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ELECTRICAL COIL STRUCTURE

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3,056,071

Fig. 1.

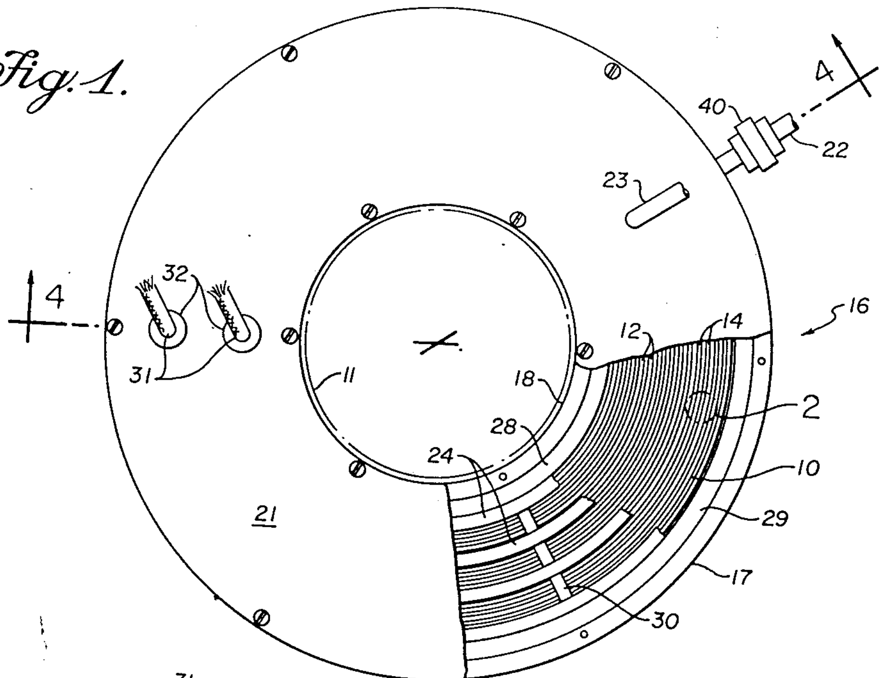
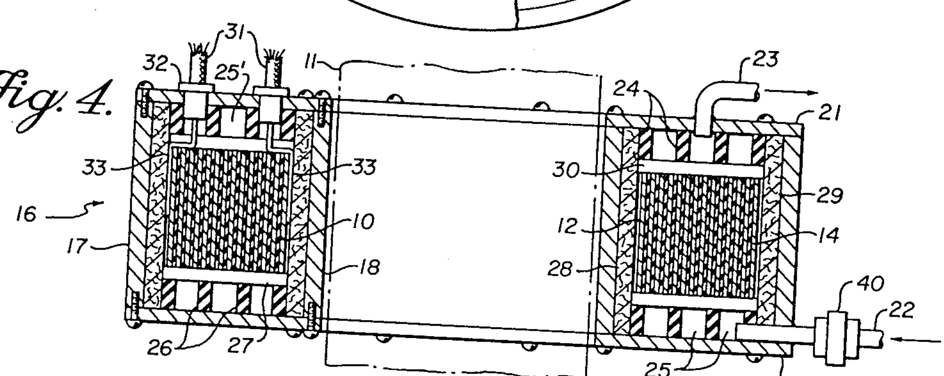


Fig. 4.



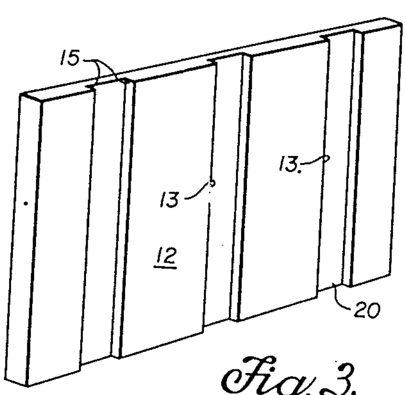


Fig. 3.

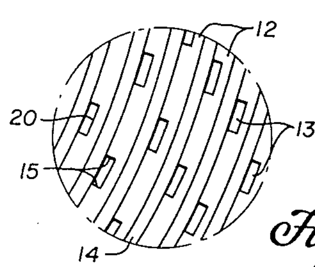


Fig. 2.

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ELECTRICAL COIL STRUCTURE

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The present invention relates to electrical coils, and more particularly to a novel structure for a high current electrical coil, such as the winding of a large electromagnet, wherein circulation of a substantial amount of coolant fluid through the coil is necessary to provide adequate cooling.

A common means for cooling large high current coils utilizes the forced coolant technique. In this method the coil is wound of hollow conductor and a coolant fluid is circulated through the axial passage of the conductor. Such a structure is subject to several disadvantages in addition to the obvious expense of manufacturing hollow conductors. One difficulty lies in efficiently forcing a coolant through the extremely long, constricted and curved coil passage. The frictional resistance to coolant flow in the passage creates a sizable pressure differential along the flow passage thereby necessitating an unduly large pumping pressure. If the hollow passage is constructed with a larger diameter cross section in order to reduce the pumping pressure required, the coil is resultingly less compactly wound, i.e., has fewer turns per cross-sectional area, with deleterious results from the electrical standpoint.

Another method commonly employed to cool electrical coils is to maintain the coil immersed in a coolant bath, such as the oil in a transformer case. If the coil is subjected to a high current the oil in some instances is circulated, or water coils are immersed in the oil bath as a means of removing heat. In either case, as the coil is wound compactly, thereby leaving little space between the turns, a substantial amount of coolant is not circulated through the interspaces between the turns, and therefore a relatively low limit exists as to the rate at which heat can be transferred to the coolant.

In view of the stated disadvantages of conventional coils a need exists for a coil structure which can carry an extremely high current and yet be sufficiently cooled without necessitating an unduly high pumping pressure to circulate a coolant. It is further desirable that maximum surface contact between a coolant and the coil turns exists without occasioning a substantial loss of coil compactness, and that in order to be generally useful, economical and adaptable to various applications the overall coil construction should be simple.

Coils having the foregoing advantageous characteristics are particularly needed in such applications as energizing large extremely powerful electromagnets of the type utilized in charged particle accelerators particularly where such magnets are of the pulsed variety. Magnets of this type are also widely employed in the current efforts to achieve controlled thermonuclear reactions. Other instances where intense currents must be circulated through a compactly wound coil are common and will suggest themselves to those skilled in the art.

The present invention overcomes the disadvantages of the conventional structures and provides a high current coil requiring only minimum coolant pumping pressure in a structure where heat transfer is maximized. Replacing the conventional hollow tubular conductor or the wrapped wire coil is a flat strip of conductor wound in a tight spiral. One surface of the conductor is scored with parallel transverse grooves which constitute, when the conductor is wound into spiral form, a plurality of short longitudinal coolant passages distributed uniformly throughout the coil. To provide insulation between adjacent turns of the coil a matching flat sheet of suitable dielectric is wound with the conductor. Coolant liquid is easily pumped through the short parallel coolant channels of the coil, and in passing therethrough effects an excellent heat transfer. The short straight channels of the coil offer relatively little resistance to coolant flow, and as a result a high rate of flow is achieved with little pressure exerted by the pump. The invention therefore not only eliminates the principal difficulties encountered in the prior structures, but is further characterized by a simplicity of construction and operation.

It is accordingly an object of the present invention to provide an improved electrical coil capable of carrying extremely high currents.

It is another object of the invention to provide a novel high current electrical coil structure which structure has provision for highly efficient cooling.

It is an important object to provide a coil structure particularly adapted for the excitation of large electromagnets.

A further object of the invention is to provide a simple and economically manufactured high current electrical coil structure.

Still a further object of the invention is to provide a high current electrical coil which is of rugged construction and capable of withstanding the thermal and magnetic shock brought about by the sudden application of intense currents.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in conjunction with the accompanying drawing, in which:

FIGURE 1 is a top view of the apparatus, with portions of the upper surface thereof broken away,

FIGURE 2 is an enlarged view of the encircled portion of FIGURE 1 illustrating the detailed structure of the winding in the coil,

FIGURE 3 is a perspective view of a section of the conductor of which the coil is wound, and

FIGURE 4 is a section view taken along line **4—4** of FIGURE 1 and further clarifying the general construction of the coil.

Referring now to the drawing and more particularly to FIGURE 1 thereof, there is shown in phantom cross section a simple cylindrical electromagnet core **11**, which in the present embodiment constitutes the element about which a coil is disposed. It should be emphasized that the core **11** may be any desired configuration about which coils are normally wound, for example, C-shaped magnets, U or H-shaped magnets and the like, which magnets are configurated for various purposes understood in the art. The coil **10** may also be an integral component of a transformer, inductor or other apparatus which utilizes high current coils, and is particularly suitable, as exemplified by the present embodiment, for exciting large high current electromagnets. It should further be understood that the core **11** is not an element of the invention but is shown merely to illustrate one application thereof, the invention being usable in the construction of air-core coils.

The coil **10** comprises a long flat rectangular strip **12** of electrical conductor such as copper, copper being ductile as well as a good conductor, although other conductors more rigid than copper may be wound in this fashion when heated. Disposed against one face of the conductor **12** is a matching flat rectangular strip **14** composed of a dielectric material which material is also preferably ductile or flexible. The two strips **12** and **14** are tightly wound in a spiral thereby forming the annular coil structure **10**, which structure is thus characterized by tightly wound alternate turns of conductor and dielectric, as best shown in the enlarged FIGURE 2.

Referring now to FIGURE 3, which shows a perspective view of a small section of the conductor **12**, one face of the conductor is scored by parallel grooves **13**, the grooves being aligned transverse to the long dimension of the conductor. Without departing from the general principles of the invention or the advantageous properties thereof, the grooves **13** may also be disposed parallel with the long dimension of the conductor **12**, slant diagonally across the conductor surface, or be arranged in any other suitable pattern across the conductor surface. The grooves **13** need not necessarily be straight or parallel, although such form results in minimum length of the grooves and therefore minimizes the resistance to coolant flow.

The grooves **13** are preferably shallow and have relatively short sidewalls **15** and a wide base surface **20**. Such shallow grooves **13** minimize differences in resistance to electrical current offered by different portions of the conductor **12** along the total conductor surface and maximize the effective heat transfer between the conductor and coolant circulating through the grooves.

The grooves **13** collectively form a plurality of short parallel coolant passages, distributed uniformly throughout the coil structure **10** when the conductor **12** is wound into spiral form. Obviously the more shallow the grooves **13** the more compactly the conductor **12** and dielectric **14** can be wound. Very shallow grooves can be made wider in order to maintain a selected cross-sectional groove area and thereby avoid unduly constricted coolant fluid flow through the passages. It should be observed that, as the grooves **13** are formed in the conductor **12**, a coolant fluid flowing through the groove passages has direct contact with the heat generating conductor surface throughout the passages through the coil, and therefore heat is directly and efficiently transferred to the coolant fluid. It will be apparent, however, that the grooves can be made in the dielectric **14**, if desired, rather than in the conductor **12**.

As shown in FIGURES 1 and 4, the coil **10** is disposed inside an annular casing or housing **16**, the central bore thereof being occupied by the electromagnet core **11**; the casing comprising an outer sidewall **17**, an inner sidewall **18**, a flat annular bottom plate **19**, and a matching top plate **21**. Such casing **16** serves to provide a fluid tight enclosure for the coil structure **10** in order to facilitate the circulation of the coolant through the coil.

Transpiercing the lower portion of the outer sidewall **17** is a coolant inlet conduit **22**, and extending from the top plate **21** is an outlet conduit **23**, the conduits being connectable to a source of liquid coolant under pressure. A filter element **40** is disposed inside the inlet conduit **22** near the casing **16** in order to strain the coolant and thereby assure smooth flow thereof through the grooves **13**. While the invention has been described as utilizing a liquid coolant, it will be understood that in some adaptations of the invention a gaseous coolant such as air may be preferable.

Although in the present embodiment the coil **10** and enclosing casing **16** are disposed with the axis thereof upright, it should be observed that other orientations are possible without loss of operating efficiency; for example, the structure can just as readily be disposed on its side.

To provide means for dispersing the coolant flow to all of the grooves **13** there are disposed between the top plate **21** and the top of the wound coil **10** a plurality of annular, concentric, spaced apart ribs **24** composed of dielectric material which ribs are secured to the top of insulative radial crosspieces **30** that extend between the inner sidewall **18** and the outer sidewall **17** of the casing **16**. Similarly disposed between the bottom plate **19** and the bottom of the wound coil **10** is another set of spaced annular ribs **26**, which are secured to the bottom surfaces of a second set of radial crosspieces **27**. The insulative crosspieces **27** and **30** contact relatively small areas of the bottom and top ends of the wound coil **10** and accordingly coolant flow blockage at the ends of the grooves **13** is negligible. The coolant fluid, in this instance transformer oil, enters the casing **16** through the inlet conduit **22**, flows through the channels **25** between the bottom ribs **26**, up through the grooves **13**, through the channels **25'** between the top ribs **24**, and exits through the outlet conduit **23**. In operation, all of the interspaces inside the casing **16** are filled with the rapidly flowing transformer oil. The ribbed structures efficiently provide insulative support for the wound coil **10** and appropriate spacing of the coil apart from the casing top and bottom plates **21** and **19**. To facilitate coolant distribution various other suitable spacer and support mechanisms might be employed consistent with design requirements of a particular embodiment of the invention.

To insulate the conductor **12** from the inner sidewall **18** and from the outer sidewall **17** of the casing **16** an annular insulation band **28** is disposed between the inner sidewall and the conductor, and another larger insulation band **29** is disposed between the conductor and the outer sidewall, glass fiber bands being a suitable material.

As shown in FIGURE 4, current is supplied to the conductor **12** through two electrical leads **31**, which enter the casing top plate **21** through insulative bushings **32**, each lead terminating in a thin copper strip **33**, one strip being connected to the innermost turn of the coil **10**, the other strip connected to the outermost turn. Because of the efficiency of the described cooling means as built into the coil structure, the electrical current carried by the conductor **12** can be extremely high. Heat generated by electrical resistance is transferred from the conductor **12** directly to the flowing coolant which coolant is circulated out of the coil. As the grooves **13** from which heat is removed are an integral part of the conductor **12**, the conductor is maintained at a temperature well below that which would cause softening or melting of the conductor or charring of the adjacent dielectric material **14**.

In operation, excitation current is supplied to the conductor **12** through leads **31** resulting in the production of heat. The coolant oil entering the casing **16** through the inlet conduit **22** fills the channels **25** between the bottom annular ribs **26** and is forced upward therefrom through the parallel straight grooves **13** of the conductor **12** and through the upper ribs channels **25'** into the outlet conduit **23**. In passing through the grooves **13** the coolant oil absorbs the internally generated heat from the conductor **12**.

A substantial amount of coolant can be pumped through the groves **13** at a high flow rate, and in being pumped therethrough creates a relatively small pressure differential, for the numerous straight grooves **13** offer minimum resistance to the coolant flow.

In general, the coil structure herein described may replace any coil cooled by the forced coolant method. Numerous modifications of the simple, basic structure, i.e., alternate layers of grooved, flat conductor and flat dielectric spirally wound to form a coil having longitudinal coolant passages, are possible and will readily suggest themselves to those skilled in the art.

Thus while the invention has been disclosed with respect to a single embodiment, it will be apparent to those skilled in the art that numerous variations and modifications may be made within the spirit and scope of the invention and thus it is not intended to limit the invention except as defined in the following claims:

What is claimed is:

1. An electrical coil for use in high current circuits comprising, in combination, a long flat strip of electrical conductor formed in an open-centered spiral configuration, at least one surface of said conductor having a plurality of generally transversely aligned shallow grooves said grooves being recessed in said conductor surface and being separated by relatively broad flat areas of said sur-

face, terminal means at each end of said conductor for applying electrical current thereto, and a quantity of electrically insulative material formed in a spiral configuration similiar to that of said strip of conductor material and interlaminated therewith to form a unitary annular coil structure characterized by alternated turns of conductor and insulator and further characterized by transverse coolant passages formed by said grooves.

2. An electrical coil substantially as described in claim 1 and in which said transverse grooves are equally distributed along substantially the entire length of said surface of said conductor.

3. An electrical coil structure substantially as described in claim 1 and wherein said shallow grooves are linear and evenly spaced along said surface of said conductor and are aligned substantially at right angles to the long dimension thereof.

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