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[21] Appl. No. **694,146**
[22] Filed **Dec. 28, 1967**
[45] Patented **Dec. 1, 1970**
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[32] Priority **Dec. 28, 1966**
[33] **France**
[31] **No. PV-89180**

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Attorney—Craig, Antonelli, Stewart & Hill

[54] **ELECTRICAL CONDUCTOR CONFIGURATION**
PROVIDING LENGTH STABLE WITH
TEMPERATURE
11 Claims, 11 Drawing Figs.

[52] U.S. Cl. 174/129,
29/193.5, 174/15, 174/126
[51] Int. Cl. H01v 11/02
[50] Field of Search 174/(SC),
15, 126, 126.2, 126.3, 128, 113, 117, 129, 119,
133, 106, 102.31; 335/216; 29/183—183.5, 195.5,
193.5, 193, 161/109; 1/125; 336/55—60; 338/206

ABSTRACT: An electrical conductor, comprising a metal strip in which bending areas are formed to take up longitudinal stresses exerted on the said strip, so that the said conductor may be deformed in its plane under the action of thermal stresses without any change in length.

The metal strip has a plurality of slots. The strip may be of normal metal and within the strip can be embedded a plurality of superconductive wires.

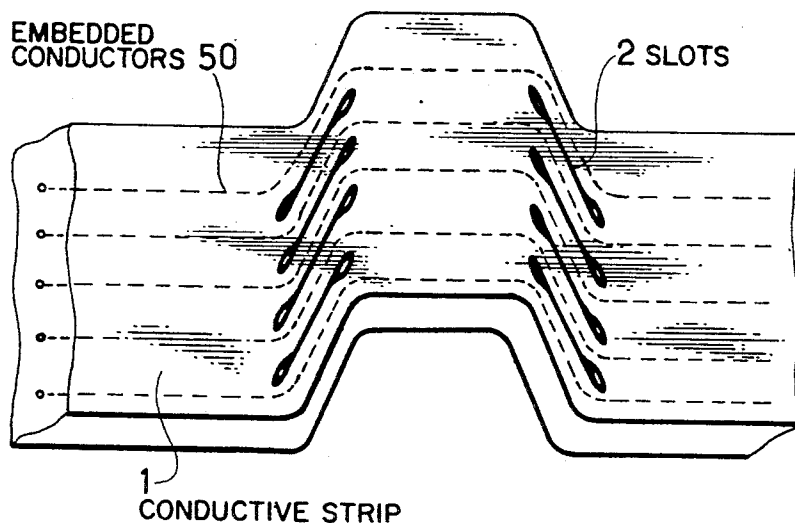


FIG. 1

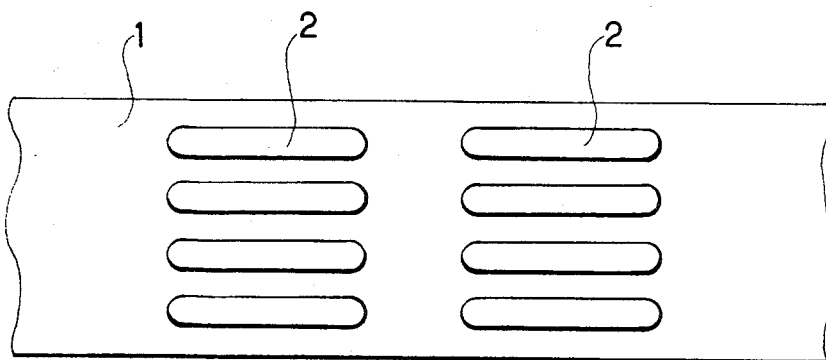


FIG. 2

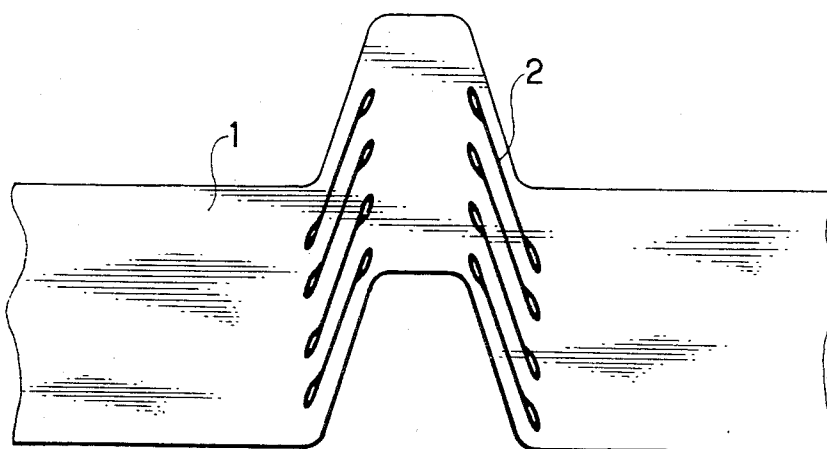


FIG. 3

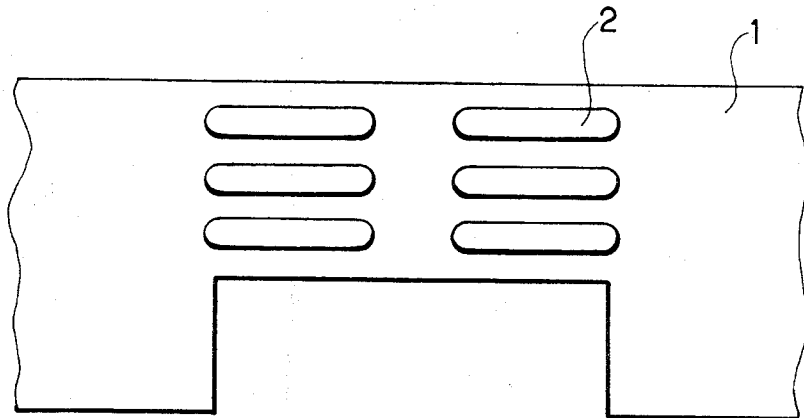


FIG. 4

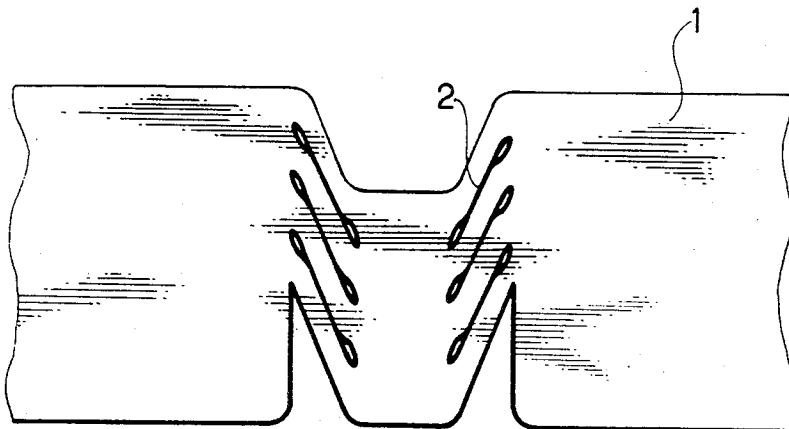


FIG. 5

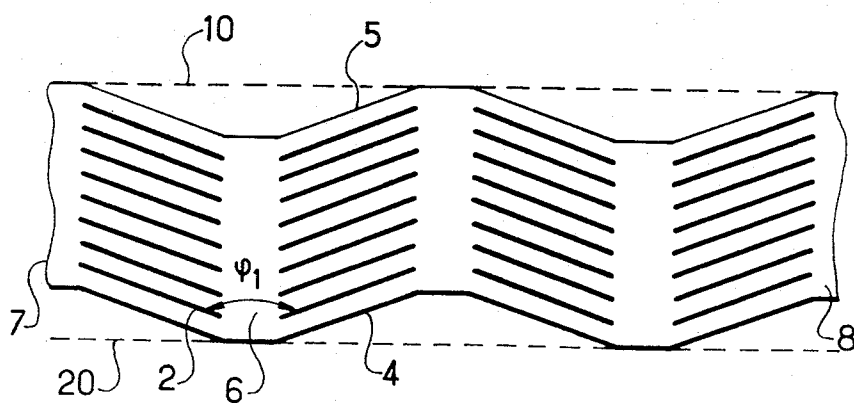


FIG. 6

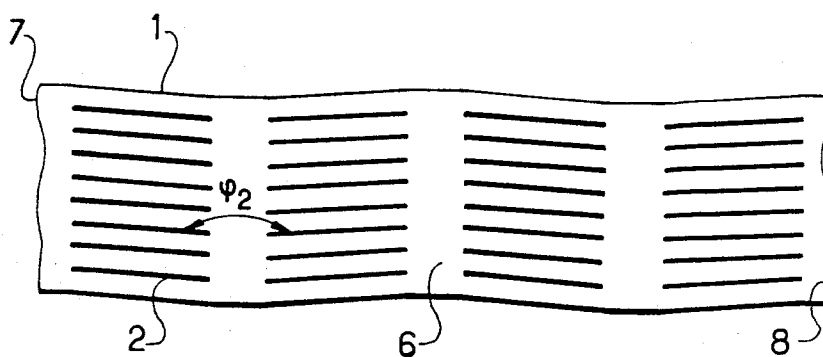


FIG. 7

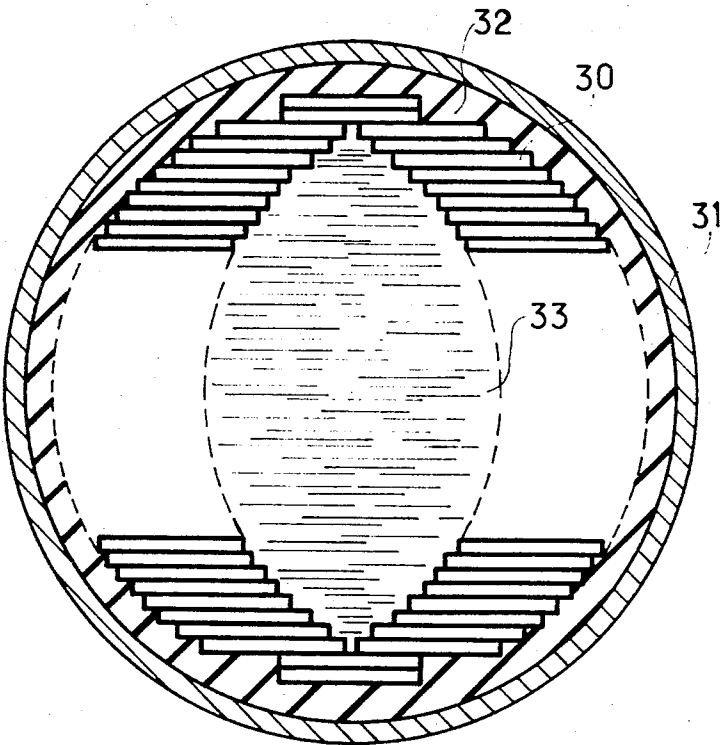


FIG. 8

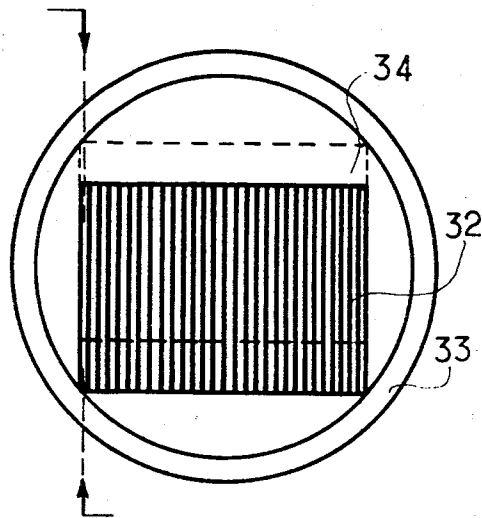


FIG. 9

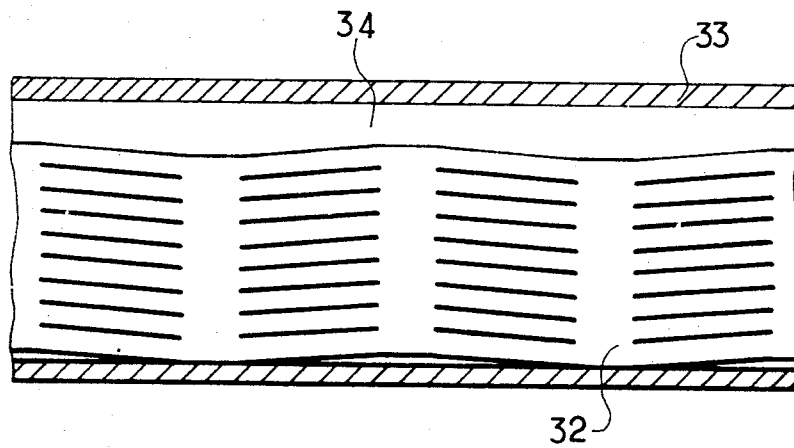


FIG. 10

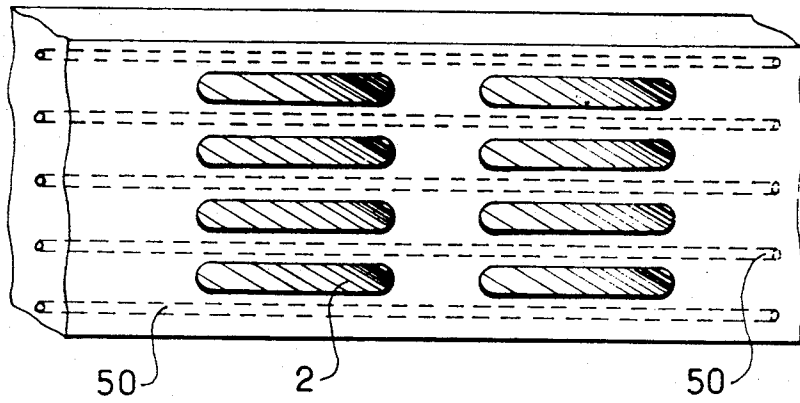
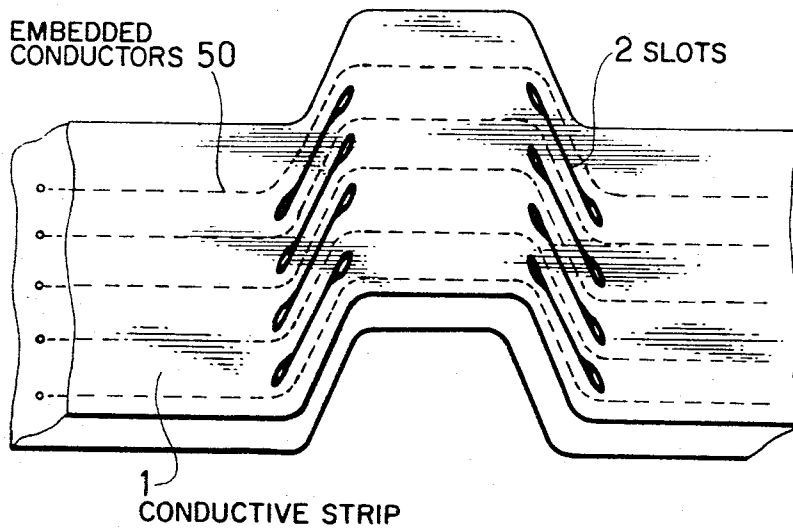


FIG. 11



ELECTRICAL CONDUCTOR CONFIGURATION PROVIDING LENGTH STABLE WITH TEMPERATURE

The present invention relates in general to conductors, and more particularly to an electrical conductor having a structure which is characterized by the fact that its length does not vary as a function of temperature.

This conductor may be employed singly, or in a set with other identical conductors to form electric cables. It may be considered for operation with direct current or with single-phase or multiphase alternating current, and its operating temperature may either lie above ambient temperature in the case of conductors or cables of normal conductivity, or below ambient temperature in the case of hyperconductive or superconductive conductors or cables.

It is known that when electrical conductors of great length are brought to their rated temperature from ambient temperature, they undergo substantial mechanical stresses unless the material of which they are constituted is provided with the possibility of displacement, for example, expansion in the case of conventional conductors, or contraction in the case of superconductive or hyperconductive conductors.

As an example, an aluminum conductor will contract by as much as 4.2 percent when its temperature passes from ambient temperature to an operating temperature close to 20° K. Since this contraction may occur in a conductor of very great length, the stresses thus engendered cause a substantial plastic deformation in the longitudinal direction of the material—the elastic limit at 20° K. corresponding to a relative elongation of 0.5 percent linked with a stress of 3.4 kgs./mm.². The plastic deformation engendered in this case reaches eight times the limit of permissible elastic deformation.

The disadvantages which are to be eliminated and which are linked with thermal expansion or contraction, are numerous. For example, the expansions and contractions produce destructive reactions on the anchoring points of the conductor. In addition, there is destruction to the conductor itself arising from entering of the material within the range of plastic deformation, such as creep, strain hardening, premature wear and fracture. In the case of conductors made of hyperconductive materials, there is also experienced an increase in resistivity coupled with strain hardening.

The invention has for its primary object the provision of an electrical conductor of appropriate structure, which does not incur the aforesaid disadvantages when brought to the operating temperature.

It is another object of the present invention to provide an electrical conductor which may be deformed in its plane under the action of thermal stresses while its length remains substantially unchanged. It is a further object of the present invention to provide an electrical conductor of the type described which is simple in construction and economical to manufacture.

It is still another object of the present invention to provide an electrical conductor of the type described which is capable of absorbing in an efficient manner both expansive and contractive stresses due to temperature deviation in the conductor.

It is still a further object of the present invention to provide an electrical conductor capable of internally absorbing thermal stresses and isolating the anchoring points of the conductor from these stresses.

The conductor according to the invention is essentially characterized in that it consists of a metal strip in which are formed bending areas for absorbing forces exerted longitudinally on the strip, in such manner that the conductor may be deformed in its plane under the action of thermal stresses while its length remains substantially unchanged.

In a preferred embodiment, the said areas or sections comprise at least one set of parallel slots.

The invention will now be described with reference to the accompanying drawings, which illustrate several embodiments of the invention but in no restrictive sense.

FIG. 1 shows a plan view of a portion of a conductor according to a first embodiment of the invention, before being shaped to assume its final form.

FIG. 2 illustrates the conductor of FIG. 1 after having been formed to proper shape ready for application.

FIG. 3 is an illustration in plan view of a partially finished conductor according to a first modification of the invention, prior to being formed to proper shape.

FIG. 4 illustrates the conductor of FIG. 3 after being formed to proper shape ready for application.

FIGS. 5 and 6 illustrate the appearance of a conductor according to a second modification of the invention, when at ambient temperature and at low temperature, respectively.

FIG. 7 shows the cross section of a cable comprising a plurality of conductors corresponding to the conductor of FIG. 4.

FIGS. 8 and 9 show the cross section and longitudinal section, respectively, of a cable comprising a plurality of conductors corresponding to the conductor of FIG. 5.

FIGS. 10 and 11 illustrate a conductor having the same general form as that illustrated in FIGS. 1 and 2, but within which are contained wires of superconductive material.

FIG. 1 illustrates the blank or partially finished form of a conductor consisting of a conductive strip 1 in which areas of lesser resistance to stresses exerted in the plane of the strip, substantially perpendicularly to its axis have been obtained periodically along the length of the strip by cutting slots 2 in the strip extending parallel to the length of the strip. The conductor is then deformed in the areas of the slots in such a manner as to obtain the form illustrated in FIG. 2. The edges of each corresponding slot in the two angular surfaces being joined together or not in accordance with the degree of deformation depending on the intended application.

This conductor may be employed as a cryogenic conductor operating at very low temperature. With the shape illustrated in FIG. 2 and with its slots as shown, the conductor has its extremities secured to fixed elements (not shown) at ambient temperature. After cooling, the conductor contracts with a small reduction in the height of the V-shaped bend accompanied by a spreading of the slots.

The conductor may also be employed as a conventional conductor at a higher operating temperature than ambient temperature. To this end, the conductor is wrought to have the form illustrated in FIG. 2 at ambient temperature, but while maintaining a specific width of the slots, in such manner as to promote subsequent deformations due solely to thermal actions. The unconfined conductor then has its extremities anchored still at ambient temperature. While in operation at a temperature exceeding ambient temperature, the conductor will expand and undergo lateral deformations, assuming the form of FIG. 2, the initial width of the slots being reduced. The length of the conductor will remain constant and its restoration to ambient temperature after operation will not engender any harmful strains.

The nature of the material employed for the conductor depends on its subsequent application. Standard grades of copper and aluminum may be employed for conductors intended for conventional application. Electrolytic aluminum or copper of a high degree of purity will preferably be employed for conductors of the hyperconductive type.

Refined electrolytic aluminum of high purity, coated by one or more layers of a superconductive material, for example lead, columbium-zirconium or columbium-titanium alloy, or columbium-tin compound, may be employed for conductors of the superconductive type. FIGS. 10 and 11 show a superconductive conductor based upon the configuration of FIGS. 1 and 2 and consisting of wires 50 of superconductive material imbedded in a strip 1 of stabilizing metal, such as aluminum for example, the slots 2 being out between the superconductive wires.

One versed in the art may easily determine the number, length and width of the slots, in consideration of the coefficient of expansion of the material of the conductor, or its limit of elastic deformation and the maximum difference in tem-

perature to which it may be exposed. The increase in the resistance of the conductor, which should remain within acceptable limits, should equally be taken into account.

As an example, it is frequently desirable in an aluminum conductor operating at a cryogenic temperature, that each area of deformation should comprise parallel slots. Each group of slots is wrought along the entire width of the conductor, and the width of each slot may, for example, be equal to the distance separating two adjacent slots. The length of the slots amounts to between 20 and 100 times their width.

The separate areas of deformation are identical and separated by a distance substantially equal to 30 times the length of an area of deformation. It is demonstrable that, in such case, the relative increase in electrical resistance of the conductor is smaller than 20 percent which is acceptable in the majority of applications.

FIG. 3 illustrates a modified form of a conductor according to the invention, in which the area of deformation comprises a row of slots 2 parallel to each other and to the edges of the strip, and adjacent to which a rectangular piece of metal has been cut away. On forming the strip to shape corresponding to FIG. 4, this arrangement renders it possible to prevent a local increase in the width of the conductor adjacent to the area of deformation.

FIGS. 5 and 6 illustrate another embodiment of a conductor according to the invention. FIG. 5 illustrates the configuration at ambient temperature in plan view of a conductor according to this modified form. From a metal strip delimited by the dashed lines 10 and 20 have been cut metal pieces of trapezoidal shape alternating regularly on both edges of the strip in such a manner as to produce a planar element substantially possessing a generally serpentine shape.

The deformed areas are produced by making cuts such as 2 in the strip, parallel to the inclined sides 4 and 5 and substantially of the same length as these sides. The portions 6 which are not slotted, and extend to the truncated corners, retain satisfactory mechanical resistance against contraction stresses caused by a reduction in temperature. The conductor is assumed to be anchored at its extremities 7 and 8. Contrary to the embodiments described above, the width of the cuts is very small, the edges of the cuts being almost in contact.

FIG. 6 illustrates the appearance of the conductor when its temperature reaches a substantially lower level than ambient temperature, in the case of hyperconductive or superconductive conductors. The extremities of the conductor being anchored, its contraction has caused a rotation of the slotted portions about the unslotted parts, so that the angle Φ_1 of the order of 160° has changed to an angle Φ_2 close to 180° , the distance between the extremities 7 and 8 being constant in practice and the conductor being unaffected by any harmful longitudinal strain.

The areas of deformation described and illustrated are obviously not given in any restrictive sense and obvious modifications may be introduced therein without thereby departing from the scope of the invention.

The invention equally relates to a cable comprising a plurality of conductors of nature combined into a cable configuration. As an example, FIG. 7 illustrates the cross section of a cable comprising a stack of hyperconductive or superconductive conductors having the form illustrated in FIG. 2 or FIG. 4. The conductors are stacked and secured against the inner side of an outer tube 31. An insulating material 32 may be situated between the conductors and the tube. The central space 33 acts as a duct for circulation of a cryogenic fluid. The conductors may carry direct current, in which case they will be connected in parallel. The cable may equally be employed for single-phase alternating current in the same conditions of application. In a modified construction, a three-phase cable may be formed by separating different conductors or groups of conductors allotted to one and the same phase by means of insulating strips.

Another embodiment of a cable in accordance with the invention is illustrated in cross section in FIG. 8 and in longitu-

dinal section in FIG. 9. This cable consists of a plurality of conductors 42 of analogous shape to that illustrated in FIGS. 2, 4 or 5. In the case of a direct current cable, as illustrated, the conductors are positioned closely to each other, are electrically connected in parallel and are enclosed in an insulating sheath 43. The dotted outline enclosing the space 44 is occupied by the conductor.

The conductors are positioned "in phase" geometrically, that is to say in such manner that the slotted portions of one conductor are situated against the slotted portions of the adjacent conductor. The method of securing the conductors within the sheath does not lie within the scope of the present invention and has not been illustrated. Analogously, the devices for thermal insulation and cryogenic arrangements have not been illustrated either.

The invention is in no way limited to the specific forms of the embodiments described and illustrated, which were not given in any restrictive sense, and modifications of detail and technically equivalent means may be incorporated therein without thereby exceeding the scope of the invention.

In particular, the conductors according to the invention may be applied in cables of coaxial structure, employing a plurality of conductors, such as those illustrated in FIGS. 1-6 and 10 and 11, and with deformations formed to trough-shape.

We have shown and described several embodiments in accordance with the present invention. It is understood that the same is not limited thereto but is susceptible of numerous changes and modifications as known to a person skilled in the art and we, therefore do not wish to be limited to the details shown and described herein but intend to cover all such changes and modifications as are encompassed by the scope of the appended claims.

We claim:

1. An electrical conductor comprising a metal strip in which spaced deformed portions lying in the plane of that strip are each provided with a plurality of slots, said slots being angularly disposed with respect to the longitudinal edges of said metal strip and having a lesser resistance to deformation in said plane than the remaining portions of the strip.

2. An electrical conductor comprising a metal strip in which spaced deformed portions of the strip are each provided with a plurality of slots and have lesser resistance to be deformed in said plane than the remaining portions of the strip.

3. An electrical conductor as defined in claim 2 wherein said slots extend parallel to the longitudinal edges of said metal strip.

4. An electrical conductor as defined in claim 3 wherein a notch is cut into said metal strip adjacent said sets of slots and extending to at least one edge of said strip.

5. An electrical conductor as defined in claim 3 wherein notches are cut into said metal strip adjacent said sets of slots in either longitudinal edge thereof alternately to provide for said strip a plane serpentlike configuration.

6. An electrical conductor as defined in claim 2 wherein said strip is made of a metal of standard conductivity and includes a plurality of wires embedded therein extending longitudinally of the strip and made of a superconductive material.

7. An electrical conductor as defined in claim 6 wherein said strip is made of aluminum and said wires are made of a metal selected from the group consisting of lead, columbium-zirconium alloys, columbium-titanium alloys and columbium-tin alloys.

8. A cable comprising a plurality of electrical conductors as defined in claim 3 positioned together in contiguous relationship within a tubular member, an insulating material being provided between said conductors and said tubular member.

9. A cable as defined in claim 8 wherein said electrical conductors are stacked so as to provide a central passage for circulation of cryogenic fluid.

10. A cable as defined in claim 8 wherein said electrical conductors are positioned so that slotted portions of one con-

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ductor are positioned against slotted portions of the adjacent conductor.

two consecutive deformed portions are angularly disposed with respect to one another in the plane of the strip.

11. An electrical conductor as defined in claim 2 in which

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