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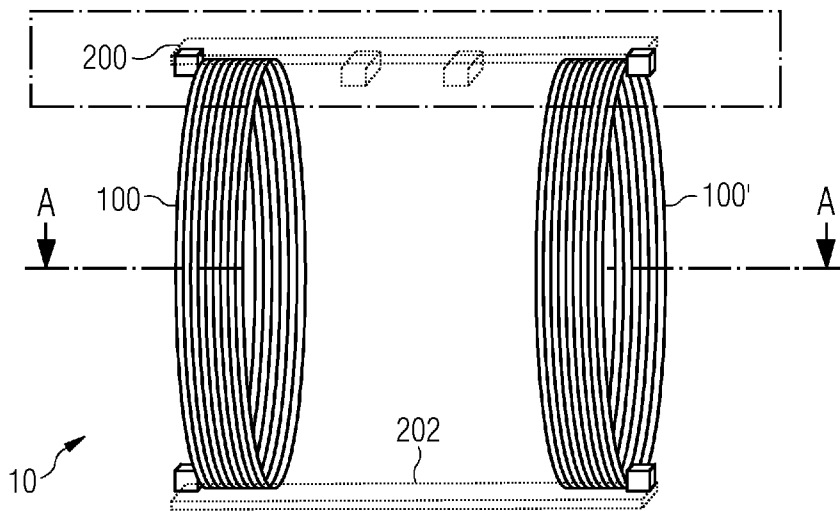
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FIG 1



(57) Abstract: An electromagnet (100) for a Magnetic Resonance Imaging (MRI) apparatus. The electromagnet (100) comprises a coil (110) for generating a magnetic field. The coil (110) has a first axially outer surface (112), and a support element (120) for mounting the coil (110) in the MRI. The support element (120) is bonded to the first axially outer surface (112) of the coil (110).



## ELECTROMAGNET FOR MRI WITH MECHANICAL SUPPORT STRUCTURE

The present disclosure relates to an arrangement for mounting an electromagnet suitable for applications in Magnetic Resonance Imaging.

In particular the disclosure relates to an electromagnet and an electromagnet  
5 assembly for a Magnetic Resonance Imaging apparatus.

**Background**

In Magnetic Resonance Imaging a plurality of electromagnets comprising superconducting coils is energised to generate a magnetic field which is both strong and spatially confined. This causes interaction between the electromagnets, thus  
10 subjecting them to electromagnetic loads. Moreover, transportation and installation may also subject the electromagnets to loads. In order to maintain the desired performance of the electromagnets, such loads need to be managed by the means used for supporting the coil.

A known means for supporting electromagnets involves a mechanically-supported  
15 journal into which the coil is wound. This arrangement, however, may not sufficiently restrain relative movement of the journal and the electromagnets.

Another known means for supporting electromagnets involves a tensile support wrapped around the electromagnets. This arrangement may not provide sufficient rotational restraint to effectively manage transportation loads. Additionally such an  
20 arrangement may be difficult to configure to adequately achieve small tolerances required for spatially locating the electromagnets. Any deviation from an optimal relative position of the electromagnets may result in local stress concentration detrimental to performance.

Hence an arrangement which allows for accurate and secure mounting of an  
25 electromagnet of a MRI device is highly desirable.

The invention of the present application has certain features in common with the invention of International patent application PCT/EP2018/075940.

### **Summary**

According to the present disclosure there is provided an apparatus and method as set forth in the appended claims. Other features of the invention will be apparent from the dependent claims, and the description which follows.

- 5 Accordingly there may be provided an electromagnet 100 for a Magnetic Resonance Imaging MRI apparatus. The electromagnet 100 may comprise a coil 110 for generating a magnetic field, the coil 110 having a first axially outer surface 112, and a support element 120 for mounting the coil 110 in the MRI. The support element 120 may be bonded to the first axially outer surface 112 of the coil 110.
- 10 Thus the bonded support element provides a means for securing the coil to a support structure and, thereby, inhibit axial and rotational movement of the electromagnet.

The support element 120 may be configured for being mechanically fastened to a support structure 200.

- 15 The support element 120 may comprise a bonding face 122 by which the support element 120 is bonded to the first axially outer surface 112. The bonding face 122 may be configured to have a reduced stiffness towards its periphery and a higher stiffness towards a central area of the bonding face.

- 20 Thus the support element is configured to reduce a stress concentration which may arise at the periphery of the bonding face in response to a force acting on the electromagnet.

A plurality of support elements 120 may be bonded to the first axially outer surface. The plurality of support elements 120 may be equally spaced around the first axially outer surface 112.

- 25 According to other examples, the plurality of support elements may be irregularly spaced. That is to say, the plurality of support elements 120 may be unequally distributed around the first axially outer surface 112.

The coil 110 may comprise a second axially outer surface 114 opposite to the first axially outer surface 112. A further support element 120' (Fig. 14) may be bonded to the second axially outer surface 114.

The electromagnet 100 and the support element 120 may be bonded using an adhesive suitable for cryogenic applications.

The coil 110 and the support element 120 may be resin-impregnated to form a monolithic structure.

- 5 According to another example there may be provided an electromagnet assembly 10 for a MRI apparatus, comprising: the electromagnet 100 according to the present disclosure, and a support structure 200 comprising a support plate 220, wherein the support element 120 is mounted to the support plate 220.

10 An extension tube 310 may be fitted around a pin 300 for making a pinned connection between the support plate 220 and the support element 120. The extension tube 310 may be configured to abut against the support plate 220 and the pin 300 to maintain radial compression on the support element 120 when the coil 110 is in its superconducting state.

15 Thus the extension tube is configured to maintain compression in a case where the support element 120 has a greater coefficient of thermal contraction than the pin 300.

The support plate 220 may be configured to press the support element 120 and the further support element 120' against the coil 110 when the coil is in its superconducting state.

20 Thus the support element 120 and the further support element 120', if any, are configured to secure the coil. In use, the support element and the further support element may cooperate with the support plate to press against the first axially outer surface 112 of the coil 110 and the second axially outer surface 114 of the coil 110.

The support element 120 and the support plate 220 may be configured to make a pinned connection for securing the electromagnet 100 to the support structure 200.

- 25 According to another example there may be provided an MRI apparatus comprising the electromagnet assembly 10 as described above.

According to another example there may be provided a method of manufacturing an electromagnet for an MRI apparatus. The method may comprise winding a superconductor wire into a mould to form a coil 110, arranging a support element 120

against a first external surface 112 of the coil 110, impregnating the coil 110 and the support element 120 with a thermosetting resin, and removing the coil 110 and the support element 120 from the mould.

The method of manufacturing may comprise placing a further support element 120' against a second external surface 114 of the coil 110, the second external surface 114 being opposite to the first external surface 112 of the coil 110.

### **Brief Description of the Drawings**

Examples of the present disclosure will now be described with reference to the accompanying drawings, in which:

- 10            Figure 1 is a schematic perspective view of an electromagnet assembly;
- Figure 2 shows a radial cross-section of the electromagnet assembly of Figure 1;
- Figure 3 shows a radial cross-section of an electromagnet according to Figures 1 and 2;
- 15            Figure 4 shows a tangential cross-section of the electromagnet of Figure 3;
- Figure 5 is a radial cross-section of the electromagnet assembly;
- Figure 6 shows a tangential cross-section of the electromagnet of Figure 5;
- Figure 7 shows a radial cross-section of a first variant of the electromagnet assembly;
- 20            Figure 8 shows a tangential cross-section of the electromagnet assembly of Figure 7;
- Figure 9 is a radial cross-section of an electromagnet according to Figures 7 and 8;
- Figure 10 is a radial cross-section of a second variant of the electromagnet assembly;
- 25            Figure 11 shows a tangential cross-section of another electromagnet;

Figure 12 shows a tangential cross-section of yet a further electromagnet;

Figures 13A, 13B show further variants of the electromagnet assembly of the present invention; and

5 Figure 14 shows a perspective view of further example of an electromagnet according to the present disclosure.

### **Detailed Description**

The present application is concerned with an electromagnet suitable for being mounted in an electromagnet assembly which restrains the electromagnet axially and circumferentially, thereby preventing distortion of the electromagnet arrangement  
10 along or around its assembly axis A-A (described below).

Figure 1 shows a schematic illustration of a perspective view of an electromagnet assembly 10 according to the present disclosure.

In use, the electromagnet assembly 10 forms part of a Magnetic Resonance Imaging (MRI) apparatus (or 'scanner'). For such a purpose the electromagnet assembly may  
15 be contained within a housing which, in operation, contains an inert gas as a coolant, for example helium. Hence the housing forms a cryogen vessel, which enables the electromagnet assembly to be cooled to sufficiently low temperatures to optimise performance.

The electromagnet assembly 10 is generally rotationally/circumferentially symmetrical,  
20 defining an assembly axis A-A, a radial direction and a circumferential direction. Accordingly, "axial" refers to a direction parallel to the assembly axis, while "radial" refers to a direction perpendicular to the assembly axis, and "circumferential" refers to a direction perpendicular to both the assembly axis and the radial direction around the assembly axis A-A. The electromagnet assembly extends axially (or "lengthwise")  
25 along the assembly axis.

The electromagnet assembly 10 comprises a pair of electromagnets 100 and a support structure 200 configured to carry the electromagnets.

The support structure 200 is arranged to retain the electromagnets 100 in a particular spatial (i.e. relatively spaced) arrangement, preventing each electromagnet from

moving along the assembly axis A-A or rotating about the assembly axis. For this purpose, the electromagnets are mechanically fastened to the support structure. According to the present example, the electromagnets 100 are mounted to at least two brackets 201, 202 of the support structure. In alternative examples a different  
5 number of brackets may be provided. For example, greater than three brackets may be provided. The number of brackets used may be (at least in part) dependent on the expected loads and the allowable deflection of the electromagnets.

Figure 2 shows a cross-sectional view of the electromagnet assembly 10 wherein the electromagnets 100 are mounted to the support structure 200.

10 According to the present example, the electromagnets 100 are configured to generate a magnetic field which, in use, actively shields a magnetic field which is generated by a main magnet of the MRI apparatus. Each electromagnet 100 comprises a coil 110 (or 'shield coil') configured to generate a magnet field.

Further, each electromagnet comprises a support element 120, which is mountable in  
15 the MRI apparatus. The support element is configured to restrain the coil against forces caused, for example, in response to electromagnetic interaction between coils. For the present example it is assumed that electromagnetic interaction causes a force on each coil which is directed outwardly with respect to the electromagnet assembly 10. That is, each coil experiences a force pressing the coil against its  
20 respective support element. Further, the support element also restrains the coil against rotational forces as may be caused, for example, during transportation.

The coil 110 is formed of a superconductor wire wound into an annular structure. The coil is therefore essentially rotationally symmetrical. The coil may be described in terms of an axial direction, a radial direction and a circumferential direction. When  
25 considered in the context of the MRI apparatus, these directions correspond to those described above in relation to the MRI apparatus as a whole. In particular, the coil possesses rotational symmetry about the assembly axis A-A.

Figures 3 and 4 show the coil 110 and the support element 120.

The coil 110 has a first axial end face 112 and, opposite thereto, a second axial end  
30 face 114. The pair of axial end faces delimits an extent of the coil along the axial direction. Similarly, the coil has a first radial surface 116 (or 'inner radial surface') and,

opposite thereto, a second radial surface 118 (or 'outer radial surface'). The pair of radial surfaces delimits an extent of the coil along the radial direction.

The support element 120 is fixed to the coil 110 and provides a means for mounting the coil in the MRI and, more specifically, to the support structure 200. The support  
5 element has a bonding face 122 which is bonded to the coil. The support element, or at least the bonding face, is configured to be bonded using an adhesive suitable for cryogenic applications. According to the present example, the support element is bonded to the first axial end face 112 of the coil.

The support element 120 possesses a pair of mating surfaces 124, 126 configured for  
10 being brought into abutment/contact with the support structure 200. According to the present example, the mating surfaces 124, 126 are substantially flat so as to sit flat against a corresponding portion of the support structure 200.

According to the present example, in which the support element 120 is bonded to the first axial end face 122, the mating surfaces are separated by a distance which is  
15 greater than the radial extent (or 'radial thickness') of the coil 110. Thereby the curvature of the coil may be accommodated between the mating surfaces. Radial expansion of the coil, in response to energising, is also accommodated by suitably spacing the mating surfaces.

The support element 120 is configured for mounting the coil to the support  
20 structure 200. Accordingly, the support element 120 comprises means for mechanically securing to the support structure 200. Any suitable means may be used such as, for examples, bolts, pins or other suitable mechanical elements. In the present example the support element comprises an aperture 128 for receiving a pin and thus make a pinned connection with the support structure. By way of example, a  
25 pin 300 is shown in Figure 13. However, for clarity, the pins (or other mechanical elements) are not shown in Figures 2 to 12.

Figures 5 and 6 show the electromagnet 100 comprising coil 110 mounted in the support structure 200. More particularly, Figure 5 shows a radial cross-section of the support structure, the coil 110 and the support element 120, while Figure 6 shows a  
30 corresponding tangential cross-section.

The support structure 200 comprises a single support plate 220 configured to receive the electromagnet 100. According to the present example, the support plate 220 includes a substantially flat section 222 which matches the substantially flat mating surfaces 116, 118 of the support element. As explained with reference to Figure 1, the example electromagnet assembly 10 comprises at least two brackets 201, 202. Each bracket comprises a single support plate 220.

The single support plate may have features formed into it or added to it to improve axial stiffness. The single support plate may be located on the radially outer (A2) or radially inner (A1) sides of the coils. The choice of radially inner or radially outer sides of the coils may be determined by the expected coil deformation forces, and the requirement for reducing the outer diameter of the magnet coil assembly. If the single support plates are located on the radially inner side of the coils, then no radial space is taken up by the support plate. If the single support plates are located on the radially outer side of the coils, then surrounding structures such as cryogen vessel or thermal radiation shield will need to be increased in diameter to accommodate the support plates.

The support plate 220 may be flat or formed, to determine required stiffness, to manage stress and deflections where necessary to provide optimum operating conditions for the superconducting coils.

According to the present example, where a pair of electromagnets 100 is carried by the single support plate 220, each support plate extends from a first electromagnet 100 to a second electromagnet 100'.

When received on the single support plate 220, the support element 120 is anchored to the support plate. Suitably an aperture 206 is provided in each support plate 220. For securing the support element, the aperture 128 of the support element 120 is aligned with the aperture 206 of the support plate. A pin 300 (Figures 13A, 13B) is then fitted through the aligned apertures 206, 128, thus bringing the electromagnet assembly 10 from a circumferentially unlocked configuration into a circumferentially locked/fixed configuration. Other mechanical attachment means may be provided in place of the pin 300 to achieve the circumferential locking function. In the circumferentially locked configuration, relative movement between the support element 120 and the support structure 200 is restrained (or 'inhibited').

A bracing element 230 may be provided. The size and/or location of the bracing element is chosen to modify the stiffness of the support element 220, where necessary, in order to accommodate expected loads acting on the electromagnet assembly 10. Such loads may be caused by ferrous building material present where  
5 the electromagnet assembly will be operated (for example metal reinforcement rods or girders in floors and walls). Other loads may be caused internally, particularly in response to interaction between magnetic fields. More particularly, an inwardly-acting compressive coaxial force may be caused on each electromagnet 10. That is, the electromagnet assembly 10 may also be configured to operate in compression if the  
10 electromagnetic load direction is reversed. Sufficient bracing of the single support plate 220 will be required to prevent buckling, and the bracing element(s) 230 may be sized and/or located suitably.

For applications relating to Magnetic Resonance Imaging, it is considered convenient to assemble an MRI apparatus completely, or as much as feasible, before  
15 transportation to its destination. This may save days or weeks of assembly time. Also, without requiring initial assembly and final assembly, this may reduce the amount of coolant required, thus saving precious resources resulting in a 'greener' final product. During transportation of a fully or partially assembled apparatus, however, rotational loads may act on the coils 110. If unchecked, the forces can misalign or deform the  
20 coils and, consequently, adversely affect performance of the assembly.

However the provision of the bonded support elements 120 according to the present invention provides axial restraint and rotational (or 'circumferential') restraint of each electromagnet 100 relative to the support structure 200.

Additionally, during operation the electromagnetic interaction between the coils 110 is  
25 restrained by the interaction of the support elements 120 and support structure 200, thus preventing relative axial and radial movement of the coils, thereby optimising performance of the device.

Hence the bonded support elements 120 of the present disclosure provide support for the coils 110 against rotational (circumferential) loads to inhibit distortion or rotation of  
30 the assembly during transit and in operation, thus increasing the chance of optimised performance of the final product.

The exemplary electromagnet 100 according to the present disclosure may be manufactured using any suitable process of manufacturing.

An example process by which the electromagnet 100 may be manufactured relates to the known process of resin-impregnation. As part of this process, superconductor wire  
5 is wound into a mould. The support element 120 is arranged with the coil so formed, locating the support element against an external surface of the coil. Where a plurality of support elements are located on the external surface, they may be arranged with equal spacing.

The resulting structure is then impregnated with a thermosetting resin and the resin  
10 allowed or caused to set. Subsequently the electromagnet is removed from the mould as a monolithic structure.

According to the example process described, the step of forming the coil by winding superconductor wire is essentially unaffected by the later addition of the support element 120. That is, the coil is formed into a shape optimised for performance,  
15 essentially without consideration for bonding to or being carried by the support element.

The bonding between the coil 110 and the support element 120 may also be achieved using resin-impregnation, either at the same time as forming the coil, or once the coil is formed. Resin-impregnation is known to provide great structural strength to a coil,  
20 but according to the present disclosure said structural strength is used also for bonding the coil and the support element. Notably, the bond may be reinforced, for example through the addition of glass fibre to the resin, to provide a bond sufficiently strong for the intended application. In particular, the bond may be made strong enough to withstand a tensile force which may be caused in response to a reversal of  
25 the electromagnetic interaction between the electromagnets 100.

Alternatively the support element 120 is secured to a resin-impregnated coil 110 in a separate manufacturing step. This may be achieved using an adhesive suitable for, where desired, cryogenic applications.

The prepared electromagnet 100 is mounted to the support structure 200 to form the  
30 electromagnet assembly 10. This process includes locating the support element 120 to the support plate 220, aligning the aperture 128 of the support element with the

aperture 206 of the support plate, and fitting a pin 300 through the aligned apertures. The support element 120 and the single support plate 220 are provided with appropriate features to accept the pin 300, or to accept equivalent mechanical fasteners where pins are not used. It is noted that shape-matching of pins, particularly round pins, in corresponding apertures is efficiently achievable to high accuracy. This provides for a predictable load distribution to ensure optimal performance of the electromagnets. Multiple pins may be provided for a single support element 120, according to loading conditions. The sizes and positions of the pins may also be selected according to loading conditions. The pins 300 should be close fitting to the apertures 128, 206 to ensure reproducible stress distribution. Other fastener types may be used to provide the equivalent mechanical function.

Particularly for applications relating to cryogenic applications, which includes Magnetic Resonance Imaging, the electromagnets 100 are cooled below a critical temperature at which the coils 110 enter a superconducting state. For efficient cooling it is beneficial to expose a large surface area of the coils to the coolant. Conveniently, the electromagnet 10 according to the present disclosure allows for relatively small support elements 120 so that a relatively large surface area of each coil 110 remains exposed.

Figures 7, 8 and 9 show an alternative arrangement of the electromagnet assembly 10 which is configured to support particularly against compressive loads.

Figure 7 is a radial cross-sectional view of the electromagnet assembly 10, while Figure 8 is a plan view of the electromagnet assembly, and Figure 9 shows a tangential cross-section of the electromagnet 100. Similar to Figures 5 and 6, Figures 7 and 8 are partial views in the sense that only a right-hand side of the electromagnet assembly 10 is depicted. That is to say, the essentially identical left-hand side is omitted from the figure.

According to the example shown in Figures 7 and 8, the single support plate 220 extends only partway between the pair of electromagnets 100, 100'. This is in contrast to the example of Figure 5 in which the single support plate extends all of the way from the first electromagnet 100 to the second electromagnet 100'. Put another way, in the example of Figures 7, 8 each electromagnet 100 is provided with its own single support plate 220. A bracing element 230 is provided to each single support plate 220. A rod 240, which may also be provided in the above example, extends between the

bracing elements 230. The rod 240 may be mechanically mounted to the inner structure of the magnet assembly. The single support plate 220 must be sufficiently strong to prevent buckling. This may be achieved by control of the material, shape and/or thickness of the single support plate 220.

5 The example of Figures 7, 8 and 9 also illustrates an alternative shape of the support element 120. According to this example, the bonding face 122 possesses reduced stiffness towards the periphery delimiting the bonding face. That is to say, the support element 120 is formed to be more flexible on its bonding face 122 towards a periphery of the bonding face than towards a central area of the bonding face, the central area  
10 being delimited by the periphery. This arrangement is suitable for minimising “edge effects”. “Edge effects” may arise in response to stresses exerted on the coil 110, irrespective of whether compressive or tensile loads are concerned. As regards a compressive load where the coil 110 is pressed against the bonding face 122, the edge effects may result in a stress concentration at the periphery (or ‘edge’) of the  
15 bonding face which may cause damage to the coil or the support element. As regards a tensile load where the coil is pulled along an axial direction away from the bonding face, a stress concentration at the periphery of the bonding face may cause damage to the bond between the coil and the bonding face. Reducing edge effects will thus also reduce the likelihood of failure of the bond between the support element 120 and  
20 coil 100.

In further embodiments, the support element may be mounted axially inboard of the coil, thereby being configured for operation in compression. Figure 16 shows such an arrangement, in views similar to Figures 5 and 4, described above. In the embodiment of Figure 16, coil 110 is provided only with axially inner support elements  
25 120'. Figure 17 shows another view of such an embodiment, in a view similar to the view of Figure 6.

Figure 10 shows a radial cross-sectional view of a part of an alternative example of an electromagnet assembly 10' according to the present disclosure. According to the example depicted in Figure 10, the electromagnet assembly is configured to operate  
30 in compression. That is, in use the electromagnetic load direction acts to bring the coils 100, 100' together along the assembly axis A-A. To improve resistance to buckling, the support plate 220 and the bracing element 230 are formed integrally. The support plate 220 and the bracing element 230 may comprise solid or hollow

sections. For example the support plate 220 and the bracing element 230 may be solid or hollow section extrusions. Additionally, the passage/cavity 215 corresponds to a local cut-out sized to accommodate the support element 120 only. This arrangement therefore provides for a relatively large bracing element and a relatively small passage 215, providing a particularly high resistance to buckling under compression. With suitable configuration and/or choice of materials, for example those of the coil surface 112 and the bonding face 122, this example electromagnet assembly may also be operable in tension, where the integral bracing element 230 supports the induced loads.

Figure 11 illustrates an alternative shape for the support element 120. According to this example, the support element has a generally trapezoid cross-sectional shape. The legs (or non-parallel sides) of the trapezoid shape are convex to further reduce stiffness towards the periphery.

Figure 12 shows another alternative shape for the support element 120 configured to reduce edge effects. According to this example, the support element comprises cutaway sections towards the periphery of the bonding face 122, which provides the periphery of the bonding face with greater flexibility.

Figures 13A and 13B show alternative examples of an electromagnet assembly according to the present disclosure. According to this example, the electromagnet 100 is mounted to the support structure 200 such that a compressive load exerted by the pinned connection is maintained after cooling the system below the critical temperature of the superconductor coil 110. Where the support element 120 has a higher coefficient of thermal contraction than the pin 300 or pins used to make the pinned connection, as the system is cooled compression cannot be maintained so that the electromagnet is not fully secured. According to the present example, an extension tube 310 is fitted around the pin, wherein the extension tube (or 'sleeve') has a lower coefficient of thermal contraction than the pin. The extension tube is configured to abut against the support plate 220 and the pin 300 to compress the support plates against the support element even when cooled, and thus maintain compression. Figure 13A shows an example where the extension tube 310 is located on an opposite side of the support plate 220 to the support element 120, while Figure 13B shows an example where the extension tube 310 is located on a same side of the support plate 220 as the support element 120.

Figure 14 shows a perspective view of a variant of the electromagnet 100. In the examples described above, at least one support element 120 is bonded to the first axial end face 112. In other examples, at least one support element 120 may be bonded to each axial end face 112, 114 or, more generally, to each pair of opposing external surfaces of the coil. That is, a first support element is bonded to a first outer surface of the coil, a second support element is bonded to a corresponding location of a second outer surface which is opposite to the first outer surface. According to Figure 14, the first support element 120 is bonded to the first axial end face 112, while the second support element 120' is bonded to the second axial end face 114.

It is considered convenient to provide a support structure configured to compress the coil along the assembly axis A-A when the support structure and the coil are cooled and/or the coil is energised. For this purpose, the support structure 200 may be configured to possess greater thermal contraction than the coil along the axial direction. Additionally or alternatively, the support structure and the coil are configured so that an expansion of the coil on being energised results in the support structure pressing the support elements against the coil. Conveniently, the described arrangement may reduce misalignment of the coil on being energised and may improve durability of the bonding.

In relation to the examples where the support elements 120, 120' are bonded to the axial end faces, the first support element is located at a particular circumferential location on the first axial end face 112, and a second support element is located in on essentially the same circumferential location on the second axial end face 114.

Where a support element 120 is bonded to a radial surface, the bonding face 122 of said support element is suitably curved, convex or concave, dependent on the particular radial surface to which it is mounted. Further, the support structure is suitably adapted for mounting an electromagnet 100 having a support element or elements 120 on a radial surface or surfaces 116, 118 (Fig. 3).

As illustrated for example in Figure 15, structures similar to those described above may be employed in constructing coils that constitute the inner (main) magnet of the MRI system. When used for the inner (main) magnet, it is preferable that the single support plate 220 should be placed on the radially outer (A2) surface of the coils. This

avoids reducing the available inner diameter of the coils, ensuring that the open bore of the final MRI system is as large as possible. Typically, the coils of the inner (main) magnet are, in use, in a state of compression, that they are subjected to an axial force which tends to drive them towards the centre of the magnet. For that reason, it may be appropriate to use a structure similar to that shown in Figures 16, 17 as described above, where each coil 110 is provided with an axially inner support element 120'. The other features of such as embodiment are as described above with reference to other embodiments. Fig. 15 shows a partial cross-section, in which one-quarter of the magnet is represented. The remaining structure will be essentially symmetrical about axis A-A and centreline C-C. In a preferred embodiment, the individual coils are connected to a longitudinal compression support plate by similar pin joints. The pin jointed structure minimises the interaction between the coils and the remainder of the inner magnet structure.

Attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

Each feature disclosed in this specification (including any accompanying claims, abstract and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

The present invention differs from the invention disclosed in PCT/EP2018/075940 in that only a single support plate 220 is provided to each coil. In PCT/EP2018/075940, two support plates are provided to each coil, one adjacent the respective axially inner surface and one adjacent the respective axially outer surface. The present invention provides the advantages that fewer components are required with attendant savings in weight and material cost. Furthermore, use of a single support plate, as provided by the present invention, may allow smaller components such as thermal shield and outer vacuum container to be used, as support plates 220 need not be provided radially outside of the outer coils, or radially inside the inner (main) coils. In turn, this may mean that the clear bore of the final MRI system may be enlarged by comparison to embodiments of the invention of PCT/EP2018/075940, or smaller diameter coils may be used for a given bore size, reducing material cost and weight of the magnet.

**CLAIMS**

- 1 An electromagnet assembly (10) for an MRI apparatus, comprising: an electromagnet (100) for a Magnetic Resonance Imaging (MRI) apparatus, the electromagnet (100) comprising:
  - a coil (110) for generating a magnetic field, the coil (110) having a first axially outer surface (112; 114), and
  - a support element (120; 120') for mounting the coil (110) in the MRI apparatus;wherein the support element (120; 120') is bonded to the first axially outer surface (112; 114) of the coil (110); and
  - a support structure (200) comprising a single support plate (220);
  - wherein the support element (120) is mounted to the single support plate (220), and wherein
  - the support element (120) is mechanically fastened to the single support plate (220).
- 2 The electromagnet (100) according to claim 1, wherein the support element (120; 120') is configured for being mechanically fastened to a support structure (200).
- 3 The electromagnet (100) according to claim 1 or 2, wherein the support element (120; 120') comprises a bonding face (122) by which the support element (120; 120') is bonded to the first axially outer surface (112; 114), and wherein the bonding face (122) is configured to have a reduced stiffness towards its periphery and a higher stiffness towards a central area of the bonding face.
- 4 The electromagnet (100) according to any previous claim, wherein a plurality of support elements (120; 120') is bonded to the first axially outer surface, and wherein the plurality of support elements (120; 120') is equally spaced around the first axially outer surface (112; 114).

- 5 The electromagnet (100) according to any previous claim, the coil (110) comprising a second axially outer surface (114; 112) opposite to the first axially outer surface (112; 114), and wherein a further support element (120'; 120) is bonded to the second axially outer surface (114; 112).
- 6 The electromagnet (100) according to any previous claim, wherein the electromagnet (100) and the support element (120; 120') are bonded using an adhesive suitable for cryogenic applications.
- 7 The electromagnet according to any previous claim, wherein the coil (110) and the support element (120; 120') are resin-impregnated to form a monolithic structure.
- 8 The electromagnet assembly (10) according to any preceding claim, comprising an extension tube (310) fitted around a pin (300) for making a pinned connection between the single support plate (220) and the support element (120; 120'), the extension tube (310) configured to abut against the single support plate (220) or the pin (300), configured to maintain compression on the support element (120; 120') when the coil (110) is in its superconducting state.
- 9 The electromagnet assembly (10) according to any one of claims 7 to 8 when dependent on claim 5, wherein the single support plate (220) is configured to press the support element (120; 120') and the further support element (120'; 120) against the coil (110) when the coil is in its superconducting state.
- 10 The electromagnet assembly (10) according to any one of claims 7 to 9, wherein the support element (120; 120') and the single support plate (220) are configured to make a pinned (300) connection for securing the electromagnet (100) to the support structure (200).
- 11 An MRI apparatus comprising the electromagnet assembly (10) according to any preceding claim.

FIG 1

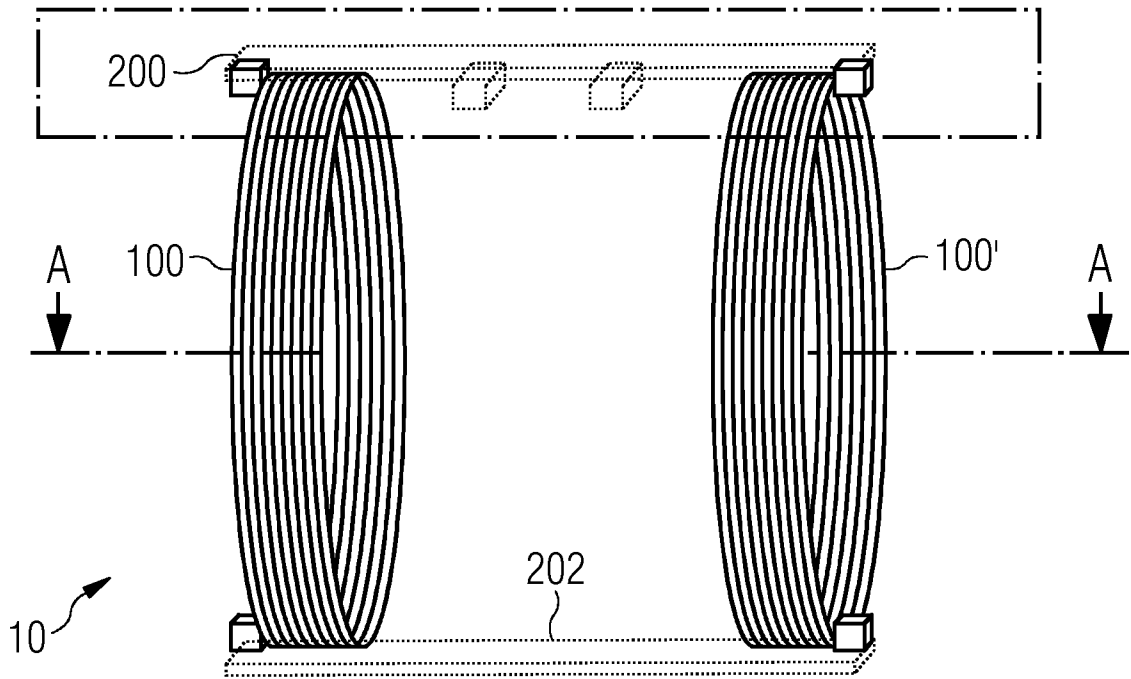


FIG 2

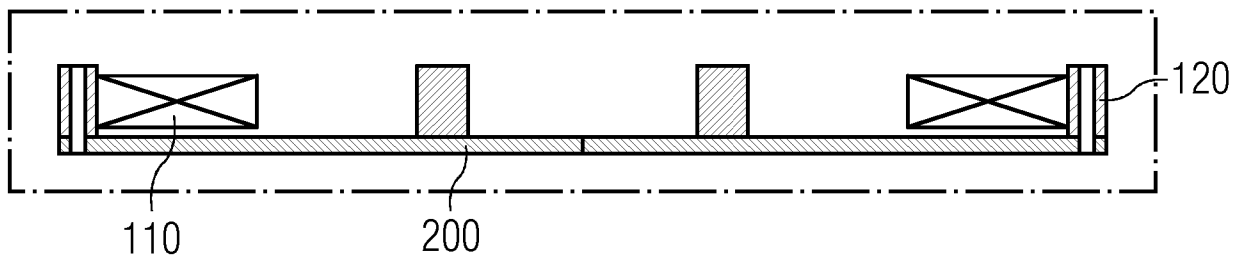


FIG 3

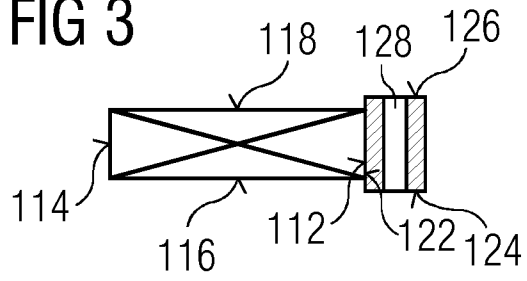


FIG 4

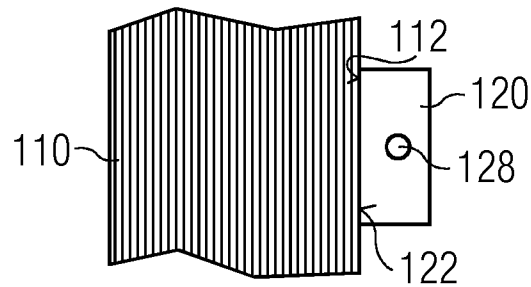


FIG 5

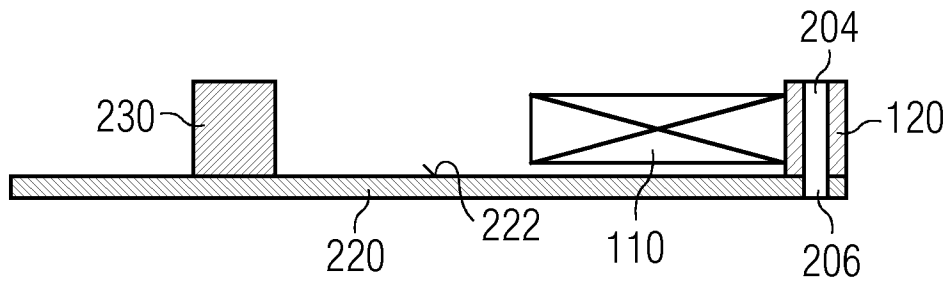


FIG 6

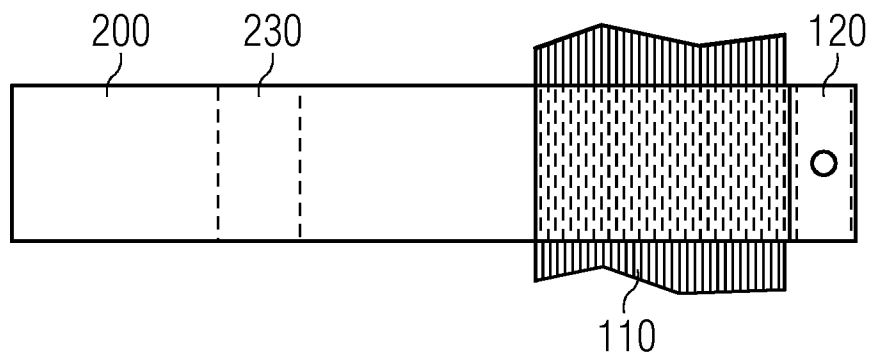


FIG 7

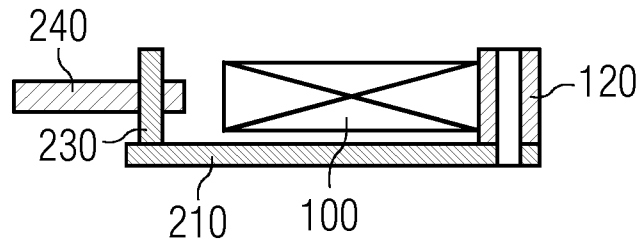


FIG 8

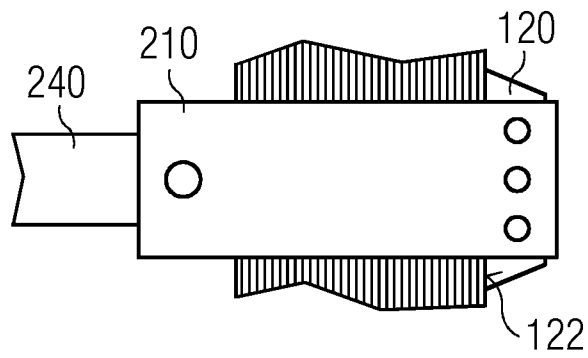


FIG 9

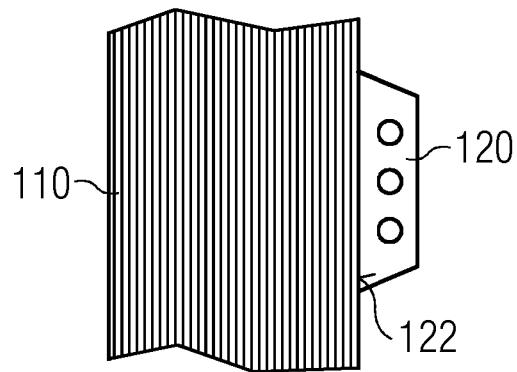


FIG 10

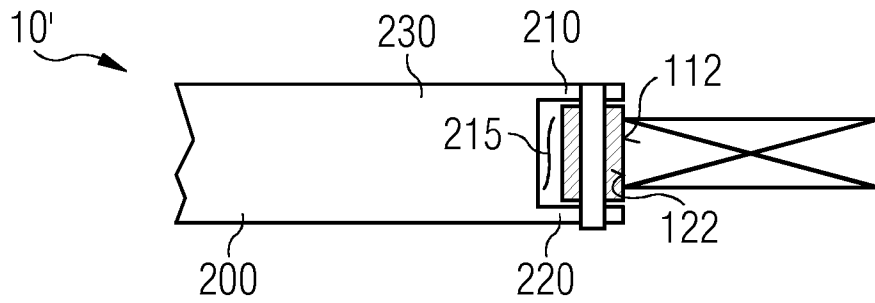


FIG 11

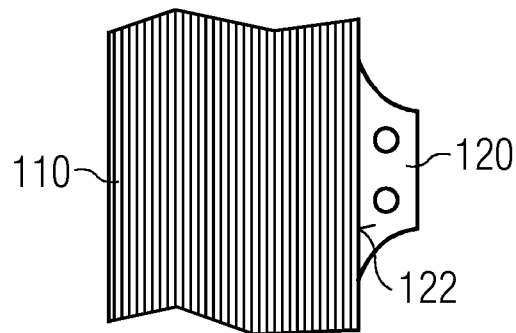


FIG 12

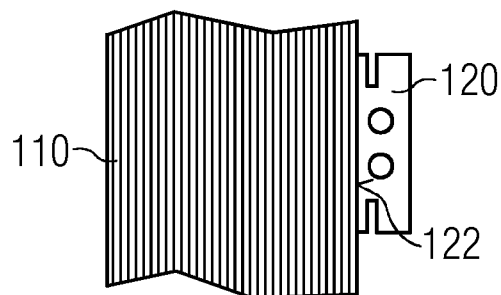


FIG 13A

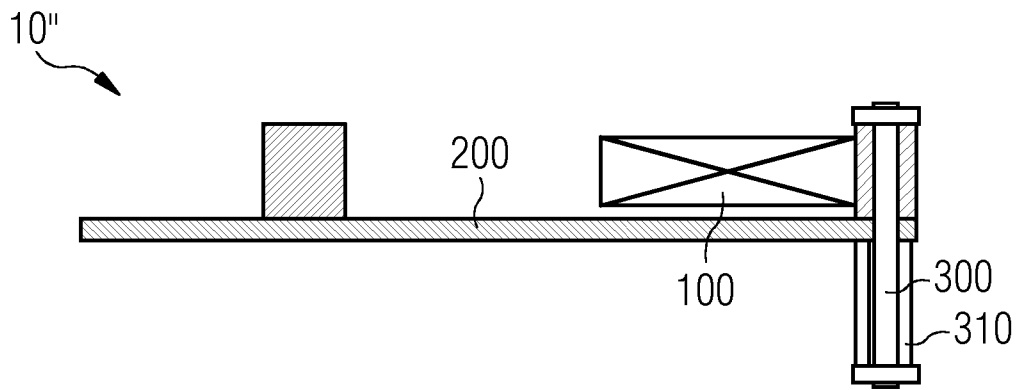


FIG 13B

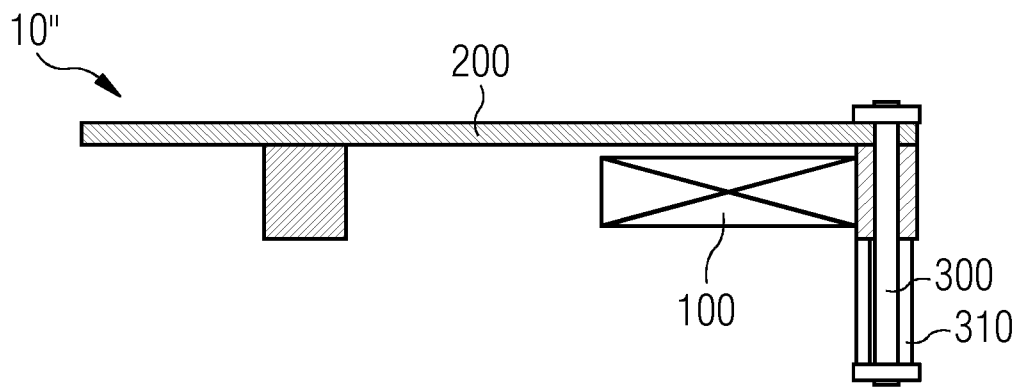


FIG 14

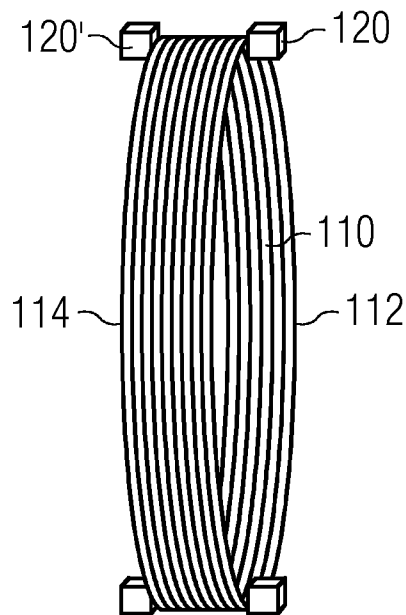


FIG 15

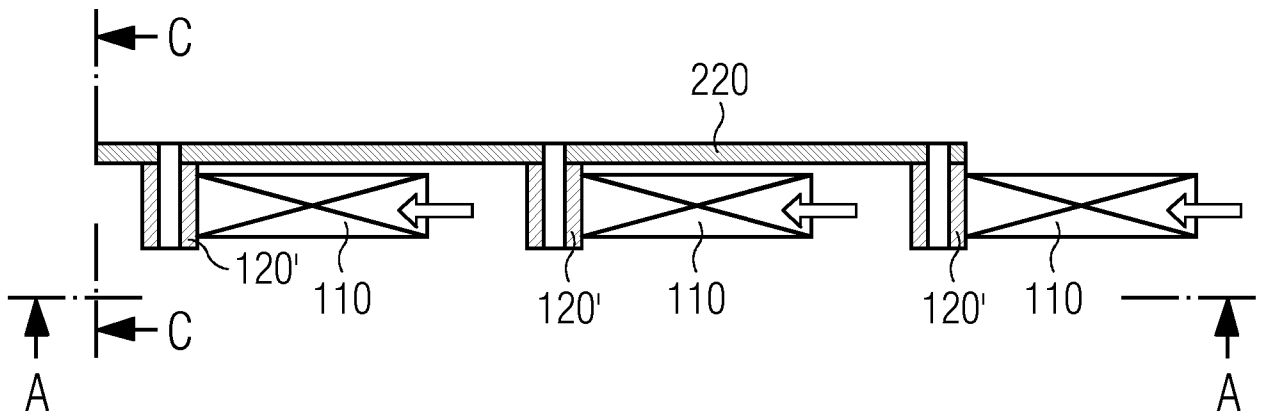


FIG 16

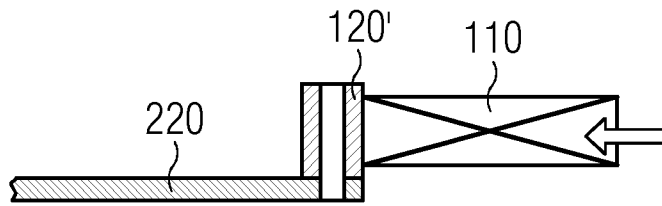
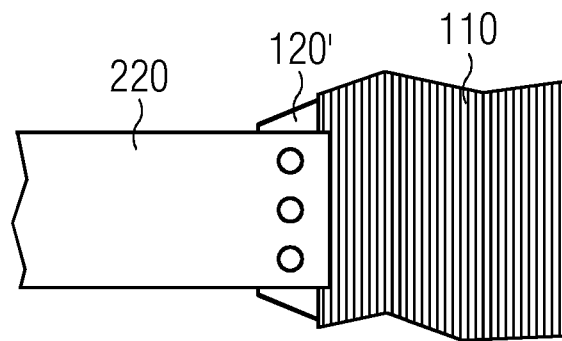


FIG 17



INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2019/058328

A. CLASSIFICATION OF SUBJECT MATTER  
INV. G01R33/38  
ADD. G01R33/3815 H01F6/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
G01R H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
EPO-Internal, BIOSIS, COMPENDEX, EMBASE, INSPEC, IBM-TDB, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010/295640 A1 (TAMURA HAJIME [JP]) 25 November 2010 (2010-11-25) paragraph [0002] paragraph [0029] - paragraph [0030] paragraph [0044] - paragraph [0047] figures 6-8	1,2,4-7, 10,11
X	JP S61 99046 U (TOSHIBA) 25 June 1986 (1986-06-25) figures 3, 4	1,2,4-7, 10,11
X	EP 0 452 046 A2 (GEN ELECTRIC [US]) 16 October 1991 (1991-10-16) column 5, line 15 - column 6, line 28 figures 1, 4-6	1,2,4-8, 10,11
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Further documents are listed in the continuation of Box C.

See patent family annex.

\* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search  5 December 2019	Date of mailing of the international search report  20/12/2019
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer  Streif, Jörg Ulrich
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## INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2019/058328

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/291782 A1 (CALVERT SIMON JAMES [GB]) 1 December 2011 (2011-12-01) paragraph [0023] - paragraph [0037] figures 1-3 -----	1,2,4,6, 7,10,11
E	WO 2019/072545 A1 (SIEMENS HEALTHCARE LTD [GB]) 18 April 2019 (2019-04-18) page 5, line 9 - page 13, line 11 -----	1-11

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International application No PCT/EP2019/058328
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