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Critchlow et al.

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[45] **Aug. 20, 1974**

[54] **MULTI-FILAMENT COMPOSITE SUPERCONDUCTOR WITH TRANSPOSITION OF FILAMENTS AND METHOD OF MAKING SAME**

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[22] Filed: **Sept. 11, 1973**

[21] Appl. No.: **396,282**

Related U.S. Application Data

[62] Division of Ser. No. 286,625, Sept. 6, 1972.

[52] **U.S. Cl.**..... **29/599,** 174/126 CP, 174/128, 174/DIG. 6

[51] **Int. Cl.**..... **H01v 11/14**

[58] **Field of Search**..... 29/599; 174/114 S, 126 CP, 174/128, 129 S, DIG. 6

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Primary Examiner—Charles W. Lanham
Assistant Examiner—D. C. Reiley, III
Attorney, Agent, or Firm—Larry R. Cassett and H. Hume Mathews

[57] **ABSTRACT**

A multi-filament superconducting composite composed of a plurality of segments that is intrinsically stable. The individual segments are multi-filament composites that have been twisted after assembly and mechanical working and thereafter subsequently deformed. The deformed segments can be triangular or rectangular and are assembled into a second composite. After assembly the second composite is once again twisted. This second twisting transposes the filaments within the segments, thereby producing a superconductor that is resistant to flux jumps induced by self-field losses.

7 Claims, 9 Drawing Figures

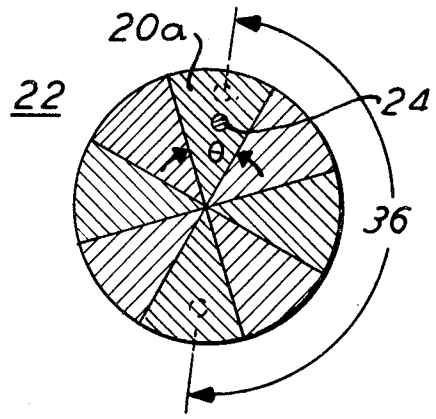


FIG. 1

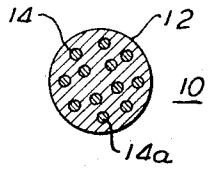


FIG. 2

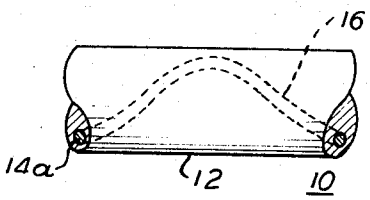


FIG. 3

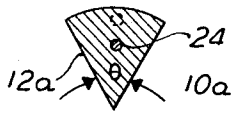


FIG. 4

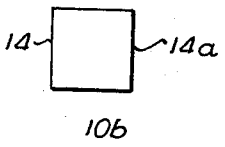


FIG. 7

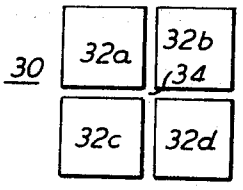


FIG. 5

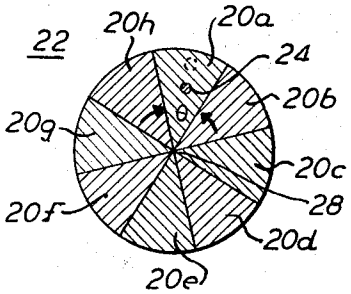


FIG. 6

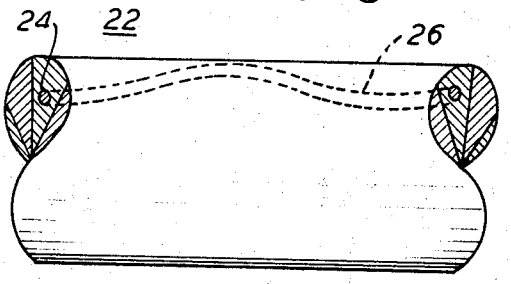


FIG. 8

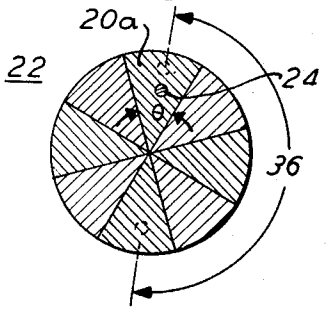
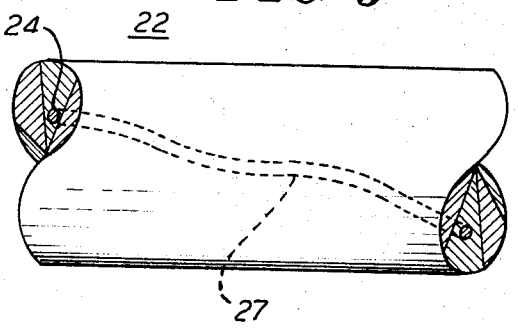


FIG. 9



MULTI-FILAMENT COMPOSITE SUPERCONDUCTOR WITH TRANSPOSITION OF FILAMENTS AND METHOD OF MAKING SAME

This is a division of application Ser. No. 286,625 filed Sept. 6, 1972.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to superconductors and more specifically to multi-filamentary superconductor composites that are intrinsically very stable.

2. Prior Art

A significant factor in the development of superconductors and superconducting devices is the attainment of adiabatic stability. This is essential in order to attain reliable performance in superconducting devices. Excellent superconducting properties have been attained in laboratory testing of short samples. However, when superconducting devices were fabricated from long superconductor wire, performance comparable to short sample testing was not attained.

Failure to obtain short sample performance in superconducting devices has been attributed, in part, to flux jumps. Flux jumps cause degradation in superconducting devices by creating sudden local releases of energy resulting in a premature transition to the normal state and thereby preventing reliable attainment of high current densities.

It is theorized that flux jumps occur when an external field is applied to a superconducting device inducing loops of current at the critical current density which are unstable and may suddenly decay rapidly with a release of energy. This sudden release of energy causes a transition in the superconducting device from the superconducting state to the normal or resistive state thereby causing degradation of the superconductor. This sudden reversal can result in serious physical damage to the superconducting device.

Various techniques have been developed to improve the stability of superconductors by minimizing degradation caused by flux jumping. In the paper, "Multifilamentary Superconducting Composites", by P. R. Critchlow, E. Gregory and B. Zeitlin, published in Cryogenics, February 1971, pp. 3–10, recent developments that have contributed to the production of stable superconducting composites are discussed. One such development is the production of superconductors from composites having 50–1000 superconducting filaments in a matrix of high purity copper. However, the apparent advantages offered by miltifilamentary composites were not fully realized because these wires behaved in some respects essentially the same as an equivalent solid single core conductor and the occurrence of flux jumping was unchanged.

This paper points out a technique whereby flux jumps induced by an external field can be reduced and the full advantages of multifilamentary composites attained. If the composite is twisted, the wire is effectively cut into lengths equal to half the twist pitch. The twisted wire should, therefore, behave as a collection of isolated filaments and consequently be more stable than a comparable untwisted multifilament composite.

Critchlow et al disclose that a twisted composite is still susceptible to degradation and loss from self-field effects. The self-field of the wire is produced by the transport current flowing in it. This results in an unequal current distribution in which the outer filaments carry more current than the inner ones. A flux jump may occur thereby producing more uniform current distribution with a concomitant transition to the normal state.

Twisting alone will not eliminate self-field effects because the filaments never change their radial position. Transposition will arrange the individual filaments so that they occupy successively every position of the cross-section. The filaments in an individual wire cannot be transposed. However, by winding a number of these wires into a braid or cable, a transposed conductor can be constructed.

By forming a braid or cable insures that the inner wires get to the outside of the conductor cross-section. These techniques, however, are not entirely satisfactory because rigidity and high packing factor cannot be attained. Rigidity or wires in a superconducting device is necessary to prevent objectionable wire motion. The shape of braided or cabled superconducting wire does not produce a high packing factor. This restricts the amount of wire that can be contained in a magnet thereby affecting the size of the magnet.

Accordingly, the present invention provides a novel superconductor composite comprised of a plurality of segments and method of making same that utilizes superconducting filaments embedded in a normal matrix. The segments are twisted so as to obviate eddy current type losses resulting from external magnetic fields and the individual filaments are also transposed so that they occupy the same relative radial position within the superconductor cross-section, thereby also avoiding or eliminating self-field losses.

SUMMARY OF THE INVENTION

An object of this invention is to provide an intrinsically stable milti-filament superconductor.

A further object of this invention is to provide an intrinsically stable milti-filament supercondcutor composed of a plurality of segmented composites.

Still a further object of this invention is to provide a superconductor that is free from degradation resulting from self-field losses.

Still a further object of this invention is to provide a method for producing intrinsically stable multifilament superconductors.

A further object of this invention is to provide a method for producing intrinsically stable multifilament superconductors composed of a plurality of segmented composites.

These and other objects are obtained by assembling a first composite composed of a plurality of superconducting rods in a normal matrix. This first assembly is then mechanically worked until the superconductor rods are reduced to a filament of a diameter approximating the desired final diameter. The mechanically reduced composite is then twisted and segmented. As used herein, the term segmented means to alter mechanically the cross-section of the superconductor composite from round to triangular or rectangular by passing the composite through a forming device. A second composite of rectangular or circular cross-section is made by assembling a plurality of the previously formed segments. This second composite is then mechanically worked until the diameter of the filaments is reduced to approximately 0.3 to 1.4 mil. The mechani-

cally worked composite is then twisted a second time.

The individual segments constitute composites composed of a suitable number of superconducting filaments in a matrix of normal material having a twist of the necessary pitch. The segments are resistant to flux jumping induced by an external magnetic field and are thereby stabilized against this form of degradation. However, the filamentary strands within each individual segment will not vary in their radial location from the center of such segment and the segment will not avoid instability resulting from generated self-fields. The individual segments are combined to form a second composite. The second composite is then mechanically worked and twisted to a predetermined pitch. The convoluted filaments contained within each segment of this second composite assume a path of varying radial position along their lengths from the center of the final conductor. Such varying distribution of the individual filaments produces a more uniform sharing of each filament of the cross-section of the composite conductor so that each filament shares substantially equally in the conducting current. Thus the tendency towards instability resulting from self-generated fields is avoided.

The advantages of the superconductor of this invention will be apparent from the following drawings and detailed descriptions in which:

BRIEF DESCRIPTION OF THE SEVERAL VIEWS

FIG. **1** is a diagrammatic transverse schematic of a first composite of this invention consisting of superconductor rods in a normal matrix.

FIG. **2** is a diagrammatic longitudinal schematic of a first composite of this invention showing the position of an outside filament after twisting.

FIG. **3** is a diagrammatic transverse schematic of a first composite after segmenting.

FIG. **4** is a diagrammatic transverse schematic of another embodiment of a first composite after segmenting.

FIG. **5** is a diagrammatic transverse schematic of a second composite consisting of a plurality of triangular segments. FIG. **6** is a diagrammatic longitudinal schematic of a second composite showing the position of a filament within the composite.

FIG. **7** is a diagrammatic transverse schematic of another embodiment showing a second composite consisting of a plurality of rectangular segments.

FIG. **8** is a diagrammatic transverse schematic of a second composite after twisting.

FIG. **9** is a diagrammatic longitudinal schematic of a second composite showing the position of a transposed filament within a segment after twisting.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1**, there is shown a superconducting composite **10** consisting of a normal matrix **12** such as OFHC copper and superconducting alloy rods **14** distributed therein. The superconducting alloy can be, for example, niobium-titanium containing approximately 50 percent of each element. After assembly, the composite can be fabricated in a manner well known in the art, for example, extrusion rolling, drawing, swaging and heat treatment are well known processing techniques utilized to obtain a composite of a specified reduced cross-section and optimum superconducting properties. In this instance composite **10** is reduced to a diameter approximating the desired final diameter.

After fabrication, composite **10** is twisted. As shown in FIG. **2**, after twisting representative filament **14***a* follows path **16.** The pitch or rate of twist is dependent upon the rate at which the superconducting device will be charged. For most applications a pitch of ½ to 5 twists per inch is acceptable. The intermediate diameter must be of such a magnitude so that reduction to the final diameter will not remove the original twist by elongating the wire. Generally speaking, this intermediate diameter must not be more than twice the final desired diameter.

FIGS. **3** and **4** show two different embodiments, **10***a* and **10***b*, of segmented composite **10.** After composites **10***a* or **10***b* are mechanically worked to an intermediate diameter and twisted, they are then segmented by mechanical shaping. Shaping to the desired cross-section may be performed by using dies, grooved rolls or a Turks-head. A Turks-head consists of 4-hardened steel rolls set in planes at right angles to each other. The narrow face of the rolls, as set in the framework, is adjustable on the same plane so that the assembly of the overlapping roll edges facing each other will project a contour of the opening so formed, into the desired shape of the cross-section of the product to be made.

Preferably the angle θ in FIG. **3** should be a subdivision of 360°, i.e., **10, 12, 15, 20, 24, 30, 45, 60, 72, 90, 120,** etc., so that the triangular or rectangular segments **10***a* or **10***b* so produced by the Turks-head can be assembled to form a second composite **22** or **30** as shown in FIGS. **5** and **7,** respectively. After mechanically forming segments **10***a* or **10***b*, the segments can be further treated in order to facilitate assembly of composites **22** or **30.** The segments may be passed through a solder bath of silver-tin (3% Ag, 97% Sn). This coating of solder will hold the segments together during further processing. The assembly can also be formed by ultrasonically welding the segments together.

FIG. **5** shows a second composite **22** composed of triangular segments **20***a*, **20***b*, **20***c*, **20***d*, **20***e*, **20***f*, **20***g* and **20***h*. The angle θ formed during drawing first composite **10** through the forming dies is 45°. As shown in FIG. **6,** representative filament **24** in segment **20***a* is transposed along the path **26.**

FIG. **7** shows another embodiment of a second composite **30** composed of rectangular segments **32***a*, **32***b*, **32***c* and **32***d*.

As shown in FIGS. **5** and **7,** after assembly the mating segments have a common junction point, **28** and **34,** which is located at the center of the second composite. This places some of the filaments which were formerly situated at the outside of the original composite on the inside or near junction point **28** or **34** of the second composite. These filaments were originally twisted and they will retain their position in the interior of the segment cross-section after assembly of the second composite. Furthermore, filaments originally located near the center of the segments, such as filament **24,** will now be located near the outside of the second composite. When the second composite is twisted after assembly, the heretofore centrally located filaments will now be transposed and occupy varying positions within the superconductor cross-section.

FIG. **8** shows second composite **22** after mechanical reduction to final size. The multi-filaments contained within segments **20***a* through **20***h* are not shown for

reasons of clarity. However, the diameter of these filaments is approximately 0.3–0.4 mil in diameter. After final reduction the composite may be heat treated in a manner well known in the art in order to obtain a metallurgical micro-structure that will produce the optimum superconducting properties.

FIG. 9 shows the segmented second composite after twisting. This twisting serves to decouple the filaments electromagnetically as hereinbefore discussed. The rate of twist is represented by numerical **36** in FIG. **8.** The segmented composite is now stabilized against self-induced flux jumps. Representative filament **24** in segment **20** a is transposed along the path **27.**

Superconducting wire produced by the novel method of this invention has several distinct advantages over superconducting wire produced by conventional prior art methods. Some of the more apparent advantages include:

A solid superconducting wire of equivalent diameter and equal superconductor alloy to normal material ratio will exhibit more losses than a segmented superconductor composite produced by the invention disclosed herein. The windings of superconducting devices, such as magnets, will be more rigid with less wire motion when wound with this novel segmented wire as compared to other intrinsically stable superconducting wires, such as braid or cable. Furthermore, the shape of this wire produces a higher packing factor than braid or cable, resulting in more wire per superconducting device. Still further, a composite with a like number of small diameter filaments merely twisted and not transposed will not be stable against self-induced losses and the advantages of small diameter filaments will not be fully realized.

SPECIFIC EXAMPLE

First Composite

A first composite was assembled by inserting 360 rods of a Nb-Ti alloy (Containing 55 percent by weight Nb) into an eight inch diameter copper billet. This composite was then mechanically worked until the diameter of the composite was approximately 11 mil.

The mechanically worked composite was then twisted. The rate of twist was from about one-half turns to five turns per linear inch.

Segmenting First Composite

The 11 mil composite was then passed through a Turks-head. The rolls of the Turks-head were adjusted to produce a square wire approximately 10 mil square.

Second Composite

The square segment was then passed through a bath of silver-tin solder (3% Ag, 97% Sn). A second composite was formed by paying out four solder-coated segments from four bobbins. This composite **30** is shown in FIG. **7.** The payed out segments were passed through a series of closely-spaced aligning dies. The properly aligned segments then passed through a tapered die wherein a square composite was formed. At some convenient location heat was applied to the composite, melting the solder and bonding the segments together. The formed composite was twisted at a rate from about one-half turns to about five turns per linear inch.

The finished intrinsically stable composite contained four segments and was approximately 20 mil square. The individual segments each contained 360 filaments approximately 0.3–0.4 mil in diameter.

From the foregoing, it is apparent that by the present invention there has been provided a particularly advantageous method for producing a novel intrinsically stable superconducting wire. The invention has been described with reference to a presently preferred embodiment, however, it is intended to cover such modifications as fall within the spirit and the scope of the invention as hereinafter claimed.

We claim:

1. A method for producing intrinsically stable superconducting wire comprising the steps:

a. assembling a first composite by inserting rods of a superconductive alloy in a matrix of normal material;

b. working said composite so as to substantially reduce the diameter of said composite and form filaments of said superconductive alloy rods;

c. twisting said composite at a rate from about one-half turns to about five turns per linear inch of said composite;

d. forming said composite into a segment by passing said composite through forming rolls;

e. assembling a second composite by arranging a plurality of said segments in a geometric configuration; and

f. twisting said second composite so as to transpose said superconductive filaments so that the filaments substantially share equally the cross-section of said segments.

2. A method as recited in claim **1** wherein said segments are bonded together before twisting said second segment.

3. A method as recited in claim **2** wherein said segments are passed through a molten bath of solder.

4. A method as recited in claim **2** wherein said segments are ultrasonically welded together.

5. A method as recited in claim **1** wherein said segments are traingular in cross-section.

6. A method as recited in claim **1** wherein said segments are rectangular in cross-section.

7. A method as recited in claim **1** wherein said second composite is twisted at a rate from about one-half turn to about five turns per linear inch.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,829,964 Dated August 20, 1974

Inventor(s) Philip R. Critchlow & Bruce A. Zeitlin

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

1. Col. 2, line 18, "or" should be --of--

2. Col. 2, line 67, "1.4" should be --0.4--

Signed and sealed this 21st day of January 1975.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

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UNITED STATES PATENT OFFICE

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