May 9, 1950 H. W. FULBRIGHT 2,507,301

APPARATUS FOR CONTROLLING MAGNETIC FIELDS

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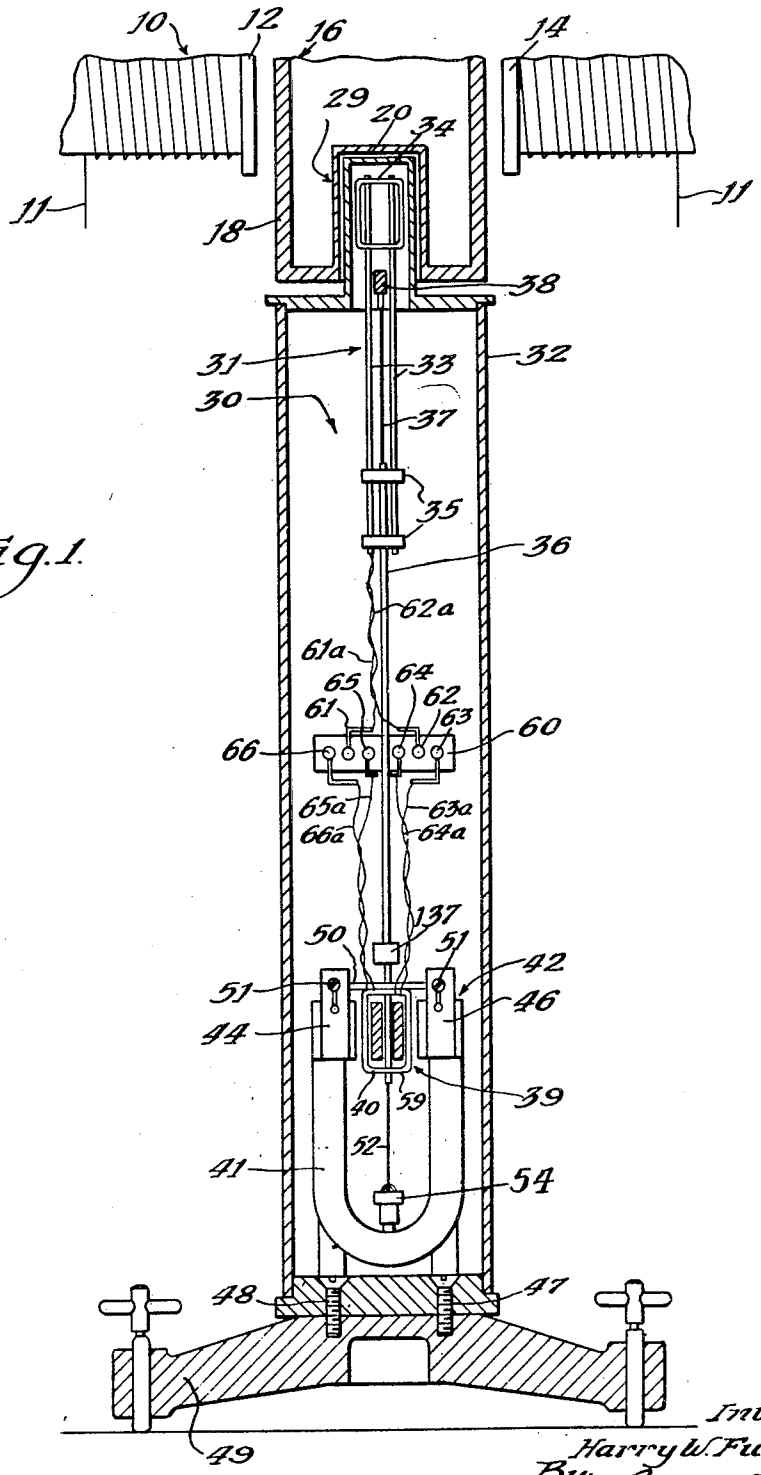

Fig. 1.

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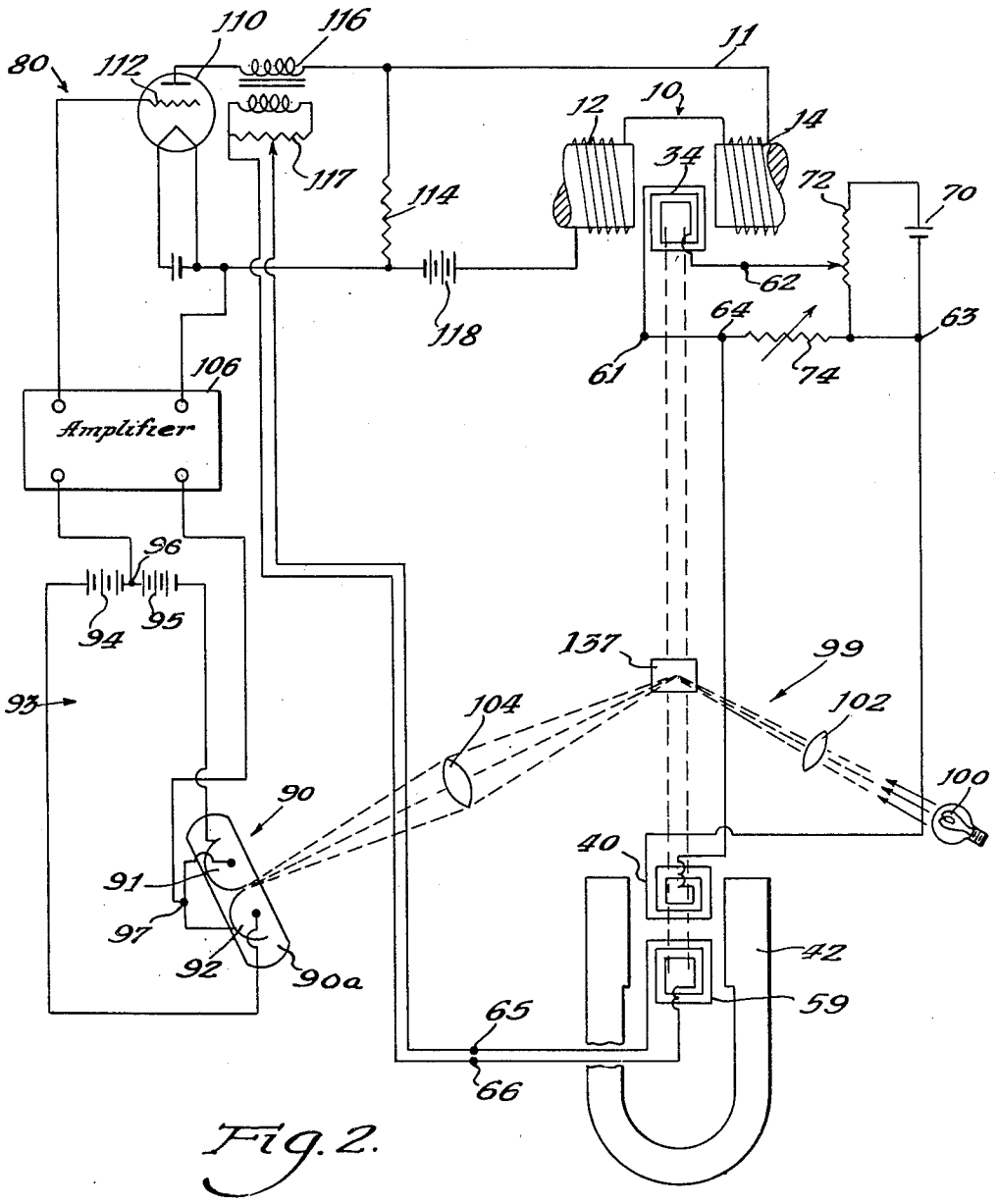

Fig. 2.

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APPARATUS FOR CONTROLLING MAGNETIC FIELDS

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7 Claims. (Cl. 175—335)

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This invention relates to a magnetic field controller, and is concerned with the provision of a novel improved apparatus whereby the controller automatically controls a magnetic field by varying the current through the windings of an associated electromagnet.

The invention is of particular utility in the maintenance of a constant magnetic field when operating a magnetic momentum selector. In the utilization of the controller in conjunction with a magnetic momentum selector, such as a mass spectrograph, it is desirable to maintain a constant magnetic field over a long period of exposure time; and when operating the selector as a spectrometer, it is desirable that a reproducible magnetic field be maintained when making successive exposures. Inherent difficulties which arise due to the hysteretic losses produced in the iron core of the electromagnet will make the conventional field current measurements of the electromagnet substantially inaccurate. Therefore, it is of importance that the measurement of the magnetic field be made directly and not rely on secondary current measurements.

It is an object of the present invention to provide a magnetic field controller which will automatically compensate for a variation in a magnetic field.

It is a further object to provide a device of the above nature having a compensating optical-electrical network which will automatically vary the current through the windings of an electromagnet corresponding to changes in a varying magnetic field.

Other features of the invention will be hereinafter described and claimed.

In the drawing Figure 1 is a vertical cross-sectional view, partially in elevation, of the galvanometer unit embodying the principles of the invention;

Figure 2 is a diagrammatic view of the controller showing the inter-relationship between the associated optical and electrical system and the galvanometer unit.

Referring now to the drawings, the numeral 10 generally designates an electromagnet consisting of pole pieces 12 and 14 of ferro-magnetic material and an electrical winding 11 which is wound around the periphery of said pole pieces 12 and 14. A portion 16 of a magnetic momentum selector is disposed in the air gap between the associated pole pieces 12 and 14 and said portion 16 of the selector being defined by the side walls 18 constructed of non-magnetic material.

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A re-entrant chamber 20 is disposed in the side walls 18 of the magnetic momentum selector.

The galvanometer unit generally described by numeral 30 is encased in a unit housing 32 having an upper portion inserted in the re-entrant chamber 20 of the magnetic momentum selector. The galvanometer unit 30 consists of two galvanometer elements generally indicated by numerals 29 and 39 wherein the first galvanometer element 29 is defined by a coil winding 34 and the magnetizable structure of the electromagnet 10. This combination including the coil winding 34 and the electromagnet 10 shall be designated, for purposes of illustration, as the "first" galvanometer element. A "second" galvanometer element 39 is defined by a coil winding 40 and a permanent magnet 42 consisting of a U-shaped yoke 41 of ferro-magnetic material defining two pole pieces 44 and 46. The U-shaped yoke is attached to the lower portion of the housing 32 by means of stud bolts 47 and 48 mounted to a base plate 49.

The galvanometer unit 30 comprises an upper member 31 consisting of two similar upright members 33 which are constructed of light tubular material, such as aluminum. Attached to the upper portion of said members 33 is the first coil winding 34 which is disposed in the magnetic field produced by the electromagnet, said field being the magnetic field which is to be controlled. The upright members 33 are inter-connected by a plurality of cross-members 35 and attached to a central member 36 of the galvanometer unit 30. The central member 36 is attached to a suspension fiber 37 made of a non-magnetic material such as phosphor copper. The upper extremity of said fiber 37 is attached to a cross-piece 38 which is rigidly mounted to the galvanometer housing 32. A cross-member 50 is attached at the lower portion of the center member 36 and attached thereto is the second coil winding 40. Said cross member 50 is adapted to perform as a stopping bar so as to prevent large angular rotation of the galvanometer unit 30; and the angular rotation of the galvanometer unit 30 may be limited by adjusting the stopping screws 51 mounted in the associated pole pieces 44 and 46 respectively. At the lower portion of the central member 36 a lower fiber suspension 52 is attached thereto; and the lower extremity of said fiber 52 is attached to a mounting 54 which is fixed to the inner portion of the yoke 41. The fiber 52 affords a lower mounting means so as to prevent translational motion of the galvanometer unit 30.

The first coil winding 34 is electrically connected to a central electrical connection block 60, which is firmly mounted to the housing 32. The lead wires 61a and 62a of said winding 34 are connected to the binding posts 61 and 62 respectively. The second winding 40 is connected by means of lead wires 63a and 64a to the binding posts 63 and 64 respectively.

A third coil winding 59 is attached to the lower extremity of the central member 36 and mounted in the field of the standard permanent magnet 42. For purposes of the illustration in Fig. 1 the third winding 59 is superimposed upon the second winding and appears to be a composite coil except for the lead wires 65a and 66a which extend therefrom and are attached to the block 60 by means of the binding posts 65 and 66 respectively.

Referring to Figure 2 it shall be noted that the binding posts 61, 62, 63, 64, 65, and 66 are schematically illustrated on said drawing so that the corresponding connections can be noted in the circuit diagram. A battery 70 affords a source of current which flows through a potentiometer 72 so as to allow a small amount of direct current to pass through the first coil 34. By varying the variable resistor 74, a proportional amount of direct current will be allowed to pass through the second coil 40. Since a small amount of current is allowed to pass through each coil 34 and 40 in such a manner that the torques exerted on the galvanometer unit 30 by the magnetic forces acting on the first coil 34 and the second coil 40 are mutually in opposition, a null position of the galvanometer unit 30 may be attained. For any ratio of currents in the two windings 34 and 40, there is one and only one value of field strength of the electromagnet 10, for which the suspended galvanometer unit 30 will be in equilibrium at its null position. Thus, it is necessary only to adjust the field current flowing through the winding 11 of the electromagnet 10 so as to keep the suspended galvanometer unit 30 in equilibrium at its null position in order to keep the magnetic field strength developed across the air gap of the electromagnet 10 constant. This manner of control is accomplished by the use of an electronic amplifier generally indicated by numeral 80, controlled by means of a dual photocell circuit generally indicated by numeral 90, said photocell circuit 90 being actuated by an associated optical system 99 wherefrom a beam of light is reflected from a mirror 137 which is attached centrally to the central member 36.

In operation a source of light from a light bulb 100 is directed through a condensing lens 102 and reflected from the mirror 137 onto a second condensing lens 104 so as to concentrate the light beam at a point intermediate between dual cathodes of the photoelectric cells 91 and 92 of the photoelectric tube 90A. This position intermediate between the cathodes of the photoelectric tube is considered the null position of the galvanometer unit 30. An electrical bridge circuit 93 consisting of batteries 94 and 95 comprising adjacent balancing arms of fixed voltage ratio, is connected in series with the current paths of the photoelectric cells 91 and 92, the latter comprising adjacent balancing arms of variable voltage ratio. The conjugate points 96 and 97 of the bridge are connected by conductors through a conventional direct voltage amplifier 106. The output of the amplifier 106 is coupled to the grid 112 of the thermionic amplifier tube 110. The current output of the current amplifier tube 110 is transformer coupled by means of a transformer 116 to the winding 11 of the electromagnet 10. The current amplifier stage generally indicated by numeral 80, in the particular instance, employs a 2A3 thermionic tube wherein a fraction of the output of the amplifier stage 80 is employed as the field current of the electromagnet 10. The balance of the output current in said amplifier 80 is dropped through a plate load resistor 114. In actual operation four 2A3's are normally used and these tubes can handle approximately 600 milliamperes without operating beyond the conventional ratings. Normally the plate load resistor 114 is adjusted so that the current amplifier 80 will carry approximately one to two hundred milliamperes, since the field current developed usually increases as the potential developed by the battery 118 in the associated circuit drops. The normal operating voltage of the battery 118 is 112 volts, and if the voltage drops to 90 volts or less the sensitivity of the controller correspondingly decreases.

The galvanometer unit 30 in conjunction with the associated photoelectric circuit 90, the optical system 99 and the current amplifier stage 80 are generally designated as the magnetic field controller.

When the current flowing through coils 34 and 40 which is supplied by the 1½ volt battery 70, exceeds 1 milliampere the operation of the controller is substantially unaffected by slight current variations since it is the ratio of the currents flowing through the coils 34 and 40 respectively which controls the field strength. This is important, since it permits a simple unregulated source of current to be used in the coils 34 and 40. When the current flowing through the coils 34 and 40, respectively, is increased approximately 50 times, the sensitivity of the controller will increase greatly. However, it is not possible to raise the current flowing through the coil 34 and 40 beyond a few milliamperes because of periodic oscillations which will develop. These oscillations are due to the mechanical angular vibrations set up in the galvanometer unit 30. This difficulty is somewhat eliminated by using a large, thin-walled piece of aluminum tube as the central member 36 of the unit 30; but it has been found that this change will increase the moment of inertia of the galvanometer unit 30 and will reduce the speed of response of the controller.

When a deflection is transmitted by the galvanometer unit 30 by varying magnetic field developed across the electromagnet 10, the unit 30 will swing the light source image, thereby unbalancing the current flowing through the two cells 91 and 92 of the phototube 90a. Stops 51 are provided so that the unit 30 cannot rotate beyond the range of the photocells 91 or 92. When the galvanometer unit 30 is deflected because of a change in the direct current potential of the magnet power supply, which may be due to an unbalancing current from the phototube 90a amplified many times, current developed by the amplifier 80 is impressed upon the winding 11 of the electromagnet 10 in the proper sense so as to restore the galvanometer unit 30 to a null position. If one of the field current circuit conditions is changing constantly, such as a fluctuating voltage in the battery 118, the galvanometer unit 30 will hunt back and forth continuously around the null position. In actual operations changes in the circuit conditions are relatively slow and generally monotonic functions of time, so that the controller hunts only over an extremely small hysteresis loop because of statis-

tical variations in conditions. Because of the possibility that hunting of the galvanometer unit **30** might break into violent oscillations, a certain amount of degenerative coupling between the magnet field current circuit and the galvanometer unit **30** is provided. A third coil **59** is wound along in a composite manner with the second coil **40** at the lower end of the galvanometer unit **30** so that damping currents may be supplied to the third coil winding **59** so as to suppress oscillations. These currents are obtained from inductive coupling of the winding **59** with the field current circuit through a transformer **116**. A potentiometer **117** is shunted across the secondary winding of the transformer **116** so as to provide a varying current in the feed-back circuit of the third coil **59**. It has been found that the controller will not operate satisfactorily without the use of the third damping winding **59**. By disconnecting the third coil winding **59** when the controller is in operation, violent oscillations occur, which can be immediately suppressed by re-connecting the third coil winding **59**. The third coil winding **59**, is transformer coupled to the electrical winding **11** of the electromagnet **10**, so that for any given change in the amount of current flowing through the winding **11** of the electromagnet **10** there will be a transient current transmitted through the third coil winding **59** which will exert a transient deflecting force sufficient to suppress the oscillatory motion of the galvanometer unit **30**.

The response of the controller to changes in the magnetic field developed across the electromagnet **10** is fairly rapid; approximately one second being required for a complete readjustment of the field current transmitted through the electromagnet **10** in order to offset the effect of shorting out 10% of the field winding **11**. This rapid response is due to the fact that the magnetic torques operating on the galvanometer unit **30** are large compared with the restoring torque of the fiber suspension **37**; and the fact that the movement has a relatively small moment of rotation inertia. The inductance of the magnet field winding **11** also lengthens the response time somewhat. Shorting out about 25% to 50% of the field winding **11** leads to a change of less than 0.2% in the field strength measured with a conventional flip coil.

For spectrographic operation a controller can be set to maintain field strength, over a large energy range from about 20 KEV to 10 MEV. In order to change the field strength, it is only necessary to change the shunting resistance supplied by the potentiometer **72** and resistor **74**, thereby altering the ratio of the current in the coil windings **34** and **40**, respectively. These are the only changes required over this large energy range. For spectroscope use the magnetic field can be adjusted by changing resistance value of the rheostat **74**, which will vary the ratio of the currents flowing through coils **34** and **40**; and this change can be calibrated in terms of field strength. This manner of calibration will do away with the necessity of checking individual field strengths.

In general, it may be said that the device disclosed in the present application is illustrative, rather than limiting in scope, and that all of the numerous modifications which would naturally occur to those skilled in the art are included in the scope of the present invention. Only such limitations as are indicated in the appended

claims should be imposed on the scope of this invention.

What is claimed is:

1. Apparatus of the class described comprising a plurality of similar galvanometer elements each having a magnetizable structure and an electrical winding movable in the field thereof and each having a constant current in the winding thereof, said windings being mechanically interconnected so as to transmit a positive torque therebetween, means adapted to produce in the field of one of the magnetizable structures magnetic fluxes having a unidirectional component substantially opposite to the magnetic fluxes developed in the field of the other magnetizable structure, and means responsive to the angular motion of said galvanometer elements to vary the current through said electromagnet.

2. In a device of the class described, in combination, two galvanometer elements each having a stationary magnetizable structure and an electrical winding deflectable in the field thereof and each having a constant current in the winding thereof, said windings being mechanically interconnected so as to form an integral deflectable unit, means for producing in the field of one magnetizable structure a constant magnetic flux having a unidirectional component substantially opposite to the magnetic flux produced in the field of the other magnetizable structure, said other magnetizable structure being an electromagnet, and means responsive to the deflection of said unit to compensate for variation in the magnetic field of the electromagnet by varying the electrical current flowing therethrough.

3. Apparatus for controlling the magnetic field of an electromagnet, said apparatus comprising, in combination, a first winding disposed in said magnetic field, a standard magnetic field, a second winding disposed in said standard magnetic field, means for mechanically coupling said windings so that a rotative force exerted upon one winding constitutes a rotative force upon the other winding, means for flowing a constant current through both of said windings so that the rotative forces exerted upon said windings by a given magnetic field of the electromagnet and the standard magnetic field, respectively, are equal and opposite, and means responsive to an inequality of said forces to change the current through said electromagnet.

4. In an apparatus of the class described, in combination, two galvometer elements, one having a stationary electromagnet and a coil winding deflectable in the field thereof and the other having a stationary permanent magnet and a coil winding deflectable in the constant magnetic field thereof, means for mechanically coupling said coils to a rigid member so as to form an integrally deflectable unit, means for flowing a constant current through both of said coils so that the rotative forces exerted upon said coils by a given magnetic field of the electromagnet and the constant magnetic field, respectively, are equal and opposite, and means responsive to an inequality of said forces to vary the current through said electromagnet.

5. Apparatus for controlling the magnetic field of an electromagnet, said apparatus comprising, in combination, a first winding disposed in said magnetic field, a permanent magnet producing a standard magnetic field, a second winding disposed in said standard magnetic field, means for mechanically coupling said windings so that a

rotative force exerted upon one winding constitutes a rotative force upon the other winding, said mechanical means comprising a rigid member interconnecting said windings thereby defining a unit, means for flowing a constant current through both of said windings so that the rotative forces exerted upon said windings by the magnetic field of the electromagnet and the standard magnetic field, respectively, are equal and opposite, electrical damping means comprising a third winding adapted to prevent periodic oscillatory motion of the galvanometer unit, said third winding being firmly attached to said unit and mounted in the field of the standard magnet, and means responsive to an inequality of said forces to change the current through said electromagnet.

6. Apparatus as recited in claim 5 wherein the last-mentioned means comprises a reflecting surface rigidly attached to said unit, a photoelectric circuit adapted to produce a current in response to the angular deflection of said reflecting surface from an original null position, an electrical direct voltage amplifier means responsive to the current output of the photoelectric circuit, and a current amplifier means, said direct voltage amplifier being coupled to said current amplifier, and said current amplifier being connected to the windings of the associated electromagnet and adapted to vary the current therethrough.

7. In an apparatus of the class described, in combination, two galvanometer elements, the first element having a stationary electromagnet and a coil winding deflectable in the field thereof, and the second element having a stationary permanent magnet and a coil winding deflectable in the constant magnetic field thereof, means for mechanically coupling said coils to a rigid member

so as to form an integrally deflectable unit, means for flowing a constant current through both of said coils so that the rotative forces exerted upon said coils by a given magnetic field of the electromagnet and the constant magnetic field, respectively, are equal and opposite, means responsive to the inequality of said forces to change the current through the electrical winding of the electromagnet, and a third coil winding being rigidly attached to said deflectable unit and mounted in the field of the standard magnet, said third coil winding being transformer coupled to the electrical winding of the electromagnet so that for any given change in the amount of current flowing through the winding of the electromagnet there will be a transient current transmitted through the third coil winding adapted to exert a transient deflecting force sufficient to suppress oscillatory motion of said deflectable unit.

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