

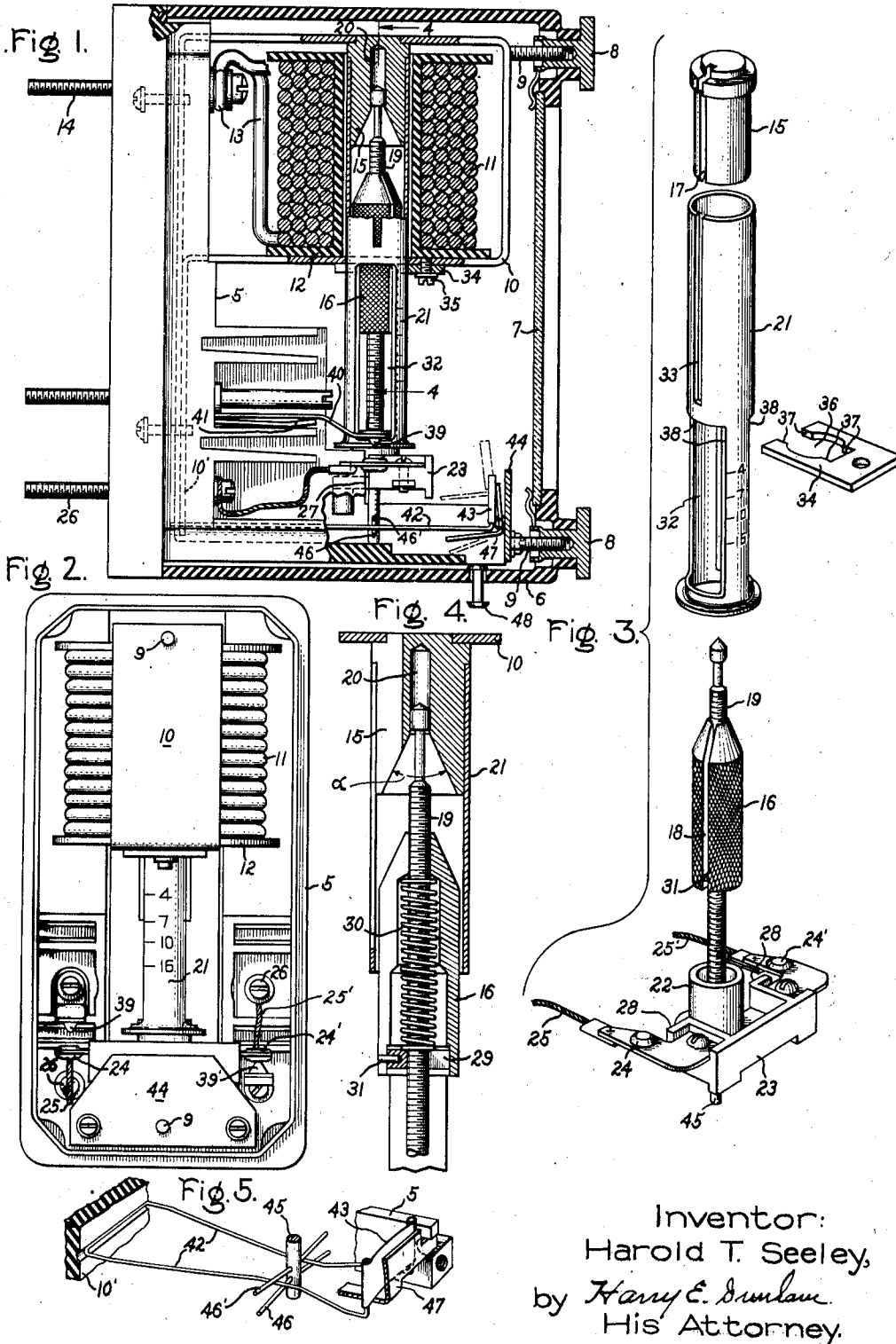
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ELECTRORESPONSIVE DEVICE

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ELECTRORESPONSIVE DEVICE

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My invention relates to improvements in electroresponsive devices and particularly relays having armatures of the plunger type so mounted that they can be set to be actuated in response to different predetermined values of an electric quantity, such as current or voltage, especially for protecting electric systems on the occurrences of abnormal or faulty conditions.

In high-speed protective relays having armatures of the plunger type and responding merely to overcurrent or undervoltage, when used as fault detectors in protective arrangements of the carrier-current pilot or direct-current pilot-wire type, the ratio between dropout and pickup currents should be as near unity as possible in order quickly to restore the normal protective setup on sound-line sections after the clearing of an external fault. Also, in such relays, the ratio of dropout to pickup should be constant throughout a given calibrating range. Moreover, it is desirable that the contact travel should be the maximum possible consistent with such constancy of ratio to obtain better contact operation. Incidentally, the longer the length of contact travel, the greater is the length of the scale for a given calibrating range and, therefore, the less crowded are the scale graduations. With constancy of the dropout-pickup ratio, the calibrating scale has a logarithmic characteristic such as to insure the same percentage of accuracy for all settings in a given calibrating range. This is important in consequence of the finite width of the calibrating marks and the error in setting or adjusting the armature to any particular mark. From the standpoint of relay burden on the current and potential transformers, it is also important that in the attracted position of the armature at the minimum pickup setting, the magnetic circuit be as nearly closed as possible in order to minimize the necessary coil input for a given total weight of moving parts. Further important factors are facility and simplicity of adjustment as well as permanence of the calibration for each setting or pickup position so that shocks or jars may not disturb the adjustment. For fineness of adjustment, it is also desirable that the adjustment be of a continuous character instead of a step-by-step variation.

An object of my invention is to provide an improved fast acting and relatively low burden relay which has a plunger type of armature and in which the ratio between the dropout and pickup currents is nearly unity and substantially constant throughout the calibrating range of the pickup values. Another object of my invention

is to provide a relay structure whose armature adjustment for different pickup currents is stepless, relatively simple, and quickly made, and is, moreover, not likely to be disturbed by shocks, jars, and the like. A further object of my invention is to provide an easily assembled armature mounting which insures that nicety of alignment between armature and pole piece necessary to maintain the desired operating characteristic of the relay. These and other objects of my invention will hereinafter appear in more detail.

My invention will be better understood from the following description when considered in connection with the accompanying sheet of drawings, and its scope will be pointed out in the appended claims.

In the accompanying sheet of drawings, Fig. 1 is a vertical elevation partly in section of an electromagnetic device embodying my invention. Fig. 2 is a front elevation of the embodiment of my invention shown in Fig. 1. Fig. 3 illustrates in perspective certain elements of the armature mounting of the embodiment of my invention shown in Fig. 1; Fig. 4 is a section, to an enlarged scale, on the line 4—4 of Fig. 1, and Fig. 5 is a perspective view of a target and reset feature which may be used in relays embodying my invention.

In the illustrated embodiment of my invention, I have shown a relay comprising a base 5 and a cover 6, both of which may be of molded insulating material as shown. The cover is provided with a suitable window 7 of transparent material such as glass. As illustrated, the cover 6 is secured to the base 5 by thumb screws 8 which are rotatably mounted in the cover and are engageable with screws 9 mounted on the base structure. Secured to the base 5 is an electromagnet comprising a closed rectangularly shaped frame 10 of magnetic material in which is mounted a solenoid or energizing coil 11. As shown, this coil is wound on a suitable form, such as a spool 12 and is provided with leads 13 connected to suitable studs 14, which are mounted in the base 5 and only one of which appears in Fig. 1. The magnetic structure further includes a pole piece 15 which extends from the upper side of the frame 10 into the opening of the solenoid 11. Cooperating with the pole piece 15 is a plunger armature 16 which extends through the opposite or lower side of the frame 10 into the solenoid 11. As illustrated, the armature 16 is of the shell or hollow type, and both the pole piece 15 and the armature 16 are provided with slits 17 and 18

respectively in order to minimize eddy current heating.

In order to maintain that nicety of alignment between the axes of the pole piece 15 and the armature 16 necessary in carrying out my invention, I mount the armature on a movable rod 19 of non-magnetic material, which extends through the armature into a central bore 20 in the pole piece 15. Further, to maintain the alignment of the plunger in all positions I provide a guiding member such as a tube 21 of non-magnetic material, which is concentric with the pole piece and embraces as much of the length of the pole piece 15 as is conveniently possible. In order to hold the rod 19 in the desired axial alignment, I provide suitable means for guiding the lower end of the rod. As shown, this means comprises a cylindrical hub 22 whose diameter is such as to insure a sliding engagement with the tube 21 throughout the travel of the armature 16 between the attracted and unattracted positions. The cylindrical hub 22 may be molded directly onto the rod 19. Moreover, as illustrated, the cylindrical hub 22 comprises a part of a contact carrying member 23, which may also be of molded insulating material and on which are mounted the movable contacts 24 and 24'. Associated with these movable contacts 24 are leads 25 and 25', the former of which extends to a stud 26 as shown in Fig. 1. In order to prevent rotation of the contact carrier 23 and the rod 19 which is rigidly associated therewith, suitable means such as shouldered portions 27 are provided on the base 5 to oppose faces 28 on the contact carrier 23.

In order to control the response of the armature 16 or the pickup thereof for different currents, the upper end of the armature is in threaded engagement with the rod 19 as shown. Further, in order to simplify adjustment of the pickup, I provide means for yieldingly restraining the armature 16 against rotation relatively to the rod 19 such that the adjustment may be made solely with the fingers without the necessity for any tools and without danger that the adjustment will be disturbed by shocks, jars, and the like. As shown, this means comprises a nut 29 in threaded engagement with the rod 19 adjacent the lower end of the armature 16. Between the upper face of this nut and the upper inside portion of the armature 16 and around rod 19, as shown, is a spring 30 which in the structural arrangement illustrated is a compression spring assembled under such stress as to prevent any likelihood of the rotation of the armature under shocks, jars, etc., and yet allowing forced rotation of the armature by grasping with the fingers and turning.

In order to prevent relative rotation of the nut 29 and the armature 16, I provide means which, as shown, comprises a projection such as a pin 31 on the nut 29 extending into the slit 18 of the armature. In order that the armature may be readily grasped with the fingers, the tube 21 is suitably apertured, as at 32, on opposite sides of the plunger. These apertures together with a slit 33 in the upper end of the tube 21 help to minimize eddy currents in the tube. To help maintain the tube 21 in place and prevent any possibility of rotation of the tube, I provide the clamping plate 34 which is secured to the lower side of the frame 10 by suitable means such as a screw 35. The large opening 36 in this plate, shown more clearly in Fig. 3, has a circular portion of a diameter substantially equal to the in-

ner diameter of the tube 21. And consequently, the shouldered portions 37 of the opening adjacent the arcuate portions thereof about the cut-out edges 38 of the tube 21 and positively hold it against turning. In addition to its guiding function, the tube 21 further carries on one of its cylindrical segments adjacent the window portions calibration marks according to which the armature 16 may be adjusted for different pickup values of current in or voltage on the solenoid 11.

For completing the control of circuits by the movement of the contacts 24 and 24', there are provided cooperating relatively stationary contacts 39 and 39' which may be resiliently mounted on the base 5 as on leaf spring members 40 so as to provide a wiping action and which are provided with stop members 41. As shown more clearly in Fig. 2, the contacts 24 and 39 are circuit closing contacts and the contacts 24' and 39' are circuit opening contacts.

In order to have an indication of the operation of the relay, there may be provided a cradle mechanism shown in the form of a wire frame 42, which is pivoted in a groove in the base 5 in back of a vertical extension 10' of the armature frame 10 at the lower rear corner of the base 5, as shown more clearly in perspective in Fig. 5. The cradle 42 carries a suitably colored target 43, which in the released or unattracted position of the armature lies behind a plate 44 at the front of the relay. As shown, the cradle 42 is actuated by movement of the armature through an extension 45 of the rod 19, which carries a transverse pin 46 above which the arms of the cradle are positioned. When the cradle 42 is lifted by the attraction of the armature from the full line position shown in Fig. 1 to the dotted line position, a latch 47 pivotally supported in notches in the base 5 at the front of the relay turns counterclockwise under the front end of the cradle 42 to hold the cradle in the dotted line position shown in Fig. 1. If it is desired to have the armature and contacts hand-reset instead of self-resetting, the rod extension 45 may be provided with an upper transverse pin 46' just above the cradle 42. Then when this cradle is held up by the latch 47, the armature 16 will not return to the unattracted position. When this target and armature holdup arrangement is provided, I mount in the cover 6 a releasing member such as a pin 48, the upward movement of which turns the latch 47 clockwise from under the target end of the cradle 42 so as to permit the cradle and armature to fall.

In certain applications of fault responsive relays in protective systems, it is absolutely necessary in order to avoid false operation especially after clearing a fault, that the relays drop out on current or pick up on voltage values approximately the same as the pickup current value or the dropout voltage value. This problem is particularly difficult in relays such as those of the plunger armature type wherein the effect of a varying air gap is present not only in armature movement under attractive effects but also in the pickup adjustment. Moreover, constancy of the ratio between dropout and pickup values throughout the calibrating range together with the greatest possible travel of the moving contacts is desirable. In accordance with my invention, I am able to obtain in relays of the type illustrated herein a ratio of dropout to pickup as high as 0.92 throughout the calibrating range of the relay together with the desired contact travel.

In order to accomplish this, I form the inner end of the pole piece 15 in the shape of a hollow cone and provide the upper end of the armature 16 with a conical tip substantially conforming to the shape of the inner end of the pole piece 15, as shown more clearly in Figs. 1 and 4. Although, because of structural limitations, the conical portions are actually frustra of cones, it is important that the diameter of the smaller end of the conical portions be as small as possible. Then in accordance with my invention, I so correlate the slope of the conical surfaces of the pole piece and plunger tip and the length of the pole piece within the magnetic frame 10 that the ratio of dropout to pickup is substantially constant for all settings within the pickup calibrating range of the plunger 16. I shall hereinafter refer to the slope of the hollow conical face of the pole piece 15 and the conical tip of the plunger 16 as the coning angle by which I mean the angle at the vertex of the cone between two diametrically opposite elements of the conical surface or with reference to Fig. 4, the angle α .

In one embodiment of my invention, in a current relay for a dropout current equal to 90 per cent of the pickup current for all settings of the armature 16 within the calibrating range I have found that with a frame depth of $1\frac{1}{8}$ inches between the inner faces of the top and bottom portions of the frame 10 and the pole piece 15 projecting downward from the inner face of the top portion of the frame $1\frac{1}{16}$ inch, the value of the coning angle is 40° .

In another embodiment of my invention, in a current responsive relay designed for hand reset operation of the contacts as well as the target, the percentage of dropout is of course of itself unimportant because the relay is not self-resetting, but the target lift and latch requirement is such that the pull must be sufficient to deflect the stationary contact spring 40 and clear the latch 47 of the target and hand reset feature heretofore described, at the same value of current which starts the armature moving. Thus, in order to keep the ratio between the force in the picked-up position and the force in the dropped-out position above the critical value determined by the above consideration and yet avoid unnecessary crowding of the calibrating scale, this ratio must be kept at a substantially constant value near the critical value. This constant value which is higher than that required for the 90 per cent dropout form previously described can be obtained, I have found, by the use of a coning angle of 70 degrees, and a pole piece projection of $3\frac{1}{32}$ inch into the frame 10 with the frame depth $1\frac{1}{8}$ inches as before.

Another embodiment of my invention is designed as a voltage relay that is for operation with a shunt coil instead of a series coil. The operation is such as to permit the coil current to decrease as the reactance increases due to the armature 16 rising within the solenoid 11. This raises the percentage of dropout above the value obtained with a series coil in the same magnetic structure. In order to avoid floating action which would result in operation of the normally open contacts 24 and 39 and the normally closed contacts 24' and 39' at different voltage values and in gradual closure of the contacts, I have found that an increase of the coning angle from 40° to 50° , a pole piece length of $29\frac{1}{32}$ inch and a frame depth of $1\frac{1}{8}$ inches gives the desired con-

stancy of ratio between the pickup and dropout values.

In consequence of the constancy of the ratio between the dropout and pickup values throughout the calibrating range in devices embodying my invention, the calibrating scale becomes logarithmic. This has the advantage that with a given total scale length all settings within a given calibrating range may be made with the same percentage of accuracy regardless of the finite width of the calibrating marks and the error in setting the armature to the mark.

Since commercial or market requirements provide certain considerations which have to be met in connection with carrying out my invention so as to obtain the desired results, I will summarize these as an aid to a better understanding of my invention along with certain technical features. For example, the overall height of the relay is determined on the basis of market requirements. This height comprises the case thickness plus clearance at top and bottom, the length of the magnetic frame 1 (slightly more than the coil length), the minimum extension of the plunger which will permit turning it, the calibrating scale, the contact arms, and target structure. The frame length plus the minimum armature extension plus the calibrating scale is fixed by the above considerations, and it is clear that the frame length should be about half of this total. If the frame is too short, the top or upper end of the armature will too soon pass out of the hole in the bottom of the frame and, therefore, out of the range of approximately logarithmic response since the lowest position of the armature for a logarithmic calibrating scale is limited by the fact that the pull on the armature decreases rapidly after the tip of the armature begins to pass out through the hole in the bottom of the frame. If the frame is too long, the remaining space available for a calibrating scale will be less than that over which a logarithmic scale could be obtained with an armature of length appropriate to the frame length. It is, of course, assumed in all cases that the coil length is as great as the frame length will permit, since any lesser length decreases the current carrying capacity of the coil and also the length of the logarithmic scale.

Another consideration in the design is that in the picked-up position at the minimum pickup setting the magnetic circuit should be as nearly closed as possible in order to make the necessary coil input as low as possible for a given total weight of moving parts. This is contrary to the usual practice in high dropout relays which have usually provided a certain minimum air gap between the armature and the pole piece for no other reason than to maintain the high dropout which is desired in order to avoid the over-current relay being held up by load current after removal of a fault by the action of some other circuit breaker than the one controlled by this relay. The fact that the least gap requires the least input follows from the fact that the pull necessary for pickup requires a certain total flux and, therefore, a certain voltage, and the necessary magnetizing current is proportional to the necessary flux and also to the reluctance of the magnetic circuit. Since the total input is the product of the volts and the amperes, the minimum input for a given force is obtained with the minimum gap. It is for this reason that the constant ratio of dropout to pickup, which results in the logarithmic

calibrating scale, is extended to zero gap by proper selection of the coning angle and other features in accordance with my invention. This requirement of using the least possible gap in the upper plunger position requires using the same angle of coning for both the armature and the pole piece so as to avoid flux concentration at the tip or the rim as the two parts approach each other.

The usual proportions of coil yield an approximately logarithmic scale distribution over the lower part of the calibrating scale without special design. Inasmuch as text books on magnets show how different shapes of winding sections effect the resulting pull curves, no details on that part of the problem need be given here. Lower and upper as here used refer to relative position of the armature and not to relative pickup settings. However, in accordance with my invention, I control the top portion of the curve which depends on pole piece position and coning angle. Thus in order further to clarify the problem, it is here pointed out that the distribution in the lower part of the scale is determined almost entirely by the relation between the field strength H at a given point on the axis of the coil and the distance of this point from the end of the coil, but that the distribution in the upper part of the scale is determined largely by the coning angle irrespective of the distribution of field strength H . The maximum pickup is infinite and the minimum pickup is practically independent of pole piece position as long as the pole piece does not extend completely through the coil. Accordingly, the total calibrating range in amperes is only slightly affected by pole piece position. Therefore, the longer the pole piece for a given length of coil and frame the more crowded the calibrating scale. Consequently, it is desirable to make the pole piece as short as possible. If a long pole piece is used, a coning angle can be found such that a curve of plunger position plotted on a linear scale against amperes to pickup plotted on a logarithmic scale will be practically a straight line so that the calibrating scale will be logarithmic. If the curve near zero gap is too nearly parallel to the axis of plunger position, the coning is too steep for this pole piece position. If the curve near zero gap is too nearly parallel with the axis of amperes to pickup, the coning is too flat. If a shorter pole piece is used, a steeper coning angle can be found by similar methods which will give a new longer scale, which is also logarithmic over about the same range of current, although the current values will all be slightly higher. If the pole piece is chosen too short in an attempt to extend the scale still further, it will be found that the scale will depart from logarithmic distribution in a short range between the zone where the distribution is logarithmic by reason of the usual relation between plunger position and field strength H and the zone where the distribution is determined by the coning angle. Such a pole piece is too short, and the scale length corresponding to it cannot be obtained with logarithmic distribution unless the coil and frame lengths are increased.

When the minimum usable pole piece length for a given coil and frame has been determined as the dividing line between the zones described in the preceding paragraph, the armature location for maximum pickup is thereby fixed and it is immediately evident whether or not there is space available for using a longer armature.

If this can be done and if a longer calibrating scale is desired, this condition can be approached more closely by increasing the lengths of the pole piece, coil, frame, armature, and coned portion of the armature and pole piece, all in the same proportion. As a check a subsequent test should be made and the results plotted on semi-logarithmic paper to check the correctness of the new coning angle.

Successful use of the steep coning angles found necessary in accordance with my invention requires accurate and rigid restraint to maintain the tip of the armature cone concentric with that of the pole piece and to maintain the axes of the armature 16 and the pole piece 15 in alignment. As will be obvious from the description of my invention herein, the feature of concentricity is obtained by having the tip of the armature 16 threaded onto the rod 19, which is in turn guided in the central bore 20 of the pole piece. The alignment of the pole piece and the armature is insured by having the calibrating tube 21 surround the pole piece through as much of the length thereof as possible, by guiding the lower end of the plunger rod in the same calibrating tube, and by using at the lower end of the hollow armature 13 the round nut 29 to hold the end of the armature concentric with the plunger rod.

While I have shown and described my invention in considerable detail, I do not desire to be limited to the exact arrangements shown, but seek to cover in the appended claims all those modifications that fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An electromagnetic device comprising a solenoid, a pole piece at one end of the opening of said solenoid, a tubular member rigidly positioned within the opening of said solenoid and projecting from the other end of the opening, a linearly movable element positioned within said tubular member and having one end slidably engaging said pole piece, a plunger armature rotatably mounted on said element within said tubular member, a linearly movable member rigidly secured to the other end of said element and having a portion in slidable engagement with said tubular member, means for preventing rotation of said linearly movable member, and means for yieldingly restraining said armature against rotation relatively to said linearly movable element.

2. An electromagnetic device comprising a solenoid, a pole piece extending into the opening of said solenoid at one end thereof and provided with a central bore, a cooperating hollow plunger armature, a movable threaded rod extending through said armature into the bore of said pole piece and in threaded engagement with the end of the armature adjacent the pole piece, a nut within said armature adjacent the other end thereof and in threaded engagement with said rod, interlocking means on said armature and said nut for preventing relative rotation thereof, stressed resilient means within said armature between said nut and the end of the armature adjacent said pole piece, and means for preventing rotation of said rod.

3. An electromagnetic device comprising a solenoid, a pole piece extending into the opening of said solenoid at one end thereof and provided with a central bore, a cooperating hollow plunger armature, a movable rod extending through said armature into the bore of said pole piece in

threaded engagement with the end of the armature adjacent the pole piece, a nut within said armature adjacent the other end thereof and in threaded engagement with said rod, means for preventing relative rotation of said nut and said armature, means within said armature between said nut and the end of the armature adjacent the pole piece for yieldingly restraining said armature against rotation relatively to said rod, and means for preventing rotation of said rod.

4. An electromagnetic circuit controlling device comprising a solenoid, a pole piece extending into the opening of said solenoid at one end thereof, an apertured cylindrical calibrating tube rigidly positioned within the opening of said solenoid and projecting from the other end of the opening therein, a linearly movable threaded rod positioned within said tube and having one end slidably engaging said pole piece, a plunger armature rotatably mounted on said rod within said tube, a contact carrier rigidly secured to the other end of said rod and having a cylindrical portion in slidable engagement with said tube, a contact mounted on said carrier, a relatively stationary contact mounted in the path of movement of the contact on said carrier and engageable thereby upon actuation of said armature, means for preventing rotation of said contact carrier, and yielding means for restraining said armature against rotation relatively to said rod.

5. An electromagnetic device comprising a solenoid, a pole piece extending into the opening of said solenoid at one end thereof and provided with a central bore, a cooperating hollow plunger armature provided with a longitudinal slot, a movable threaded rod extending through said armature into the bore of said pole piece and in threaded engagement with the end of the armature adjacent the pole piece, a nut within said armature adjacent the other end thereof and in threaded engagement with said rod, a projection on said nut engaging the slot in said armature to prevent relative rotation of the nut and the armature, a stressed compression spring around said rod within said armature between said nut and the end of the armature adjacent said pole piece, and means for preventing rotation of said rod.

6. An electromagnet comprising a frame of magnetic material, a solenoid positioned in said frame, a pole piece extending from one side of said frame into the opening of said solenoid, the end of said pole piece within said solenoid having a hollow conical form, a plunger of magnetic material extending through the opposite side of said frame into the opening of said solenoid and having a conical tip substantially conforming to the shape of the inner end of said pole piece, means for varying the position of the plunger relatively to the pole piece to change the value of the current necessary to pick up the plunger, the slope of the conical surfaces of said pole piece and plunger tip relatively to the axis of the solenoid and the position of the inner end of the pole piece relatively to the opposite side of said frame being so correlated that the pickup-dropout ratio is substantially constant for all settings within a pickup calibrating range including a minimum setting which results in substantially zero air gap in the attracted position of the plunger.

7. An electromagnet comprising a frame of magnetic material, a solenoid positioned in said frame, a pole piece extending from one side of said frame into the opening of said solenoid, the end of said pole piece within said solenoid having

a hollow conical form, a movable element positioned within the opening of said solenoid, means guiding said element for translatory movement substantially in line with the axis of the conical portion of the pole piece, a plunger of magnetic material mounted on said element so as to extend through the opposite side of said frame into the opening of said solenoid and having a conical tip substantially conforming to the shape of the inner end of said pole piece, means adapted to be operated to vary the position of the plunger relatively to the position of the pole piece whereby to change the value of the current necessary to pick up the plunger, the coning angle of the pole piece and plunger and the length of the pole piece relatively to the depth of the frame being so proportioned as to provide a substantially constant pickup-dropout ratio for all settings within a pickup calibrating range including a minimum setting which results in substantially zero air gap in the attracted position of the armature.

8. An electromagnet comprising a frame of magnetic material, a solenoid positioned in said frame, a pole piece extending from one side of said frame into the opening of said solenoid, the end of said pole piece within said solenoid having a hollow conical form, a movable element positioned within the opening of said solenoid, means guiding said element for translatory movement substantially in line with the axis of the conical portion of the pole piece, a plunger of magnetic material rotatably mounted on said element so as to extend through the opposite side of said frame into the opening of said solenoid and having a conical tip substantially conforming to the shape of the inner end of said pole piece, means for yieldingly restraining said armature against rotation relatively to said element adapted to be operated manually to vary the position of the plunger relatively to the position of the pole piece whereby to change the value of the current necessary to pick up the plunger, the coning angle of the pole piece and plunger and the ratio of the length of the pole piece to the depth of the frame being so correlated that the pickup-dropout ratio is substantially constant for all settings within the pickup calibrating range including a minimum setting which results in substantially zero air gap in the attracted position of the plunger.

9. An electromagnetic device comprising a solenoid, a pole piece extending into the opening of said solenoid at one end thereof, the end of the pole piece within said solenoid having a hollow conical form, a plunger of magnetic material extending into the opening of the solenoid at the other end and having a conical tip substantially conforming to the shape of the inner end of said pole piece, and means for positively maintaining the axis of the plunger in alignment with the axis of the pole piece comprising a movable member extending through and adjustably supporting the plunger and means for guiding both ends of said member whereby to effect movement thereof in substantially the same straight line whenever the plunger is actuated from the unattracted to the attracted position and vice versa.

10. An electromagnetic device comprising a solenoid, a pole piece extending into the opening of said solenoid at one end thereof, the end of the pole piece within said solenoid having a hollow conical form, a plunger of magnetic material extending into the opening of the solenoid at the other end and having a conical tip substantially conforming to the shape of the inner end of said pole piece, and means for positively maintaining

the axis of the plunger in alignment with the axis of the pole piece comprising a movable member extending through and adjustably supporting said plunger and having one end in slidable engagement with said pole piece, a tubular member extending into said solenoid and embracing said pole piece, and means on the other end of said movable member slidably engaging the outer end of said tubular member.

11. An electromagnetic device comprising a solenoid, a pole piece extending into the opening of said solenoid at one end thereof, the end of the pole piece within said solenoid having a hollow conical form, a plunger of magnetic material extending into the opening of the solenoid at the other end and having a conical tip substantially conforming to the shape of the inner end of said pole piece, and means for positively maintaining the axis of the plunger in alignment with the axis of the pole piece comprising a movable member having one end in slidable engagement with said pole piece, a tubular member extending into said solenoid and embracing said pole piece, and means on the other end of said rod slidably engaging the outer end of said tubular member, and means for preventing rotation of the slidably engaging means on said rod.

12. An electromagnetic circuit controlling de-

vice comprising a frame of magnetic material, a solenoid positioned in said frame, a pole piece extending from one side of said frame into the opening of said solenoid, the end of said pole piece within said solenoid having a hollow conical form, an apertured cylindrical calibrating tube rigidly positioned within the opening of said solenoid and projecting from the other end of the opening therein, a linearly movable threaded rod positioned within said tube and having one end slidably engaging said pole piece, a plunger armature rotatably mounted on said rod within said tube and having the end toward the pole piece in the form of a conical tip with substantially the same coning angle as the end of the pole piece within the solenoid, a contact carrier rigidly secured to the other end of said rod and having a cylindrical portion in slidable engagement with said tube, a contact mounted on said carrier, a relatively stationary contact mounted in the path of movement of the contact on said carrier and engageable thereby upon actuation of said armature, means for preventing rotation of said contact carrier, and yielding means for restraining said armature against rotation relatively to said rod.

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