Sept. 30, 1958 T. R. McGUIRE ET AL 2,854,608

HIGH INTENSITY SOLENOID

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FIG. 1.

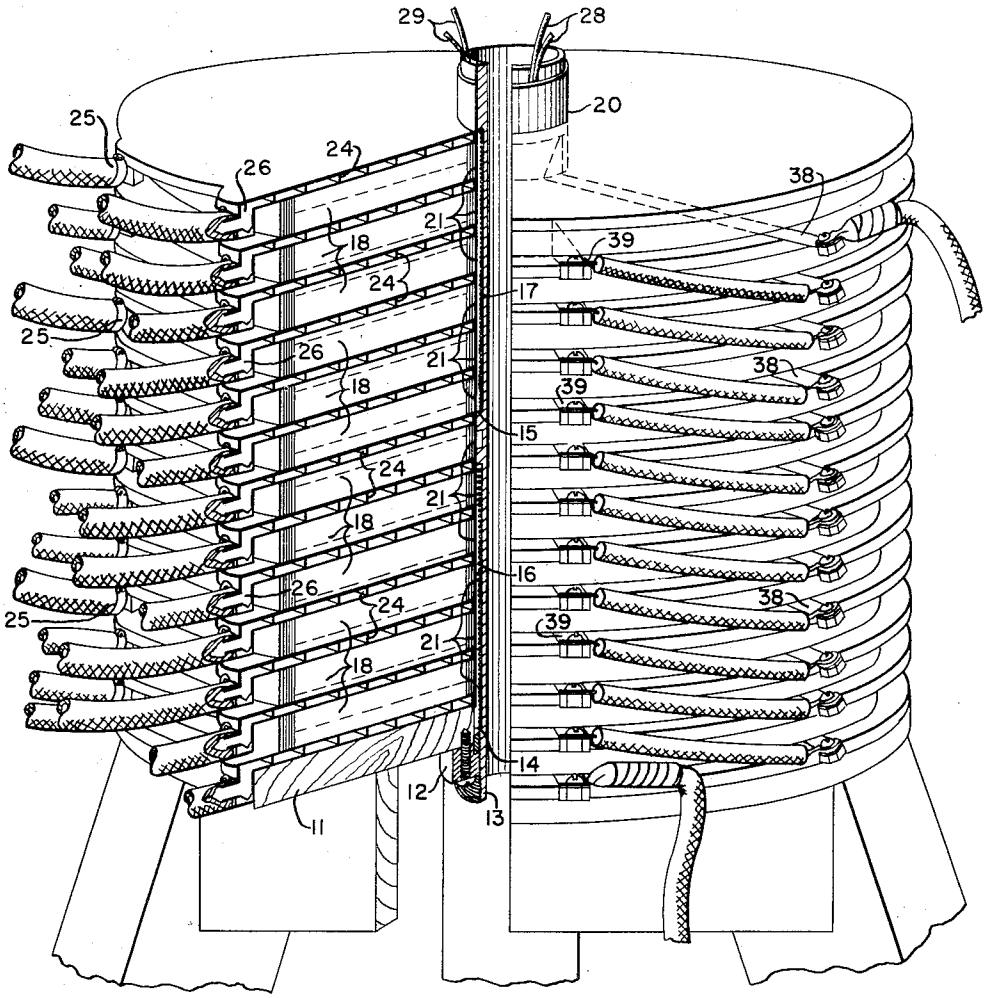
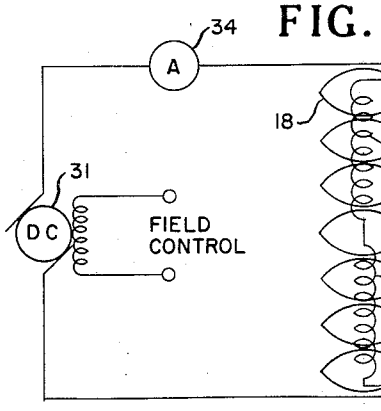


FIG. 6.



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FIG. 2.

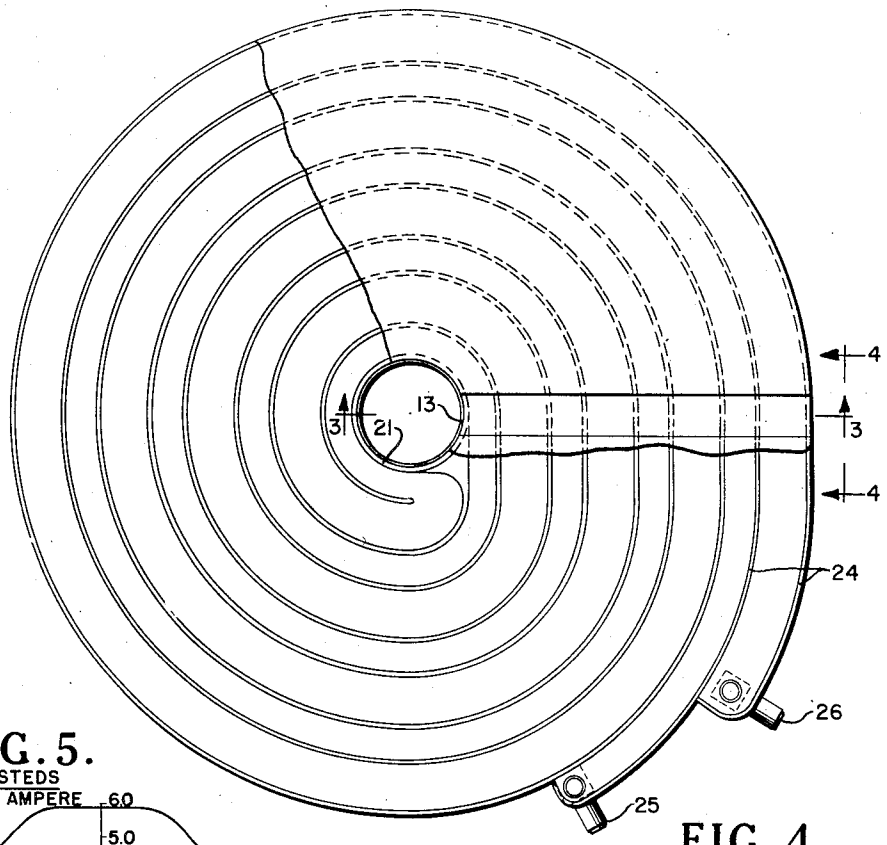


FIG. 5.

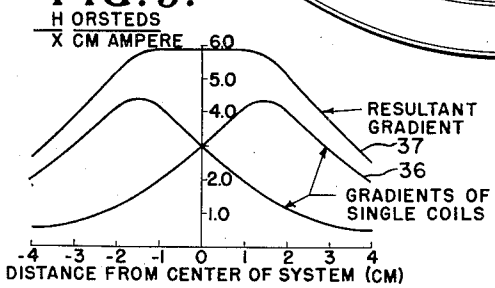
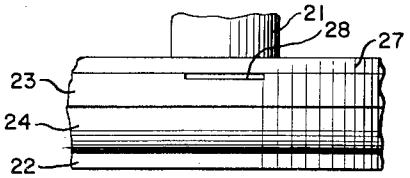


FIG. 4.



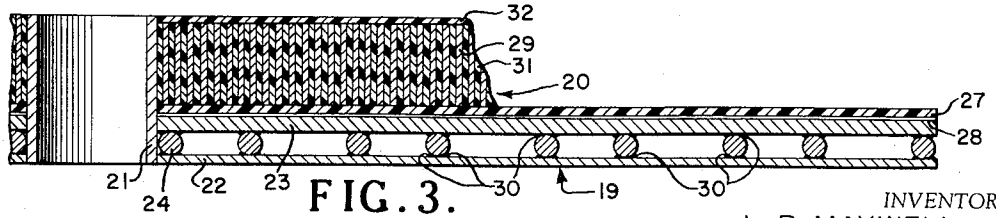


FIG. 3.

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HIGH INTENSITY SOLENOID

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Application August 17, 1954, Serial No. 450,560

2 Claims. (Cl. 317—158)

(Granted under Title 35, U. S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

The invention relates to a high intensity magnetic field solenoid for establishing a variable magnetic field gradient which is substantially uniform over an appreciable volume along the axis of said solenoid. More particularly this invention relates to the construction of a solenoid which is capable of establishing a magnetic field gradient of substantially uniform strength over a considerable volume along the axis of the solenoid while dissipating large amounts of power to establish a strong magnetic field within the solenoid.

Prior known high intensity magnetic field solenoids did not have an efficient cooling system and therefore were limited in their ability to operate at sustained high power levels. Also in prior solenoids of the type which employed gradient coils to control the field gradient within the solenoid these gradient coils have been of the Helmholtz type which resulted in a uniform magnetic field gradient only at a particular point within the solenoid.

Still another defect in prior art high intensity magnetic field solenoids was the inclusion within the solenoid structure of large volume of magnetically inert material, such as insulating material on the windings, which reduced the volume and effectiveness of the active winding in producing a high intensity magnetic field within the solenoid.

This invention has for one of its objects the creation of a high intensity magnetic field having a high power handling ability.

A second object is to produce a high power solenoid having a high cooling efficiency.

A third object is to construct a new and improved solenoid having gradient coils which are solenoidal in form and extend axially along the solenoid for an appreciable length.

Another object is to construct a solenoid for producing a high intensity magnetic field in which the total volume of the solenoid windings consists of a maximum amount of an electro-conductive material.

Another object of the present invention is to provide a solenoid comprising a plurality of stacked coil members which are easily disassembled to facilitate adjustment and repair of the device.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

Fig. 1 is a sectionalized perspective view of a preferred embodiment of the present invention;

Fig. 2 is a plan view of one of the coil forms with part of one of the surface members broken away to show the cooling channels;

Fig. 3 is a sectional view taken along line 3—3 of Fig. 2;

Fig. 4 is a fragmentary view of the edge of the coil form taken in the direction of arrows 4—4 in Fig. 2 showing the slot to receive the return lead of a coil winding;

Fig. 5 is a graphic illustration showing the effects of the gradient coils; and

Fig. 6 is a circuit schematic suitable for use with the present invention.

Referring now to figures of the drawings wherein corresponding numerals designate corresponding parts throughout the several views, a more detailed description of the embodiment of the invention shown thereon will be given.

As shown in Fig. 1, the device of the present invention comprises a platform **11** of non-magnetic material, such as wood, which has attached to it an internally threaded collet **12**. Threadedly engaged in the collet is a tubular member **13**, the diameter of which is reduced at **14** and **15** to receive gradient windings **16** and **17** which have pairs of leads **28** and **29**. Surrounding the tubular member **13** and coaxial therewith is mounted a plurality of power coil members **18**.

Each of the coil members **18** comprises a coil form, generally indicated at **19**, a winding **20**, and a collar portion **21**, as clearly shown in Fig. 3. This collar is surrounded by and attached to a pair of disc like annular members **22** and **23** of a non-magnetic heat conductive material, suitable for the purpose such, for example, as brass or the like. These annular members are held in spaced relation by an arrangement of rods or rod like members **24**. The rods are arranged in a double spiral over the opposed inner surfaces of the member **22** and **23** and secured thereto as at **30** to form a continuous circulatory path or duct for a coolant. The channels formed between the rods **24** are connected together at their interior ends adjacent the collar **21** and have hose connections **25** and **26** at their exterior ends, Fig. 2. The member **23** has its surface, remote from the member **22**, covered with an insulating material **27** and has a groove **28** through which the inner end of the electrically conductive coil winding and its required insulation may be brought to the outside of the coil as at **38**, the outer end of the coil winding being shown at **39**. In practice this winding is composed of a conductive ribbon **29** tightly wound spirally about the collar with a layer of insulating material **31** between the successive layers of the ribbon. After the winding is complete, a thin sheet or layer of insulation **32** is placed over the exposed edges of the winding turns. It should be noted that by insulating the windings in the above described way during the construction of the coil, the amount of insulating material required is reduced to a minimum and air interstices are eliminated with the result that the amount of electro-conductive material is a maximum for each coil.

The coils **19** and coil forms **20** are stacked, as previously indicated about the tubular member **13**, which carries the gradient coils **16** and **17**. The windings of the power coils **19** in the preferred embodiment are connected in series aiding relation and the gradient coils **16** and **17** are connected in series opposition. The coolant connections **25** and **26** are connected to a source of coolant (not shown) to provide flow through the channels within the coil forms.

A circuit for the solenoid is shown in Fig. 6 wherein the power coils **18** are supplied by a direct current generator **31** which is preferably amplidyne controlled. The gradient coils **16** and **17** are supplied from a D. C. source such as the battery **32** illustrated through a rheo-

stat **33**. Included in both the power coil and gradient coil circuits are meters **34** and **35**, respectively for indicating the current flow.

In the development of this solenoid, the desirability of particular gradient coils was discovered after considering the curves of a graph such as that shown in Fig. 5. Considering each of the gradient coils as a separate solenoid, the graph of the field strength of each coil results in a curve such as indicated at **36**, Fig. 5. From the graph of such a curve it was noted that if a second similar solenoidal gradient coil were connected in series opposition to the first gradient coil, the resultant gradient field would be constant over a volume much larger than that produced by the well known Helmholtz gradient coils of the same diameter. This resultant curve is indicated at **37** in the graph.

In operation, the power coils having been connected in series aiding relationship, are connected to a source of current such as the D. C. generator **31**. The current flow is regulated to the desired operating level to give a high intensity magnetic field extending substantially the entire length of tube **13**. The cooling circuit is connected through couplings **25** and **26** to cause a flow of coolant through the ducts in each coil form to dissipate the heat generated in the coil windings.

The field gradient is controlled by the current flowing through opposedly connected gradient coils **16** and **17** and thence through a regulating means, such as rheostat **33**, to a source of direct current **32**.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A high intensity magnetic field solenoid comprising a plurality of annular power coils, each of said power coils having a winding of an uninsulated electrically conducting ribbon and a thin layer of insulating material interlayered between the turns thereof, a plurality of coil forms, each coil form comprising an annular disc-like cooling member having an upstanding collar surrounding the central opening upon which each of said power coils is wound, an insulating material layered upon the surface of said form adjacent said winding, and a tubular member of non-magnetic material on which said power coils are coaxially mounted, said cooling member comprising a first disc-like annular member mounted on said collar, a pair of separator members arranged as a double spiral about said collar and attached to said first member to form a pair of spiral channels, one of said separator members being shorter than the other and arranged so that at its end adjacent the collar said channels are in fluid communication, and a second disc-like annular member mounted on said collar to overlie said separator members and being attached thereto, said channels providing a continuous duct for the circulation of a coolant.

2. A solenoid according to claim 1 in which means are provided for establishing an external fluid connection from the outer ends of said duct to a source of liquid coolant and an exhaust means respectively.

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