April 19, 1966 J. L. RUSSELL 3,247,344

SUBMINIATURE POLARIZED ELECTRICALLY ACTUATED CONTACTOR

Filed June 26, 1962 4 Sheets-Sheet 1

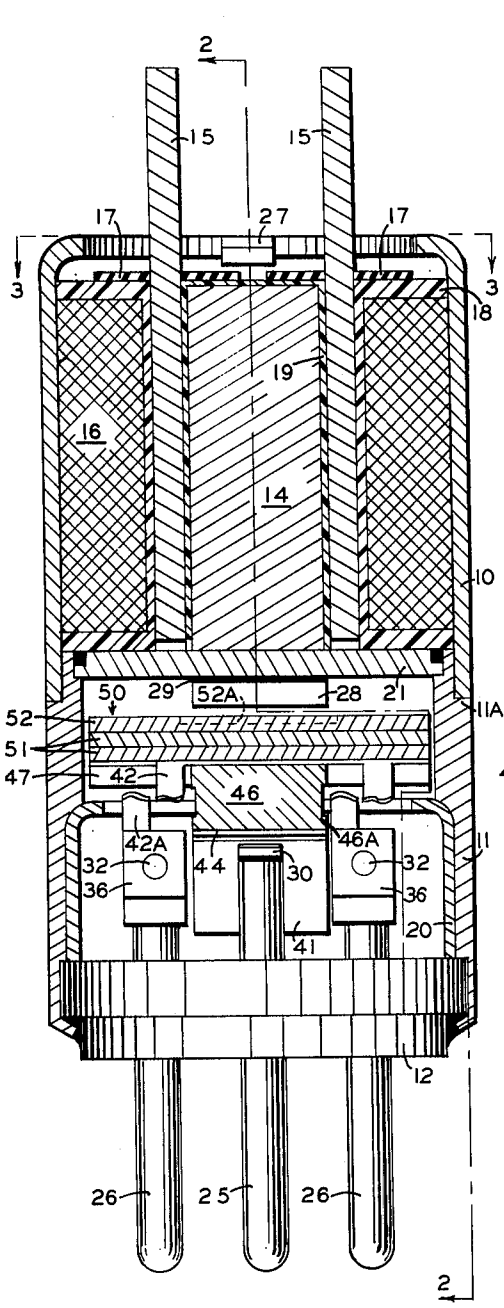



FIG 1

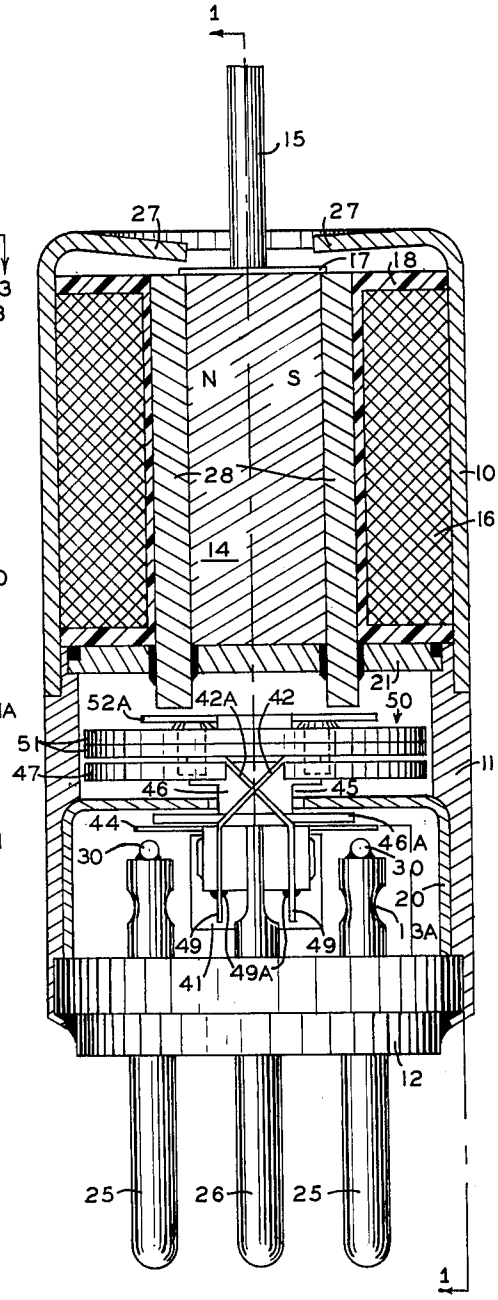



FIG 2

SUBMINIATURE POLARIZED ELECTRICALLY ACTUATED CONTACTOR

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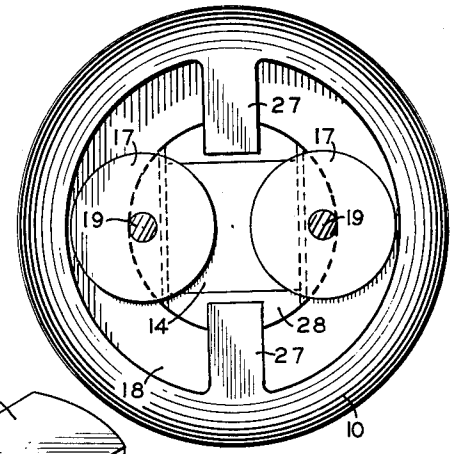



FIG. 3

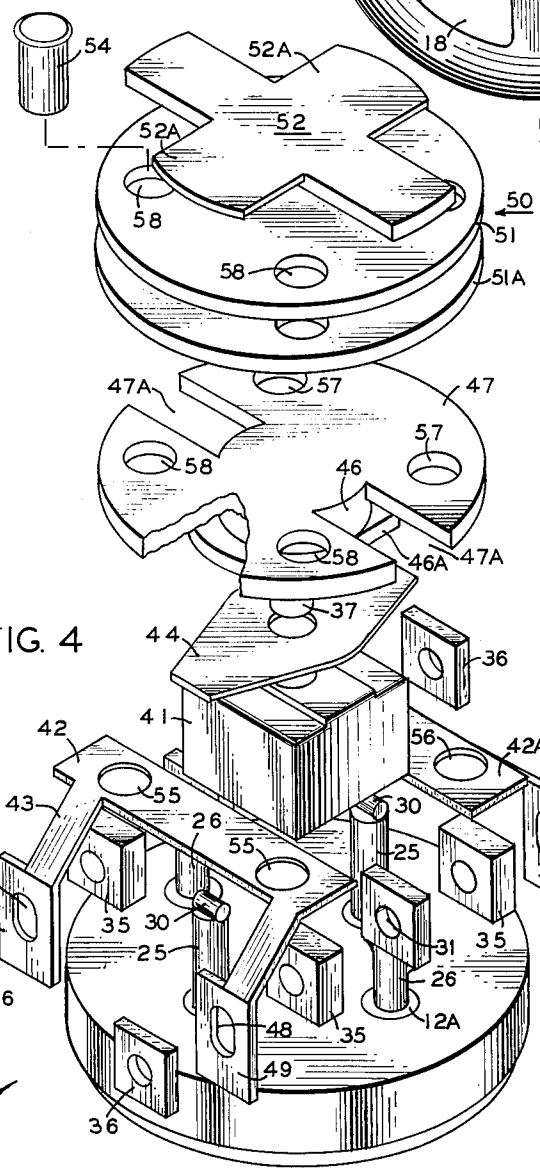



FIG. 4

FIG. 1

FIG. 2

SUBMINIATURE POLARIZED ELECTRICALLY ACTUATED CONTACTOR

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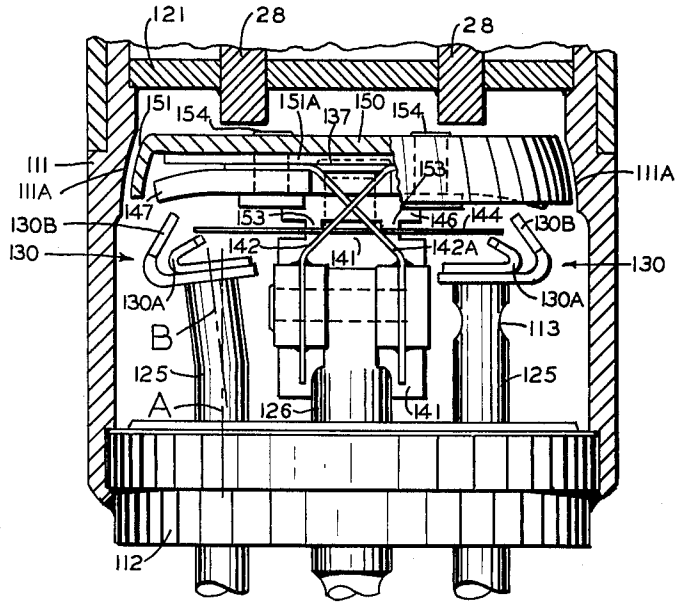



FIG. 5

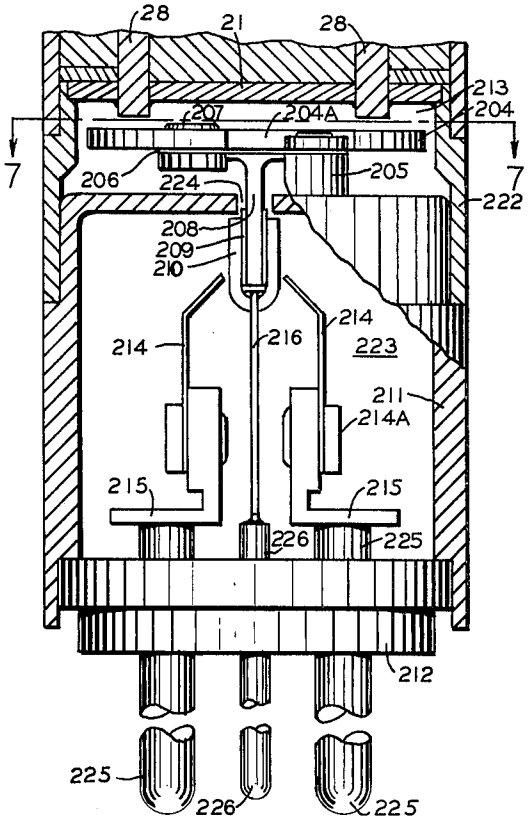



FIG. 6

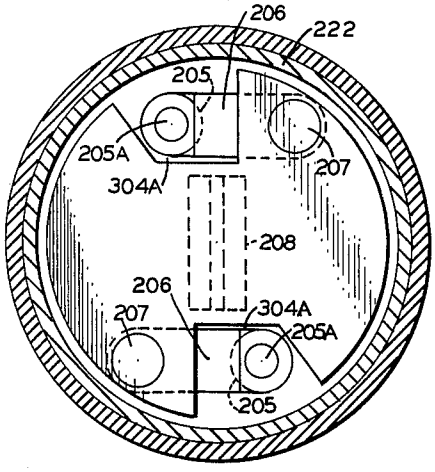



FIG. 7

SUBMINIATURE POLARIZED ELECTRICALLY ACTUATED CONTACTOR

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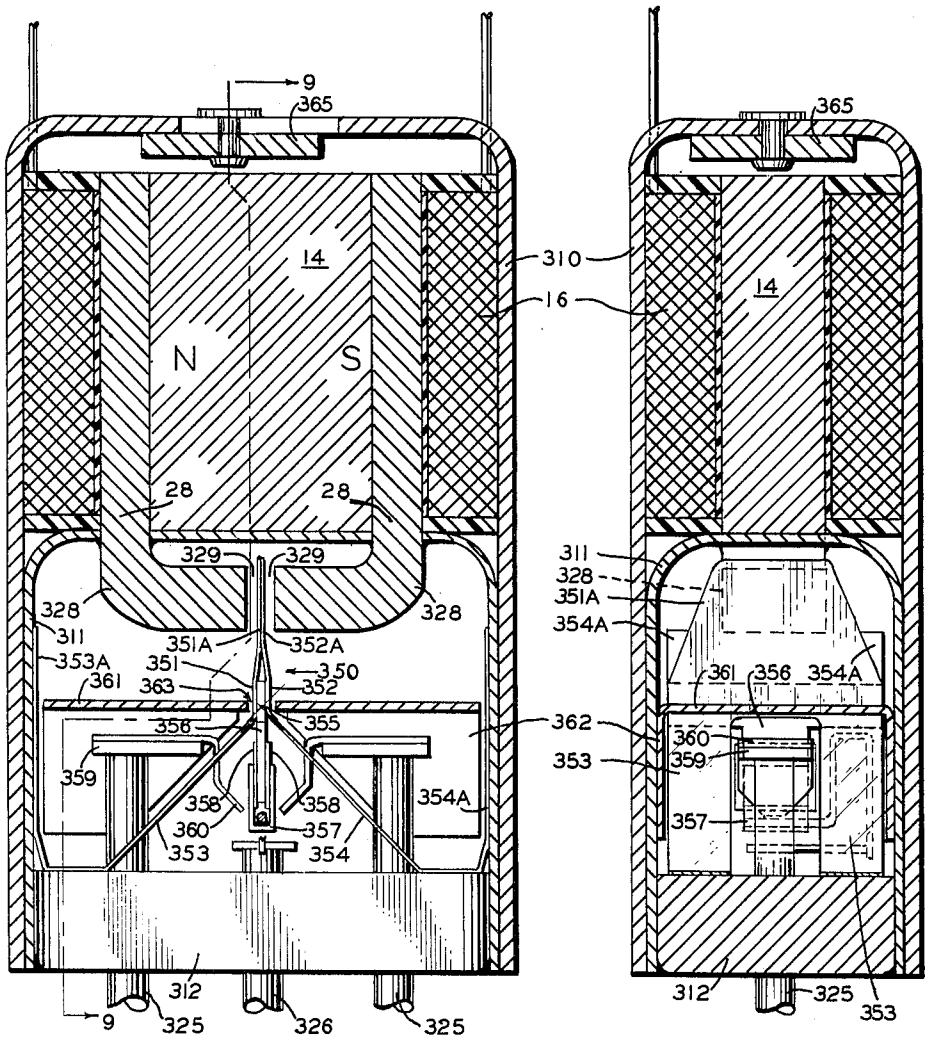



FIG. 8

FIG. 9

United States Patent Office 3,247,344 Patented Apr. 19, 1966



3,247,344

# SUBMINIATURE POLARIZED ELECTRICALLY ACTUATED CONTACTOR

John L. Russell, Waterbury, Conn., assignor to The Bristol Company, Waterbury, Conn., a corporation of Connecticut

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20 Claims. (Cl. 200—93)

This invention relates to electrically actuated contactors and, more especially, to a form of electromagnetic contactor known as a contact modulator, or "chopper," adapted for interrupting an electric circuit at a relatively high frequency in synchronism with an alternating driving current. As a class, these are commonly used for purposes of the measurement and control of very small electrical voltages or currents with a high degree of precision and reliability.

Present day development in the electronic art applied, for example, to missiles and rockets, has imposed stringent requirements on circuit modulation devices of this class. A complete electromagnetic, polarized chopper providing at least single-pole, double-throw contact action is required to occupy a volume of the order of one-tenth cubic inch overall. Furthermore, the device must operate over temperature ranges from about —65° C. to 125° C. and retain reliability in the presence of extreme shock and vibration of maximum values of the order of 30 G and frequencies up to 2000 cycles per second. Noise voltages generated internally in the contacts are required to be very low, in the order of microvolts, necessitating complete electrostatic and electromagnetic isolation of the driving coil from the contacts even though they must of necessity be in extremely close physical proximity due to the small overall size requirements.

Electromechanical choppers may be designed to depend on resonance or to be strictly non-resonant to the operating frequencies. The resonant chopper can advantageously store considerable energy in its moving system when operating at or near the resonant frequency. However, at true resonance, the ratio of total energy stored in the system to the energy dissipated per unit time or cycle of operation is high and operating characteristics such as phase relationships between the driving voltage and contact action, are found to be unstable. Any variation in the driving frequency or voltage or the temperature is likely to produce significant changes in operation. To stabilize the characteristics, the resonant type of chopper is commonly designed to operate at a frequency near, but not at, the resonant frequency and still make use of the enhanced contact motion at low excitation values inherent in this type of operation. A common arrangement of the system provides that the point of resonance is made only slightly above the span of operating frequencies thus accomplishing a definite amplification of the resultant motion of the armature through the storage of mechanical energy in the moving system while avoiding instability. Either the resonant or non-resonant mode of operation may be provided, within the principles of the invention set forth.

Of greatest practical importance is the factor of noise generated in the output circuits due mainly to electromagnetic coupling between contacts and exciting coil but also to electrostatic coupling. In view of the close physical proximity of these members imposed by the above spatial requirements, the desired isolation presents a problem of great difficulty, the solution of which is of great practical significance and value.

It is, thus, a principal object of this invention to provide a contacting device which may be manufactured in an extremely small and compact form, in which spurious



voltages are minimized and which is especially well suited for use in the measurement and control of extremely small voltages or currents.

It is a further object of the invention to provide a subminiature contacting device in which there is provided an effective electromagnetic and electrostatic shield for the contacts, thus minimizing induced noise effects in the output circuits.

It is another object of the invention to provide a subminiature contacting device adapted to hermetic sealing of the armature and contacts in which the driving coil and the permanent magnet are located outside the hermetic enclosure and in which there is provided means for ready adjustment after assembly, both before and after sealing.

It is a further object of the invention to provide a subminiature contacting device characterized by temperature stability, immunity from shock and vibration, and minimum of circuit noise particularly from internal effects.

It is a more sepecific object of the invention to provide such a device in which the armature forms an effective electromagnetic and electrostatic shield for the contacts.

It is another more specific object of this invention to provide a subminiature contacting device in which the armature, among other things, is closely magnetically coupled with the source of magnetic flux so as to provide a low reluctance return path for the magnetic flux to the source.

Further objects as well as advantages of this invention will be apparent from the following description of preferred embodiments thereof and the accompanying drawings, in which:

FIGURE 1 is a view showing in vertical elevation, partly in section, an electromagnetic chopper embodying the principles of the invention;

FIGURE 2 is a sectional view through the line 2—2 of FIGURE 1;

FIGURE 3 is an end view, partially in section, taken though the line 3—3 of FIGURE 1;

FIGURE 4 is an isometric exploded view of the armature and contact assembly of the embodiment of FIGURE 1;

FIGURE 5 is a sectional view, similar to FIGURE 2, of another embodiment of the invention, partially broken away for convenience;

FIGURE 6 is a sectional view of yet another embodiment of the invention;

FIGURE 7 is a sectional view through the line 7—7 of FIGURE 6;

FIGURE 8 is a sectional view of yet another embodiment of the present invention; and

FIGURE 9 is a sectional view through the line 9—9 of FIGURE 8.

Now, referring to FIGURES 1 to 4, inclusive, a conventional mounting base **12** bears a shell, or enclosure, formed in two sections, the lower section **11** which is hermetically sealed, and the upper section **10** in which, preferably, after assembly, the components may be fixed by encapsulating in a resin or cementing compound. Enclosure sections **10** and **11** are of ferromagnetic material and form a ferromagnetic shield, while base **12** may be formed of any suitable material for sealing thereto, nonmetallic or metallic including ferromagnetic or nonmagnetic material. In the present instance base **12** is preferably formed of nonmagnetic steel. The bottom edge of the lower enclosure **11** is rolled over the rim of base **12** and soldered in vacuum-tight relation thereto. At the upper end, the shell member **11** is provided with grooves, or rabbets, one to facilitate juncture with the upper shell section **10** and another to facilitate sealing with a barrier plate **21**.

Within the upper shell 10 is disposed centrally a rectangular permanent magnet 14 extending along the vertical axis of the contactor as viewed in FIGURES 1 and 2. This is formed of a magnetic material characterized by high coercive force. In this case, as will be seen, magnetic materials of the ceramic type are particularly useful in that the presence of such materials, because of their high electrical resistivity and low incremental permeability do not add significantly to the inductance of the associated driving coil. It has been found also that the alloy "Alnico" (trademark of the General Electric Company, Schenectady, New York) is satisfactory since it adds only a slight amount to the inductance of the coil. The magnet 14 is magnetized in a direction perpendicular to the vertical axis.

On opposite sides of the magnet 14 are placed high-permeability ferromagnetic polar members 28 having a D-shaped cross section the flat side of each being juxtaposed to a side of the magnet 14 as is most clearly shown in FIGURE 3. The polar members 28 extend the full length of opposite sides of the field magnet 14 and through and beyond a nonmagnetic, preferably metallic barrier plate 21 of high electrical conductivity to which they are brazed or soldered, as at 29.

An energizing coil 16, wound on a circular coil insulating form 18, snugly encloses the magnet 14 and polar structures 28 within the enclosing shell section 10. Two spaces formed between alternate faces of the magnet 14 and the interior surface of the coil form 18 accommodate two oppositely disposed terminals 15 to which are attached the connecting leads to the coil 16. Terminals 15 are insulated electrically from the permanent magnet by a layer of insulating material 19 and are provided with insulating washers 17, fixed thereto to prevent insertion far enough to make contact with plate 21.

The outer shell section 10 engages the coil 16 making good thermal contact therewith. This provides optimum transfer of Joulean heat from the winding to the exterior of the housing whence it may be readily dissipated. It may also be observed that a further thermal path is formed by the polar members 28 and the plate 21, both of which have good thermal conductivity, to the external housing. The soldering of the pole pieces to the plate provides a good thermal bond therebetween and further assists in eliminating temperature gradients within the device. Filling the upper shell with sealing compound after assembly also serves to improve thermal relationships as well as to rigidize the structure mechanically. The purpose of controlling thermal gradients by these means is, among other things, to prevent such gradients from affecting the contacting surfaces (yet to be described) so as to avoid thermoelectric voltages which if produced can contribute to unwanted spurious electromotive force, or "noise," in output circuits.

The lower enclosed space within the shell section 11 houses all moving parts, contacts, etc., and preferably contains no organic insulating materials. This novel arrangement thus provides for hermetically sealing of this space for complete evacuation or for gas-filling independent of the upper structure. The base 12 is of conventional construction and is formed of metal through which are sealed four symmetrically arranged lead-in pins 25, 25 and 26, 26. Glass 12A serves to insulate each of the terminal pins from the base 12. On the inside of the chamber, the two pins 25 are formed for direct mounting of fixed contacts 30 which take the form of short cylinders of a noble metal welded or soldered in place.

The terminal pins are preferably constructed of ductile metal for a purpose which will be more fully described hereinbelow and such brittle metals as molybdenum and tungsten are avoided. In the present instance, terminal pins 25 and 26 are similar and of solid construction formed from austenitic stainless steel to which the noble metal contact material 30 may be readily joined, as by welding. Among other things, such a construction has



the advantage of minimizing thermoelectric potentials which can contribute to disturbing electrical output circuit "noise."

The terminals 25 of the base member 12 function as mounting posts and are formed with mounting holes 31 to accommodate stacked mounting assemblies forming the support for the armature system. This may be seen conveniently in detail in FIGURE 4, together with parts of the armature proper. Washers 35 and 36 serve as spacers in locating two double-leaf flexure springs 42, 42A formed of thin, resilient metal. Each of the springs 42, 42A comprises a pair of elongated leaf members 43 angularly disposed relative to tabs 49 at one end thereof and a mounting plate at the other end thereof. It is to be noted that the leaf members 43 of spring 42 are offset from those of spring 42A. Mounting holes 55 and 56 are formed in the mounting plates of springs 42 and 42A, respectively. The tabs 49 have slotted holes 48 formed therein for adjustably mounting the same in the stack assembly which is held together and to the mounting posts by the rivets 32.

An armature 50 comprises three circular plates 51, 51A and 47, mounted with plates 51 and 51A above and plate 47 below the mounting plates of the springs 42, 42A. Soldered or welded to the surface of plate 51 presented toward the polar members 28, is a cross-shaped member 52 made of a ferromagnetic material of relatively high permeability and low coercive force. The arms 52A of the cross which are juxtaposed to the polar members 28 are thinner than the opposite arms of the cruciform member and are spaced a small distance from the plate 51 in order to allow bending for purposes of adjustment of air gaps with the polar members. The plates 51 and 51A together form a laminated structure and are also formed of ferromagnetic material. Plate 47 formed of electrically conductive and preferably non-magnetic material, has slots 47A formed therein to provide clearance for the leaf members 43. Mounting holes 57 and 58 are formed in the plates 47, 51 and 51A which register in turn with mounting holes 56 and 55 through all of which rivets 54 pass to rigidly clamp the spring mounting plates between armature plates 47 and 51A. With the parts assembled, the mutually inclined leaf members 43 of the springs 42, 42A cross as is most clearly shown in FIGURE 2. This flexure system, it may be noted, provides a center of rotation substantially at the center of gravity of the moving system.

The lower plate 47 has a central portion of increased thickness forming a hub 46 having a circular recess 45 and terminating in a thin annular flange 46A. The flange 46A is generally of prolate configuration having a wider diameter as viewed in FIGURE 2 than as viewed in FIGURE 1. Below the flange 46A, the hub 46 terminates in a centrally located rivet 37 by which contact plate 44 and a counterweight 41 are joined to the armature assembly which forms the moving system of the device.

In the present embodiment of the invention, intended for operation in the zone of near-resonance, the rather massive armature system is preferably provided with balancing force formed by the counterweight 41, in order to bring the center of gravity of the system substantially in coincidence with the center of rotation located below the plate 47 and above the washers 35. This provides balance against external vibration and shock. The counterweight 41 is a rectangular block dimensioned and disposed to meet the dynamic requirements of the system just described.

Electrical contact between the armature and the fixed contacts 30 is made through the contact plate 44 which is in the form of an elongated leaf spring and is held centrally clamped between the flange 46A and the counterweight 41, the contact plate 44 extending radially outward beyond flange 46A and counterweight 41 to preclude any undesired interference with the resilient cantilever portions of the contact spring 44. Under some conditions it

is possible to limit the amplitude of contact travel by bending downwardly the sides of flange 46A.

An inverted cup-shaped shielding member 20 of ferromagnetic material is positioned on base 12 in a recess formed in the interior of the shell section 11 which serves to lock it in place. The upwardly presented base of the cup-shaped shield member 20 is cut away forming a rectangular opening to provide access for the leaf members 43. The shielding member 20 is conveniently formed in two parts and after being assembled about the armature assembly these two parts are welded or soldered together.

The outer ferromagnetic shell section 11 has been mentioned as providing the enclosure for contacting and moving parts of the system. It also provides part of the return path of the operating flux and, as well, of preventing radiation of coil flux beyond the housing.

Other features of design and operation of my invention may be summarized with the note that they are of greatest significance in miniaturized devices of the type herein described, wherein the maximum efficiency in utilization of space is required.

In the embodiment of FIGURES 1–4, the fixed magnetic structure is circular in section and is maintained in a separate section which can be separately sealed as desired. The polar members are interposed between the permanent polarizing field and the energizing field and form for both the flux path to the armature. The armature space is likewise separate and this is sealed separately, preferably hermetic, since all organic insulation can be excluded. The polar members extend into this latter space and, thus, with the armature and the walls of the enclosure, they form complete flux paths.

In operation, terminals 15 of the coil 16 are connected to a suitable source of A.-C. current. The fixed contacts 30 may be connected to a source of low voltage which is to be measured or controlled while the movable contact 44 may be connected through terminals 26 to a utilization device. The movable armature assembly 50 oscillates at a frequency corresponding to that of the A.-C. source about a horizontal axis established by the flexure members 42, 42A. Thus the contact spring 44 is alternately brought into engagement with first one and then the other of the fixed contacts 30.

Essentially, the moving armature system may be considered the entire disc structure 50. It should be recognized that the appended cruciform tongue member 52 is for adjusting purposes only, as has been already noted. The armature is, thus, disposed at right angles to the axis of the coil. It coacts with the field poles to establish two separate air gaps which have a magnetic direction parallel with the axis of the coil. The field flux passing through these gaps, which are magnetically in series, is carried by the armature. The armature is extended radially to form a narrow air gap with the outer housing, forming a ferromagnetic shield, thus providing a low reluctance return for the coil flux. The opposite ends of the polar members terminate in further air gaps which are juxtaposed to the upper end of the housing 10. As shown in FIGURE 3, it is preferred not to fully close the ferromagnetic cover at this end but to leave a rolled-over edge thereof except for one or two tabs 27. This may then be employed as an adjustable reluctance introduced in the flux paths by the adjustable association of a tab with corresponding pole piece 28. This provides for final electromagnetic balancing of the system after assembly and, when accomplished, the adjustment is preserved by filling the open spaces of this upper assembly with a plastic sealing compound or encapsulating resin.

An important advantage of the contactor resides in the ease with which operational adjustments may be carried out. First, as mentioned above, the arms 52A of the cross-shaped member 52 can be bent slightly on assembly to adjust the air gaps between the armature and the pole pieces. Either or both of the springs 42, 42A may be shifted somewhat as is provided for by the elongated holes 48 formed in the mounting tabs 49, thereby shifting the orientation of the armature 50. After this adjustment, the positions may be fixed by soldering as indicated at 49A in FIGURE 2. Electrical connection to the contact spring 44 is provided by either or both of the terminal pins 26 through the flexure members 42, 42A and the plate 47. Furthermore, as mentioned above, some dissymmetry in the magnetic paths may be introduced by the tabs 27 (see FIGURE 3) formed in the top of the upper housing 10. Contact spacing may be adjusted within small limits by squeezing, as with pliers, the terminal members as at 13A (FIGURE 2), between the fixed terminals and the mountings. This treatment effectively elongates this portion of the terminal and tends to close the space between fixed and movable contacts.

Another embodiment of the invention will now be described in connection with FIGURE 5 where there is shown the movable armature assembly 150 which extends transverse to the vertical axis, and the contact structure within the hermetically sealed enclosure defined by the base 112, the separator plate 121, and the cylindrical enclosure 111. Above the plate 121, the present enbodiment is the same as that described in connection with FIGURES 1–4 and is, thus, not shown in FIGURE 5.

The movable armature 150 comprises a ferromagnetic outer member 151 which as viewed appears as an inverted dish-shaped member in which a plate 151A, and a clamping plate 147 are positioned and retained by rivets 154. The plate 151A is provided when it is desired to add to the weight of the moving system and, hence, to affect its resonant characteristics. Preferably, plate 151A is formed of high electrical conductivity metal to inhibit noise in the output members by reducing potentials due to eddy currents in the armature structure. The flexure pivot members 142, 142A are similar to the spring members 42 and 42A and are held clamped between the plates 151A and 147 as in the first-mentioned embodiment, and the structure is rigidly joined by the rivets 154. The outer ferromagnetic member 151, exposed to the influence of the juxtaposed polar members 28, as hereinbefore described in connection with the previous embodiment, has its depending circular skirt portion covering the other portions of the armature structure. The portion 111A of the wall of the enclosure 111 adjacent to the armature skirt portion is conformed to the curvature of this skirt portion and both are spherically curved about a point lying on the axis of rotation of the moving parts. Thus, the path of magnetic flux across the air gap formed therebetween is reduced to a practical minimum and held constant in length and effective area as the armature 150 moves.

Dependent from the clamp plate 147 and preferably formed integrally therewith is a central hub 146. The downwardly presented surface of the hub 146 is formed with a pair of parallel lands 153 against which an elongated contact spring 144 is clamped by a counterweight 141 secured by an axially extending rivet 137. The upper face of the counterweight 141 is formed with a land 141A registering with lands 153 and by their engagement with the opposite surfaces of the contact spring 144 serve to limit and definitely determine the points of flexure of the two resilient arm portions of the cantilever contact spring 144.

The terminal pins 126 bear the flexure members 142, 142A for the armature structure as in the previously described embodiment. Terminal pins 125 have welded thereto the fixed contact assemblies 130 which are formed of precious metal. These latter contacts, as shown, comprise two U-shaped members 130A and 130B, members 130A extending within the latter and having free ends which engage resiliently with the opposite end portions of the movable contact 144. The free ends of the larger members 130B are positioned to engage the adjacent portion of the plate 147, forming the base of the armature assembly, and thereby limit the travel of the armature.

An important feature of this invention is the facilities provided for making essential adjustments during assembly. The adjustment of contact spacing has already been described by means of squeezing one or the other or both of the terminal pins within the housing as indicated by the deformed area 113. A further important means for adjustment is provided by bending one or more of the terminal pins 125 as shown in FIGURE 5. By means of pliers, or a suitable tool, the terminal pin may be bent away from the vertical but in the plane common to the axes of both fixed and movable contacts. Thus, after being bent, the axis B of one of the terminal pins 125 deviates from the vertical axis A. The effect of such a shift in the fixed contact is to change the effective spring rate of the juxtaposed cantilever portion of the movable contact spring 144 and, thereby, balance the effects of the two coacting pairs of contacts.

A still further adjustment is provided for limiting overtravel of the armature 150 especially during resonant operation. The projections of the members 130B extend toward the plate 147 of the armature assembly which is curved cylindrically adjacent each of the members 130B about points which coincide respectively with the points about which the pins 125 are bent to shift their axes.

In the further embodiment of the invention shown illustratively in FIGURES 6 and 7, the structure above the barrier plate 21 is preferably the same as that previously described in connection with FIGURES 1 and 2 and is not shown in FIGURE 6.

The enclosure below plate 21 is preferably formed of two ferromagnetic parts 211, 222 for hermetic sealing. Member 211 is cup-shaped and closed at its open end by a base member 212 through which are insulatively sealed terminal pins 225, 226, for connection to external circuit elements. Enclosure member 222 is in the form of a spacer ring having one end hermetically sealed to the lower enclosure member 211 about the closed end of the latter. The other end of the member 222 is hermetically sealed by the barrier plate 21 through which the polar members 28 extend and are sealed. Thus, the enclosure member 222 together with the barrier plate 21 and the end wall of the closure member 211 forms a chamber 213 which communicates with a chamber 223 enclosed by the member 211 through a small centrally located opening 224 formed in the end wall of member 211.

The armature consists of the flat plate 204 which may be generally circular in shape. Recesses 204A formed by cutting away portions of the plate 204, are provided at opposite sides of this plate. Flat resilient metal flexure pivots 206 are fastened at one end thereof by rivets 207 to the armature plate adjacent to each of the recesses 204A and extend perpendicular to a diameter of the plate 204 adjacent the respective recesses 204A. At their opposite ends, the pivots 206 are each secured by a rivet 205A and a spacer 205 to the upper surface of the enclosure member 211. Depending from the armature plate 204 is a tongue member 208 which extends downwardly through the small aperture 224 into the space defined by the lower enclosure 211. This tongue may advantageously be formed of non-electrically-conductive material, such as, for example, ceramic, and bears at its lower end a contacting member 210 which is usually formed of a precious metal suitable for electrical contacts. The contact member 210 is fastened to the tongue by cementing or by soldering to an intermediate plated layer 209 formed on the tongue 208. Electrical connection between the terminal pin 226 and the contact 210 is conveniently made through a wire 216 which may be double-looped to present minimum restraint on the moving armature system. The tongue 208 may be joined to the armature plate by conventional means, as, for example, in the case of a tongue member 208 formed of ceramic, by soldering to a metallized portion of the surface of the ceramic body.

The fixed contacts are shown illustratively as juxtaposed to the movable armature contact 210 and on opposite sides thereof. Each, as shown in FIGURE 6, comprises a bracket portion 215 mounted directly on a terminal pin 225 to which is fastened, as by rivet 214A, a resilient contact portion 214. Means similar to those provided in the previous embodiments, though not shown in detail, may be utilized to effect adjustment for contact spacing, resonance of the moving system, etc.

It may be observed that in this embodiment of my invention the magnetic circuit elements have been effectively isolated from the internal electrical circuit elements by the almost complete separation of the two enclosed spaces. One advantage of this is the achieving of minimum noise in the output circuits without dependence on extremely small air gaps in the magnetic circuit path between armature and adjacent enclosure walls as in the hereinbefore described embodiments.

Important advantages of the present invention are also attained when, as will now be described in connection with the embodiment shown in FIGURES 8 and 9, the movable armature extends in a transverse gap formed by the oppositely presented tips of the polar members. Turning to FIGURES 8 and 9, the structure above the hermetically sealed enclosure is preferably similar to that described in connection with FIGURES 1 and 2 but has a rectangular rather than circular configuration. In the present embodiment, enclosure 311 corresponds in general to the enclosure formed by the barrier plate 21 and enclosure section 11 of FIGURE 1 and like the latter is sealed by base 312, here rectangular, through which the pins 325 and 326 are insulatively sealed. In the present instance, enclosure 311 is formed of nonmagnetic material such as glass or metal as shown through which the polar members 28 are sealed and is enclosed by the ferromagnetic shield or enclosure 310. For economy of space, both the enclosure 311 and the shield 310 are generally rectangular in cross section. Within the enclosure 311, the polar members 28 terminate in pole tips 328 which are turned inward to form a transverse main operating gap 329 in which the free end of the armature 350 extends. In effect, each of the pole tips 328 forms a gap 329 with a side of the armature but, unlike the operating gaps in the hereinbefore described embodiments, the present operating gaps are formed with opposite sides of the armature.

The armature 350 comprises a pair of ferromagnetic, resilient metallic members 351 and 352 joined to form a Y-shaped assembly and mounted inverted so that the extensions 351A and 352A thereof extend upward into the gap 329. The free ends of the armature extensions 351A and 352A are welded together at their upper ends. The central portions 351 and 352 of the armature are bent away from each other and are bifurcated so that they each terminate in a pair of downwardly sloping spaced arms 353 and 354, respectively. The arms 353 extend down to and along the base 312 to which they are anchored by welding, soldering, or a suitable cement, as when base 312 is of glass, on opposite sides of one of the pins 325. In addition, the arms 353 each have relatively large area portions 353A thereof which extend back up along the interior surface of the enclosure 311 so as to provide minimum reluctance for magnetic flux return paths to the outer enclosure 310. Similarly, the downwardly extending spaced arms 354 are anchored to the base 312 and have large area portions 354A juxtaposed through the wall of the enclosure 311 with the outer enclosure 310.

The center of rotation of the free end of the armature structure is effectively located about an axis 355 at the intersection of the planes in which the sloping arms 353 and 354 extend. The center of gravity of the moving parts is also located in this axis 355. A non-magnetic metallic arm 356 is positioned with its upper end engaged between the lower portions of the armature legs 351 and 352, welds being formed parallel to the axis 355 to permanently unite the three members. Contact member 357 is fastened to the arm 356, insulation 358 provid-

ing the necessary electrical isolation between the arm **356** and the contact **357**.

The fixed contacts are shown juxtaposed to the movable armature contact **357** and on opposite sides thereof. Each, as shown, comprises a mounting portion **359** mounted directly on a terminal pin **325** and to which is secured a resilient contact portion **360**.

Because the polar members have their tip portions **328** extending in relatively close spaced relation with the contact structures and the output current-carrying pins **325**, preferably a shield **361** formed of ferromagnetic material is positioned so as to extend transversely substantially entirely across the enclosure **311** between the pole tips **328** and the contacts **360**. The shield **361** has large area, depending tabs **362** which extend close to the interior surface of the enclosure **311** so as to provide minimum reluctance for flux return paths to the outer housing **310**. The shield **361** is also formed with a central elongated slot **363** formed therein through which the armature assembly **350** extends.

Assembly and adjustment of the present embodiment will be apparent from the embodiments previously described. Here, as most clearly shown in FIGURE 8, the ferromagnetic shield **310** is closed at its upper end and, instead of the adjusting tabs **27** (FIGURES 1 and 2), there is provided a ferromagnetic plate **365** slidably mounted on the interior of the shell **310** opposite the ends of the pole pieces **28**. The plate **365** is slid laterally relative to the ends of the pole pieces **28** for adjusting to a desired value the relative magnetic reluctance between the ends of the polar members **28** and the ferromagnetic shell **310**. When properly positioned, the plate **365** is fixed in place preferably by welding. As in the case of the adjustment of the tabs **27**, this adjustment is carried out to introduce a counterbalancing degree of dissymmetry to the end that symmetrical contact action is provided.

An important advantage of the embodiment described in connection with FIGURES 8 and 9, flows from the unique armature assembly in conjunction with the ferromagnetic shell which together complete the magnetic flux return path of the magnetic circuit.

The inverted Y-shaped armature **350** facilitates provision of a statically balanced armature having a rigid, controlled center or axis about which the movable portion thereof rotates but yet which is extremely light in weight. The folded back arms **353A** and **354A** which present large areas for magnetic coupling with the outer ferromagnetic shell **310** provide for magnetically tying the armature back to the shell **310** whereby to facilitate provision of as close a magnetic coupling as desired in the flux return path between the armature and the source of magnetic flux. This is important in achieving minimization of internally induced noise in the contact circuits particularly in such extremely small choppers as described herein.

The bifurcated armature members **351**, **352** significantly contribute to the attainment of a compact structure. On the other hand, to achieve more perfect magnetic shielding of the contact assemblies, the members **351** and **352** are not bifurcated but are solid, with the armature structure extending unbroken and interposed between the contact assemblies and the sources of magnetomotive force, thereby providing with the outer magnetic shield virtually complete magnetic shielding for the contact assemblies.

It is evident that the present invention is susceptible to wide variation without departing from the spirit thereof and the appended claims. For example, in the interest of some reduction in overall weight, the ferromagnetic outer shell such as the enclosure **310** may be reduced to an inverted U-shaped strap extending aligned with the polar members **28** and the armature arms **353A** and **354A** for magnetic shielding. The adjusting plate **365** may be attached thereto in the same manner as illustrated in FIGURE 8 in connection with the shell **310**.

The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed.

I claim:

**1.** An electrically actuated contactor, comprising a ferromagnetic shield, means for producing a variable magnetomotive force including a coil within said shield, ferromagnetic polar members extending in said coil substantially parallel with the magnetic axis thereof, permanent magnetic field producing means in said shield and having opposite polar surfaces engaging respective ones of said polar members, a movable ferromagnetic armature forming operating magnetic gaps with said polar members, the mutually remote portions of said armature and said polar members forming low reluctance gaps with said shield, said shield closely magnetically coupling said mutually remote portions of said armature and said polar members and forming therebetween a return path for the operating flux of said coil and permanent magnetic field producing means, means supporting said armature for movement relative to said polar members whereby movement of said armature relative to said polar members changes the relative magnetic reluctance of said operating gaps, said armature having a ferromagnetic portion thereof extending transversely in said shield with said coil and said permanent magnetic field producing means on one side thereof, and contact means actuated by said armature and on the side thereof away from said coil and permanent magnetic field producing means.

**2.** An electrically actuated contactor, comprising a ferromagnetic shield, means for producing a variable magnetomotive force including a coil within said shield, ferromagnetic polar members extending in said coil substantially parallel with the magnetic axis thereof, permanent magnetic field producing means in said shield and having opposite polar surfaces engaging respective ones of said polar members, a movable ferromagnetic armature forming operating magnetic gaps with said polar members, the mutually remote portions of said armature and said polar members forming low reluctance gaps with said shield, said shield closely magnetically coupling said mutually remote portions of said armature and said polar members and forming therebetween a return path for the operating flux of said coil and permanent magnetic field producing means, means for adjusting the relative magnetic reluctance between said remote portions of said polar members and said shield, means supporting said armature for movement relative to said polar members whereby movement of said armature relative to said polar members changes the relative magnetic reluctance of said operating gaps, said armature having a ferromagnetic portion thereof extending transversely in said shield with said coil and said permanent magnetic field producing means on one side thereof, and contact means actuated by said armature and on the side thereof away from said coil and permanent magnetic field producing means.

**3.** An electrically actuated contactor as set forth in claim **2** wherein said adjusting means comprises said ferromagnetic shield being formed with an externally accessible pair of readily deformable tab portions, one for each of said polar members and extending adjacent to the portions thereof remote from said armature.

**4.** An electrically actuated contactor as set forth in claim **2** wherein said adjusting means comprises said ferromagnetic shield being formed with an aperture adjacent to the portions of said polar members remote from said armature, a ferromagnetic plate, and means movably

supporting said plate in said aperture for selectively positioning the same relative to said portions of said polar members.

5. An electrically actuated contactor, comprising a ferromagnetic enclosure, means for producing a variable magnetomotive force including a coil within said enclosure, ferromagnetic polar members extending through said coil substantially parallel with the magnetic axis thereof, permanent magnetic field producing means in said enclosure having opposite polar surfaces engaging respective ones of said polar members, said polar members having one end thereof forming low reluctance magnetic gaps with said enclosure, a ferromagnetic armature extending entirely outside said coil and forming magnetic operating gaps with the other ends of said polar members, means including further ferromagnetic portions of said armature extending transversely in said ferromagnetic enclosure with said coil and said permanent magnetic field producing means on one side thereof, said further ferromagnetic portions of said armature supporting the same for movement relative to said other ends of said polar members whereby movement of said armature relative to said polar members changes the relative magnetic reluctance of said operating gaps, said further ferromagnetic portions of said armature being fixed and in close magnetically coupled relation with said enclosure, said enclosure closely magnetically coupling said portions of said armature and said one end of said polar members and forming therebetween a return path for the operating flux of said coil and permanent magnetic field-producing means and contact means actuated by said armature and on the side thereof away from said coil and permanent magnetic field producing means.

6. An electrically actuated contactor, comprising a ferromagnetic shield, means for producing a variable magnetomotive force including a coil within said shield, means in said coil for producing a unidirectional magnetic field, ferromagnetic polar members extending along opposite sides of said unidirectional magnetic field producing means between the latter and said coil, a movable ferromagnetic armature extending adjacent to one end of said coil and said unidirectional magnetic field producing means, said polar members forming operating magnetic gaps with said armature, the mutually remote portions of said armature and said polar members forming low reluctance gaps with said shield, said shield closely magnetically coupling said mutually remote portions of said armature and said polar members and forming therebetween a return path for the operating flux of said coil and permanent magnetic field producing means, means supporting said armature for movement relative to said polar members whereby movement of the armature changes the relative magnetic reluctance of said operating gaps, contact means actuated by said armature, a sealed enclosure surrounding said armature and said contact means and interposed between the same and said coil and unidirectional magnetic field producing means, and said polar members extending sealed through the wall of said enclosure.

7. An electrically actuated contacting device, comprising a ferromagnetic enclosure, an electrical shielding member extending in and across said enclosure, means for producing a variable magnetomotive force including a coil within said enclosure and on one side of said shielding member, permanent magnetic field producing means extending within said coil and having its magnetic axis oriented normal to the magnetic axis of said coil, a pair of ferromagnetic polar members extending within said coil in engagement with the opposite polar surfaces of said permanent magnetic field producing means between the latter and said coil, a movable ferromagnetic armature on the other side of said shielding member, said polar members each having one end thereof forming low reluctance gaps with said enclosure, the other ends of said polar members extending through said shield member and forming operating magnetic gaps with said armature, said armature having portions thereof in close magnetically coupled relation with said enclosure, said enclosure closely magnetically coupling said armature and said polar members and forming therebetween a return path for the operating flux of said coil and permanent magnetic field producing means, means supporting said armature for movement relative to said polar members whereby movement of the armature changes the relative magnetic reluctance of said operating gaps, and contact means actuated by said armature.

8. An electrically actuated contacting device, comprising an hermetic enclosure having an end wall closing one end thereof, an armature extending transversely in said enclosure, means outside of said enclosure for applying a constant magnetic field and a variable magnetomotive force to said armature and including low reluctance polar means sealed through said end wall and extending in close spaced relation to and forming operating magnetic gaps with one side of said armature, said enclosure having a ferromagnetic portion thereof extending adjacent to said armature, means for supporting said armature for movement about an axis extending substantially parallel to said end wall, and contact means on the other side of said armature and controlled thereby.

9. An electrically actuated contacting device, comprising means for producing a substantially constant magnetic field, elongated low reluctance polar members juxtaposed to the opposite sides of said constant magnetic field producing means, means for producing a variable magnetomotive force including a winding surrounding said polar members and said constant magnetic field producing means with the latter extending along the axis of said winding, the axis of magnetization of said constant magnetic field producing means extending substantially normal to the axis of said winding, a shield member extending transversely to the axis of said winding adjacent to one end thereof, an armature member extending substantially parallel to and on the side of said shield member away from said winding and constant magnetic field producing means, said armature member having a ferromagnetic portion forming the side thereof presented toward said shield member and a nonmagnetic, electrically conductive portion extending along said ferromagnetic portion on the side thereof away from said shield member, said polar members extending through said shield member into close spaced relation with the ferromagnetic side of said armature member, means supporting said armature member for movement relative to said polar members, and contact means on the nonmagnetic side of said armature member and controlled thereby.

10. An electrically actuated contacting device, comprising a tubular ferromagnetic enclosure, an electrically conductive member extending transversely in said enclosure, a base sealing one end of said tubular enclosure and forming therewith and with said conductive member an hermetically sealed compartment in said enclosure, means for producing a substantially constant magnetic field in said enclosure on the side of said conductive member external to said compartment, a pair of elongated low reluctance polar members one positioned adjacent to each of the oppositely polarized sides of said constant magnetic field producing means, means for producing a variable magnetomotive force including a winding surrounding said polar members and said constant magnetic field producing means with the latter extending along the axis of said winding, said polar members extending substantially parallel to the axis of said winding, an annular plate-like armature member extending transversely of said enclosure in said compartment with its periphery in close spaced relation with the inwardly presented surface of said enclosure, said polar members being sealed through said conductive member and extending into said compartment in close spaced relation with the side of said armature member presented toward said conductive member, a cup-

shaped magnetic shield member in said compartment on the other side of said armature member and having an aperture formed in the base thereof presented toward said armature member, a movable contact member, means connected to said armature member extending through said aperture and supporting said movable contact member within said cup-shaped shield member, a pair of fixed contacts positioned adjacent to said movable contact member, and resilient means supporting said armature for movement relative to said polar members.

11. An electrically actuated contacting device, comprising a generally cylindrical ferromagnetic enclosure open at one end thereof, a base sealing the other end of said enclosure, an electrically conductive member extending transversely in said enclosure spaced from the ends thereof and forming with said enclosure and said base a hermetically sealed compartment in said enclosure, means for producing a constant magnetic field axially disposed in said enclosure on the side of said conductive member toward said open end and with its axis of magnetization extending normal to the axis of said enclosure, a pair of elongated low reluctance polar members one positioned adjacent to each of the oppositely polarized sides of said constant magnetic field producing means, means for producing a variable magnetomotive force including a winding within and coaxial with said enclosure, said winding surrounding said polar members and said constant magnetic field producing means, said enclosure being formed with readily deformable tab portions extending in the open end thereof one adjacent to each of said polar members, a circular armature extending transversely in said compartment with its peripheral surface in close spaced relation with a portion of the interior surface of said enclosure, said armature comprising at least one ferromagnetic member and a nonmagnetic electrically conductive member all interconnected in stacked relation with said nonmagnetic member presented toward said base and said one ferromagnetic member presented toward said first mentioned conductive member, said polar members being sealed through said first mentioned conductive member and extending into said compartment with each of said polar members extending into close spaced relation with said one ferromagnetic member, means supporting said armature for movement about an axis extending substantially normal to the axis of said enclosure within said compartment, said supporting means including a pair of resilient support members each connected at one end thereof to said armature and at the other end thereof to said base, said armature having a central portion thereof extending axially toward said base, an elongated contact member carried by said armature and extending substantially normal to the axis of said enclosure, a pair of lead-in members sealed through said base and extending into said compartment adjacent to said contact member, a pair of fixed contacts one mounted on the end of each of said lead-in members, and a second pair of lead-in members sealed through said base and connected to said resilient support members.

12. An electrically actuated contacting device, comprising a generally cylindrical ferromagnetic enclosure open at one end thereof, a base sealing the other end of said enclosure, an electrically conductive member extending transversely in said enclosure spaced from the ends thereof and forming with said enclosure and said base hermetically sealed compartment in said enclosure, means for producing a constant magnetic field axially disposed in said enclosure on the side of said conductive member toward said open end and with its axis of magnetization extending normal to the axis of said enclosure, a pair of elongated low reluctance polar members one positioned adjacent to each of the oppositely polarized sides of said constant magnetic field producing means, means for producing a variable magnetomotive force including a winding within and coaxial with said enclosure, said winding surrounding said polar members and said constant magnetic field producing means, said enclosure being formed with readily deformable tab portions extending in the open end thereof one adjacent to each of said polar members, a circular armature extending transversely in said compartment with its peripheral surface in close spaced relation with a portion of the interior surface of said enclosure, said armature comprising at least one ferromagnetic member and a nonmagnetic electrically conductive member all interconnected in stacked relation with said nonmagnetic member presented toward said base and said ferromagnetic member presented toward said first mentioned conductive member, said polar members being sealed through said first mentioned conductive member and extending into said compartment with each of said polar members extending into close spaced relation with said one ferromagnetic member, means supporting said armature for movement about an axis extending substantially normal to the axis of said enclosure within said compartment, said supporting means including a pair of resilient support members each connected at one end thereof to said armature and at the other end thereof to said base, said armature having a central portion thereof extending axially toward said base, an elongated contact member carried by said armature and extending substantially normal to the axis of said enclosure, a pair of lead-in members sealed through said base and extending into said compartment adjacent to and with the transverse ends thereof presented toward said contact member, a pair of fixed contacts one mounted on said transverse end of each of said lead-in members, said lead-ins being readily deformable so as to elongate when subjected to transverse compressive forces whereby to shift the fixed contact carried thereby toward said elongated contact member, and a second pair of lead-in members sealed through said base and connected to said resilient support members.

13. An electrically actuated contacting device, comprising a substantially cylindrical hermetic enclosure having a substantially planar nonmagnetic electrically conductive end wall at one end thereof, a substantially circular armature extending transversely in said enclosure substantially parallel to and spaced from said end wall, means outside said enclosure for applying a substantially constant magnetic field and a variable magnetomotive force to said armature and including a pair of low reluctance polar members sealed through said end wall and extending into close spaced relation with one side of said armature and forming operating magnetic gaps therewith, a cup-shaped magnetic shield member in said enclosure coaxial therewith on the other side of said armature and having its base presented toward said armature, the base of said cup-shaped shield member having a central aperture formed therethrough, said armature member having a central extension thereof extending along the axis of said enclosure through said aperture into said cup-shaped shield member, an elongated contact supported on said extension in said cup-shaped member, a pair of fixed contacts supported within said enclosure and juxtaposed to the opposite sides of said elongated contact, and resilient means connected to the base of said cup-shaped member and supporting said armature for movement relative to said polar members.

14. In an electrically actuated contacting device, having an enclosure, an armature, means for impressing a variable magnetomotive force and a substantially constant magnetic field upon said armature, first and second contacts, said first contact being movably mounted for engagement with said second contact in accordance with the direction in which said armature is displaced, a lead-in pin extending into said enclosure and having an end portion thereof presented toward the said first contact, means connecting said second contact to said end portion of said lead-in, and said lead-in being readily deformable under transverse compressive forces so as to

elongate and shift the position of said second contact toward said first contact.

15. In an electrically actuated contacting device, a substantially disk-shaped armature, means for impressing a variable magnetomotive force and a substantially constant magnetic field upon said armature and including a pair of polar members extending into close spaced relation with one side of said armature, means supporting said armature for movement relative to said polar members about an axis extending normal to a plane which extends through and substantially parallel with both of said polar members, and ferromagnetic means extending in close spaced relation with the periphery of said armature and being conformed to form a gap therewith such that the distance across the gap remains substantially constant as said armature moves relative to said polar members.

16. An electrically actuated contacting device, comprising a ferromagnetic enclosure, means for producing a variable magnetomotive force including a coil within said enclosure, a pair of spaced elongated ferromagnetic polar members extending through said coil substantially parallel with the magnetic axis thereof, permanent magnetic field producing means positioned in said coil with opposite polar surfaces thereof engaging respective ones of said polar members, said polar members extending beyond one end of said coil into confronting relation and forming a magnetic gap therebetween, an armature having a resilient flexible ferromagnetic portion thereof extending in operative relation with said gap and having ferromagnetic portions thereof extending transversely in said enclosure with said coil and said permanent magnetic field producing means on one side thereof, ferromagnetic portions of said armature remote from said gap being in fixed magnetically close coupled relation with said enclosure, means supporting said armature for movement relative to said gap, and contact means actuated by said armature and on the side thereof away from said coil and permanent magnetic field producing means.

17. An electrically actuated contacting device, comprising a ferromagnetic enclosure, an electrostatic shield extending transversely in said enclosure, means for producing a variable magnetomotive force including a coil within said enclosure on one side of said shield, a pair of ferromagnetic polar members extending in spaced relation through said coil substantially parallel with the magnetic axis thereof, permanent magnetic field producing means having opposite polar surfaces engaging respective ones of said polar members, an armature on the other side of said shield and having a resilient flexible ferromagnetic portion thereof extending toward said shield, said polar members extending through said shield into confronting relation with opposite sides of said portion of said armature and forming operating gaps therewith, ferromagnetic portions of said armature remote from said gap extending in fixed close magnetically coupled relation with said enclosure, means supporting said armature for movement relative to said operating gaps, and contact means actuated by said armature.

18. An electrically actuated contacting device, comprising a ferromagnetic enclosure, an hermetic enclosure having a nonmagnetic electrically conductive wall portion thereof extending transversely in said ferromagnetic enclosure, means for producing a variable magnetomotive force including a coil within said ferromagnetic enclosure and outside said wall portion, a pair of ferromagnetic polar members extending in spaced relation through said coil substantially parallel with the magnetic axis thereof, permanent magnetic field producing means in said coil between said polar members and having opposite polar surfaces engaging respective ones of said polar members, a magnetic shield extending transversely in said hermetic enclosure spaced from said wall portion and having an aperture formed therethrough, an inverted resilient Y-shaped ferromagnetic armature in said hermetic enclosure having a ferromagnetic leg portion thereof extending through said aperture toward said wall portion, the arms of said armature connecting the same to said hermetic enclosure on the side of said magnetic shield away from said wall portion, said armature arms extending in close magnetically coupled relation with said ferromagnetic enclosure, said polar members extending sealed through said wall portion into confronting relation with opposite sides of said armature leg portion and forming operating gaps therewith, and contact means in said hermetic enclosure on said side of said magnetic shield and actuated by said armature.

19. In an electrically actuated contacting device, an armature, means for impressing a variable magnetomotive force upon said armature, means for producing a substantially constant magnetic field and including low reluctance polar members having portions thereof forming a gap in operating relation with said armature, a first contact mounted adjacent to said armature, a resilient second contact having a free end and movably mounted for engagement with said first contact in accordance with the direction in which said armature is displaced, means supporting said armature for displacement relative to said gap, and means for adjusting the spring rate of said resilient second contact including means for shifting the position of said first contact relative to the free end of said second contact.

20. In an electrically actuated contacting device, an armature, means for impressing a variable magnetomotive force upon said armature, means for producing a substantially constant magnetic field and including low reluctance polar members having portions thereof forming a gap in operating relation with said armature, a first contact mounted adjacent to said armature, a resilient second contact carried by said armature and having a free end portion thereof extending toward said first contact for engagement with the latter in accordance with the direction in which said armature is displaced, means supporting said armature for displacement relative to said gap, and means for adjusting the spring rate of said resilient second contact including means for shifting the position of said first contact relative to the free end of said second contact.

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ROBERT K. SCHAEFER, *Acting Primary Examiner.*

BERNARD A. GILHEANY, *Examiner.*