CONTROLLABLE INDUCTOR

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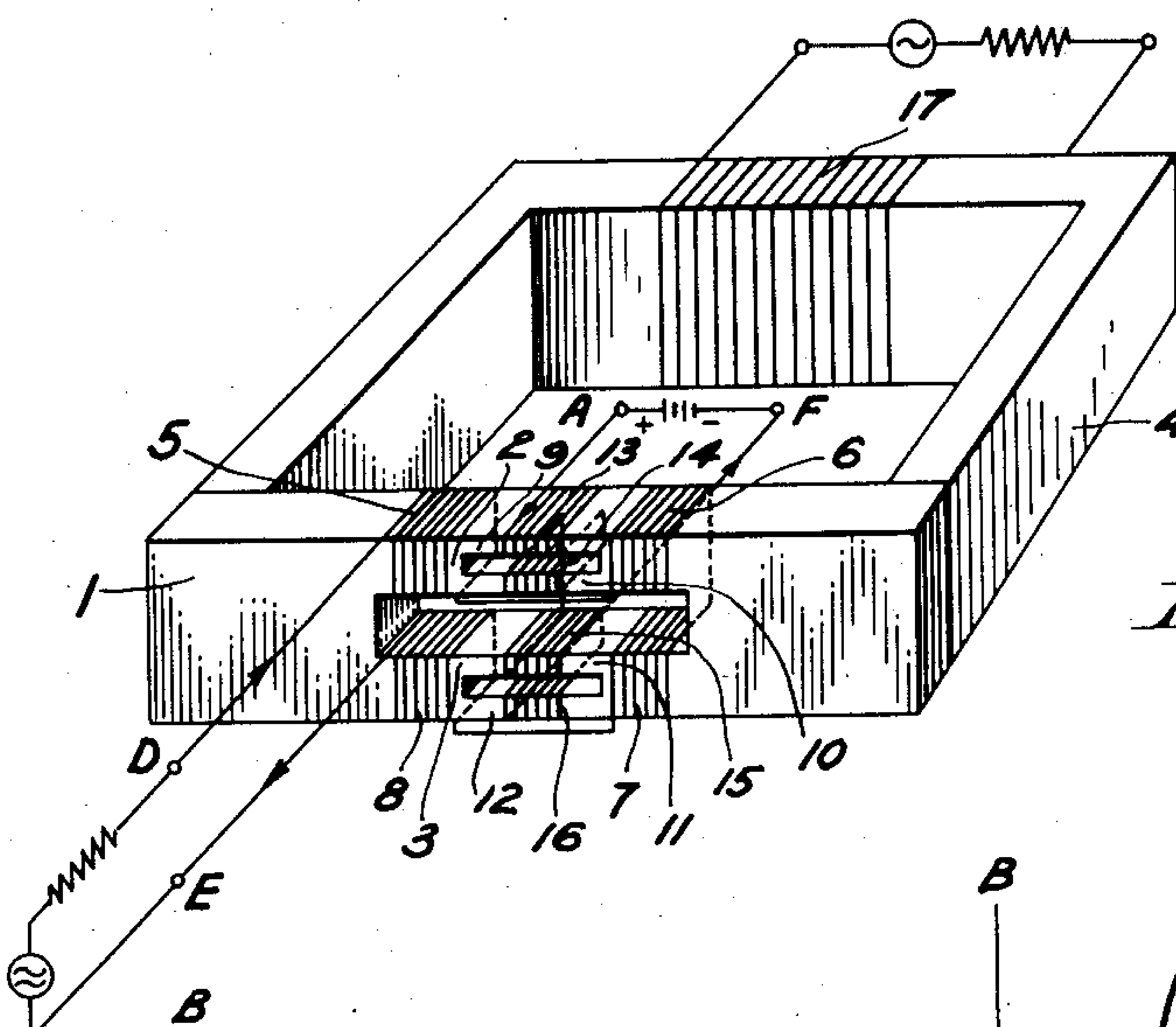

Fig. 1.

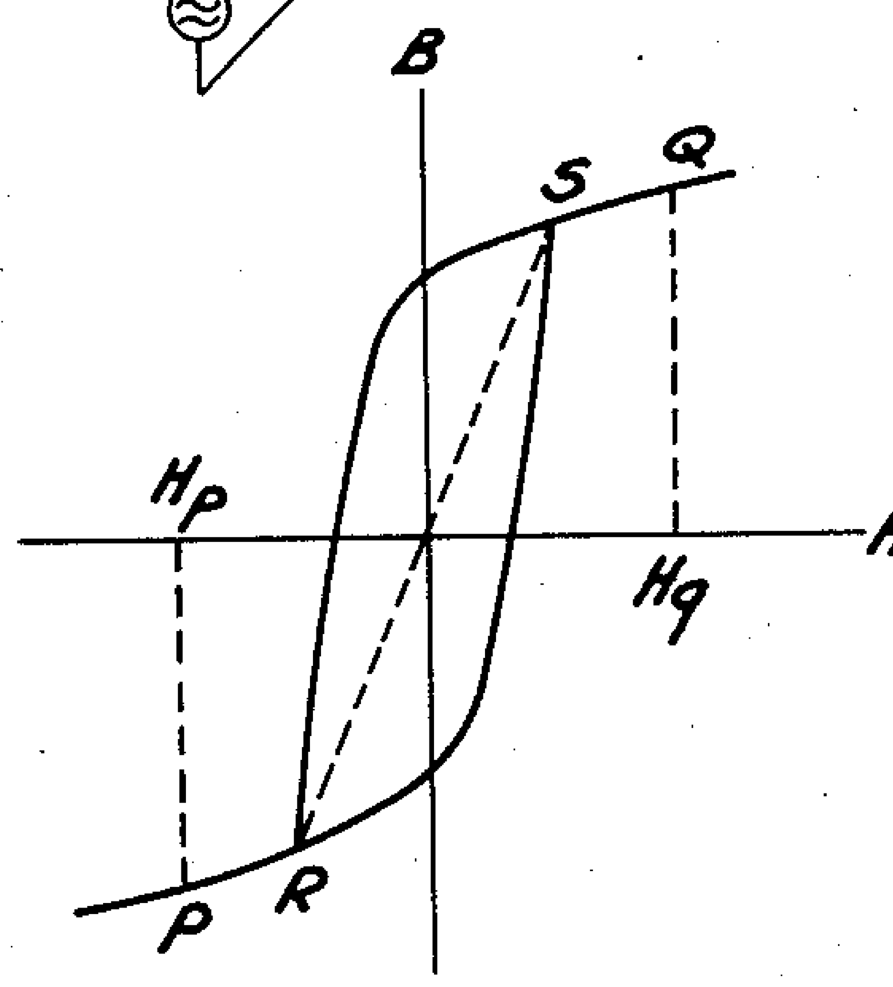

Fig. 2.

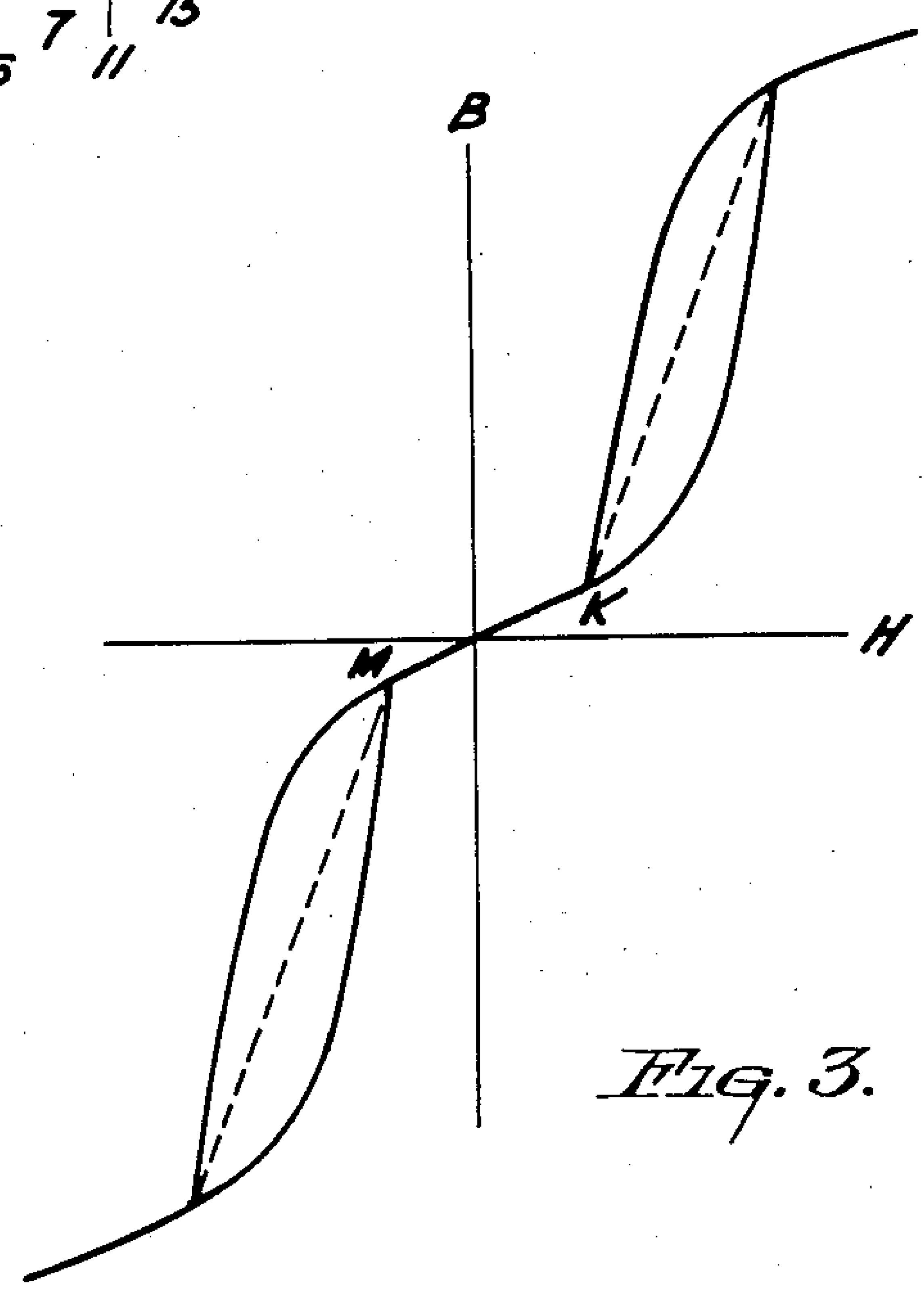

Fig. 3.

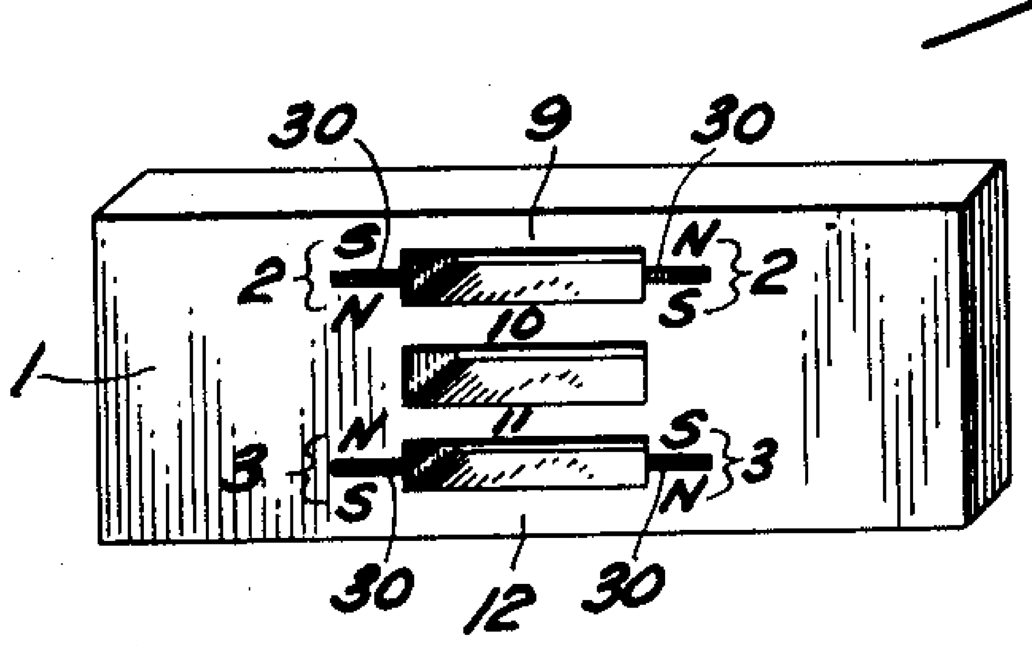

Fig. 6.

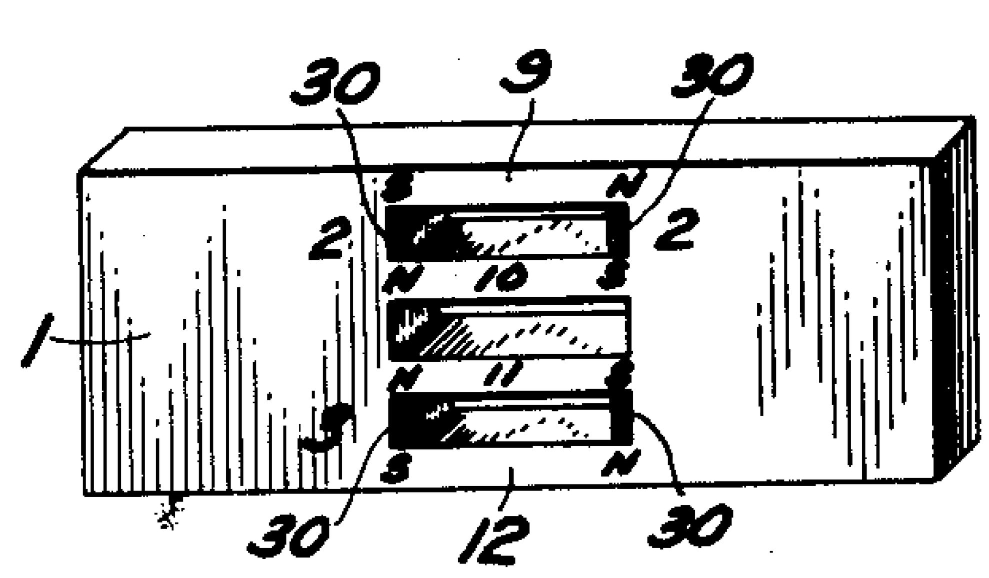

Fig. 7.

INVENTOR.
SIMON DUINKER
BY
[signature]
AGENT.

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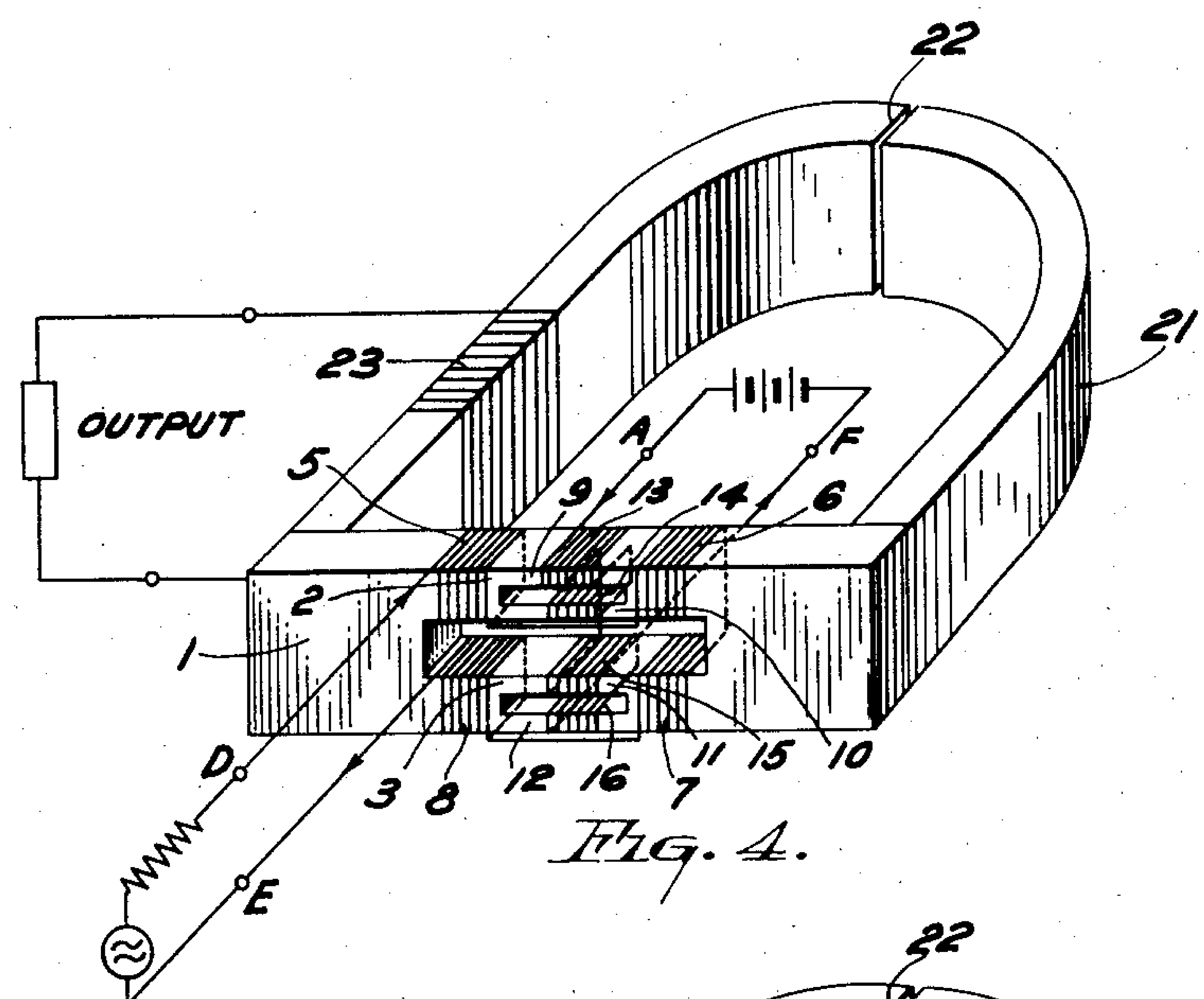

Fig. 4.

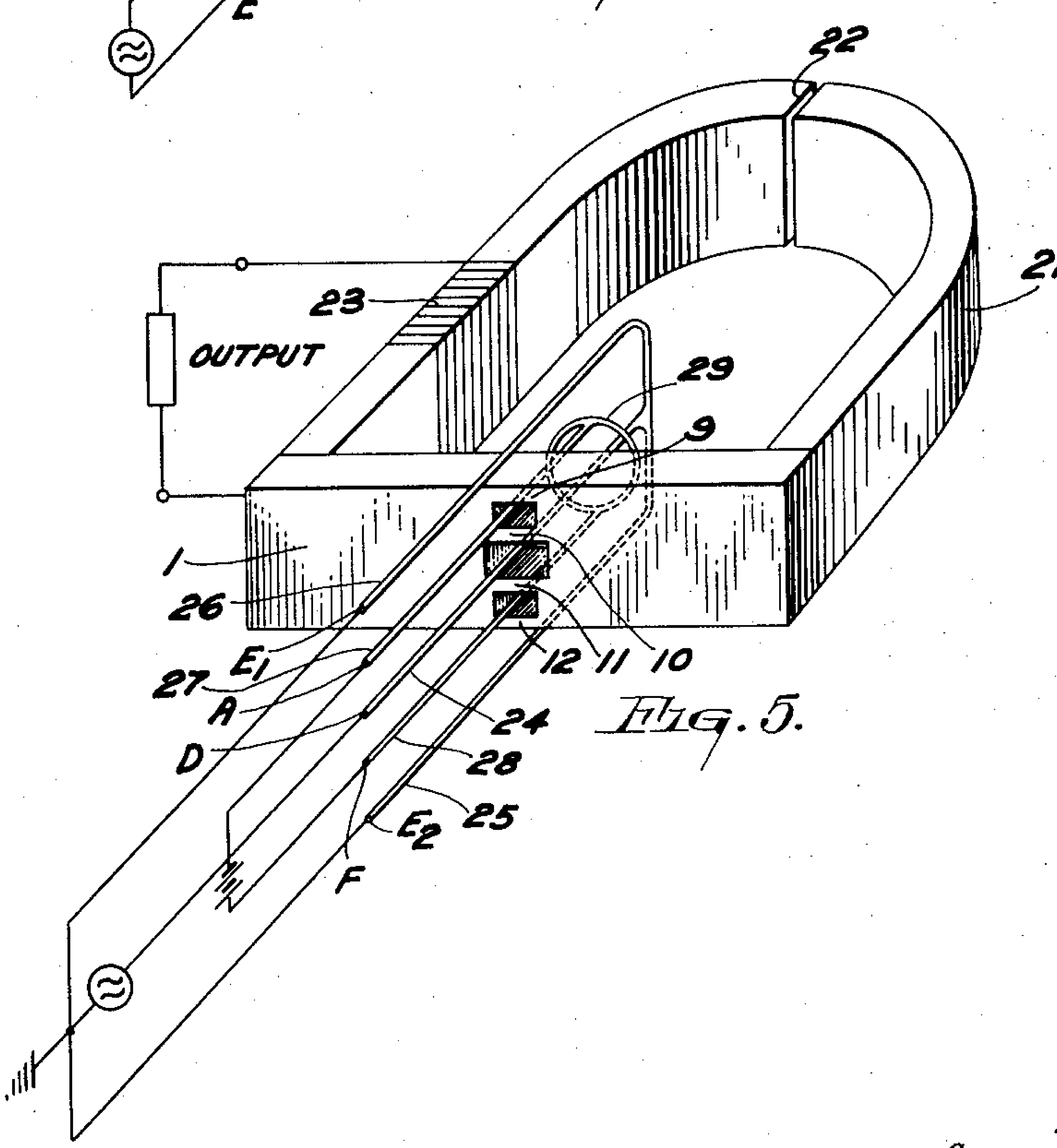

Fig. 5.

INVENTOR.
SIMON DUINKER

BY
Fred M. Vogel
AGENT.

United States Patent Office

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CONTROLLABLE INDUCTOR

Simon Duinker, Eindhoven, Netherlands, assignor, by mesne assignments, to North American Philips Company, Inc., New York, N.Y., a corporation of Delaware

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7 Claims. (Cl. 323—89)

This invention relates to controllable inductances, more particularly suitable for high-frequency purposes and comprising at least one signal coil having a closed ferromagnetic core which is included in a yoke, also of ferromagnetic material, it being possible to vary the inductance of said coil in that the magnetic field produced in the core by the action of an alternating current traversing the coil has modulated on it another magnetic field produced in the said yoke.

Such inductances may be used, for example, in magnetic modulators, controllable oscillatory circuits, trigger-circuits, etc. The core in these cases comprises a closed yoke, the said other magnetic field being produced by a current flowing through a control coil coupled to the yoke. The first-mentioned signal coil is connected to an alternating-current source, the magnetic field produced by the alternating current bringing about in the core magnetic fluxes which are influenced by the said other magnetic field.

Such inductances are also used in magnetic recorders and magnetometers. The core in these cases is included in a yoke having an air gap, the fluxes which occur in the core and which are produced by a current flowing through the first-mentioned coil being influenced by means of a magnetic field set up across the air-gap.

As is well-known, the dimensions of the core must be as small as possible, more particularly for high frequencies of the alternating current flowing through the first-mentioned coil. This is substantially due to the fact that, before the material of the core can have a modulating action, this material must be driven till it is saturated, with the result that the hysteresis loop of the material must be traversed almost completely. Now, the resulting losses which manifest themselves as a development of heat in the material of the core are proportional to the product of the frequency at which the hysteresis loop is traversed, the area of the hysteresis loop and the volume of the core. Consequently, for a given frequency, said losses increase in proportion with the volume of the core and hence with the third power of a longitudinal dimension. However, the surface of the core which can dissipate the heat developed increases only with the square of the longitudinal dimension, so that for larger dimensions of the core this development of heat soon becomes prohibitive. Furthermore, the output of the alternating-current source naturally also increases to a considerable extent. However, the very small dimensions of the core which are desirable in view of the foregoing at high frequencies (say from 0.5 to 10 mcs./s.) render the manufacture of the core and the winding very difficult.

If the area of the hysteresis loop traversed by the action of the alternating current could be suppressed to a considerable extent, it appears from the foregoing that it is possible, on the one hand, to increase the dimensions of the core at constant frequency and, on the other hand, to increase the frequency with constant dimensions. Both possibilities have evident advantages.

According to the invention, the losses of the core due to hysteresis are considerably suppressed due to each of the two active parts of the core being divided into two branches in which direct current fluxes are produced which compensate one another in the undivided parts and which cause each branch to be saturated.

In order that the invention may be readily carried into effect, it will now be described, by way of example, with reference to the accompanying drawing.

Figs. 1, 4, 5, 6 and 7 show embodiments of controllable inductors according to the invention and Figs. 2 and 3 show characteristic curves to clarify the principles of the invention.

Fig. 1 shows one embodiment of controllable inductance according to the invention which may be used, for example, as a part of a magnetic amplifier. Reference numeral **1** indicates the ferromagnetic core comprising a body of material preferably having low electric conductivity, e.g. a ferrite material (see Teletech 11, May 5, 1952, page 50) or a laminated nickel-iron alloy. **2** and **3** are those parts of the core which are actually active when the inductance is influenced by the said other magnetic field and which are hereafter referred to as the active main portions. The signal coil or winding of the inductance is constituted by the coil parts **5**, **6**, **7**, **8**, which are connected in series.

A control coil **17** is wound on a closed yoke **4**, also consisting of ferromagnetic material, e.g. soft iron or also a ferrite material. A current flowing through the coil **17** produces a magnetic field which influences or controls the magnetic fluxes which occur in the body **1** by the action of an alternating current supplied to terminals D—E of the signal coil parts **5**, **6**, **7**, **8**. Each of the parts **2** and **3** is divided into two branches **9**, **10** and **11**, **12** respectively. By means of direct current supplied to terminals A and F of two pairs of coils **13**, **14** and **15**, **16** respectively, which are connected in series, direct current fluxes are produced in said branches in such manner that the direct current flux in branch **9** has the same value, but the opposite direction to the direct current flux in branch **10**, and that the direct current flux in branch **11** has the same value, but the opposite direction to the direct current flux in branch **12**. The values of said direct current fluxes are such that each branch is magnetically saturated.

Fig. 2 shows the hysteresis loop of the material of the core **1**. Assume now that the parts **2** and **3** of the core are not divided, such as in known devices. The controllability of an inductance is based on the non-linearity which exists in the relationship between the magnetic inductance B and the magnetic field strength H. Fig. 2 shows in dashed line the relationship between B and H for the core **1**, when the losses due to hysteresis are disregarded. However, this relationship shows that the said non-linearity in the assumed case manifests itself in a useful way only if the magnetic field produced by means of the current flowing through the coils **5**, **6**, **7** and **8** of the inductance can drive the material till it is saturated and hence till beyond one of the points R and S. However, this implies that in known devices, unless the controlling magnetic field produced in the yoke **4** is very great, during each cycle of said alternating current a large proportion of the hysteresis loop which actually always occurs is traversed and even almost the whole hysteresis loop is traversed if the controlling magnetic field has low values.

However, according to the invention, the parts **2** and **3** are each divided into two branches which are traversed by direct current fluxes in such manner that each branch is saturated, said direct current fluxes compensating one another in the undivided portions of the parts **2** and **3**. The direct current flowing through the coil **13** adjusts, for example, the core part constituted by the branch **9** of part **2** to point Q of the hysteresis loop (see Fig. 2). The direct current flowing through the coil **14** adjusts the core part constituted by branch **10** of part **2** to point P of the hysteresis loop (see also Fig. 2). The direct current fluxes in the branches **9** and **10** consequently have opposite directions. Since the two fluxes are furthermore of equal values, there is no direct-current flux component in the undivided portion of part **2** or main portion.

The effective hysteresis loop of the part 2, as it manifests itself for the magnetic fields produced by the alternating current flowing in the signal coil parts **5** and **6** and in the yoke **4**, is represented by the characteristic curve shown in Fig. 3.

The occurrence of such a characteristic curve will be evident when considering that for said magnetic fields in branch **9**, H_Q, that is the field strength corresponding to point Q, constitutes the new zero point of the H-axis for this branch, and in branch **10**, H_P, that is the field strength corresponding to point P, constitutes the new zero point of the H-axis for this branch. The magnetic inductance B for the whole part **2** is simply constituted by summation of the inductances which occur in the branchs **9** and **10** taking into consideration the transformation of the new H-axis.

Similarly, the effective hysteresis loop for the part **3** has the shape shown in Fig. 3.

Fig. 3 also shows in dashed lines the relationship between B and H, if the losses due to hysteresis are disregarded. In this case the non-linearity manifests itself in a useful way if the magnetic field produced by means of the current flowing through the signal coil of the inductance drives the parts **2** and **3** till beyond one of the points M and K.

It is to be noted in this connection that, according as the points P and Q of Fig. 2 are closer to the points R and S (by giving lower values to the direct current through the coils **13**, **14** and **15**, **16**) the points M and K also more closely approach one another, so that the field strength required to bring the core into its non-linear portion may also be smaller.

It will readily be evident from Fig. 3 that the losses due to hysteresis in the controllable inductance according to the invention are reduced to a considerable extent, since during the largest portion of the cycle of said alternating current traversing the signal coil parts **5**, **6**, **7**, **8**, the branches **9**, **10**, **11**, **12** are saturated, where these losses are very small and theoretically even zero. Only for very high values of the controlling magnetic field when the parts **2** and **3** are driven far beyond one of the points M and K, the losses again increase to a considerable extent. The fact that, as a rule only small controlling magnetic fields are available, makes this disadvantage unimportant.

It is preferable that the magnetic reluctance of the undivided portions of the parts **2** and **3** should be given a low value with respect to that of the brances **9**, **10**, and **11**, **12** respectively, in order to avoid that considerable losses may still occur in said undivided portions. According to a further feature of the invention, the sum of the cross-sections of each pair of branches is thus smaller than the cross-section of the associated undivided or main portion.

Fig. 4 shows one embodiment of a controllable inductance according to the invention, which may be used, for example, for reading out information registered on a suitable carrier of ferromagnetic material. Reference numeral **1**, as before, indicates the magnetic core comprising a body of material preferably having low electric conductivity, and **2** and **3** are those main parts of the core which are actually active when the inductance is influenced by the said other magnetic field. In this case also the signal coil of the inductance is constituted by the coil parts **5**, **6**, **7** and **8**, which are connected in series. The yoke **21** has an air-gap **22**. The principle which underlies such a magnetic recording head formed in the shape of a controllable inductance is known per se. The alternating current flowing in the signal coil parts **5**, **6**, **7**, **8** produces in the parts **2** and **3** magnetic fluxes on which the magnetic field occurring across the air-gap **22** are modulated. Said modulated magnetic fluxes or components thereof are converted by means of a winding **23** arranged on the yoke **21** into an alternating voltage, which, after being rectified, provides a current or a voltage proportional to the scanned magnetic field. Such a device affords the advantage over an ordinary magnetic recording head that the current or voltage which is a measure of the scanned magnetic fields is substantially independent of frequency and that, in view thereof, very low frequencies and direct current fields may be scanned and reproduced thereby without objection. Furthermore, in most cases an amplifying stage may be omitted.

The very small dimensions of the core which are desirable at high frequencies not only render the manufacture of the core and the winding very difficult, but also in this case have the additional disadvantage that the magnetic reluctance of the parts **2** and **3** becomes so high that a large proportion of the magnetic fields occurring across the air-gap **22** is set up as a stray field across this gap, so that only a small part has a modulating action. The invention provides in this case also the possibility of increasing the dimensions of the core at constant frequency of the alternating current flowing through the signal coil parts **5**, **6**, **7**, **8** and of increasing the frequency of said alternating current with constant dimensions of the core without an prohibitive increase in heat development in the core being involved. According to the invention, for this purpose the parts **2** and **3** are each divided, as before, into two branches **9**, **10** and **11**, **12** respectively. By means of coils **13**, **14** and **15**, **16** respectively, direct current fluxes are produced in said branches in such manner that the direct current flux in branch **9** has the same value, but the opposite direction to the direct current flux in branch **10** and that the direct current flux in branch **11** has the same value, but the opposite direction to the direct current flux in branch **12**. The values of the direct current fluxes are such that each branch is saturated. It is thus ensured that the effective hysteresis loop both of the parts **2** and the part **3**, as it becomes manifest for the magnetic fields produced by means of the alternating current flowing in the signal coil parts **5**, **6**, **7**, **8** and produced in the yoke **21** is represented by the characteristic curve as shown in Fig. 3, with the result that the losses due to hysteresis are again reduced to a very considerable extent.

Finally, it is mentioned that the coil configurations as shown in Figs. 1 and 4 are naturally not essential for the invention. Thus, for example, each of the coil halves **5**, **6** and **7**, **8** may be united to form a single signal coil surrounding completely the coils **13**, **14** and **15**, **16**, respectively, of its associated main portion. Another possibility is that the signal coil of the inductance is constituted by a single conductor led through the gap, which exists between the parts **2** and **3** of the core and that also the coils for producing the direct current fluxes in the branches **9**, **10** and **11**, **12** respectively, are constituted by single conductors. Fig. 5 shows this configuration. The corresponding parts of Figs. 4 and 5 are indicated correspondingly, **24** indicating the coil of the inductance. In view of the desirable symmetries in such devices, the coil **24** comprises, at one extremity, two parallel branches **25** and **26**, of which the terminals E_1 and E_2 may be connected to the same terminal of the alternating current source. The coils for producing the direct current fluxes are constituted by conductors **27** and **28**, which are connected in series by means of a circular conductor **29** surrounding the conductor **24**. However, it is alternatively possible for the said direct current fluxes to be produced by means of small permanent magnets which are incorporated, for example, in the branches **9, 10, 11** and **12**, naturally with suitable strength and proper polarity. Said permanent magnets need not be arranged in the branches themselves, but can alternatively be arranged in the non-divided portions or even in the gaps between the branches, as shown in Figs. 6 and 7, in which only the ferromagnetic core **1** is shown with the parts **2** and **3**, which are divided into the branches **9, 10** and **11, 12** respectively. The small permanent magnets are indicated by **30**.

What is claimed is:

1. A controllable inductor adapted for operation with high-frequency currents comprising an apertured ferromagnetic member providing a closed core having a pair of active substantially parallel leg portions, each of said leg portions having an aperture defining two branches so that a total of four branches are present, a signal coil surrounding said active leg portions, means coupled to said coil for passing alternating current therethrough to establish a magnetic field in said active leg portions, means including another ferromagnetic member coupled to said closed core for introducing therein another magnetic field which interacts with the magnetic field produced by the coil, and means continuously establishing in the two branches of each leg portion equal and opposite D.-C. magnetic fluxes which saturate each of said branches, whereby the operating frequency of said inductor may be materially increased.

2. An inductor as set forth in claim 1 wherein the last-named means includes coil means surrounding the branches and a source of direct current coupled to said coil means.

3. An inductor as set forth in claim 1 wherein the last-named means includes permanent magnets located near the branches.

4. An inductor as set forth in claim 1 wherein the means for introducing the other magnetic field includes a yoke member and a control coil surrounding said yoke member.

5. An inductor as set forth in claim 1 wherein the means for introducing the other magnetic field includes a yoke member and a modulating gap in said yoke member.

6. An inductive device comprising a closed ferromagnetic core including a pair of active parallel main portions, each of said main portions comprising two distinct parallel branch portions, thereby establishing a total of four parallel branch portions, means continuously establishing a direct-current magnetic field in all the branch portions of sufficient magnitude always to saturate magnetically each branch portion and such that the field is in opposite directions in the branch portions of each main portion, a pair of connected signal windings each coupled to one of said main portions and arranged so that the field produced in the associated main portion when current traverses the signal windings is in the opposite direction to that produced in the other main portion, means for passing alternating current through the signal windings while the branch portions are maintained in a saturated condition, and means coupled to said core for establishing in the same direction in the main portions a modulating magnetic field, thereby to modulate the inductance exhibited by said windings when traversed by the alternating current.

7. A device as set forth in claim 6 wherein the combined reluctance of the two branch portions of each main portion is greater than the reluctance of the adjacent, undivided main portion.

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