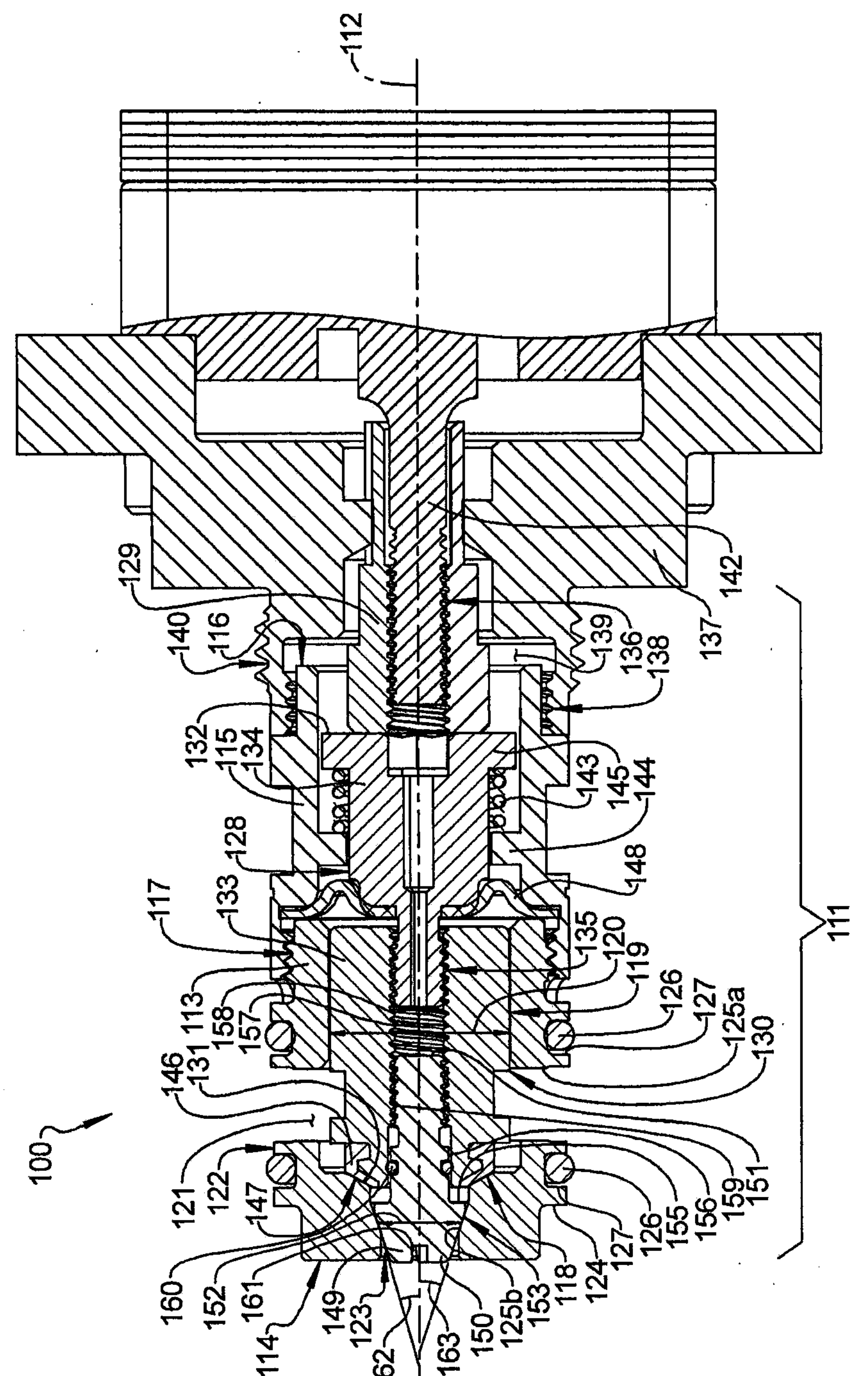

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FIG. 7

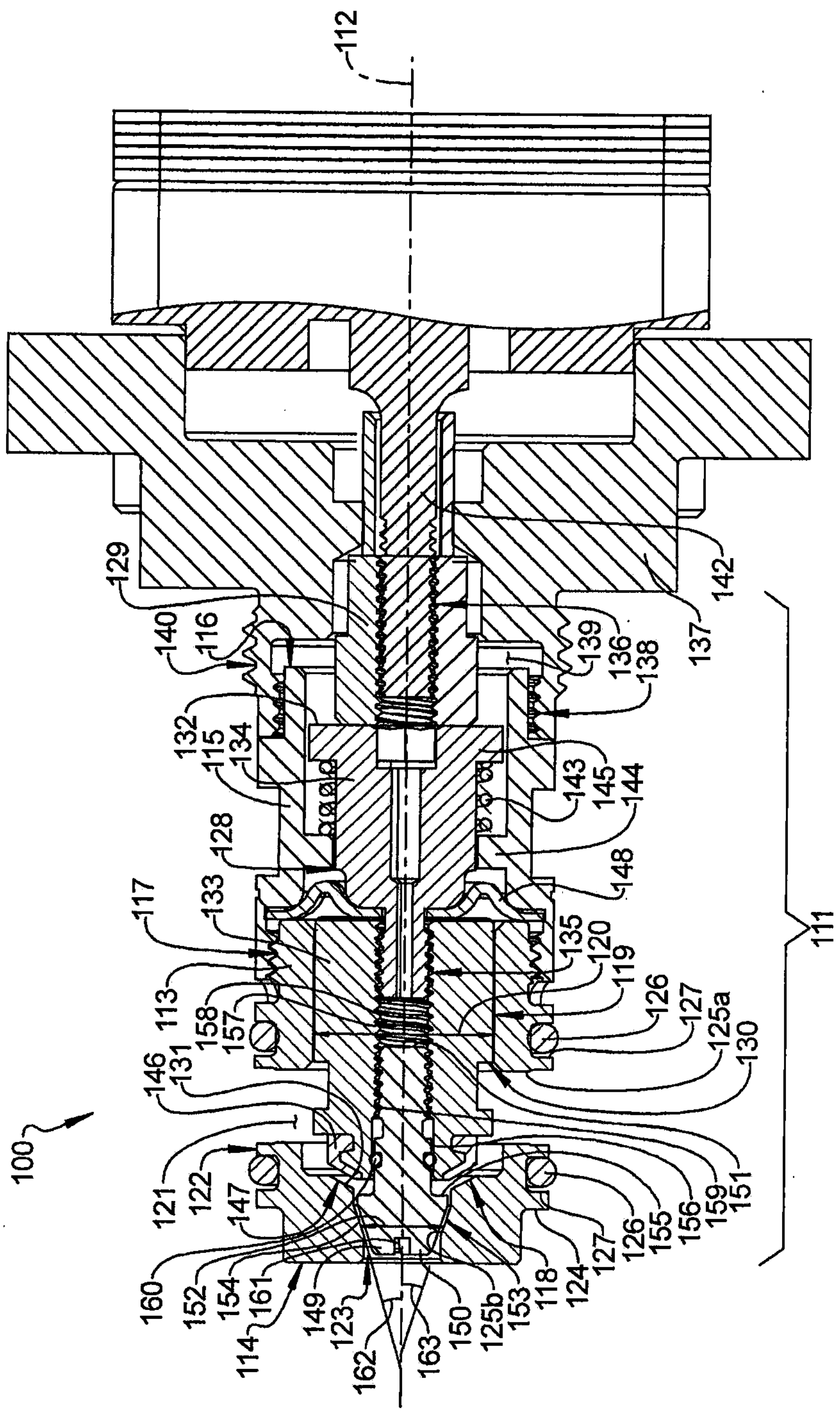
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FIG. 8

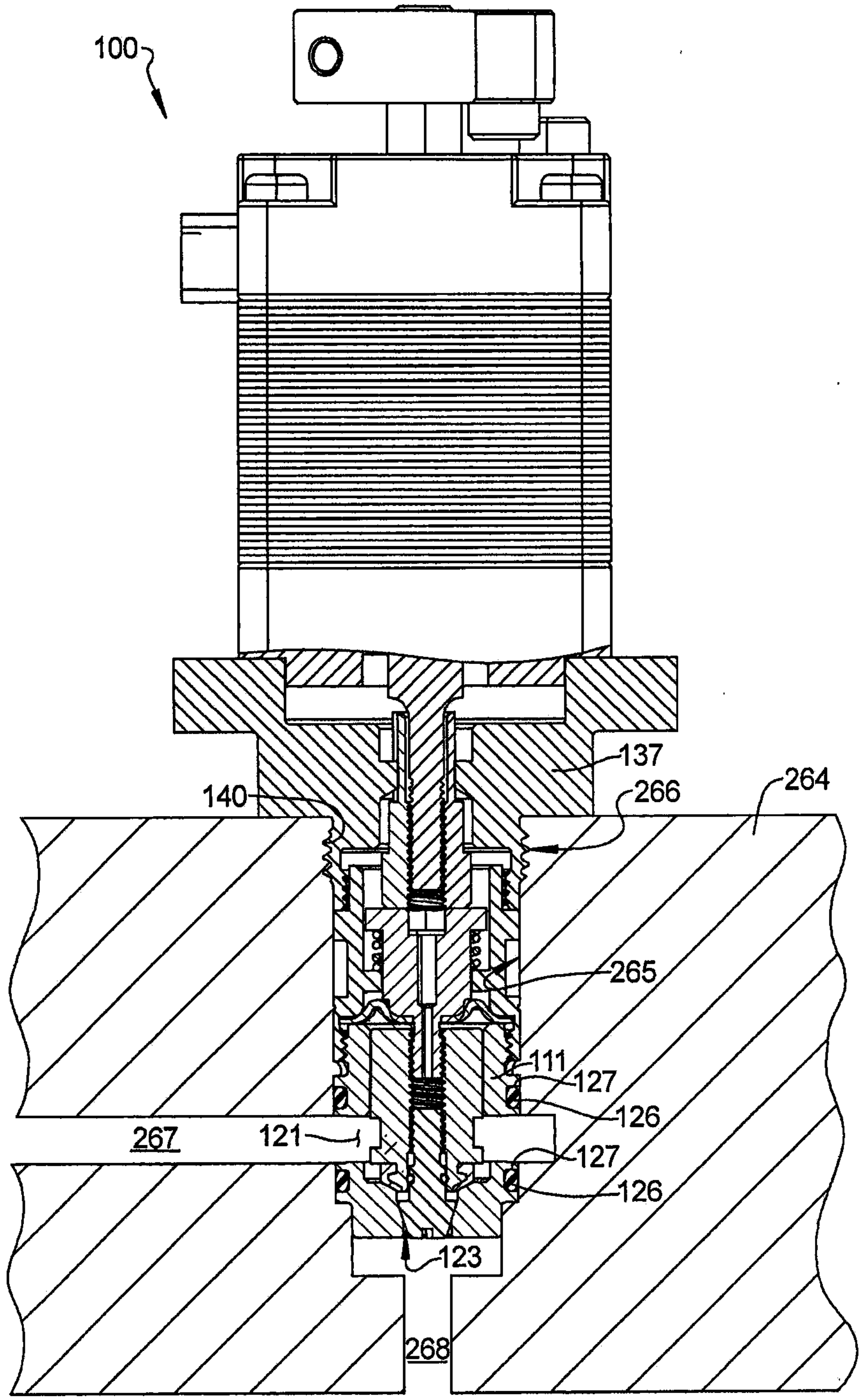

FIG. 9