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SWITCH HAVING AN IMPROVED CONTACT ARRANGEMENT

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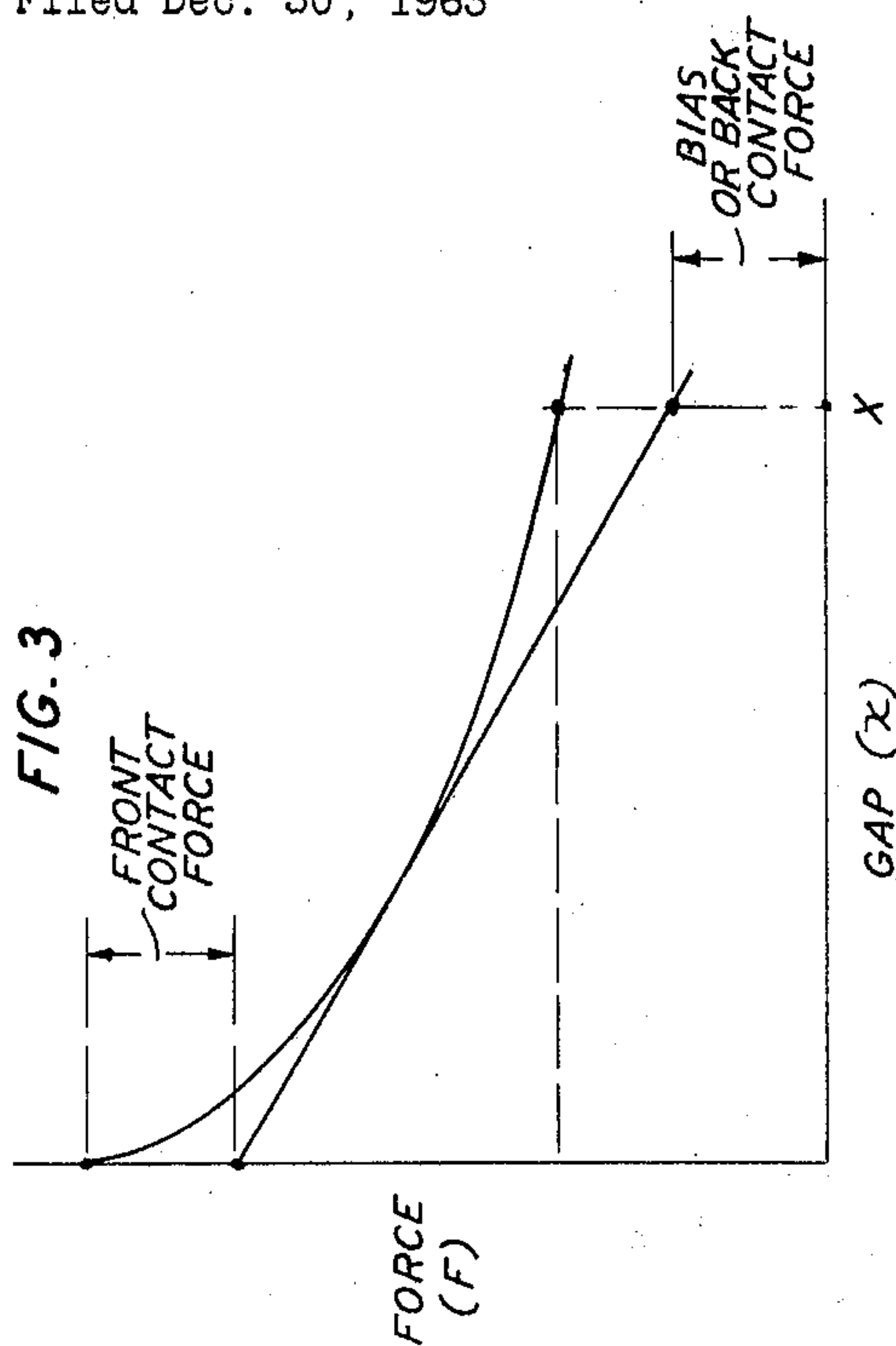
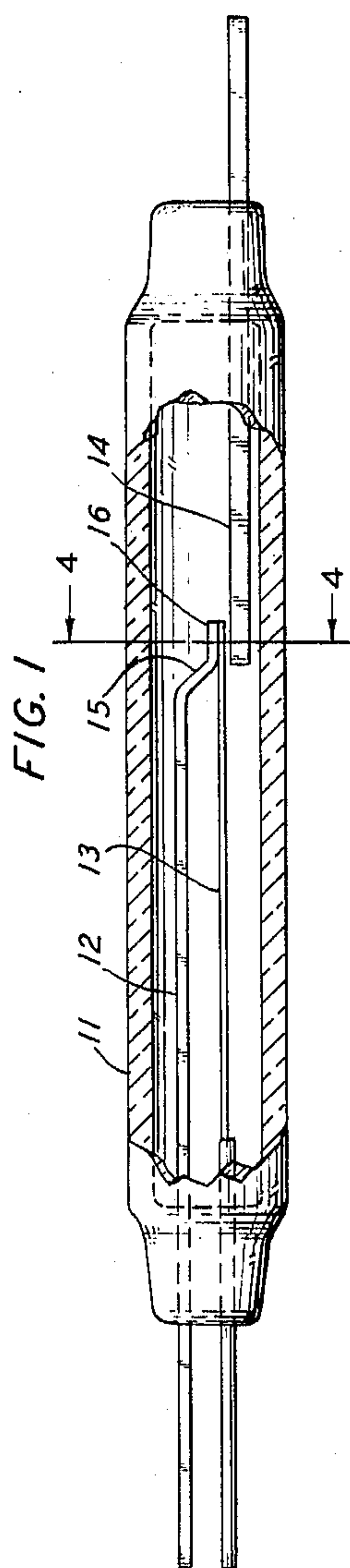


FIG. 4

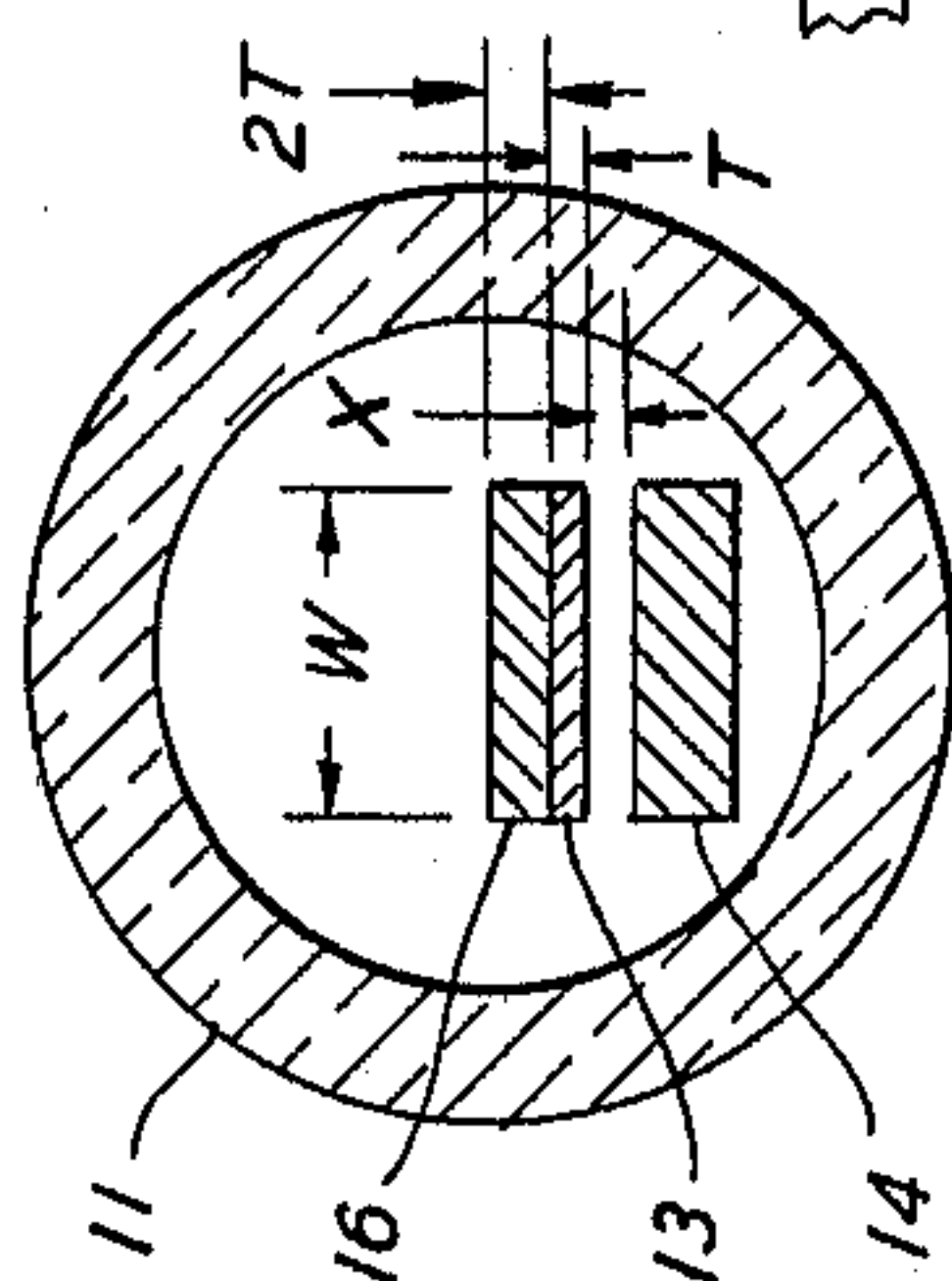
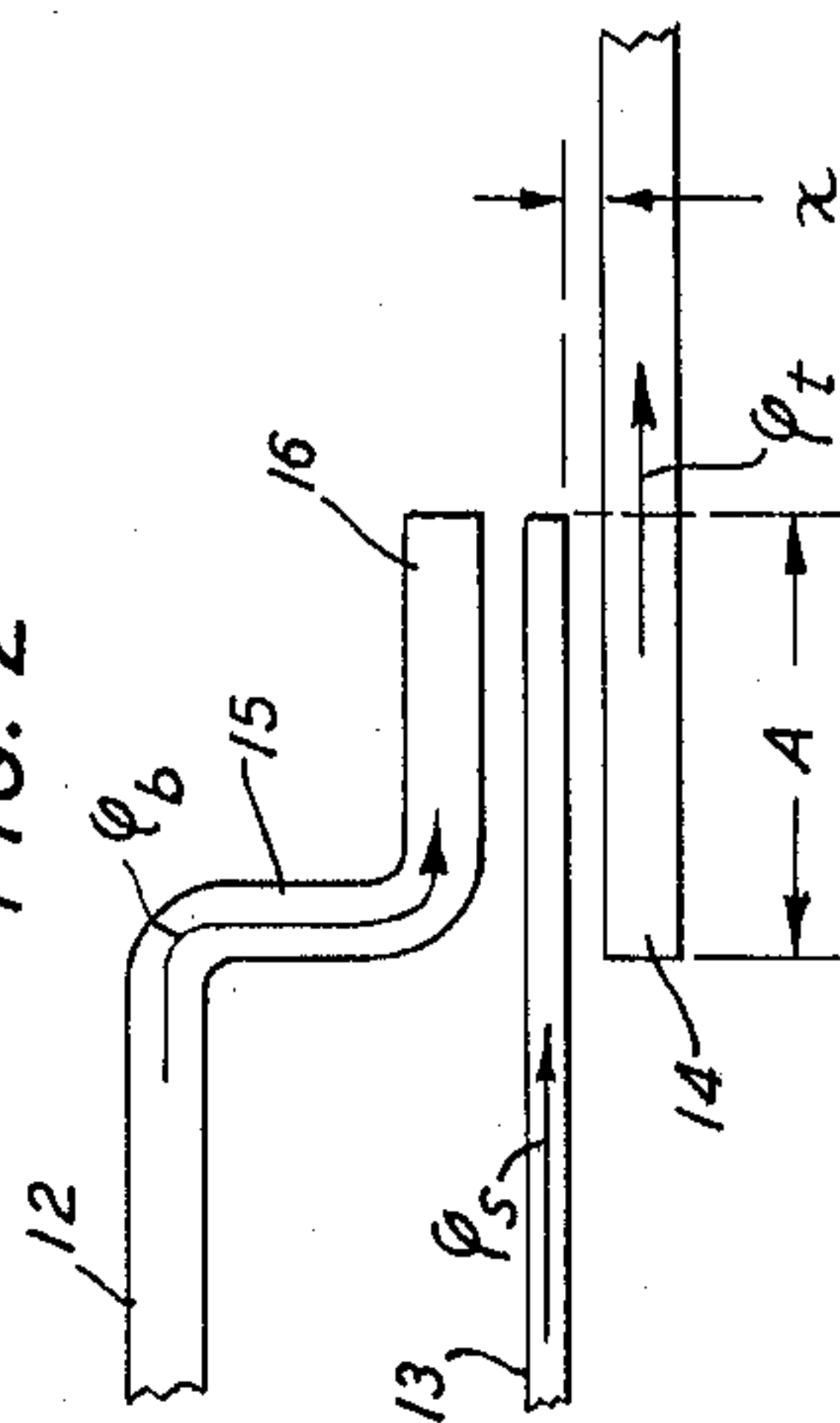


FIG. 2



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SWITCH HAVING AN IMPROVED CONTACT ARRANGEMENT

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This invention relates to electromagnetic switching devices and more particularly relates to three-element reed switches of the transfer type generally disclosed in Patent 2,929,895, issued to M. S. Shebanow on March 22, 1960.

In its basic form, a reed switch comprises two elongated reeds respectively sealed in opposite ends of an evacuated glass tube with their tips overlapping so as to provide a make-break switching function. This type of switch was developed in order to satisfy a need for a small but reliable switch which required little energy to operate. As illustrated by the aforementioned patent, the make-break function of the basic reed switch has been extended by adding a swinger reed in the air gap between the existing reeds. With this arrangement, a transfer switching function occurs as the swinger reed alternates between the fixed reeds.

In developing a commercially acceptable reed transfer switch, however, many problems have been encountered. These problems arise principally because the internal operating characteristics of the switch are critical and difficult to control. For example, it is desirable that contact resistance be maintained at a low level in order to avoid unwanted attenuation of signals carried by the contacts.

Contact resistance is principally a function of the force exerted by one reed on another and goes down in magnitude as the magnitude of force goes up. Force, in turn, is a function of the stiffness of the swinger reed and the magnetic flux appearing in the gap between reeds. Flux, however, is a function of parameters such as overlap, permeability, and the flux conducting cross-sectional area of the reeds.

Accordingly, control of contact resistance may be obtained by adjusting the flux manipulating reed parameters such as overlap, permeability, and cross-sectional area. Adjustments, however, cannot be at the expense of small switch size. Therefore, the manner in which the aforementioned parameters are adjusted must be one in which maximized results will occur in a minimized package.

It is, therefore, an object of this invention to improve the construction and operation of reed transfer switches.

It is another object of this invention to achieve the smallest size possible for a reed transfer switch while at the same time maintaining a low contact resistance.

In accordance with this invention, the manner in which these objects are obtained comprises an arrangement wherein a flux conducting back contact is oppositely directed or opposed to a front contact and coextensive with a swinger contact whereby additional flux is obtained in an air gap between the swinger contact and the front contact. Furthermore, the back contact is characterized by an offset and a cross-sectional area at least 50 percent greater than the cross-sectional area of the swinger contact. With the offset, each contact effectively overlaps every other contact, an arrangement providing the most efficient use of available flux. Further, use of the specified cross-sectional area for the back contact results in an arrangement whereby a predetermined ratio between flux carried by the swinger and flux carried by the back contact can be maintained.

A complete understanding of this invention may be obtained from the following detailed description and the accompanying drawing in which:

FIG. 1 is a side elevation of one embodiment of this

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invention with parts broken away to show the relationship of the contact members contained therein;

FIG. 2 is an illustration of the configuration used for relating the contacting portions of the reed members embodied in this invention;

FIG. 3 is a force-gap diagram showing the interaction of such switch parameters as cross-sectional area, swinger stiffness, and air gap; and

FIG. 4 is a section view taken through FIG. 1 for the purpose of illustrating the relationship between cross-sectional areas of the reed members.

In FIG. 1, a three-element reed transfer switch is illustrated wherein a vessel 11 is shown encapsulating three reeds disposed from opposite ends therein as cantilevers. All three reeds are made of ferromagnetic material and comprise a back reed or contact 12, a swinger reed 13 disposed coextensively with the back contact 12 and in overlapping relationship with the end of an oppositely directed parallel front reed or contact 14.

In the unoperated state as shown, the swinger 13 is biased against the back contact 12 and separated from the front contact 14 by a working air gap. When the switch is operated, magnetic flux is conducted serially by the front contact 14 and the parallel combination comprising the back contact 12 and the swinger 13. Switching action takes place when the swinger 13 moves out of engagement with the back contact 12 and into engagement with the front contact 14.

Movement of the swinger 13 occurs as a result of a complex interaction of various switch parameters. Accordingly, a complete understanding of this invention requires an analysis of the manner in which the various switch parameters interact.

Analysis begins with the determination of a fundamental parameter. In reed switches, force may conveniently be taken as the fundamental parameter. In three-element reed switches of the type shown in FIG. 1, the parameter of force appears in two forms.

The first is the bias or back contact force. Bias or back contact force is the force required to overcome the stiffness of the swinger 13 and cause it to deflect into contact with the back contact when the switch is in the unoperated state. Bias force is ordinarily constant and may be acquired in any convenient manner. For example, it may be obtained mechanically as a result of a moment established in the swinger 13 at the time the switch is assembled, or it may be obtained magnetically by making the back contact 12 out of a remanent material.

The second form of force is magnetic or pull force. In accordance with magnetic theory, a force develops between two surfaces when a magnetic flux is passed from one to the other. Accordingly, when a magnetic flux leaves the swinger 13 and enters the front contact 14; or vice versa, a pull force is developed which, when sufficiently large, will overcome any forces in the swinger 13 and move it against the front contact 14. As resistance between contacting reeds is inversely proportional to the force of contact, the foregoing illustrates the advantage of producing as much flux as possible in the working gap between the swinger 13 and the front contact 14.

The relationship between the foregoing two forms of force is shown by the graph in FIG. 3. In the graph, force is the ordinate and the gap between the swinger 13 and the front contact 14 is the abscissa. The straight line relates force to the distance the swinger is deflected and represents swinger stiffness. As it appears, the stiffness line illustrates a condition wherein a back contact force has been acquired by developing a moment of force in the swinger.

The curved line relates pull force to the gap between

the swinger 13 and the front contact 14 and represents a particular magnitude of magnetic flux in the air gap. Since the pull force curve represents a given air gap flux, it also represents a given flux conducting cross section of the reeds. As a result, a family of pull force curves could be plotted in place of the one shown wherein each would be characterized by a particular value of flux conducting reed cross section. Selection of a proper pull force curve is made by balancing all of the forces interacting within the switch into an optimum relationship.

FIG. 3 graphically illustrates how pull force acts in opposition to bias force and stiffness of the swinger. When the optimum relationship between all the forces interacting within the switch is used in selecting a pull force curve, a stiffness line can be plotted which has the steepest slope possible. This is a desirable result because the steepest possible slope of the stiffness line determines the maximum permissible swinger stiffness; a determination which in turn fixes the shortest permissible swinger length. The slope of the stiffness line, however, is limited in that it may not intersect the pull force curve in an operative switch. Accordingly, maximum steepness in an operative switch is obtained when the stiffness line is tangent to the pull force curve.

Swinger stiffness is a function of swinger length and cross-sectional area. Swinger cross-sectional area, however, becomes fixed when a given pull force curve is selected. Accordingly, when the stiffness line is tangent to the selected pull curve, the resulting magnitude of stiffness represents the shortest length a swinger may have and still remain operable by the available flux. From these considerations it is readily apparent why selecting a pull force curve and a stiffness line which are related in an optimum relationship will produce the shortest possible switch.

Determining the aforementioned optimum relationship begins with a consideration of pull force in view of bias or back contact force requirements. In order to maintain contact resistance between the back contact and the swinger at a suitable value, the back contact force must have a substantial magnitude. As a consequence, the pull force must be large in order to overcome the back contact force and still have sufficient net pull force to move the swinger into engagement with the front contact. Moreover, when the swinger engages the front contact, it is necessary that the net pull force be large enough to establish a connection between contacts that is firm enough to produce a low contact resistance. This requirement is satisfied when the magnitude of the front contact resistance equals the magnitude of the back contact resistance; i.e., when the front contact force equals the back contact force. The graph in FIG. 3 illustrates this condition.

In practice, production of a net pull force having a magnitude within a usable range requires a large amount of magnetic flux in the working air gap. As a consequence, it is clear that the optimum relationship between the pull force curve and the stiffness line is one in which as much flux as possible is delivered to the working air gap.

In three-element reed switches, magnetic flux can be delivered to the working air gap in several ways. One way is through the swinger reed. In this arrangement, ordinarily the back contact is non-magnetic and the swinger is flux saturated during operation. As a result, the amount of flux delivered to the working air gap is controlled by adjusting the flux conducting cross section of the swinger. When an increase in the amount of flux in the air gap is desired, the cross-sectional area of the swinger must be increased. However, increasing the cross section of the swinger will also increase its stiffness. With a stiffer swinger, more force or flux will be necessary in order to move the swinger into engagement with the front contact.

An increase in stiffness can be avoided and the stiffness maintained reasonably constant by increasing swinger length. However, since shorter, not longer switches are desired, it is not feasible to increase swinger length to offset the increased stiffness caused by an increase in flux conducting cross section. As a result, it is undesirable to increase the cross section of the swinger in order to obtain additional flux in the working air gap.

Another way of delivering flux to the working air gap is by using a flux conducting path parallel to the swinger. For example, a magnetic back contact may be used. With this arrangement, flux conducted by the back contact is passed through the swinger tip and delivered to the working air gap between the swinger and the front contact. Accordingly, by using a flux conducting back contact, the amount of flux in the working air gap can be increased without an increase in switch size.

FIG. 2 illustrates a configuration wherein a flux conducting back contact is used. A back contact 12 is shown disposed coextensively with the swinger 13. The back contact 12 includes an offset 15 by which the back contact 12 is spaced apart from the swinger 13, an arrangement whereby the effect of flux fringing therebetween is reduced. A portion 16 of the offset 15 overlaps the ends of the swinger 13 and the front contact 14. The front contact 14 is arranged in opposed relationship to the back contact 12 and the swinger 13.

Each contact conducts magnetic flux. The various paths of the magnetic flux from an external source (not shown) are represented by arrows for the purposes of illustration and are labeled ϕ_t (total flux), ϕ_s (swinger flux), and ϕ_b (back contact flux). The flux ϕ_t flows in the front contact 14 and passes through the working air gap between the swinger 13 and the front contact 14. The flux ϕ_t is the sum of ϕ_s , the flux conducted by the swinger 13, and ϕ_b , the flux supplied by the back contact 12. As a consequence, flux in the working air gap between the swinger 13 and the front contact 14 is increased by the amount supplied by the back contact 12.

Added advantage is obtained with the arrangement illustrated in FIG. 2 when the back contact 12 is made of remanent material such as remendur. When the back contact 12 is remanent, the remanent or holding flux remaining in the back contact 12 in the unoperated state circulates in a path which includes the swinger 13. As a consequence, the swinger 13 need not be biased by a mechanical force in order to maintain contact with the back contact 12 in the unoperated state. Control of the resistance between the swinger 13 and the back contact 12 may conveniently be obtained by adjusting the level of the remanent or holding flux left in the swinger 13 in the unoperated state.

Where either a remanent or non-remnant back contact 12 is used, however, not all of the pull force developed between the swinger 13 and the front contact 14 by the flux ϕ_b is available to move the swinger 13 and front contact 14 into engagement. This occurs because the flux ϕ_b causes forces to be created which act on the swinger 13 in opposite directions. For example, when the flux ϕ_b leaves the back contact 12 and enters the near surface of the swinger 13, a pull force between the swinger 13 and the back contact 12 is developed. This force is in opposition to the desired pull force created by the same flux as it leaves the far surface of the swinger 13 and enters the front contact 14. Consequently, instead of one gap, two working gaps developing opposed pull forces exist in the reed transfer switch during operation. As a result, only a net pull force is available from the back contact flux ϕ_b to assist the pull force from the swinger flux ϕ_s in overcoming any biasing force acting on the swinger 13. From the foregoing, it is clear that careful control is required to obtain efficient use of all available flux.

The most efficient use of flux occurs when the swinger is saturated and each reed overlaps every other reed by

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an equal amount. From magnetic theory, pull force is directly proportional to flux density. Accordingly, if the overlap between the swinger and the front contact exceeds the overlap between the swinger and the back contact, the net pull force for operating the switch is reduced. Conversely, if the overlap between the swinger and the back contact exceeds the overlap between the swinger and the front contact, magnetic flux is wasted. Waste occurs because a portion of the flux from the overlapping back contact must pass through the swinger in order to reach the front contact. The swinger, however, although not saturated in the direction of the air gap flux, is saturated along its length. Accordingly, that portion of flux from the back contact which is required to pass along the swinger ineffectively fringes and does not reach the air gap. The most efficient arrangement for the reeds, therefore, is obtained when each reed overlaps every other reed by an equal amount.

FIG. 1 illustrates one way in which equal overlaps of the reed tips can be obtained wherein advantage is taken of an offset 15 used to reduce fringing effects by spacing the back contact 12 and the swinger 13 apart. As shown, the offset 15 is substantially L-shaped and includes a part 16 which is disposed to overlap the swinger 13 a precise amount; as for example, a distance A as shown in FIG. 2. Therefore, by using the offset 15 each reed is made to effectively overlap every other reed by an equal amount.

Recognition of the relationship existing between reed parameters graphically illustrated by FIG. 3, and the optimum efficiency of flux usage obtained by equal reed overlaps illustrated in FIG. 2, has led to the discovery that the magnitude of the flux carried by a back contact and the flux carried by a swinger are related mathematically. It has been discovered, moreover, that this relationship has an optimum value which is obtained when the ratio of back contact flux to swinger flux has a certain magnitude; namely, the quantity A/KX . In this ratio, A is the amount by which the reed tips overlap, X is the gap between the swinger and front contact, and K is a constant used to compensate for fringing effects and has a magnitude in the order of 10.

The ratio A/KX has a practical magnitude in the order of three quarters ($3/4$); a magnitude that indicates the flux supplied by a back contact should be less than that conducted by a swinger. From this, it would appear that a back contact need not have as large a flux conducting cross section as a swinger in order to maintain an optimum flux condition in the air gap. Magnetic theory, however, as applied to parallel flux conducting reeds has led to a contrary result. The back contact must have a cross-sectional area greater, not less, than the cross-sectional area of the swinger. Where the cross sections are the same and where the amount of flux lost to fringing does not absolutely preclude operation, the back contact operates near the knee of the B—H curve. As a consequence, small variations in the flux source are amplified into large changes in the back contact flux. Such large changes result in erratic switch action. In order to avoid the foregoing difficulties, it is clear that the cross section of the back contact must exceed the cross section of the swinger. In the course of testing these conclusions, it was discovered that the cross-sectional area of a back contact should be at least 50 percent greater than the cross-sectional area of a swinger in order to maintain the required ratio of fluxes.

FIG. 4 shows the manner in which the foregoing discovery has been embodied in this invention. Each of the reeds 12, 13, and 14 have the same width W. The swinger 13, however, has a thickness T. Consequently, the smallest cross section of the back contact 12, as taken through the offset 15, has a thickness in accordance with this invention of at least $2T$. The thickness of the front contact 14 is selected so that it cannot be

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saturated with the combined flux delivered by the back contact 12 and the swinger 13.

In summary, there has been disclosed herein a three-element reed switch having a novel configuration which provides an optimized switching function in a minimized package. It is to be understood, however, that the above-described structure is illustrative of the principles of the invention. Numerous other modifications of the structure may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In a switching device operated by a magnetic flux, the combination comprising three elongated flux conducting contacts wherein all three contacts have end portions disposed to overlap each other by an equal amount, said three contacts comprising two oppositely directed rigid contacts and a flexible contact, said flexible contact swingably disposed between said two rigid contacts in coextensive relationship with one rigid contact for alternately engaging said two rigid contacts in response to said magnetic flux, said one rigid contact having a flux conducting cross-sectional area perpendicular to its longitudinal axis at least 50 percent greater than the flux conducting cross-sectional area perpendicular to the longitudinal axis of the flexible contact.

2. A switching device in accordance with claim 1 wherein the end portion of said one rigid contact includes an offset, said offset having a part disposed in parallel overlapping relationship with the end portions of the remaining rigid contact and the flexible contact.

3. A switching device in accordance with claim 2 wherein said offset comprises an L-shaped foot.

4. In a switching device operated by a magnetic flux, the combination of three flux conducting contacts comprising two opposed outer contacts having end portions arranged to mutually overlap each other by an equal amount and a swingable inner contact, said swingable inner contact disposed between said two outer contacts in coextensive relationship with a first outer contact, said first outer contact having a flux conducting cross-sectional area perpendicular to its longitudinal axis at least 50 percent greater than the flux conducting cross-sectional area perpendicular to the longitudinal axis of the swingable inner contact, said swingable inner contact having an end portion disposed to overlap the end portion of each of said two outer contacts by an equal amount for engaging one of said two outer contacts in response to said magnetic flux.

5. A switching device in accordance with claim 4 wherein the end portion of said first outer contact includes an offset, said offset having a part disposed in parallel overlapping relationship with the end portions of the remaining outer contact and the swinger contact.

6. A switching device in accordance with claim 5 wherein said offset comprises an L-shaped foot.

7. In a magnetically operated switching device, the combination of three elongated flux conducting contacts disposed in parallel planes comprising two oppositely directed outer contacts having mutually overlapping end portions and a tipped inner contact for engaging said two outer contacts in response to a magnetic flux, said inner contact swingably disposed between said two outer contacts in coextensive relationship with one outer contact and with the tip thereof overlapping the end portion of each said two outer contacts by an equal amount, said one outer contact having a cross-sectional area perpendicular to its longitudinal axis at least 50 percent greater than the cross-sectional area perpendicular to the longitudinal axis of said inner contact.

8. A switching device in accordance with claim 7 wherein the end portion of said one outer contact includes an offset, said offset having a part disposed in parallel overlapping relationship with the end portion of the remaining outer contact and the tip of the inner contact.

9. A switching device in accordance with claim 8 wherein said offset comprises an L-shaped foot.

10. In a switching device operated by a magnetic flux, the combination of three flux conducting contacts wherein all three contacts have end portions disposed to overlap each other by a amount A, said combination comprising two oppositely directed rigid contacts separated by an air gap and a flexible contact swingably disposed therebetween, said flexible contact having an end portion spaced a distance X from an end portion of a first rigid contact while in the unoperated state and disposed coextensively with the second rigid contact for alternately engaging said two rigid contacts in response to said magnetic flux, said second rigid contact having a cross section perpendicular to its longitudinal axis large enough to conduct a magnetic flux having a magnitude $A/10X$ times the magnitude of the flux conducted by said flexible contact.

11. In a switching device, the combination of three contacts comprising a swinger; a cantilevered front contact in overlapping relation with said swinger to define on said swinger a distance A and separated therefrom by a gap X; a cantilevered back contact disposed coextensively with the swinger, said back contact having an end portion disposed to overlap said distance A on said swinger, said swinger stiffly cantilivered to alternately swing into engagement with the back and front contacts with a force F in response to a magnetic flux, the stiff-

ness of said swinger having a magnitude equal to $4.8 F/X$, said back contact having a cross-sectional area perpendicular to its longitudinal axis sufficient to conduct a magnetic flux $A/10X$ times the magnetic flux conducted by said swinger; and means for holding the three contacts as cantilevers.

12. A switching device in accordance with claim 11 wherein the ratio A/X has a magnitude of at least 7.5.

13. A switching device in accordance with claim 11 wherein said end portion of the back contact comprises an offset depended from the end of said back contact with a part disposed parallel to the swinger, the front contact and the back contact.

14. A switching device in accordance with claim 13 wherein said offset comprises an L-shaped foot.

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