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[54] PROPORTIONAL SOLENOID

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[52] **U.S. Cl.** **335/268**; 335/256; 335/262
[51] **Int. Cl.** **H01f 7/18**
[58] **Field of Search** .... 335/268, 258, 256, 255, 335/262, 263, 200, 251; 174/15 R; 310/16

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Primary Examiner—Harold Broome
Attorney, Agent, or Firm—Biebel, French & Bugg

[57] **ABSTRACT**

Proportional single and double acting solenoids are disclosed of the type in which a conical pole piece becomes selectively saturated at locations opposite the armature. These solenoids are subject to side loading and the alignment and centering of the armature shaft is achieved by providing the bearing housings and adjacent bases with matching interfitting tapers to reduce or eliminate side loads on the armature shaft by assuring concentricity. The solenoids also have improved heat transfer by the use of a coil form in the shape of a spool or bobbin made of aluminum, in which one of the radial end walls is provided with a channel or groove in which the magnet leads and the external lead-in wires are connected and mechanically protected, so that the full radial surface of the side wall may be used for heat conduction without air gaps. High temperature silicone grease is employed at the interfaces of the coil, the base, the hub, and the case to improve the efficiency of heat transfer.

7 Claims, 9 Drawing Figures

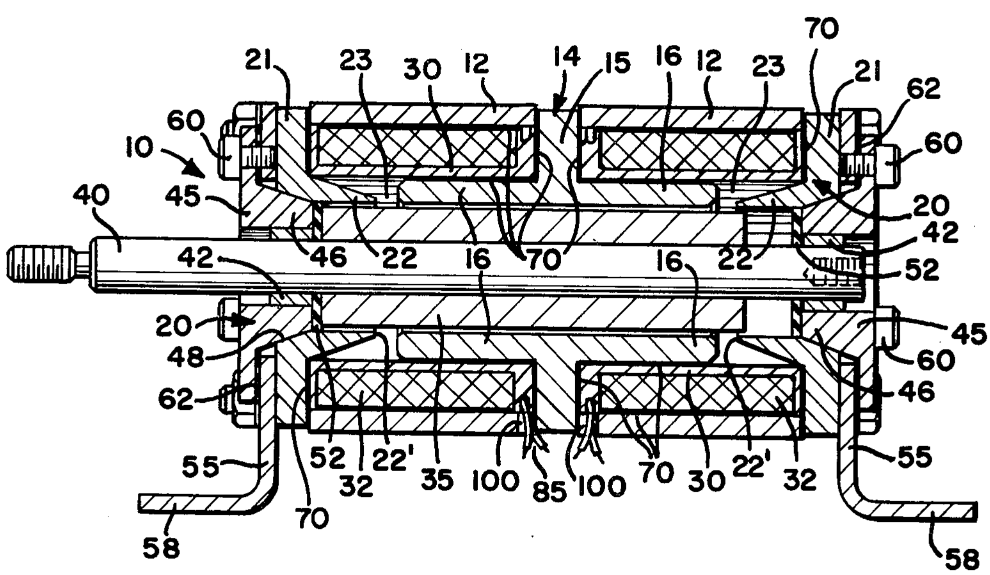


FIG-1

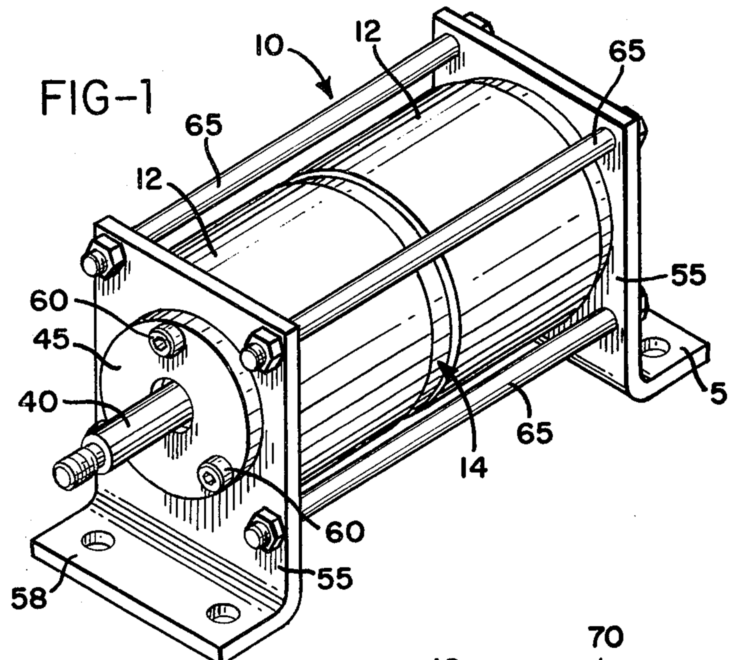


FIG-2

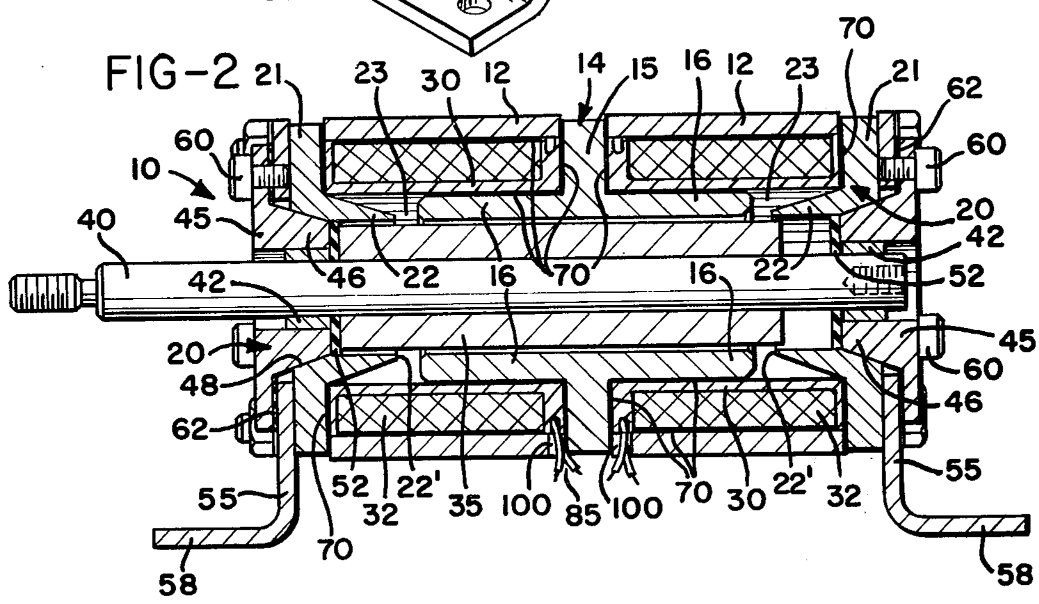


FIG-3

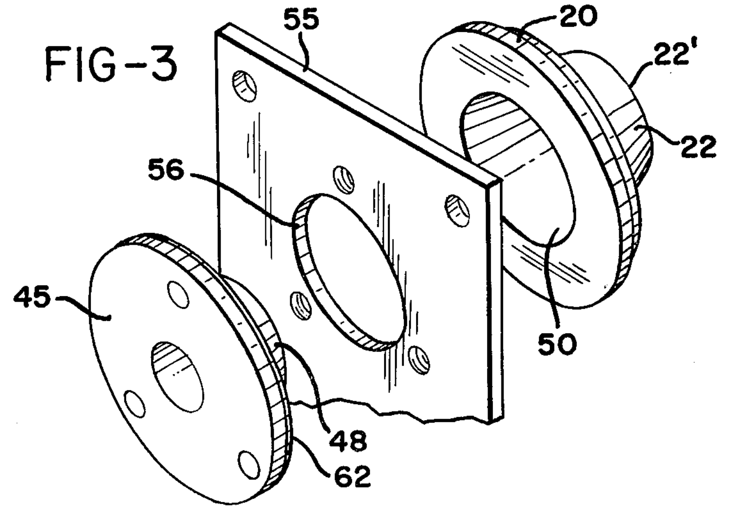


FIG-4

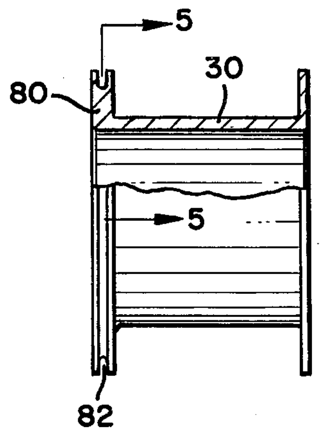


FIG-5

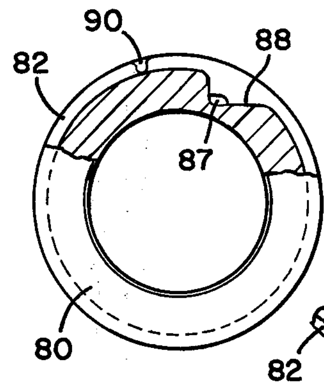


FIG-5A

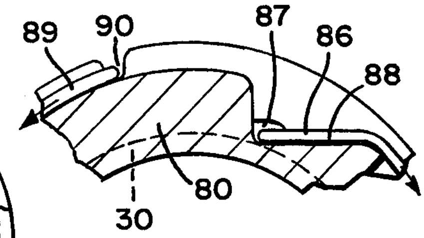


FIG-5B

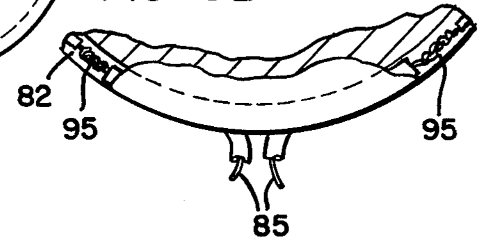


FIG-6

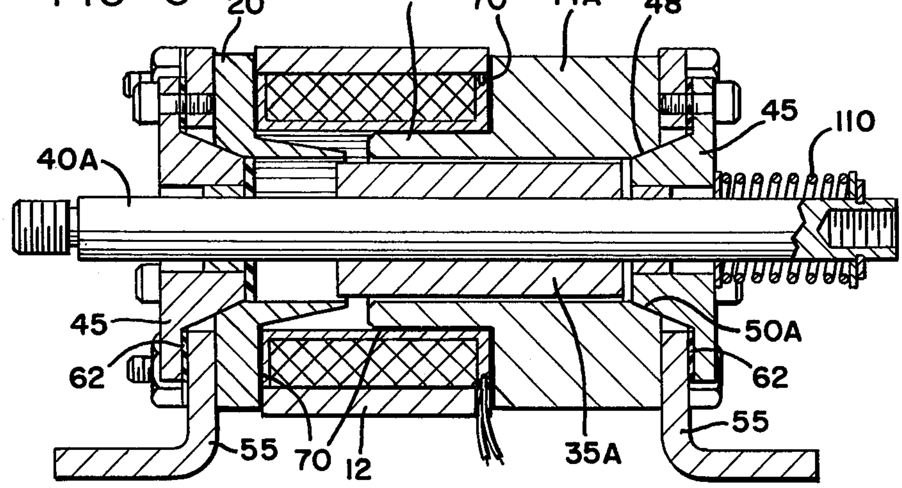
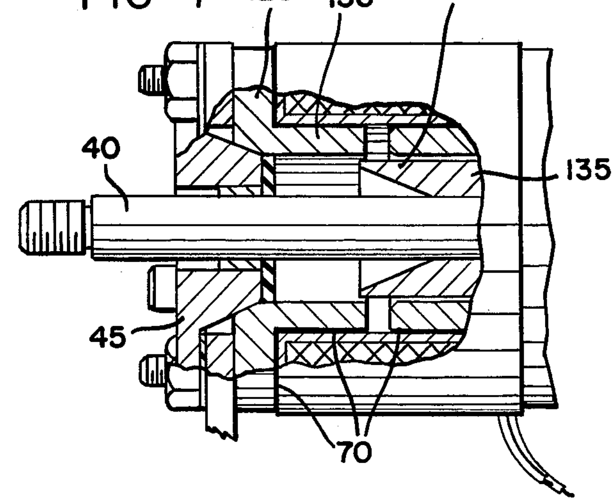


FIG-7



PROPORTIONAL SOLENOID

BACKGROUND OF THE INVENTION

This invention relates to proportional actuators of the general type disclosed in German Auslegeschrift 1,270,178 published June 12, 1968, in which relatively movable cylindrical and conical members are separated by a constant air gap and move by an amount which has a proportion to the amount of energy applied to the solenoid coil. As the armature advances from the apex of the cone formed by the pole piece toward the base of the cone, the material of the pole piece becomes saturated in the region directly across from the armature. The shape or slope of the force curve produced by this type of a solenoid is determined by the configuration of the cone, and the amount of energy or linear force produced is a function of the rate of change of area on the conical member. German Patentschrift No. 847,465, cited in Auslegeschrift 1,270,178, shows arrangements by which the shape or slope of the force curve may be modified by selecting the configuration of the cone, in a single-acting proportional solenoid.

An inherent characteristic of the general type of solenoid or actuator described above is that there can be substantial side loading of the armature over that which occurs with conventional conical or flat pole construction, due to the fact that many of the lines of flux are perpendicular to the line of motion of the armature. Thus, any misalignment or lack of concentricity of the armature in the hub and/or base can result in large side loads being placed on the armature by the magnetic field. This places a high stress on the armature support bearings, induces friction, and causes accelerated wear of the bearings.

Additionally, the construction of commercially suitable solenoids of this type requires considerations with respect to optimizing the rate of heat transfer so that sufficiently high mechanical force can be obtained from a unit of given size, with an allowable rise in temperature.

It is common practice to use a coil spool or bobbin in the simple form of a spool with which the magnet wires are brought out through the outside surface of one of the end flanges to be connected to the lead wires. Such constructions, however, do not permit the end flanges of the bobbin to be in intimate contact with the adjacent solenoid parts such as the base or the hub, and the air gaps thus produced result in poor heat transfer. Often, little attention is paid to the further problem of removing the heat from the hub and bases to a remote point or heat sink for continuous operation.

A different type of prior single-acting proportioning solenoid is shown in the U.S. Pat. of Cowan No. 3,725,747 of 1973 in which the armature is shaded to produce high magnetic leakage path and saturation loss. In one embodiment, an electrical solenoid coil is wound on a metal spool which, itself, forms the bore through which the armature moves. To reduce friction, synthetic buttons or piston rings are mounted on the armature and engage the inside surface of a metallic spool. In another embodiment, the bore is formed by a sleeve of low friction synthetic material. However, the armature of the Cowan type of solenoid is not subject to unusual non-axial or side-loading due to the fact that the lines of force are primarily maintained parallel to the line of movement of the armature, as in conventional solenoid construction.

SUMMARY OF THE INVENTION

An important object of the invention is the provision of double and single-acting proportional solenoids incorporating cone-like pole piece members, having an improved efficiency and a construction for maintenance of concentricity of the parts. Efficiency is enhanced by assuring an optimum rate of heat transfer from the coil forms or bobbins to the adjacent contacting structures. To this end, the bobbins are preferably formed of high heat conductivity, non-ferrous material, preferably aluminum, although copper or aluminum filled nylon may be used. Where an aluminum bobbin is employed the surface is preferably hard anodized to provide a dielectric or insulating coating.

From experience, it is known that the maximum coil temperature in a solenoid coil is reached at or near the inside diameter of the coil. The bobbin design employed in the present invention is one which provides a direct path for this heat to flow off to the base and to the hub of the solenoid, to minimize temperature rise and to obtain more force.

A further feature of the invention resides in an electric coil construction which includes a circumferential channel or groove at the outer surface of one of the bobbin end walls, thus forming a space within which the lead-in wires may be joined to the magnet wire, permitting full and unobstructed surface contact at the end of the bobbin, and thus eliminating the usual air gap. As a further means for eliminating air gaps, high temperature grease, such as silicone grease, is applied to the contacting surfaces of the coil to provide continuity of contact and optimum heat transfer.

The heat transfer efficiency is enhanced by the provision of mounting brackets which are arranged to receive the heat from the bases as well as from the hub and transfer it outwardly to a mounting surface, so that the heat is removed in a continuous manner. Preferably, the mounting brackets are made of aluminum and, in the double acting enbodiment, are in direct heat transfer relation to the opposite bases. In the single acting version, one bracket engages a base while the other bracket is in direct engagement with the hub. In either embodiment, the heat flows out of the coil through paths which are provided by the hub, the bases, and the cylindrical cases within which the coils are received. The solenoid is held together by external tie bolts which extend between the mounting brackets.

It is also important to maintain a circularly constant air gap between the relatively moving magnetic parts, and to maintain these parts in true concentric relation to minimize side-loading which would otherwise be generated by the magnetic field resulting in wear on the bearings, and friction. To this end, the bases in the double acting embodiment are provided with internal concentric cone-shaped tapered surfaces which face outwardly, into which a bearing housing is fitted. The bearing housing is provided with a matching or mating external concentric taper, that is, a taper having the same slope as the internal taper formed on the base. In the single acting embodiment, the same base and housing arrangement is used while the hub is formed with the cooperating taper for the opposite bearing housing.

The bearing housings are mounted on mounting brackets. Gaskets between the mounting brackets and bearing housings provide assurance that the cooperating and mating tapers come into full engagement by compressing the gasket material.

This mating taper arrangement and gaskets between the mounting brackets and bearing housings minimize the chances of cocking of the bearing housing due to rough handling by assuring full contact between the interfitted parts. The mating tapers also assure that the armature always rides in the center of the clearance openings in the bases.

An important object of the invention is the provision of either double or single acting proportional solenoids which are of novel design and which particularly assure accurate centering of a movable armature and which provide for improved heat dissipation from the coil.

A more particular object of the invention is the provision of an improved coil assembly for solenoids in which there is provided a groove or recess at one end wall of the bobbin or coil form within which the electrical connections may be made, while providing for direct flow of heat from the end walls of the bobbin into a surrounding structure.

Another particular object of the invention is the provision of a solenoid base and bearing housing provided with mating cone-shaped tapers to assure concentricity.

These and other objects and advantages of the invention will be apparent from the following description, the accompanying drawings and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a double acting solenoid according to this invention;

FIG. 2 is a longitudinal section through the solenoid of FIG. 1;

FIG. 3 is an exploded perspective view showing the relation of one of the bases, the mounting brackets and the adjacent end wall;

FIG. 4 is an elevation, partially in section, of the bobbin or spool;

FIG. 5 is an end elevation of the bobbin of FIG. 4, partially in section, with the sectioned portion looking generally along the line 5—5 of FIG. 4;

FIG. 5A is an enlarged fragmentary detail of FIG. 5 showing the magnet wires entering the groove;

FIG. 5B is another enlarged detail of the coil form of the bobbin showing the lead-in wires entering the groove;

FIG. 6 is a transverse section through a single-acting solenoid according to this invention; and,

FIG. 7 is a fragmentary detail of a modification of the armature and pole pieces.

DESCRIPTION OF PREFERRED EMBODIMENTS

An embodiment of the invention as applied to a double-acting proportional solenoid is illustrated generally at **10** in FIGS. **1–3**. This embodiment includes a pair of identical sleeve-like cylindrical cases **12** which are formed of ferro-magnetic material. The cases **12** are positioned on axially opposite sides of an annular hub **14**. The hub **14** is formed with a central radial body portion **15** and a pair of axially extending sleeve portions **16**. The inner ends of the cases are in heat transfer abutment with the adjacent radial faces of the body portion **15**, as shown in FIG. **2**. The hub **14** is also formed of ferro-magnetic material, and the sleeve portions **16** define an armature-receiving bore or opening therethrough.

A pair of identical bases **20** are also formed of ferro-magnetic material and are provided with disc-shaped bodies **21**. The bodies **21** have radially inwardly-facing surfaces which abut against the outer ends of the cases in heat transfer relation.

Each base terminates in an inner radially-tapered cone-shaped pole portion **22**. The pole portion **22** is offset from the body **21** inwardly toward the adjacent sleeve portion **16** of the hub. The apex **22'** of each of the bases **20** is spaced axially from the adjacent terminal end of a sleeve portion **16** by a substantial gap **23** to reduce leakage. Preferably, only the outer surface of the pole portion **22** is tapered, while the inside surface thereof defines a cylindrical opening which has substantially the same inside diameter as the opening defined by the sleeve portion **16** of the hub **14**, although it is not essential that these inside diameters be precisely the same.

In the double acting embodiment of the solenoid **10**, a pair of identical electrical coil assemblies are employed which are positioned symmetrically on either side of the radial body portion **15** of the hub **14**. The electrical coil assemblies each includes a generally spool-shaped coil form or bobbin **30**. The bobbins **30** are formed of non-magnetic material and have an inside diameter proportioned to be received over one of the sleeve portions **16** in the axial space between the radial faces of the base and hub. The construction of the bobbins **30** is described in further detail in connection with FIGS. **4** and **5**. An electrical coil **32** is wound on each bobbin **30** and the outside diameter of the coil is a close fit with the inside diameter of the associated case **12**.

An axially-extended cylindrical armature **35** is received within the armature openings formed by the sleeve portions **16** and the pole portion **22**. The armature is also made of a suitable ferro-magnetic material, and has a length which is slightly greater than the spaced-apart distances of the bases as defined by the base portions **22**, so that when one end of the armature **35** is fully telescoped within one of the conical base portions **22**, the other end is just entering the opposite base portion at the apex **22'** thereof. The sleeve portions **16** of the hub **14** cooperate with the armature **35** to provide a long, non-working air gap.

The armature **35** is mounted for axial movement within the solenoid on a central support shaft **40**. The shaft **40** is received within low-friction bearings **42** mounted in identical combined solenoid end walls and bearing housings **45**. The bearing housings **45** cooperate with the bases **20** in a special way to assure concentricity of the armature with respect to the bases. Ideally a radially constant-clearance air gap is maintained about the armature **35** with respect to the bases and the hub, although a different clearance may be provided between the armature and the bases on the one hand and between the armature and the hub on the other hand.

To maintain base-to-armature concentricity, the housing **45** is provided with an inwardly extending portion **46**, the outer surface **48** being defined by a cone-shaped taper which precisely mates with a matching inside cone-shaped tapered surface formed on each base **20**. When the matching surfaces **48** and **50** (FIG. **3**) 3) are interfitted, the shaft **40** is held precisely in concentric relation with respect to the cylindrical opening in the tapered base portion **22**. The interfitting and matching tapers defined on each of the bearing housings and bases assure an alignment condition which is not subject to being knocked out of alignment by usage or rough handling. Cushion washers **52** may be placed at the inside faces of the bearing housings to absorb any shock of contact by the armature.

When the bases **20** and the housings **45** are interfitted as described, there is an axial clearance space between each bearing housing and its associated base. Aluminum mounting brackets **55** are received in these spaces, and they are provided with a central opening **56** as shown in FIG. 3 through which the conical extended portion of the bearing housings **45** is received. The brackets **55** are terminated in outwardly turned legs **58** forming mounting feet. The bearing housings **45** are assembled to the brackets **55** by threaded screws **60.** A gasket **62** is interposed between the radial inside wall of the housing **45** and the adjacent flat surface of the bracket **55.** Four tie bolts **65** extend externally of the cases **12** and hub between the opposite mounting brackets to retain the entire assembly by urging the mounting brackets tightly into abutment with the outside radial surfaces of the adjacent bases. The brackets **55** thus have optimum direct surface contact with the bases to receive heat therefrom and conduct the same away to the mounting structure. The gaskets **62** permit the matching tapers on the base and the bearing housing to fully mate with each other, by compression of the gasket material, when the screws **60** are tightened.

As previously mentioned, the invention provides for improved heat flow characteristics from the coil **32** and the bobbins **30,** and to this end, the bobbins **30** are preferably made of high heat conductive non-ferrous metal, such as aluminum. The outside radial surface of one end of each bobbin is in abutment with the adjacent radial surface of the hub **14,** and the opposite outside radial surface of the bobbin **30** is in full abutment with the adjacent inside radial surface of the base **20.** The inside cylindrical surface of the bobbin is formed as a close fit on the outside of the sleeve portion **16** of the hub **14.**

The interfaces between the coil assembly, on the one hand, and between the hub, the base, and the case on the other hand, are coated with a high temperature heat-conductive or heat transfer material **70,** such as a silicone compounded grease. Such greases are semi-solid mixtures of silicone fluids and thickeners or inert fillers which have an ability to maintain their viscosity or consistency over wide temperature ranges without melting and running away, smoking, charring or solidifying. Particularly suitable materials for this purpose consist of silicone compounds G-640 and G-641 of General Electric Company, Silicone Products Department, Waterford, N.Y. The compound may also be applied at the mutually contacting radial faces of the cases **12** and the hub and bases. The compound **70** thus eliminates any air gaps particularly between the coil assembly and the adjacent contacting components to provide for continuity and improved heat conductivity.

The heat from each of the bobbins may flow directly to the adjacent base **20** through one radial end of the bobbin. Also, additional heat paths are provided. Thus, the heat may flow directly outwardly to the case **12** and then through the base to the mounting brackets **55.** The radial flat engagement of the ends of the case with the base and hub provide for optimum heat transfer. Also, since a substantial inner portion of the bobbin is received directly on a sleeve portion **16,** a good deal of the heat will be thereby transferred to the hub **14,** and the mechanical connection between the hub **14** and the adjacent case **12** permits the heat to be transferred from the hub to the case, and again through the base to the mounting bracket. The heat thus may flow, in the double acting embodiment, in either direction depending upon temperature differential. For example, if one of the two electrical coil assemblies is in use, it is apparent that paths are provided so that the heat may flow therefrom in either direction into the opposite mounting brackets, again depending upon temperature differential.

The solenoid construction includes a specially formed bobbin as shown in FIGS. **4** and **5,** by means of which electrical connections are made to the coil while maintaining full face contact at both ends thereof. For this purpose, the inside radial wall **80** of the bobbin **30** is provided with a circumferential groove or channel **82** to receive the leads of the winding **32** and to receive the external power leads **85** and to provide a space for the electrical connections. Since the channel **82** is formed in the outer surface of the wall **80** it does not adversely affect the conduction of heat along the bobbin and through the ends thereof, and since the electrical connections are made within the channel, the lead wires are not brought out through the bobbin ends, as in conventional construction, which would result in an air gap. Also, the channel **82** provides mechanical protection for the lead-in wires and for the magnet wires.

As shown in FIG. **5A,** the inside magnet wire **86** is brought into the channel **82** through an opening **87** extending to the inside surface of the bobbin, and this lead may be dressed along an outwardly tapered wall **88** into the groove **82.** The outside magnet wire **89** may be brought into the groove **82** through a shallow cut **90** and turned in the opposite direction. The lead-in wires **85** are shown in FIG. **5B** as being brought in at the top of the bobbin adjacent the channel **82,** and to turn in opposite directions and to make electrical connections **95** with the magnet wires **86** and **89** entirely within the dimensions of the channel **82.** The cases **12** are formed with shallow axial slots **100** (FIG. 2) providing access openings for the wires **85.** The bobbin **30** is preferably hard-anodized over its entire surface to form an electrical insulation coating.

The invention is applicable to a single-acting solenoid as well as a double-acting solenoid, by utilizing many of the same parts which have been described in connection with FIGS. **2** and **4.** However, a modified hub **14A** is employed which may be formed from the same material as the hub **14** except that the sleeve portion **16A** extends only in one direction, the remainder of the hub being of constant thickness to provide a low leakage flux path. However, in this case, the inside taper **50A** is formed on the inside of the modified hub **14A** to receive the corresponding taper **48** of the adjacent bearing housing **45,** to assure alignment for the shaft **40A.** The modified armature **35A** carried on the shaft is, of course, shorter as it cooperates only with one base **20.** A return spring **110** may be mounted on the extended end of the shaft **40A** against the outside surface of the housing **45A** to resist the movement of the armature **35A,** in a single-acting unit.

A further modification which may be applied to either a single or double-acting solenoid version is shown in FIG. **7** in which the conically tapered portion of the pole is applied in the armature **135** as shown at **135A**, and in which the base **120** is formed with a non-tapered cylindrical pole portion **136.** All other parts may remain as described above.

In the operation of both the single and double-acting solenoids, the electrical coils may be operated in an open loop condition, or may be operated in a closed loop using the control circuit disclosed and claimed in the copending application of Myers, entitled Solenoid Servomechanism, Ser. No. 439,324, filed Feb. 4, 1974, and assigned to the same assignee as this invention.

As the armature advances toward the base of the cone defined by the base portion **22** in the embodiments of FIGS. **2** and **6,** each section of the cone saturates directly across from the armature. The shape or slope of the force-stroke curve is determined by the angle and slope of the cone, and the amount of energy produced is a function of the rate of change of area in the cone.

It is also important that the I.D. of the hub **14** be positioned and maintained in a concentric relation with respect to the armature **35** and the bases, to thus provide a constant air gap around the armature. This may be accomplished by the assembly of the bases and the hub on a precision mandrel. The concentric relation of the hub and bases is then maintained by the tie bolts **65** which apply a compressive force to the bases **20,** this compressive force being transmitted through the cases **12** and to the radial portion **15** of the hub **14.** The tie bolts **65** firmly clamp the bases **20** and the hub **14** in the predetermined concentric relation. The bearing housings **45** may be attached or removed by the screws **60** without disturbing the assembly of the base, cases and hub.

The cone-shaped matching tapers between the bearing housings and bases of FIGS. **2** and **3**, or in the case of the single acting embodiment, between the bearing housing and the hub **14A**, assure maintenance of a true concentricity between the armature and the bases. The gaskets **62** assure proper mating of the tapers and absorb the shock of rough handling or the like as may be applied to the mounting brackets **55.** If it should be necessary to remove or reassemble the housings **45,** they are automatically aligned into proper concentric relation by reason of the mating tapers. An important advantage of the structure described above is that the tolerance and concentricity between the I.D. and the O.D. of the hub, bases and bearing housings can be liberal.

The heat formed in the electrical coils, is generally concentrated about the inside turns of the coil, and the improved bobbin or coil forms of this invention thus provide direct paths for this heat to flow from the bobbin, as described. The channels **82** provide mechanical isolation for the magnet wires and lead-in wires and helps prevent shorting at the connections. The ends of the spool make direct heat transfer contact with the adjacent structure. The contact about the bobbin and the coil with the adjacent structure is enhanced by the use of the high temperature grease at the contacting surfaces.

While the coil forms or bobbins are shown as having a completely circumferential channel or groove **82,** it will be appreciated that wire-receiving grooves or channels formed in, or by, one of the end walls need not extend completely around the wall. In some instances, it may be desirable to provide channels of only limited arcuate length, sufficient to provide a mechanical recess for the lead-in wires and for the ends of the magnet wires, and to provide a region within which the electrical connections may be made. Further, it is preferred to position the somewhat wider channel end of the coil form adjacent the hub, which places the thinner opposite end wall of the coil form adjacent the base, thus providing a more direct heat transfer relation between the electrical coil itself and the base. Also, while the improved electrical coil assembly has been disclosed in connection with its use in a proportional solenoid, where the solenoid may be operated for a long period of time, it is obviously within the scope of the invention to use the improved coil assembly in conventional solenoids where its heat flow characteristics and its mechanical protection for the wires would also be of advantage.

Additionally, the proportional solenoid embodiments of the invention may be useful merely as long-stroke solenoids in conventional applications, where a load is to be moved over a substantial distance and where the usual non-linear force curve of a conventional solenoid is undesirable.

While the forms of apparatus herein described constitute preferred embodiments of the invention, it is to be understood that the invention is not limited to these precise forms of apparatus, and that changes may be made therein without departing from the scope of the invention.

What is claimed is:

1. For use with double and single acting solenoids, the combination comprising an annular hub having an abutment portion defining a radial wall and a cylindrical sleeve portion, a base axially spaced from said hub, means on said base forming an annular pole portion and having means defining a second radial wall in axially spaced relation to said hub wall, a cylindrical axially extended armature, means mounting said armature for axial movement within said hub, an electrical coil assembly including a spool-shaped coil form made essentially of high heat conductive material, said coil form having an inside surface received on said hub sleeve portion and having radial end faces in respective heat transferring abutment with said hub and base walls, an electrical coil wound on said form, and one end of said coil form having means defining a radially outwardly opening channel proportioned to receive the magnet wire of said coil and to receive the external power leads therein providing a space for electrical connection with said coil wires.

2. A proportional solenoid comprising an annular hub having an abutment portion defining a radial wall, a base axially spaced from said hub, means on said base forming an annular pole portion extending axially toward said hub and having means defining a second radial wall in axially spaced relation to said hub wall, a cylindrical axially extended armature, means mounting said armature for axial movement within said hub and base, an electrical coil assembly including a spool-shaped coil form made essentially of high heat conductive material, said coil form having an inside surface received in heat transfer relation on said hub and having radial end faces in respective heat transferring abutment with said hub and base walls, an electrical coil wound on said form, said form having means therein defining a circumferential outwardly-spacing channel formed in one end of said form and proportioned to receive the magnet wire of said coil and to receive the external power leads thereon providing a space for electrical connections with said coil wires, and high temperature grease at the interfaces between said coil form and said hub and base to eliminate air gaps and to improve the heat transfer rate from said coil assembly.

3. In proportional solenoids including an armature mounted on an elongated axially extending shaft and further including an annular hub and at least one axially spaced annular base surrounding said armature, said base and hub defining a path for movement of said armature, in which said armature is subject to side-loading due to magnetic lines of force between said armature and said base, the improvement in shaft mounting and centering means comprising a bearing housing, a bearing positioned centrally of said housing for supporting one end of said shaft for axial movement, said bearing housing having a wall portion defined by an external inwardly-facing annular taper, means on said base defining an internal outwardly-facing annular taper proportioned to mate with said housing taper, and means joining said bearing housing and said base with said tapers in mating relation to maintain a condition of concentricity of said armature with respect to said base.

4. The improvement of claim **3** further comprising a second said base axially spaced from said one base, and a second said bearing housing in mating relation thereto and having a bearing therein receiving the other end of said shaft.

5. The improvement of claim **3** further comprising a second said bearing housing member, means in said hub defining an internal, outwardly-facing taper proportioned to mate with the external taper on said second bearing housing, said second bearing housing having a bearing therein receiving the other end of said shaft, and means joining said second housing to said base with the tapers thereof in mating relation.

6. A double acting proportional solenoid comprising a hub having a symmetrically annular sleeve portion and a generally centrally positioned radial portion, a pair of electrical coil assemblies mounted on said sleeve portion respectively on opposite axial sides of said radial portion, a pair of axially-spaced bases having radial body portions in abutment with one of said coil assemblies, and each said base having an inwardly-extending annular tapered pole portion terminating in an apex spaced from said hub sleeve portion forming an air gap therebetween, a cylindrical armature mounted within said hub having opposite ends in interfitting relation to said pole portions so that selective energization of either of said coil assemblies will create a force tending to urge said armature axially in one direction or the other with respect to said bases, means on said armature defining an axially extending shaft, means mounting said armature shaft concentrically on said bases including a correspondiing pair of bearing housings, means on said housings and said bases defining cooperating mating concentric tapers, and bearings in said housings engaging said shaft adjacent the ends thereof and supporting said shaft and armature for said axial movement.

7. In electric solenoids including an armature on an axially movable shaft and further including a hub and at least one annular base cooperating with said armature to define a circumferential air gap therebetween, said armature being subject to magnetic side-loading upon the occurrence of a lack of concentricity between said armature and said base, the improvement in shaft mounting and centering comprising a bearing housing having means defining a bearing supporting one end of said shaft for axial movement therethrough, said bearing housing having a wall portion defined by an annular taper formed concentrically of said shaft, means on said base defining an annular taper proportioned to interfit and mate with said housing taper, and means joining said bearing housing and said base with said tapers in interfitted relation to maintain a circumferentially constant air gap between said armature and said base.

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