United States Patent

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[54] **SOLENOID CONSTRUCTION**
28 Claims, 9 Drawing Figs.

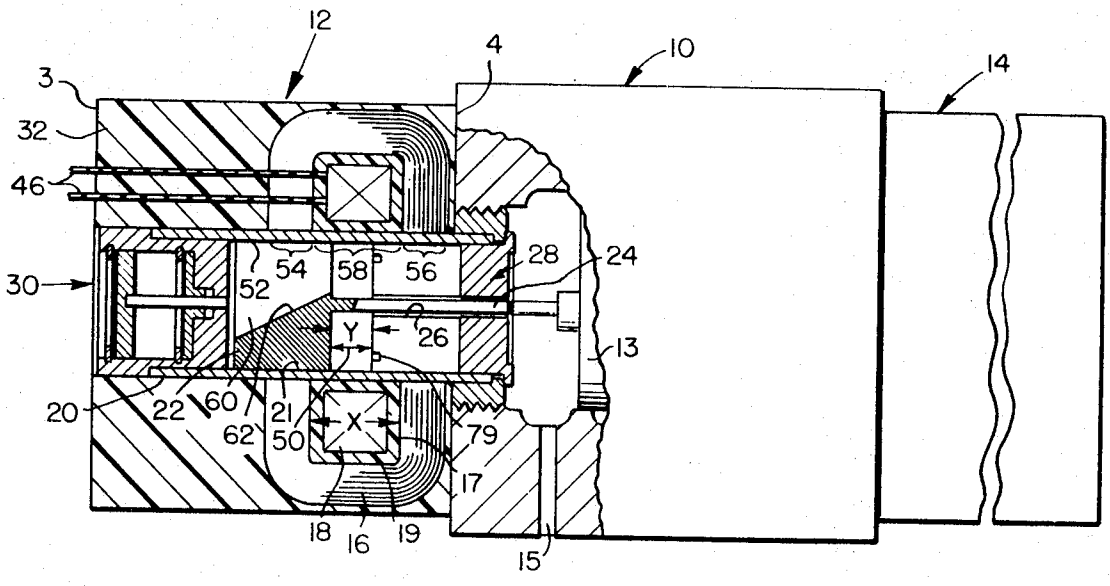
[52] **U.S. Cl.** **335/255,** 335/279
[51] **Int. Cl.** **H01f 3/00**
[50] **Field of Search** 335/255, 138, 236, 251, 132, 278, 260, 261, 271, 281, 282, 279

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ABSTRACT: High-pressure and low-pressure AC push solenoid apparatus and method and pull solenoids of the armature in tube type for operating hydraulic valves. The solenoids include unique overall structural configurations and also improved armature tubes, armatures, push pins, yokes and a preferred range for the ratio of coil length to working gap lengths, providing high-force and stabilized operating temperatures.



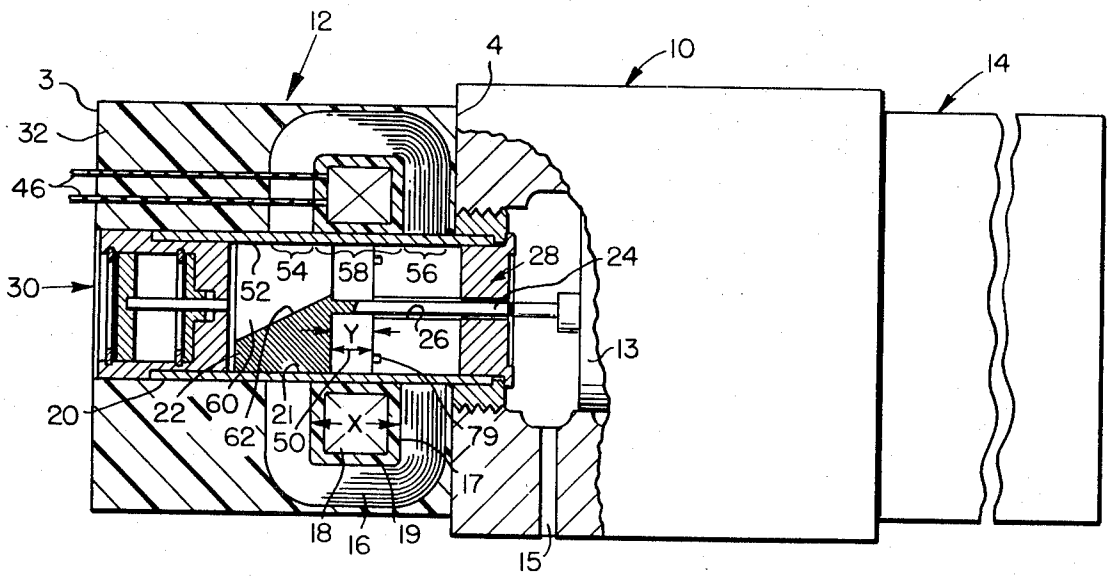


FIG. 1

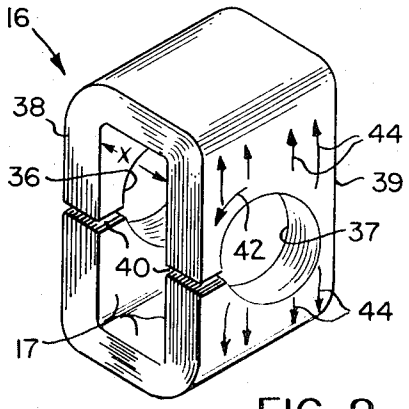


FIG. 2

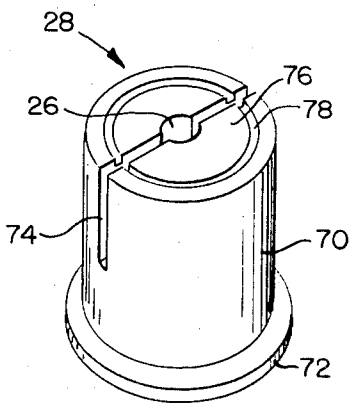


FIG. 3

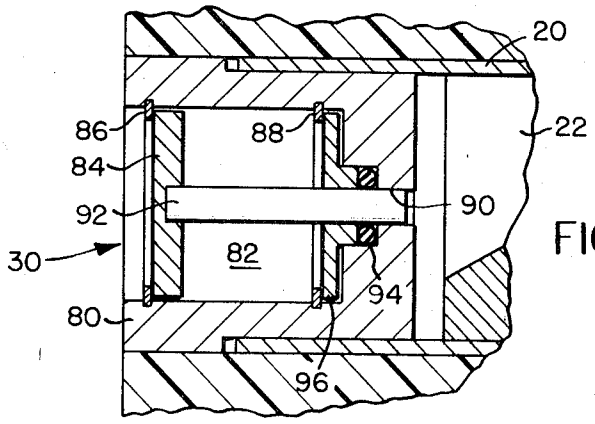


FIG. 4

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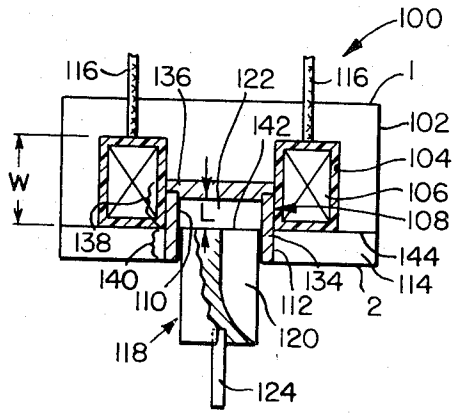


FIG. 5

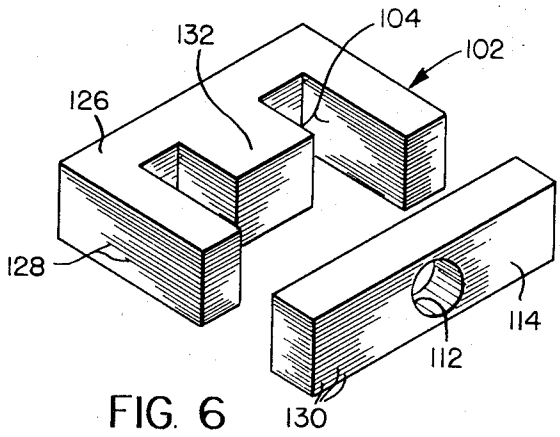


FIG. 6

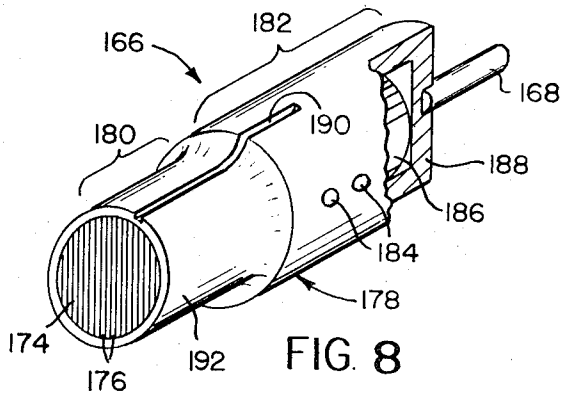


FIG. 8

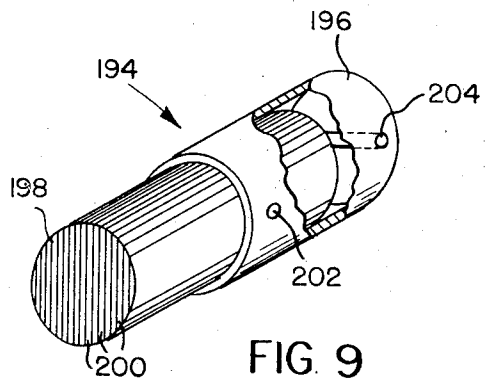


FIG. 9

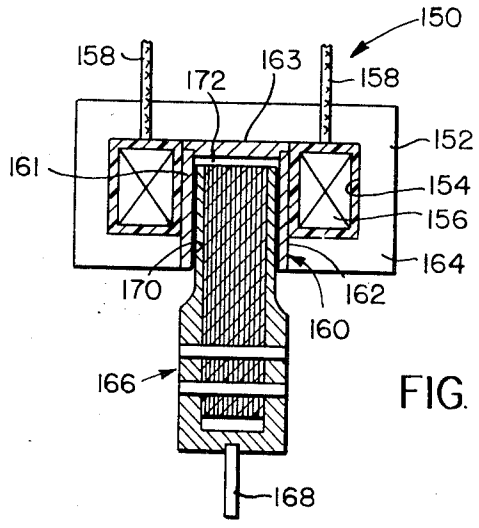


FIG. 7

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SOLENOID CONSTRUCTION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to AC solenoids and more particularly to solenoids of the armature-in-tube type for use with hydraulic valves.

2. Description of the Prior Art

Two general types of solenoids for operating hydraulic valves are known. In such solenoids, the solenoid coils are usually sealed from the fluid, and the fluid must be prevented from leaking out from the solenoid-valve assembly.

A first known type of solenoid employs a solenoid frame and armature constructed from magnetic steel laminations riveted together. Because this construction cannot seal off system pressure from the inside to the outside of the valve, an O-ring is used as a dynamic seal against the solenoid push pin. About 5 percent of the solenoid force is lost in having to overcome the drag force of the O-ring on the solenoid pushpin; this drag force increases greatly as the operating fluid pressure increases and in some cases the drag force may be higher than the solenoid force necessitating that the fluid pressure be reduced to a fraction of the operating pressure, in order that the solenoid will be capable of operating the hydraulic valve. The laminated construction does not hold up well under impact loads; it will not provide a seal when operating a hydraulic valve; and the O-ring seal is a constant source of friction and leakage. Further, the O-ring seal often fails (by beginning to leak) after about 4 million cycles, requiring replacement by a new O-ring seal that is usually difficult to install. Further, the installation procedure requires that the hydraulic valve be taken out of service and disassembled during replacement of the seal.

A second known type of solenoid (to which type the present invention relates) offers certain advantages over the above-discussed first type by virtue of the second type being built around an armature tube containing a solid armature in oil, thus eliminating the need for, and the disadvantages attendant on the use of, a dynamic O-ring seal. However, this second type of solenoid is subject to serious drawbacks in that it is usually associated with relatively low force levels and is generally plagued by excessive heating due to circulating eddy currents in the solid metal parts of the magnetic circuit and due to the solenoid always having a relatively high holding current (actually an inrush current) due to the nonmagnetic armature tube being in the path of the magnetic lines of force. Further, this second type of solenoid, due to its very low force output can be used only to operate the smallest of valves, unless a pilot valve is used to operate the main valve, however, using such a pilot valve adds considerable complication and expense to the assembly. The solenoid of the present invention eliminates the above-mentioned problems of the known second type of solenoid.

The present invention is of the above-described second type of solenoid. For purpose of the present specification and claims the above second type of solenoid is hereby defined as, and will hereinafter be referred to as, the "armature-in-tube" type of solenoid. The solenoids of the present invention have all of the advantages of the prior art armature-in-tube solenoids, plus they also have force levels and stabilized temperatures comparable to those of the fully laminated, above-described first type of solenoid.

SUMMARY OF THE PRESENT INVENTION

The improved solenoids of the present invention overcome the disadvantages inherent in both of the above-discussed types of prior art solenoids. The solenoids of the present invention employ many rigid, nonlaminated parts which hold up well under impact, and slotted solid parts to reduce heating due to circulating eddy currents. Both the high-pressure push and the high-pressure pull solenoids of the present invention employ an improved, one-piece semiaustenitic armature tube treated to have magnetic and nonmagnetic sections to eliminate high holding current consumption. Both of the low-pressure solenoids of the present invention (both the push and the pull) employ a very thin, very high strength, all magnetic armature tube. The push solenoids (both the high and low pressure) further employ an improved yoke, armature, push-pin, and a particular range for the ratio of coil length to working gap length. The pull solenoids (both low pressure and high pressure) employ a capped armature tube, improved yokes, and improved armatures.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more fully understood by reference to the following detailed description thereof, when read in conjunction with the attached drawings, wherein like reference numerals refer to like elements and wherein:

FIG. 1 is a partial cross-sectional, partial diagrammatic block diagram, of a push solenoid **12** of the present invention shown connected to a hydraulic valve;

FIG. 2 is a perspective view of an improved yoke **16** of the solenoid **12** of FIG. 1;

FIG. 3 is a perspective view of an improved stop **28** of the solenoid **12** of FIG. 1;

FIG. 4 is an enlarged cross-sectional view through the manual override **30** of the solenoid **12** of FIG. 1;

FIG. 5 is a cross-sectional view through an improved pull solenoid **100** of the present invention;

FIG. 6 is a perspective view of the yoke **102** of the solenoid **100** of FIG. 5;

FIG. 7 is a cross-sectional view through another preferred pull solenoid **150** of the present invention.

FIG. 8 is a perspective, partially cutaway view of the preferred solenoid armature **166** of the solenoid **150** of FIG. 7; and

FIG. 9 is a perspective, partially cutaway view of another embodiment of an armature **194** useful in the solenoid **150** of FIG. 7.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

For ease of understanding, the following detailed description of the various aspects of the present invention is separated into the two main sections of (1) PUSH SOLENOID and (2) PULL SOLENOID. Throughout the present specification and claims, the terms "high pressure" and "low pressure" refer to the operating fluid pressure, in pounds per square inch, in a hydraulic valve operated by the solenoids of the present invention. The term "low pressure" is hereby defined as the range of 0 to 1,000 p.s.i., and the term "high pressure" is herein defined as all pressures over 1,000 p.s.i., normally 1,000 to 3,000 p.s.i.. To provide a convenient reference system throughout the present specification and claims regarding the orientation of the solenoids, the terms "stop" and "bottom" of a solenoid are hereby defined as follows. With reference to FIG. 5, the vertically arranged solenoid **100** has a top **1** and bottom **2**; similarly, solenoid **12** of FIG. 1 has a top **3** and a bottom **4**. In each case, the pull pin **168** and the push pin **24**, respectively, extend from the bottom of the solenoid, and it is therefore the bottom of the solenoid to which the valve, (e.g. valve **10** of FIG. 1) is connected. These terms are arbitrary in that the solenoids of the present invention may have any desired orientation. The term "normal" position of the armature is hereby defined as its unenergized position, as contrasted to the position it occupies after the solenoid has been energized, causing the armature to move through the working gap to its "energized" position.

PUSH SOLENOID

High-Pressure Push Solenoid

With reference to the drawings, FIGS. 1 through 4 show the preferred AC, high-pressure push solenoid **12** of the present invention.

Before describing the details of the solenoid **12**, it is believed that a brief description of an overall view of one particular application for the solenoid **12** will be helpful. FIG. **1** shows a fluid valve **10** connected at opposite ends thereof to one of a pair of identical high-pressure push solenoids **12** and **14**, made according to the present invention. The valve **10** constitutes a part of a fluid control circuit (not shown), and operation of the valve **10** by either of the solenoids **12** or **14** will produce a certain desired result in the fluid circuit. For example, when the solenoid **12** is energized, it causes a spool **13** in the valve **10** to move to the right (as viewed in FIG. **1**) creating fluid communication between certain passages (such as passage **15**) in valve **10** and interrupting fluid communication between certain other passages in valve **10**. The passages are connected via ports to fluid pressure lines (not shown) of the fluid circuit. The valve **10**, the fluid circuit (not shown), and the connection means (not shown) between the valve **10** and the fluid circuit are all well known in the art, form no part of the present invention, and therefore need not be described in further detail herein.

With detailed reference now to the solenoid **12** of FIG. **1**, the solenoid **12** comprises a yoke **16** (shown in more detail in FIG. **2**) defining a coil window **17**, an annular coil **18** positioned in the coil window **17**, and a hollow cylindrical armature tube **20** defining an armature cavity **21**, positioned inside the yoke **16** and the coil **18**. A cylindrical armature **22** is positioned in the armature cavity **21** for axial sliding movement therein. A pushpin **24** is positioned against (and is separate from) the armature **22** and is slidably positioned within an axial bore **26** of a stop **28** (shown in more detail in FIG. **3**) connected to the armature tube **20**. The stop **28** limits the extent of travel of the armature **22** when the solenoid is energized. The armature **22** is shown in FIG. **1** in its unenergized or "normal" position; upon energization of the solenoid **12**, the armature **22** moves into contact with the stop **28**. A manual override **30** is connected to the left end (as viewed in FIG. **1**) of the armature tube **20**. A layer **32** of epoxy preferably surrounds the various elements of the solenoid.

Detailed reference will now be made to various subassemblies and individual elements of the solenoid **12**. FIG. **2** shows the yoke **16** which is of the wound type having a substantially rectangular coil window **17** for accommodating the coil **18**. The yoke **16** has a pair of circular openings **36** and **37**, through the opposed long sides **38** and **39** thereof respectively, to accommodate the armature tube **20** (see FIG. **1.**). In addition, the yoke **16** is provided according to the present invention, with a slot **40** to break up eddy current paths (indicated by arrow **42**) and to therefore reduce the circulation of eddy currents that would contribute to the heating of the metal yoke **16**. The slot **40** does not interfere with the desired paths (indicated by arrow **44**) of the magnetic field. The slot **40** can alternatively be positioned on the opposite side of the openings **36** and **37** from that shown in FIG. **2**, and can alternatively be on *both* sides of openings **36** and **37**, if desired, although in the latter case, mechanical means for holding the two halves of the yoke **16** together would be required.

The coil **18** is of known design and configuration and is connected to lead wires **46** which extend exteriorly of the solenoid **12** in a manner well known to those skilled in the art for connecting the solenoid to a source of electrical energy. The coil **18** can be encapsulated in a protective coating **19** of epoxy resin.

The armature tube **20** seals the coil **18** from the fluid in the solenoid **12**, and also forms the cylindrical armature cavity **21**, between the manual override **30** and the stop **28**. The tube **20** is made sufficiently thick to withstand the desired operating pressure of the fluid in the armature cavity **21**. According to the present invention, the tube **20** is preferably made of semiaustenitic steel, such as that known as 17–7 P.H. (precipitation hardening) stainless steel. The tube **20** is in its *magnetic* (martensitic) condition in axial sections **54** and **56** thereof to provide a *minimum* of hindrance to the magnetic field in passing radially through the wall of the tube **20** in these sections **54** and **56**. On the other hand, the tube **20** is in its *nonmagnetic* (austenitic) condition in axial section **58**, to provide the *maximum* possible hindrance to the portion of the magnetic field trying to pass axially through section **58** of the tube **20**. This construction forces as much as possible of the magnetic field to cross a working gap **50** and to thus produce useable solenoid force. Various methods are well known for selectively treating different sections of semiaustenitic steel and such methods can be used to produce the tube **20** of the present invention having sections **54** and **56** in their magnetic condition and having section **58** in its nonmagnetic condition.

Semiaustenitic alloys have austenitic (nonmagnetic) structures in the solution treated condition (annealed condition). The transformation of austenite to martensitic (magnetic) structures can be accomplished by a thermal treatment that conditions the austenite for transformation upon cooling. Cold working (approximately 60 percent reduction) also produces the austenite-to-martensite transformation. My armature tube **20** can be produced starting with tubing in the annealed condition: accomplishing the martensitic transformation of the whole tube by oven heat treating; then selectively annealing one section thereof. An alternative method is to start with cold-worked tubing (already in the martensitic condition) and selectively annealing one section.

The tube **20** of the present invention is much less expensive than the prior art tube comprising two separate pieces, one magnetic and one nonmagnetic, butt-welded together.

The armature **22** is a cylindrical body having a slot **60** (the cross-sectional view in FIG. **1** is taken through the slot **60**). The slot **60** is relatively narrow (e.g. less than one-eighth inch) and is in a plane parallel to the axis of the solenoid **12**. The slot **60** reduces the circulation of eddy currents in the armature **22**. The slot **60** also serves to aid fluid transfer from one end of the armature cavity **21** to the other end during operation. A bottom surface **62** of the slot **60** is positioned at an angle to the solenoid axis, as shown in FIG. **1**, to provide maximum reduction of eddy currents, while still providing an uninterrupted contact surface for the pushpin **24**, so that the transfer of solenoid force to the pushpin **24** is not impaired.

The pushpin **24** is preferably made of a material sold under the trademark "Tantung G," the composition of which is:

Cobalt	45–50%
Chromium	27–32%
Tungsten	14–19%
Carbon	2–4%
Tantalum or Columbium	2–7%
Manganese	1–3%
Iron	2–5%

The pushpin **24** made of "Tantung G" has a hardness of about Rockwell 60 and is nonmagnetic. Such hardness is desirable to prevent mushrooming the ends of the pushpin **24** under impact. The magnetic flux which travels in the prior art magnetic steel pushpins represents about a 10 percent loss of solenoid force, and the pushpin **24** of the present invention eliminates this loss, while it maintains the hardness of a magnetic pin.

The stop **28** is shown in more detail in FIG. **3**, and comprises a cylindrical body **70** having a retaining flange **72** on the bottom end thereof and having the axial bore **26** extending completely therethrough to accommodate the pushpin **24**. The stop **28** is also provided with a relatively narrow slot **74**, parallel to the solenoid axis, to reduce the circulation of eddy currents in the stop **28**. The slot **74** extends through that portion of the stop **28** that is positioned axially within the yoke **16** and coil window **17**. The top surface **76** of the stop is provided with a circular groove **78** to receive and hold a shading coil **79** (see FIG. **1**), the purpose of which shading coil **79** is well known in the art.

The manual override **30** is shown in an enlarged cross-sectional view in FIG. **4**, and comprises an end plate **80** fixedly secured to the armature tube **20** and provided with a cylindrical chamber **82** in which an override button **84** is positioned for axial sliding movement between a pair of snap rings **86** and

88. The end plate 80 is also provided with an axial bore 90, to accommodate an override pushrod 92 connected to the override button 84. The chamber 82 (and therefore the exterior of the solenoid 12) is sealed from fluid pressure in the solenoid 12 and in the valve 10 by means of an O-ring seal 94 held in place against the pushrod 92 by an O-ring retainer 96, which is, in turn, held in place by the snap ring 88. Leakage from the valve 10 through the solenoid 12 is thus prevented by the O-ring 94.

In operation, it is clearly seen that the armature 22 and the pushpin 26 can be caused to move to the right (as viewed in FIG. 1) to operate the valve 10 by manually pushing inwardly on the override button 84.

It has been discovered that the ratio of the length X of the coil 18 (FIG. 1), to the length Y of the working gap 50, is preferably in the range of from about 3 to 6. If the ratio is much less than 3, then the flux leakage will increase to a point where the solenoid's force will be significantly diminished. If the ratio is much greater than 6, then core losses will increase at a rate causing heating which more than offsets the small decrease in flux leakage.

It will thus be seen that, by virtue of the above-described preferred construction of the high-pressure push solenoid of the present invention, the objects and advantages set forth above are accomplished. For example, by eliminating the prior art O-ring seal on the pushpin to seal the solenoid from the valve, Applicant has eliminated the loss in solenoid force caused by the drag of the O-ring on the pushpin. Also, by using a laminated yoke, a selectively magnetized and demagnetized armature tube, a slotted yoke, a semiaustenitic armature tube, a "Tantung G" pushpin, and by using a preferred ratio of coil length to length of working gap, much higher force and much cooler operation is achieved.

LOW-PRESSURE PUSH SOLENOID

The low-pressure push solenoid of the present invention is identical to the high-pressure push solenoid 12 described in detail above, except that in the low-pressure push solenoid, an armature tube is used that is made very thin and is *all* magnetic. The armature tube in the low-pressure embodiment is about half as thick as the tube in the high-pressure embodiment, for example, in a -inch diameter armature tube, the tube wall thickness in the high-pressure solenoid is about 0.028 inch, while in the low-pressure solenoid it is about 0.014 inch. In the preferred construction the armature tube is heat treated to a very high strength to permit utilization of a very thin wall. The thin wall tube being of a magnetic material, offers relatively little resistance to magnetic flux passing radially thru the tube wall at locations thereof corresponding to sections 54 and 56 of FIG. 1. On the other hand, the same thin wall will both restrict the amount of flux passing axially thru the tube [at a location corresponding to section 58 (see FIG. 1)] and will also present a reduced path area for eddy current circulation in the tube. The tube is preferably of a material having a low maximum magnetic permeability (about 200) to further inhibit the passage of flux linearly thru the tube at a location corresponding to section 58. The tube wall is sufficiently thin that the reduced permeability will not significantly inhibit the flux passing radially thru the tube wall at locations corresponding to sections 54 and 56. The utilization of the thin tube of the present invention will permit the reduction of solenoid holding current to a value below that achieved with even a magnetic and nonmagnetic composite tube, and will provide a higher solenoid force level than a single-piece nonmagnetic tube.

Manufacturing costs of the thin tube are significantly less than that of the composite tube, and compares favorably with the nonmagnetic one-piece tube.

It has been found that the overall effect of any loss in efficiency due to some magnetic lines of force traveling linearly through the middle section of the tube (corresponding to section 58 of tube 20 of FIG. 1) is more than compensated for by the increased efficiency due to minimizing the hindrance of the magnetic field traveling radially through the outer sections of the armature tube (corresponding to sections 54 and 56 of tube 20 of FIG. 1). The use of the thin all magnetic armature tube of the present invention thus provides increased efficiency over the prior art use of a thick, all nonmagnetic armature tube.

PULL SOLENOID

High-Pressure Pull Solenoid

With reference to the drawing, FIGS. 5 and 6 show one preferred high-pressure pull solenoid 100 of the present invention, FIGS. 7 and 8 show another preferred high-pressure pull solenoid 150, and FIG. 9 shows a modified armature 194. It is to be particularly noted that by virtue of the solenoid constructions shown in FIGS. 5 and 7, the prior art armature stop has been eliminated. The elimination of the stop is very desirable because the stop was probably the highest producer of core losses in the solenoid, for the reason that the stop had to seal off hydraulic system pressure and therefore could not be laminated or even effectively slotted.

The pull solenoid 100 of FIG. 5 comprises: a yoke 102 defining a coil window 104, an annular coil 106 of known construction positioned in the coil window 104, and a hollow, cylindrical, armature tube 108, having an armature cavity 110 centrally positioned within the yoke 102 and the coil 106 and extending externally thereof through a circular opening 112 in a laminated sideplate 114 of the yoke 102. The coil 106 is provided with lead wires 116 as will be understood by one skilled in the art. A solid, cylindrical, nonlaminated, armature 118 is positioned within the armature cavity 110 in the armature tube 108, for axial sliding movement therein from the "normal" position (shown in FIG. 9) to its energized position in contact with cap 139. The armature 118 includes a thin slot 120 extending at least through that portion of the armature 118 that extends inside of the solenoid 100. The slot 120 is parallel to, and extends at least through the axis of the armature 118. The slot 120 can also extend through that portion of the length of the armature 118 that exists outside of the solenoid 100 to provide a fluid passage to allow the necessary fluid transfer between a fluid valve (not shown) to which solenoid 100 is connected, and a working gap 122 in the armature cavity 110. The armature 118 does not need a separate groove for this purpose. A pull pin 124 is connected to the armature 118, and when the solenoid 100 is energized, the armature 118 is caused to move upwardly (as viewed in FIG. 5) through the working gap 122, thus actuating a fluid valve (not shown) connected to the pull pin 124.

With reference now to the exploded view of the yoke 102 in FIG. 6, the yoke 102 is formed from two separate, laminated parts; one part is a main body member 126 having the shape of a capital E and the other part is the straight, elongated sideplate 114. Both the member 126 and the sideplate 114 are formed from a vertical stack of thin, flat stampings 128 and 130, respectively. After the coil 106 has been placed in position in the cavity 104 of member 126, the plate 112 is attached to member 126, for example, by using a channel frame or by applying a layer of epoxy adhesive to the contacting surfaces of member 126 and plate 114, as will be understood by one skilled in the art. The yoke 102 does not require a slot such as the slot 40 in the wound yoke 16 of FIG. 2, because the eddy current paths in yoke 102 are interrupted by insulative coating on each of the stampings 128 and 130.

A center leg extension 132 of member 126 serves (along with a cap 136 of the armature tube 108) as a stop for the armature 118, and because extension 132 is laminated, it allows the working gap 122 of the solenoid 100 to be positioned in the middle of the coil window 104 without incurring a high eddy current loss penalty as would result if an unlaminated stop were used in place of the extension 132. The extension 132 should extend as far as possible into the coil window 104. Also, with the design of FIGS. 5 and 6, a shorter length of the

armature tube **108** can be used. Because the armature tube **108** is nonlaminated and is therefore a generator of heat due to eddy currents within it, the shorter tube **108** results in a reduction of the amount of heat generated by the solenoid **100**. Furthermore, a shorter armature tube **108** withstands the internal fluid pressure therein better than does a longer armature tube, and consequently the shorter tube **108** can be of a thinner wall thickness, thus resulting in improved overall solenoid performance. An additional advantage with this design is that a shorter armature **118** is used, and it can be nonlaminated.

The armature tube **108** comprises a tubular element **134** connected by welding or brazing to a magnetic steel cap **136** (see FIG. **5**); the wall of the tubular element **134** is just thick enough to properly sustain the operating pressure within the tube **108**. The cap **136** has a thickness about twice that of the element **134** because the cap must not only sustain operating pressure but must also withstand impact of the armature **118**. The tubular element **134** is made of a semiaustenitic material and has a nonmagnetic portion **138** and a magnetic portion **140** for the same reasons discussed in detail above with respect to the armature tube **20** of the push solenoid **12** of FIG. **1**. The tube **108** can be connected to the sideplate **114** by known means, such as welding.

A top surface **142** of the armature **118** should be positioned, as shown in FIG. **5**, in its normal position. In this position, the surface **142** is "in line" with an inner surface **144** of plate **112**.

It has further been found, according to the present invention, that the width W (see FIG. **5**) of the coil **106** should preferably bear a certain relationship to the length L (FIG. **5**) of the working gap **122** of the solenoid **100**. This preferred relationship is: $3L \leq W \leq 6L$; in other words, the ratio W/L should be between 3 and 6. A preferred dimension is: W equals about one-fourth inch and L equals about one-sixteenth inch.

FIG. **7** shows another embodiment of a high-pressure pull solenoid **150** of the present invention. The solenoid **150** is similar in many respects to the solenoid **100** of FIG. **5** described above.

The pull solenoid **150** of FIG. **7** comprises a yoke **152** defining a coil window **154**, an annular coil **156** (connected to lead wires **158**) of known structure positioned in the coil window **154**, and a hollow, cylindrical, armature tube **160** (comprising a tubular element **161** and a cap **163**) centrally positioned within the yoke **152** and the coil **156**, and extending externally from the yoke **152** through a circular opening **162** in a sidewall **164** of the yoke **152**. As in the solenoid **100** of FIG. **5**, the cap **163** is about twice as thick as element **161** and is welded or brazed thereto. A solid, cylindrical armature **166** connected to a pull pin **168** is positioned for axial sliding movement within a cylindrical armature cavity **170** of the armature tube **160**. The solenoid **150** is shown in its unenergized or "normal" position; upon energization, the armature **166** is caused to move upwardly (as viewed in FIG. **7**) through a working gap **172** to actuate a fluid valve (not shown) such as valve **10** of FIG. **1**.

With reference now to FIG. **8** showing an enlarged view of the armature **166**, the armature **166** comprises a stack **174** of individual laminations **176**, which stack **174** has been turned or ground cylindrical, and a magnetic sleeve **178** has been press-fitted over the entire length of the stack **174**. The sleeve **178** constrains and holds the laminations **176** in their cylindrical configuration. A thin portion **180** of the length of the sleeve **178** is turned down to provide an extremely thin wall; e.g. about 0.007 inch to 0.009 inch thick.

The thin portion **180** of the sleeve **178** is that portion which is to be inside the magnetic circuit of the solenoid **150**. The thin wall portion **180** produces a minimum of core losses and maintains the laminations **176** in their cylindrical configuration without the necessity for any additional bonding there between such as epoxy adhesive, to constrain and hold the laminations together. A thicker portion **182** of the sleeve **178** that is outside of the magnetic circuit is left thick for overall rigidity. The portion **182** is sufficiently long to provide a space for a pair of rivets **184** extending through the sleeve **178** and through all of the laminations **176**. All rivets (e.g. **184**) are outside of the magnetic circuit and therefore do not contribute to core loss. The portion **182** also preferably extends beyond an end **186** of the stack **174**, to provide a good connection to the pull pin **168**, such as by connecting the pull pin **168** to an end wall **188** of the sleeve **178**. There is preferably a small clearance between the armature **166** and the inside surface of the tube **160** (of about 0.001 inch per side for a 400 c.p.s. solenoid); a longitudinal groove **190** (see FIG. **8**) in armature surface **192** allows the necessary fluid flow between a fluid valve (not shown) and the working gap **172**. The groove **190** can alternatively be a slot completely through the thickness of the sleeve portion **180**.

The solenoid **150** of FIG. **7** is similar to the solenoid **100** of FIG. **5** except that the yoke **152** of FIG. **7** comprises a single stack of rectangular laminations that form a simple rectangular coil window **154**. The yoke **152** does not include the extension **132** of the yoke **102** of FIG. **5**. The yoke **152** is less expensive to manufacture than the yoke **102** of FIG. **5**, in part because the yoke **152** can be made in one piece. Both of the solenoids **100** and **150** of FIGS. **5** and **7**, respectively, can use any of the three armatures **118**, **166** and **194** of FIGS. **5**, **7**, and **9** respectively.

FIG. **9** shows an alternative armature **194** for use in the solenoid **150** (FIG. **7**). In the armature **194**, a sleeve **196** (which need not be magnetic as is sleeve **178** of FIG. **8**) is pressed only part way over the length of a stack **198** of individual laminations **200**, which laminations **200** have been turned or ground cylindrical. The laminations **200** can also be bonded together, but because of the sleeve **196** the strength required of the bond, for example, an adhesive bond, is minimal. The armature tube **160** of FIG. **7** will encompass the individual laminations **200** and help constrain and hold the laminations **200** in their proper relationship to each other. In operation, the part of the armature **194** not within the sleeve **196** is always inside the armature tube **160** of FIG. **7**. If the laminations **200** are sufficiently thick and therefore rigid, no adhesive or other bonding is needed. A preferred construction is to use thin laminations **200** near the center of the stack **198** for good electrical performance, and thick laminations **200** near the outside of the stack **198** for rigidity. A pair of rivets **202** (only one is shown) extend through both the sleeve **196** and all of the laminations **200**, to produce a single integral unit. The force of the armature **194** is applied (for example to a fluid valve similar to valve **10** of FIG. **1**) via the sleeve **196** and not directly by the laminations **200**. A pull pin (not shown) can be connected, for example, to a force-transmitting rivet **204** extending transversely across the interior diameter of the sleeve **196**. The sleeve **196** and all rivets **202** lie outside the magnetic circuit and thus do not contribute to the core losses of the solenoid **150**.

Low-Pressure Pull Solenoid

The low-pressure pull solenoid of the present invention is identical to the high-pressure pull solenoids **100** and **150** of FIGS. **5** and **7** respectively, described above, except that in the low-pressure solenoid the armature tube is a very thin, very high strength, all magnetic tube as described above regarding the low-pressure push solenoid.

While the preferred embodiments described above relate to using the solenoids of the present invention as operators for hydraulic valves, it is to be noted that they are not limited to such use, but can be used with any kind of fluid (gas or liquid) valve, and in fact with other controls than fluid valves. While not shown above, the solenoids of the present invention can be completely encapsulated in a layer of epoxy resin. The armatures and armature cavities of the present invention are preferably circular in cross section, but can also have other shapes such as square, rectangular, and elliptical. Further, a push solenoid can be made using the construction shown in FIGS. **5** and **7** for pull solenoids; a laminated stop and a nonmagnetic pushpin would be used.

The invention has been described in detail above with particular reference to preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention as described hereinabove and as defined in the appended claims.

I claim:

1. A push solenoid of the armature-in-tube type for use with hydraulic valves comprising a laminated yoke having a coil window therein and having a pair of openings in opposed sidewalls of said yoke, an annular coil positioned in said coil window, said coil having a central opening therethrough concentric with said pair of openings, a hollow armature tube extending through said pair of openings in said yoke and also through said central opening, said armature tube having an armature chamber therein, an armature positioned in said armature chamber of said tube for axial sliding movement therein responsive to energization of said coil, a stop connected to a bottom end of said tube and having an axial bore extending therethrough, a pushpin positioned against said armature and extending exteriorly of said solenoid through said bore in said stop, means for sealing the top end of said armature tube against leakage of fluid therefrom, fluid passage means extending through said stop into said chamber and fluid passage means extending through said armature for fluid flow from one part of said chamber to another through said armature.

2. The apparatus according to claim 1 wherein the armature tube is made of a semiaustenitic material treated to be magnetic in the two sections thereof adjacent the yoke and to be nonmagnetic in a section thereof between said two sections.

3. A pull solenoid of the armature-in-tube type for use with hydraulic valves comprising a laminated yoke having a coil window therein and having an opening in a bottom sidewall only thereof, an annular coil positioned in said coil window, said coil having a central opening therethrough concentric with said opening in said yoke, a hollow armature tube positioned in said openings and having an armature chamber therein, said tube being open at a bottom end thereof adjacent said opening in said one sidewall of said yoke and being closed at the top end thereof adjacent the other sidewall of said yoke, an armature positioned in said chamber of said tube for sliding movement therein responsive to energization of said coil, and fluid passage means in said armature for fluid flow into and out of said chamber through said armature.

4. The apparatus according to claim 3 wherein said yoke is substantially rectangular and comprises a plurality of stamped laminations lying in a plane parallel to the axis of the solenoid, said yoke having two short end walls and two longer sidewalls and wherein said yoke opening is a circular opening and wherein said armature tube is cylindrical and is connected to said yoke at said single circular opening in said yoke.

5. The apparatus according to claim 3 wherein the tube is made of semiaustenitic material treated to be magnetic in one section adjacent the yoke and nonmagnetic in a section adjacent the coil.

6. The apparatus according to claim 3 wherein said yoke includes a central, axial, laminated extension extending inwardly of said coil opening and extending part way through said coil opening.

7. An armature for a solenoid comprising a stack of individual, flat, laminations, parallel to the armature axis, said stack having a cylindrical outer surface concentric to the armature axis and a cylindrical, metal sleeve tightly fitting on said surface over at least a portion of the axial length of said stack.

8. The apparatus according to claim 7 including an armature pull pin connected to said sleeve.

9. The apparatus according to claim 7 wherein said sleeve includes a first, very thin portion extending over that length of said armature positioned inside of the solenoid.

10. A hollow, solenoid armature tube made of semiaustenitic material treated to be magnetic in one section and nonmagnetic in a second section thereof.

11. In an AC solenoid including an annular coil and an axially movable armature therein movable across a working gap when the coil is energized, the improvement wherein the ratio of the coil length to the length of the working gap is between about 3 and 6.

12. In a low-pressure AC solenoid of the armature-in-tube type including a yoke, a coil in the yoke, an armature tube inside the coil and yoke, and an armature movably mounted in the armature tube, the improvement wherein said armature tube is all magnetic, heat treated to increase its strength, and has a wall thickness of about 0.014 inch.

13. A push solenoid of the armature-in-tube type comprising a laminated yoke having a coil window therein and having a pair of openings in opposed sidewalls of said yoke, an annular coil positioned in said coil window, said coil having a central opening therethrough concentric with said pair of openings, a hollow armature tube extending through said pair of openings in said yoke and also through said central opening, an armature positioned in said tube for axial sliding movement therein responsive to energization of said coil, a stop connected to a bottom end of said tube and having an axial bore extending therethrough, a pushpin positioned against said armature and extending exteriorly of said solenoid through said bore in said stop, means for sealing the top end of said armature tube against leakage of fluid therefrom, and wherein the ratio of the length of the coil to the length of the working gap is between about 3 and 6.

14. A push solenoid of the armature-in-tube type comprising a laminated yoke having a coil window therein and having a pair of openings in opposed sidewalls of said yoke, an annular coil positioned in said coil window, said coil having a central opening therethrough concentric with said pair of openings, a hollow armature tube extending through said pair of openings in said yoke and also through said central opening, an armature positioned in said tube for axial sliding movement therein responsive to energization of said coil, a stop connected to a bottom end of said tube and having an axial bore extending therethrough, a pushpin positioned against said armature and extending exteriorly of said solenoid through said bore in said stop, means for sealing the top end of said armature tube against leakage of fluid therefrom, and wherein said yoke includes slots to prevent the circulation of eddy currents in paths concentric to the solenoid axis.

15. A push solenoid of the armature-in-tube type comprising a laminated yoke having a coil window therein and having a pair of openings in opposed sidewalls of said yoke, an annular coil positioned in said coil window, said coil having a central opening therethrough concentric with said pair of openings, a hollow armature tube extending through said pair of openings in said yoke and also through said central opening, an armature positioned in said tube for axial siding movement therein responsive to energization of said coil, a stop connected to a bottom end of said tube and having an axial bore extending therethrough, a pushpin positioned against said armature and extending exteriorly of said solenoid through said bore in said stop, means for sealing the top end of said armature tube against leakage of fluid therefrom, and wherein said armature includes a thin slot therethrough parallel to the solenoid axis, the depth of the slot being at an angle to the solenoid axis to provide a solid, central portion for contacting said pushpin.

16. A push solenoid of the armature-in-tube type comprising a laminated yoke having a coil window therein and having a pair of openings in opposed sidewalls of said yoke, an annular coil positioned in said coil window, said coil having a central opening therethrough concentric with said pair of openings, a hollow armature tube extending through said pair of openings in said yoke and also through said central opening, an armature positioned in said tube for axial sliding movement therein responsive to energization of said coil, a stop connected to a bottom end of said tube and having an axial bore extending therethrough, a pushpin positioned against said armature and extending exteriorly of said solenoid through said

bore in said stop, means for sealing the top end of said armature tube against leakage of fluid therefrom, and including a manual override positioned adjacent the top end of said tube and including an override button connected to an override pushrod, said pushrod being movable into contact with said armature for manually moving said armature to its energized position, and wherein said fluid seal means comprises an O-ring seal in sealing engagement with said override pushrod.

17. A pull solenoid of the armature-in-tube type comprising a laminated yoke having a coil window therein and having an opening in a bottom sidewall only thereof, an annular coil positioned in said coil window, said coil having a central opening therethrough concentric with said opening in said yoke, a hollow armature tube positioned in said openings, said tube being open at a bottom end thereof adjacent said opening in said one sidewall of said yoke and being closed at the top end thereof adjacent the other sidewall of said yoke, an armature positioned in said tube for sliding movement therein responsive to energization of said coil, and wherein said closed end of said armature tube is positioned immediately adjacent the inside surface of the other sidewall of said yoke.

18. A pull solenoid of the armature-in-tube type comprising a laminated yoke having a coil window therein and having an opening in a bottom sidewall only thereof, an annular coil positioned in said coil window, said coil having a central opening therethrough concentric with said opening in said yoke, a hollow armature tube positioned in said openings, said tube being open at a bottom end thereof adjacent said opening in said one sidewall of said yoke and being closed at the top end thereof adjacent the other sidewall of said yoke, an armature positioned in said tube for sliding movement therein responsive to energization of said coil, and wherein the ratio of the length of said coil to the length of the working gap is between about 3 and 6.

19. A pull solenoid of the armature-in-tube type comprising a laminated yoke having a coil window therein and having an opening in a bottom sidewall only thereof, an annular coil positioned in said coil window, said coil having a central opening therethrough concentric with said opening in said yoke, a hollow armature tube positioned in said openings, said tube being open at a bottom end thereof adjacent said opening in said one sidewall of said yoke and being closed at the top end thereof adjacent the other sidewall of said yoke, an armature positioned in said tube for sliding movement therein responsive to energization of said coil, wherein said yoke includes a central, axial, laminated extension extending inwardly of said coil opening and extending part way through said coil opening, wherein said armature is solid and includes a slot parallel to the axis of the solenoid for reducing the circulation of eddy currents therethrough, and wherein the top end of said armature is in line with the inner surface of the bottom sidewall of the yoke, when the armature is in its "normal" position.

20. A pull solenoid of the armature-in-tube type comprising a laminated yoke having a coil window therein and having an opening in a bottom sidewall only thereof, an annular coil positioned in said coil window, said coil having a central opening therethrough concentric with said opening in said yoke, a hollow armature tube positioned in said openings, said tube being open at a bottom end thereof adjacent said opening in said one sidewall of said yoke and being closed at the top end thereof adjacent the other sidewall of said yoke, an armature positioned in said tube for sliding movement therein responsive to energization of said coil, wherein said armature comprises a cylindrical stack of flat, individual laminations, parallel to the axis of said solenoid, and including a sleeve tightly fitting over at least a portion of the axial length of said stack to hold said laminations together.

21. The apparatus according to claim 20 including an armature pull pin connected to said sleeve.

22. The apparatus according to claim 20 wherein said sleeve includes a first, very thin portion extending over that length of said armature positioned inside of said yoke.

23. The apparatus according to claim 22 wherein said sleeve also includes a second thicker portion covering that length of said armature that remains outside of said yoke.

24. An armature for a solenoid comprising a stack of individual laminations, parallel to the armature axis, and a sleeve tightly fitting over at least a portion of the axial length of said stack, wherein said sleeve includes a first, very thin portion extending over that length of said armature positioned inside of the solenoid, and wherein said sleeve also includes a second thicker portion covering that length of said stack that remains outside of said solenoid.

25. The method comprising forming the armature tube of an armature-in-tube type of solenoid of semiaustenitic material, and treating said tube to be magnetic in at least one section and nonmagnetic in at least one other section.

26. The method comprising forming a solenoid armature as a cylindrical stack of flat, individual laminations parallel to the solenoid axis and with the cylindrical surface concentric with said axis, and holding said laminations together, in the portion thereof to be received within a solenoid, by providing a tightly fitting cylindrical sleeve over at least that portion of said stack.

27. The method comprising employing for the ratio of coil length to the length of the working gap, in a push-type solenoid, a value between about 3 and 6.

28. The method comprising forming the armature tube of a low-pressure AC solenoid of the armature-in-tube type, of very thin magnetic material having a wall thickness of about 0.014 inch, and heat treating said material to increase its strength.

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