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(54) **Current-conductive coil and method for manufacturing the same.**

(57) A hollow conductor (22) which is rectangular in section is wound in a spiral to form a single pancake coil (20). A prepreg tape (40) is sandwiched between the already-wound portion (28) and the to-be-wound portion (30) of the conductor (22) when the conductor is wound. The single pancake coil (20) which has been wound with the prepreg tape (40) sandwiched is press-fixed by a metal frame, for example, and then heated, whereby resin impregnated in the prepreg tape is made liquid to fill between the overlapped faces of the conductor (22) so as to make the conductor (22) adhered at its overlapped faces and to electrically insulate one of the overlapped faces from the other. In the case of coaxially putting the single pancake coils (20) one upon the other to form a double pancake coil, a prepreg sheet (42) is sandwiched between the single pancake coils (20) and then heated to fix the single pancake coils with each other and to insulate the single pancake coils from each other.

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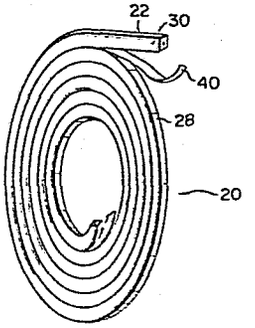

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Current-conductive coil and method for manufacturing the same

The present invention relates to a current-conductive coil of a direct cooling type which is used in diagnostic nuclear magnetic resonance devices, nuclear fusion research devices, and the like, and a method for manufacturing the same.

The current-conductive coil employed in diagnostic nuclear magnetic resonance devices, nuclear fusion research devices, and the like is an air core coil of a direct cooling type. In the case of this current-conductive air core coil of a direct cooling type, cooling water is flowed through the hollow portion of a coil conductor to remove heat caused by a current flowing through the coil conductor, thus cooling the coil conductor.

One unit of this current-conductive air core coil represents either the single pancake coil 2 as shown in Fig. 1 or the double pancake coil 4 as shown in Fig. 2. The single pancake coil 2 is constructed by winding a hollow conductor in a spiral and double pancake coil 4 is constructed by connecting pancake coils 6 and 8 at the inner ends thereof, said pancake 6 and 8 having been wound in opposite directions to form a spiral, respectively. The double pancake coil 4 may be constructed by winding a hollow conductor.

One coil unit is formed by piling several or ten

and several units of pancake coils one upon the other, and a plurality of these coil units is connected with one another to form a current-conductive air core coil. When the current-conductive air core coil is current-applied, cooling liquid is flowed through each unit of the pancake coil. The reason why water cooling system is provided for each unit of the pancake coil resides in equalizing the temperature distribution over the whole of the current-conductive air core coil to lower flow resistance in the cooling water passage and to enhance the cooling efficiency.

Diagnostic nuclear magnetic resonance devices and nuclear fusion research devices are demanded to use an equalized magnetic field. The strength of the magnetic field caused by the current-conductive air core coil is determined by the coil shape and the current flowing through the coil, while the uniformity thereof is determined by the coil shape. It is therefore necessary that the shape dimension of the coil product is accurate in order to make uniform the magnetic field caused by the current-conductive air core coil.

The conventional current-conductive coil is manufactured, as shown in Fig. 3, in such a manner that an insulating tape 12 is wound around a hollow conductor 10 in the process of winding the conductor 10, whose section is rectangular, in a spiral, and that the single or double pancake coil thus formed is fixed by fixing the conductor by prepreg. As described above, the troublesome process of winding the insulating tape 12 around the conductor 10 when the conductor is wound in a spiral is needed to insulate the conductor from its adjacent one. Therefore, the process of insulating the conductor from its adjacent one in the course of manufacturing the conventional current-conductive coil is a cause which makes it difficult to shorten its manufacturing time. A long air core coil conductor ranging from several hundred meters to several thousand

meters is used particularly by diagnostic nuclear magnetic resonance devices and nuclear fusion research devices, and the insulating process for the conductor used, accordingly, takes an extremely long time to manufacture.

The insulating tape 12 is wound around the conductor 10 in such a way that the insulating tape 12 is partly overlapped upon itself. Therefore, steps corresponding to the thickness of the overlapped insulating tape 12 are formed on the surface of the insulating tape wound around the conductor. The dimension accuracy of the single or double pancake coil thus wound is poor because of these steps, thus making it difficult to create a uniform magnetic field using the conventional current-conductive coil.

As shown in Figs. 3 and 4, a reliably sufficient insulation is achieved by winding the insulating tape 12 around the conductor 10. However, in the case of diagnostic nuclear magnetic resonance devices, a high degree of insulation is achieved, though the current flowing through the conductor is small. In short, the insulation process applied to the conventional conductor is more than enough in the case of diagnostic nuclear magnetic resonance devices.

An object of the present invention is to provide a current-conductive coil and a method for manufacturing the current-conductive coil, which simplifies its electrically-insulating process in order to substantially shorten its manufacturing time.

Another object of the present invention is to provide a current-conductive coil and a method for manufacturing the current-conductive coil, which enables its dimension accuracy to be made extremely high in order to create a highly-equalized magnetic field.

According to the present invention, there is provided a current-conductive coil comprising a conductor wound in a spiral and having a pair of inner

and outer fixing faces when viewed in the direction in which it is wound in a spiral, and a prepreg tape interposed between the adjacent fixing faces of the conductor, said prepreg tape having a width enough to cover the fixing face, extending along the fixing face, and being heated to fix the fixing faces so as to electrically insulate the fixing face of the conductor from its adjacent one.

Further, according to the present invention, there is provided a method for manufacturing the current-conductive coil comprising a first process of winding a conductor in a spiral and sandwiching a prepreg tape between the already-wound portion and to-be-wound portion of the conductor to form a single pancake coil, said prepreg tape having substantially same width as that fixing face of the already-wound portion of the conductor where the to-be-wound portion of the conductor is wound, and a second process of heating the single pancake coil, which has been wound with the prepreg tape sandwiched, under pressurized conditions to thereby fix the wound coil conductor and to insulate the fixing face of the conductor from its adjacent one.

Furthermore, according to the present invention, there is provided a current-conductive comprising two pancake coils each including a conductor wound in a spiral and having a pair of inner and outer fixing faces when viewed in the direction in which it is wound in a spiral, and a prepreg tape interposed between the adjacent fixing faces of the conductor, said prepreg tape having a width enough to cover the fixing face, extending along the fixing face, and being heated to fix the fixing faces so as to electrically insulate the fixing faces of the conductor from its adjacent one, the pancake coils having ring-shaped plain faces, and a prepreg sheet sandwiched between the two pancake coils which are coaxially put one upon the other with their wound-directions opposed to each other, said

prepreg sheet being heated to fix the pancake coils with each other and to electrically insulate the pancake coils from each other. This current-conductive coil can be manufactured by adding a third process between the first and the second processes, of coaxially putting the two single pancake coils, each of which has been wound with the prepreg tape sandwiched after the first process, one upon the other with a prepreg sheet sandwiched between them. Then, these two single pancake coils are heated under a pressurized condition in the second process. The current-conductive coil may also be manufactured by adding a fourth process of coaxially putting the two single pancake coils one upon the other with a prepreg sheet sandwiched between them, and a fifth process of heating the thus-formed two single pancake coils under pressurized condition.

According to the present invention, the troublesome process of winding the insulating tape around the conductor, as done conventionally to insulate the conductor from its adjacent one, is made unnecessary. Instead, the conductor may be wound with the prepreg tape sandwiched between the fixing face of the conductor wound and its adjacent one, thus enabling the current-conductive coil to be manufactured with greater ease and at a higher speed. In addition, the prepreg tape is only sandwiched between the conductor wound and its adjacent one, thus eliminating the steps which are conventionally formed by partly putting the insulating tape one upon the other when it is wound around the conductor. This enables the dimension accuracy of the coil wound to be made so high that a uniform magnetic field may be created. Further, the double pancake coils can be manufactured by putting the two single pancake coils one upon the other with the prepreg sheet sandwiched between them, and heating the prepreg sheet to fix the single pancake coils with each other and to insulate them from each other. The double

pancake coils can be thus manufactured more easily. In summary, the present invention enables the current-conductive coil to be manufactured with greater ease, at higher speed and with a lower cost in order that a uniform magnetic field may be created by the current-conductive coil.

This invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a perspective view showing a single pancake coil;

Fig. 2 is a perspective view showing a double pancake coil;

Fig. 3 is a perspective view showing the conventional method of manufacturing the current-conductive coil;

Fig. 4 is a perspective view showing the conventional current-conductive coil sectioned partly;

Fig. 5 is a perspective view showing a method for manufacturing the current-conductive coil according to the present invention;

Fig. 6 is a perspective view showing a single pancake coil sectioned partly;

Fig. 7 is a perspective view showing a process of insulating a double pancake coil; and

Fig. 8 is a sectional view showing a modification of the conductor.

Figs. 5, 6 and 7 show manufacturing processes of current-conductive coils embodied according to the present invention, in which Fig. 5 is a perspective view showing a process for winding the conductor, Fig. 6 a perspective view showing a single pancake coil sectioned partly, and Fig. 7 a perspective view showing an insulating process performed when single pancake coils are put one upon the other to make a double pancake coil.

A single pancake coil 20 shown in Fig. 5 includes

a hollow conductor 22 wound in a spiral, and a prepreg tape 40 interposed along the conductor 22 when this is wound. The conductor 22 has a substantially rectangular section, and a hollow portion 24 in the center of its section extending along its longitudinal axis and through which cooling water flows. Four corners of the conductor 22 are chamfered to form chamfered portions 26.

The prepreg tape 40 is prepared by cutting the prepreg in such a way that it is wide enough to cover the face of the conductor where the conductor is brought into contact with its adjacent inside one during the winding process. The prepreg itself is made by impregnating a sheet-shaped reinforcing material such as fabric, paper and mat with thermosetting resin. The thermosetting resin may be polyester, epoxydiaryl phthalate, phenol or solamine. The reinforcing material may be cloth of glass fabric, mat, rope, robe, paper, cotton fabric, nonwoven polyester fabric, or kraft paper. The glass cloth, for example, is immersed in epoxy resin liquid to impregnate both faces of the cloth with epoxy resin, thus making the prepreg. The prepreg is not sticky, and is easy to cut and treat. When the prepreg is heated under pressurized conditions, the resin impregnated in it becomes liquid to fill the space between the conductor and its adjacent inside one, and then hardens to fix the conductor.

When the hollow coil conductor 22 is wound in a spiral, it is wound with the prepreg tape 40 interposed between its already-wound portion 28 and its to-be-wound portion 30, as shown in Fig. 5. As the result, the prepreg tape 40 is sandwiched between the outer circumferential face (fixing or overlapping face) of its inside portion and the inner circumferential face (fixing or overlapping face) of its outside portion to cover the whole of each of these faces, so that the single pancake coil 20 in which its inside portion (or

already-wound portion) has been electrically insulated from its outside portion (or to-be-wound portion) can be obtained.

Two single pancake coils 20 are then coaxially put one upon the other with prepreg sheets 42 sandwiched between them. In this case, however, the direction in which one of the pancake coils 20 is wound is made opposite to that of the other. The prepreg may be cut in a ring and then arranged on one of the pancake coils 20. However, it is preferable that the prepreg be cut into four prepreg sheets 42, for example, corresponding to the shape devided from the ring-shaped plain face of the pancake coil 20, and that these four prepreg sheets 42 are connected with one another in the circumferential direction of the pancake coil 20 and then arranged thereon. The dimension errors relating to the plain face of the pancake coil 20 and the shape of the prepreg sheets can be thus absorbed by the manner of arranging four prepreg sheets 42 on the plain face of the pancake coil 20. As a result, the plan face of the pancake coil 20 can be covered completely by the prepreg sheets 42 to thereby insulate one of the pancake coils 20 from the other electrically.

These two pancake coils 20 are then fixed under a pressurized condition by means of a tool such as a metal frame. The pancake coils 20 thus pressurized and fixed are heated and dried in a heating furnace such as an electric furnace. The resin impregnated in the prepreg tape 40 and sheets 42 thus becomes liquid to fill the spaces between the inner and outer circumferential faces of the conductors 22 and also between the pancake coils 20. As it hardens, insulating layers of resin are formed between the circumferential faces of the conductors 22, and between the plain faces of the pancake coils 20 to fix the conductors 22.

When a prepreg made by impregnating glass cloth with epoxy resin is used, the resin becomes hardened by

heating the prepreg at 130 to 150°C for 8 to 10 hours. On the other hand, when another prepreg made by impregnating unwoven polyester fabric with epoxy resin is used, the resin becomes hardened by heating the prepreg at 120°C for two hours.

The conductor 22 has chamfer portions 26 formed at the four corners thereof, and these chamfer portions 26 serve as passages through which the heated resin moves and through which the excessive resin escapes, thus enabling the insulating layer of resin to be uniform. Even if any error is caused when the prepreg is cut to a tape 40 or even if any positional error is caused when the conductor 22 is wound, the conductor 22 is separated from its adjacent inside and outside ones at their chamfer portions, thus preventing any insulating trouble from happening.

The thickness of the prepreg tape 40 or sheet 42 is determined by voltages applied to the coil line and between the pancake coil lines. In the case of the hollow coil employed in the diagnostic nuclear magnetic resonance device, for example, it is enough to create a magentic field of several kilo-gausses. Therefore, a voltage of only several tens volts is applied between the pancake coils. Since the insulating resistance of epoxy resin is larger than 10^{14} Ωcm when expressed by the ratio of volume resistance, resistance larger than 30 MΩ can be obtained when the area of the resin layer is $10^4 \pi\ cm^2$ and its thickness is 0.1 mm. Therefore, the prepreg layer, about 0.1 mm thick, is enough to serve as the insulator in the above application. The prepreg tape 40 or sheet 42 whose thickness is larger than 0.1 mm is usually employed, taking safety into consideration. In the case of the prepreg impregnated with epoxy resin, resistance larger than 100 MΩ can be obtained at a common temperature when the prepreg tape or sheet whose thickness is 0.32 mm is used. When it is intended to form a layer of prepreg whose thickness is

0.6 mm, for example, it is preferable that prepreg tapes or sheets of 0.3 mm thick are used in an overlapped manner rather than the prepreg tapes or sheets of 0.6 mm thick. This is becuase even if one of the prepreg tapes is slightly shifted from the circumferential face of the conductor 22, some portions of the circumferential face are left uncovered. However, when the tape is overlapped on the circumferential face, the other tape can cover these uncovered portions to secure insulation between the circumferential face and its adjacent one. It is also preferable that the outermost circumferential face of the conductor is covered by a prepreg tape whose thickness is 0.5 mm so as to establish higher insulation, becuase the outermost circumferential face of the conductor is likely to be subjected to severe circumstances.

It is relatively easy to obtain a coil conductor whose shape dimension is highly accurate, and a prepreg tape or sheet whose thickness is highly accurate. According to the present invention, the conductor is not wound by the insulating tape, but the prepreg tape 40 is overlapped onto the circumferential face of the conductor 22, thus enabling the insulating layer to be high in its dimension accuracy. Therefore, the dimension accuracy of the current-conductive coil is high. The diameter of the finished coil is different by only about 2 mm from the desired diameter even if the coil is a large-sized hollow coil for use in diagnostic nuclear magnetic resonance devices. When the current-conductive coil according to the present invention is used, therefore, a uniform magnetic field can be created. In addition, the insulating process is easily done in the case of the method for manufacturing the current-conductive coil according to the present invention, thus allowing the current-conductive coil to be manufactured with more simplicity and at higher speed.

Two pancake coils 20 are press-fixed with the prepreg sheets 42 interposed between them, and then heated to make the conductors adhere as in the above-described embodiment. However, each of the single pancake coils may be formed and then heated to make the conductors also adhere, and the two pancake coils 20 can be press-fixed with the prepreg sheets 42 sandwiched between them, and then heated to make these two pancake coils 20 adhere to each other. The conductor is not limited to having a rectangular section; it may also be flat in section, as shown in Fig. 8. In short, it may have a linearly-extending portion at the edge of that area where its inner and outer sections 32 and 34 are opposed face to face. Further, its hollow portion 24 through which the cooling water flows is not limited to having a circular section; it may also be rectangular in section, as shown in Fig. 8.

The pancake coils press-fixed by metal frame have been heated in a heating furance in the above-described embodiment. However, the resin may be heated by that resistance heat of the conductors themselves which is caused by applying current to the conductors in the pancake coils which have been press-fixed by a metal frame.

Claims:

1. A current-conductive coil comprising:

a conductor (22) wound in a spiral and having a pair of inner and outer fixing faces when viewed in the direction in which the conductor is wound in a spiral; characterized by comprising

a prepreg tape (40) interposed between the adjacent fixing faces of the conductor (22), said prepreg tape (40) being wide enough to cover the fixing face, extending along the fixing face, and being heated to fix the fixing faces so as to electrically insulate the fixing face of the conductor from its adjacent one.

2. A current-conductive coil according to claim 1, characterized in that the conductor (22) has a rectangular section.

3. A current-conductor coil according to claim 2, characterized in that the conductor (22) has chamfer portions (26) formed at its four corners.

4. A current-conductive coil according to claim 1, characterized in that the prepreg tape (40) is made by impregnating a reinforcing sheet with thermosetting resin, the resin being made liquid to fill between the fixing faces and then hardened to fix said fixing faces when it is heated.

5. A current-conductive coil according to claim 4, characterized in that said reinforcing sheet is of glass fabric cloth, and the thermosetting resin is of epoxy.

6. A current-conductive coil comprising:

two pancake coils (20) each including a conductor (22) wound in a spiral and having a pair of inner and outer fixing faces when viewed in the direction in which the conductor is wound in a spiral;

characterized in that the two pancake coils (20) each including a prepreg tape (40) interposed between the adjacent fixing faces of the conductor, said prepreg tape (40) having a width enough to cover the

fixing face, extending along the fixing face, and being heated to fix the fixing faces so as to electrically insulate the fixing faces of the conductor from its adjacent one; and ring-shaped plain faces, and

characterized by comprising a prepreg sheet (42) sandwiched between the two pancake coils (20) which are coaxially put one upon the other with their wound-directions opposed to each other, said prepreg sheet (42) being heated to fix the pancake coils (20) with each other and to electrically insulate the pancake coils from each other.

7. A current-conductive coil according to claim 6, characterized in that the conductor (22) has a rectangular section.

8. A current-conductive coil according to claim 7, characterized in that the prepreg sheet (42) consists of four portions which are laid on the ring-shaped plain face of the pancake coil (20), and are arranged in the circumferential direction of the pancake coil.

9. A current-conductive coil according to claim 8, characterized in that the conductor (22) has a rectangular section.

10. A current-conductive coil according to claim 9, characterized in that the conductor (22) has chamfer portions (26) formed at its four corners.

11. A current-conductive coil according to claim 10, characterized in that the prepreg tape (40) and sheet (42) are made by impregnating a reinforcing sheet with thermosetting resin, the resin being made liquid to fill between the fixing faces and also between the pancake coils and then hardened to fix the fixing faces with each other and also the pancake coils with each other, when it is heated.

12. A current-conductive coil accoding to claim 11, characterized in that the reinforcing sheet is of glass fabric cloth and the thermosetting resin is of epoxy.

13. A method for manufacturing the current-conductive coil characterized by comprising:

a first process of winding a conductor (22) in a spiral and sandwiching a prepreg tape (40) between the already-wound portion (28) and to-be-wound portion (30) of the conductor (22) to form a single pancake coil (20), said prepreg tape (40) having substantially same width as that fixing face of the already-wound portion (28) of the conductor where the to-be-wound portion (30) of the conductor is wound; and

a second process of heating the single pancake coil (20), which has been wound with the prepreg tape (40) sandwiched, under a pressurized condition to fix the wound conductor and to insulate the fixing face of the conductor from its adjacent one.

14. A method of manufacturing the current-conductive coil according to claim 13, characterized by further comprising a third process betwteen the first and the second process, of coaxially putting two single pancake coils (20), each of which has been wound with prepreg tape sandwiched after the first process, one upon the other with a prepreg sheet (42) interposed between them, and characterized in that in said second process these two single pancake coils (20) are heated under a pressurized condition to fix the coil conductor itself and the single pancake coils to each other and to electrically insulate the fixing face of the conductor from its adjacent one and one of the single pancake coils (20) from each other.

15. A method for manufacturing the current-conductive coil according to claim 13, characterized by further comprising:

a fourth process of coaxially putting two single pancake coils (20), each of which has been heated under a pressurized condition after the second process, one upon the other with a prepreg sheet (42) sandwiched between them; and

a fifth process of heating the thus-overlapped two single pancake coils (20) under a pressurized condition to fix the single pancake coils (20) with each other and to electrically insulate the single pancake coils (20) from each other.

16. A method according to claim 14, characterized in that the prepreg tape (40) and sheet (42) are made by impregnating a reinforcing sheet with thermosetting resin, the resin being made liquid to fill between the fixing faces of the conductor and also between the pancake coils, and then hardened to fix the fixing faces of the conductor and also the pancake coils with each other, when it is heated.

17. A method according to claim 16, characterized in that the reinforcing sheet is of glass fabric cloth and the thermosetting resin is of epoxy, and the heating temperature ranges from 130°C to 150°C while the heating time ranges from 8 to 10 hours.

18. A method according to claim 14, characterized in that the prepreg sheet consists of four portions (42) which are laid on the ring-shaped plain face of the pancake coil (20) and are arranged in the circumferential direction of the pancake coil.

FIG. 1

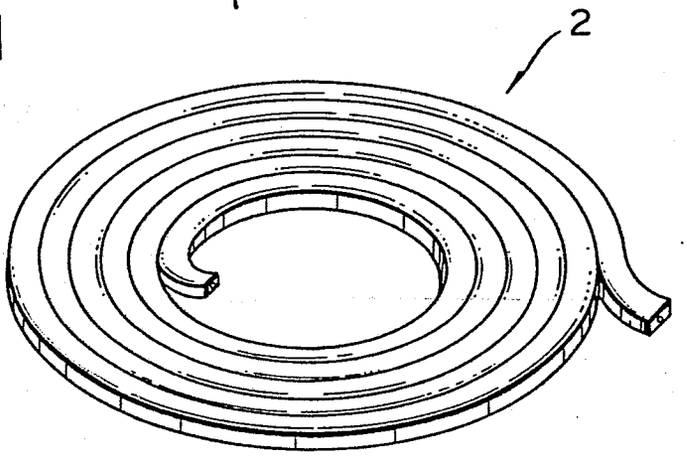


FIG. 2

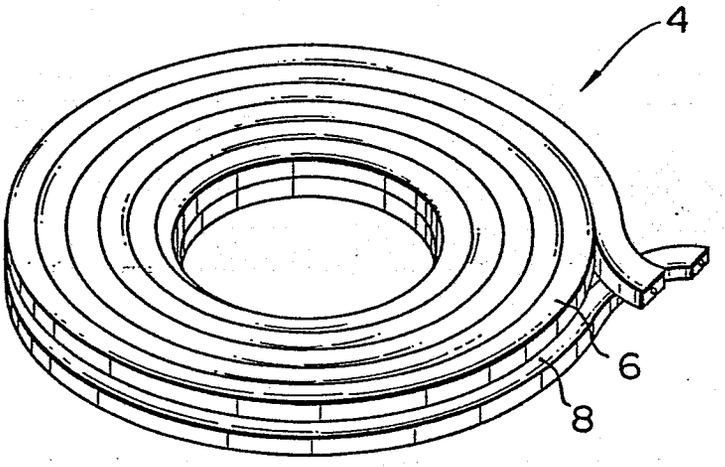


FIG. 3

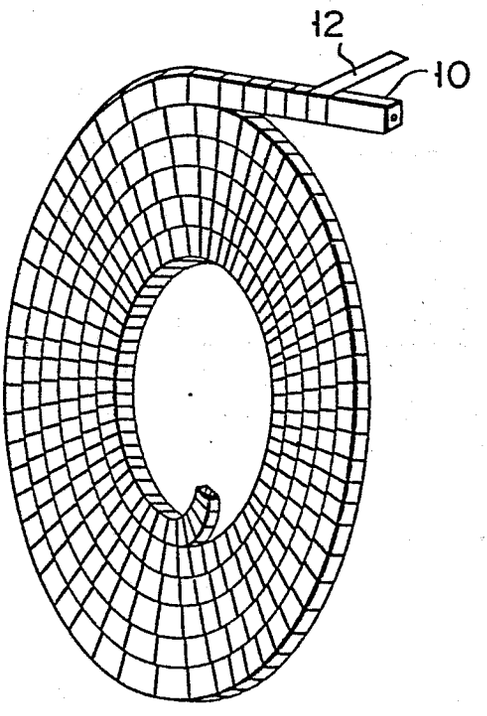


FIG. 4

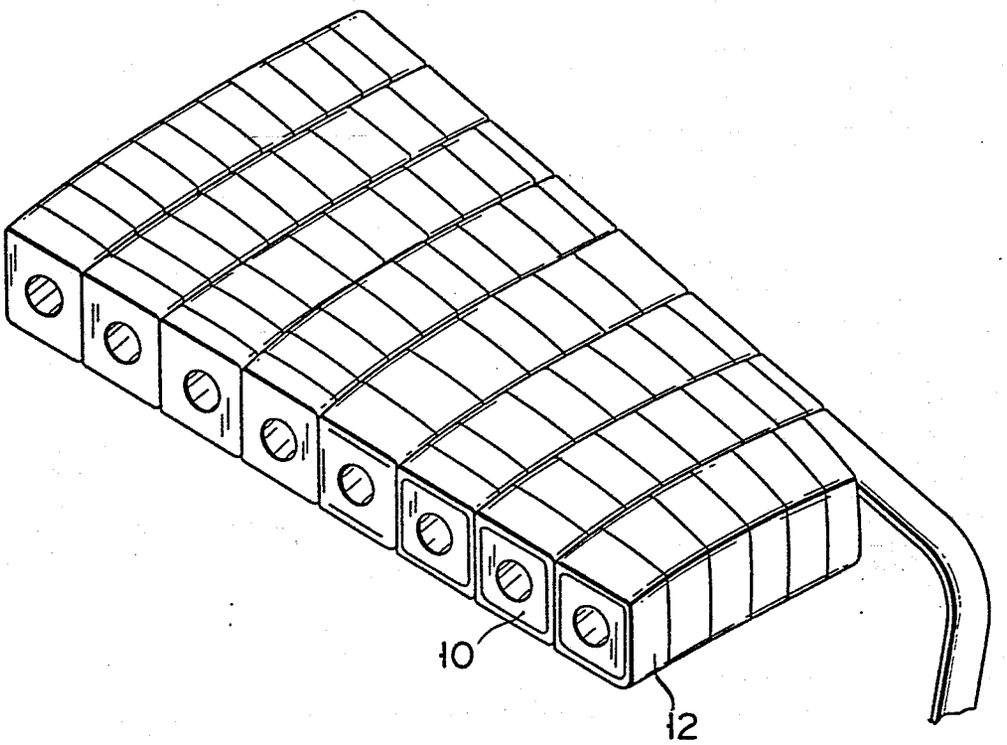


FIG. 5

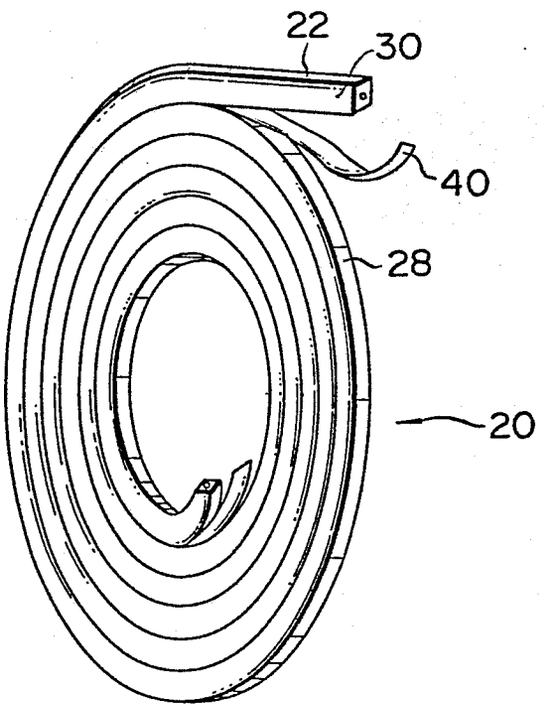


FIG. 6

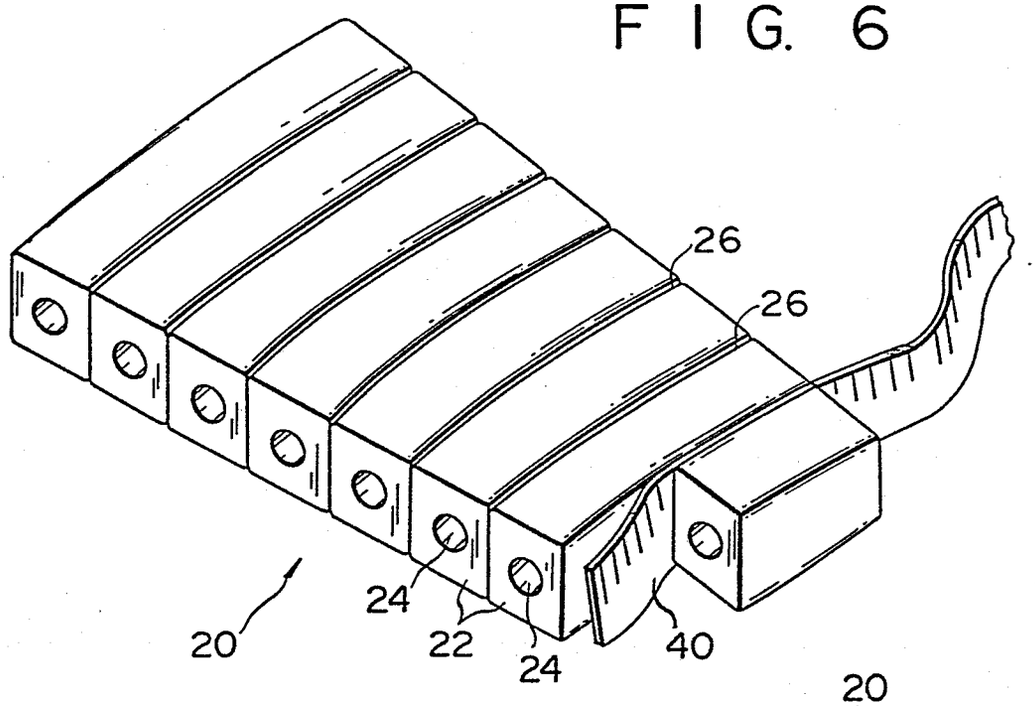


FIG. 7

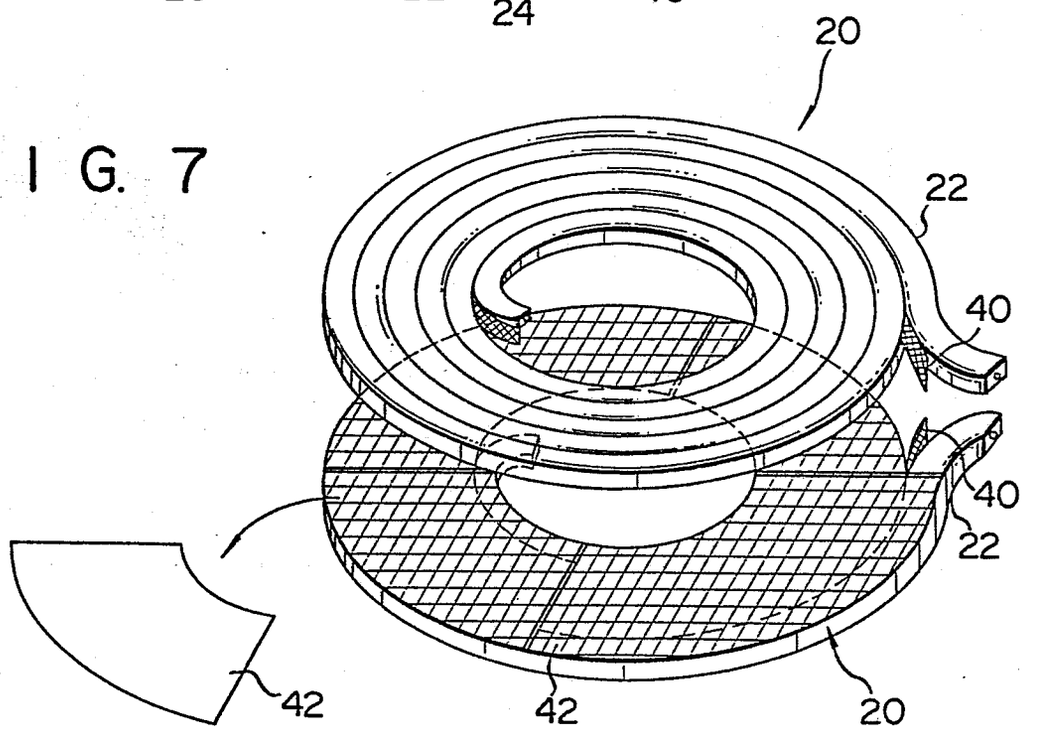
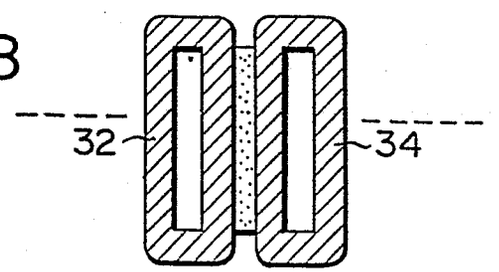


FIG. 8



0116367
Application number
EP 84 10 1233

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EUROPEAN SEARCH REPORT

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. ³)
X	AU-B- 521 297 (THE ENGLISH ELECTRIC CO.) * Page 7, last paragraph; page 9 * ---	1,4,5, 13	H 01 F 41/12 H 01 F 5/06
Y	PATENTS ABSTRACTS OF JAPAN, vol. 6, no. 123 (E-117)[1001], 8th July 1982 & JP - A - 57 52 107 (TOKYO SHIBAURA DENKI K.K.) 27-03-1982 * Abstract * ---	1-5,13	
Y	PATENTS ABSTRACTS OF JAPAN, vol. 3, no. 13 (E-88), 7th February 1979, page 115 E 88 & JP - A - 53 141 401 (HITACHI SEISAKUSHO K.K.) 09-12-1978 * Abstract * ---	1-5,13	
A	PATENTS ABSTRACTS OF JAPAN, vol. 5, no. 40 (E-49)[712], 17th March 1981 & JP - A - 55 163 812 (MITSUBISHI DENKI K.K.) 20-12-1980 ---		H 01 F 41/00 H 01 F 5/00 H 01 F 27/00
A	PATENTS ABSTRACTS OF JAPAN, vol. 7, no. 21 (E-155)[1166], 27th January 1983 & JP - A - 57 180 104 (NIPPON GENSHIRYOKU KENKYUSHO) 06-11-1982 ---		
A	EP-A-0 030 338 (ASEA) --- -/-		

TECHNICAL FIELDS SEARCHED (Int. Cl. ³)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	15-05-1984	VANHULLE R.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
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Application number

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EP 84 10 1233

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. ³)
A	US-A-3 068 433 (SYLVANIA)		
A	US-A-1 389 149 (WESTINGHOUSE)		
A	US-A-3 868 766 (FORD MOTOR CO.)		
A	DE-B-1 049 007 (OERLIKON)		
A	GB-A- 715 226 (DOWTY EQUIPMENT LTD.)		

TECHNICAL FIELDS SEARCHED (Int. Cl. ³)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	15-05-1984	VANHULLE R.

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