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(54) Semi-compacted litz-wire cable strands spaced for coolant flow about individual insulated strands.

(57) An electromagnetic induction coil (38) for a magnetofluidynamic device (36) includes a cable (22) enclosed within an insulator sheath (18) and composed of multiple individually-insulated conductor strands (24) wound in Litz-wire fashion in a relatively loose relationship to one another to form a semi-compacted bundle. The strands in the semi-compacted bundle define a plurality of empty spaces (26) between individual strands (24) for permitting coolant flow within the sheath (18) and through the bundle along and about the individual strands (24) such that amount of surface area of the strands (24) exposed to contact by the coolant is greater than in a compacted bundle of strands thereby enhancing the heat transfer capability of the cable (22).

EP 0 408 230 A2

SEMI-COMPACTED LITZ-WIRE CABLE STRANDS SPACED FOR COOLANT FLOW ABOUT INDIVIDUAL INSULATED STRANDS

Field of the Invention

The present invention relates generally to electromagnetic (EM) induction coils for magnetofluidynamic (MFD) devices and, more particularly, is concerned with semi-compacted Litz wire cable strands spaced for coolant flow about individual insulated strands.

BACKGROUND OF THE INVENTION

Under high-frequency excitation, an electrical conductor's current density ceases to be uniform. The well-known "skin effect" causes current to move away from the center of the conductor and crowd into a layer just beneath the surface. The effect is also present in a coil of many turns, wherein the self-fields of each conductor turn induce current density changes in adjacent turns.

The overall effect on the terminal resistance of a coil can be dramatic. For example, data taken from a solenoidal coil (5 turns per layer, 6 layers, 88.4 x 44.45 millimeters in cross-section) showed that the coil resistance at 100 kHz has increased nearly two orders of magnitude over the actual DC resistance of the coil conductors. At the frequency range often used to effect the flow of liquid steel (10 to 50 kHz), for example, the effective resistance due to frequency effects in the coil was on the order of 10 to 35 times the DC base value. The ultimate result is that standard multi-turn conductor coils develop such high ohmic heating at medium to high frequencies that providing cooling to the individual conductors becomes increasingly difficult. Hot conductors can mean increased power loss, deteriorating insulation, or thermal instability conditions.

The conventional practice in the art of induction heating is to utilize thin-sheet current carrying conductors, cooled by means of radial fins attached to the conducting sheet, as a means to improve heat removal. Usually, the excitation frequencies are around 1 kHz or less. This methodology works well since there is ample cooling ability.

At higher frequencies, the above method can work well assuming a liquid heat transfer medium is used, such as water. However, in many applications, such as where very high ampere-turns are required, or where the presence of water can be a potentially serious hazard, such as above an open pool of liquid steel, the finned-sheet coil method provides only marginal ability to cool the conductors by gas coolant methods.

Transposed stranded wire conductors, particularly suited for high frequency applications, are commercially available under the name Litzendrant conductor, or Litz-wire. The Litz-wire cable is formed by transposing individual insulated strands or wires within small groups of wires and then transposing the groups within the cable. The immediate effect of this cabling method is to equalize the flux linkages of each individual strand, thus causing the current to divide evenly among the strands. Ohmic heating is lower, approaching D.C. values, and is more evenly distributed in the coil volume. This allows easier and more efficient heat removal as compared to sheet or ribbon, or solid or hollow conductor, winding configurations.

Cooling techniques previously employed in insulated stranded wire induction coils have included compacted Litz-wire cable (the usual manufactured form) contained in a jacket or sheath, into which water is injected. The water is directed to flow either outside the compact bundle or through a center channel around which the insulated multiple strands of Litz-wire have been compressed. However, the heat transfer capability of these cooling techniques are substantially less than optimal.

Consequently, there is a need for an alternative technique for cooling the insulated multiple strands of Litz-wire cable, particularly for high-power density applications, such as the electromagnetic valve or flow control device disclosed in U.S. Patent 4,842,170 entitled "Liquid Metal Electromagnetic Flow Control Device Incorporating A Pumping Action" issued June 27, 1989 in the name of R. M. Del Vecchio et al. and assigned to the Westinghouse Electric Corporation.

DISCLOSURE OF THE INVENTION

The present invention provides a Litz-wire cable composed of a semi-compacted insulated multiple strand bundle designed to satisfy the aforementioned needs. The semi-compacted strand bundle of the present invention provides space for coolant flow therethrough about individual strands to both minimize coil losses and enhance heat transfer capability for optimal performance of induction coils used in MFD devices.

The invention in its broad form is a electromagnetic induction coil for a magnetofluidynamic device, characterized by a cable composed of multiple individually-insulated conductor strands wound in Litz-wire fashion in a relatively loose relationship to one another to form a semi-compacted bundle; and an insulator sheath enclosing the cable; the strands in the semi-compacted bundle defining a plurality of empty spaces between individual strands for permitting coolant flow within the sheath and through the bundle along and about the individual strands such that the amount of surface area of the strands exposed to contact by the coolant is greater than in a compacted bundle of strands thereby enhancing the heat transfer capability of the cable.

Preferably, the empty space between individual strands in the semi-compacted bundle is from two to three times more than in a compacted bundle of the same strands. Further, the semi-compacted insulated conductor strands fill from 40 to 50 percent of the cross-sectional area within the sheath and are uniformly distributed across the cross-sectional area of the sheath.

Additionally, the present invention is directed to a magnetofluidynamic device which comprises: (a) the above-defined electromagnetic induction coil; and (b) a holder composed of non-conductive material having channels therein for housing the coil. The coil strands in the semi-compacted bundle define a plurality of empty spaces between individual strands for permitting coolant flow through the holder channels and bundle and along and about individual strands.

These and other features and advantages of the present invention will become apparent to those skilled in the art upon a reading of the following detailed description when taken in conjunction with the drawings wherein there is shown and described an illustrative embodiment of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

In the course of the following detailed description, reference will be made to the drawings in which:

Fig. 1 is a schematical cross-sectional view of a prior art Litz-wire cable having a compacted bundle of multiple insulated conductor strands.

Fig. 2 is an enlarged cross-sectional view of one of the insulated conductor strands of the Litz-wire cable of Fig. 1.

Fig. 3 is a schematical cross-sectional view of a Litz-wire cable of the present invention having a semi-compacted bundle of multiple insulated conductor strands.

Fig. 4 is a fragmentary sectional view of a prior art induction coil employing fin-cooled thin-sheet conductors.

Fig. 5 is a fragmentary sectional view of an induction coil employing the semi-compacted bundle of multiple strands of the Litz-wire cable of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following description, like references characters designate like or corresponding parts throughout the several views. Also in the following description, it is to be understood that such terms as "forward", "rearward", "left", "right", "upwardly", "downwardly", and the like, are words of convenience and are not to be construed as limiting terms.

In General

Referring now to the drawings, and particularly to Figs. 1 and 2, there is shown, in a schematical cross-section, a prior art cable 10 composed of multiple insulated conductor strands 12. As seen in Fig. 2, each strand 12 is composed of an inner cylindrical core in the form of an electrical conductor 14 and an outer cylindrical layer 16 of insulating material enclosing the conductor 14. Thus, each of the strands 12 of the cable 10 is insulated from one another.

As is conventional practice, the multiple insulated strands 12 are wound together in a Litz-wire fashion. The Litz-wire wound configuration is well-known and so need not be illustrated in the drawings. As generally understood, the Litz-wire configuration is a helical pattern wherein each strand 12 of the bundle thereof assumes a transposed relation to others. The transposed relation means that each strand 12 at one point along the cable 10 is located along the periphery of the bundle and at another point is located inwardly from the periphery of the bundle, whereby the current flow is substantially uniformly distributed through the strands 12 of the cable.

As provided heretofore, in the Litz-wire configuration the bundle of strands 12 have been wound in a tightly compacted relation and wrapped by an insulator sheath 18 to retain them in the compacted bundle. Typically, in a compacted bundle the insulated conductor strands fill from 75 to 85 percent of the cross-sectional area within the sheath. In the winding operation, steps are taken to form a central channel 20 through the center of the bundle of strands 12 for allowing coolant flow through the bundle center. The central channel 20 can be merely the space remaining between the strands along the center of the cable 10 or defined by a tube (not shown) running along the center of the cable 10 around which the strands 12 are wound.

Semi-Compacted Litz-Wire Cable Strands

The heat transfer capability of the prior art Litz-wire cable 10 of Fig. 1 is enhanced by the modifications introduced thereto in accordance with the principles of the present invention as embodied in the improved Litz-wire wound cable 22 of Fig. 3. The primary difference between the improved cable 22 of Fig. 3 and the prior art cable 10 of Fig. 1 is that in the improved cable 22 the bundle of multiple insulated conductor strands 24 are wound in a loose, semi-compacted relationship to one another.

With the multiple insulated strands 24 of the improved cable 22 arranged in the semi-compacted or loose bundle, a plurality of empty spaces 26 are defined between the individual strands 24 for permitting coolant flow through the bundle along and about the individual strands 24. Preferably, the empty space between individual strands 24 in the semi-compacted bundle is from two to three times more than in a compacted bundle of the same strands. Further, the semi-compacted insulated conductor strands 24 fill from 40 to 50 percent of the cross-sectional area within the sheath 18 and are uniformly distributed across the cross-sectional area of the sheath. The amount of surface area of the strands 24 now exposed to coolant is significantly greater in the improved cable 22 than in the prior art cable 10. Direct contact by the coolant with the increased amount of surface area of the individual strands 24 substantially increases and enhances the heat transfer capability of the cable 22.

The improved cable 22 has particular application to an electromagnetic induction coil for an magnetofluidynamic (MFD) device, such as the electromagnetic valve or flow control device disclosed in U.S. Patent 4,842,170. The coil composed of the semi-compacted insulated conductor strands has an A.C. excitation operating capacity within the frequency range of from 1 to 50 kHz, making it particularly suited for use in such application. Fig. 4 shows a cross-section of a prior art annular MFD device 28 with an induction coil employing thin-sheet conductors 30 which are fin-cooled (only one conductor being shown). The device 28 has channels 32 with a series of spaced fins 34 mounted therein past which coolant flows within the channels 32. Most of the current flows within the inner portion 30A of the conductor 30 such that almost no current flows through the fins 34 which directly contact the coolant resulting in less than optimal transfer of heat from the conductor 30 to the coolant.

Fig. 5 shows a MFD device 36 having an induction coil 38 employing the semi-compacted, spaced, multiple, Litz-wire wound, insulated strands 24 of the cable 22 of the present invention. The device 36 includes a holder 40 composed of non-conductive material, such as glass or epoxy, and having channels 42 therein for housing the coil 38. The insulated conductor strands 24 of the coil 38 are provided in the semi-compacted bundle as described above with respect to Fig. 3. Thus, coolant, such as a gas or liquid freon can flow through the spaces 26 within the bundle along and about individual strands 24 at reduced pressure compared to a compacted bundle of the same strands. Further, the amount of surface area of the semi-compacted strands 24 which is exposed to contact by the coolant is significantly greater than in a compacted bundle of the same strands thereby enhancing the heat transfer capability of the coil 38.

It is thought that the present invention and many of its attendant advantages will be understood from the foregoing description and it will be apparent that various changes may be made in the form, construction and arrangement thereof without departing from the spirit and scope of the invention or sacrificing all of its material advantages, the form hereinbefore described being merely a preferred or exemplary embodiment thereof.

Claims

1. An electromagnetic induction coil (38) for a magnetofluidynamic device (36), characterized by:

(a) a cable (22) composed of multiple individually-insulated conductor strands (24) wound in Litz-wire fashion in a relatively loose relationship to one another to form a semi-compacted bundle; and

(b) an insulator sheath (18) enclosing said cable (22);

(c) said strands (24) in said semi-compacted bundle defining a plurality of empty spaces (26) between individual strands (24) for permitting coolant flow within said sheath (18) and through said bundle along and about said individual strands (24) such that the amount of surface area of said strands (24) exposed to contact by the coolant is greater than in a compacted bundle of strands thereby enhancing the heat transfer capability of said cable (22).

2. The coil (38) as recited in Claim 1, wherein said spaces (26) between individual strands (24) in said semi-compacted bundle is from two to three times more than in a compacted bundle of the same

strands.

3. The coil (38) as recited in Claim 1, wherein semi-compacted insulated conductor strands (24) fill from 40 to 50 percent of the cross-sectional area within said sheath (18) and are uniformly distributed across the cross-sectional area thereof.

4. The coil (38) as recited in Claim 1, wherein said cable (22) composed of said semi-compacted insulated conductor strands (24) has an A.C. excitation operating capacity within the frequency range of from 1 to 50 kHz.

5. The coil (38) as recited in claim wherein said coil (38) is disposed in a holder (40) composed of non-conductive material having channels (42) therein for housing said coil (38).

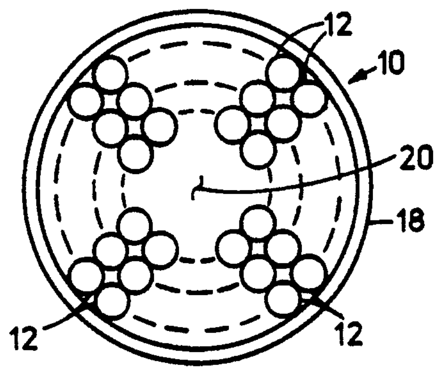

FIG. 1
(PRIOR ART)

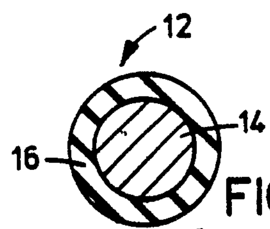

FIG. 2
(PRIOR ART)

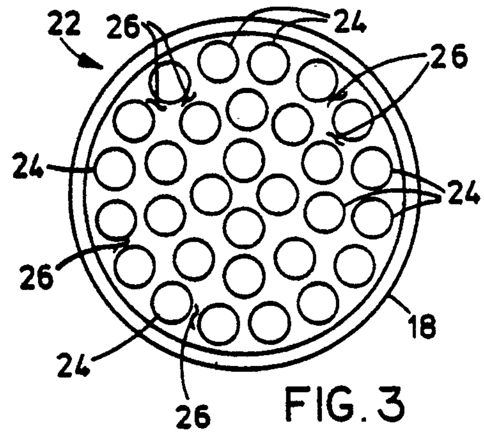

FIG. 3

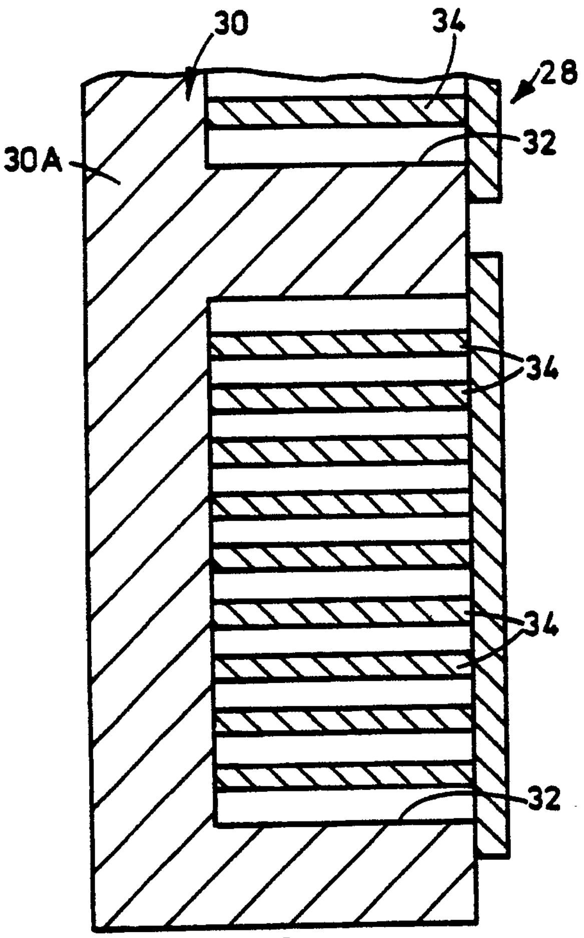

FIG. 4
(PRIOR ART)

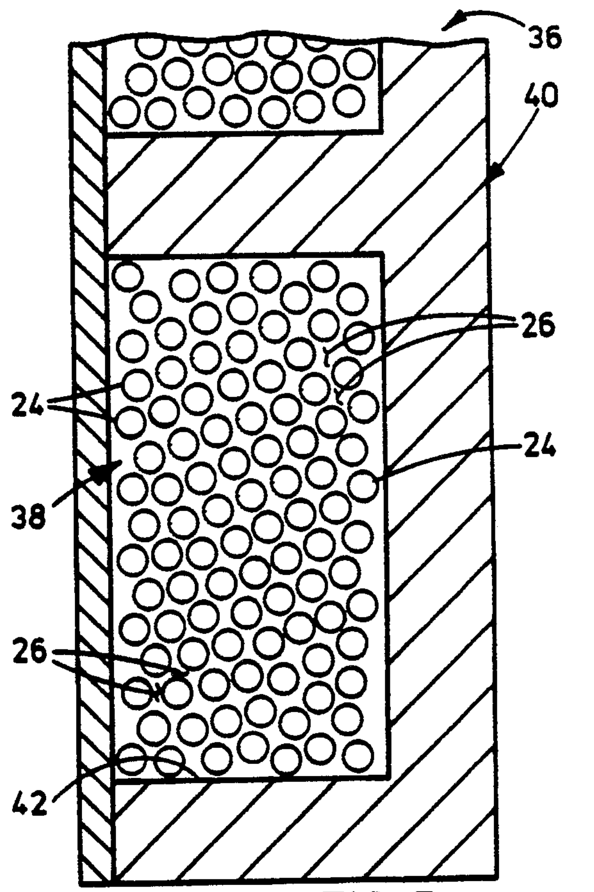

FIG. 5