Oct. 19, 1954 H. Y. FISHER 2,692,354

SOLENOID WITH ELECTROMAGNETIC PLUNGER CUSHIONING MEANS

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Fig. 1.

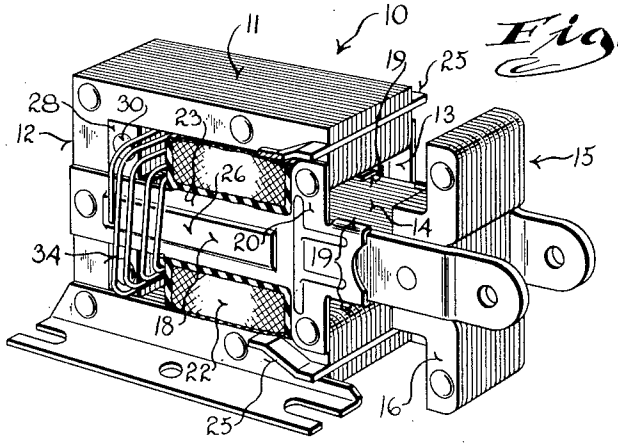


Fig. 2.

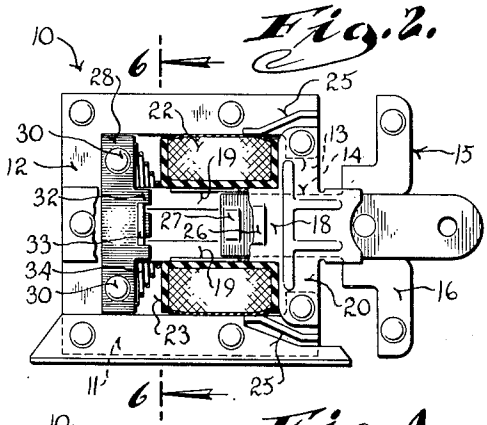


Fig. 3.

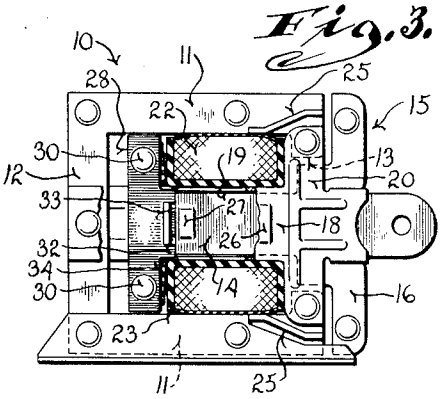


Fig. 4.

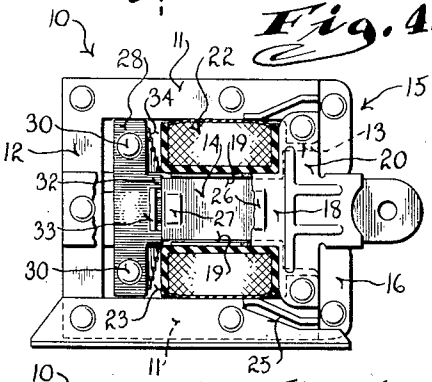


Fig. 5.

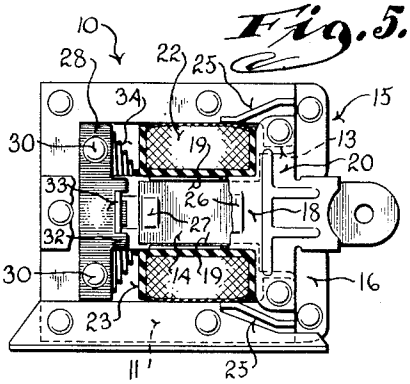


Fig. 6.

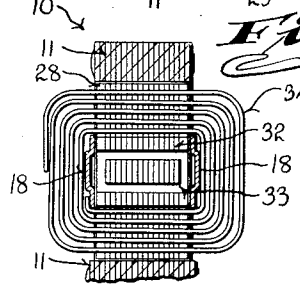
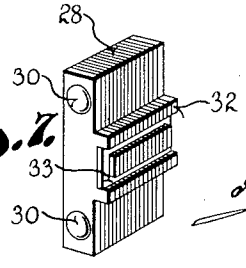


Fig. 7.



Inventor
Hardin Y. Fisher
By Dearmitt & Jones
Attorneys

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Fig. 8.

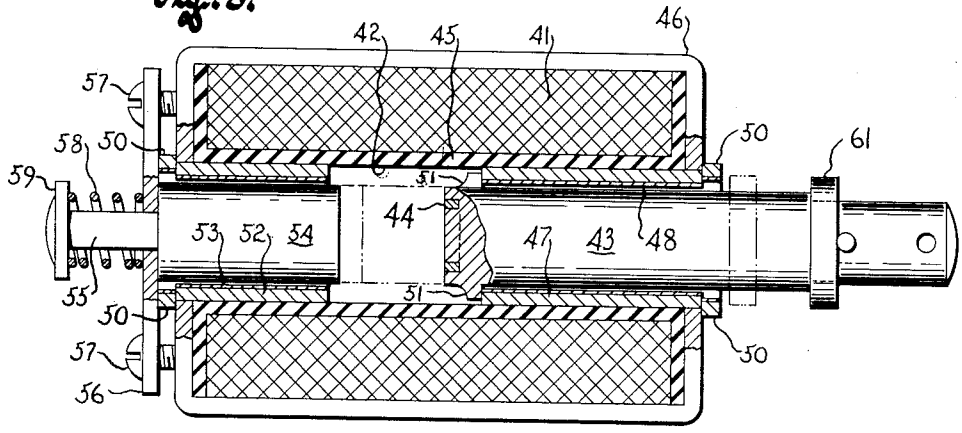


Fig. 9.

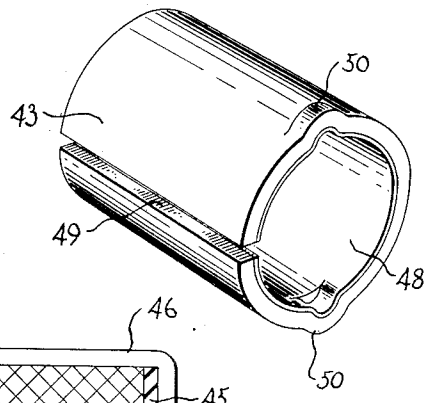
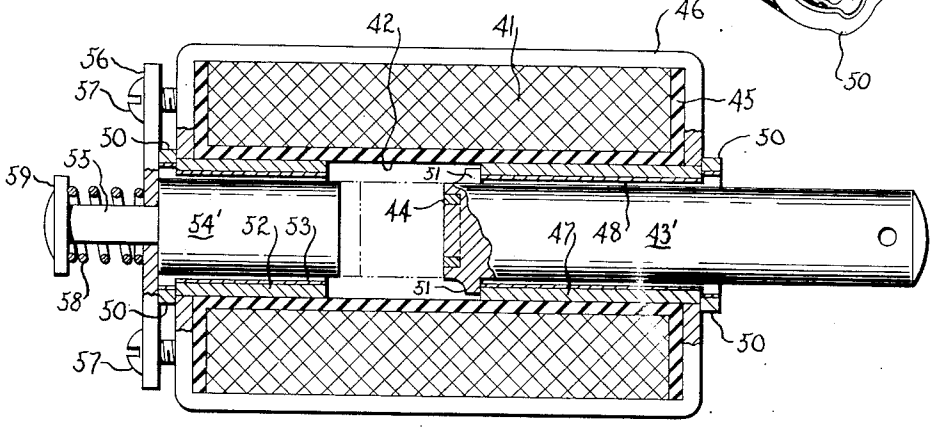


Fig. 10.



Inventor
Hardin Y. Fisher
By Dearmitt & Jones
Attorneys

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SOLENOID WITH ELECTROMAGNETIC PLUNGER CUSHIONING MEANS

Hardin Y. Fisher, Hillside, Ill., assignor, by mesne assignments, to Soreng Products Corporation, a corporation of Delaware

Application October 9, 1952, Serial No. 313,931

8 Claims. (Cl. 317—191)

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This invention relates to solenoids and, more particularly, to improvements in solenoids intended primarily, although not exclusively, for alternating current service. This application is a continuation-in-part of the co-pending applications of Hardin Y. Fisher, Serial No. 236,299, filed July 12, 1951, and Serial No 191,162, filed October 20, 1950, now abandoned.

In a typical double working gap solenoid to which the invention applies, a plunger is slidable axially inwardly of a C- or U-frame, upon energization of a winding embraced by the frame, to a fully attracted position defined by cooperating stops fixed with respect to the plunger and the frame. In its attracted position, the inner end of the plunger of the prototype, though spaced by an air gap from the bight of the frame was nevertheless closely adjacent to the frame so that the highest possible tractive force was exerted on the plunger. However, the conditions conducive to achievement of the greatest tractive force on the plunger inevitably resulted in a hammer blow upon the plunger and frame stops when the plunger slammed home; chattering occurred so long as the winding remained energized by alternating current; and the residual magnetism between the inner end of the plunger and the frame bight opposed the initial extending movements of the plunger after deenergization of the winding. The object of this invention, broadly, is to overcome these defects while increasing the efficiency of the solenoid.

The previous palliative provisions of a plunger cushioning spring, along with an air gap and shading coils for the inner end of the plunger each produced outweighing disadvantages of overall power loss, loss of seal pull, and overheating. Heretofore, an air gap at the inner end of the plunger sufficiently large to prevent sticking of the latter by residual magnetism broke the magnetic circuit between the frame and plunger, thus requiring a larger winding, more current and caused more heating. When shading coils were used, they tended to function as shorted-secondary windings, thus producing objectionable internal heat. While the usual cushioning springs reduced the hammer blows of the plunger to some extent, and, subsequently, pushed the plunger outwardly to overcome the residual magnetism upon de-energization of the winding, such springs also required that the winding produce sufficient additional power to compress them, and they increasingly opposed the final seating movements of the plunger during which the greatest seal pull on the plunger was needed.

One of the most important objectives of this

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invention is to minimize or even eliminate the effects of residual magnetism between the core means and the armature or plunger of an electromagnetic instrumentality upon de-energization of the winding thereof, while obtaining substantially all the attributes of a closed magnetic circuit through the core means and the armature or plunger so long as the winding is energized. For this purpose, it is proposed to render a part of the core means movable to a position closing the magnetic circuit through the core means and the armature or plunger in consequence to energization of the winding, against a biasing force which does not oppose the magnetic force holding the plunger in its seated position but instead acts on said movable parts to move the same out of its circuit making position upon de-energization of the winding. In a preferred form of the invention this movable core part also serves as a movable anvil to be met by the main plunger near the end of its attraction stroke for more effectively absorbing the hammer blow.

Another object of the invention is to augment the seal pull of the solenoid during and after the final seating movements of the armature or plunger. While ordinarily, the stored energy resulting when a cushioning spring partially absorbs a hammer blow opposes the final attraction or seating of the plunger and thus effects a net loss in seal pull, it is proposed now to provide for almost complete absorption of the hammer blow, while increasing seal pull to the extent of 50% or more even over uncushioned solenoids whose tractive forces have not been diminished by springs.

In the furtherance of this object, the solenoid of this invention is provided with an auxiliary plunger, having a substantial mass of magnetic material, axially movable at the rear of the frame and normally biased rearwardly by a spring engaged between it and a member, such as the coil or the spool upon which the coil is wound, to a position normally abutting the frame so that when the coil is energized, the auxiliary member advances against the bias thereon under the magnetic influence of the winding to meet the plunger near the end of the latter's attraction stroke. It is thus possible not only to absorb the hammer blow of the plunger in the mass of the auxiliary plunger; establish a closed magnetic circuit between the frame and main plunger through the auxiliary plunger; but also to add the rearwardly directed mechanical forces of the spring to the rearwardly directed tractive forces of magnetism applied to the main plunger.

Yet another object of the invention is to pro-

vide a solenoid in which the previously deleterious effects of wear and pounding resulting from repeated seating of the plunger are overcome. In solenoids having an air gap between the inner end of the plunger and the solenoid frame in the seated position of the plunger, the pounding down of the cooperating plunger and frame stops decreased the air gap and increased the residual magnetism; and plunger cushioning springs subjected to heating and pounding weakened with age. According to this invention, however, it is possible to so arrange and utilize a spring that the effects of the hammer blows of the plunger are not directed against the spring, and to diminish and utilize the effects of hammer blows of the plunger against the auxiliary member rather than the plunger stops so that the intended air gap obtained upon de-energization of the solenoid may actually increase with wear without ill effects.

Of perhaps more importance than the elimination of the problem of variations in air gap resulting from wear is the fact that the solenoid of this invention has no air gap at all when the plunger is held in its attracted position by the energized winding. When the solenoid is energized there always occurs a metal-to-metal contact between the main plunger end and the auxiliary plunger, and when the solenoid is de-energized, the air gap resulting when the auxiliary plunger is spring propelled away from the adjacent end of the main plunger is always greatly in excess of that needed to combat residual magnetism. A co-related object is to provide an air gap for combatting residual magnetism only after the solenoid is de-energized and without the overloading and overheating of the winding previously resulting from air gaps large enough to be effective.

Another proposed accomplishment of the invention is to reduce the speed of the plunger at the point where the magnetic tractive forces exerted on it rise abruptly. In a T-head plunger such as used in the preferred form of the invention, this point is reached as the head of the plunger closely approaches the end of the frame against which it abuts in the fully seated position of the plunger. By juxtaposing the point of impact of the main plunger with the auxiliary plunger to coincide with the point at which the magnetic tractive forces on the main plunger rise abruptly, the momentive forces of the main plunger are substantially dissipated so that it closes under the most forceful magnetic influences at reduced speed, with assistance from the energy stored in the spring compressed between the auxiliary plunger, and the rear end of the winding.

An additional object with respect to reduction of hammer blow is to reduce the noise and shock heretofore considered inherent in the forceful closing of a solenoid. Although cushioning springs and split plungers have been used in various combinations for noise reduction, the major forces exerted at or near the end of the attraction stroke of the plunger were exerted or transmitted to the solenoid frame in the plunger-closing direction. The object of this invention is to confront the main plunger, near the end of its closing stroke, with the mass of the auxiliary plunger, the latter being movable in the closing stroke direction relatively independently of the frame so that the momentum of the main plunger is largely offset by the inertia of the auxiliary floating plunger, thereby leaving but

negligible momentive forces to be applied to the frame in the final closing movement of the main plunger. An intention is further to reduce the impact of the final, rearwardly directed forces of the closing plunger by the forwardly directed, magnetic tractive forces exerted on the auxiliary plunger, the latter being greater at the point of impact by the main plunger and of decreasing effect as the auxiliary plunger moves rearwardly away from the winding as the main plunger finally closes.

A still further objective in the reduction of noise is the elimination of chattering while the solenoid remains energized, a defect heretofore caused primarily by poor physical contact between the frame and plunger when the latter was fully seated, with resultant vibratory shifting of the plunger, mostly in lateral directions. In this invention it is intended to use not only the conventional shading coils at the front of the frame, but another shading coil in the forwardly facing end of the auxiliary plunger in order to concentrate the flux density at its point of contact with the rear end of the main plunger, all to the result that the main plunger is firmly held at both ends.

Among the other objects are the more economical manufacture of a solenoid with longer life; a solenoid designed without critical tolerances previously necessary to maintain the compromise in air gap between one large enough to militate against residual magnetism and one small enough to prevent overheating; a solenoid designed for maximum power with minimum magnetizing current and, consequently, with minimum heating of the winding; and a solenoid with increased tractive force with less heating of the shading coils.

The foregoing objects of this invention are likewise obtainable in a solenoid of the single working gap type in which a solid or "one piece" plunger is reciprocable in one end of the aperture of an annular winding toward and from a magnetically permeable pole piece comprising a plunger stop in the other end of the winding aperture, if provision is also made for movement of the pole piece, against yielding bias, toward an attracted position engaging the plunger in response to energization of the winding.

For solenoids of this latter type it is another object of this invention to provide means for not only concentrating the magnetic flux at the inner end of the plunger stem, but which will also assure a very low reluctance magnetic circuit around the winding whenever the same is energized.

With the above objects in view, and with others appearing as the description proceeds, this invention resides in the novel construction, combination and arrangement of the parts substantially as hereinafter described and more particularly defined by the appended claims, it being understood that such changes in the precise embodiment of the herein disclosed invention may be made as come within the scope of the claims.

The accompanying drawings illustrate several examples of the invention constructed according to the best modes so far devised for the practical application of the principles thereof, and in which:

Figure 1 is a perspective view of the solenoid of this invention, with portions of its coil broken away;

Figure 2 is a side elevational view of the sole-

noid of this invention with portions thereof broken away, showing the parts in their inoperative positions, i. e. with the plunger extended and the winding de-energized.

Figure 3 is a view similar to Figure 2, but showing the parts in their relative positions after energization of the winding and as the plunger nears the end of its attractive stroke;

Figure 4 is a view similar to Figure 3, but showing the relative positions of the parts after seating of the plunger at the end of its attractive stroke;

Figure 5 is a view similar to Figure 4 but showing the relative position of the parts immediately after de-energization of the winding;

Figure 6 is a cross sectional view taken vertically through the solenoid along the line 6—6 of Figure 2, looking in the direction of the arrows;

Figure 7 is a perspective view of the auxiliary plunger per se;

Figure 8 is a longitudinal sectional view of a solenoid of the single working gap type modified to illustrate the application of this invention thereto;

Figure 9 is a perspective view of the plunger sleeve which characterizes the solenoid shown in Figure 8; and

Figure 10 is a view similar to Figure 8 showing another embodiment of the invention.

Referring now to the drawings, in which like reference numerals denote like elements throughout the several views, the solenoid shown in Figures 1 to 5, inclusive, is generally similar to that of U. S. Patent No. 2,468,052 issued April 26, 1949, to Hardin Y. Fisher. It comprises a stationary core portion or frame 10, and a movable armature 15. The frame is substantially C-shaped and of the usual laminated construction, and it has opposite arms 11 projecting forwardly in parallel relationship from the closed end or bight 12 of the C.

At the front of the frame the space between the outer ends of the arms 11 provides an opening 13 into the frame through which the stem 14 on the armature or plunger 15 of the solenoid passes. Cooperating stops on the plunger and the frame limit travel of the plunger stem inwardly into the frame and define the fully seated or attracted position of the plunger. These stops may be located wherever convenient but in the solenoid illustrated the plunger stop comprises a T-head 16 on the outer end of the plunger stem, and the forward extremities of the arms 11 provide frame stops engageable with the underside of the T-head on the plunger to define the fully seated or attracted position of the plunger.

The stem 14 of the plunger is constrained to endwise reciprocatory motion parallel to and midway between the arms 11 of the frame by means of a plunger guide comprising cooperating guide plates 18 fixed to opposite sides of the frame. These plates preclude lateral motion of the stem toward one side or the other of the frame, and have flanges 19 thereon to engage over the plunger stem and preclude motion thereof toward and from either one of the legs 11 of the frame. The plunger guide, of course, is made of non-magnetic metal, and in the present case, the guide plates have T-heads 20 thereon adjacent to the front of the frame which span the space between the extremities of the legs 11 and provide for securement of the front ends of the plates to the frame. In the present case, however, the flanges 19 on the guide plates terminate a substantial distance short of the bight 12 of the C-frame for a purpose to be later described.

The winding or coil 22 of the solenoid is embraced by the outer end portions of the legs 11 of the frame, and is wound upon a hollow spool or bobbin 23 of insulating material. The bobbin, of course, encircles and is seated upon the flanged portion of the plunger guide plates, so that the plunger stem in effect reciprocates inside the hollow interior of the coil. It is important to note that the winding has an axial length such that when its front end is engaged with the undersides of the T-heads 20 on the plunger guide plates, the rear end of the winding is spaced a substantial distance from the closed end or bight 12 of the C-frame; while the rear extremities of the flanges 19 on the guides terminate inside the rear end portion of the winding.

Outward embostures 26 on the guide plates slidingly fit over outwardly-extending lugs 27 on the plunger stem, and at their extreme forward ends, the embostures limit outward extension of the plunger. The particular construction of the plunger guide plates, however, forms no part of the present invention and any conventional stop means may be used to limit outward extension of the plunger.

On its opposite sides, the outermost laminae of the plunger are extended forwardly beyond the T-head 16 to provide pull bars through which the tractive forces of the plunger may be utilized; and each of the legs 11 has a shading coil or ring 25 encircing its outer end portion as in the aforementioned U. S. Patent No. 2,468,052.

Slidable within the rear end of the C-frame between the guide plates 18 rearwardly of the flanges 19 thereon is a generally rectangular auxiliary plunger 28 which actually comprises a movable part of the core or frame 10. As detailed in Figure 7, the auxiliary plunger is a build-up of magnetically permeable laminae, held flatwise together by rivets 30. Most of the laminae comprising the auxiliary plunger are identical rectangular strips of magnetic material with projections on one side edge forming a nose or anvil 32 of the same width as the plunger stem but slightly larger than the stem as measured along the long dimension of the auxiliary plunger. Cut-out portions in the anvil 32 hold a third shading coil or ring 33 formed of a flat, closed loop of electrically conductive non-magnetic material.

As seen best in Figures 1 and 6, the auxiliary plunger 28 is confined against sidewise displacement by the guide plates 18 on each side, but may slide axially back and forth within the bight end of the C-frame between the bight 12 and the rear end of the coil 22, which thus provide stops to confine the auxiliary plunger to limited travel away from the winding a distance less than the normal distance of travel of the main plunger in its attractive stroke. This assures that the auxiliary plunger will always reach its attracted position contiguous to the rear of the winding prior to seating of the main plunger upon energization of the winding.

The auxiliary plunger is biased rearwardly away from the winding by a coil spring 34, encircling the plunger guide, and engaged always under compression between the forwardly facing side of auxiliary plunger 28 and the rear end of the winding. Coil spring 34 is formed as an Archimedean spiral so that it may be compressed substantially flat when the auxiliary

plunger 28 moves forwardly toward the coil. It is noteworthy that the spring 34, by its engagement with the winding spool, also holds the winding in a forward position against the undersides of the T-heads 20 on the plunger guide plates.

The general proportions and characteristics of the components are preferably as follows: the stem 14 of the main plunger 15 is sufficiently long so that its rear end lies near the rear end of the winding 22 when the T-head on the plunger is engaged against the front of the C-frame; the anvil 32 on the auxiliary plunger 28 slidably fits within the rear end of the winding spool 23, and extends forwardly enough so that, taking the flat thickness of spring 34 into account, the anvil lies well within the rear end of the winding 22 when the auxiliary plunger 28 is in its foremost position; the relative lengthwise dimension of the rear end of frame 10 and the fore-and-aft dimension of auxiliary plunger 28 are such that when the auxiliary plunger is in its rearmost position engaged against the inner side of the bight 12 of the frame, a much larger air gap exists between the forward end of its anvil 32 and the rear end of main plunger stem 14 than could be tolerated in a solenoid of conventional design. In the illustrated embodiment of the invention, the auxiliary plunger may have $\frac{1}{16}$ of an inch or more travel rearwardly from the rear end of main plunger stem 14 when the latter is fully seated.

Spring 34 is strong enough to bias the auxiliary plunger to its rearmost position, but is sufficiently weak to be easily overcome by the magnetic tractive forces forwardly exerted on the auxiliary plunger 28 when the winding 22 is energized; and the rearwardly exerted tractive forces exerted by the winding, when energized, on main plunger 15 are greatly in excess of the forwardly exerted magnetic tractive forces on the auxiliary plunger.

Figures 2 to 5, inclusive, illustrate the operation of the solenoid. In the Figure 2 position, the winding 22 is de-energized, plunger 15 is extended, and auxiliary plunger 28 is held in its rearmost position, by spring 34, against the closed end of the frame 10. Upon energization of winding 22, the auxiliary plunger 28 is pulled forwardly toward the winding under the magnetic influence thereof to the position illustrated in Figure 3, thereby compressing and storing energy in spring 34. Meanwhile, main plunger 15 moves rearwardly with great speed, but just before its head 16 would slam against the front end of frame 10, the rear end of its stem 14 hits the anvil of the auxiliary plunger 28, and the main plunger is slowed down by the floating anvil action of the auxiliary plunger while the latter receives the main blow of the plunger before it seats fully. The relative positions of the main and auxiliary plungers 15 and 28, respectively, at the instant of impact therebetween at which the hammer blow of the main plunger is absorbed quietly by the auxiliary plunger are illustrated in Figure 3; wherein, it will be seen, plunger head 16 is at that point of nearness to frame 10 where the magnetic attraction therebetween rises most abruptly.

During the transition from the Figure 3 point of impact position to the Figure 4 completely attracted position, main plunger 15 is in engagement with and consequently directly magnetically coupled to auxiliary plunger 28, thereby closing the magnetic circuit at the rear of the assembly through the auxiliary plunger from the legs 11 of the frame to the rear end of main plunger stem 14, the magnetic efficiency being augmented by shading coil 33. As plunger head 16 nears the front end of the frame, the rearwardly exerted tractive force on the main plunger rises sharply until it reaches maximum when the plunger head contacts the frame, thereby completing the magnetic circuit at the front of the assembly.

Meanwhile, the energy stored in the spring 34 urges auxiliary plunger 28 rearwardly and, of course, this spring force augments the rearwardly directed magnetic forces on the main plunger, now coupled to the auxiliary plunger. As auxiliary plunger 28 moves rearwardly from its foremost position of Figure 3 to its intermediate position of Figure 4, the distance between its major mass and the rear end of winding 22 sharply reduces the forwardly directed magnetic forces exerted on it, thereby rendering them negligible against the seal pull of the main plunger 15.

Figure 4 illustrates the main plunger 15 in its fully attracted position where it and the auxiliary plunger will stay so long as the winding 22 is energized. In this fully seated position of the main plunger, there is no air gap between it and the frame, and the closed metal-to-metal contact of both ends of the auxiliary plunger with the forward arms together with the engagement between the main and auxiliary plungers creates a completely closed, well-balanced magnetic circuit around winding 22, with low loss, low heating, maximum work throughout. Chattering is precluded by the firm holding of the main plunger at both ends; auxiliary plunger 28 and the rear end of main plunger stem 14 cannot tip nor move laterally because of the close, flat surface engagement of the rectangular upper and lower ends of the auxiliary plunger within the frame and because of the sidewise restraint of guide plates 18 on both the auxiliary plunger and on the main plunger stem 14; and the front end of the main plunger is held firmly by the close engagement of its head 16 against the front end of the frame. In this last respect the shading coils 25 on the legs 11 of the frame increases the stability of the front end of the main plunger when the solenoid is energized.

Figure 5 illustrates the conditions resulting immediately after winding 22 is de-energized. The magnetic field of the winding collapses, and the induced forces formerly directly coupling the main and auxiliary plungers cease; the residual magnetism tending to hold the plungers together is overcome by the spring 34 which forces the auxiliary plunger 28 to its rearmost position, thereby establishing a generous air gap between the anvil 32 and the rear end of main plunger stem 14. As can be estimated from Figure 5, the established air gap is far in excess of that practical in conventional solenoids, and is amply sufficient to render ineffective the residual magnetism which otherwise would oppose the extending movements of the main plunger. In addition, the resulting air gap is so great that variations in the configuration or dimensions of the engaging surfaces of the main plunger stem 14 and auxiliary plunger anvil 32, or the main plunger head 16 and the front end of frame 10, either as a result of non-critical manufacture or from extensive wear, are unimportant.

From the description thus far it will be readily appreciated that while the auxiliary plunger is

illustrated as slidable to and from engagement with the inner end of the main plunger stem to effect completion of the magnetic circuit around the winding upon energization thereof, that the same advantage of a closed magnetic circuit will be obtained in the energized condition of the winding regardless of whether the magnetic circuit at the inner end of the plunger stem is closed by a slidable auxiliary plunger engaging the main plunger stem, as long as a movable core part is provided in addition to the main plunger to be movable between an attracted position cooperating with the remainder of the core to complete the circuit around the winding and a retracted position toward which it is normally held by a biasing spring and in which position the magnetic circuit around the winding is completely broken.

While the foregoing description dealt with one particular form of solenoid, this invention is likewise applicable to other forms of solenoids such as that disclosed in the copending application of Robert W. Bachi, Serial No. 288,263, filed May 16, 1952; or the single gap type shown in Figures 8 and 10. For instance, substantially all of the advantages of the double working gap type of solenoid previously described may be obtained in the solenoid of Figure 8. This solenoid comprises an annular winding or coil 41, having a circular axial aperture 42 therethrough of substantially uniform diameter throughout its length, and a plunger 43 is endwise reciprocable in the front end portion of the winding. Although the plunger is shown as cylindrical, it will be appreciated that it may have a rectangular or other cross sectional shape. In addition, the plunger may have a shading coil 44 recessed in its inner end, and as is conventional the winding is wound upon a spool-like bobbin 45 of suitable insulative material.

Surrounding the winding is a magnetically permeable frame 46 which may be either in the nature of a strap or a substantially cylindrical shell encompassing the entire winding. In either event the frame extends longitudinally around the winding and the ends thereof have apertures therein coaxial with and of diameters substantially corresponding to that of the aperture 42 in the winding.

The plunger 43 is guided for endwise reciprocatory motion in the aperture, coaxially thereof, by a sleeve 47 encircling the plunger. As will now be brought out, this sleeve overcomes many of the disadvantages inherent in bushings of the type previously employed for the same purpose in solenoids of the solid cylindrical plunger type.

Referring to Figure 9, the sleeve 47 is essentially a longitudinally slit tube of magnetically permeable material having a relatively thin lining 48 of brass or other non-magnetic bearing material. The sleeve 47 extends only part way into the aperture 42 at the front of the winding, and to prevent the sleeve from acting as a short circuiting turn within the winding its longitudinal slit 49 extends along the entire length of the sleeve.

The sleeve has a snug press fit in the plunger aperture in the frame and thus the permeable material comprising the exterior of the sleeve is in intimate contact with the magnetic material of the frame adjacent to the plunger aperture so that an excellent flux path is provided between the frame and sleeve. A pair of diametrically opposite shoulders or stops 50, pressed radially outwardly from the wall of the sleeve

at the projecting forward end thereof, abut the outer surface of the frame to define the maximum depth of insertion of the sleeve into the coil. Attention is directed to the fact that the stops, because they overlie and intimately contact the end surface of the frame, also serve to improve the flux path between the frame and the permeable material of the sleeve.

One important function of this sleeve is to materially reduce the reluctance of the non-permeable interval which invariably exists between the plunger and the end of the frame through which it passes. In this case this interval comprises the thin non-magnetically permeable lining 48 of the sleeve and the very slight clearance space between said lining and the plunger, but the reluctance of this interval is extremely low because of its large surface area at the junction between the permeable and non-permeable laminae of the sleeve. To minimize reluctance at this area of the solenoid, of course, the non-permeable lining of the sleeve should be as thin as possible consistent with good wearing characteristics.

Another important advantage afforded by this sleeve derives from the fact that its inner end is spaced a substantial distance outwardly of the inner end of the plunger, and that the sleeve affords, in effect, a flux path around the plunger leading from the front of the frame rearwardly toward the inner end of the plunger, to preclude heavy flux concentrations at the outer or front end portion of the plunger. The lines of force of the flux thus diverted from the outer end portion of the plunger are brought into the inner end portion of the plunger, thereby providing a very desirable condition of concentrating a high flux density in the inner portion of the plunger which projects rearwardly from the sleeve.

In this connection it is, of course, necessary to insure that in its most extended position the plunger will always have its inner end projecting rearwardly from the inner end of the sleeve, and for this purpose the plunger may be provided with radial lug-like stop abutments 51 at a suitable distance from its inner end and adapted to engage the inner end of the sleeve to define the fully extended position of the plunger; or the load or mechanism (not shown) which is to be actuated by the plunger may be so constructed or arranged as to effect the same result.

In addition to the sleeve 47 hereinbefore described, the solenoid has a second sleeve 52 which extends into the winding aperture from the opposite end thereof. The sleeve 52 is preferably provided with a non-magnetically permeable inner lining or bearing surface 53, just as in the sleeve 47, although this lining may be omitted without serious consequences. The forward end of the sleeve 52 is spaced a substantial distance from the rear end of the plunger sleeve 47, and the sleeve 52, like the plunger sleeve is provided at its projecting rear end with outwardly sheared shoulders or stops 50 which engage the adjacent end of the frame to limit insertion of the sleeve into the coil and to improve the flux field path to the sleeve in the manner already described.

A cylindrical core part or auxiliary plunger 54 is endwise slidably mounted in the rear sleeve 52 and is reduced in diameter at its rear to provide a concentric rivet-like pin 55 extending rearwardly through a hole in a yoke or strap 56 which is secured across the outer end of the sleeve 52, as by means of screws 57 received in the rear end of the frame.

The movable core part 54 of the solenoid shown

in Figure 8 is yieldingly biased rearwardly away from the inner end of the plunger, by a compression spring 58 which is confined between a head 59 on the outer end of the pin 55 and the outer face of the yoke 56. Upon energization of the winding 41, the core part or auxiliary plunger 54 will be attracted forwardly toward the plunger simultaneously with rearward movement of the plunger, to lessen the air gap between it and the inner end of the armature, and thus cause an unusually strong pull to be exerted on the armature at the start of its travel into the winding. The core part 54 will thus in effect advance to meet the plunger, and the two will collide at a time when the plunger has not reached its fully attracted position, as indicated in construction lines in Figure 8, and while the movable core part is spaced from the yoke 56, so that the inertia of the movable core part is utilized to effectively absorb or cushion the seating of the plunger and eliminate the hammer blow characteristic of seating of the plungers of most solenoids.

Immediately after the armature has struck the movable core part 54, the armature completes its attraction stroke, that is, it is drawn further into the winding to its fully seated position defined by the engagement of an abutment 61 on its front end portion with the projecting end of the sleeve 47. In this seated position of the armature, of course, the movable core part 54, which corresponds to the auxiliary plunger of the previously described solenoid, is held in an attracted position engaged with the armature and intermediate its retracted position and that at which it was struck by the armature, so that the magnetic circuit around the coil is completed. Upon deenergization of the winding, the spring 53 propels the movable core part 54 rearwardly to its retracted magnetic circuit breaking position against the yoke 56 while the armature 43 is held against further inward travel, to thus break residual magnetism in the core parts and allow the armature to be retracted freely.

The solenoid of Figure 8, therefore, has substantially all of the advantages of the double working gap solenoid previously described and among the more important of which are quiet and highly efficient operation and the elimination of residual magnetism in the core parts following deenergization of the winding. Wherever residual magnetism can ordinarily be overcome by the load to which the armature is attached, a solenoid like that illustrated in Figure 10 may be provided. As herein shown, the movable core part 54' is the same as that of the Figure 8 solenoid, but since the armature 43' has no abutment on its outer end to engage the frame and define the fully attracted position of the armature, the movable core part itself comprises an internal end stop for the armature. As will be apparent, however, the movable core part 54' is also attracted forwardly toward the armature to intercept the latter in its attraction stroke and thus cushion the seating of the armature, but after such interception, the armature moves rearwardly, by magnetic attraction, and aided by the spring 58, pushes the movable core part 54' rearwardly until it comes to rest in its retracted position against the yoke 56, where these two movable core parts remain in engagement with one another as long as the winding is energized to substantially complete the magnetic circuit around the winding.

Attention is directed to the fact that the initial advance of the end stop 54' toward the plunger decreases the air gap and thus desirably increases the tractive force exerted by the plunger during the initial stages of its attraction. It is also important to note that the end stop 54' will be capable of protracted engagement with the inner end of the plunger at times when the load to which the plunger is connected prevents full attraction of the plunger. Under such conditions, the end stop remains in a forwardly attracted position and engaged with the inner end of the plunger to assure closure of the magnetic circuit where otherwise the circuit would be open by reason of an objectionable air gap between the stop and the inner end of the plunger. In this latter instance, residual magnetism is effectively overcome upon deenergization of the winding in the same manner as set forth in connection with the solenoids previously described; by the action of the spring 58 which forces the end stop 54' rearwardly out of attracted position, away from engagement with the plunger to re-establish a large magnetic circuit breaking air gap between the end stop and the inner end of the plunger.

Highly important advantages of the solenoids of Figures 8 and 10 are the elimination of the need for careful and often highly critical adjustment of the plunger stroke to assure closure of the air gap at its inner end in the energized condition of the solenoid; for as stated the movable core parts 54 and 54' are movable toward the inner end of the armature to close the air gap even though the armature may be prevented for any reason from reaching its fully attracted position.

From the foregoing description taken together with the accompanying drawings, it will be evident to those skilled in the art that this invention by virtue of the novel construction herein described, has the following advantages, among others, over previous solenoids of the general types here under consideration:

1. It affords a complete magnetic circuit about the coil during energization thereof without the presence of magnetic flux bottlenecks and/or high air gap reluctance;

2. It provides means for using a spring force on a movable part of the core to overcome the increased residual magnetism resulting from completion of the magnetic circuit through a continuous permeable metal path without having the spring force oppose the force of magnetic attraction holding the armature in its attracted position in the solenoid;

3. It enables utilization of the full tractive effort of the solenoid;

4. It enables the provision of an efficient solenoid in which the hammer blow of the plunger or armature may be absorbed and dampened by a movable auxiliary plunger or end stop, and

5. All of the foregoing features being incorporated in a solenoid without critical design and manufacturing tolerances or variations in operating characteristics throughout a long and active life.

What I claim as my invention is:

1. In a solenoid of the type having an annular winding with an axial aperture therethrough; an elongated magnetically permeable plunger endwise reciprocable in one end of said aperture between attracted and extended positions; a magnetically permeable end stop mounted inside the other end of said aperture for axial reciprocatory motion to and from an inner position at which it is directly engageable by the plunger upon attraction of the plunger so that the inertia of the

end stop is utilized to cushion seating of the plunger when the winding is energized; a magnetically permeable longitudinally slit sleeve fixed in said other end of the aperture and surrounding said end stop to provide a bearing in which the end stop slides; means yieldingly urging the end stop in one direction; means mounting the plunger for endwise reciprocation and for concentrating a high flux density at the inner end portion of the plunger, comprising a magnetically permeable longitudinally slit sleeve fixed in the plunger end of the aperture and in which the plunger is slidably mounted, said sleeve extending into the aperture a distance short of the inner end of the plunger; and a magnetically permeable frame embracing the winding and connecting said end stop in magnetic circuit with said sleeves.

2. The solenoid of claim 1 further characterized by the fact that said sleeves are connected to the permeable frame, and further characterized by the fact that the sleeve surrounding the end stop has its inner end spaced a substantial distance from the inner end of the plunger sleeve.

3. In a solenoid of the type having an annular winding with an axial aperture therethrough; an elongated magnetically permeable plunger endwise reciprocable in one end of said aperture between attracted and extended positions; a magnetically permeable pole piece mounted on the solenoid adjacent to the other end of the winding for axial reciprocatory motion coaxial with said aperture toward and from the inner end of the plunger, said pole piece being attracted toward the plunger upon energization of the winding and being directly engageable by the plunger upon such energization so that inertia of the pole piece is utilized to cushion seating of the plunger; means yieldingly urging the pole piece away from the plunger; and longitudinally slit magnetically permeable sleeves fixed in the aperture at opposite ends of the solenoid and in which the plunger and pole piece are slidably received, the inner opposing ends of said sleeves being spaced apart a distance greater than the distance of travel of the plunger between its attracted and extended positions.

4. In a solenoid of the character described: a winding; magnetically permeable core means for the winding all portions of which have a cross sectional area sufficient to provide an extremely low reluctance magnetic circuit around the winding upon energization thereof, said core means comprising a first movable core part providing a work performing armature movable to and from an attracted position engaging a portion of the core means and toward which position the armature travels in response to energization of the winding, and a second movable core part for closing and opening said magnetic circuit, said second core part being movable by magnetic attraction from a defined circuit open position toward an attracted position spaced therefrom and cooperating with the attracted armature and the remainder of the core means to establish an extremely low reluctance closed magnetic circuit around the winding, and being capable of being held in an attracted magnetic circuit closing position by magnetic attraction when the winding is energized; a fixed stop engageable by said second core part during motion thereof away from circuit closing position, to define the circuit open position of said second core part; and biasing means acting upon said second core part in a direction tending to hold the same in its circuit open position, said biasing means being readily overcome by the magnetic attractive force which the energized winding exerts upon said second core part but having sufficient force to propel said second core part to its circuit open position and thus disrupt residual magnetism in the core means when the winding is de-energized, to thereby facilitate retraction of the armature.

5. In a solenoid of the character described: a winding; magnetically permeable core means for the winding all portions of which have a cross sectional area sufficient to provide an extremely low reluctance magnetic circuit around the winding upon energization thereof, said core means including a first movable core part providing a work performing armature movable to and from an attracted position toward which it travels in response to energization of the winding, and a second movable core part movable between a retracted position and an attracted position toward which it travels in response to energization of the winding, and capable of being held in an attracted position cooperating with the armature and the remainder of the core means to establish an extremely low reluctance substantially closed magnetic circuit around the winding; and means for propelling said movable core part to its retracted position upon de-energization of the winding to thereby open said magnetic circuit and disrupt residual magnetism to facilitate retraction of the armature, without influencing the magnetic circuit about the winding when the latter is energized, said last named means comprising a biasing member acting upon said second core part to be loaded by attractive motion of said second core part, said biasing member reacting against a part fixed with respect to the winding and in nowise opposing the attractive stroke or seal pull of the armature.

6. A solenoid of the character described, comprising: a winding having front and rear ends; magnetically permeable core means for the winding all portions of which have a cross sectional area sufficient to provide an extremely low reluctance magnetic circuit around the winding upon energization thereof, said core means comprising a fixed part extending lengthwise along the exterior of the winding from the front to the rear thereof, a first movable core part providing a work performing armature having a stem projecting into the winding from the front thereof and having a head engageable with the front and said fixed core part to close the magnetic circuit at the front of the winding upon energization thereof and to define the fully attracted position of the armature, and a second movable core part in direct magnetic flux transfer relation with said fixed core part at the rear of the winding and movable forwardly by magnetic attraction toward an attracted position at which it is engaged by the armature stem during the attraction stroke of the latter to receive and absorb hammer blow from the armature before the latter reaches its fully attracted position, said second core part being capable of being held in an attracted position engaging the armature stem when the winding is energized to close the magnetic circuit at the rear of the winding; and means for separating said movable core parts upon de-energization of the winding to thereby open said magnetic circuit and thus disrupt residual magnetism to facilitate retraction of the armature, without influencing the magnetic circuit about the winding when the latter is energized, said last named means comprising a biasing member acting upon said second

core part to be loaded by attractive motion of said second core part, said biasing member reacting against a part fixed with respect to the winding so that separation of said core parts is effected without subjecting the armature to a force which opposes the seal pull of the armature.

7. A solenoid of the character described, comprising: a winding; magnetically permeable core means for the winding all portions of which have a cross sectional area sufficient to provide an extermely low reluctance magnetic circuit about the winding upon energization thereof, said core means comprising a first movable core part providing a work performing armature having a stem projecting into the winding from one end thereof, a second movable core part adjacent to the other end of the winding for opening and closing said magnetic circuit, said second core part being engageable by the stem of the armature upon response of said movable core parts to energization of the winding to complete the magnetic circuit through the interior of the winding, and a third core part connected with one of said movable core parts in direct flux transfer relation thereto, exteriorly of the winding, and engageable by the other of said movable core parts upon response of said movable core parts to energization of the winding to complete the magnetic circuit around the exterior of the winding, said movable core parts being capable of being held in attracted positions engaged with one another when the winding is energized to maintain a completely closed extremely low reluctance magnetic circuit about the energized winding; and means for separating said movable core parts upon de-energization of the winding to thereby open said magnetic circuit and disrupt residual magnetism to facilitate retraction of the armature, without influencing the magnetic circuit about the winding when the latter is energized, said last named means comprising a biasing member acting upon said second core part to be loaded by attractive motion of said second core part, said biasing member reacting against a part fixed with respect to the winding so that separation of said core parts is effected without subjecting the armature to a force which opposes the seal pull of the armature.

8. In a solenoid of the character described: a winding having front and rear ends; a U-shaped frame of magnetically permable material having its arms embracing said winding and substantially parallel to the axis thereof, and having its bight spaced from the rear of the winding; an auxiliary plunger of magnetically permeable material movably supported and said frame in direct flux transfer relation thereto at the rear of said winding and constrained to motion between a forward attracted position adjacent to the rear end of said winding in consequence of energization thereof and a retracted position engaging the bight of the frame; biasing means acting upon said auxiliary plunger and normally yieldingly holding the same in its retracted position, said biasing means being sufficiently weak as to be overcome by the magnetic tractive forces exerted on the auxiliary plunger by said winding when the latter is energized; a main plunger of magnetically permeable material comprising a stem projecting into the front of the winding and constrained to axial reciprocatory motion toward and from engagement with the auxiliary plunger; and cooperating stops on the frame and main plunger, independent of the auxiliary plunger, engageable to define the fully attracted position of the main plunger in which the rear end of the stem thereon holds the attracted auxiliary plunger in an intermediate position away from the rear of the winding, the attraction stroke of the main plunger being longer than that of the auxiliary plunger whereby upon energization of said winding, the auxiliary plunger reaches its attracted position first and intercepts the main plunger near the end of its attraction stroke to absorb the hammer blow thereof, and whereby upon de-energization of said winding, said biasing means moves said auxiliary plunger from its intermediate position to its rear position to establish an air gap between it and the stem of the main plunger, to disrupt residual magnetism and facilitate retraction of the armature.

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