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G01R 33/34

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(56) Documents Cited:
US 5990681 A **US 5841279 A**
US 5374890 A **US 5304932 A**

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INT CL^7 **G01R**
Other: **EPODOC, WPI, JAPIO, INSPEC, TXTE**

(54) Abstract Title: **A BODY COIL FOR A MAGNETIC RESONANCE IMAGING APPARATUS**

(57) Magnetic Resonance Imaging apparatus has a magnet body (1) which is surrounded by a magnet enclosure (12). This magnet enclosure surrounds and delimits an interior space (21), with there being located in this interior space (21) a gradient coil system (2) and in the latter in turn as an inner encapsulating cylinder a body-coil (28) which has an HF-antenna and a support tube, and with the magnet enclosure (12) and the gradient coil system (2) being closed off both visually and acoustically by the body-coil (28) and a screen (29) at the end faces and in the interior space (21), with the body-coil (28) being produced by means of a vacuum casting or vacuum die-casting method.

FIG 1

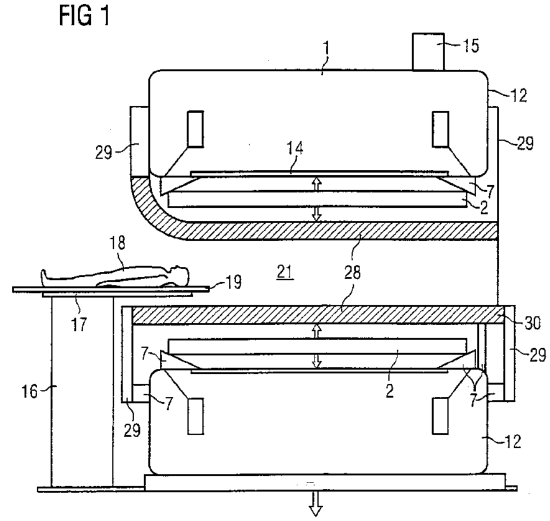

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FIG 1

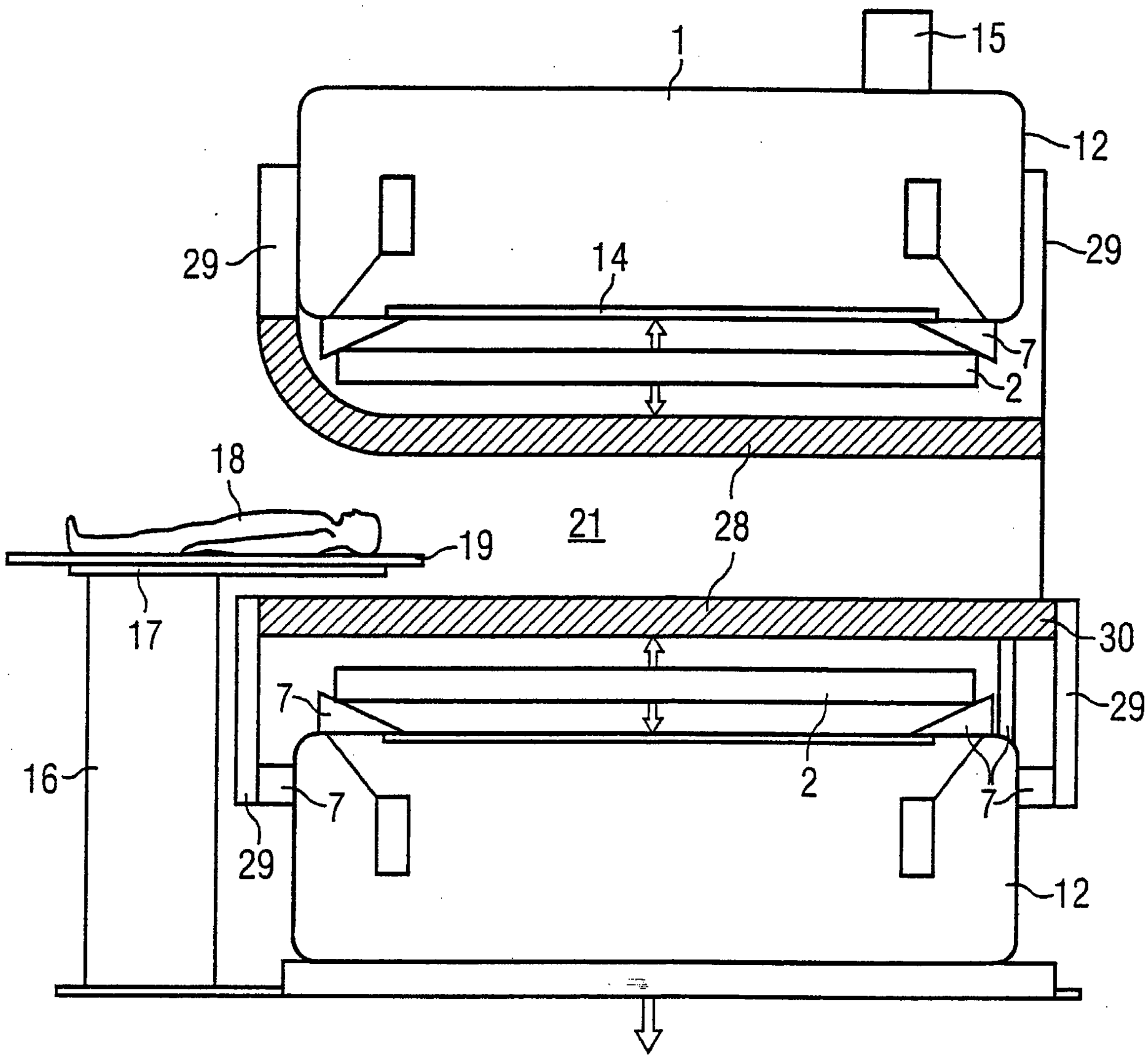
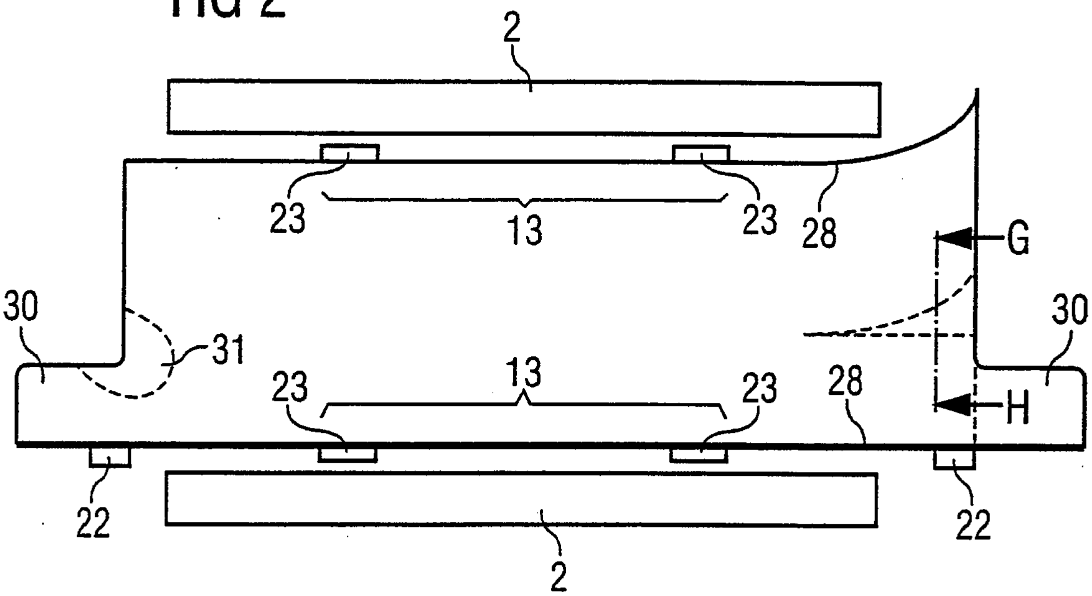


FIG 2



View G-H

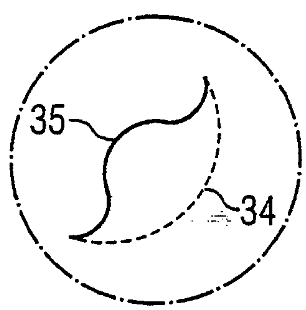


FIG 3A

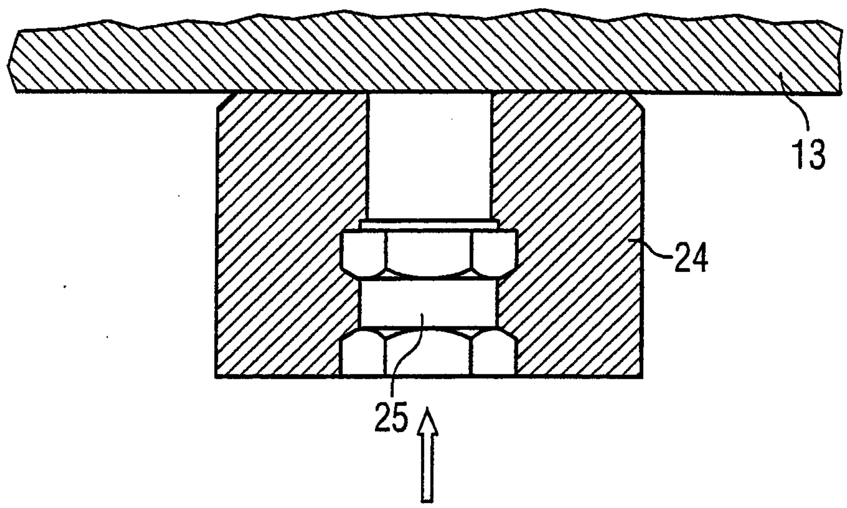


FIG 3B

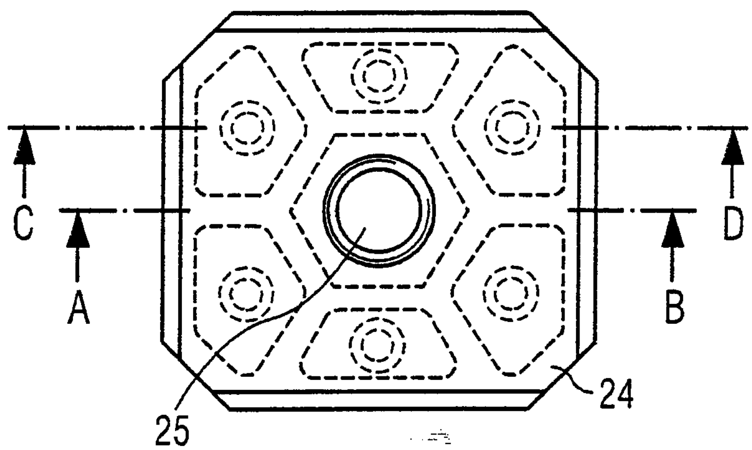


FIG 3C

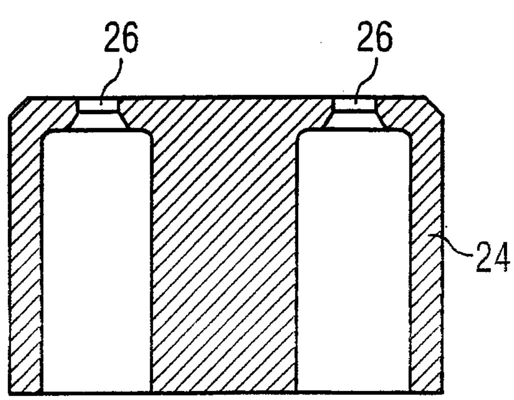


FIG 4A Section E-F

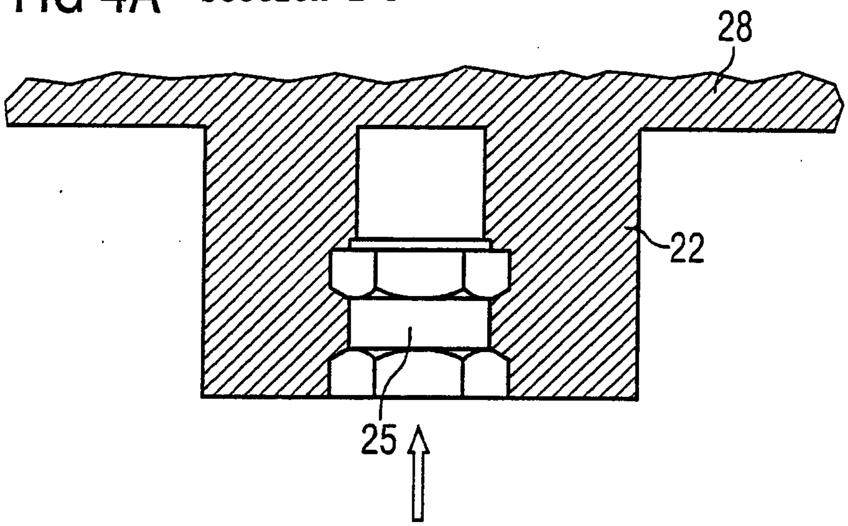


FIG 4B

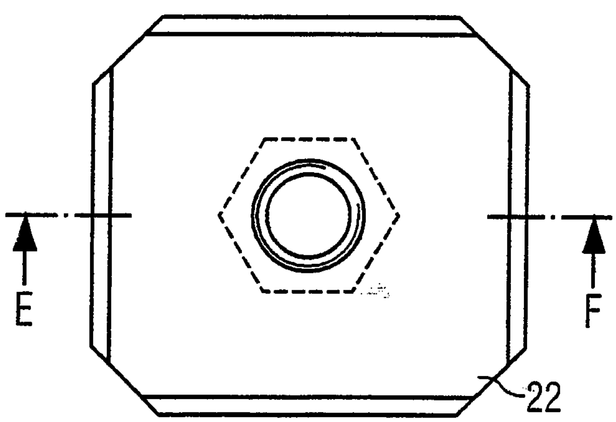


FIG 5

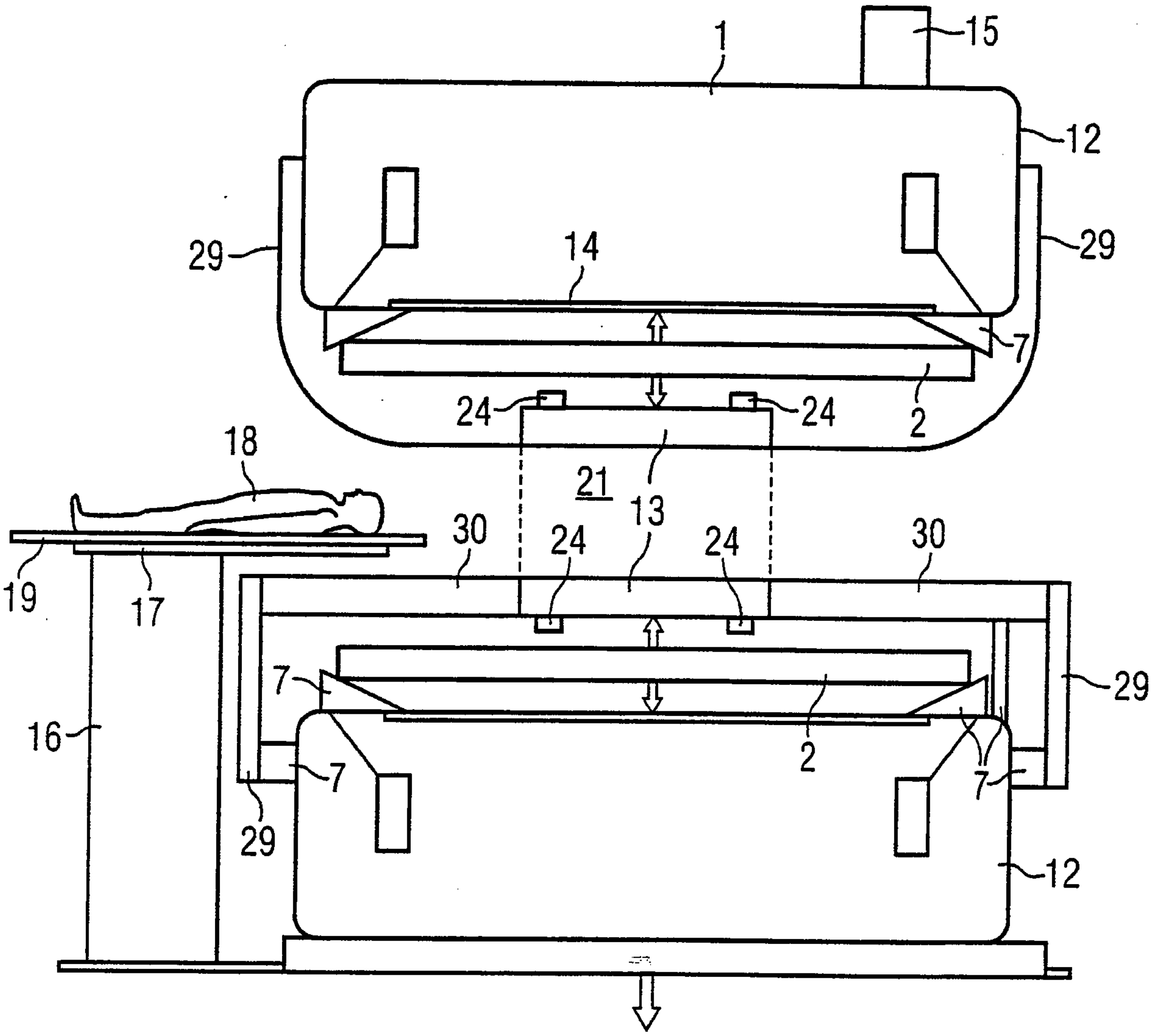


FIG 6

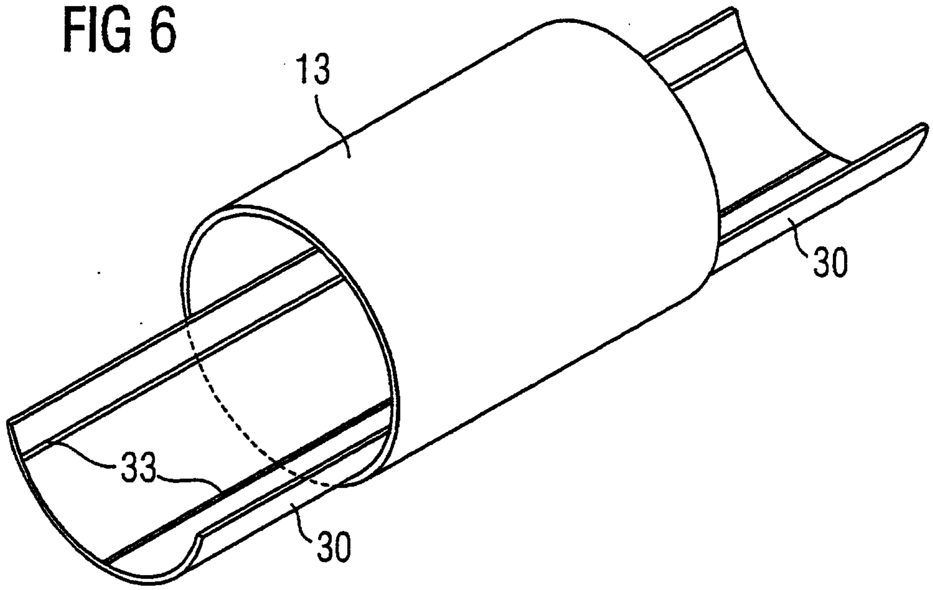
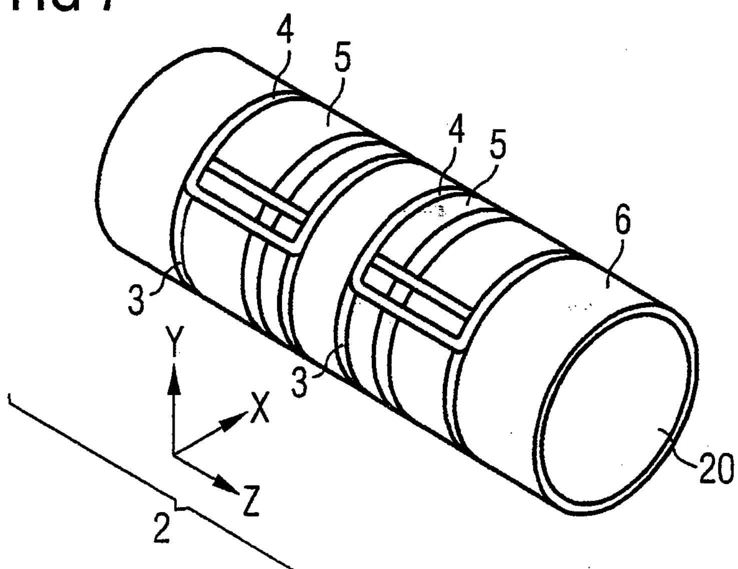


FIG 7



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A BODY COIL FOR A MAGNETIC RESONANCE TOMOGRAPHY APPARATUS

The present invention relates in general to nuclear spin tomography (synonym: magnetic resonance tomography; MRT) as used in medicine to examine patients. In this connection, the present invention relates in particular to a nuclear spin tomography apparatus whose support tube of the body-coil is produced in accordance with the invention by means of vacuum casting or vacuum die-casting methods and a process for manufacturing the HF-antenna support tube (body coil) of a magnetic resonance tomography apparatus.

MRT is based on the physical phenomenon of nuclear spin resonance and has been used successfully as an image-producing method for over fifteen years in medicine and biophysics. In the case of this method of examination, the object is exposed to a strong, constant magnetic field. As a result, the nuclear spins of the atoms in the object, which were previously oriented in a random manner, are aligned. High-frequency waves can now excite these "ordered" nuclear spins to give a specific oscillation. In MRT this oscillation generates the actual measurement signal which is picked up by means of suitable receiving coils. As a result of the use of inhomogeneous magnetic fields, generated by gradient coils, the object of measurement can be spatially coded in all three directions in space. The method allows there to be free choice of the layer that is to be imaged, as a result of which sectional images of the human body can be taken in all directions. MRT as a sectional-image method in medical diagnostics is distinguished in the first place as a "non-invasive" method of examination by its versatile contrast capability. MRT today makes use of applications with a high gradient rating that enable there to be excellent image quality with measuring times of the order of magnitude of seconds and minutes.

The continuous further technical development of the components of MRT apparatus and the introduction of rapid imaging sequences have opened up more and more fields of application for MRT in medicine. Real-time imaging to assist with minimally invasive surgery, functional image-transmission in neurology and perfusion measurement in cardiology are just a few examples.

Figure 5 shows a diagrammatic section through an MRT apparatus according to the prior art. The section shows further components of the interior space enclosed by the basic field magnet 1. The basic field magnet 1 contains superconducting magnet coils located in liquid helium and is surrounded by a magnet enclosure 12 in the form of a two-shell tank. The so-called cold head 15 that is fitted on the outside of the magnet enclosure 12 is responsible for keeping the temperature constant. The gradient coil 2 is suspended concentrically by way of supporting elements 7 in the interior space that is enclosed by the magnet enclosure 12 (also called magnet container). A support tube having the high-frequency antenna applied thereto is introduced in turn, likewise concentrically, into the interior of the gradient coil 2. The support tube and HF-antenna are termed the HF-resonator or "body-coil" (BC) 13 in the following (but the term "body coil" can also be used to denote the support tube alone). The gradient coil 2 and body-coil 13 thus represent two cylinders which are pushed one into the other and the radial spacing of which - in the form of an air gap -

only amounts to approximately 3 cm. The HF-antenna has the task of converting the HF-pulses that are emitted by a power transmitter into an alternating magnetic field in order to excite the atomic nuclei of the patient 18 and subsequently of changing the alternating field that originates from the precessing nuclear moment into a potential that is supplied to the receiving branch. The upper portion of the body-coil 13 is mechanically connected to the magnet enclosure 12 by way of a casing 29 which, for reasons of design technology, is in the form of a funnel. Installed on the lower portion of the body-coil 13, adjoining it, there are so-called tongues 30 (see Figure 6) by way of which the body-coil 13, in turn by way of a casing 29 and also by means of support elements 7, is mechanically connected to the lower portion of the magnet enclosure 12. The tongues 30 and also the body-coil 13 are mechanically reinforced by rest-rails 33. It is possible for the tongues 30 to be counted as part of the body-coil 13. The patient 18 is transported into the opening or the interior space of the system on a patient-rest 19 by way of slide rails 17. The patient-rest is mounted on a vertically adjustable support frame 16.

The gradient coil 2 also consists of a support tube 6 which on the outside has three partial windings (partial coils) that generate a gradient field that is proportional to the respective impressed current and each of which is spatially perpendicular to the other. Applied to the inside of the support tube 6 there is a so-called high-frequency shield (HF-shield) 20 which shields the partial coils from the high-frequency field of the HF-antenna. As shown in Figure 7, the gradient coil 2 comprises an x-coil 3, a y-coil 4 and a z-coil 5, which, in each case, are wound about the support tube 6 and thus generate a gradient field expediently in the direction of the cartesian coordinates x, y and z. Each of these coils is equipped with its own power supply in order to generate independent current pulses in an accurate manner in terms of amplitude and timing in accordance with the sequence that is programmed in the pulse sequence control. The currents that are required are approximately 250 A. Since the gradient switching times are to be as short as possible, rates of current rise that are of the order of magnitude of 250 kA/s are necessary. In an extraordinarily strong magnetic field, such as that generated by the basic field magnet 1 (typically between 0.22 and 1.5 tesla), such switching operations, on account of the Lorentzian forces that occur thereby, are associated with strong mechanical oscillations that result in considerable noise.

The following demands are made on the body-coil 13 of an MRT apparatus:

For reasons of space, only a tube-wall thickness of up to 10 mm can be tolerated. The material of the body-coil should have as little power absorption of HF-power as possible and must therefore be electrically non-conductive. The body-coil must be MR-compatible, that is, not image-transmitting in the sense of magnetic resonance (for example, it may not contain any water). Since the body-coil is to support the patient-rest with the patient, the body-coil must have high mechanical dimensional stability. In order to screen the noise, predominantly generated by the gradient coil, in the best possible way, the body-coil should be as long as possible without having any interruptions. For reasons of design technology, however, the funnel-shaped widening (casing 29) of the patient tunnel is also to start as far as possible inside, although this results in a very short body-coil and does not meet the demands in terms of noise technology.

In the case of the previous solutions in accordance with the prior art, short cylindrical glass-fibre reinforced synthetic-material tubes made of epoxy resin are used for a body-coil to which the function elements of the HF-antenna in the form of planar copper conductors are applied. In order to produce such tubes, resin-impregnated glass-fibre strands (rovings) are wound around a mandrel, whilst it is rotating, and cured (possibly with the introduction of heat). In the case of this solution it is a question of making compromises, each one of which has a distinct disadvantage with regard to one of the two aspects of noise or design: whilst the body-coil is admittedly short, the funnel-shaped widening is not part of the body-coil, but consists of its own plastics portion (casing 29). This only meets the noise-reducing requirements to an insufficient extent, since it does not have the mass and rigidity that are required. On the other hand, the interface between the body-coil and funnel-shaped casing also represents an acoustic weak point.

It is therefore desirable to optimize the noise and design properties and also the electro-mechanical stability of a nuclear spin tomography apparatus.

This object is achieved in accordance with the invention by means of the features of the independent claims. The dependent claims develop the central idea of the invention further in a particularly advantageous way.

Embodiments of the invention show a nuclear spin tomography apparatus that has a magnet body. The latter is surrounded by a magnet enclosure which surrounds and delimits an interior space, with there being located in this interior space a gradient coil system and in the latter in turn as an inner encapsulating cylinder a body-coil which has an HF-antenna and a support tube, and with the magnet enclosure and the gradient coil system being closed off both visually and acoustically by the body-coil and a screen at the end faces and in the interior space. In accordance with the invention embodiments, the body-coil (in particular, the support tube) is produced by means of a vacuum casting or vacuum die-casting method.

A body-coil that is produced in such a way brings a large number of advantages with it.

On the one hand, the casting technique allows there to be substantially more freedom in shaping of the body-coil/support tube.

In order to meet optimum requirements with regard to noise technology, the body-coil can, for example, be cast in such a way that in total it has a length that is greater than that of the gradient coil that lies behind it.

In order (in addition) to meet optimum requirements with regard to the design, the body-coil can be cast in such a way that it is widened in a funnel-shaped manner on one or on both end faces. This is only possible to a limited extent and with considerable outlay in the case of the winding technique currently used.

If tongues and/or rest-rails are provided in the lower region of the body-coil, in accordance with invention embodiments these can be cast with the body-coil to form a unit, this resulting in considerably better overall mechanical stability.

In the same way, as a result of producing the body-coil by means of vacuum casting or vacuum die-casting methods, function elements - which are currently adhered to the wound body-coil - can be cast with the body-coil to form a stable unit.

The mode of functioning of the HF-antenna or its shielding by the HF-shield can be greatly improved as a result of producing the body-coil by means of vacuum casting or vacuum die-casting methods in that function elements of the HF-antenna of the body-coil are cast with the body-coil at any radius thereof. In the same way, capacitances of the HF-antenna can be cast therein as concrete components or as overlapping structures and as a result are protected in an optimum way against external arcing or other disturbing effects.

As a result of producing the body-coil by means of vacuum casting or vacuum die-casting methods, cooling elements can also be cast in the body-coil, which cooling elements consequently have a far higher level of efficiency than cooling elements which are applied to the surface of the body-coil.

In regions of the support tube of high electric field intensity, when producing the body-coil by means of vacuum casting or vacuum die-casting methods material that has a small dielectric constant can be introduced locally into the casting mould and subsequently be cast therein, as a result of which dielectric losses are kept low or the capacitive coupling of the HF-field to the patient is improved.

Advantageously, mechanically weak regions of the surface of the body-coil can be reinforced, for example, in that the reinforcement is already introduced into the casting mould before casting.

Rovings and/or woven-fabric mats and/or prepregs are used in accordance with the invention for reinforcement purposes.

The casting material can also be optimized advantageously by adding fillers.

Further advantages, features and properties of the present invention shall now be explained with the aid of exemplary embodiments with reference to the accompanying drawings, in which:

Figure 1 shows a diagrammatic section through an MRT apparatus with a body-coil in accordance with the invention;

Figure 2 shows, in detail, a diagrammatic section through the body-coil in accordance with the invention that is suspended in the gradient coil,

Figure 3a shows a first section through the bearing of the body-coil in accordance with the prior art that is adhered to the wound body-coil in the form of an injection die-cast portion,

Figure 3b shows the plan view of the bearing as an injection die-cast portion that is to be adhered thereto,

Figure 3c shows a second section through the bearing,

Figure 4a shows a section through a bearing of the body-coil in accordance with the invention that is cast with the body-coil,

Figure 4b shows the plan view of the bearing of the body-coil in accordance with the invention,

Figure 5 shows, in accordance with the prior art, a diagrammatic section through an MRT apparatus with a conventional body-coil,

Figure 6 shows a perspective representation of the body-coil in accordance with the prior art,

Figure 7 shows a perspective representation of the gradient coil with the three part windings and the HF-shield.

Figure 1 shows a diagrammatic section through an MRT apparatus with a cast body-coil 28 which has been produced in accordance with invention embodiments (by means of vacuum casting or vacuum die-casting technology). The production technology allows there to be an extension of the body-coil 28 beyond the gradient coil that lies behind it with at the same time funnel-shaped one-sided widening of the upper portion. The tongues 30 are also cast, with the stabilizing rest-rails 33, in the body-coil 28. The screen 29 in the upper portion of the MRT apparatus is shortened in a corresponding manner. All the other components of the MRT apparatus, as have already been shown in Figure 5, remain unchanged.

Figure 2 shows, in detail, a diagrammatic section through the body-coil 28 that is suspended in the gradient coil 2. Mechanical weak points 31 are reinforced by introducing mechanically stabilizing elements into the corresponding regions of the casting mould. Stabilizing circumferential reinforcements 23 or bearings 22, which in accordance with previous technology were adhered or applied to the body-coil 13 after the latter had been wound, are fixedly cast with the body-coil 28 by means of vacuum or vacuum die-casting technology.

The difference between the winding technique in accordance with the prior art and the vacuum or vacuum die-casting technique is illustrated further with the aid of Figures 4a and 4b and also Figures 3a, 3b and 3c.

Figure 3b shows the plan view of a mechanical component 24. According to the prior art, this is an injection die-cast portion which is used to mount or suspend the HF-resonator 13. For this purpose, a brass bush with an internal thread 25 is cast therein in the centre. According to the conventional method - as shown in Figure 3a - the injection die-cast portion 24 is adhered to the HF-resonator 13. In order to establish a better connection between the injection die-cast portion 24 and the HF-resonator 13, provided concentrically about the bush 25 there are undercuts 27 which have smaller diameters 26 on the HF-resonator side. The adhesive, during adhesion, penetrates through the smaller openings 26 and fills a portion of the more voluminous undercuts 27, as a result of which after the adhesive has dried a type of "rivet effect" is produced that ensures that there is a firmer connection between the injection die-cast portion 24 and the HF-resonator 13 than would be the case with a purely planar connection of the two portions.

In the case of a method in accordance with embodiments of the present invention, such undercuts 26, 27 are no longer necessary (Figure 4b), since adhesion is also no longer required. The bearing 22 is taken up in the casting mould (mandrel or shell); the threaded bush 25 is secured to the casting mould with fixing aids (for example screws). After casting, the bearing 22 with the threaded bush 25 is a fixed component part of the body-coil 28 and with the latter forms a compact unit (Figure 4a).

It is thus proposed that the body-coil be produced by means of casting such as special vacuum casting or vacuum die-casting technology. Epoxy resin and also other resins or other castable materials can be used as casting material. The casting properties of the respective material used can be optimized by the addition of fillers (for example quartz powder). The mechanical strength can be increased by the introduction of rovings and/or woven-fabric mats and/or prepregs (**pre**im**preg**nated material) into the casting mould. Prepregs are woven glass-fibre, aramide or carbon-fibre mats that have been pretreated (with resin) and which are cured at a high temperature after the desired shaping and positioning.

A casting mould may be used which consists of a mandrel on the inside and of a shell on the outside. Both end faces are closed off by means of flanges. Function elements (later described further in more detail) are introduced into the mould with fixing aids (for example made of glass-fibre reinforced synthetic material) and placed at the desired point or integrated into the mandrel or shell from the start.

In the case of vacuum casting technology, the casting mould is evacuated before casting. Located at the highest point of the casting mould there is an overflow. With, for example, a casting mould that is set up vertically, evacuation takes place at the lower flange; the upper flange contains the overflow. Given a planar upper edge, the upper side can also be open. In this case, a flange with an overflow is not necessary. A closed upper side with an overflow, however, makes any non-planar closing edge possible. The latter is necessary, for example, if the tongues 30 are also to be integrated into the body-coil 28 using casting techniques.

This new method of production of the body-coil of an MRT apparatus brings a plurality of advantages with it which shall now be set out in detail:

1. In contrast with the previous winding technique, with the casting technique it is possible to extend the body-coil beyond the gradient coil and to configure this extension in such a way that it is widened in a funnel-shaped manner. It is also possible as well to take up the tongues, if need be even on both sides, in the casting mould of the body-coil. A body-coil that is modified in such a way is represented in hatched lines in Figure 1. The funnel-shaped widening at the one end and in the upper region of the body-coil meets the requirements which have already been mentioned with regard to design technology. The total length projects over both end faces of the gradient coil and thus ensures that the noise-screening is the best possible. The tongues which receive the patient-rest are

shortened in a corresponding manner and are an integral component part of the novel body-coil.

2. The casting technique allows there to be substantially more degrees of freedom when shaping. In contrast with the wound tube - if desired - wall thicknesses that are exactly equal are obtained without the need for any mechanical re-working. In addition, variations of windable forms are possible, such as, for example, variable outside diameters, any external contours (see view G-H in Figure 2) or (funnel-shaped) widening of the diameter (see the front region of the body-coil in Figure 1 and 2). Local weak points 31 can be reinforced in a simple way by thickening the wall thickness (for example, by means of reinforcing fibres, by means of rovings, woven-fabric mats or prepregs). The mechanical properties of the corresponding weak point 31 (for example, deflection when loaded) can be substantially improved by optimum alignment of the reinforcing fibres and also through choice of the corresponding mesh width, without being tied to a specific winding angle.

3. As a result of the vacuum or vacuum die-casting technique, function elements (mechanical components such as, for example, bushes) in particular of the antenna (copper strips or bars, plates with conductive structures etc.) can be introduced within the wall in a defined manner at any radius. In particular when applying the HF-antenna to the surface, savings are made in terms of the subsequent adhesion, as currently carried out. Since the properties of the antenna can also greatly depend *inter alia* upon the radial distance to the patient and also to the surrounding HF-shield, optimization with regard to irradiation and shielding

of the HF-field can be effected by suitable placement of the antenna within the body-coil.

4. Capacitances of the HF-antenna can also be cast as concrete components (for example, capacitors) or as overlapping structures (for example, made of copper) and are protected in an optimum manner as a result against external arcing or other disturbing effects (such as, for example, corona discharges).

5. It may possibly be expedient or necessary to configure the electrical properties of the body-coil differently in regions. For example, dielectric losses can be kept low or the capacitive coupling of the HF-field to the patient can be improved by introducing locally, in the regions of high electric fields, material that has a small dielectric constant (for example, rigid foam with large closed pores). A procedure such as this can be carried out simply with the production method in accordance with the invention embodiments without weakening the (outer) layers that are important for the mechanical properties.

6. With the vacuum or vacuum die-casting technique, cooling elements can also be integrated simply. Thus, for example, plastics tubes for air-cooling or cooling tubes for cooling with MR-neutral liquids in the same way as copper pipes for water-cooling can be cast therein in a simple manner. Integrated cooling elements have a far higher degree of efficiency than cooling elements which are applied to the outer surface of the body-coil, as currently happens.

7. Furthermore, the vacuum or vacuum die-casting technology renders possible the integration of further function elements, such as rest-rails 33, applications

23, securing or bearing elements 22, and so on. Up until now such components have been adhered to the body-coil. Compared with adhesion, casting these components in the casting portion simplifies the manufacturing or assembly process and increases the mechanical strength. To this end, the components are secured during construction with adhesive tape or by being screwed to the shell or mandrel. It is also possible as well to accommodate the corresponding component in the mould (shell or mandrel).

The vacuum or vacuum die-casting technique for producing the body-coil 28 ultimately results in an MRT apparatus that is modified in accordance with the invention embodiments as shown in Figure 1. As a result of transforming the body-coil 28 in such a way, noise reduction is achieved. All in all, the manufacturing and assembly process is simplified with due regard to the acoustic limiting conditions and those of design technology.

List of reference numerals

1	Magnet body, basic field magnet
2	Gradient coil (GC)
3	x-coil
4	y-coil
5	z-coil
6	Support tube of the gradient coil
7	Supporting element
12	Magnet enclosure
13	High-frequency resonator (body-coil, BC) (HF-antenna on wound support tube)
14	Inside of magnet
15	Cold head
16	Support frame
17	Slide rail
18	Patient
19	Patient-rest
20	HF-shield
21	Interior space
22	Bearing integrated in the casting
23	Circumferential application
24	Bearing as an injection die-cast portion (adhered)
25	Threaded bush (made of brass)
26	Through-opening for adhesive
27	Undercut for rivet effect (to claw in the adhesive)
28	Vacuum-cast body-coil
29	Visual screening (made of thin plastics material)
30	Tongue
31	Thickening of material at point under great load
33	Rest-rail
34	Winding line for wound support tube according to prior art
35	Desired form (only possible with cast tube)

CLAIMS:

1. A nuclear spin tomography apparatus having a magnet body surrounded by a magnet enclosure which surrounds and delimits an interior space, wherein located in this interior space there is a gradient coil system and located in the latter in turn as an inner encapsulating cylinder there is a body-coil which has an HF-antenna and a support tube, and the magnet enclosure and the gradient coil system are closed off both visually and acoustically by the body-coil and a screen at the end faces and in the interior space, wherein the body-coil is of cast construction

2. A nuclear spin tomography apparatus according to claim 1, wherein the body-coil in total has a length that is greater than that of the gradient coil that lies behind it.

3. A nuclear spin tomography apparatus according to claim 1 or 2, wherein the body-coil is cast in such a way that it is widened in a funnel-shaped manner on one or on both end faces.

4. A nuclear spin tomography apparatus according to any of the preceding claims, wherein the body-coil has, in the lower region, tongues cast with the body-coil to form a unit.

5. A nuclear spin tomography apparatus according to any of the preceding claims, wherein the body-coil has, in the lower region, rest-rails cast with the body-coil to form a unit.

6. A nuclear spin tomography apparatus according to any of the preceding claims, wherein the body-coil has

function elements cast with the body-coil to form a unit.

7. A nuclear spin tomography apparatus according to any of the preceding claims, wherein function elements of the HF-antenna of the body-coil are cast in the interior of the body-coil at any radius.

8. A nuclear spin tomography apparatus according to any of the preceding claims, wherein cooling elements are cast in the body-coil.

9. A nuclear spin tomography apparatus according to any of the preceding claims, wherein material that has a small dielectric constant is introduced locally and cast in body-coil regions that have high electric field intensity.

10. A nuclear spin tomography apparatus according to any of the preceding claims, wherein mechanically weak regions of the surface of the body-coil are reinforced.

11. A nuclear spin tomography apparatus according to claim 10, wherein the reinforcement is already introduced into the casting mould before casting.

12. A nuclear spin tomography apparatus according to claim 10 to 11, characterised in that rovings and/or woven-fabric mats and/or prepregs are used for reinforcement purposes.

13. A nuclear spin tomography apparatus according to any of the preceding claims wherein the casting material is optimized by adding fillers.

14. A nuclear spin tomography apparatus according to any of the preceding claims, wherein capacitances of the HF-antenna are cast in the body-coil as concrete components or overlapping structures.

15. A nuclear spin tomography apparatus according to any of the preceding claims, wherein the body-coil is produced by means of a vacuum casting or vacuum die-casting method.

16. A method of producing a body-coil for a nuclear spin tomograpy apparatus wherein the body-coil is cast to include further components of the nuclear spin tomography apparatus with the casting.

17. A method according to claim 16, wherein the casting includes any of the further components defined in claims 4 to 14.

18. A body-coil of a nuclear spin tomography apparatus comprising an HF-antenna and a support tube, wherein the body coil is of cast construction.

19. A body-coil according to claim 18 further including any of the additional features of claims 3 to 14.

20. A nuclear spin tomography apparatus, body-coil of a nuclear spin tomography apparatus or method of producing a body-coil for a nuclear spin tomography apparatus substantially as described in the description and/or shown in Fig. 1.

Application No: GB 0310050.0
Claims searched: 1 to 20
Examiner: Peter Davies
Date of search: 27 January 2004

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A		US 5304932 (UNIVERSITY OF CALIFORNIA)
A		US 5841279 (GE YOKOGAWA)
A		US 5990681 (PICKER) - see liner 76
A		US 5374890 (PICKER) - see cosmetic sleeve 34

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{W}:

G1N

Worldwide search of patent documents classified in the following areas of the IPC^{7}:

G01R

The following online and other databases have been used in the preparation of this search report:

WPI, EPODOC, JAPIO, INSPEC, TXTE