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(54) **DESIGN OF CONTACTS FOR SUPERCONDUCTING BUSBARS AND CABLES**

(57) The invention relates to a contact assembly and a respective method for contacting superconducting busbars, cables or other superconducting components comprising coated conductor superconducting tapes. The contact assembly comprises a pair of conductive walls and a plurality of contact units (101), each contact unit being configured for connecting one (121) of the coated conductor superconducting tapes of a first superconducting component and a corresponding one (141) of the coated conductor superconducting tapes of the second superconducting component. Each contact unit comprises:
a first contact section (F2F) for connecting a first portion

of the coated conductor superconducting tape (121) of the first superconducting component and a first portion of the coated conductor superconducting tape (141) of the second superconducting component via a face-to-face connection;
a second contact section (FCuF) for connecting a second portion of the first superconducting coated conductor superconducting tape (121) of the first superconducting component to a second portion of the coated conductor superconducting tape (141) of the second superconducting component via a conductive bridge (20) of not superconducting material. The conductive bridges of the contact units contact the conductive walls.

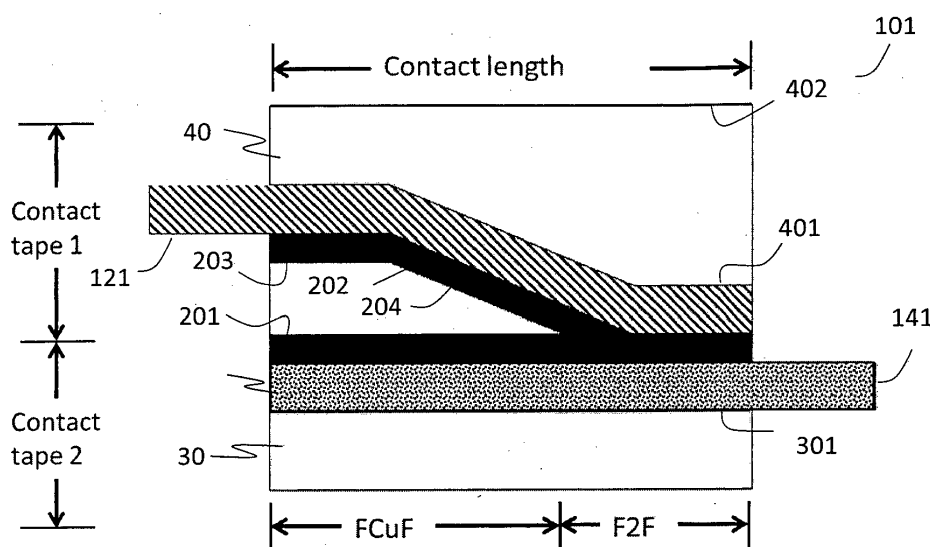


Fig. 4

Description

[0001] The invention relates to contacting superconducting busbars, cables or other superconducting components comprising coated conductor superconducting tapes.

[0002] Coated superconducting tapes (CC tapes) comprise a superconducting layer or layers applied on a substrate and optionally further layers, such as for example a buffer layer. The superconducting layer may be for example made of a high temperature superconductor (HTS). The CC tapes as well as the superconducting cables and busbars made with CC tapes have various applications, such as for power transmission cables, rotor coils for motors and generators, transformers, magnets, to name a few.

[0003] In many of these applications it is desirable or necessary to connect pairs of CC tapes, for example to form a longer superconducting cable. Various approaches for connecting CC tapes have been proposed.

[0004] One approach for connecting CC tapes is the direct face-to-face contact (see Publication 1). A face-to-face is a contact between two CC tapes established by contacting the side of one of the CC tapes that has the superconducting layer with the superconducting layer of the other CC tape. This type of contact is advantageous, since the current transfer length may be minimized along with minimizing the Joule losses given by the contact. However, if one of the tapes has lower critical current (I_c) than its contacted counterpart, the current will be limited to follow the path given by both tapes. Hence, the critical current of the two contacted tapes will be largely dominated by the tape with the lower critical current. Thus, this approach relies on having a very large uniformity in the critical current of the tapes, which is very difficult if at all possible to achieve, since the local critical current I_c of a tape is given by a probabilistic distribution, hence always allowing for non-zero tolerances.

[0005] Another method for connecting superconducting tapes uses a massive metallic joint, for example, a large Cu contact (see Publication 2). The use of a massive metallic contact allows the current to be redistributed in the connected superconducting tapes, thus alleviating the problem of the reduction and redistribution of the critical current in case of a non-uniform distribution of the critical current. However, the Joule losses are considerably larger than that of face-to-face contact, since the entire current has to follow the larger resistive path. Further, the massive metallic joints are typically made very long so that by increasing the overlapping, the Joule losses can be reduced. Since the Joule losses depend linearly on the length of the contact, reducing the Joule losses requires a significant increase of the joint's size. In addition, since the CC tapes would have to overlap over a considerable distance, the length of CC tapes is increased.

[0006] Still another alternative used to connect HTS stacked-tape cable conductors is to employ additional

1G (First generation) tapes (made for example of BSCCO in a silver matrix) sandwiching the tapes to be contacted (see Publication 3). However, this method is only suitable for compact designs and requires doubling the soldering per tape to be contacted. Further, this method is more expensive as the 1 G tapes should overlap both sections of the CC tapes to be contacted. In addition, the tapes have to be contacted one by one, making this a complicated process, especially considering that the superconducting layer in the CC tapes is brittle and likely to be damaged if exposed to excessive mechanical manipulation.

Cited prior art documents:

[0007]

Publication 1: N. Yanagi, et al., "Design and development of high-temperature superconducting magnet system with joint-winding for the helical fusion reactor", Nuclear Fusion 55 (2015) 053021, doi:10.1088/0029-5515/55/5/053021;

Publication 2: D. Ungletti, et al., "Test of 60 kA coated conductor cable prototypes for fusion magnets", Supercond. Sci. Technol. 28 (2015) 124005, doi: 10.1088/0953-2048/28/1/014011;

Publication 3: M. Takayasu et al., "HTS twisted stacked-tape cable conductor", Supercond. Sci. Technol. 25(2012) 014011, doi:10.1088/0953-2048/28/12/124005.

[0008] It is an object of the invention to provide an improved contact between superconductor components comprising coated conductor superconducting tapes. In particular it is an object of the invention to provide a contact with a better current distribution without introducing large ohmic residual contact. A further object is to provide a contact having small transfer length and ohmic resistance.

[0009] The above objects are solved by a contact assembly and a method for connecting superconducting components as set forth in the independent claims, respectively.

[0010] In particular, a first aspect of the invention relates to a contact assembly for electrically connecting superconducting components, each superconducting component comprising a plurality of coated conductor superconducting tapes (in the following also referred to as a CC tape). The contact assembly comprises a pair of conductive walls and a plurality of contact units arranged between the conductive walls. Each contact unit is configured for electrically connecting one of the plurality of coated conductor superconducting tapes of the first superconducting component (first coated conductor superconducting tape) and a corresponding one of the plurality of coated conductor superconducting tapes of the

second superconducting component (second coated superconducting tape). In other words, each contact unit is configured for connecting a pair of tapes, namely one coated conductor superconducting tape of the first superconducting component and one coated conductor superconducting tape of the second superconducting component.

[0011] Each contact unit comprises:

a first contact section for connecting a first portion of the first coated conductor superconducting tape and a first portion of the second coated conductor superconducting tape via a face-to-face connection;

a second contact section for connecting a second portion of the first superconducting coated conductor superconducting tape to a second portion of the second coated conductor superconducting tape via a conductive bridge of not superconducting material.

[0012] Further, the conductive bridges of each of the contact units are in contact with the conductive walls. For example, the plurality of contact units may be arranged between the conductive walls so that the conductive bridges of all contact units contact the conductive walls directly or through a solder layer.

[0013] A second aspect of the invention relates to a method for (electrically) connecting superconducting components, each superconducting component comprising a plurality of coated conductor superconducting tapes. The method comprises connecting each of the plurality of coated conductor superconducting tapes of the first superconducting component and a corresponding coated conductor superconducting tape of the plurality of coated conductor superconducting tapes of the second superconducting component by:

forming a plurality of contact units, each contact unit being configured for connecting one of the plurality of coated conductor superconducting tapes of the first superconducting component and a corresponding one of the plurality of coated conductor superconducting of the second superconducting component, wherein each contact unit comprises:

a first contact section for connecting a first portion of the coated conductor superconducting tape of the first superconducting component and a first portion of the coated conductor superconducting tape of the second superconducting component via a face-to-face connection; and

a second contact section for connecting a second portion of the superconducting coated conductor superconducting tape of the first superconducting component to a second portion of the coated conductor superconducting tape of the second superconducting component via a

conductive bridge of not superconducting material; and

contacting a pair of conductive walls to the conductive bridges of the plurality of contact units. The contacting of conductive walls to the conductive bridges may comprise directly contacting the conductive walls to the conductive bridges or contacting the conductive walls to the conductive bridges through a solder layer. As explained above, the contact units may be arranged between the conductive walls, so that all conductive bridges contact the pair of conductive walls.

[0014] The superconducting components may be for example superconducting cables, busbar sections or other superconducting components made of at least one coated conductor superconducting tape.

[0015] The proposed contact design is based on using a contact assembly that allows each CC tape to have a double contact, one direct contact and one through a normal (i.e. not superconductive) conductive bridge, for example a metal bridge. In an embodiment the two contact sections are arranged to be adjacent to each other, i.e. to border each other.

[0016] Each contact unit of the contact assembly thus comprises a first contact section allowing for a direct face-to-face contact between the pair of CC tapes to be connected. In this section, the CC tapes are arranged such that the superconducting layers of the two CC tapes to be connected are facing each other. The two superconducting layers may be directly connected without a layer interposed between them. Optionally, a small amount of solder or metal (such as for example Indium) may be used as an interlayer between the superconducting layers of the two face-to-face connected CC tapes. For example, the thickness of the interlayer may be in the range of 1 μm to 2 mm, for example between 2 μm and 20 μm . In the following, the first contact section will be also referred to as F2F section.

[0017] The second contact section introduces a normal (i.e. not superconducting) conducting material between the two CC tapes to be contacted, the conducting material forming a conductive bridge. The conductive bridge (also referred to as contact bridge or joint) may be made of metal, for example of Cu, Ag, In, solder or any other suitable conductive material. The thickness of the conducting material constituting the conductive bridge (i.e. the thickness of the conductive bridge) may be for example in the range of 10 μm to 2 cm, for example in the range of about 10 μm to 1 cm, further for example between 0.5 mm and 5 mm and still further for example between 1 mm to 3 mm. The length of the conductive bridge may be for example in a centimetre range, for example about 0.5 cm to 20 cm, further for example about 1 cm to 5 cm. In the following the second contact section will also be referred to as FCuF section. The overall contact length (including the length of the first, direct, face-to-face contact section

and the second contact section through the metal bridge) may be about 0.5 to 40 cm, for example about 1.2 cm to 10 cm. Thus, the length of the conductive bridge may be around 0.1 to 0.9, preferably around 0.5 of the overall contact length of the two CC tapes. The contact height per pair of tapes (i.e. the height of one contact unit) may be about 0.1 mm to 2 cm, for example about 1 mm to 4 mm. The overall height of the contact (i.e. of the contact assembly) is proportional to the number of tapes contacted (i.e. the number of contact units) and the contact height per pair of tapes (i.e. the height of each contact unit). The overall width of the contact (contact assembly) may be about 2 mm to 20 cm, for example about 6 mm to 15 mm.

[0018] The above dimensions are exemplary and may vary depending on the tapes to be connected. Typical tape widths are about 1 mm to 10 cm, for example about 2 mm - 12 mm.

[0019] The conductive bridges of the contact units constituting the contact assembly contact (electrically) the conductive walls surrounding the contact units. The conductive walls are made of normal (i.e. not superconductive) material. For example the conductive walls may be made of metal, for example of Cu, Ag, In, solder or any other suitable conductive material. The shape of the conductive walls may be any suitable shape, for example the conductive walls may have a substantially plate form. The thickness of the conductive walls may be for example in the range of 0.1 mm to 5 cm, for example about 0.5 mm to 1 cm.

[0020] In the above contact assembly, when the two contacted CC tapes have similar critical currents, the current flows using the F2F section of the contact assembly (i.e. the first contact section). When one of the CC tapes has a lower critical current than the tape it is directly contacted to, only a portion of the current will flow through the F2F section, the remaining excess current will flow through the FCuF section (i.e. through the second section) and will be redistributed among the other tapes through the bridge of normal conductive material, for example a bridge of normal metal, and the conductive walls. More specifically, the conductive bridges and the conductive walls achieve together a redistribution of current, since the excess current will flow from the respective conducting bridge to the conductive walls and from them to the other conductive bridges, where it will flow to other tapes. Thus, the FCuF section allows the excess current that cannot flow in the corresponding paired tape to be able to reach the other tapes, i.e. to be redistributed.

[0021] The conductive bridge may be made for example by a laminated conductor. The conductive bridge may be formed as a layer having a uniform thickness in the above indicated thickness ranges (for example in the range of about 0.5 mm to 2 cm, further for example in the range of about 1 mm to 3 mm). In another example, the conductive bridge may have a wedge or step form with a gradually or step-wise decreasing thickness, respectively. For example the conductive bridge may have

a first substantially planar surface and a second opposite surface. The second (composite) surface may have a first planar section that may be substantially parallel to the first surface and a second section, which is included with respect to the first surface, such that the thickness of the conductive bridge gradually decreases. The maximal thickness of the conductive bridge (measured at the highest portion of the conductive bridge) may be in the above indicated thickness ranges (for example in the range of about 0.5 mm to 2 cm, further for example in the range of about 1 mm to 3 mm).

[0022] The contact unit may further comprise a top portion made of (normal) conductive material arranged so as to face the first CC tape and a base portion made of (normal) conductive material arranged so as to face the second CC tape, wherein the conductive bridge is arranged between the base portion and the top portion.

[0023] The top and base portions may be made of metal, such as Cu, Ag, In, solder or any other suitable (normal) conductive material. The top and the base portions may be of the same material, which may also be the same as the conductive material of the conductive bridge.

[0024] The base portion may have a substantially plate like form having two substantially planar surfaces that are substantially parallel to each other. One of the CC tapes (for example the second CC tape) may be placed on one of the planar surfaces of the base portion (the inner surface). The top portion may have a substantially planar outer surface and an inner surface that is in contact with the other CC tape (for example the first CC tape). The two CC tapes are arranged such that their superconducting layers face each other. The superconducting layers of the two CC tapes may be connected directly or through a solder layer.

[0025] In the second contact section (FCuF) contact section, the conductive bridge may be arranged between the base and the top portion, such that it separates the superconducting layers of the two CC tapes. For example, one of the major surfaces of the conductive bridge (for example the first, substantially planar surface of the conductive bridge) may face the superconducting layer of one of the CC tapes (for example the second CC tape) placed on the base portion. The other major surface of the conductive bridge (for example the second, composite surface of the conductive bridge) may face the superconducting layer of the other one of the CC tapes (for example the first CC tape) in contact with the inner surface of the top portion. Optionally, solder layers may be provided between the respective conducting bridge surfaces and the superconducting layers of the first and second CC tapes. The portion of the inner surface of the top portion and the surface of the conducting bridge that faces the inner surface of the top portion may have complementary shapes. Thus, a reliable contact may be established, while keeping the contact assembly compact.

[0026] The contact unit may further comprise a first tape accommodating space for accommodating a front end portion of the first CC tape and a second tape ac-

commodating space for accommodating a corresponding front end portion of the second CC tape. In the first contact section (F2F) the first tape accommodating space and the second tape accommodating space may be joined together to form a common space, in which the two CC tapes are accommodated. In the second contact section (FCuF) the first tape accommodating space and the second tape accommodating space may be separated through the conductive bridge. The front end portion of the first and the second conductor coated superconducting tapes is the portion at the end of the respective CC tape where the two CC tapes contact each other.

[0027] The first and the second tape accommodating spaces may communicate with respective openings provided in a contact body of the contact assembly through which the first CC tape and the second CC tape pass, respectively. The first tape accommodating space and the second tape accommodating space may be formed between the top portion, the conductive bridge and the base portion.

[0028] For example, in the FCuF contact section, one of the tape accommodating spaces (for example the first tape accommodating space) may be formed between the inner surface of the top portion and one of the major surfaces of the conductive bridge (for example the second composite surface). The other one of the tape accommodating spaces (for example the second tape accommodating space) may be formed between the inner surface of the base portion and the other one of the major surfaces of the conductive bridge (for example the first, substantially planar surface). In the F2F contact section, the common tape accommodating space formed by merging the first and the second tape accommodating spaces may be formed between the inner surface of the base portion and the inner surface of the top portion. In other words, in the FCuF contact section, the inner surface of the top portion and one of the major surfaces of the conductive bridge constitute the border surfaces of the first tape accommodating space and the inner surface of the base portion and the other one of the major surfaces of the conductive bridge may constitute the border surfaces of the second tape accommodating space. The inner surfaces of the top and base portions may constitute the border surfaces of the common space. The width of the first and second tape accommodating spaces may suitably selected depending on the tapes to be connected, respectively.

[0029] The width and height of the tape accommodating spaces may be selected depending on the dimensions of the two tapes to be connected.

[0030] Each of the superconducting components may comprise a plurality of CC tapes. The contact assembly may accordingly comprise a plurality of contact units or cells, each configured for connecting corresponding pairs of CC tapes of the first and the second superconducting component. The contact units may be arranged in a linear, matrix or other pattern. For example, the contact units may be stacked or arranged on top of each

other.

[0031] The contact assembly can be produced using various commercially available design and manufacturing processes for manufacturing of Cu terminations or contacts. Soldering of the CC tapes can be achieved with soldering techniques known in the art.

[0032] For example, each contact unit with the first and the second contact sections may be formed by stacking or laminating, in this order, a base portion, the second conductor coated superconducting tape, optionally a solder layer, the conductive bridge, optionally a solder layer, the first conductor coated superconducting tape and a top portion.

[0033] The stack may be subjected to a pressure, for example in the range of 1 MPa to 100 MPa, for example 40 MPa to 50 MPa. Further, the stack may also be subjected to a temperature treatment. Thus, the reliability of connection may be improved. Said temperature could be between 60 °C and 500 °C, for example between 100 °C and 250 °C.

[0034] In another example, the contact assembly may comprise a monolithic contact body provided with respective tape accommodating spaces, in which the front end portions of the two coated conductor superconducting tapes to be connected are accommodated with their superconducting layers facing each other. The tape accommodating spaces may be arranged such that a double contact comprising a second, FCuF contact section and a first, F2F contact section may be established between the two CC tapes. For example, in the FCuF contact section, the two tape accommodating spaces may be separated by the conductive bridge and in the F2F contact section, the two tape accommodating spaces may be merged together to form a common space into which both tapes may be accommodated, as explained above. To facilitate insertion of the front end portions of the coated conductor superconducting tapes in respective tape accommodating spaces, one or more of the sidewalls of a the contact assembly may be removable or detachable.

[0035] The contact assembly and/or the method for contacting superconducting components according to any of the above aspects provides for one or more of the following advantages and technical effects with respect to conventional designs:

- It allows for a direct face-to-face transfer of current between the two CC tapes that are being contacted;
- It allows for the redistribution of current to CC tapes that are not contacted face-to-face allowing for minimized transfer length and resistance. This is of particular importance in the case of systems where the CC tapes to be contacted have different or non-uniform critical currents;
- It allows for a repartition of current in all the CC tapes. Therefore, the use of all the superconducting tapes in every section of the busbar or cable to be contact-

ed can be optimized;

- It allows for a larger critical current of the whole device while introducing a minimum resistance from the metal in the contacts;
- Having a larger critical current, the losses due to alternating or ripple currents are reduced;
- The conductive (for example metal) joint contacts (i.e. the conductive bridge) can be manufactured using for example wedges or laminated conductors, therefore making the system modular;
- It is possible to easily increase or decrease the number of tapes in the contact.

[0036] The contact assembly and method for contacting two superconducting components according to any of the above aspects may have various applications. For example, the contact assembly may be used to connect superconducting cables and busbar systems based on CC tapes. However, the proposed contact design allows a significant performance increase when compared with conventional designs. Therefore, any product that requires a connection of bundles of superconducting CC tapes could benefit from it.

[0037] The above and other aspects will now be described in detail with reference to the following drawings:

Fig. 1A and 1B show perspective views of an exemplary design for a contact assembly having two contact sections;

Fig. 2 shows a perspective view of the contact assembly shown in Figs. 1A and 1B with part of the contact body being removed;

Fig. 3 shows an exploded view of the individual components making up one contact unit for connecting two CC tapes;

Fig. 4 shows a cross sectional view through one contact unit along the length of the contact unit;

Fig. 5 shows different cross-sectional views of the exemplary contact assembly, wherein Fig. 5A shows a cross sectional view along the length of the contact unit, Fig. 5B shows a cross sectional view along the width of the contact unit in the FCuF contact section, Fig. 5C shows a cross sectional view along the width of the contact unit in the F2F contact section and Fig. 5D shows a cross sectional view along the width of the contact unit in the area between the FCuF and F2F contact sections.

[0038] Throughout the description and in the drawings, similar or corresponding features are identified by the

same reference numerals.

[0039] **Fig. 1A and 1B** show perspective views of an exemplary design for a contact assembly 10 for connecting a plurality of coated conductor superconducting tapes (CC tapes) 121-123 with CC tapes 141-143, respectively. The CC tapes 121-123 and 141-143 may be for example a part of a superconducting cable or a busbar section. In the figures, the CC tapes 121-123 of the first superconducting cable or a busbar section are indicated by a diagonal hatch pattern filling and their corresponding metallic contacts are shown in white. The CC tapes 141-143 of the second superconducting cable or busbar section are indicated by a dot pattern filling and their corresponding metallic contacts are shown in white.

[0040] An optional interlayer 16 and/or 17 (for example a solder layer) may be applied on the superconducting layer of each of the CC tapes to be connected 121-123 and 141-143. The optional interlayer is indicated in the figures by a black filling.

[0041] The contact assembly comprises a contact body 18, which may be made (at least in partially) of metal, for example copper Cu, Au, In or other suitable conductive material. In the example shown in Figs. 1A-B, the contact body 18 has substantially a rectangular prism shape having two opposite faces or side walls 181 and 182 (face side walls), two opposite sidewalls 183 and 184 (lateral side walls), a top wall 185 and a bottom wall 186. The CC tapes to be connected extend or protrude through the faces or side walls 181 and 182, respectively, with CC tapes 121-123 protruding through the face (face side wall) 181 and the CC tapes 141-143 protruding through the face (face side wall) 182. The side walls 183 and 184 (lateral side walls) are made of conductive material and extend along the length of the contact. The top wall 185 and the bottom wall 186 in this example are also made of conductive material.

[0042] The dimensions of the contact body 18 may vary depending on the dimensions and the number of the tapes to be connected. For example, the contact body 18 may have a length of 0.5 cm to 20 cm, further for example about 1 cm to 5 cm, a width of about 2 mm to 20 cm, for example about 4 mm to 15 mm. The height per pair of tapes may be about 0.1 mm to 2 cm, for example about 1 mm to 4 mm. The overall height of the contact body 18 is proportional to the number of tapes contacted. However, the form of the contact body is not restricted to a rectangular prism form and may be any other suitable form, for example a substantially cylindrical form. The contact body 18 may be monolithic or modular. For example, the front wall of the contact body 18 may be removable to facilitate the insertion of the CC tapes. In another example, the contact body 18 may be made up of individual components stacked together or laminated as it will be explained in more detail further on.

[0043] **Fig. 2** shows a perspective view of the contact assembly shown in Fig. 1 with part of the contact body 18 (the front lateral side wall 183) being removed or made transparent. **Fig. 3** shows an exploded view of the indi-

vidual components making up one contact unit 101 for connecting two CC tapes, wherein one sidewall is made transparent for simplicity. **Fig. 4** shows a cross sectional view through one contact unit 101 along the line A-A', i.e. along the length of the contact unit. The views are enlarged for better readability and not up to scale.

[0044] As shown in Fig. 2, the contact assembly 10 comprises a plurality of contact units (in this example 3) corresponding to the plurality of pairs of CC tapes to be connected. Each contact unit (hereinafter also referred to as cell) comprises a first, face-to-face (F2F) contact section and a second (FCuF) contact section. The contact units may be arranged in a linear or matrix form or in any other suitable form. In the example shown in Fig. 2 the contact units are stacked on the top of each other. It is of course possible to vary the number of connection units in the connection assembly depending on the number of CC tapes of the superconducting components that are to be connected.

[0045] In the first contact section (F2F section) the first CC tape 121 and its counterpart second CC tape 141 are arranged such that the superconducting layer of the first CC tape 121 faces the superconducting layer of the second CC tape 141. For example, the first and the second CC tapes may be arranged such that the superconducting layer of the first CC tape 121 is facing down and the superconducting layer of second CC tape 141 is facing up. The two superconducting layers are connected via a solder interlayer 16. The solder layer 16 may be made of In, Sn, Pb, Commercial $Pb_{40}Sn_{60}$, $Pb_{38}Sn_{62}$ or other solder suitable for soldering coated superconductor tapes. The thickness of the solder layer 16 may be in the range of 1 μm to 2 mm, for example about 2 μm to 100 μm . It is also possible to directly connect the two superconducting layers by placing them on top of each other without a solder interlayer between them.

[0046] In the second contact section (FCuF section) the first CC tape 121 and its counterpart second CC tape 141 are also arranged such that the superconducting layer of the first CC tape 121 faces the superconducting layer of the second CC tape 141. Unlike in the first contact section, the two superconducting layers are connected via a conductive bridge 20, in this example a metal bridge made of copper (Cu). The conductive bridge 20 may be connected to the superconducting layers of the first CC tape 121 and the second CC tape 141 directly or, as shown in Fig. 3, via solder layers 17 and 16, respectively. The two solder layers 16 and 17 may be of the same material and may have the same thickness.

[0047] The conductive bridge 20 has a wedge-like form with a gradually decreasing thickness. More specifically, the conductive bridge 20 has a first substantially planar surface 201 and a second surface 202 opposite to the first surface. The second surface 202 may be a composite surface having a first planar section 203 that is substantially parallel to the first surface 201 and a second section 204, which is inclined with respect to the first surface 22, so that the thickness of the conductive bridge 20 gradu-

ally decreases. The maximal thickness of the conductive bridge (measured at the highest portion of the conductive bridge) may be in the range of 0.5 mm to 2 cm, for example about 1 mm to 3 mm. The first, substantially planar surface 201 of the conductive bridge 20 faces the superconducting layer of the second CC tape 141 and is connected to it directly or through the solder layer 16. The second, composite surface 202 of the conductive bridge 20 faces the superconducting layer of the first CC tape 121 and is connected to it directly or through a respective solder layer 17.

[0048] The side walls 183 and 184 are made of conductive material, which may be any (normal) conductive material, for example the same conductive material as that of the conductive bridge. The conductive bridges 20 of each of the contact units constituting the contact assembly 10 are in contact with the conductive side walls 183 and 184. The conductive side walls 183 and 184 may be contacted to the conductive bridges 20 directly or via soldering layers similar to the ones used to contact the tapes.

[0049] The conductive side walls 183 and 184 may have a substantially plate or planar form having a thickness in the range of 0.1 mm to 5 cm, for example about 0.5 mm to 1 cm.

[0050] The contact unit 101 comprises further a base portion 30 having a substantially plate form having thickness in the range of 0.1 mm to 1 cm, for example about 0.5 mm to 3 mm. The base portion 30 may be made of metal, such as Cu, Ag, In. For example, the base portion may be made of the same material as the conducting bridge. The base portion 30 is arranged such that one of its planar surfaces (the inner surface 301) faces the second CC tape 141. The second CC tape 141 is placed on the inner surface 301 of the base portion 30 with its superconducting layer facing up, i.e. such that the face of the second CC tape 141 bearing the superconducting layer is on the side opposite to the inner surface 301 of the base portion 301. In case the contact assembly comprises a plurality of stacked contact units, the base portion 30 of the bottom most contact unit may constitute the bottom wall 186 of the contact body 18.

[0051] The contact unit 101 comprises further a top portion 40. The top portion 40 may be made of metal, such as Cu, Ag, In. For example, the top portion may be made of the same material as the conducting bridge. The top portion 40 has an inner surface 401 facing the first CC tape 121 and an outer surface 402 opposite the inner surface 401. The outer surface 402 is a substantially planar surface. The portion of the inner surface of the top portion 40 that is in the second (FCuF) contact section has a form complementary to the form of the second (composite) surface 202 of the conductive bridge 20. The portion of the inner surface 401 of the top portion 40 that is in the first (F2F) contact section is a substantially planar surface. In case the contact assembly comprises a plurality of stacked contact units, the top portion 40 of the top most contact unit may constitute the top wall 185 of

the contact body 18. The first CC tape 121 is in contact with the inner surface 401 of the top portion 40. The first tape 121 is arranged such that its superconducting layer is facing down, i.e. such that the face of the first CC tape 121 bearing the superconducting layer is on the side opposite to the inner surface 401 of the top portion 40.

[0052] The contact units 101 are arranged on top of each other to form a stack, with the top portion 40 of the lower contact unit being in contact with the bottom portion 30 or, in case the bottom portion 30 is omitted, the second CC tape of the upper contact unit arranged on top of the lower contact unit.

[0053] Fig. 3 shows an exploded view of the individual components making up one contact unit 101 for connecting a pair of CC tapes. The individual components are shown before the closing of the contact.

[0054] Fig. 5 shows different cross-sectional views of the contact assembly. Fig. 5A shows a cross sectional view through one contact unit along the line A-A', i.e. along the length of the contact unit. Fig. 5B shows a cross sectional view along the line B-B', i.e. along the width of the contact unit in the FCuF contact section (the second contact section). As shown in Fig. 5B, in the FCuF contact section the CC tapes to be connected (with their respective solder layers) are separated by the layer of conductive material of the conductive bridge. The thickness of the conductive material in this section is maximal. Fig. 5C shows a cross sectional view along the line C-C', i.e. along the width of the contact unit in the F2F contact section (the first contact section). As shown in Fig. 5C, in the F2F contact section the two CC tapes are separated only by the (optional) solder layer. Fig. 5D shows a cross sectional view along the line D-D', which is positioned in the area between the first and the second contact sections, i.e. along the width of the contact unit in the area between the first and the second contact sections. The thickness of the conductive material separating the two CC tapes to be connected (with their solder layers) is considerably smaller than in the FCuF contact section.

[0055] The overall contact length may be about 0.5 to 40 cm, for example about 1.2 cm to 10 cm. The overall contact length may be the sum of the contact length in the F2F contact section (i.e. the length of the F2F contact section) and the contact length in the FCuF contact section (i.e. the length of the FCuF contact section). The length of the FCuF (second) contact section may be about 0.1 to 0.9 of the contact length, for example may be about the half of the overall contact length

[0056] As shown in Fig. 5C, there is a direct face-to-face transfer in the F2F section. In the FCuF section, shown in Fig. 5B, current distribution is possible through the conductive bridge (for example a metal bridge) and the conductive side walls 183 and 184.

[0057] In particular, as explained above, the excess current that cannot flow in the corresponding paired tape can reach the other tapes or be redistributed to the other tapes by flowing from the conducting bridge 20 to the

side walls 183 and 184 and from them to the other conductive bridges 20, where it flows to other tapes.

[0058] The following non-limiting example illustrates the redistribution of the excess current in a system of two CC tapes (for example tapes 121-122) being contacted to other two CC tapes (for example tapes 141-142).

[0059] Let the critical currents I_c of the tapes be as follows:

I_c of Tape121 (I_{c_121})=100 A
 I_c of Tape122 (I_{c_122})= 100 A
 I_c of Tape 141 (I_{c_141})=90 A
 I_c of Tape 142 (I_{c_142})= 110 A.

[0060] Clearly $I_{c_121} + I_{c_122} = I_{c_141} + I_{c_142} = 200$ A. However, not all of the current from tape 121 can flow into tape 141, since only 90 A can go there. The remaining (excess) 10 A flow to the tape 142 along the following path: The excess current flows from tape 121 to the bridge 20 between tape 121 and 141. From there, it flows to the conductive side walls 183 and 184. Then it flows to the bridge between tapes 122 and 142. Finally, it flows to tape 142. That path following both bridges and conductive walls is for the excess 10 A only. In the F2F contact sections tape 121 transfers 90 A to tape 141 and tape 122 transfers 100 A to tape 142.

[0061] A similar consideration can be made for a system connecting more tapes.

[0062] Accordingly, even in the case when one cable had a lower critical current than the other, the critical current of the connected system would be equal to the one of the cables with lower critical current, but to achieve that, the currents in the individual tapes need to be redistributed when the corresponding pairing tapes do not have the same critical current.

[0063] The contact assembly can be constructed using commercially available design and manufacturing processes for manufacturing of Cu terminations or contacts. Soldering of the CC tapes can be achieved with soldering techniques known in the art. The solder layer may, for example be applied by laminating or by moulding.

[0064] For example, the contact assembly may be produced by stacking or laminating in this order the base portion 30, the second CC tape 141 (more specifically a front end portion of the second CC tape), optionally a solder layer 16, the conductive bridge 20, optionally a solder layer 17, the first CC tape 121 (more specifically the front end portion of the first CC tape) and the top portion 40. The conductive bridge 20 does not extend along the whole contact length of the two CC tapes, but only in the second contact section (FCuF section). As explained above, the inner surface of the top portion facing the first CC tape 121 and the surface of the conductive bridge 20 facing the first CC tape 121 have complementary shapes. This enables the realization of compact connect assembly. To form a plurality of contact units, the above steps are repeated for each contact unit. In this case, except for the bottom most contact unit, the base

portion of the contact units may be omitted. The final stack thus comprises a plurality of contact units arranged or stacked on top of each, as shown for example in Figs. 2 and 5.

[0065] To establish a reliable contact, the whole assembly may be pressed together, i.e. subjected to a pressure. Optionally, the contact assembly may be further subjected to a temperature treatment with a temperature being between about 60°C to about 500°C, for example between about 100°C to 250°C. The conductive walls (for example lateral sidewalls 183 and 184) may be provided before subjecting the assembly to a pressure and optionally temperature treatment. For example, the conductive walls may be contacted to the stack produced as explained above via pressure that may be in the range of 1 to 100 MPa, further for example in the range of 40 to 60 MPa. In addition or alternatively, the conductive walls may be contacted to the stack via soldering layers similar to the ones used to contact the tapes.

[0066] In another example, the contact assembly may comprise a monolithic contact body 18 having for example the form described in connection with the above Figs. 1 to 5 having two conductive side or lateral walls 183 and 184 in contact with the plurality of conductive bridges 20 of each of the contact units constituting the contact assembly. The CC tapes to be connected 121 and 141 (more specifically the respective front end portions of the CC tapes to be connected) may be inserted in respective tape accommodating spaces provided in the contact body, with their superconducting layers facing each other. The tape accommodating spaces may be arranged such that a double contact may be established between the two tapes, the double contact comprising a FCuF contact section and a F2F contact section.

[0067] For example, two of the opposing face sidewalls (for example the sidewalls 181 and 182) of the contact body 18 may be provided with at least one opening through which the CC tapes 121-123 and the CC tapes 141-143 pass, respectively. The openings may communicate with the respective tape accommodating spaces. The plurality of openings may be arranged in any suitable manner, for example in a line or a matrix form.

[0068] More specifically, to accommodate the CC tapes 121 and 141, each contact unit may comprise a first tape accommodating space for accommodating a front end portion of the first CC tape 121 and a second tape accommodating space for accommodating a corresponding front end portion of the second CC tape 141. The first tape accommodating space may communicate with the corresponding opening (for example provided in the face sidewall or face 181) through which the first CC tape 121 passes. Similarly, the second tape accommodating space may communicate with the corresponding second opening (for example provided in the opposite face sidewall or face 182) through which the second CC tape 141 passes.

[0069] The first tape accommodating space may have a step-like or Z-like form. The second tape accommodat-

ing space may be substantially straight and extend substantially along the entire contact length of the two CC tapes to be connected. The first tape accommodating space and the second tape accommodating space may be joined (merged) together in the first contact section (F2F section), thereby forming a single space (common space) for accommodating the two CC tapes to be connected (CC tapes 121 and 141), so that a face-to-face contact can be established as explained above. In the second contact section (FCuF section), the first tape accommodating space and the second tape accommodating space may be separated from each other by the conductive bridge 20, so that a FCuF contact may be established.

[0070] Further, each contact unit may comprise a base portion 30 and a top portion arranged such as to form, together with the conductive bridge 20, the first and the second tape accommodating spaces. The form and the arrangement of the base portion, the conductive bridge 20 and the top portion 40 may be those shown in Figs. 1 to 5. As described above, the portion of the inner surface 401 of the top portion 40 that is in the second (FCuF) contact section may have a shape or form complementary to the shape or form of the second (composite) surface of the conductive bridge. The portion of the inner surface 401 of the top portion 40 that is in the first contact section (F2F section) may be a substantially planar surface.

[0071] For example, in the FCuF contact section, the first tape accommodating space may be formed between the inner surface 401 of the top portion 40 and the second composite surface 202 of the conductive bridge. In other words, the surfaces 401 and 202 may constitute the border surfaces of the first tape accommodating space in the FCuF contact section. The second tape accommodating space in the FCuF contact section may be formed between the inner surface 301 of the base portion 30 and the first, substantially planar surface 201 of the conductive bridge. In other words, the surfaces 301 and 201 may constitute the border surfaces of the second tape accommodating space in the FCuF contact section.

[0072] In the F2F contact section, the common tape accommodating space formed by merging the first and the second tape accommodating spaces may be formed between the inner surface 301 of the base portion 30 and the inner surface 401 of the top portion. In other words, the inner surfaces 301 and 401 may constitute the border surfaces of the common space in the F2F contact section. The width of the first and second tape accommodating spaces may suitably selected depending on the tapes to be connected, respectively.

[0073] The CC tapes 121 and 141 may be inserted in the respective tape accommodating spaces with their superconducting layers facing each other, thereby establishing a double contact having a F2F and a FCuF portion. To facilitate insertion, at least one of the sidewalls of the contact body (for example one of the conductive side walls 183 or 184) may be removable. The contact as-

sembly may further comprise fastening means configured to apply pressure on the contact assembly, so as to improve the contact between the CC tapes.

[0074] A number of examples have been described. Nevertheless, it will be understood that various modifications of these examples may be made. For example, even though examples and embodiments are separately described, single features thereof may be combined to additional examples and embodiments. Further, the steps described can be performed in a different order and still achieve desirable results. In addition, although the above examples relate to connecting superconducting cables and busbar systems based on CC tapes, the proposed contact assembly can be applied to any product that requires a connection of bundles of superconducting CC tapes, where it allows a significant performance increase when compared with conventional designs. In particular, the proposed contact assembly provides for one of more of the following advantages:

- a better current distribution in the connected cable or busbar without introducing a large residual ohmic contact,
- an increase of the critical current of your contacted cable or busbar without introducing a large residual ohmic contact;
- reduction of the AC losses of the contacted system; and
- reduction of the impact of a CC tape with lower critical current (or a defective tape) on the system.

[0075] The invention may be applied to many different fields. Some non-limiting application fields include applications that requires joining bundles of superconducting CC tapes, for example in applications such as busbars or cables. These could relate to current transport, in particular in systems with currents of large amplitudes, such as in power distribution, connection of power systems, busbars for smelting plants, large magnet coils, medical applications, etc.

List of Reference Numerals

[0076]

10	contact assembly
101	contact unit
121-123	first CC tapes
141-143	second CC tapes
16, 17	solder layer
18	contact body
181, 182	face side walls of the contact body
183, 184	conductive walls (e.g. lateral side walls of the contact body)
185	top wall of the contact body
186	bottom wall of the contact body
20	conductive bridge
201	first surface of the conductive bridge

202	second, composite surface of the conductive bridge
203	first section of the second surface of the conductive bridge
204	second section of the second surface of the conductive bridge
30	base portion
301	inner surface of the base portion
40	top portion
401	inner surface of the top portion
402	outer surface of the top portion
F2F	first contact section
FCuF	second contact section

Claims

1. A contact assembly (10) for connecting superconducting components, each superconducting component comprising a plurality of coated conductor superconducting tapes (121-123, 141-143), said contact assembly (10) comprising a pair of conductive walls (183, 184) and a plurality of contact units (101) arranged between the conductive walls (183, 184), each contact unit (101) being configured for connecting one of the plurality of coated conductor superconducting tapes (121-123) of the first superconducting component and a corresponding one of the plurality of coated conductor superconducting tapes (141-143) of the second superconducting component, wherein each contact unit (101) comprises:

a first contact section (F2F) for connecting a first portion of the one of the coated conductor superconducting tapes (121-123) of the first superconducting component and a first portion of the corresponding one of the coated conductor superconducting tapes (141-143) of the second superconducting component via a face-to-face connection;

a second contact section (FCuF) for connecting a second portion of the one of the superconducting coated conductor superconducting tapes (121-123) of the first superconducting component to a second portion of the corresponding one of the coated conductor superconducting tapes (141) of the second superconducting component via a conductive bridge (20) of not superconducting material, and wherein the conductive bridges (20) of the plurality of contact units (101) contact the conductive walls (183, 184).

2. The contact assembly (10) according to claim 1, wherein the conductive bridge (20) has a wedge form with gradually decreasing thickness and/or wherein the conductive bridge (20) is made of metal.

3. The contact assembly (10) according to claim 1 or 2, wherein the maximal thickness of the conductive bridge (20) is in the range of 0.5 mm to 2 cm, optionally in the range of 1 mm to 3 mm.

4. The contact assembly (10) according to any one of the preceding claims, wherein the thickness of the conductive walls (183, 184) is in the range of 0.1 mm to 5 cm, for example about 0.5 mm to 1 cm.

5. The contact assembly (10) according to any one of the preceding claims, wherein in the first contact section (F2F) the two superconducting layers are connected through a solder interlayer (16, 17) having a thickness in the range of 1 μm to 2 mm, optionally in the range of 2 μm to 100 μm .

6. The contact assembly (10) according to any one of the preceding claims, wherein each contact unit further comprises a top portion made of conductive material arranged so as to face the first coated conductor superconducting tape (121) and a base portion (30) made of conductive material arranged so as to face the second coated conductor superconducting tape (141), wherein the conductive bridge (20) is arranged between the base portion (30) and the top portion (40).

7. The contact assembly (10) according to any one of the preceding claims, wherein each contact unit comprises:

a first tape accommodating space for accommodating a front end portion of the first coated conductor superconducting tape (121) and a second tape accommodating space for accommodating a front end portion of the second coated superconducting tape (141), wherein in the first contact section (F2F) the first tape accommodating space and the second tape accommodating space are joined together to form a common space; and in the second contact section (FCuF) the first tape accommodating space and the second tape accommodating space are separated through the conductive bridge (20).

8. A contact assembly according to any one of the preceding claims, wherein the superconducting components are superconducting cables or busbar sections.

9. A method for connecting superconducting components, each superconducting component comprising a plurality of coated conductor superconducting tapes, said method comprising connecting each of the plurality of coated conductor superconducting tapes (121-123) of the first superconducting compo-

nent and a corresponding tape of the plurality of coated conductor superconducting tapes (141-143) of the second superconducting component by:

forming a plurality of contact units (101), each contact unit (101) being configured for connecting one of the plurality of coated conductor superconducting tapes (121-123) of the first superconducting component and a corresponding one of the plurality of coated conductor superconducting tapes (141-143) of the second superconducting component, wherein each contact unit comprises:

a first contact section (F2F) for connecting a first portion of the coated conductor superconducting tape (121-123) of the first superconducting component and a first portion of the corresponding coated conductor superconducting tape (141-143) of the second superconducting component via a face-to-face connection; and

a second contact section (FCuF) for connecting a second portion of the superconducting coated conductor superconducting tape (121-123) of the first superconducting component to a second portion of the corresponding coated conductor superconducting tape (141) of the second superconducting component via a conductive bridge (20) of not superconducting material; and

contacting a pair of conductive walls (183, 184) to the conductive bridges (20) of the plurality of contact units.

10. The method according to claim 9, wherein the conductive bridge (20) has a wedge form with gradually decreasing thickness and/or wherein the conductive bridge (20) is made of metal.

11. The method according to claim 9 or 10, wherein in the first contact section (F2F) the two superconducting layers are connected through a solder interlayer (16) having a thickness in the range of 1 μm to 2 mm, optionally in the range of 2 μm to 100 μm .

12. The method according to any one of claims 9 to 11, wherein the thickness of the conductive walls (183, 184) is in the range of 0.1 mm to 5 cm, for example about 0.5 mm to 1 cm.

13. The method according to any one of claims 9 to 12, wherein the forming of each contact unit (101) comprises stacking, in this order, a base portion (30), the second CC tape (141), optionally a first solder layer (16), the conductive bridge (20), optionally a second solder layer (17), the first CC tape (121) and a top

portion (40).

- 14.** The method according to claim 13, further comprising subjecting the stack to a pressure and/or temperature treatment.

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- 15.** The method according to any one of claims 9 to 14, wherein the superconducting components are superconducting cables or busbar sections.

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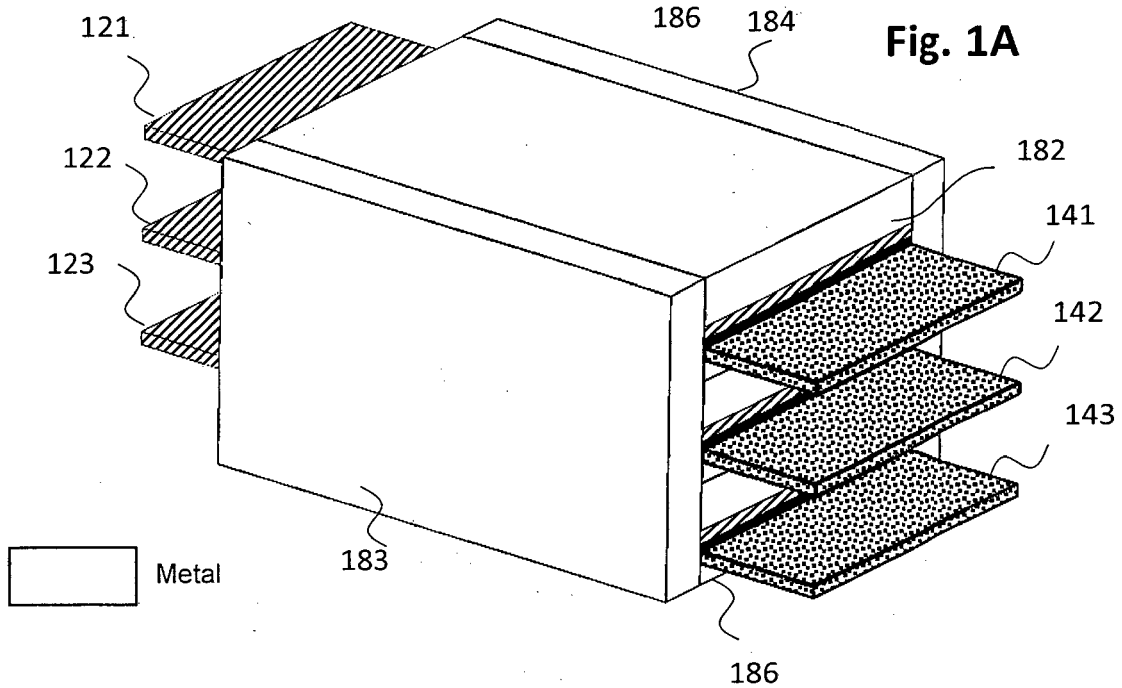
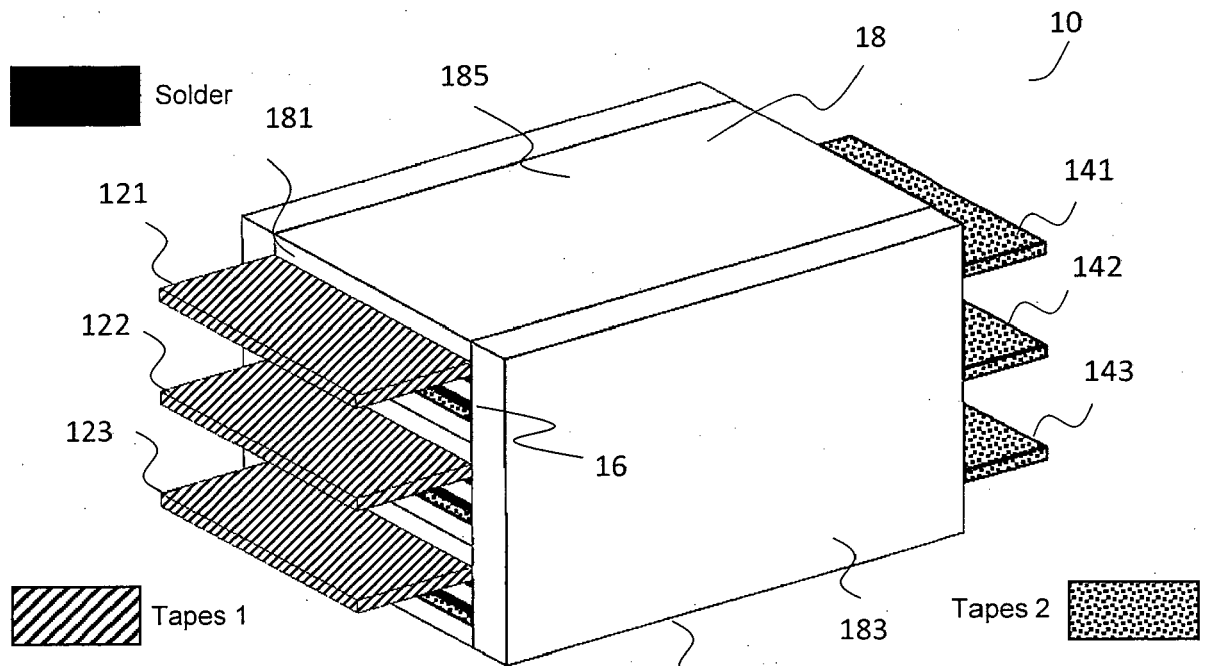
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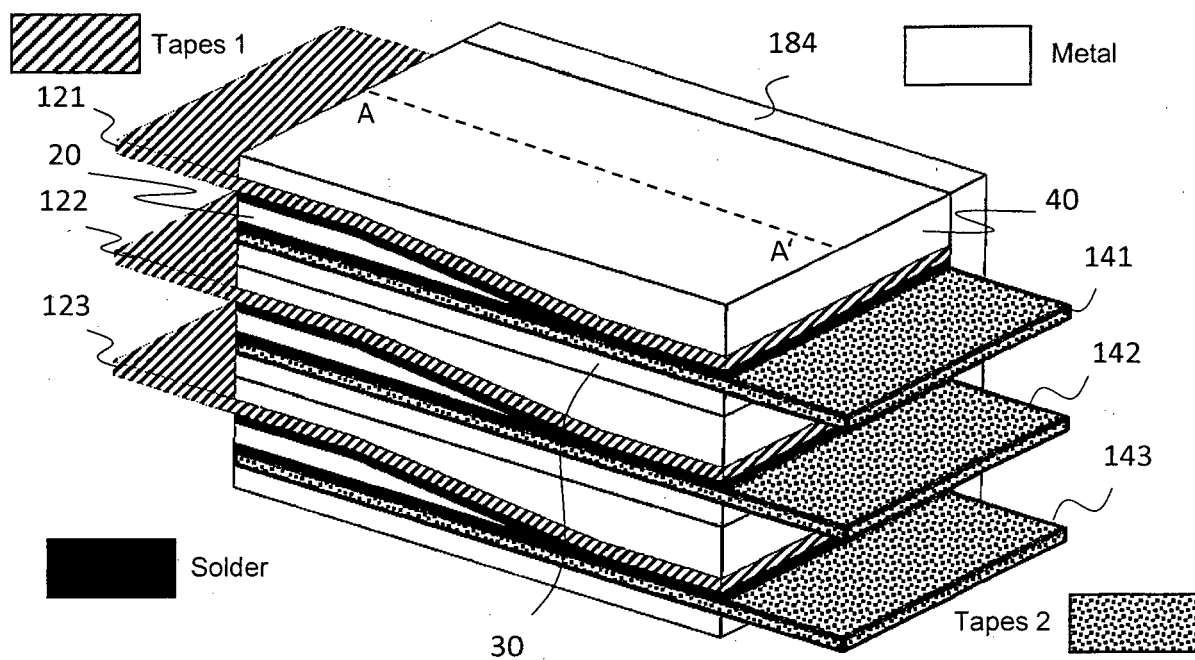


Fig. 2

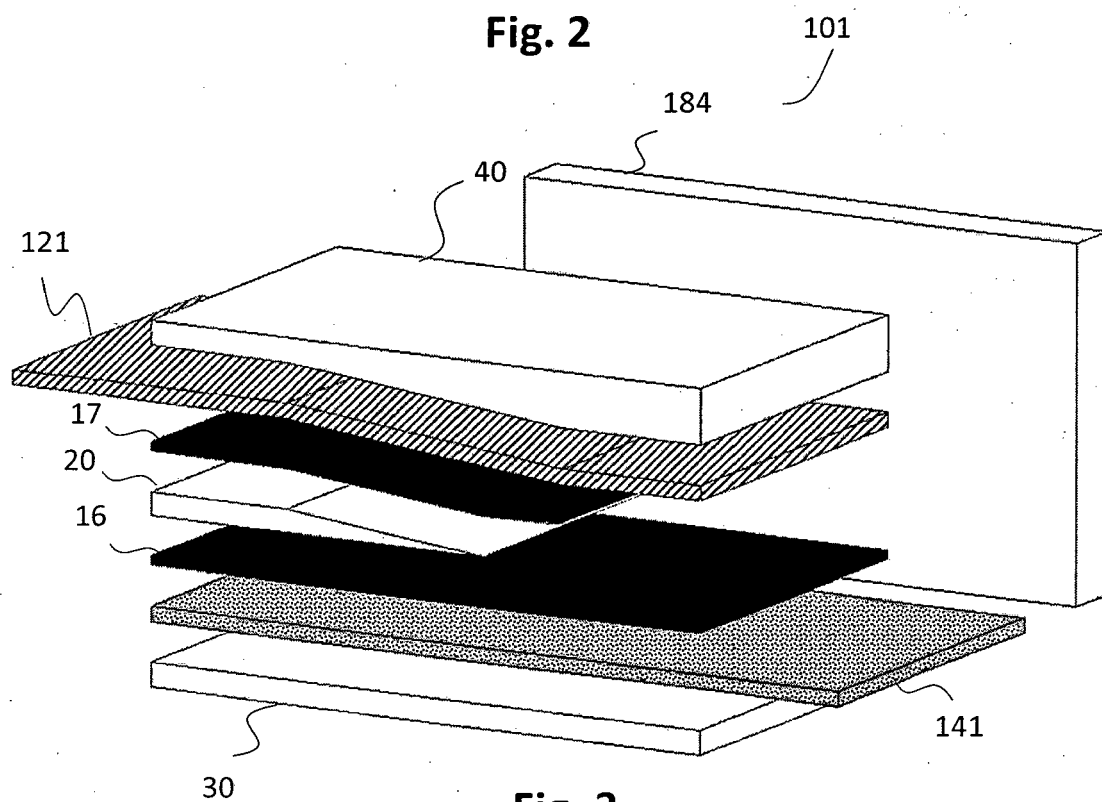


Fig. 3

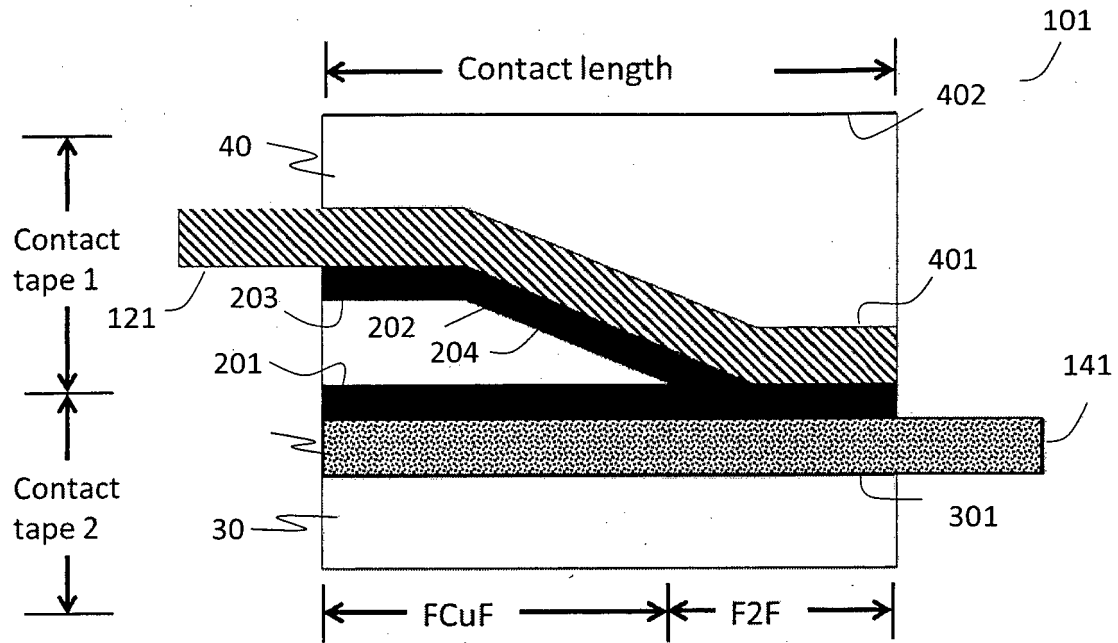


Fig. 4

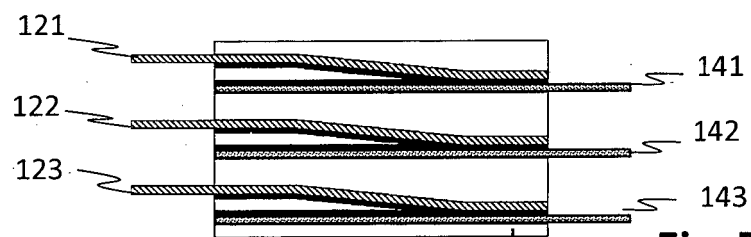


Fig. 5A

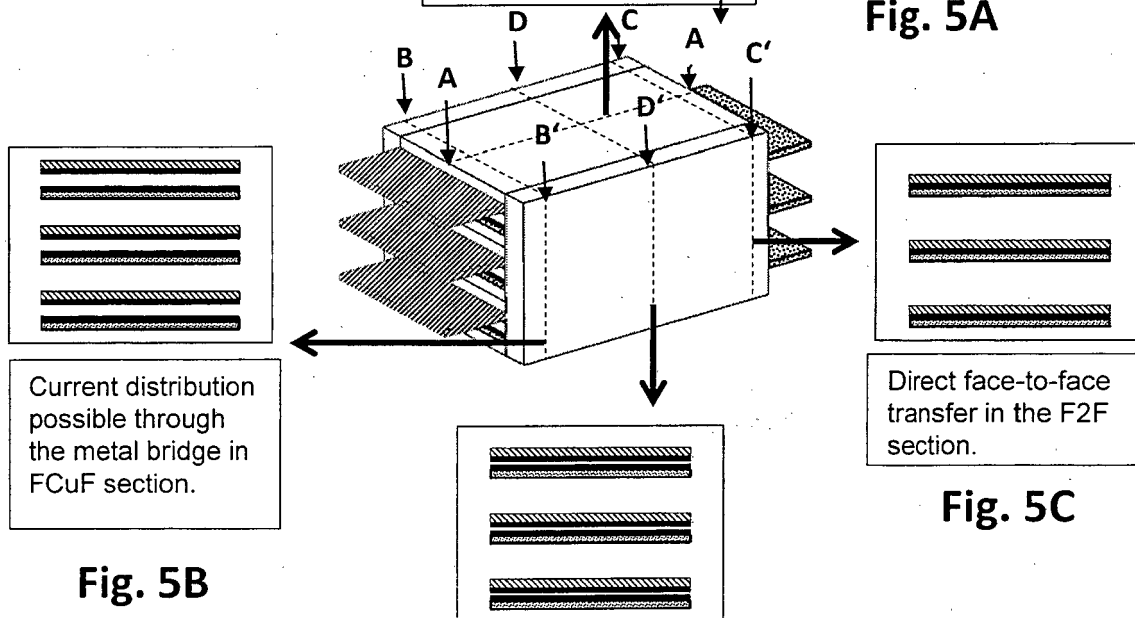


Fig. 5B

Fig. 5D



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 EP 17 00 0099

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