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# D E C I S I O N
## of 15 July 1996

**Case Number:** T 0567/93 - 3.4.2

**Application Number:** 87101198.7

**Publication Number:** 0231879

**IPC:** G01N 24/06

**Language of the proceedings:** EN

**Title of invention:**
Self-shielded gradient coils for nuclear magnetic resonance imaging

**Applicant:**
GENERAL ELECTRIC COMPANY

**Opponent:**
-

**Headword:**
-

**Relevant legal provisions:**
EPC Art. 56 and 84

**Keyword:**
"Claims - clarity (yes)"
"Inventive step - (yes) after amendment"

**Decisions cited:**
-

**Catchword:**
-

Case Number: T 0567/93 - 3.4.2

# D E C I S I O N
## of the Technical Board of Appeal 3.4.2
## of 15 July 1996

**Appellant:** GENERAL ELECTRIC COMPANY
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**Decision under appeal:** Decision of the Examining Division of the European Patent Office posted 25 January 1993 refusing European patent application No. 87 101 198.7 pursuant to Article 97(1) EPC.

**Composition of the Board:**

**Chairman:** E. Turrini
**Members:** W. W. G. Hofmann
B. J. Schachenmann

## Summary of Facts and Submissions

I. The Appellant (Applicant) lodged an appeal against the decision of the Examining Division on the refusal of the application No. 87 101 198.7 (publication number 0 231 879).

The Examining Division had held that the application did not meet the requirements of Articles 52(1) and 56 EPC, having regard to the document

(D2) EP-A-0 167 243.

Further documents particularly considered during the examining procedure are

(D1) EP-A-0 140 259,
(D3) US-A-3 466 499 and
(D4) EP-A-0 216 590 (prior art under Article 54(3) EPC).

II. Oral proceedings were held at the end of which the Appellant requested that the decision under appeal be set aside and a patent granted on the basis of Claims 1 to 10 submitted at the oral proceedings, with the description and, if necessary, the drawings to be adapted.

III. The wording of the independent Claims 1, 8 and 10 according to the single request on file at the time of the present decision reads as follows:

"1. A coil system for producing a time changing substantially linear gradient magnetic field in an NMR apparatus comprising:
a first coil (20) adapted to be coupled to a source of current for providing a first surface current

distribution on the surface of a first cylinder having a radius $r_i$ and an axial length $2z_i$; and

a second coil (30) adapted to be coupled to a source of current for providing a second surface current distribution on the surface of a second cylinder substantially coaxial with said first cylinder and having a radius $r_0$ greater than $r_i$ and an axial length $2z_0$;

said first and second surface current distributions being concurrently designed and mutually providing a magnetic field having said gradient in a predetermined direction and a substantially constant value across the other two directions within the volume enclosed by said first coil and having a substantially zero value in the volume outside of said second coil, whereby

(a) a series of points is chosen as a representation of the desired gradient magnetic field in the imaging volume enclosed by the first coil near the origin and the further condition is imposed that the magnetic field is equal to zero outside the second coil,

(b) an initial inner coil length and an initial set of stream function coefficients to work with is selected, said stream function coefficients being defined as optimization parameters of the stream function of the first and second coil and describing the surface current distribution of the first and second coil,

(c) the magnetic field is calculated outside the second coil and at each selected point in the imaging volume enclosed by the first coil for each coefficient, and

(d) the coefficients are then modified to minimize the sum of the squares of the difference between the desired gradient magnetic field and the calculated gradient magnetic field in the volume enclosed by the first coil and to minimize the sum of the squares of the difference between the desired zero magnetic field and the calculated magnetic field outside the second coil to provide shielding such that the magnetic field in the volume outside the second coil has a substantially zero value."

"8. A magnetic resonance system comprising:
a main magnet (40) for establishing a uniform magnetic field in an imaging volume in the interior of said main magnet;
radio-frequency means (42) for pulsing said imaging volume with electromagnetic energy for stimulating nuclear magnetic resonance of nuclei within said imaging volume;
detecting means (43) for sensing the nuclear magnetic resonance of nuclei within said imaging volume; and
a coil system as defined in one of claims 1 to 7."

"10. A method for providing a coil system for producing a time changing substantially linear gradient magnetic field in an NMR apparatus comprising the steps of:
providing a first coil (20) adapted to be coupled to a source of current for providing a first surface current distribution on the surface of a first cylinder having a radius $r_i$ and an axial length $2z_i$; and
providing a second coil (30) adapted to be coupled to a source of current for providing a second surface current distribution on the surface of a second cylinder substantially coaxial with said first cylinder and having a radius $r_0$ greater than $r_i$ and an axial length $2z_0$;
determining said first and second surface current distributions by concurrently designing and mutually providing a magnetic field having said gradient in a predetermined direction and a substantially constant value across the other two directions within the volume enclosed by said first coil and having a substantially zero value in the volume outside of said second coil, by

(a) choosing a series of points as a representation of the desired gradient magnetic field in the imaging volume enclosed by the first coil near the origin and imposing the further condition that the magnetic field is equal to zero outside the second coil,
(b) selecting an initial inner coil length and an initial set of stream function coefficients to work with, said stream function coefficients being defined as optimization parameters of the stream function of the first and second coil and describing the surface current distribution of the first and second coil,
(c) calculating the magnetic field outside the second coil and at each selected point in the imaging volume enclosed by the first coil for each coefficient, and
(d) modifying the coefficients to minimize the sum of the squares of the difference between the desired gradient magnetic field and the calculated gradient magnetic field in the volume enclosed by the first coil and to minimize the sum of the squares of the difference between the desired zero magnetic field and the calculated magnetic field outside the second coil to provide shielding such that the magnetic field in the volume outside the second coil has a substantially zero value."

Claims 2 to 7 and 9 are respectively dependent on Claims 1 and 8.

IV. The Appellant substantially argued as follows:

As compared with D2, the present invention solves the problem of further reducing the magnetic field outside the coil system while less disturbing the linear gradient field in the interior of the coil system. For achieving this goal, particular surface current distributions of the first and second coils are determined. In Claims 1 and 10, these current distributions are defined through the process by which they are calculated. While D2 starts from the assumption that the distribution of the current in the shielding coil should be the same as that of the inner coil (apart from a scale factor), according to Claims 1 and 10 these current distributions are concurrently designed without any such preconditions. A set of parameters is chosen for describing the stream functions of the current distributions and a method of least square fit is used for determining the set of parameters for which the calculated magnetic field is optimally adapted to the desired ideal magnetic field distribution inside and outside the coil system. D2 is primarily concerned with NMR main magnets which produce a homogeneous field. As far as calculations are made for these magnets, they differ fundamentally from the present calculations, and for gradient coils no calculations are mentioned at all. Moreover, while according to D2 the windings of the coils are positioned on spherical surfaces, the present method of determining the current distributions opens up the way for choosing cylindrical surfaces for the coils, as specified in Claims 1 and 10. Spherical gradient coils would be very unpractical since gradient coils have to be positioned inside the main magnet and should not consume too much space.

The subject-matter of Claims 1 and 10 is novel over D4 since D4 designs its shielding coils according to a different principle and, moreover, needs two additional coils, instead of a single one, for shielding a gradient magnetic field.

## Reasons for the Decision

1. The appeal is admissible.

2. *Clarity of the claims*

Claim 1 is directed to a coil system for producing a gradient magnetic field in an NMR apparatus. It is in agreement with the indicated use in an NMR apparatus that the field to be produced is time changing and the gradient of the field is substantially linear ("linear gradient" being a term usual in NMR technics for indicating a linearly varying field distribution).

The surface current distributions of the two coils are defined by means of the method of determining them. The Board is satisfied that the complex distribution of the currents according to the invention, on the one hand, could not be expressed directly and, on the other hand, is a function of the method used for calculating it, and thus the indication of the method of calculation is an acceptable way of defining the surface current distributions.

The method of calculation refers to "stream function coefficients" ("optimization parameters") which are first selected and then modified to approximate the magnetic field calculated on the basis of these coefficients to the desired field distribution. In the Board's view the skilled reader understands that these coefficients are the coefficients of a series expansion describing the stream function, for which series expansion an example is given on page 9 of the description. The claim does not specify a particular type of series expansion for which the coefficients are defined. However, the Board has no reason to doubt the

Appellant's assertion that the specific type of series expansion used is not crucial for achieving an improved magnetic field distribution, ie for solving the problem of the invention.

Method Claim 10 contains essentially the same features as Claim 1, which features anyway have in part the character of method steps.

No questions arise with respect to the clarity of the remainder of the claims.

Thus, the claims are clear in the sense of Article 84 EPC.

3. *Amendments*

Present Claim 1 is essentially based on a combination of the original Claims 1, 2 and 5. Those further features which have additionally been inserted are originally disclosed as follows:

"Time changing gradient field": page 2, lines 10/11 and page 5, line 33 to page 6, line 1;
"substantially linear gradient": page 2, line 31;
"concurrently designed": page 9, lines 8 to 10;
"a series of points is chosen ... ": page 10, lines 3 to 5;
"the further condition is imposed that the magnetic field is equal to zero ...": page 6, lines 12/13;
"an initial inner coil length and an initial set of stream function coefficients ... is selected": page 10, lines 1 and 5 to 7;
"defined as optimization parameters ... describing the surface current distribution ...": page 9, lines 11, 17, 19, 24 and page 10, lines 1/2;

"the magnetic field is calculated outside the second coil and at each selected point in the imaging volume ... for each coefficient": page 6, lines 15 to 18; page 10, lines 7, 8 and 12;
"the coefficients are modified to minimize the sum of the squares ... substantially zero value": page 10, lines 8 to 12.

The added features in Claim 10 correspond to those of Claim 1.

The requirements of Article 123(2) EPC are therefore fulfilled.

4. *Novelty*

4.1 D2 (see in particular abstract; page 7, line 2 to page 8, line 6; Claims 1 and 3; Figures 2 to 4) describes a coil system for producing a magnetic field in an NMR apparatus which, in correspondence with the subject-matter of Claim 1, comprises a first coil 20, 22, 24 for providing a first surface current distribution on a first surface and a second coil 26, 28, 30 for providing a second surface current distribution on a second surface, the second surface being substantially coaxial with and having a greater radius than the first surface. The said surface current distributions are designed in dependence upon one another and "mutually" provide a magnetic field having substantially the desired distribution within the volume enclosed by the first coil and a substantially zero value in the volume outside of the second coil (see page 4, line 15 to page 5, line 18; page 10, line 28 to page 11, line 12; page 12, lines 24 to 27; page 14, line 7 to page 15, line 13; Figure 4). On page 18, lines 15 to 29, D2 indicates that the disclosed technique for cancellation of the external fields can also be used for producing the gradient fields required in NMR imaging (ie time changing fields having a substantially linear gradient) and cancelling the external fields thereof. (On pages 9 and 10, D2 also mentions a mathematical description of the field of two concentric solenoids, ie of a current distribution on first and second cylinders. However, this teaching relates to the production of a homogeneous central field and is not connected to the mention of gradient field production on page 18. There is no indication that the gradient field coils should be on cylindrical surfaces.)

Thus, the coil system according to Claim 1 differs from that according to D2 by the cylindrical shape of the first and second coil surfaces and by the distributions of the currents on the first and second surfaces. The method defined in Claim 1 for determining these current distributions comprises arranging the general expression for the two stream functions in a form involving coefficients which are then determined by a least square fit procedure of fitting the field distribution calculated for the generally expressed stream functions to the ideal field distribution (zero field outside the second coil, linear gradient in one direction within the first coil). There is no doubt that this method of calculation leads to current distributions basically different from those shown eg in Figure 2 of D2 (homogeneous internal field), and it must be noted that D2 does not show any current distributions or methods of calculating current distributions at all for the case of a gradient field.

4.2 D1 (see in particular abstract and Figure 11) describes a coil providing, on a cylindrical surface, a current distribution for producing a time changing linear gradient magnetic field in an NMR apparatus.

However, D1 neither mentions a second coil surrounding the first coil, nor specifically describes the form of the current paths or the method of calculating them.

4.3 D3 describes a coil system for producing a gradient magnetic field in the volume enclosed by a first coil provided on a first cylindrical surface, wherein the first coil is surrounded by a second coil on a second cylindrical surface and wherein the current distributions are such that the magnetic field outside of the second coil is substantially zero.

However, D3 does not relate to an NMR apparatus, but to a particle accelerator, so that the magnetic field in the inner volume is not oriented in the axial direction (as is necessary for NMR gradient fields), but vertically to the axial direction. Thus, the current distributions and the method of determining them are different from those according to Claim 1.

4.4 D4 constitutes prior art under Article 54(3) EPC, but only in so far as its content is covered by the oldest one of the three claimed priorities, ie the priority document GB 8 523 326 with the corresponding priority date of 20 September 1985. This prior art mentions a coil system for producing a time changing linear gradient magnetic field in an NMR apparatus comprising concentric coils on cylinders of different radii (see in particular in D4: page 1, lines 1 to 8; page 15, line 36 to page 16, line 26; Figure 15; and in the said priority document: page 1, lines 1 to 8; page 8, line 31 to page 9, line 21; Figure 15). This coil system is designed so that the field in the inner volume is substantially a linear gradient field and the field in the exterior volume is substantially zero.

However, for calculating the current distributions, D4 follows the principle of determining the currents induced in an assumed superconducting massive shield surrounding the first coil, in contrast to the least square fit method indicated in Claim 1. It is credible that the current distributions obtained according to Claim 1 constitute quite another approximation to the ideal distribution than those resulting from the calculations of D4.

4.5 The same considerations as above are also applicable with respect to device Claim 8 and method Claim 10. Claim 8 is directed to a magnetic resonance system which comprises the coil system defined in Claim 1 and thus has all the features specified in Claim 1 in addition to further features of the NMR apparatus. The features of Claim 10 substantially correspond to those of Claim 1.

The subject-matter of Claims 1, 8 and 10 is thus novel in the sense of Article 54 EPC.

5. *Inventive step*

5.1 Since D4 represents prior art under Article 54(3) EPC and is thus not to be considered in the judgment of inventive step, D2 is clearly the document closest to the present subject-matter.

As far as the current distributions to be used for active shielding of a magnetic field and the method of determining them are concerned, the only specifications given in D2 relate to the case of homogeneous internal fields (as required in the main magnet of an NMR apparatus). It is mentioned that these specifications can be adapted to the production of shielded gradient fields (page 18, lines 15 to 29), but no teaching is given as to how the adaptation is to be made.

Thus, the object of the present subject-matter is to provide a coil system for producing a magnetic field having a substantially linear gradient in the interior of the coil system and having a substantially zero value exterior of the coil system (see page 2, lines 29 to 33 of the description). (The reduction of the interaction between the main magnet and the gradient coils and the elimination of currents in the main magnet induced by the magnetic fields of the gradient coils, also mentioned in the paragraphs bridging pages 2 and 3 of the description, are only automatic consequences of the substantially zero external field.)

5.2 As already mentioned above, D2 does not give any teaching, apart from the general advice that adaptation to gradient fields is possible, how the current distribution of the gradient coils should be chosen. It thus remains to be examined whether the teaching given for homogeneous fields could lead a person skilled in the art to the solution according to present Claim 1.

The basic idea of D2 is (see page 4, line 15 to page 5, line 18 and page 7, lines 2 to 21) that each one of the first and second coils should be constructed so that each internal field is as ideally homogeneous as is realizable in practice. For an ideally homogeneous internal field the external field is an ideal dipole field. Therefore, if both coils are combined (with opposite orientation of the magnetic fields), the difference of the two internal homogeneous fields is again a homogeneous field, while the external dipole fields can be made to cancel out. Those higher orders of the external field which nevertheless exist may then also be suppressed to some degree. This principle has nothing in common with the principle on which present Claim 1 is based, ie performing a least square fit procedure for adapting the calculated total magnetic field for both coils to the desired total field. Thus, even apart from the fact that the step of adapting the construction principle of the set of homogeneous field coils to gradient coils is not disclosed in D2, no suggestion leading to the construction defined in Claim 1 can be derived from D2.

Moreover, it is not evident how the construction principle of D2 for homogeneous field coils would have to be adapted to gradient coils. This is the less evident since, for reasons of space requirement inside the main magnet, gradient coils are arranged on cylindrical surfaces (as specified in Claim 1), in contrast to the spherical surfaces shown eg in Figure 2 of D2. (On pages 9 and 10, D2 mentions two concentric long solenoids, but only as a mathematical model for didactic reasons. This model is not linked to and cannot provide a suggestion for the construction of a gradient coil set.)

5.3 Neither D1, nor D3 describes a least square fit procedure for determining the required surface current distribution. Moreover, D1 does not even relate to active shielding of the magnetic field and consequently mentions only a single coil on one surface, and D3 deals with particle accelerators requiring a direction of the magnetic field different from that of NMR gradient coils. Thus, these documents could not suggest a surface current distribution for the set of shielded gradient coils mentioned in D2.

The other documents cited in the search report are even less relevant.

5.4 Least square fit procedures may, quite in general, be a well known mathematical tool for approximating functions. However, it cannot be considered obvious to use this tool in a specific technical context, where the results to be expected cannot be easily assessed beforehand.

5.5 For these reasons, the subject-matter of Claim 1 involves an inventive step in the sense of Article 56 EPC. Claim 1 is therefore allowable (Article 52(1) EPC).

Since the independent Claims 8 and 10 contain substantially the same features as Claim 1 (Claim 8 even containing further features), the above argumentation applies to these claims as well. They are therefore also allowable.

Claims 2 to 7 and 9 are allowable due to their dependence on Claims 1 and 8, respectively.

6. The description needs adaptation to the claims and acknowledgment of the relevant prior art. Regarding compatibility with the claims, the attention of the Examining Division is drawn to the first example, given on page 7, line 22 to page 9, line 7, for the procedure of determining the surface current distribution.

In order to have the necessary amendments performed, the case is remitted to the Examining Division.

**Order**

**For these reasons it is decided that:**

1. The decision under appeal is set aside.

2. The case is remitted to the Examining Division with the order to grant a patent on the basis of Claims 1 to 10 submitted at the oral proceedings, with the description and, if necessary, the drawings to be adapted.

The Registrar: The Chairman:

E. Görgmaier E. Turrini