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ABSTRACT

A control valve having a valve body, seat member, valve member, and solenoid including a housing, bobbin, and coil. The valve member has a head portion disposed within the bobbin and a valve portion, disposed within the valve body, that has a seat engagement member operating to open and close ports in the valve body when the valve member slides between first and second positions. A permanent magnet, disposed within the bobbin, applies an attractive force of variable magnitude to the valve member in a direction opposing a biasing force created by a biasing component. Pulses of electric current applied to the coil change the variable magnitude. The permanent magnet pulls the valve member to the second position when the attractive force is greater than the biasing force and the valve member returns to the first position when the attractive force is less than the biasing force.

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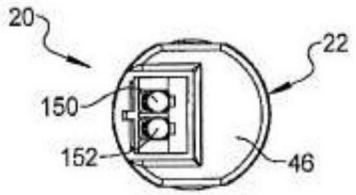


FIG 2

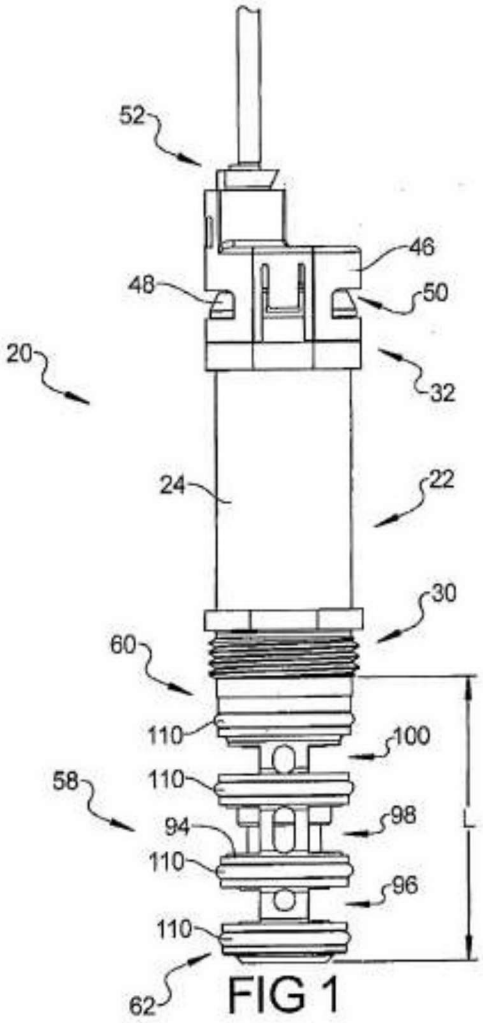


FIG 1

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LATCHING PNEUMATIC CONTROL VALVE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 62/576,257, filed on October 24, 2017. The entire disclosure of the application referenced above is incorporated herein by reference.

FIELD

[0002] The present disclosure relates to control valve assemblies. More particularly, the present disclosure relates to self-latching solenoid actuated valve assemblies, which may find use in various applications including, without limitation, pneumatics.

BACKGROUND

[0003] This section provides background information related to the present disclosure which is not necessarily prior art. The discussion is not an acknowledgement or admission that any of the material referred to is or was part of the common general knowledge as at the priority date of the application.

[0004] Solenoids are well known electromechanical devices used to convert electrical energy into mechanical energy and particularly into short stroke mechanical motion. As such, solenoids have long been employed to actuate valves in response to an electrical signal. For example, it is known in the related art to employ a solenoid to move a valve member in an actuation direction against the biasing force of a return spring. When electrical power is supplied to a coil in the solenoid, a magnetic field is created in the solenoid that moves the valve member from a rest position to an actuated position. When electrical power to the

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solenoid is interrupted, the return spring biases the valve member back to the rest position. However, this approach suffers from the disadvantage that the coil of the solenoid must remain powered at all times to hold the valve member in the actuated position against the biasing force of the return spring. Unexpected, inadvertent, or even planned interruption of electrical power to the coil results in return of the valve member to the rest position, regardless of whether that is desired or not. In applications where the power consumption of the solenoid is of concern, such as where there is a limited source of electrical power (e.g. battery powered valves), solenoids that must be continually powered to hold the valve member in the actuated position are not desirable. Additionally, significant heat build-up can occur in solenoids that must be continually powered to hold the valve member in the actuated position.

[0005] To decrease the power consumption of a solenoid and heat build-up, particularly in applications where the solenoid is to be retained in the actuated position for significant time periods, permanent magnets (PM) have been used to hold the mechanical output of the solenoid in one position or the other without requiring continuous power to the coil of the solenoid. Conventional self-latching solenoids known in the related art typically employ a sliding push pin and a fixed permanent magnet, which can be latched or un-latched by a pulse of electric current. Electrical current flowing through the coil of the solenoid in one direction increases (i.e., strengthens) the attractive force of the permanent magnet and causes the permanent magnet to repel the push pin and push it against the valve member in opposition to the biasing force of the return spring. The return spring biases the valve member in the opposite direction when electrical current flows through the coil of the solenoid in a reverse direction that reduces (i.e., weakens) the attractive force of the permanent magnet. In this way, the valve member may be moved to, and maintained in, any predetermined position by actuation

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of the solenoid after a relatively short pulse of electrical current flows through the coil of the solenoid. After the attractive force of the permanent magnet has been increased (i.e., strengthened) or reduced (i.e., weakened), electrical power can be switched off and the valve member will remain in its current position, whether that is the actuated position or the rest position. While the self-latching solenoid actuated valves are known in the related art, there continues to be a need for improved self-latching solenoid actuated valves. This is especially true for small pneumatic valves.

SUMMARY

[0006] This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

[0007] The subject disclosure describes an improved latching control valve assembly. The latching control valve assembly has a solenoid including a housing, a bobbin, and a coil. The bobbin is disposed within the housing and a coil extends around the bobbin. The housing extends longitudinally between a first housing end and a second housing end and the bobbin defines a solenoid bore that extends along a longitudinal axis. The latching control valve assembly also includes a valve body, a seat member, and a valve member. The valve body extends longitudinally from the first housing end of the solenoid. The valve body defines a valve body bore and the seat member is disposed within the valve body bore. The valve member has a head portion that is slidingly disposed within the solenoid bore and a valve portion that is slidingly disposed within the valve body bore. The valve portion of the valve member has a seat engagement member that extends outwardly to engage the seat member during sliding motion of the valve member in the solenoid bore and the valve body bore. The valve member slides within the solenoid

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bore and the valve body bore between a first position where the seat engagement member is displaced away from the first housing end of the solenoid and a second position where the seat engagement member is displaced towards the first housing end of the solenoid. The valve body includes a ported face. The seat engagement member operates to open and close one or more ports in the ported face of the valve body when the valve member slides longitudinally between the first and second positions. A biasing component operates to apply a biasing force to the valve member. The biasing force biases the valve member toward the first position. A permanent magnet is disposed at least partially within the solenoid bore. The permanent magnet has a magnetic field and operates by applying an attractive force to the valve member. The attractive force generated by the permanent magnet points towards the second housing end of the solenoid such that the attractive force of the permanent magnet opposes the biasing force of the biasing component. A pole piece is also disposed within the solenoid bore. The pole piece is positioned longitudinally in the solenoid bore between the permanent magnet and the head portion of the valve member. The attractive force of the permanent magnet has a variable magnitude. When the coil of the solenoid receives a pulse of electric current in a specific polarity, the variable magnitude of the attractive force generated by the permanent magnet changes. The attractive force of the permanent magnet operates to displace the valve member towards the second position when the variable magnitude of the attractive force is greater than the biasing force of the biasing component. On the other hand, the biasing force of the biasing component operates to displace the valve member towards the first position when the variable magnitude of the attractive force is less than the biasing force of the biasing component. This is accomplished by reversing the polarity of the pulse of current applied to the coil of the solenoid.

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[0008] The attractive force of the permanent magnet in the latching control valve assembly disclosed herein acts on the valve member itself, pulling the valve member towards the pole piece. Advantageously, this eliminates the need for the sliding push pin of conventional self-latching solenoid actuated valves. The subject design also eliminates the need to position the biasing component at a distal end of the valve body, reducing the length of the valve body. This means that the latching control valve assembly disclosed herein requires a shallower cavity in the valve manifold into which it is installed, providing for a more compact and efficient use of space. At the same time, the latching control valve assembly disclosed herein retains the benefits associated with self-latching solenoid actuated valves, including significantly reduced power consumption and heat build-up as compared to traditional solenoid actuated valves. This makes the latching control valve assembly disclosed herein a suitable candidate for battery powered applications and/or applications where the solenoid must hold the valve member in an actuated position for long time periods.

[0009] The subject disclosure further describes an improved latching control valve assembly comprising:

a solenoid including a housing, a bobbin disposed within said housing, and a coil extending around said bobbin;

said housing extending longitudinally between a first housing end and a second housing end;

said bobbin defining a solenoid bore that extends along a longitudinal axis;

a valve body extending longitudinally from said first housing end and defining a valve body bore;

at least one seat member disposed within said valve body bore;

a valve member having a head portion that is slidingly disposed within said solenoid bore and a valve portion that is slidingly disposed within said valve body bore;

said valve portion of said valve member having a seat engagement member that extends outwardly to engage said seat member during sliding motion of said valve member in said solenoid bore and said valve body bore between a first position where said seat engagement member is displaced away from said first housing end and a second position where said seat engagement member is displaced towards said first housing end;

said valve body including a ported face and said seat engagement member being operable to open and close one or more ports in said ported face of said valve body when said valve member translates longitudinally between said first and second positions;

a biasing component operable to apply a biasing force to said valve member that biases said valve member toward said first position;

a permanent magnet disposed at least partially within said solenoid bore that operably applies an attractive force to said valve member, said attractive force pointing towards said second housing end such that said attractive force of said permanent magnet opposes said biasing force of said biasing component;

a pole piece disposed within said solenoid bore that is positioned longitudinally between said permanent magnet and said head portion of said valve member;

a control circuit electrically connected to said coil and programmed to send pulses of electric current to said coil; and

said permanent magnet being made of a material with a coercivity that provides a magnetic field that is responsive to said pulses of electric current sent through said coil where said pulses of electric current alter a variable magnitude of said attractive force of said permanent

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magnet, said attractive force of said permanent magnet operably pulling said valve member towards said second position when said variable magnitude of said attractive force is greater than said biasing force of said biasing component and said biasing force of said biasing component operably pushing said valve member towards said first position when said variable magnitude of said attractive force is less than said biasing force of said biasing component.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Other advantages of the present invention will be readily appreciated, as the same becomes better understood by reference to the following detailed description of an embodiment(s) of the invention when considered in connection with the accompanying drawings wherein:

[0011] Figure 1 is a side elevation view of an exemplary latching control valve assembly constructed in accordance with the subject disclosure;

[0012] Figure 2 is a top elevation view of the exemplary latching control valve assembly illustrated in Figure 1;

[0013] Figure 3 is a front elevation view of the exemplary latching control valve assembly illustrated in Figure 1 and an exemplary valve manifold for receiving the exemplary latching control valve assembly illustrated in Figure 1;

[0014] Figure 4 is a side cross-sectional view of the exemplary latching control valve assembly illustrated in Figure 1 where the valve member is shown in a first position; and

[0015] Figure 5 is another side cross-sectional view of the exemplary latching control valve assembly illustrated in Figure 1 where the valve member is shown in a second position.

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DETAILED DESCRIPTION

[0016] Referring to the Figures, wherein like numerals indicate corresponding parts throughout the several views, a latching control valve assembly **20** is illustrated.

[0017] 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.

[0018] 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.

[0019] 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.

[0020] 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.

[0021] Spatially relative terms, such as "inner," "outer," "interior," "exterior," "beneath", "below", "lower", "above", "upper", "proximal", "distal", "inboard", "outboard" 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

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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. The terms "longitudinal" and "longitudinally" means alignment in a direction that is along or parallel to the longitudinal axis described below. The terms "threadably engages" and "threadably engaged" describes an interface between two components where male and female threads mate and hold the two components together.

[0022] With reference to Figures 1-5, the latching control valve assembly **20** disclosed herein includes a solenoid **22**. The solenoid **22** has a housing **24**, a bobbin **26**, and a coil **28**. The bobbin **26** is disposed within the housing **24** and the coil **28** is disposed radially between the bobbin **26** and the housing **24**. The housing **24** of the solenoid **22** extends longitudinally between a first housing end **30** and a second housing end **32**. The bobbin **26** includes an exterior surface **34** and an interior surface **36**. The interior surface **36** of the bobbin **26** defines a solenoid bore **38** that extends along a longitudinal axis **40**. The coil **28** includes windings **42** of a conductive wire that extend about the exterior surface **34** of the bobbin **26**. In the embodiment shown, the windings **42** of the coil **28** are wound in a clockwise direction about the bobbin **26** when viewed from a point **44** disposed along the longitudinal axis **40** adjacent the second housing end **32** (i.e. when the solenoid **22** is viewed from above, as shown in Figure 2). It should be appreciated that the coil **28** may be wound in a counter-clockwise direction about the bobbin **26**; however, other corresponding changes to the latching control valve assembly **20** would have to be made, which will be described below. The conductive wire of the windings **42** may be made from a variety of different materials. By way of example and without limitation, the conductive wire of the windings

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42 may be made of an enamel coated copper (Cu). It should also be appreciated that the housing **24** and the bobbin **26** may have a variety of different shapes without departing from the scope of the subject disclosure. By way of non-limiting example, the housing **24** and the bobbin **26** may generally be cylindrical in shape as shown in the appended figures.

[0023] The latching control valve assembly **20** illustrated in Figures 1-5 includes an end cap **46** that is retained on the second housing end **32** of the solenoid **22**. The end cap **46** may be fastened to the housing **24** of the solenoid **22** in a variety of different ways. In the illustrated example, the end cap **46** is secured to the second housing end **32** of the solenoid **22** by snap elements **48**. The snap elements **48** have a ramped shape and snap into openings **50** in the end cap **46** to hold the end cap **46** in place. The latching control valve assembly **20** also includes at least two electrical connectors **52** that are electrically connected to the coil **28** of the solenoid **22**. For example, the at least two electrical connectors **52** may include a first terminal **54** and a second terminal **56**. The first and second terminals **54, 56** may have a variety of different shapes and configurations. In the illustrated example, the first and second terminals **54, 56** are electrically conductive pins that extend longitudinally outward from the second housing end **32** and through the end cap **46**.

[0024] The latching control valve assembly **20** also includes a valve body **58**. The valve body **58** extends longitudinally from the first housing end **30** and has a proximal end **60**, a distal end **62**, and a length **L** that is measurable between the proximal end **60** and the distal end **62** of the valve body **58**. The proximal end **60** of the valve body **58** is disposed adjacent to the first housing end **30** and the distal end **62** of the valve body **58** is longitudinally spaced away from the first housing end **30**. The proximal end **60** of the valve body **58** is attached to the first housing end

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30 of the solenoid **22**. By way of example and without limitation, the proximal end **60** of the valve body **58** may be threadably engaged with the first housing end **30** of the solenoid **22**.

[0025] As best seen in Figures 4 and 5, the valve body **58** defines a valve body bore **64** that is oriented coaxially with the longitudinal axis **40** of the solenoid bore **38**. The valve body bore **64** has a bore diameter **66**, which extends across the valve body bore **64** in a direction that is transverse to the longitudinal axis **40**. One or more seat members **68a, 68b** are disposed within the valve body bore **64**. While other configurations are possible, the seat members **68a, 68b** in the illustrated example extend into and are threadably engaged with the valve body bore **64**. The seat members **68a, 68b** may be cylindrical in shape and have an internal diameter **70**, which extends across the seat members **68a, 68b** in a direction that is transverse to the longitudinal axis **40**. The seat members **68a, 68b** may also include seals **72** that seal the seat members **68a, 68b** within the valve body bore **64** to prevent fluid leaks within the valve body bore **64** between the seat members **68a, 68b** and the valve body **58**.

[0026] The latching control valve assembly **20** includes a valve member **74** that is oriented coaxially with the longitudinal axis **40**. The valve member **74** has an outer surface **76**, a head portion **78**, and a valve portion **80**. As shown in Figures 4 and 5, the valve member **74** is a single-piece component where the head portion **78** and the valve portion **80** of the valve member **74** are integral with each other. The head portion **78** is slidingly disposed within the solenoid bore **38** and the valve portion **80** is slidingly disposed within the valve body bore **64** such that the valve member **74** can translate longitudinally between a first position (Figure 4) and a second position (Figure 5). Along the head portion **78**, the outer surface **76** of the valve member **74** faces and is arranged in a slip fit with the interior surface **36** of the bobbin **26**. Optionally, the outer surface **76** of the valve member **74** may have a cylindrical shape along the head portion **78**.

[0027] The valve portion **80** of the valve member **74** includes a seat engagement member **82** that extends radially outwardly to engage the seat members **68a, 68b** during sliding motion of the valve member **74** in the valve body bore **64**. The seat engagement member **82** may have a circular cross-sectional shape and may define an outer diameter **84**, which extends across the seat engagement member **82** in a direction that is transverse to the longitudinal axis **40**. As shown in Figure 4, when the valve member **74** slides to the first position, the seat engagement member **82** is displaced away from the first housing end **30** of the solenoid **22**. As shown in Figure 5, when the valve member **74** slides to the second position, the seat engagement member **82** is displaced towards the first housing end **30** of the solenoid **22**. The seat engagement member **82** may be made from a variety of different materials. For example and without limitation, at least part of the seat engagement member **82** may be made of a resilient material, such as rubber. The valve portion **80** of the valve member **74** may also have a variety of different shapes. For example, the valve portion **80** of the valve member **74** may have a poppet valve shape (illustrated) or a spool valve shape (not shown). When the valve portion **80** of the valve member **74** is configured as a poppet valve, the outer diameter **84** of the seat engagement member **82** is greater than the internal diameter **70** of the seat members **68a, 68b**. When the valve portion **80** of the valve member **74** is configured as a spool valve, the outer diameter **84** of the seat engagement member **82** approximately equals the internal diameter **70** of the seat members **68a, 68b**.

[0028] The valve portion **80** of the valve member **74** may also include a first piston **86** adjacent the distal end **62** of the valve body **58** and a second piston **88** adjacent the proximal end **60** of the valve body **58**. The first and second pistons **86, 88** operate to seal against the seat members **68a, 68b**. Optionally, the first and second pistons **86, 88** may have substantially equal diameters such that a pressurized fluid acting oppositely against the first and second pistons **86, 88**

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results in balanced pressure forces acting on the valve member **74**. Such a configuration is sometimes described as a pressure balanced valve. Each of the first and second pistons **86, 88** may include an annular groove **90** and a resilient piston seal **92** disposed in the annular groove **90** that slidably and sealingly engages the seat members **68a, 68b** with a close tolerance fit to prevent fluid leaks in the valve body bore **64** between the first and second pistons **86, 88** and the seat members **68a, 68b**.

[0029] The valve body **58** includes a ported face **94**, a first port **96**, a second port **98**, and a third port **100**. The first port **96** extends through the valve body **58** from the valve body bore **64** to the ported face **94** and is positioned within the valve body **58** adjacent to the distal end **62**. The second port **98** extends through the valve body **58** from the valve body bore **64** to the ported face **94** and is positioned longitudinally between the first and third ports **96, 100**. The third port **100** extends through the valve body **58** from the valve body bore **64** to the ported face **94** and is positioned within the valve body **58** adjacent to the proximal end **60**. The first port **96** and the third port **100** are longitudinally positioned on opposite sides of the seat engagement member **82** of the valve member **74**. When the valve member **74** is in the first position (Figure 4), the seat engagement member **82** contacts and seals against seat member **68a** to close the first port **96** and open the third port **100**. Thus, a first fluid flow path **102** is created when the valve member **74** is in the first position where fluid can flow through the valve body bore **64** from the second port **98** to the third port **100** or from the third port **100** to the second port **98**. When the valve member **74** is in the second position (Figure 5), the seat engagement member **82** contacts and seals against seat member **68b** to open the first port **96** and close the third port **100**. Thus, a second fluid flow path **104** is created when the valve member **74** is in the second position where fluid can flow through

the valve body bore **64** from the first port **96** to the second port **98** or from the second port **98** to the first port **96**.

[0030] With reference to Figure 3, the ported face **94** of the valve body **58** is configured to be received in a cavity **106** of a valve manifold **108**. In the illustrated example, the valve body **58** is threadably engaged in the cavity **106** of the valve manifold **108**; however, the valve body **58** may be secured to the valve manifold **108** by alternative structure. The valve body **58** may also include O-rings **110** that seal the valve body **58** within the cavity **106** in the valve manifold **108** to prevent fluid leaks within the cavity **106** between the valve body **58** and the valve manifold **108**. The valve manifold **108** may include one or more fluid passageways (not shown) that communicate fluid to or from the first, second, and third ports **96, 98, 100** in the valve body **58**. For example and without limitation, the valve manifold **108** may be configured such that the first port **96** in the valve body **58** operates as an inlet port that receives fluid, the second port **98** operates as an outlet port that discharges fluid, and the third port **100** operates as an exhaust port that also discharges fluid.

[0031] With reference to Figures 4 and 5, the latching control valve assembly **20** may also include a bushing **112** disposed within the housing **24** of the solenoid **22**. The bushing **112** may include a flange portion **114** positioned within the first housing end **30** and a neck portion **116** that extends into the solenoid bore **38** such that the neck portion **116** is positioned radially between the head portion **78** of the valve member **74** and the bobbin **26**. While other configurations are possible, the flange portion **114** of the bushing **112** threadably engages the first housing end **30** and the neck portion **116** of the bushing **112** is cylindrical in shape in the illustrated example. The latching control valve assembly **20** also includes a biasing component **118** that is positioned longitudinally between the second piston **88** of the valve member **74** and the flange portion **114** of

the bushing **112**. The biasing component **118** operates to apply a biasing force **120** to the valve member **74**. The biasing force **120** generated by the biasing component **118** points towards the distal end **62** of the valve body **58** and therefore biases the valve member **74** toward the first position. Although the biasing component **118** may take several forms, the biasing component **118** in the illustrated example is a compression spring that extends helically/annularly about the head portion **78** of the valve member **74**.

[0032] The latching control valve assembly **20** further includes a permanent magnet **122** that is disposed within the second housing end **32** of the solenoid **22**. The permanent magnet **122** has an inboard end **124** that faces the head portion **78** of the valve member **74** and an outboard end **126** that faces the end cap **46**. In the illustrated example, the permanent magnet **122** is disposed entirely within the solenoid bore **38**; however, in other embodiments the permanent magnet **122** may only partially extend into the solenoid bore **38** with portions of the permanent magnet **122** positioned outside the solenoid bore **38**. In operation, the permanent magnet **122**, sometimes abbreviated PM, can selectively generate a magnetic field and apply an attractive force **128** to the valve member **74**. The attractive force **128** that is generated by the permanent magnet **122** points towards the second housing end **32** of the solenoid **22** such that the attractive force **128** of the permanent magnet **122** opposes the biasing force **120** of the biasing component **118**.

[0033] The latching control valve assembly **20** also includes a pole piece **130** disposed within the solenoid bore **38** and positioned longitudinally between the inboard end **124** of the permanent magnet **122** and the head portion **78** of the valve member **74**. The pole piece **130** extends longitudinally between a first end **132** that faces the head portion **78** of the valve member **74** and a second end **134** that abuts the inboard end **124** of the permanent magnet **122**. The magnetic field of the permanent magnet **122** holds the permanent magnet **122** against the pole

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piece **130**. As a result, contact between the second end **134** of the pole piece **130** and the inboard end **124** of the permanent magnet **122** remains constant during operation of the latching control valve assembly **20**. In other words, the permanent magnet **122** does not move longitudinally relative to the pole piece **130** during operation of the latching control valve assembly **20**. However, the permanent magnet **122** does move longitudinally with the pole piece **130** relative to the bobbin **26** when the longitudinal position of the pole piece **130** is adjusted in the manner explained below.

[0034] When the valve member **74** is in the first position (Figure 4), the head portion **78** of the valve member **74** and the first end **132** of the pole piece **130** are longitudinally spaced from each other by a gap **136**. When the valve member **74** is in the second position (Figure 5), the head portion **78** of the valve member **74** moves into close proximity to the first end **132** of the pole piece **130** such that the gap **136** is minimized or reduced. The size of the gap **136** is critical to the performance of the solenoid **22**. Adjustment of the pole piece **130** provided by the subject design advantageously allows the gap **136** to be set for optimal performance. The pole piece **130** is arranged in threaded engagement with the bobbin **26** to provide adjustable longitudinal positioning of the pole piece **130** relative to the head portion **78** of the valve member **74**. The interior surface **36** of the bobbin **26** has female threads **138** while the pole piece **130** has male threads **140** adjacent the first end **132** of the pole piece **130**. The male threads **140** of the pole piece **130** threadably engage the female threads **138** of the bobbin **26** such that relative rotation of the pole piece **130** within the solenoid bore **38** of the bobbin **26** longitudinally displaces the pole piece **130**. Rotation of the pole piece **130** within the solenoid bore **38** of the bobbin **26** changes the gap **136** that exists between the head portion **78** of the valve member **74** and the first end **132** of the pole piece **130** when the valve member **74** is in the first position. To facilitate the adjustment of the longitudinal position of the pole piece **130** within the solenoid bore **38**, the second end **134**

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of the pole piece **130** may optionally include a tool engagement interface **142**. The pole piece **130** is made of a material that extends the magnetic field of the permanent magnet **122** to encompass at least a part of the head portion **78** of the valve member **74**. By way of example and without limitation, the pole piece **130** may be made of a nickel plated AISI 12L14 carbon steel or AISI 430F stainless steel.

[0035] The attractive force **128** generated by the permanent magnet **122** has a variable magnitude (i.e. the strength and/or direction of the attractive force **128** that the permanent magnet **122** applies to the head portion **78** of the valve member **74** is changeable). In operation, the coil **28** of the solenoid **22** receives a pulse of electric current. The variable magnitude of the attractive force **128** generated by the permanent magnet **122** changes in response to the pulse and polarity of electric current passing through the coil **28** of the solenoid **22**. Once the attractive force **128** of the permanent magnet **122** is increased (i.e., strengthened), by the pulse of electrical current through the coil **28**, the increased magnitude of the attractive force **128** generated by the permanent magnet **122** will move the valve member **74** and position the head portion **78** into close proximity to the pole piece **132** reducing the gap **136** enough, that when the pulse of electrical current is stopped and the attractive force **128** is reduced, there is enough residual attractive force **128** from the permanent magnet **122** to maintain the valve member **74** in the second position. This residual attractive force **128** of the permanent magnet **122** can be reduced further by applying a pulse of electrical current in the reverse direction to the coil **28**. The coercivity of the material forming the permanent magnet **122** must be such that the magnetic field of the material is responsive to the pulses of electric current sent through the coil **28** of the solenoid **22**. Although several materials may be used for the permanent magnet **122**, in one non-limiting example, the permanent magnet **122** is made of neodymium (Nd). As shown in Figures 4 and 5, the permanent magnet **122** in the

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illustrated example has a south pole **144** at the inboard end **124** and a north pole **146** at the outboard end **126**. Alternatively, the south pole **144** of the permanent magnet **122** may be at the outboard end **126** and the north pole **146** may be at the inboard end **124**, but such a modification would require associated changes to the direction in which the windings **42** are wound about the bobbin **26** and/or a control methodology of the pulses of electric current that is different than the control methodology presented below.

[0036] The attractive force **128** of the permanent magnet **122** displaces the valve member **74** towards the second position (Figure 5) when the variable magnitude of the attractive force **128** is greater than the biasing force **120** of the biasing component **118**. On the other hand, the biasing force **120** of the biasing component **118** displaces the valve member **74** towards the first position (Figure 4) when the variable magnitude of the attractive force **128** is less than the biasing force **120** of the biasing component **118**. In other words, permanent magnet **122** pulls (i.e. attracts) the valve member **74** towards itself, from the first position to the second position, when the attractive force **128** the permanent magnet **122** generates is strong enough to overcome the biasing force **120** of the biasing component **118**. The biasing component **118** returns the valve member **74** to the first position when the attractive force **128** the permanent magnet **122** generates is weaker than the biasing force **120** of the biasing component **118**. Whether the variable magnitude of the attractive force **128** is greater than or less than biasing force **120** depends on the polarity of the pulse of electric current through the coil **28** of the solenoid **22**.

[0037] With reference to Figure 3, the latching control valve assembly **20** may further include a control circuit **148** that is electrically connected to the at least two electrical connectors **52** by a first electrical lead **150** and a second electrical lead **152**. The first and second electrical leads **150, 152** communicate electric current from the control circuit **148** to the two

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electrical connectors **52** and may take many forms, including without limitation, wires or conductive traces on a printed circuit board (PCB). The first electrical lead **150** is electrically connected to the first terminal **54** and the second electrical lead **152** is electrically connected to the second terminal **56**. In operation, the control circuit **148** supplies one or more pulses of electric current to the coil **28** via the first and/or second electrical leads **150, 152**. An exemplary operational control methodology is presented in Table I below:

OPERATION			
RED WIRE	BLACK WIRE	FLOW PATH OPEN	FLOW PATH CLOSED
+12 VDC	0 VDC	1 - 2	2 - 3
0 VDC	+12 VDC	2 - 3	1 - 2

Table I

[0038] The column in Table I labeled "Red Wire" lists the voltage of the electric current that is supplied to the first electrical lead **150**. The column in Table I labeled "Black Wire" lists the voltage of the electric current that is supplied to the second electrical lead **152**. The column in Table I labeled "Flow Path Open" lists the ports between which a fluid flow path is present (i.e. is open) within the valve body bore **64** where "1" identifies the first port **96**, "2" identifies the second port **98**, "3" identifies the third port **100**, "2-3" identifies the first fluid flow path **102**, and "1-2" identifies the second fluid flow path **104**. The column in Table I labeled "Flow Path Closed" lists the ports between which a fluid flow path is not present (i.e. is closed) within the valve body bore **64** where "1" identifies the first port **96**, "2" identifies the second port **98**, "3" identifies the third port **100**, "2-3" identifies the first fluid flow path **102**, and "1-2" identifies the second fluid flow path **104**.

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[0039] The top row (i.e. the first row) in Table I corresponds to an operational state where the valve member **74** is brought to and held in the second position (Figure 5). In this operational state, the variable magnitude of the attractive force **128** of the permanent magnet **122** increases in response to the control circuit **148** supplying a positive voltage pulse of electric current to the first electrical lead **150** and zero volts to the second electrical lead **152**. This increase in the variable magnitude of the attractive force **128** of the permanent magnet **122** causes the permanent magnet **122** to pull the valve member **74** from the first position to the second position and hold the valve member **74** in the second position against the biasing force **120** of the biasing component **118**. In the second position, the seat engagement member **82** opens the second fluid flow path **104** between the first and second ports **96, 98** and closes the first fluid flow path **102** between the second and third ports **98, 100**. As noted in Table I, the positive voltage pulse of electric current that is supplied to the first electrical lead **150** may be, for example, +12 volts direct current (VDC).

[0040] The bottom row (i.e. the second row) in Table I corresponds to an operational state where the valve member **74** is returned to the first position (Figure 4). In this operational state, the variable magnitude of the attractive force **128** of the permanent magnet **122** decreases in response to the control circuit **148** supplying zero volts to the first electrical lead **150** and a positive voltage pulse of electric current to the second electrical lead **152**. This decrease in the variable magnitude of the attractive force **128** of the permanent magnet **122** causes the valve member **74** to return to the first position as the variable magnitude of the attractive force **128** of the permanent magnet **122** falls below a magnitude of the biasing force **120** of the biasing component **118** (i.e. becomes weaker than the biasing force **120** of the biasing component **118**). In the first position, the seat engagement member **82** opens the first fluid flow path **102** between the second and third ports **98, 100** and closes the second fluid flow path **104** between the first and

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second ports **96, 98**. As noted in Table I, the positive voltage pulse of electric current that is supplied to the second electrical lead **152** may be, for example, +12 volts direct current (VDC). It should be appreciated that the variable magnitude of the attractive force **128** of the permanent magnet **122** remains constant when no electric current is supplied to the coil **28**.

[0041] Except where certain materials for a particular component have been described, the components of the latching control valve assembly described above may be made of a variety of different materials, including without limitation, metals, metal alloys, and plastics. Obviously, many modifications and variations of the disclosed latching control valve assembly are possible in light of the above teachings and may be practiced otherwise than as specifically described while within the scope of the appended claims. These antecedent recitations should be interpreted to cover any combination in which the inventive novelty exercises its utility. The use of the word "said" in the apparatus claims refers to an antecedent that is a positive recitation meant to be included in the coverage of the claims whereas the word "the" precedes a word not meant to be included in the coverage of the claims.

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CLAIMS

What is claimed is:

1. A latching control valve assembly comprising:

a solenoid including a housing, a bobbin disposed within said housing, and a coil extending around said bobbin;

said housing extending longitudinally between a first housing end and a second housing end;

said bobbin defining a solenoid bore that extends along a longitudinal axis;

a valve body extending longitudinally from said first housing end and defining a valve body bore;

at least one seat member disposed within said valve body bore;

a valve member having a head portion that is slidingly disposed within said solenoid bore and a valve portion that is slidingly disposed within said valve body bore;

said valve portion of said valve member having a seat engagement member that extends outwardly to engage said seat member during sliding motion of said valve member in said solenoid bore and said valve body bore between a first position where said seat engagement member is displaced away from said first housing end and a second position where said seat engagement member is displaced towards said first housing end;

said valve body including a ported face and said seat engagement member being operable to open and close one or more ports in said ported face of said valve body when said valve member translates longitudinally between said first and second positions;

a biasing component operable to apply a biasing force to said valve member that biases said valve member toward said first position;

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a permanent magnet disposed at least partially within said solenoid bore that operably applies an attractive force to said valve member, said attractive force pointing towards said second housing end such that said attractive force of said permanent magnet opposes said biasing force of said biasing component;

a pole piece disposed within said solenoid bore that is positioned longitudinally between said permanent magnet and said head portion of said valve member;

a control circuit electrically connected to said coil and programmed to send pulses of electric current to said coil; and

said permanent magnet being made of a material with a coercivity that provides a magnetic field that is responsive to said pulses of electric current sent through said coil where said pulses of electric current alter a variable magnitude of said attractive force of said permanent magnet, said attractive force of said permanent magnet operably pulling said valve member towards said second position when said variable magnitude of said attractive force is greater than said biasing force of said biasing component and said biasing force of said biasing component operably pushing said valve member towards said first position when said variable magnitude of said attractive force is less than said biasing force of said biasing component.

2. The latching control valve assembly as set forth in Claim 1 wherein said pole piece is arranged in threaded engagement with said bobbin to provide adjustable longitudinal positioning of said pole piece relative to said head portion of said valve member.

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3. The latching control valve assembly as set forth in Claim 2 wherein said permanent magnet extends longitudinally between an inboard end and an outboard end, said pole piece extends longitudinally between a first end that faces said head portion of said valve member and a second end that abuts said inboard end of said permanent magnet, said head portion of said valve member and said first end of said pole piece are longitudinally spaced from each other by a gap when said valve member is in said first position, and said head portion of said valve member abuts said first end of said pole piece when said valve member is in said second position such that said gap is eliminated when said valve member is in said second position.

4. The latching control valve assembly as set forth in Claim 3 wherein said bobbin has an interior surface that defines said solenoid bore, said interior surface of said bobbin has female threads, and said pole piece has male threads adjacent said first end that threadably engage said female threads of said bobbin such that relative rotation of said pole piece within said solenoid bore longitudinally displaces said pole piece and changes said gap between said head portion of said valve member and said first end of said pole piece when said valve member is in said first position.

5. The latching control valve assembly as set forth in Claim 4 wherein said second end of said pole piece includes a tool engagement interface.

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6. The latching control valve assembly as set forth in any one of Claims 1 to 5, further comprising:

at least two electrical connectors electrically connected to said coil; and

a first electrical lead and a second electrical lead that electrically connect said control circuit to said first and second electrical connectors.

7. The latching control valve assembly as set forth in Claim 6 wherein said permanent magnet extends longitudinally between an inboard end and an outboard end, has a south pole at said inboard end, and has a north pole at said outboard end.

8. The latching control valve assembly as set forth in Claim 7 wherein said coil has windings that are wound in a clockwise direction about said bobbin when viewing said bobbin from a point disposed along said longitudinal axis adjacent said second housing end.

9. The latching control valve assembly as set forth in Claim 8 wherein said variable magnitude of said attractive force of said permanent magnet increases in response to said control circuit supplying a positive voltage pulse of electric current to said first electrical lead and wherein said variable magnitude of said attractive force of said permanent magnet decreases in response to said control circuit supplying a positive voltage pulse of electric current to said second electrical lead.

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10. The latching control valve assembly as set forth in Claim 9 wherein said variable magnitude of said attractive force of said permanent magnet remains constant when no electric current is supplied to said coil.

11. The latching control valve assembly as set forth in any one of Claims 1 to 10 wherein said valve body extends between a proximal end and a distal end, said proximal end of said valve body is disposed adjacent said first housing end, and said distal end of said valve body is spaced away from said first housing end.

12. The latching control valve assembly as set forth in Claim 11 wherein said valve body includes a first port extending through said valve body from said valve body bore to said ported face adjacent to said distal end of said valve body, a second port extending through said valve body from said valve body bore to said ported face, and a third port extending through said valve body from said valve body bore to said ported face adjacent to said proximal end of said valve body such that said second port is disposed longitudinally between said first port and said third port.

13. The latching control valve assembly as set forth in Claim 12 wherein said first port and said third port are disposed on opposite sides of said seat engagement member such that said seat engagement member contacts and seals against said seat member to close said first port and open said third port when said valve member is in said first position and such that said seat engagement member contacts and seals against said seat member to open said first port and close said third port when said valve member is in said second position.

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14. The latching control valve assembly as set forth in Claim 12 or 13 wherein said ported face of said valve body is configured to be received in a cavity of a valve manifold such that said first port operates as an inlet port, said second port operates as an outlet port, and said third port operates as an exhaust port.

15. The latching control valve assembly as set forth in any one of Claims 11 to 14wherein said valve portion of said valve member has a first piston adjacent said distal end of said valve body and a second piston adjacent said proximal end of said valve body, said first and second pistons operating to seal against said valve body bore.

16. The latching control valve assembly as set forth in Claim 15 wherein said first and second pistons and said seat member have substantially equal diameters such that a pressurized fluid acting oppositely against said first and second pistons and said seat member results in balanced pressure forces acting on said valve member.

17. The latching control valve assembly as set forth in Claim 15 or 16, further comprising:

a bushing disposed within said housing, said bushing including a flange portion and a neck portion that extends into said solenoid bore and is positioned radially between said head portion of said valve member and said bobbin, wherein said biasing component is positioned longitudinally between said second piston of said valve member and said flange of said bushing.

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18. The latching control valve assembly as set forth in any one of Claims 1 to 17 wherein said bobbin has an interior surface that defines said solenoid bore, said head portion of said valve member is cylindrical in shape, said head portion of said valve member is arranged in a slip fit with said interior surface of said bobbin, and said biasing component is a compression spring that extends helically about said head portion of said valve member.

19. The latching control valve assembly as set forth in any one of Claims 1 to 18 wherein said valve member is a single-piece component where said head portion and said valve portion of said valve member are integral with each other.

20. The latching control valve assembly as set forth in any one of Claims 1 to 19 wherein said permanent magnet is made of neodymium.

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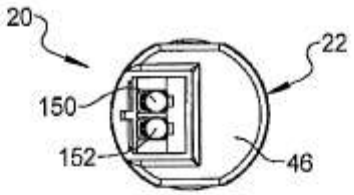


FIG 2

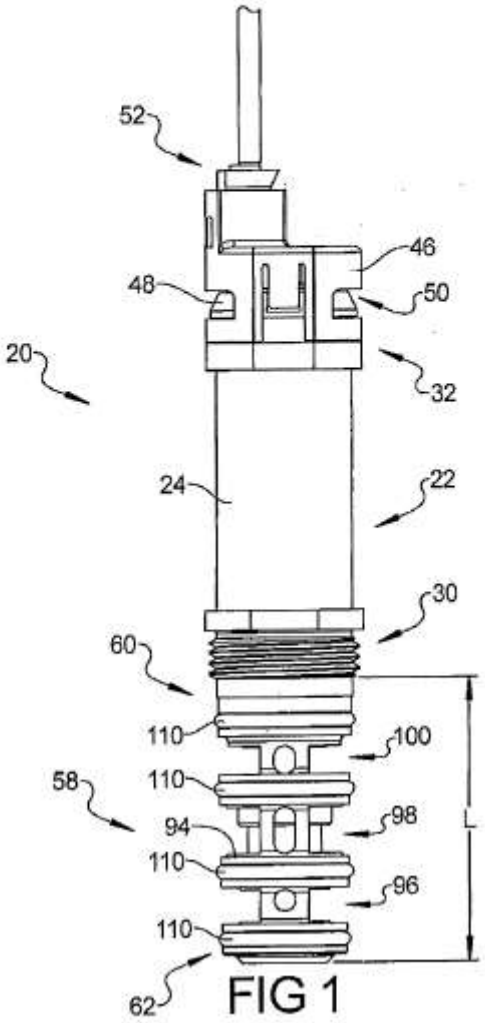


FIG 1

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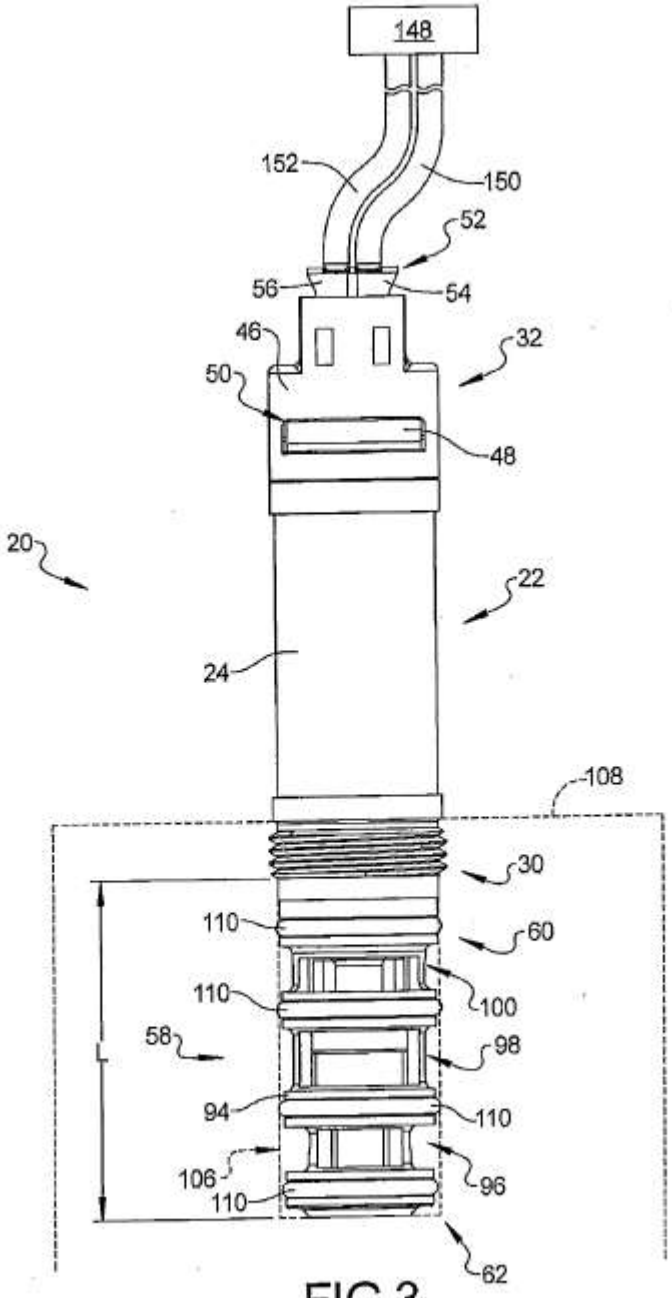


FIG 3

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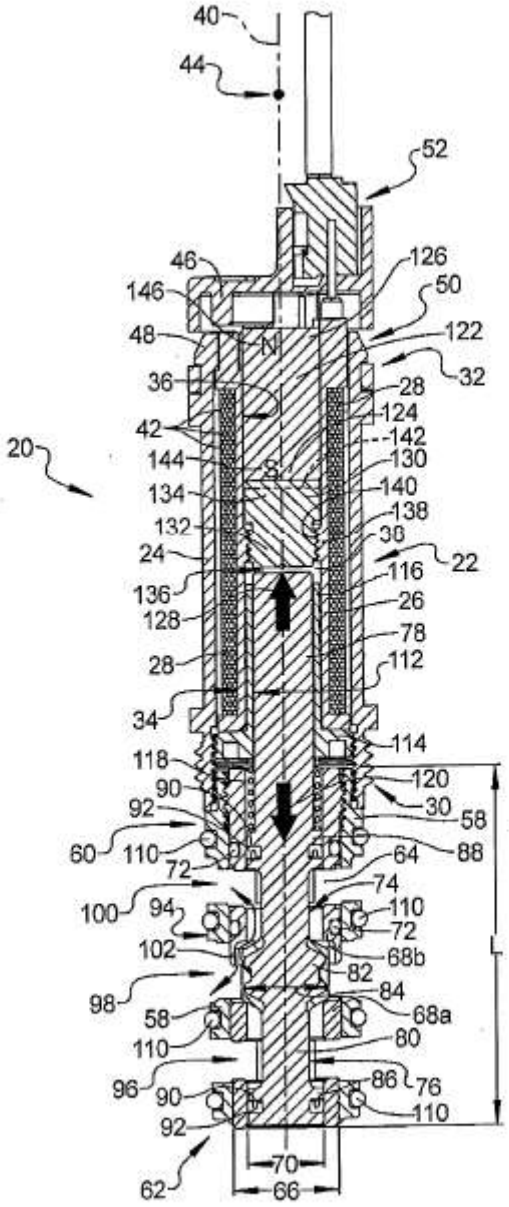


FIG 4

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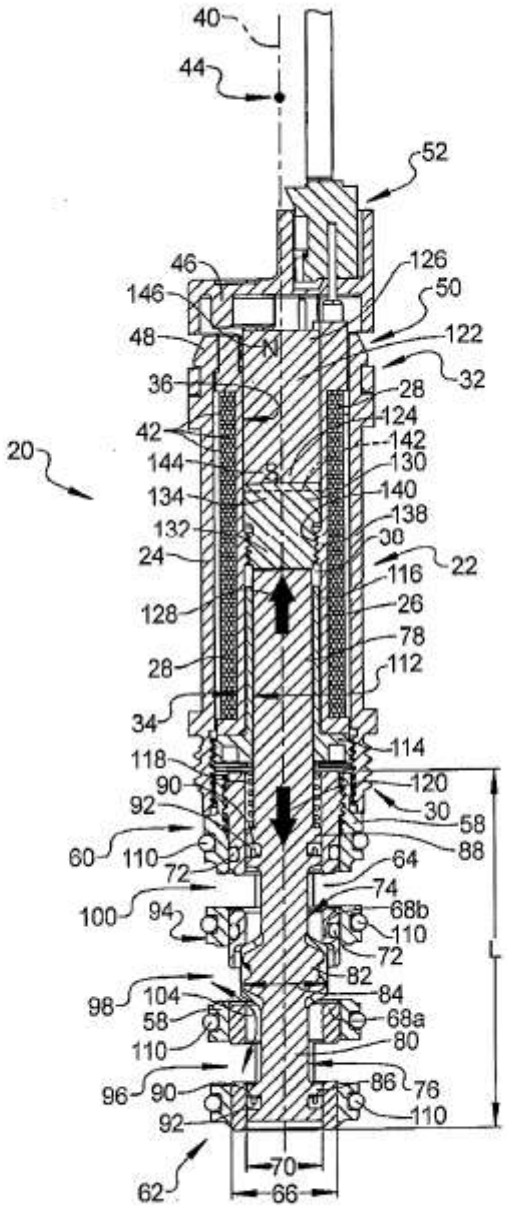


FIG 5