1,000,758

PATENT SPECIFICATION

DRAWINGS ATTACHED

1,000,758

THE PATENT OFFICE
LONDON

Date of Application and filing Complete Specification ***April 23, 1964.***
No. 16868/64.
Application made in United States of America (No. 283,035) on May 24, 1963.
Complete Specification Published Aug. 11, 1965.

Index at acceptance: —**H1** P3; **H2** B(1R12, 1R13F, 1R13H, 1R18D)
Int. Cl.:—**H 01** f//H 01 h

COMPLETE SPECIFICATION

Permanent Magnet Memory Device Using Pulse Control

We, WESTINGHOUSE ELECTRIC CORPORATION, a corporation organized and existing under the laws of the Commonwealth of Pennsylvania, United States of America, of Three Gateway Center, Pittsburgh 30, Pennsylvania, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to permanent magnet memory devices, and more particularly to permanent magnet memory devices whose memory may be controlled through electrical signals.

A permanent magnet memory device may be fabricated by sandwiching a permanent magnet of the ceramic variety, for example, between two pole pieces of a soft magnetic material. By placing a keeper of a soft magnetic material across the pole pieces at one end of the sandwich, a relatively low reluctance path will be provided between the pole piece with an attendant mechanical force holding the keeper to the device in proportion to the square of the magnetic flux passing therethrough. If, now, another keeper of a soft magnetic material is placed over the other end of the sandwich between the pole pieces, a portion of the magnetic flux provided by the permanent magnet will be diverted thereto. However, due to the magnetic memory characteristics of magnetic materials, as will be explained below, a larger portion of the flux from the permanent magnet will still pass through the first keeper. In other words, the first path established maintains a lower reluctance and so the device remembers which keeper was first placed adjacent the sandwich. Should the first keeper now be removed from the device, the flux from the permanent magnet will be diverted through the now substantially lower reluctance path including the second keeper, where a strong mechanical force, proportional to the square of the flux passing therethrough, will attract the second keeper to the permanent magnet structure. If the first keeper should be replaced, it will be attracted by a smaller mechanical force because of the magnetic memory characteristics of the device. The device thus remembers which keeper was first applied thereto. This characteristic may be used in many applications beyond pure magnetic memory, for instance in relays, door latches, steel moving hoists, and many others. However, in order to accomplish the switch in memory states of the device from a high mechanical force to a low mechanical force at a particular end of the device, it is necesary that the reluctance of the high mechanical force path be increased so that a large portion of the flux from the permanent magnet may be switched to another magnetic path of the device. Such a result may be accomplished by mechanically moving one of the keepers away from the sandwich, or by setting up another magnetic field to oppose the flux of the permanent magnet in that particular path. Because of the ready accessibility of alternating and pulse sources of electrical current, it would be very desirable to switch states of the memory device through the use of such sources.

The chief object of the present invention is to provide an improved magnetic memory device which may readily be switched between memory states, through the use of control signals.

The invention resides in a magnetic memory device operative in response to electric control signals and comprising, magnetic means providing at least two magnetic paths, the paths having a portion in common with one another, a source of magnetomotive force common to said paths to supply magnetic flux in different directions through said common portion, one of said paths having a lower reluctance than the other of said paths, and control winding means disposed in at least one of said paths and operative in response to said control signals to saturate a portion of the lower reluctance path and increase its reluctance above that of the other of said paths.

More specifically, the device is a permanent magnet memory device having a plurality of magnetic high paths therein, one of said paths having a lower reluctance than the other, wherein the reluctance of the low reluctance path may be increased by saturating a portion of that path by the application of a pulse or alternation control signal in that path. By so saturating a portion of the aforementioned path, the magnetic flux generated by the permanent magnet is realigned to switch the memory device to its other stable memory state without the need for mechanically removing a portion of one of the magnetic paths and without the necessity of setting up a bucking magnetic flux in one of the paths.

In order that the invention may be more readily understood and carried into effect, reference will now be made to the accompanying drawings, in which:

Figure 1 is a schematic drawing of a permanent magnet memory device;

Figs. 2A, 2B and 2C are schematic drawings used in the explanation of the operation of the present invention;

Fig. 3 is a plot of a hysteresis loop of a ceramic permanent magnet;

Figs. 4A, 4B and 4C are schematic diagrams used in the explanation of the operation of the present invention;

Fig. 5 is a schematic diagram of the magnetic memory device of the present invention; and

Fig. 6 is a schematic diagram of another embodiment of the permanent magnet memory device of the present invention.

Referring to Figure 1, a permanent magnet 10 is shown having a North pole and a South pole at the opposite ends thereof. Permanent magnet 10 is sandwiched between the pole pieces 12 and 14. The permanent magnet and the pole pieces taken as a unit will be sometimes referred to herein as the sandwich. The permanent magnet may be of the ceramic type, for example. The material of the pole pieces 12 and 14 may comprise, for example, a soft magnetic material such as one of the iron-nickel alloys. A pair of keepers A and B are provided, as shown in Figure 1 displaced away from the sandwich. The keepers A and B comprise a soft magnetic material. There are thus two possible magnetic flux paths between the permanent magnet, the pole pieces and the keepers. One of these paths NAS, shown by a dotted arrow, passes from the North pole N of the permanent magnet 10, through the pole piece 12, the keeper A, the pole piece 14, and back to the South pole S of the permanent magnet. The other parallel magnetic flux path, NBS shown by a dotted arrow in Figure 1, passes from the North pole N of the permanent magnet 10, through the pole piece 12, the keeper B, the pole piece 14, and back to the South pole S of the permanent magnet. It should be noted that the magnetic flux provided by the permanent magnet in the pole pieces 12 and 14 flow in opposite directions. In the pole piece 12, the flux divides and flows toward the keepers A and B. In the pole piece 14, the flux from the keepers A and B converges to return to the permanent magnet. It will be shown immediately below, if, for example, the keeper A is first placed adjacent the sandwich between the pole pieces 12 and 14, a relatively strong mechanical force will hold the keeper to the sandwich. If, then, the keeper B is placed adjacent the sandwich, the mechanical force holding the keeper A will still be substantially strong while a substantially weaker mechanical force will hold the keeper B in position against the sandwich.

To aid in the explanation of the theory of operation of a permanent magnet memory device, reference should now be made to Fig. 2A. As shown there, the keeper A is displaced away from the sandwich so that very little flux passes through the keeper A. Shown within the confines of the keeper A is its $\beta-H$ or hysteresis loop at that particular time and position, where β is the magnetic flux density within the keeper A, and H is the magnetic intensity, sometimes herein called the magnetizing force. Assuming initially that the keeper A is unmagnetized, the keeper will be operating at the origin of the $B-H$ loop at the point a.

If the keeper A is brought in contact with the sandwich between the pole pieces 12 and 14, as shown in Fig. 2B, the magnetic induction H in the soft iron keeper A will increase due to the presence of the permanent magnet supplying magnetomotive force. The flux density β will increase so that the keeper will be operating at a point b, being magnetized along the line ab.

If now the keeper A is taken away from the sandwich, as in Fig. 2C, the operating point of the soft iron keeper does not return to point a; but, rather follows the characteristic hysteresis loop of the soft iron point b to the point c. The point c is in the second quadrant of the $\beta-H$ loop at a negative magnetic intensity ($-H$) and a magnetic flux density of not quite zero, some residual magnetism remaining in the soft iron keeper. The hysteresis characteristic of the magnetic material is an important factor in the operation of the memory device as will be considered below.

Figure 3 shows the plot of a hysteresis loop of a ceramic permanent magnet. The scale for the magnetic intensity H of the ceramic permanent magnet of Fig. 3 is approximately 400 times that of the magnetic intensity for the soft iron keepers of the previous figures. Any changes in the operation of the permanet magnet 10, as utilized herein, will occur along the line de, in the second quadrant of the B—H loop between the points d and e. This line de is commonly called the " demagnetizing curve " of a permanent magnet and is used to describe the capability of a material when being used as a permanent magnet.

Using the same permanent magnet sandwich, the memory characteristics of the device can be seen when another keeper B having the same characteristics of the keeper A is brought into the picture. Figure 4A shows the keepers A and B initially demagnetized and disposed away from the sandwich. At this time and position, both the keepers A and B are operating at zero magnetic flux density β and zero magnetic intensity H, at points a and a^1 of the keepers A and B, respectively. Under these conditions, the permanent magnet is operating at the point 1 along the magnetizing line de. The permanent magnet thus is supplying a magnetizing force H_1. Because of the magnetizing force H_1 in the air around the magnet, a magnetic flux density β_1 is established between one pole piece and the other pole piece.

Now, as in Fig. 4B, if the keeper A is brought in contact with the magnetic sandwich, the flux density in the keeper A will increase from the point a to the point b at a flux density of β_b. It should be noted that the operating point of the permanent magnet 10 has now changed to point 2 at a decreased magnetizing force H_2 and at an increased magnetic flux density of β_2. It may be assumed that a large percentage of the permanent magnet flux β_2 passes through the keeper A producing the flux density β_b in the keeper A. The magnetic intensity will be H_2 which is supplied by the permanent magnet 10. This is now a steady state condition with a low reluctance path being provided from the pole piece 12, through the keeper A, back to the pole piece 14. The keeper A is held to the sandwich with a strong mechanical force proportional to the square of the magnetic flux density β_b passing therethrough.

Bringing the pole piece B into contact with the permanent magnet sandwich, as shown in Fig. 4C, will cause changes to take effect in both the permanent magnet 10 and in the keeper A. When the keeper B is placed against the sandwich another relatively low parallel reluctance path is provided through the keeper B. The operating point of the permanent magnet then changes to the point 3 at an increased flux density β_3 while at a slightly smaller magnetic intensity H_3 from point 2. The magnetic intensity H available to the parallel combination of keepers A and B is now H_3 being reduced from the previous case of Fig. 4B from H_2. With the reduction of magnetic intensity to H_3, the operating point of the keeper A is now at point c with a resulting reduction of magnetic flux density to β_c. It should be noted that the reduction of flux density occurs along the B—H loop from the point b to the point c. In the keeper B, however, the magnetizing force H increases from its demagnetized state at point a^1 to a value H_3, which produces a field β_b^1 at the point b^1 of its β—H loop. The system now is of steady state with the keeper A operating at a flux density of β_c and the keeper B operating at a substantially lower flux density β_b^1. Thus, with the application of the keeper B, there was only a slight reduction in the magnitude of the magnetic flux density (from β_b to β_c); and so only a slight reduction in the mechanical force applied to the keeper A. On the other hand, the keeper B is held to the magnetic sandwich with a much smaller force according to a mechanical force portional square of the flux density β_b^1 being provided in the keeper B at this time. In essence, a magnetic memory device is provided which retains indefinitely an unbalance of magnetic flux density between two parallel paths in response to a previous control. To state this in other terms, a once previously established low reluctance path will be sustained even after a similar parallel magnetic path is provided.

To switch the strong mechanical force from the keeper A to the keeper B, the keeper A may be mechanically moved away from the permanent magnet sandwich. The removal of the keeper A will cause the keeper B to change to a magnetic state similar to that of the keeper A in Fig. 4B. The permanent magnet 10 will supply a magnetic intensity H_2 which will permit a higher magnetic flux density to be provided through the keeper B and so a higher mechanical force will be developed. If then the keeper A is replaced on the sandwich, it will be held with a substantially lower mechanical force. The state of the memory device under these conditions will be the converse of Fig. 4C, with the mechanical forces holding the keepers A and B being reversed with keeper A being held by the weaker and keeper B by the stronger mechanical force. The memory state may then be switched with the strong mechanical force on the keeper A by a similar removal of the keeper B and then its replacement.

Although control of the memory device may be obtained manually, it is obviously a great advantage to control the memory electrically. Such electrical control may be effected by establishing a bucking magnetic field by the application of current to a coil which is suitably disposed in the magnetic circuit. The opposing magnetic field induced by the current will have the effect of reducing the amount of flux passing through one of the paths. This tends to transfer flux from the permanent magnet to the other path; thus, causing the switch of the greater mechanical force to the other of the paths. However, the control function may also be provided by increasing the reluctance electrically of one of the paths so that it appears as though one of the keepers has been removed and an air gap exists between the magnetic sandwich and the keeper.

The permanent magnet memory device shown in Fig. 5 is capable of increasing the reluctance of one of the paths for the switching operation without physically removing one of the keepers. The structure of the memory device is substantially the same as described above. However control coils or windings 16 and 18 are placed in the slots 20 and 22 in the pole piece 12 and 14, respectively. The coils 16 and 18 thus are within the magnetic path NAS. In the magnetic path NBS are disposed control coils or windings 24 and 26 within the slots 28 and 30 cut into the pole pieces 12 and 14, respectively. Thus, a pair of coils is wound about a portion of the magnetic circuits provided between the pole pieces and the keeper.

When a magnetic material is saturated, that is, supplied with a very high magnetizing force, and only with a slight increase of magnetic flux density, the permeability μ of the material drops substantially, since permeability μ is defined as the ratio of $\frac{\beta}{H}$. Conversely, as the permeability decreases, the reluctance of the material increases as these quantities are inversely proportional to each other. Therefore, if a portion of either of the magnetic paths NAS or NBS are saturated this would increase the reluctance of that path.

Assuming that the history of the memory device of Fig. 5 is such that the keeper A is applied to the sandwich, that is, it is being held by a higher mechanical force and the keeper B was later applied or being held with a lower mechanical force, the memory state of the device can be changed by increasing the reluctance of the path NAS. If an electrical control signal is applied to the terminals 32 and 34 of the coil 16 and to the terminals 36 and 38 of the coil 18 of sufficient magnitude, the portion of the path NAS associated with these coils may be either negatively or positively saturated depending upon the polarity of the signals applied thereto. The control signal applied to the coils 16 and 18 may be unidirectional, alternating of either polarity or may be one or several pulses or of any wave shape. The flux pattern established by the control signal is shown by the lines 17 and 19 around the coils 16 and 18, respectively. The flux pattern is by the use of the coils substantially isolated to the portions of the magnetic paths about the coils. The initial pulse applied to the coil drives the material into saturation greatly increasing the reluctance of the path. The flux from the permanent magnet will divide and flow through the magnetic path NBS, including the keeper B; thus creating a higher mechanical force on this keeper. Upon the removal of the saturating control signals from the coils 16 and 18, a portion of the permanent magnet flux will again pass through the path NAS, however, in a substantially reduced amount. Now the keeper A will be held by a weak mechanical force and the keeper B by a strong mechanical force. The switching of the memory function of the device is thereby accomplished.

Because of the universal availability of alternating current and in that it is difficult to obtain just one pulse from any source, a plurality of cycles of alternating current may be applied to the coils to cause switching without any adverse results in the functioning of the memory of the device. If alternating current is applied to the coils 16 and 18, the coils are so wound that the phase of the signals may be such that any stray magnetic field produced by the coils will cancel in the other parts of the magnetic circuit. Such cancellation or stray fields may be accomplished by selecting the phase of the control signals so that current flowing into the terminals 32 and 36 of the respective coils 16 and 18 will be in phase.

If switching from the now low reluctance path NBS to the path NAS is desired, the coils 24 and 26 may be energized with suitable electrical control signals, as described above. Through the application of control signals of suitable strength through the terminals 40 and 42 of the coil 24 and through the terminals 44 and 46 of the coil 24 and through the terminals 44 and 46 of the coil 26, the portions of the path NBS associated therewith will become either positively or negatively saturated. The permeability of this portion of the path is decreased increasing the reluctance of the path and causing the permanent magnet flux density from the permanent magnet to be switched to the now low reluctance path NAS. The effect of such change when the signals are removed from the coils 24 and 26 will be to switch the high mechanical force to the keeper A and have the low mechanical force applied to the keeper B.

Figure 6 shows another embodiment using the control coils of Fig. 5. In this embodiment, however, a monostable switching function is provided. That is, ordinarily the keeper A is held with a strong magnetic mechanical force, NAS being the low reluctance path. When control signals are applied to the coils 16 and 18, the low reluctance path is switched to the path NBS. When, however, the control signals are removed from the coils 16 and 18 the state of the device reverts to the high mechanical force being applied to the keeper A without any other control signals being applied.

The monostable device is provided by deleting the control coils 24 and 26 from the path NBS and substituting therefor the air gaps 50 and 52. The air gaps thus normally cause the magnetic path NBS to be of a relatively high reluctance while the keeper A is being held by a high mechanical force. When control signals are applied to the coils 16 and 18 saturating a portion of the path NAS, this causes the path NAS to have a very high reluctance causing flux from the permanent magnet to be diverted to the path NBS and causing the keeper B now to be held with a substantially higher mechanical force and the keeper A to be released to a lower mechanical force. At the termination of the control signals applied to the coils 16 and 18, the path NAS reverts to its low reluctance state, while due to the air gaps 50 and 52 in the path NBS this path is of still a relatively high reluctance so not permitting a high value of magnetic flux density to be passed through the keeper B. The keeper B is then held by a low mechanical force state, while the keeper A reverts to its high mechanical force state present before the application of the control signals to the coils 16 and 18.

Both the permanent magnet memory devices of Figs. 5 and 6 are ideally suited for latch mechanisms on relays, contactors and circuit breakers. Moreover, such devices could also be used as overcurrent or overvoltage detection. Moreover, because of the bucking action of the control windings within a pair, such devices could be used for phase detection.

WHAT WE CLAIM IS:—

1. A magnetic memory device operative in response to electric control signals and comprising, magnetic means providing at least two magnetic paths, the paths having a portion in common with one another, a source of magnetomotive force common to said paths to supply magnetic flux in different directions through said common portion, one of said paths having a lower reluctance than the other of said paths, and control winding means disposed in at least one of said paths and operative in response to said control signals to saturate a portion of the lower reluctance path and increase its reluctance above that of the other of said paths.

2. A magnetic memory device as claimed in claim 1, wherein the said source of magnetomotive force comprises a magnet, and the said magnetic means comprise keeper means disposed between the poles of the magnet.

3. A magnetic memory device as claimed in claim 2, wherein the said source of magnetomotive force comprises a permanent magnet sandwiched between a pair of pole pieces, and the said keeper means comprise a pair of keepers one disposed over each end of the sandwich between said pole pieces.

4. A magnetic memory device as claimed in claim 3, wherein said pole pieces and keepers comprise a soft magnetic material.

5. A magnetic memory device as claimed in any of claims 1 to 4, wherein the said control winding means for each path comprise a control coil disposed in a slot, which slot is located in a part of the respective path other than the said common portion.

6. A magnetic memory device as claimed in any of claims 1 to 5, and having two stable states, one of which is constituted by one of the paths having a lower reluctance than the other path, and the other of said stable states is constituted by the other of the paths as a result of the said one path being saturated to increase its reluctance above that of the said other path.

7. A magnetic memory device as claimed in claim 6, wherein each path is provided with a pair of slots, each slot containing an associated control coil.

8. A magnetic memory device as claimed in any of claims 1 to 5, and having only one stable state constituted by one of the paths having a lower reluctance than the other path, and wherein the control winding means are operative in response to the control signals to increase the reluctance of the lower reluctance path above that of the other path, the device returning to the said one stable state when the control winding means are no longer operative.

9. A magnetic memory device as claimed in claim 8, wherein the said one path is provided with a pair of slots, and the said control winding means are disposed in the said slots.

10. Magnetic memory devices substantially as hereinbefore described with reference to, and as illustrated by, the accompanying diagrammatic drawings.

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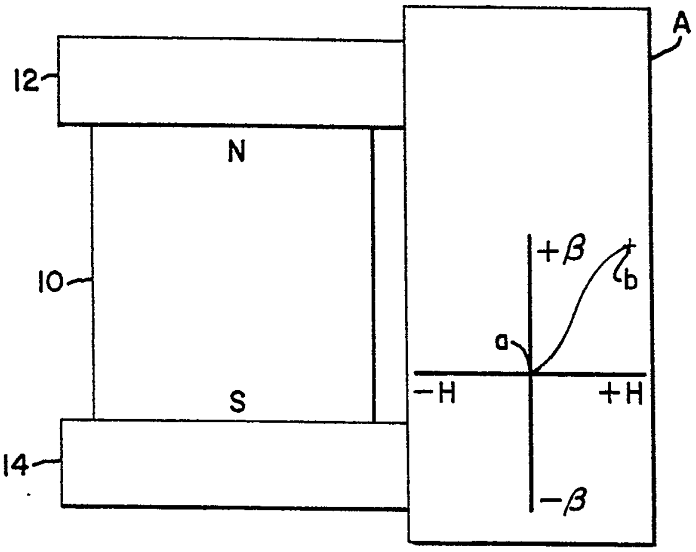
Leamington Spa: Printed for Her Majesty's Stationery Office by the Courier Press.—1965.
Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained.

Fig. 2B.



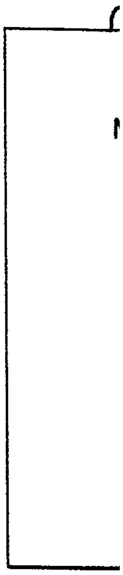
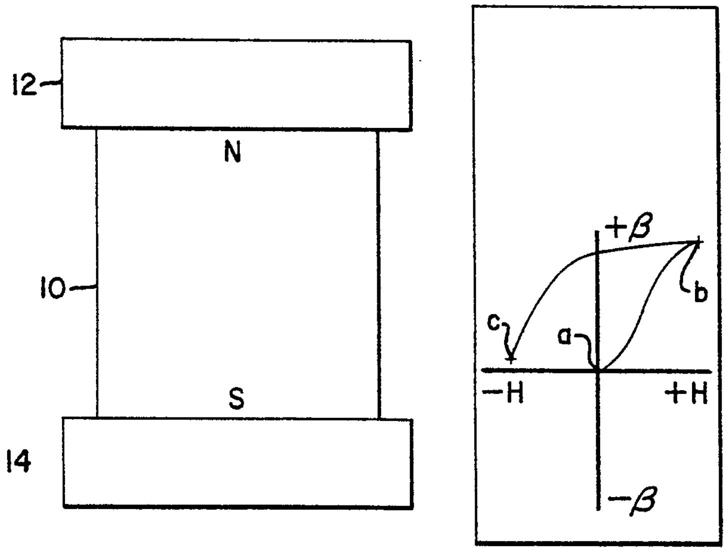


Fig. 2C.



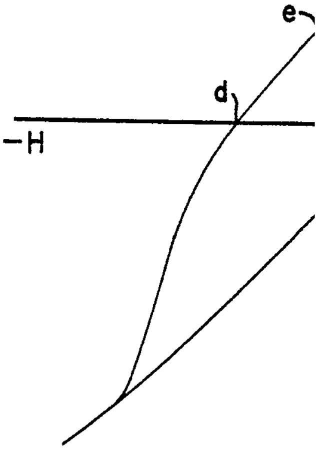
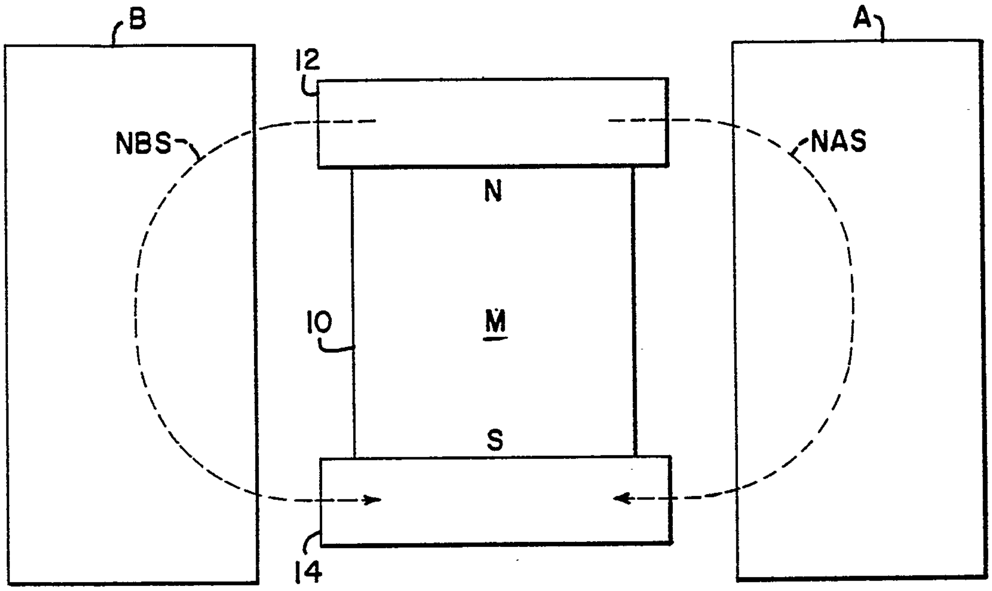


Fig.

Fig. 1.



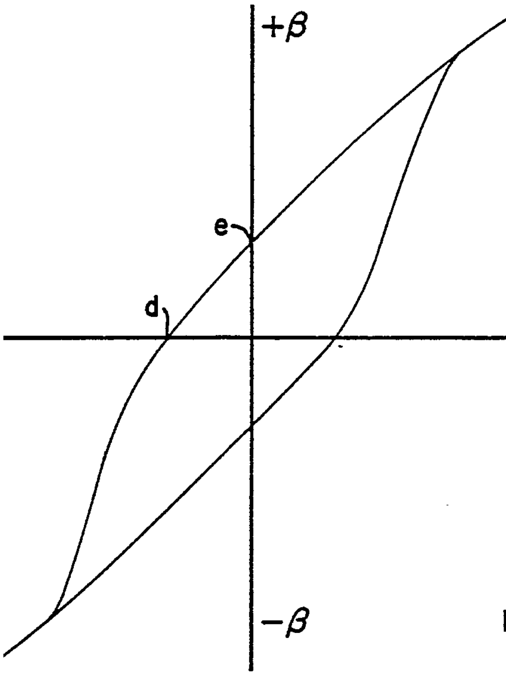


Fig. 3.

Fig. 2A.

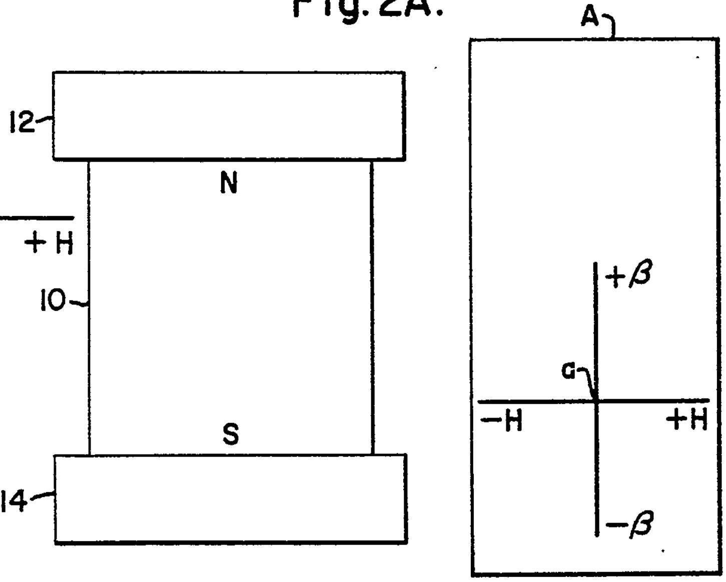


Fig. 1.

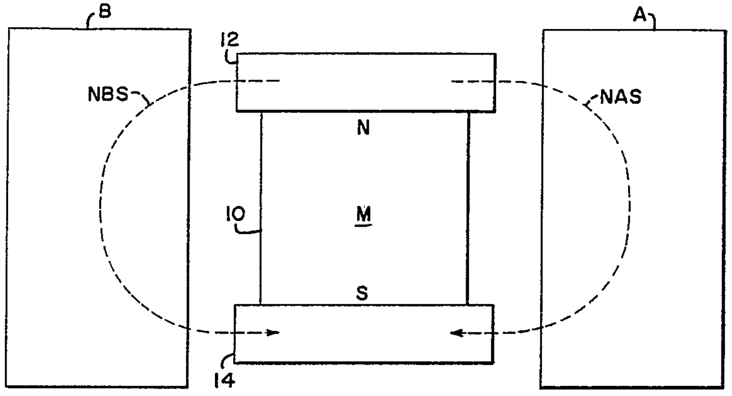


Fig. 2B.

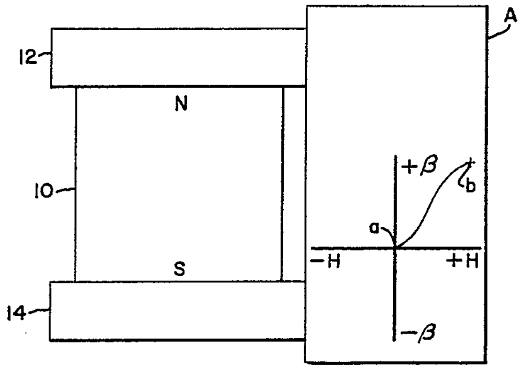
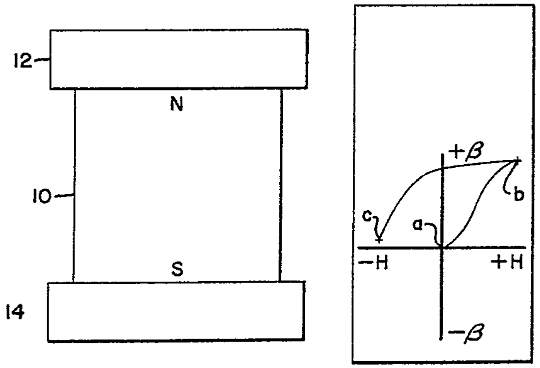


Fig. 2C.



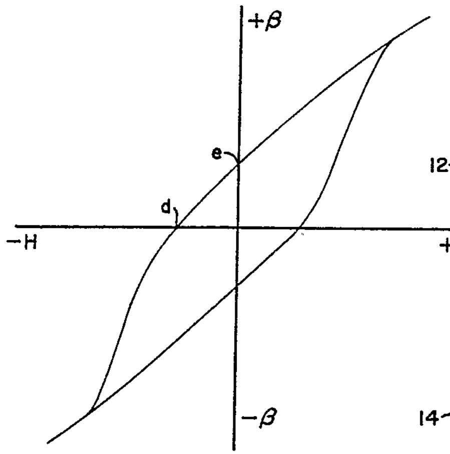
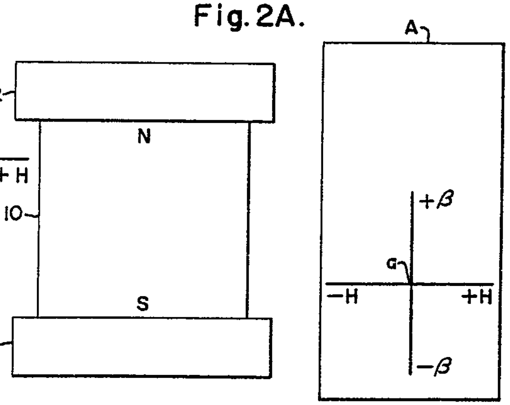
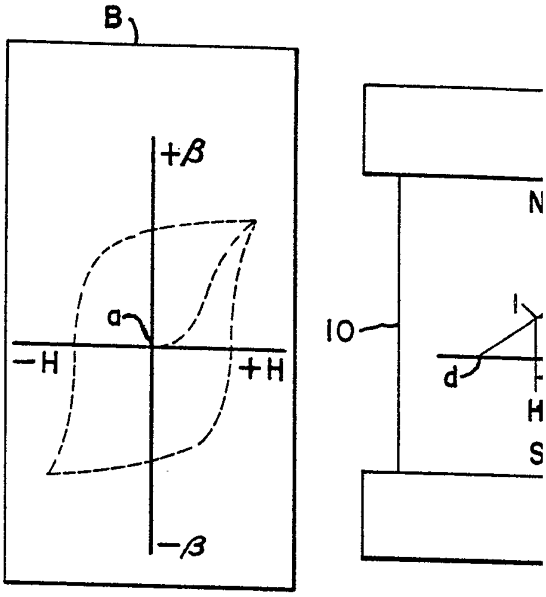


Fig. 3.

Fig. 2A.

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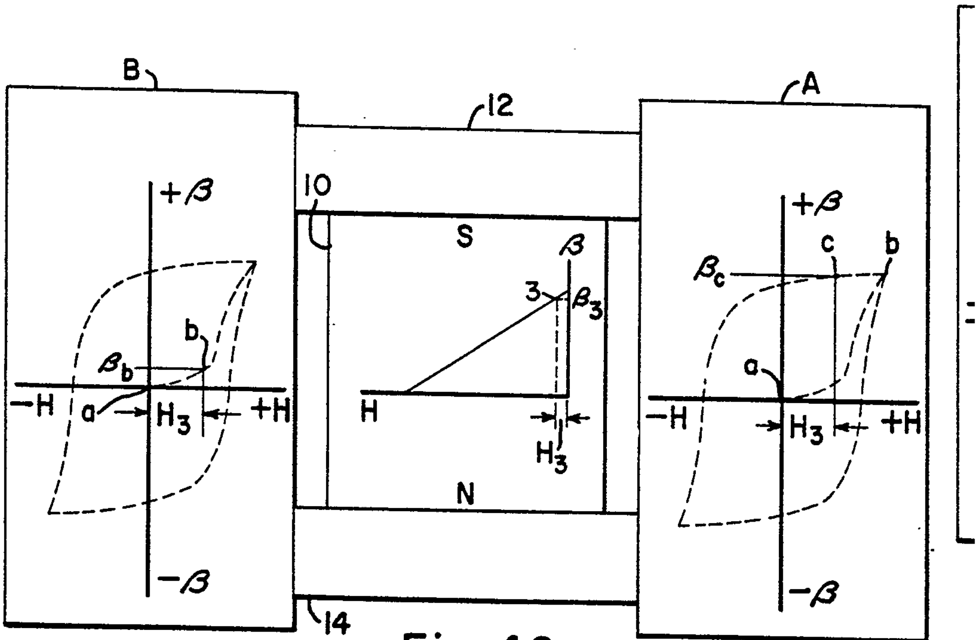
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+H
−β
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β
3
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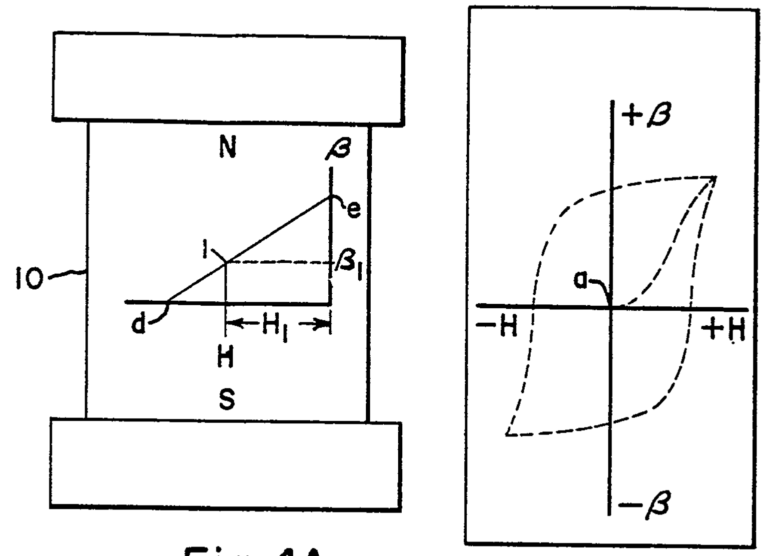
−H
H₃
+H
−β

Fig. 4C.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d
H_1
H
S
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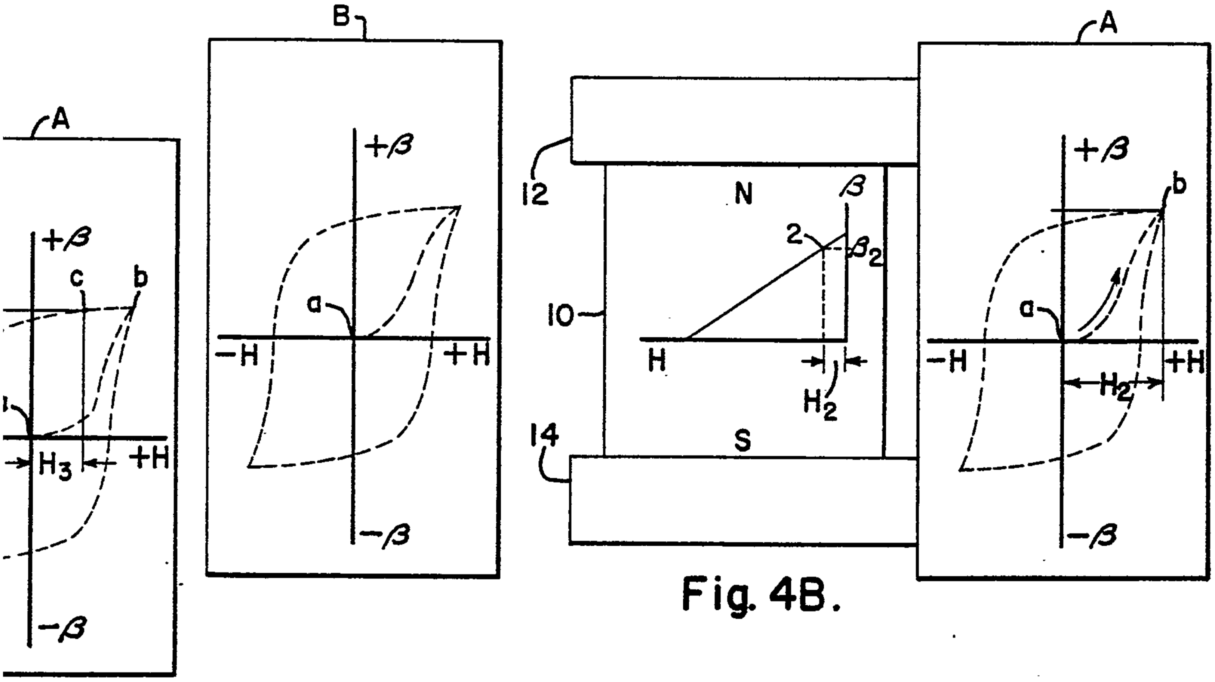
a
−H
+H
$-\beta$

Fig. 4A.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β
2
β_2
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$-\beta$

Fig. 4B.

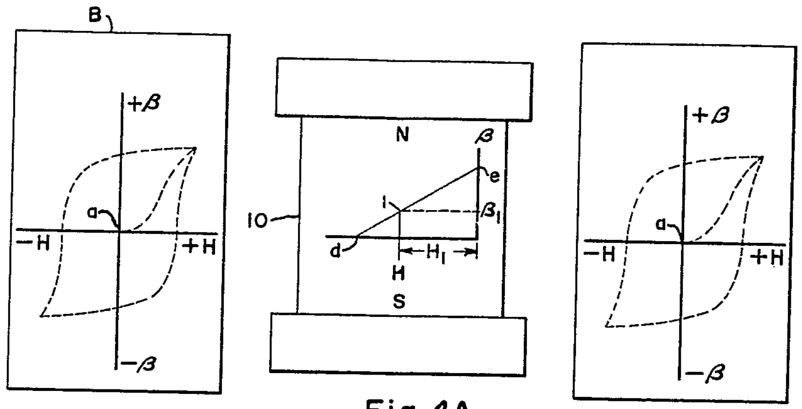

Fig. 4A.

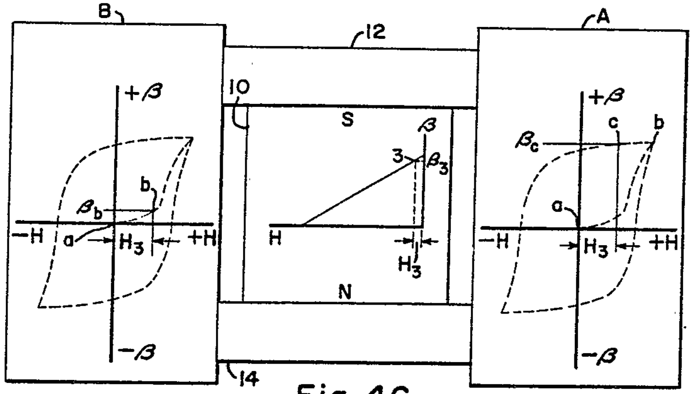

Fig. 4C.

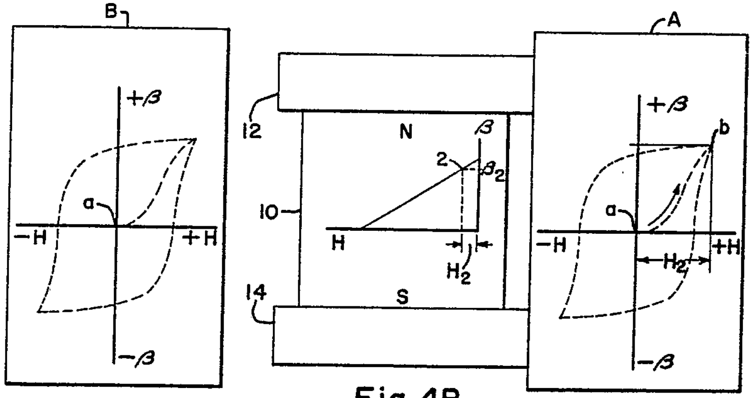

Fig. 4B.

Fig. 5.

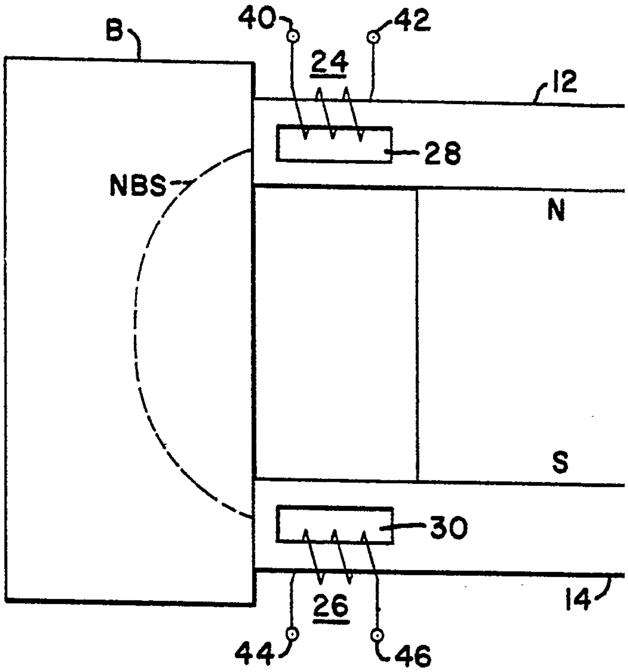

Fig. 6.

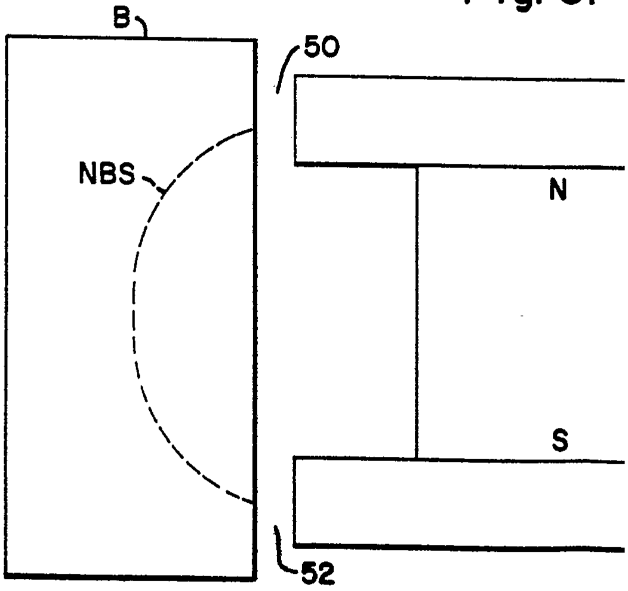

Fig. 5.

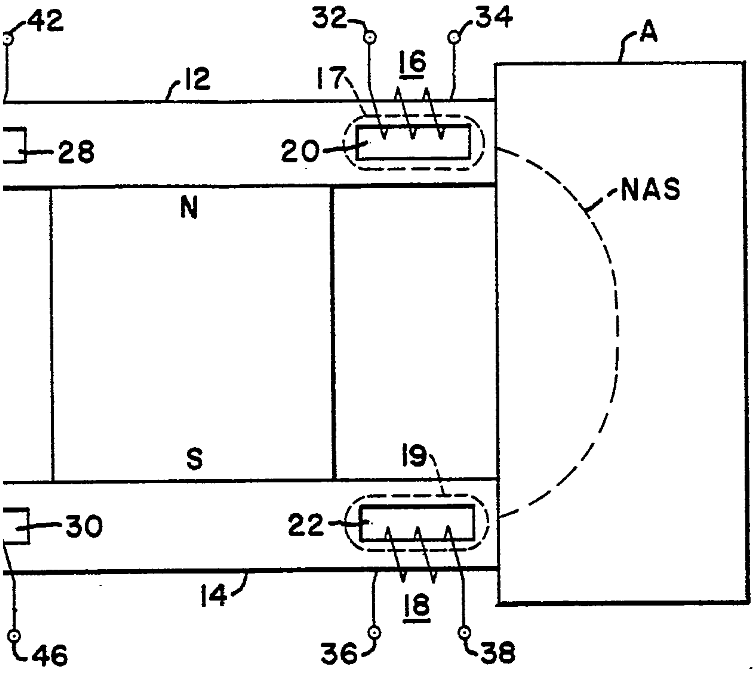

Fig. 6.

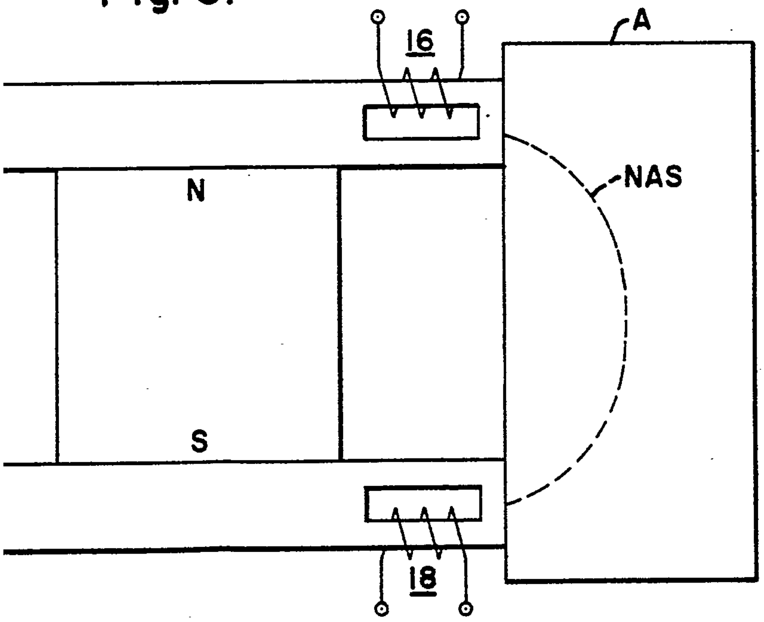

Fig. 5.

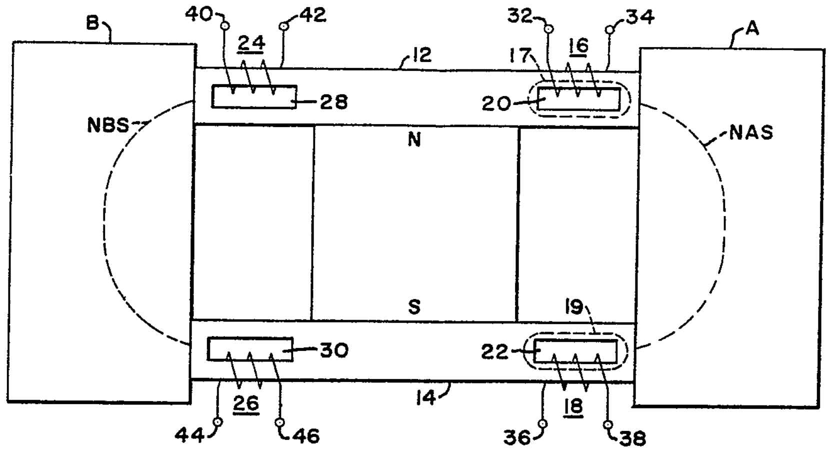
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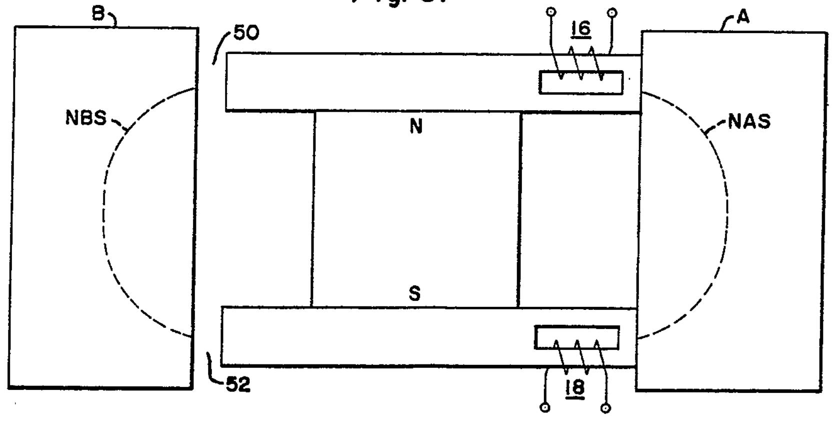
Fig. 6.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