United States Patent [19]
Shattes et al.

[11] **3,708,606**
[45] **Jan. 2, 1973**

[54] CRYOGENIC SYSTEM INCLUDING VARIATIONS OF HOLLOW SUPERCONDUCTING WIRE

[75] Inventors: **Walter J. Shattes,** Bloomfield; **William G. Marancik,** Basking Ridge; **Bradley S. Kirk,** Warren, all of N.J.

[73] Assignee: **Air Reduction Company, Incorporated,** New York, N.Y.

[22] Filed: **May 13, 1970**

[21] Appl. No.: **36,741**

[52] **U.S. Cl.** ....**174/15 C,** 174/27, 174/126 CP, 174/128, 174/DIG. 6, 335/216

[51] **Int. Cl.** **H01b 7/34,** H01v 11/00

[58] **Field of Search** .174/15 C, DIG. 6, 126 CP, 128, 174/27, 15 R, 16 R, 117 F, 28; 335/216; 29/599; 333/995

[56] **References Cited**

UNITED STATES PATENTS

3,596,349	8/1971	Boom	174/DIG. 6
3,293,008	12/1966	Allen et al.	174/DIG. 6
3,562,401	2/1971	Long	174/DIG. 6
3,366,728	1/1968	Garwin et al.	174/DIG. 6
3,472,944	10/1969	Morton et al.	174/15
3,349,169	10/1967	Donadieu	174/128
3,444,307	5/1969	Kafka	174/15
3,527,873	9/1970	Brechna et al.	174/15

FOREIGN PATENTS OR APPLICATIONS

441,457	1/1968	Switzerland	174/DIG. 6
6,701,316	7/1967	Netherlands	174/DIG. 6

Primary Examiner—Bernard A. Gilheany
Assistant Examiner—A. T. Grimley
Attorney—Melford F. Tietze, Edmund W. Bopp and H. Hume Mathews

[57] **ABSTRACT**

A core element comprising superconducting strands in a normally conducting matrix is initially extruded in a desired cross-sectional shape or configuration; and is then interposed in a prefabricated or postfabricated tube, and coreduced to a final product of desired dimensions, thus providing a matrix having a plurality of longitudinal internal channels. The core elements may assume a variety of cross-sectional shapes, such as ribbon, square, cross, triangle, star, annulus, etc., or a composite of these. In an alternative process, a cable is formed by twisting or braiding together a plurality of superconducting matrix wires, prior to coreduction in a prefabricated or postfabricated tube. In another form, a superconducting matrix strip is welded to form a tube. In a variation of this, superconductor wires are interposed in longitudinal slots in a billet of normally conducting material which is rolled into a ribbon, alternatively formed into a tube. The product of any of these techniques is finally coreduced to a wire which is formed into a coil which may be cooled internally by a forced cooling system including fluid or superfluid helium.

24 Claims, 18 Drawing Figures

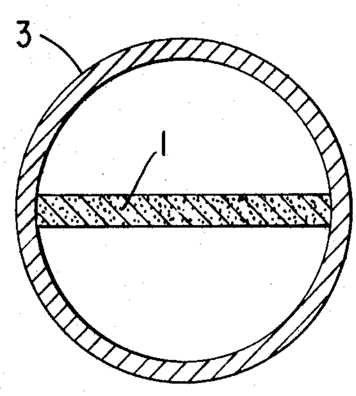


FIG. 1

FIG. 2

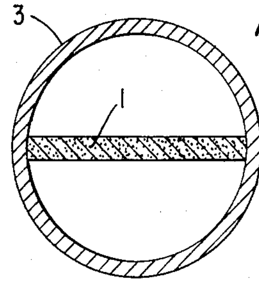


FIG. 3A

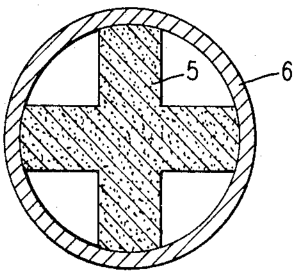


FIG. 5A

FIG. 5B

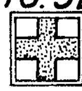


FIG. 4

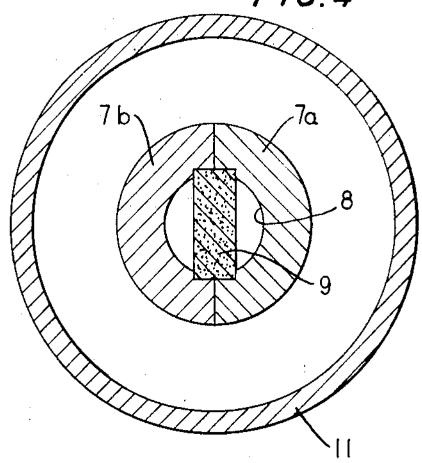


FIG. 6A

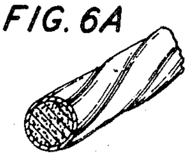


FIG. 6B

FIG. 3B

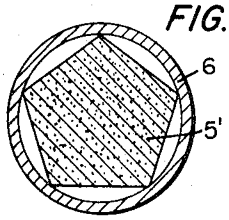


FIG. 7A

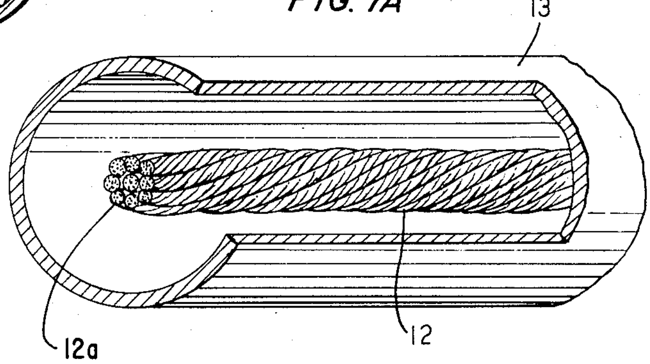
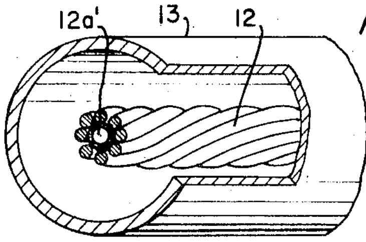


FIG. 7B



INVENTORS W. SHATTES
W. MARANCIK
BRADLEY S. KIRK

BY Melford L. Lietze
ATTORNEY

FIG. 8A

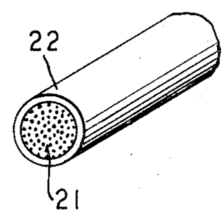


FIG. 8B

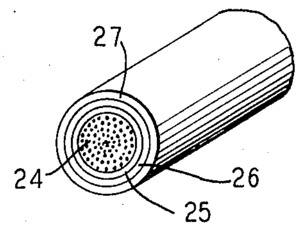


FIG. 8C

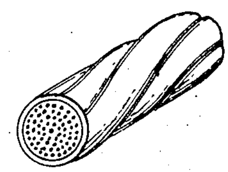


FIG. 9

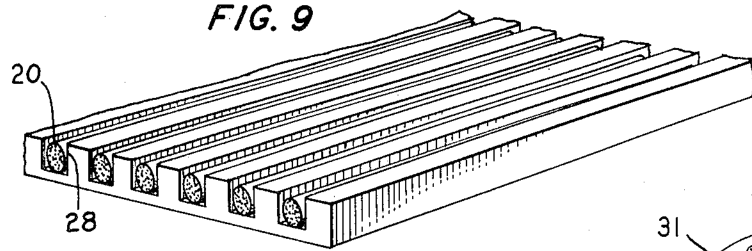


FIG. 10B

FIG. 10A

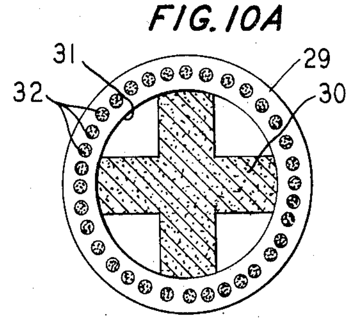
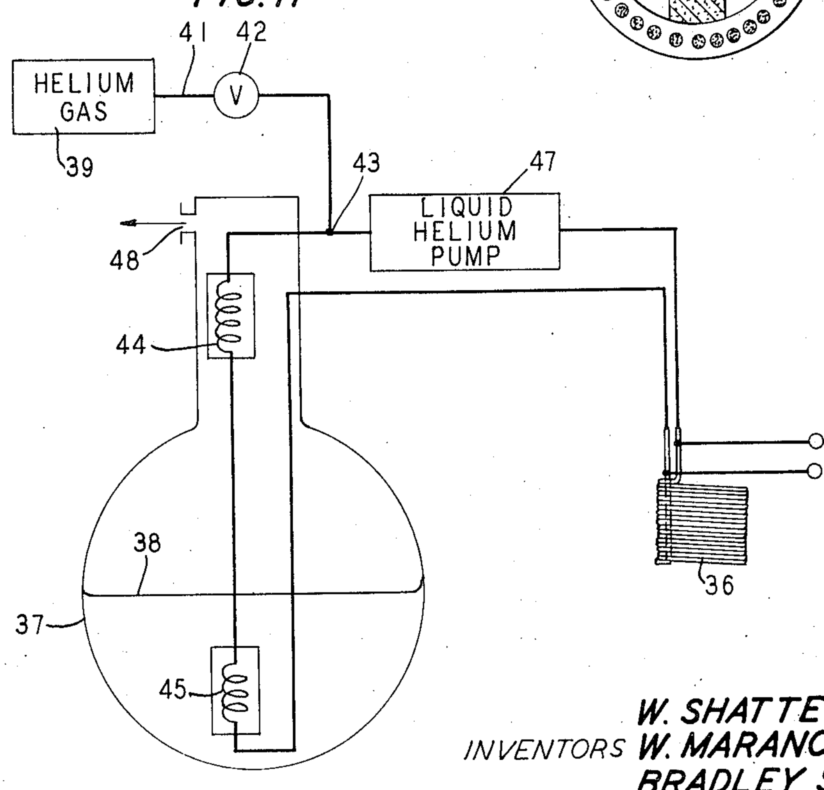


FIG. 11



W. SHATTES
INVENTORS W. MARANCIK
BRADLEY S. KIRK
BY
Melford L. Lietz
ATTORNEY

CRYOGENIC SYSTEM INCLUDING VARIATIONS OF HOLLOW SUPERCONDUCTING WIRE

BACKGROUND OF THE INVENTION

In order to maintain superconducting materials in the temperature environment necessary for operation, they are usually submersed in a bath of boiling liquid helium. Liquid helium at normal pressure has been found to be a poor medium for cryostatic systems requiring forced circulation of the coolant. However, pressurized normal (or supercritical) liquid, or superfluid, helium have been found to be an excellent coolant in forced circulation, or forced convection systems.

A most advantageous cooling system is one in which the superconductor wires are constructed to include lengthwise pores or channels through which fluid or superfluid helium can be pumped in a forced circulation system to bring it into direct contact with the superconductor.

Although prior systems have been developed utilizing supercritical helium and various conductor configurations, construction of suitable wires of this form, having optimum superconductive characteristics, requires expensive and cumbersome processes. Moreover, it has been found that certain of the superconductive configurations employed in the prior art have less than optimum current carrying characteristics, and have poor directional characteristics, exhibiting a substantial degree of anisotropy.

Accordingly, it is a primary object of the present invention to provide for the construction with greater facility of higher quality superconductor wires, particularly of a type including channels for low temperature fluid or superfluid helium. Another object of the invention is to provide channeled superconductive wires of a configuration of improved electrical characteristics in which anisotropy is reduced. Another object is to provide superconductor configurations having better heat transfer characteristics. A still further object of the invention is to provide for the manufacture of longer lengths of superconductive wire with greater facility, and of a type which tolerates twisting without fracture.

BRIEF DESCRIPTION OF THE INVENTION

These and other objects are attained in accordance with the present invention by a unique type of wire construction for use in the superconducting coil of a forced convection helium cooling system. This wire may comprise a core element including a matrix of normally conducting material containing fine superconducting strands, the core being preformed to a pre-selected cross-sectional shape, such as, for example, a ribbon, square, triangle, star, annulus, etc. or combination of the same; and which is ultimately interposed in a prefabricated or postfabricated tube, and coreduced or sink drawn to a final reduced cross-sectional wire product which contains lengthwise channels or pores.

In one alternative form, the core comprises a cable formed of a plurality of superconductive matrix wires braided or twisted together, with each other or with normally conducting strands, before being placed in a tube for further processing. In another alternative form, a superconductive matrix strip is welded at the long edges to form a tube, or placed inside an external tube comprising normally conducting material. A tube may be formed from ribbon made from a billet of normally conducting material which has been slotted to accommodate a wire of superconductive matrix material.

The product wire, after final cold or hot working and heat treatment, is used to form a coil, through the channeled interior of which helium is pumped in a forced convection cooling operation.

Particular advantages of the processes and products of the present invention are that the wire can be conveniently fabricated in longer lengths than in prior art processes. The various configurations provide for better heat transfer, and in most cases, for reducing anisotropy. Moreover, the composite strands of superconductor and matrix material can be readily twisted, prior to installation as core elements or prior to fabrication as enclosing tube elements, providing improved electrical characteristics.

These and other objects, features, and advantages will be apparent to those skilled in the art from a study of the detailed specification hereinafter with reference to the attached drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a matrix of a normally conducting material, including strands of superconducting material, which have been coreduced in an initial process;

FIG. 2 shows, in cross-section, a combination, before reduction, of a superconducting matrix element of the form indicated in FIG. 1, interposed in a tube of normally conducting material;

FIGS. 3A and 3B shows variations of the combination of FIG. 2, before reduction, in which the superconducting core element interposed in the tube respectively takes the form of a cross or a polygon;

FIG. 4 is a further variation of the elements of FIGS. 2 and 3, in which the core element interposed in the tube takes the form of two annular halves of normally conducting material, which close together to hold in place a diametrically-disposed ribbon of superconducting material;

FIGS. 5A and 5B show the general cross-sectional appearance of the final form to which the configurations of FIGS. 2 and 3 respectively may be reduced;

FIGS. 6A and 6B show a single strand twist, and multiple strand twist which can be assumed by the core elements of FIGS. 2, 3 and 4;

FIG. 7A is a further alternative form of the invention in which the central superconductive matrix comprises a plurality of wires of the type shown in FIGS; 6A or 6B, braided together.

FIG. 7B is a modification of the above in which the central element is tubular;

FIG. 8A shows a round wire element of superconductive matrix material enclosed in a thin copper coating;

FIG. 8B shows a wire element of superconductive matrix material having a plurality of coatings, including a coating of cupro-nickel sandwiched between two thin coatings of copper;

FIG. 8C shows a wire of the form of FIGS. 8A or 8B, which has been twisted;

FIG. 9 shows a slab or normally conducting material, including multiple longitudinal slots into which are interposed rods of the form of FIGS. 8A, 8B, or 8C;

FIG. **10A** shows, before reduction, a tube made from a slotted slab of the form of FIG. **9** by standard tube processes, surrounding a composite cruciform central element;

FIG. **10B** shows the configuration of FIG. **10A** after reduction; and

FIG. **11** shows in schematic a forced cooling system employing a coil of superconductive wire formed in accordance with the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

Referring in detail to FIG. **1** of the drawings, there is shown in cross-sectional view, a matrix **1** of normally conducting material, including a large number of strands **2** of superconducting material. In the present illustration, the matrix **1** may comprise a ribbon of the order of 50 mils thick, 125 mils wide, and of indeterminate length, containing of the order of 100 strands of superconducting material, each strand having a cross-sectional dimension of, say 4 to 5 mils.

This product may be fabricated by any one of several different processes well-known in the art in which, for example, a plurality of superconducting rods inserted in normal conducting tubes are packed together in a preselected configuration inside of a cylindrical shell of normally conducting material several inches in diameter. This is then evacuated and sealed. The evacuated, sealed billet is then processed by a combination of hot and cold working steps to a product of desired cross-sectional dimension and electrical characteristics. Such a process is described in detail on page **46** of a book entitled *Manufacture and Properties of Steel Wires* by Anton Pomp, published by The Wire Industry, Ltd., London (1954).

For the purposes of the present invention, the superconducting material may comprise, for example, an alloy ranging in composition from 60 percent niobium, 40 percent titanium to 40 percent niobium, 60 percent titanium. In the present illustrative embodiment the superconductor material is niobium titanium in an alloy consisting of essentially 55 weight percent niobium and 45 weight percent titanium. This is formed from what is known in the art as electron beam niobium and crystal bar titanium, the total alloy containing oxygen to the amount of about 200 – 1,000 parts per million, the remaining impurities, not including oxygen, being under about 0.11 percent by weight. It will be understood that in the fabrication of alternative embodiments, other alloys can be employed in different proportions of niobium and titanium, such as, for example, an alloy consisting essentially of 44 weight percent niobium and 56 weight percent titanium, having an oxygen content of about 600 parts per million and having impurities, not including oxygen, of less than about 0.15 percent by weight. It is contemplated that any material known as Class II or a "hard" superconductor, may be used for the purposes of the present invention.

In the present example, it is contemplated that the normally conducting material may consist of what is known in the art as "certified oxygen free high conductivity copper", known by the trademark OFHC Brand Copper, and described in detail in a technical survey entitled "OFHC Brand Copper High Conductivity Oxygen Free Copper," copyright 1957, available from The American Metal Company Ltd., 61 Broadway, New York, New York. Alternatively, it is contemplated that other normally conducting materials may be sued for this purpose such as, for example, aluminum, gold, or silver.

In accordance with another alternative, the core element may comprise strands of superconductive material in a matrix comprising high resistance normally conducting material, such as alloys of cupro nickel or German silver. In a convenient form, strands of niobium titanium encased in copper sleeves are embedded in a matrix of cupro-nickel alloy, constructed in the manner disclosed in application Ser. No. 36,740, filed by W. Shattes and W. Marancik, at even date herewith.

Assuming that the material prepared in the manner previously described has been reduced to the cross-sectional dimensions indicated with reference to FIG. **1**, such an element, which may be in the form of a ribbon as much as 1,200 feet long, may be then interposed in a tube, **3** as shown in FIG. **2**, which may be of, say, OFHC Brand Copper which in the present example is 30 mils in wall thickness and ⅝ inches in outer diameter. Alternatively, the outer tube **3** can comprise aluminum, stainless steel, or in fact any metal having the requisite strength and relative conductivity. In addition to being a single integral tube, say 30 mils thick, it can alternatively comprise a laminate of a plurality of tubes of lesser thickness fitted together coaxially. For example, an outer tube of stainless steel can be welded to an inner tube of, say, copper to provide additional strength.

The structure, as indicated, may be reduced in cross-section about 20 percent by what is known in the art as "sink drawing," in which cold working is applied to uniformly reduce the diameter of the outer tube to crimp it about the inner superconducting matrix element. The principal object of this step is to fasten the core element to the inner wall of the enclosing tube in such a manner as to form good mechanical, thermal and electrical contact. The composite is then cold worked through one or more dies until the resulting product is of the order of 50 to 80 mils in cross-section and may be shaped either to have a rectangular or circular cross-section, depending on the type of die through which it is drawn in the final processing steps. The inner or core element **1** need not necessarily be a single piece, but can comprise a laminate of layers from 2 to 25 mils thick, and each 125 mils wide. These may be superposed to form a single integral element or may be separated.

In accordance with another alternative, instead of the central element **1** being of the form of a ribbon, it may be processed by metal working techniques well-known in the art including drawing it through dies which will give it a final cross-sectional configuration in the form of a cross, such as, for example, shown as element **5** in FIG. **3A**. The latter, in a manner similar to that indicated in FIG. **2**, is interposed into a tubular shell **6** of normally conducting material which may be of a thickness and form similar to that indicated with reference to FIG. **2**. Like the element previously shown, this may also be sink drawn to reduce it to the desired cross-section. Another illustrative variation of the performed core element is shown in FIG. **3B**. It will be apparent that the core cross-section may assume many additional variations, such as rectangles, triangles, and other polygons, and stars of various shapes.

Another alternative may be, for example, of the form indicated in FIG. 4 of the drawings, in which the core element is a composite formed of two doughnut-shaped halves *7a*, *7b* of copper or other normally conducting material of the order of, say 5/8 inches in outer diameter and having an inner diameter opening **8**, say, 3/8 inches across. The two halves 7a, *7b* accommodate between them a strip or ribbon **9** running lengthwise and bifurcating the chamber formed by the inner opening **8**. The ribbon **9** comprises a matrix element of superconducting material of the general form indicated in FIG. **1**. In an alternative embodiment, the donut-shaped halves *7a*, *7b* of FIG. **4** can also be formed of superconducting material of the form indicated in FIG. **1**. The composite cone comprising the annular halves *7a*, *7b* and ribbon separator is interposed, in the manner indicated with reference to the previous figures, in an outer tube **11** of normally conducting material, having an outer diameter of 0.750 inches, and a wall thickness of about 30 mils, which is processed in the manner previously described by sink drawing it to conform to the outer diameter of the annular halves *7a*, *7b* with a reduction of about 20 percent in area. By cold working, the composite is ultimately reduced to a cross-sectional dimension of **50** to 80 mils, which may be either circular or rectangular, in the manner indicated in FIGS. **5A** and **5B** of the drawings, depending on well-known metal working techniques.

As indicated in FIGS. **6A** and **6B** of the drawings, in accordance with a preferred alternative, the inner core member, comprising the element **1** of FIG. **2**, the element **5** of FIG. **3**, and the element **9** of FIG. **4**, may be twisted, as shown in FIG. **6A** of the drawings, before it is rolled or passed through a die for forming in the desired shape for assembling in the enclosing cylinder, in each case. For example, it is contemplated that the pitch of twists may vary from several feet to one-tenth of an inch. In a further alternative form, shown in FIG. **6B**, the core elements **1**, **5** and **9** in FIGS. **2**, **3** and **6**, respectively, may comprise multistrand twists, in which strands of superconductive matrix wire are twisted together, or with strands of normal conductor. It has been found that the finer the superconductor filaments, the more electrically stable is the configuration.

In a further alternative, the twisted super conductive matrix, as shown in FIGS. **6A** and/or **6B**, may be first rolled into a flat sheet, and joined such as by welding with a metal sheet of other compositions to form a laminate. The laminate may then be formed into a tube of laminar construction with the superconductive matrix forming the innermost layer. The tube formation may be accomplished by drawing. The outer laminate is desirably a relatively stronger metal intended to afford desired structural properties and may be made from a sheet of normally conducting material or preferably, a stronger metal such as stainless steel. The tube then formed may be used as a hollow superconductive wire or may be substituted for the outer tubes disclosed in FIGS. **2**, **3**, **4**, **7** or variations of these.

An additional modification is shown in FIG. **7A** of the drawings. In FIG. **7A** a plurality of wires of composite superconducting matrix material of the type described with reference to FIG. **1** of the drawings, each having a cross-sectional diameter of about 0.1 inch, are braided together in spiral fashion as shown in FIG. **6B** to form a cable **12** about 0.450 inches in diameter. This braid may comprise only a few strands, or many strands, and may be intermixed with strands of normally conductive material. The spiral may have a pitch of from several feet to about one-tenth inch. As with the other embodiments, this may be interposed into an enclosing outer tube **13** which is 0.75 inches in diameter and about 30 mils thick, and sinkdrawn and further processed, as previously described, to the desired shape and cross-section. In a variation of this embodiment, the central or core wire **12A** of the cable can be substantially larger than the peripheral wires which may be wound about it at varying pitches and using various numbers of strands from as few as one to up to 19. In another variation, indicated in FIG. **7B** core **12a** may comprise a tube.

In accordance with a further variation of the invention, wires or rods of superconductive matrix material of the form indicated in FIG. **8A**, having a solid central element **21** formed in the manner indicated with reference to the matrix element of FIG. **1**, is coated with a thin coating **22** of normally conducting material, such as a copper coating 0.001 inches thick. A variation is shown in FIG. **8B**, in which the central superconductive matrix element **24**, which may be 0.050 inches in diameter, includes an inner coating of copper **25**, which is 0.001 inches thick, an intermediate coating of cupro-nickel **26** which is 0.001 inches thick, and an outer coating of copper **27** which is 0.001 inches thick. Either of the elements shown in FIGS. **8A** or **8B** can, in the case of a preferred alternative, be twisted as shown in FIG. **8C**.

Elements **20** of the form of any of those shown in FIGS. **8A**, **8B** or **8C** are then interposed, as shown in FIG. **9**, into a series of longitudinal slots **28** which are 0.05 inches wide and 0.07 inches deep, parallel to the long edges of a rectangular slab of normally conductive material, such as copper, say, 2 inches wide and 1 inch thick, and of indeterminate length.

This is cold worked and rolled to a thickness of 0.080 inches and a length of about, say, 1,200 feet. It can then be formed by welding the edges by tube-making processes well-known in the art, to form a tube **29**, such as indicated in FIG. **10A**, having an outer diameter of 0.5 inches and an inner channel **31**, say 0.340 inches diameter, and discrete islands **32** of superconductive matrix material. It is contemplated that a composite core element **30**, having a cruciform cross-section, and similar to core element **5** of FIG. **3**, and preferably twisted, may be interposed inside of the tubular shell **29**, before coreduction to the form shown in FIG. **10B**. It will be understood that the element **30** can also assume any of the forms shown on FIGS. **2**, **3**, and **4**, or other forms, such as rectangles, triangles, stars, and other polygons. The form of FIG. **10A** may be reduced by the usual cold working techniques to an element of the form shown in FIG. **10B**, having an outer diameter of 0.400 inches.

It is contemplated that wire formed in accordance with the specifications set forth hereinbefore may be embodied in the coil element **36** of a forced cooling convection system employing supercritical fluid helium, such as shown in FIG. **11** of the drawings. This comprises a Dewar type vessel **37**, properly insulated in the manner known in the art to maintain the helium at the desired temperature and pressure. Vessel **37** is partially filled with a bath of liquid helium **38**. Helium gas is initially introduced into the system from a source **39** through the line **41** and cryogenic valve **42** to the junction **43**, from which it flows through the heat exchanger **44** interposed in the neck of the vessel, and heat exchanger **45**, submersed in the liquid helium, to coil **36** comprising hollow superconductive wire of one of the types described with reference to the earlier figures. The helium circulated through this circuit by the action of the liquid helium pump **47** is brought to a temperature of the liquid bath **38** in the heat exchanger **45**, subsequently cooling down the superconductive coil **36**. In the present illustrative embodiment, bath **38** is maintained at about 4.2° Kelvin. The heat exchanger **44** functions to partly recuperate the enthalpy of helium vapors exhausted through vent **48** in the top of the vessel. Helium in the closed loop including heat exchangers **44** and **45** and coil **36** is maintained at high pressure, whereas pump **47** is required to produce only a small pressure drop for recirculation in the circuit. Until equilibrium is reached, helium is introduced continuously from the source **39**, valve **42** being closed when equilibrium is reached. Details of such a system are disclosed in an article entitled "Construction of a Superconducting Test Coil Cooled by Helium Forced Circulation" by M. Morpurgo of Cern, Geneva, Switzerland, reprinted from N.P. Division Report CERN 68–17 (1968).

The test coil **36** may, for example, have the form indicated in the above-named article.

The superconducting strands formed in accordance with the present invention have been found to have a current carrying capacity of 1×10^5 amps./cm.^{2} at a field of **60** kilogauss. In addition, the forms shown in FIGS. 3A and 7A, 7B are substantially isotropic in their behavior.

We claim:

1. As an article of manufacture, superconducting wire comprising in combination:

a preformed, prereduced matrix of normally conducting material containing a large number of strands of superconducting material each initially not exceeding about 10 mils in cross-section extended along the length of said wire in metallurgically bonded relation to said matrix, a composite comprising said matrix having a shape including one or more channels extending internally along the length of said wire,

said wire including said channelled composite having been reduced in cross-section through at least one post-reduction step in addition to said prereduction step.

2. An article of manufacture in accordance with claim **1** wherein said preformed, prereduced matrix has been twisted prior to installation as an element of said wire.

3. The combination in accordance with claim **2** wherein said superconducting material consists essentially of an alloy of niobium and titanium.

4. The combination in accordance with claim **3** wherein said normally conducting material is copper.

5. The combination in accordance with claim **2** wherein said composite comprises an outer tube of conducting material, and wherein said preformed, prereduced matrix comprises a core element axially disposed in said outer tube, said outer tube having a substantially larger initial cross-sectional dimension in at least one direction than the cross-sectional dimension of said core element,

said outer tube having been at least reduced to the external diameter of said core element to form a composite with said core element.

6. The combination in accordance with claim **5** wherein the preformed shape of said core element is alternatively a ribbon, cross, polygon, or annulus.

7. The combination in accordance with claim **5** wherein said core element interposed in said outer conducting tube is twisted.

8. The combination in accordance with claim **5** wherein said core element comprises a braid of twisted strands including said preformed matrix of normal and superconducting material.

9. The combination in accordance with claim **8** wherein said core element comprises a central tube about which is twisted a plurality of strands comprising said preformed matrix of normal and superconducting material.

10. The combination in accordance with claim **5** wherein said outer tube consists essentially of copper.

11. A system comprising in combination a coil of superconducting wire in accordance with claim **1**, connected in circuit relation with a source of electrical power, a source of fluid helium connected to said coil, and means for inducing the flow of fluid helium in said coil.

12. As an article of manufacture, superconducting wire comprising in combination:

an outer tube of conducting material,

a composite core axially disposed in said outer tube,

said composite core consisting essentially of a ribbon of a preformed, prereduced matrix of normally conducting material containing a plurality of superconducting strands extended along the length of said wire, said ribbon clamped between two semiannular intermediate tube halves comprising normally conducting material to form said composite core having a pair of longitudinal channels,

said outer tube having a substantially larger initial cross-sectional dimension in at least one direction than the cross-sectional dimension of said composite core, and having been at least reduced to the external diameter of said composite core to form a further composite with said core.

13. The combination in accordance with claim **12** wherein said intermediate tube halves comprise a matrix of normal and superconducting material.

14. As an article of manufacture, superconducting wire comprising in combination a composite including one or more channels extending internally along the length of said wire, said composite comprising:

an outer tube which is a laminate comprising a peripheral layer of metal of relatively higher tensile strength and an inner layer comprising copper,

a core element axially disposed in said outer tube, said core element comprising a preformed, prereduced matrix of normally conducting material containing a plurality of superconducting strands extended along the length of said wire and twisted about its long axis prior to installation in said tube, said laminated outer tube having a substantially larger initial cross-sectional dimension in at least one direction than the cross-sectional dimension of said core element, and said laminated outer tube having been at least reduced to the external diameter of said core element to form a composite with said core element.

15. The combination in accordance with claim **14** wherein said outer tube is a laminate comprising a peripheral layer of metal of relatively higher tensile strength and an inner layer of said prereduced matrix of normally conducting material containing a plurality of strands of superconducting material extended along the length of said wire.

16. The combination in accordance with claim **15** wherein said peripheral layer is stainless steel and said inner layer of prereduced matrix material has been twisted prior to rolling for formation into said tube.

17. A system comprising in combination a coil of superconducting wire in accordance with claim **14**, connected in circuit relation with a source of electrical power, a source of fluid helium connected to said coil, and means for inducing the flow of fluid helium in said coil.

18. The combination in accordance with claim **14** wherein said metal of relatively high tensile strength consists essentially of stainless steel.

19. A superconducting wire comprising a laminated tube having an inner tubular layer comprising a prereduced matrix of normally conducting material containing a plurality of strands of superconducting material, said inner tubular layer extended along the length of said wire, and an outer metal layer of different composition for strengthening said tubular wire.

20. As an article of manufacture, superconducting wire comprising in combination a composite including one or more channels extending internally along the length of said wire, said composite comprising:

an outer tube,

a core element in said outer tube, said core element comprising a preformed, prereduced matrix of normally conducting material containing a plurality of superconducting strands extended along the length of said wire, said core element twisted about its long axis prior to installation in said tube, said outer tube formed from an elongated slotted slab of normally conducting material wherein wire elements of said preformed, prereduced matrix material have been interposed into the slots, and said slab having been rolled to reduce its cross-section and formed into a tube by welding the longitudinal edges of said rolled slab, wherein said tube including said core element has been further reduced in cross-section to form a channelled superconducting wire,

said outer tube having a substantially larger initial cross-sectional dimension in at least one dimension than the cross-sectional dimension of said core element, and said outer tube having been at least reduced to the external diameter of said core element to form a composite with said core element.

21. The article of manufacture in accordance with claim **20** wherein said wire interposed in said slotted slab is twisted.

22. The article in accordance with claim **20** wherein said wire interposed in said slotted slab has been coated with an inner coating of copper, an intermediate coating of cupro-nickel, and an outer coating of copper.

23. A system comprising in combination a coil of superconducting wire in accordance with claim **20**, connected in circuit relation with a source of electrical power, a source of fluid helium connected to said coil, and means for inducing the flow of fluid helium in said coil.

24. As an article of manufacture, superconducting wire comprising in combination

a preformed, prereduced matrix consisting essentially of an alloy of cupro-nickel in which are embedded a plurality of copper coated strands of niobium titanium extended along the length of said wire,

a composite comprising said matrix having a shape including one or more channels extending internally along the length of said wire,

said wire including said channelled composite having been reduced in cross-section through at least one post-reduction step in addition to said prereduction step.

* * * * *