Sept. 4, 1956 C. G. SONTHEIMER 2,762,009

APPARATUS FOR MAGNETIC RECTIFIERS

Filed Jan. 8, 1952

FIG. 1.

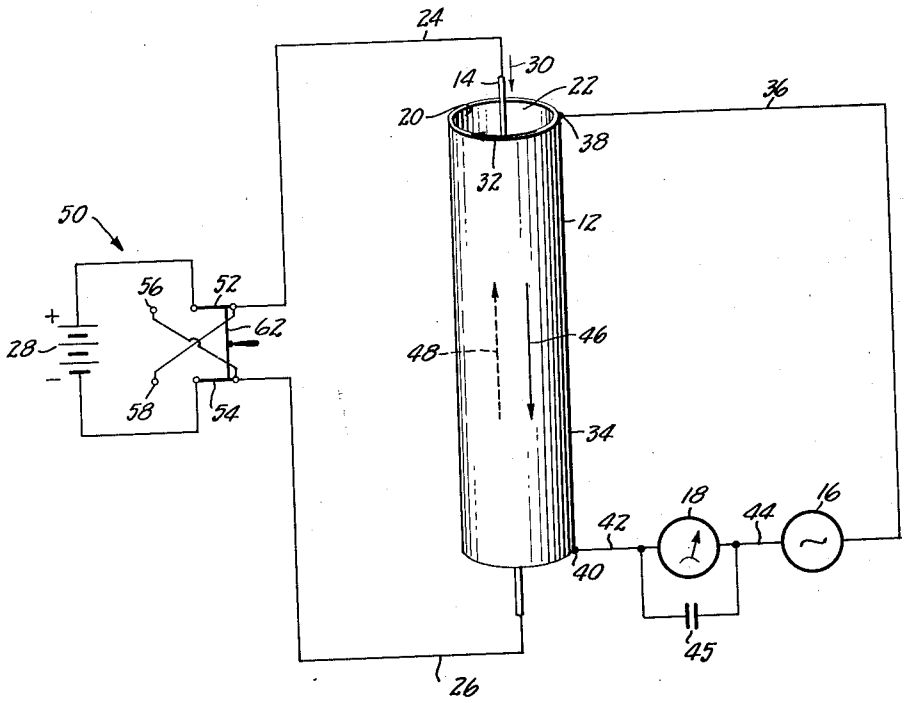
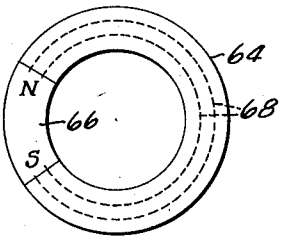


FIG. 2.



Inventor

CARL G. SONTHEIMER

By

Curtis, Morris & Safford.

Attorney

United States Patent Office 2,762,009 Patented Sept. 4, 1956

2,762,009

APPARATUS FOR MAGNETIC RECTIFIERS

Carl G. Sontheimer, Riverside, Conn., assignor to C. G. S. Laboratories, Inc., Stamford, Conn., a corporation of Connecticut

Application January 8, 1952, Serial No. 265,417

8 Claims. (Cl. 321—43)

This invention lies in the field of rectifiers, and more particularly in the field of methods and apparatus for magnetically controlling rectification from alternating into direct current. In this invention a paramagnetic element carries the alternating current components and a rectifying action is produced by magnetic control of the "skin effect" in this element.

In order to rectify alternating current it has been the practice in the past to pass the current to be rectified through a rectifying device having an inherent uni-directional current characteristic, that is, the rectifying device by its very nature allowed the flow of current through itself more readily in one direction than in the other.

This inherent uni-directional characteristic is well known in several different kinds of prior art devices, that is, the direction of low resistance to current flow is fixed once the device is constructed. For example, in thermionic vacuum tube rectifiers electrons are emitted from a hot cathode and flow toward a plate, but they cannot flow from the plate to the cathode. This direction of current flow is an inherent quality of such tubes. Other examples of rectifiers with uni-directional characteristics are those of the barrier layer and semi-conductor crystal type, the direction of low resistance to current flow being predetermined by the barrier layer or crystal material when such rectifiers are built.

According to the method of the present invention, the current to be rectified must be sufficiently high in frequency that its flow through a paramagnetic element is impeded significantly by the skin effect. Rectification is achieved by causing a periodic variation of the magnitude of this skin-effect resistance by changing the degree of magnetic saturation of the paramagnetic element. In a preferred embodiment, a steady bias magnetic field is established in the paramagnetic element and high frequency alternating current to be rectified is passed through this element in such direction that its magnetic field alternately aids and opposes this bias field. By a paramagnetic element is meant a conductor having a magnetic permeability significantly greater than unity. The bias magnetic field reacts with the field of the alternating current with the result that the magnetic saturation of the paramagnetic element alternately increases and decreases causing the skin effect resistance to change at the same rate so that the alternating current is conducted more readily in one direction than in the other, and the direction of low resistance to current flow depends upon the relationship between the direction of the bias and the alternating-current fields.

The various aspects, advantages, and objects will be in part apparent from and in art pointed out in the following description considered together with the accompanying drawing, in which:

Figure 1 is a diagrammatic and schematic representation of a rectifier embodying the present invention and

Figure 2 is an end view of a paramagnetic element embodying the present invention in which the bias magnetic field is created by a permanent magnet.

Figure 1 shows a tubular paramagnetic element **12**, formed, for instance, from soft iron, "Mu-metal," or "Permalloy," or the like, surrounding a conductor or wire **14** extending longitudinally through the element

12. A source **16** of high-frequency alternating current to be rectified is connected to the element **12** in series with a direct current responsive device, for example, a meter **18**. As explained hereinafter a greater resistance is offered to the flow of the high frequency current through the element **12** in one direction than in the other with the result that a direct current component flows through the meter **18**.

In order to create a bias magnetic field within the paramagnetic sleeve, the wire **14**, which may be separated from the inside surface **20** of the sleeve **12** by air or by a layer of solid insulating material **22** such as polystyrene, is connected by leads **24** and **26** to a source of direct current such as a battery **28**. A steady current thus flows through the conductor **14**, for example in the direction of the arrow **30**, with the result that a circular magnetomotive force is created around the conductor **14** and a bias magnetic field is established within the paramagnetic sleeve **12**. This bias field exist in a closed path through the sleeve **12** and may be represented conveniently by the arrows **32** in the direction of the lines of the bias flux. This bias field exists throughout the whole cross section of the sleeve **12**, that is, from the inside surface **20**, to the outside surface **34**.

The high-frequency source **16** is connected by a lead **36** to the sleeve **12**, as at **38**, and the circuit is completed from a connection **40** on the opposite end of the sleeve **12**, through a lead **42**, the meter **18** and a lead **44** back to the source **16**. A condenser **45** by-passes the alternating current components around the meter **18**.

In order to explain the operation of the rectifier system, consider the action during the half cycle of alternating current when it is flowing downwardly through the sleeve **12** in the direction of the arrow **46**, this being the same direction of flow as the direct current through the lead **14**.

The alternating and direct magnetomotive forces are additive during this instant of time increasing the total amount of magnetic flux **32** in the paramagnetic sleeve **12**. As the magnetic saturation of the sleeve **12** increases, its permeability decreases, and hence the resistance to the flow of high frequency current caused by skin effect decreases.

"Skin effect" is an effect which causes a non-uniform distribution of alternating current over the cross section of a conductor. Because of skin effect alternating current density is greatest at the outside surface of a conductor, decreasing toward the center. This effect increases with frequency and becomes so marked at high frequency that virtually all of the current travels through a very thin surface layer of the conductor, i. e. through the "skin" of the conductor. Thus, the present system is useful only where the resistance caused by skin effect is of significant magnitude.

The magnitude of the skin effect is given in the Text "Principles of Radar," written by the M. I. T. Radar school, second edition, 1946, chapter VIII, article 3 as follows:

$$\delta\sqrt{\frac{\rho}{\pi\mu f}} \text{ meters}$$

where δ is the thickness of the skin layer; that is, at a depth of δ below the surface of the conductor the current density is decreased to approximately ⅓ the current density at the surface. ρ is the resistivity of the conductor in meter-ohms, μ is the magnetic permeability in henries per meter, and f is the frequency in cycles per second.

The result of the fact that alternating current tends to hug the surface layer of a conductor is that the effective resistance of the conductor is correspondingly increased, because a lesser effective cross sectional conductive area is available to carry the current. At the higher fre-

quencies at which skin effect becomes more marked the alternating current resistance may be a great many times the resistance which the same conductor would present to direct current. The formula given above shows that an increase in the permeability of the conductor reduces the skin depth, or in other words, increases the skin effect and correspondingly increases the resistance of the conductor.

Under the initial assumption made above that the instantaneous value of the alternating current is such that its magnetic field aids the bias magnetic field, causing a reduction in permeability, the skin effect of the element 12, is relatively low, and its effective resistance is low.

During the next half cycle of the high frequency current when the alternating current flows in the opposite direction, indicated by arrow 48, the alternating magnetomotive force opposes the magnetomotive force of the bias field created by the current flowing through the conductor 14. Because the two magnetic fields are opposing, the total flux is reduced, reducing the saturation of sleeve 12 and increasing its permeability. Thus the skin effect and resistance of the sleeve 12 is increased.

Since the element 12 offers a low resistance to the half cycles of alternating current flowing in the direction of the arrow 46 and offers a high resistance to the intervening half cycles of alternating current flowing in the direction of the arrow 48, the sleeve 12 acts as a rectifier and a component of direct current is supplied to the meter 18, which is considered to be representative of any load circuit or direct current responsive device.

In order to reverse the direction of the rectifying action in the sleeve 12, the direction of current through the conductor 14 may be reversed by means of a reversing switch, generally indicated at 50. Two switch arms 52 and 54 are moved simultaneously into engagement with contacts 56 and 58, respectively, by means of a mechanical link 62, reversing the direction of current flow through element 14. With the direction of the bias current reversed, the sleeve 12 offers a low resistance to the half cycles flowing in the direction 48 and offers a high resistance to the half cycles flowing in the reverse direction 46. Thus, the rectifying action of the rectifier 10 is reversed merely by reversing the polarity of the bias source 28 by means of the switch 50.

In Figure 2 is shown an end view of a sleeve 64, corresponding to the sleeve 12 of Figure 1 but having a longitudinal section in the form of a permanent bias magnet 66 which serves to create a bias flux 68 flowing through the sleeve 64. With the magnet inserted in this position, the element 64 readily conducts alternate half-cycles of alternating current flowing in a direction into the plane of the drawing, for the alternating field is then aiding the steady magnetic field provided by the magnet 66. The intermediate half-cycles of alternating current, flowing out of the plane of the drawing are opposed by an increase in skin effect resistance.

The direction of the rectifying action in element 64 can be reversed by removing the bias magnet 66 and reinserting it with the north and south poles reversed, hence reversing the direction of the bias field 68.

Rectifiers according to this invention may be used to rectify alternating current of any frequency above the frequency at which the skin effect becomes significant. The strength of the bias field should be sufficient to cause a significant change in the skin effect during alternate half cycles as the alternating magnetic field alternately aids and opposes this bias field. Ordinarily the utility of this device is in the rectification of frequencies above the audio frequency range.

I claim:

1. A rectifier system including a paramagnetic element, a source of high frequency current connected in series with said element, the frequency of the current being high enough to produce significant skin effect resistance in said paramagnetic element and means for producing a unidirectional magnetic bias field within said element of sufficient strength to cause a significant change in the skin effect of said element.

2. A rectifier system as claimed in claim 1 wherein said element is a paramagnetic tube and said bias producing means includes a wire extending longitudinally through said tube and a source of unidirectional current connected thereto.

3. Apparatus as claimed in claim 2 wherein said tube is formed of iron.

4. Apparatus of the character described for producing rectification by variation in skin effect including a paramagnetic alternating-current-conduction element, a source of high frequency current connected to pass current through said element, the frequency of said high frequency current being higher than the minimum frequency which produces significant skin effects in said paramagnetic element magnetic-bias-creating means producing a bias magnetic field flowing through at least a portion of said element and establishing therein a magnetic bias field of sufficient strength to vary significantly the incremental permeability of said element during alternate half-cycles of said alternating current and thus its skin effect whereby a rectifying action is produced, and a direct current responsive device connected to said element.

5. Apparatus of the character described including a ferromagnetic alternating-current-conduction element, a source of high frequency current connected to a pair of spaced points on said element, said spaced points defining an electrical conduction path for current passing between said points and through said element, the frequency of said current being high enough to produce significant skin effect in said ferromagnetic element and magnetic-bias-creating means producing a bias magnetic field flowing through at least a portion of said element and establishing therein a magnetic bias field of sufficient strength to vary significantly the skin-effect resistance of said element, the lines of flux of said bias field in said portion being oriented substantially perpendicular to the direction of the conduction path of said high frequency current in passing between said points.

6. A rectifier system including a paramagnetic alternating-current-carrying element, a source of alternating current connected to pass current through said element, the frequency of said alternating current being high enough to produce substantial skin effect in said paramagnetic element, a magnetic field generator producing a steady bias magnetic field extending within said element, the strength of said bias field being sufficient to change significantly the "skin effect" of said paramagnetic element, and means for reversing the direction of said bias magnetic field whereby the direction of low resistance to alternating current flow through said paramagnetic element is reversed.

7. Apparatus as claimed in claim 1 wherein said magnetic bias field producing means produces a unidirectional magnetic field having a predetermined direction in said paramagnetic element and said high frequency current flows through said element substantially perpendicularly to said predetermined direction of said magnetic bias field.

8. A system as claimed in claim 1 wherein said magnetic-bias-field producing means is a permanent magnet having poles of opposite polarity, said poles being magnetically linked to spaced regions of said element and inducing a magnetic field in said element between said spaced regions.

References Cited in the file of this patent

UNITED STATES PATENTS

1,857,160	McEachron	May 10, 1932
2,142,837	Edwards	Jan. 3, 1939
2,283,697	Prince	May 19, 1942
2,329,021	Walsh	Sept. 7, 1943