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(12) (19) (CA) **Demande-Application**

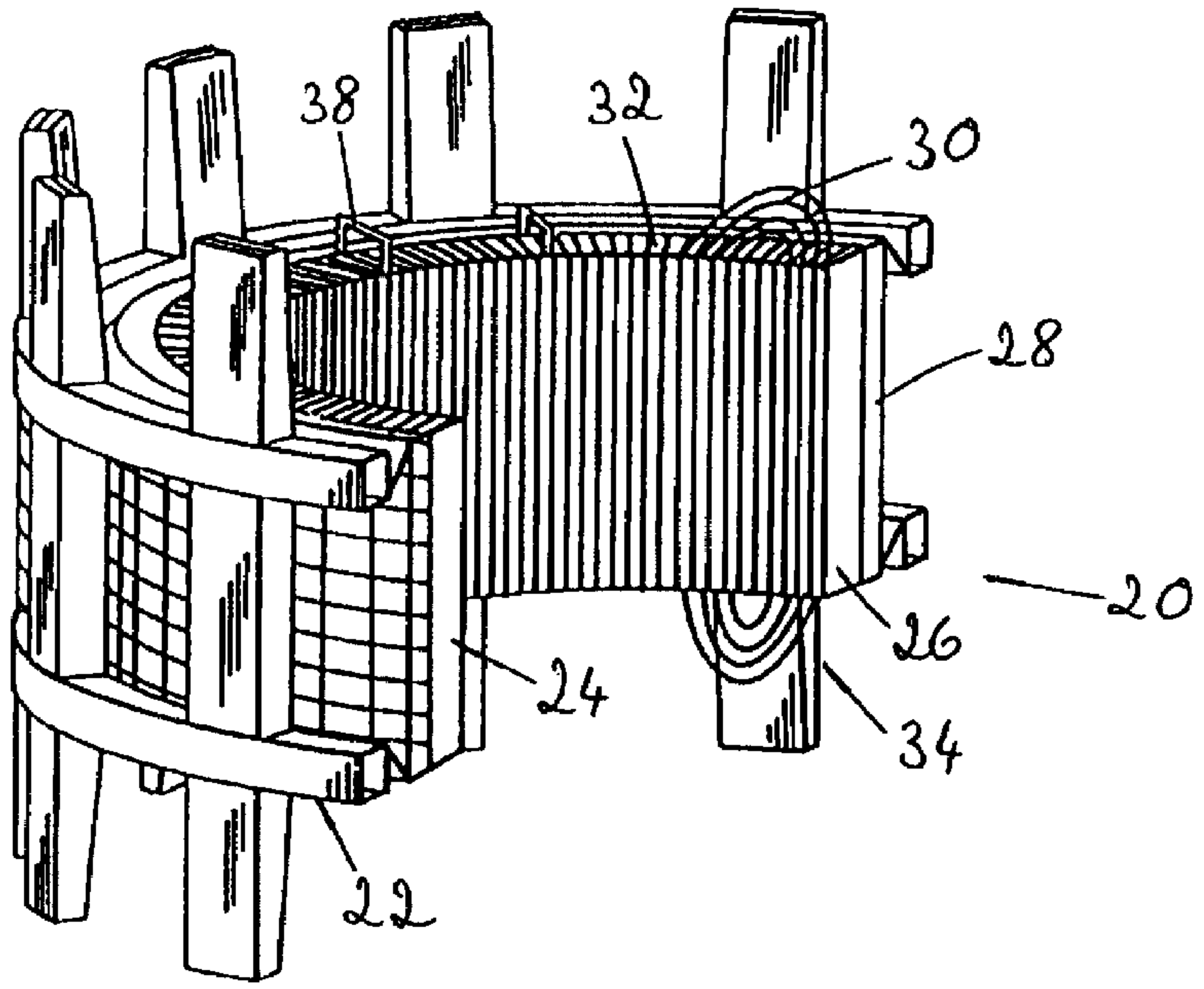
(21) (A1) **2,309,978**
(86) 1998/11/27
(87) 1999/06/10

(72) LEIJON, MATS, SE
(72) CARSTENSEN, PETER, SE
(71) ABB AB, SE

(51) Int.Cl.^{6} H02K 3/30, H02K 3/38
(30) 1997/11/28 (9704452-3) SE

(54) PROCEDE DE REPARATION D'UN SYSTEME D'ENROULEMENT, COMPRENANT L'EPISSAGE D'UN CABLE HAUTE TENSION

(54) A METHOD OF REPAIRING A WINDING SYSTEM INCLUDING SPLICING A HIGH-VOLTAGE CABLE



(57) L'invention concerne un procédé de réparation d'un système d'enroulement dans une machine électrique tournante à haute tension, laquelle est conçue pour être connectée directement à un réseau de distribution ou de transmission et comporte un stator (20), un rotor et des enroulements (30) intégrés au système d'enroulement. Les enroulements (30) comprennent des câbles haute tension qui maintiennent sensiblement le champ électrique dans les enroulements (30). Ledit procédé consiste, en cas d'endommagement du câble haute tension, à épisser le câble haute tension de sorte qu'au moins une partie d'au moins un coude de la tête de bobine d'origine soit converti en au moins une partie sensiblement droite après l'épissage, au moins un joint étant placé à l'extérieur du faisceau de la tête de bobine d'origine, l'épissage s'effectuant sans démontage de la machine électrique tournante.

(57) The present invention relates to a method of repairing a winding system in a rotary electric machine for high voltages, which machine is designed for direct connection to a distribution or transmission network and comprises a stator (20), a rotor and windings (30) included in the winding system. The windings (30) comprise high-voltage cables that substantially contain the electric field in the windings (30). The method comprises the step of, in the event of damage to the high-voltage cable, splicing the high-voltage cable in such a manner that at least one part of at least one original coil-end bend is converted to at least one substantially straight portion after the splicing, wherein at least one join is arranged outside the original coil-end bundle, which splicing is performed without dismantling the rotary electric machine.

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ^{6} : H02K 3/30, 3/38

A1

(11) International Publication Number: WO 99/29016

(43) International Publication Date: 10 June 1999 (10.06.99)

(21) International Application Number: PCT/SE98/02164

(22) International Filing Date: 27 November 1998 (27.11.98)

(30) Priority Data:
9704452-3 28 November 1997 (28.11.97) SE

(71) Applicant *(for all designated States except US)*: ASEA BROWN BOVERI AB [SE/SE]; S-721 28 Västerås (SE).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: LEIJON, Mats [SE/SE]; Hyvlargatan 5, S-723 35 Västerås (SE). CARSTENSEN, Peter [DK/SE]; Sjövägen 62, S-141 42 Huddinge (SE).

(74) Agents: ASKERBERG, Fredrik et al.; L.A. Groth & Co. KB, P.O. Box 6107, S-102 32 Stockholm (SE).

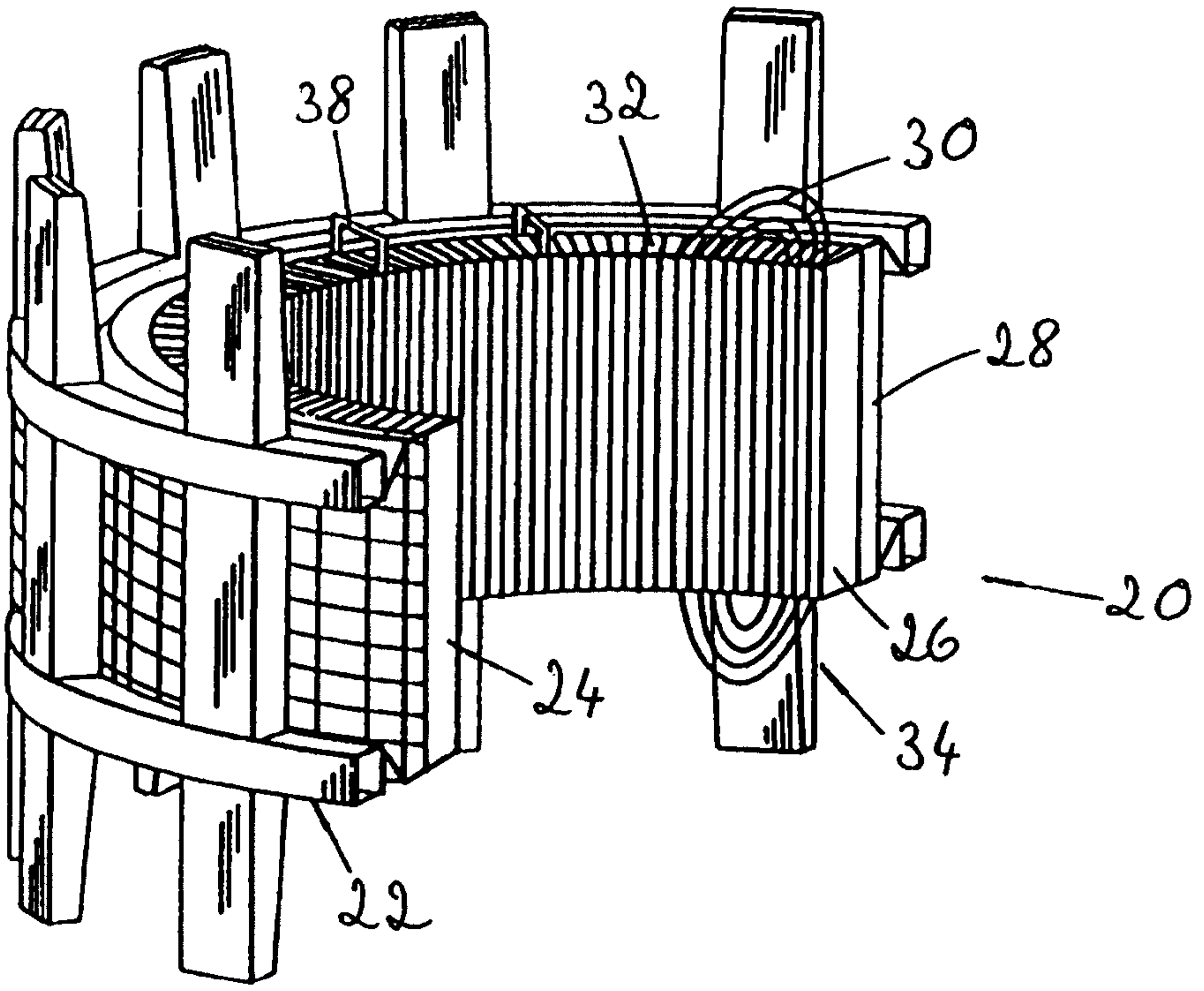
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, ES, FI, FI (Utility model), GB, GD, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: A METHOD OF REPAIRING A WINDING SYSTEM INCLUDING SPLICING A HIGH-VOLTAGE CABLE

(57) Abstract

The present invention relates to a method of repairing a winding system in a rotary electric machine for high voltages, which machine is designed for direct connection to a distribution or transmission network and comprises a stator (20), a rotor and windings (30) included in the winding system. The windings (30) comprise high-voltage cables that substantially contain the electric field in the windings (30). The method comprises the step of, in the event of damage to the high-voltage cable, splicing the high-voltage cable in such a manner that at least one part of at least one original coil-end bend is converted to at least one substantially straight portion after the splicing, wherein at least one join is arranged outside the original coil-end bundle, which splicing is performed without dismantling the rotary electric machine.



A method of repairing a winding system including splicing a high-voltage cable.

The present invention relates to a method of repairing a winding system in a rotary electric machine for high voltages, which machine is designed for direct connection to a distribution or transmission network.

The rotary electric machines to which the present invention relates may be e.g. synchronous machines, asynchronous machines, dual-fed machines, asynchronous static current converter cascades, external pole machines or synchronous flow machines.

Transformers for stepping up the voltage to the level of the network, i.e. in the range of 130-400 kV, have been used hitherto in order to connect machines of this type to distribution or transmission networks.

Generators having a rated voltage of up to 36 kV are described by Paul R. Siedler in an article entitled "36 kV Generators Arise from Insulation Research", Electrical World, 15 October 1932, pages 524-527. These generators comprise windings of high-voltage cable in which the insulation is divided into various layers having different dielectric constants. The insulating material used consists of various combinations of the three components mica-foil-mica, varnish and paper.

It has now been discovered that by manufacturing windings for the machines mentioned in the introduction out of an insulated electric high-voltage conductor with solid insulation of a type similar to cables for power transmission, the voltage of the machine can be increased to such levels that the machine can be connected directly to the power network without any intermediate transformer. A typical operating range for these machines may be 36 to 800 kV.

The insulated conductor or high-voltage cable used in the present invention is flexible and of a type described in more detail in PCT applications SE97/00874 and SE97/00875. The insulated conductor or cable is described further in PCT applications SE97/00901, SE97/00902 and SE97/00903.

Thus in the context of the invention the windings are preferably of a type equivalent to cables having solid extruded insulation which are currently used for power distribution, e.g. XLPE cables or cables with EPR insulation. Such a cable comprises an inner conductor composed of one or more strand-parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding the semiconducting layer and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the device according to the invention is based primarily on winding systems in which the winding is formed using conductors that are bent during assembly. The flexibility of a XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term “flexible” is used to indicate that the winding is flexible down to a radius of curvature in the order of 4 times the cable diameter, preferably 8 - 12 times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the layers becoming detached from each other.

The material combinations stated above should be considered only as examples. Other combinations fulfilling said conditions and the condition of being semiconducting, i.e. having a resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentane (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not, at least in the proportions required to achieve the conductivity required according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymer/nitrile rubber, butylymp polyethylene, ethylene-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have rather good elasticity with an E-modulus of < 500 MPa, preferably < 200 MPa.

The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks or other damage appear and so that the layers are not released from each other. The material in the layers is elastic and the adhesion between the layers is at least of the same order of magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalise the potential along each layer. The conductivity of the outer semiconducting layer is so great that the outer semiconducting layer has sufficient conductivity to contain the electric field in the cable, but at the same time small enough not to give rise to significant losses as a result of currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and the winding composed of these layers will substantially contain the electric field within it.

There is of course nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

Different types of damage occur in rotary electric machines of different types. In the case of hydropower generators most breakdowns occur in the stator, primarily in the stator winding. Damage in the stator is divided relatively evenly between insulation and soldered joints. Damage to the rotor derives in the majority of cases from earth faults in the rotor circuit due to fouling.

When disruptive discharge occurs in a rotary electric machine the winding is often damaged and must be repaired. In a rotary electric machine of conventional type such repairs to the winding often necessitate the stator or rotor being dismantled and consequently shutdown for a longer or shorter period. This is therefore a considerable drawback.

The object of the present invention is to provide a solution to the problems mentioned above. This is achieved with a method of repairing a winding system in a rotary electric machine for high voltages as defined in claim 1. The method is applicable to a machine designed for direct connection to a distribution or transmission network. The machine comprises a stator with slots for windings, a rotor and windings included in the winding system, wherein the windings comprise high-voltage cables that substantially contain the electric field in the windings. The method comprises the step of, in the event of damage to the high-voltage cable, splicing the high-voltage cable in such a manner that at least one part of at least one original coil-end bend is converted to at least one portion comprising a join after the splicing, wherein at least one join is arranged outside the original coil-end bundle, which splicing is performed without dismantling the rotary electric machine.

The great advantage of the method as claimed in the present invention is that the winding system can be repaired without the rotary electric machine being dismantled. The shut-down is thus considerably shorter than is the case with conventional rotary electric machines.

An advantageous embodiment of the method in accordance with the invention is obtained in cases when the damage is along a coil-end bend if the method also comprises the steps of:

- cutting the high-voltage cable to obtain two ends;
- removing the high-voltage cables with the two ends from at least one slot each;
- cutting the high-voltage cable to remove the damaged part and thereby obtaining an end;
- splicing a length of the high-voltage cable onto one of the ends;
- inserting the high-voltage cable with the splicing length into the empty slots; and
- joining together the loose ends thus obtained, so that the winding is without a break.

Another advantageous embodiment of the method in accordance with the invention is obtained in cases when the damage is not located along the coil-end bundle, if the method also comprises the steps of:

- cutting the high-voltage cable to remove the damaged part, thereby obtaining two ends;
- removing the high-voltage cables with the two ends from at least one slot each;
- joining a splicing length of the high-voltage cable in the empty slots; and
- joining together the two ends thus obtained, so that the winding is without a break.

In this connection it is an advantage if splicing is performed in the form of fully vulcanised joins.

Another advantage is gained if the joins are performed using prefabricated splicing lengths.

It is also an advantage if splicing is performed in the form of tape-wound joins.

An additional advantage is gained if the tape-wound joins are performed using self-vulcanising tape, e.g. EPDM tape.

In this connection it is advantageous for splicing to be performed using a combination of the alternatives mentioned above.

A further advantage is gained in cases when the high-voltage cable comprises an electric conductor, a first semiconducting layer surrounding the conductor, an insulating layer surrounding the first semiconducting layer, and a second semiconducting layer surrounding the insulating layer if, depending on the type of damage, the method also comprises at least one of the steps of:

- splicing the electric conductor;
- applying replacement material for the first semiconducting layer (14);
- performing vulcanisation of the first semiconducting layer (14);
- applying replacement material for the insulating layer;
- performing vulcanisation of the insulating layer;
- restoring the vulcanised insulating layer to substantially its original dimension;
- applying replacement material for the second semiconducting layer;
- performing vulcanisation of the second semiconducting layer.

In this connection it is an advantage for the winding to be a flexible winding and for its layers to adhere to each other.

A further advantage is for said layers to be of materials having such elasticity and coefficients of thermal expansion in relation to each other that the changes in volume occurring in the layers during operation as a result of temperature fluctuations can be absorbed by the elasticity of the materials so that the layers retain their adhesion to each other at the temperature fluctuations occurring during operation.

It is advantageous for the materials in the layers to have high elasticity, preferably with an E-modulus of less than 500 MPa, most preferably less than 200 MPa.

An additional advantage is for the coefficients of thermal expansion for the materials in said layers to be substantially equal.

In connection with this it is an advantage for the adhesion between the layers to be at least of the same order of magnitude as in the weakest of the materials.

Another advantage is for each semiconducting layer to constitute substantially one equipotential surface.

The invention will now be explained in more detail in the following description of preferred embodiments thereof, with reference to the accompanying drawings.

Figure 1	shows a cross section through a high-voltage cable;
Figure 2	shows a schematic view in perspective of a section diagonally through the stator of a rotary electric machine;
Figure 3	shows schematically a sector of a rotary electric machine;
Figure 4	shows a flow chart of a method in accordance with the present invention for repairing a winding system in a rotary electric machine;
Figures 5-7	show schematically the repair method in accordance with the invention in a first case; and
Figures 8-10	show schematically the repair method in accordance with the invention in a second case.

Figure 1 illustrates a cross section through a high-voltage cable 10 conventionally used for transmitting electric power. The shown high-voltage cable 10 may be a standard XLPE cable, 145 kV, but without sheath or screen. This high-voltage cable 10 comprises an electric conductor which may comprise one or more strand parts 12 made of copper (Cu), for instance, and having circular cross section. These strand parts 12 are arranged in the middle of the high-voltage cable 10. Around the strand parts 12 is a first semiconducting layer 14. Around the first semiconducting layer 14 is an insulating layer 16, e.g. XLPE insulation. Around the insulating layer 16 is a second semiconducting layer 18. In the high-voltage cable 10 shown here the three layers 14, 16, 18 are such that the adhere to each other even when the cable 10 is bent. The shown cable 10 is flexible and this property is retained throughout the service life of the cable 10.

Figure 2 shows a schematic view in perspective of a section taken diagonally through a stator of a rotary electric machine. Figure 2 shows only a part of a rotary electric machine in which the rotor has been removed to reveal more clearly how a stator 20 is arranged. The main parts of the stator 20 consist of a stator frame 22, a stator core 24 comprising stator teeth and a stator yoke. The stator 20 also comprises a stator winding 30 in the form of a high-voltage cable 10 (see Figure 1), placed in a space 32 shaped like a bicycle chain, see Figure 3, formed between each individual stator tooth 26. In Figure 3 the stator winding 30 is only indicated by its electric conductors. As shown in Figure 2, the stator winding 30 forms a coil-end bundle 34 on each side of the stator 20. Figure 3 also reveals that the insulation of the high-voltage cable is stepped in several dimensions depending on its radial location in the stator 20. For the sake of simplicity only one coil-end bundle 34 is shown in Figure 2 at each end of the stator 20.

In large conventional machines the stator frame 22 often consists of a welded steel plate construction. In large machines the stator core 24, also known as the laminated core, is normally made of core sheet, 0.35-0.50 mm, divided into stacks having an axial length of approximately 50 mm and separated from each other by partitions forming ventilation ducts 5 mm wide. However, in the machine described the ventilation ducts have been eliminated. In large machines each laminated stack is formed by placing sheet metal segments 36, punched to a suitable size, together to form a first layer, each subsequent layer being laid crosswise to form a complete laminated part of a stator core 24. The parts and partitions are held together by pressure brackets 38 which are pressed against pressure rings, fingers or segments, not shown. Only two pressure brackets 38 are shown in Figure 2.

Figure 3 shows schematically a radial sector of a machine with a sheet metal segment 36 of the stator 20 and a rotor pole 42 on the rotor 44 of the machine. It is also clear that the high-voltage cable 10 is arranged in the space 32 resembling a bicycle chain, formed between each stator tooth 26.

Figure 4 shows a flow chart for a method according to the present invention for repairing a winding system in a rotary electric machine, which machine is designed for direct connection to a distribution or transmission network and comprises a stator 20 with slots for windings (see Figure 2), a rotor (see Figure 3) and windings 30 included in the winding system. The windings 30 comprise high-voltage cables 10 (see Figure 1) that substantially contain the electric field in the windings 30. The method in accordance with the present invention comprises a number of steps which will be described below. The flow chart starts at block 50. At block 52 the step is then performed of, in the event of damage to the high-voltage cable, splicing the high-voltage cable in such a manner that at least one part of at least one original coil-end bend is converted to at least one substantially straight portion after the splicing, at least one join being arranged outside the original coil-end bundle, which splicing is performed without dismantling the rotary electric machine. Thereafter, the procedure is completed at block 54. A first variant of the method also comprises the steps of:

- cutting the high-voltage cable to obtain two ends;
- removing the high-voltage cables with the two ends from at least one slot each;
- cutting the high-voltage cable to remove the damaged part and thereby obtaining an end;
- splicing a length of the high-voltage cable onto one of the ends;
- inserting the high-voltage cable with the splicing length into the empty slots; and
- joining together the loose ends thus obtained, so that the winding is without a break.

Another variant of the method comprises the steps of:

- cutting the high-voltage cable to remove the damaged part, thereby obtaining two ends;
- removing the high-voltage cables with the two ends from at least one slot each;
- joining a splicing length of the high-voltage cable in the empty slots; and
- joining together the two ends thus obtained, so that the winding is without a break.

The splicing mentioned above may be performed in the form of fully vulcanised joins.

Another alternative is for the splicing to be performed as tape-wound joins, using self-vulcanising tape, e.g. EPDM tape.

The splicing may also be performed using prefabricated joins such as slipovers. The splicing may of course be performed using a combination of the above alternatives.

The fully vulcanised joins mentioned above are performed using a curing mould, which requires a certain amount of space, around 3-4 m. This is why the winding is removed from a number of slots.

If the high-voltage cable is as shown in Figure 1 the method can also, depending on the type of damage, comprise at least one of the steps of:

- splicing the electric conductor;
- applying replacement material for the first semiconducting layer 14;
- performing vulcanisation of the first semiconducting layer 14;
- applying replacement material for the insulating layer 16;
- performing vulcanisation of the insulating layer 16;
- restoring the vulcanised insulating layer 16 to substantially its original dimension;
- applying replacement material for the second semiconducting layer 18;
- performing vulcanisation of the second semiconducting layer 18.

The replacement material mentioned above for the first semi-conducting layer 14 consists of an identical material equivalent to the first semiconducting layer.

It should be emphasised that the number of steps out of those listed that need to be performed is dependent on how serious the damage to the winding is. If the disruptive discharge is strong the conductor may also have been damaged, in which case all the steps listed above must be undertaken, from splicing the electric conductor to vulcanising the second semiconducting layer 18. If, on the other hand, the disruptive discharge is less serious the two outermost layers of the winding, for instance, may have been damaged, in which case the insulating layer 16 and the second semiconducting layer 18 must be repaired. That is to say, the last five steps must be performed, from applying replacement material for the insulating layer 16 to vulcanising the second semiconducting layer 18.

The above-mentioned replacement material for the insulating layer 16 consists of an identical material equivalent to the insulating layer 16. The above-mentioned replacement material for the semiconducting layer 18 consists of an identical material equivalent to the semiconducting layer 18.

Figures 5-7 show schematically the repair method in accordance with the present invention in a first case. In Figures 5-7 the designation 24 indicates the stator core. The stator winding 30 forms a coil-end bundle 34 at each side of the stator (see also Figure 2). In the case shown in Figure 5 the damaged part 80 is located along a slot (X_1) in the stator core 24. The first step is to cut the winding

30 (at A, B) to obtain two ends (A and B). The high-voltage cables with the two ends (A; B) are then unwound from at least one slot (X, Y) each. Decisive for how much is unwound is how much space is needed for the splicing. The high-voltage cable is then cut (indicated at C in Figure 6) to remove the damaged part 80 and obtain an end (C). Thereafter a length 74 of high-voltage cable is spliced to the end C, i.e. the ends D and C are joined. The high-voltage cable provided with the splicing length 74 is then wound into the empty slot (X, Y). It is important to point out that no slots in the stator core 24 may be empty after this step. The two ends B and E are now on the same side of the stator core 24. The loose ends B and E are then joined and an extra long loop or bend is obtained, as shown in Figure 7. As revealed in Figure 7, at least one of the joins E, B and D, C is located on a substantially straight part and arranged outside the coil-end bundle 34.

Figures 8-10 show schematically the repair procedure in accordance with the present invention in a second case. The same designations are used as in Figures 5-7 for similar parts in Figures 8-10. In this case the damaged part 80 is located at a coil-end bend (see Figure 8). First the high-voltage cable is cut, at points A' and B' in Figure 8, to remove the damaged part 80. Thereafter the high-voltage cables with the two ends A' and B' are removed from at least one slot (X, Y) each, as shown in Figure 9. A length 74 of high-voltage cable is then spliced to the end A' and the high-voltage cable provided with the splicing length 74 is then wound into the empty slot (X, Y) so that the two ends B' and E' are now on the same side of the stator core 24. The loose ends B' and E' are then joined together so that the winding 30 is without a break as revealed in Figure 10.

Figure 7 shows the join D, C placed along a coil-end bend, i.e. it is bent. This join D, C must therefore be a fully vulcanised join. It cannot be a prefabricated join or tape-wound join since these cannot be bent to the required extent.

It is also emphasised that the joins shown in Figures 7 and 10 need not be situated at the points shown. The only condition is that at least one join is arranged outside the original coil-end bundle 34.

The invention is not limited to the embodiments shown. Several modifications are feasible within the scope of the appended claims.

CLAIMS

1. A method of repairing a winding system in a rotary electric machine for high voltages, which machine is designed for direct connection to a distribution or transmission network and comprises a stator (20) with slots (X, Y) for windings (30), a rotor (44) and windings (30) included in the winding system, **wherein** the windings (30) comprise high-voltage cables (10) that substantially contain the electric field in the windings (30), said method comprising the step of:

- in the event of damage (80) to the high-voltage cable (10), splicing the high-voltage cable (10) in such a manner that at least one part of at least one original coil-end bend (72) is converted to at least one portion comprising a join after the splicing, wherein at least one join (76, 78; 82, 84) is arranged outside the original coil-end bundle (34), which splicing is performed without dismantling the rotary electric machine.

2. A method as claimed in claim 1, **characterized** in that the method also comprises the steps of:

- cutting (A, B) the high-voltage cable (10) to obtain two ends (A and B);
- removing the high-voltage cables (10) with the two ends (A; B) from at least one slot (X, Y) each;
- cutting the high-voltage cable (10) to remove the damaged part (80) and thereby obtaining an end (C);
- splicing a length (74) of the high-voltage cable (10) onto one of the ends (A; B; C);
- inserting the high-voltage cable (10) with the length (74) into the empty slots (X, Y); and
- joining together the loose ends (A and E; B and E) thus obtained, so that the winding (30) is without a break.

3. A method as claimed in claim 1, **characterized** in that the method also comprises the steps of:

- cutting the high-voltage cable (10) to remove the damaged part (80), thereby obtaining two ends (A', B');
- removing the high-voltage cables (10) with the two ends (A', B') from at least one slot (X, Y) each;
- inserting the high-voltage cable (10) provided with the length (74) into the empty slots (X, Y); and
- joining together the two ends (A' and E'; B' and E') thus obtained, so that the winding is without a break.

4. A method as claimed in any of claims 1-3, **characterized** in that splicing is performed in the form of fully vulcanised joins.

5. A method as claimed in any of claims 1-3, **characterized** in that the joins are performed using prefabricated splicing lengths.

6. A method as claimed in any of claims 1-3, **characterized** in that splicing is performed in the form of tape-wound joins.

7. A method as claimed in claim 6, **characterized** in that the tape-wound joins are performed using self-vulcanising tape, e.g. EPDM tape.

8. A method as claimed in any of claims 4-7, **characterized** in that splicing is performed using a combination of the alternatives as claimed in claims 4-7.

9. A method as claimed in claim 4 or claim 6, **characterized** in that the high-voltage cable (10) comprises an electric conductor, a first semiconducting layer (14) surrounding the conductor, an insulating layer (16) surrounding the first semiconducting layer (14), and a second semiconducting layer surrounding the insulating layer (16) wherein, depending on the type of damage, the method also comprises at least one of the steps of:

- splicing the electric conductor;
- applying replacement material for the first semiconducting layer (14);

- performing vulcanisation of the first semiconducting layer (14);
- applying replacement material for the insulating layer (16);
- performing vulcanisation of the insulating layer (16);
- restoring the vulcanised insulating layer (16) to substantially its original dimension;
- applying replacement material for the second semiconducting layer (18);
- performing vulcanisation of the second semiconducting layer (18).

10. A method as claimed in claim 9, **characterized** in that the winding (30) is a flexible winding (30) and in that said layers adhere to each other.

11. A method as claimed in claim 10, **characterized** in that said layers are of materials having such elasticity and coefficients of thermal expansion in relation to each other that the changes in volume occurring in the layers during operation as a result of temperature fluctuations can be absorbed by the elasticity of the materials so that the layers retain their adhesion to each other at the temperature fluctuations occurring during operation.

12. A method as claimed in claim 11, **characterized** in that the materials in the layers have high elasticity, preferably with an E-modulus of less than 500 MPa, most preferably less than 200 MPa.

13. A method as claimed in claim 11, **characterized** in that the coefficients of thermal expansion for the materials in said layers are substantially equal.

14. A method as claimed in claim 11, **characterized** in that the adhesion between the layers is at least of the same order of magnitude as in the weakest of the materials.

15. A method as claimed in claim 10 or claim 11, **characterized** in that each semiconducting layer constitutes substantially one equipotential surface.

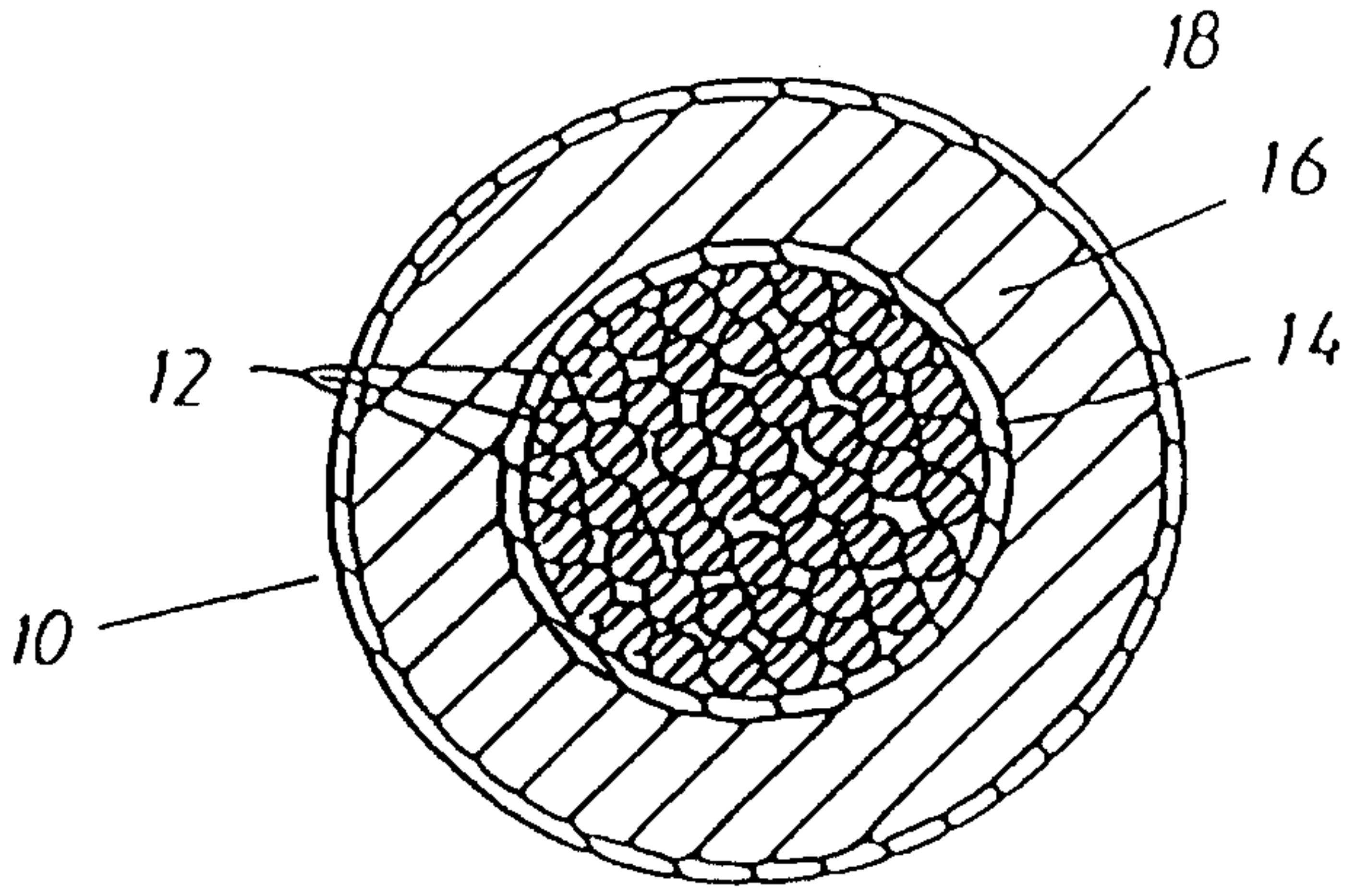


Fig. 1

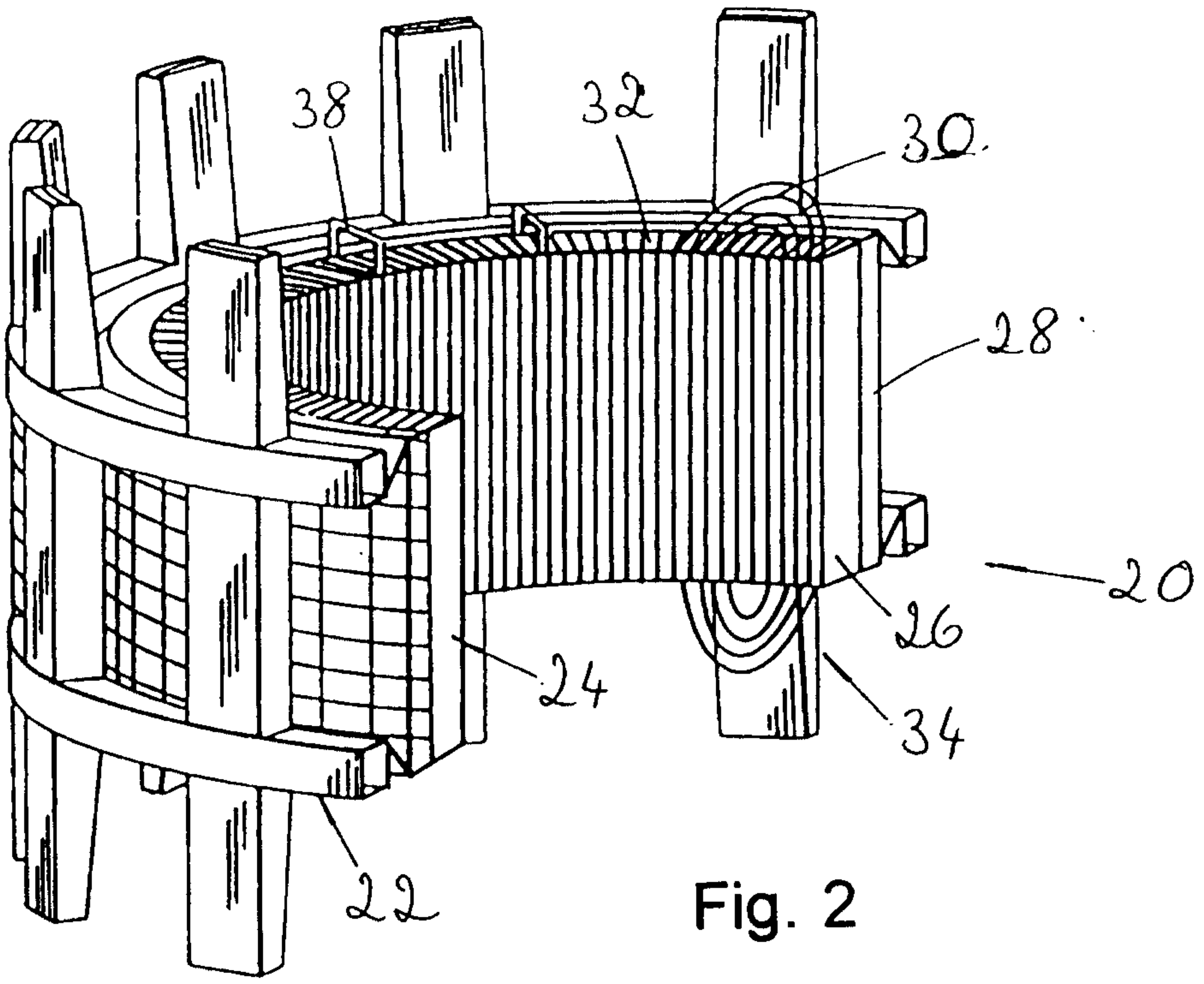


Fig. 2

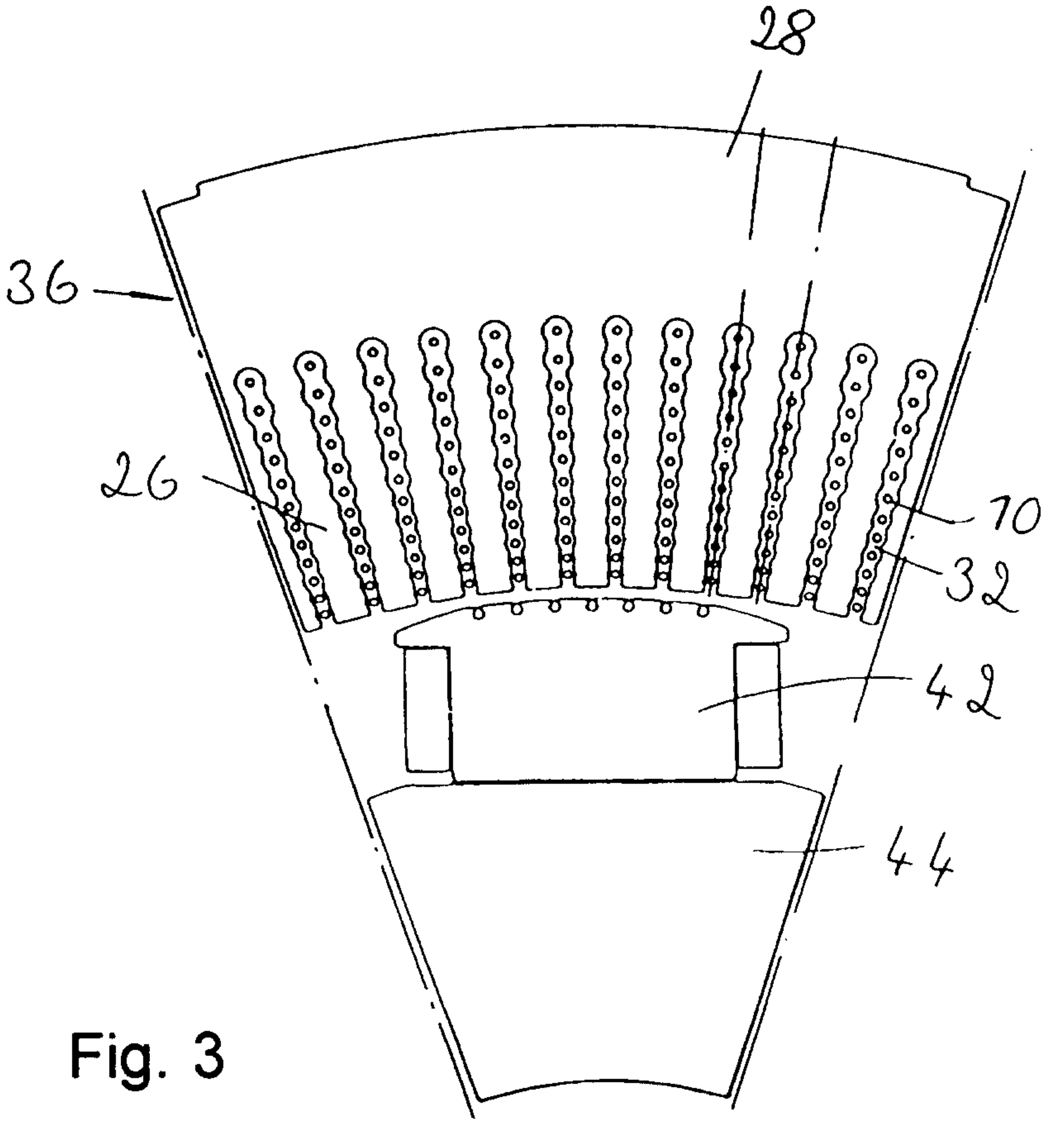


Fig. 3

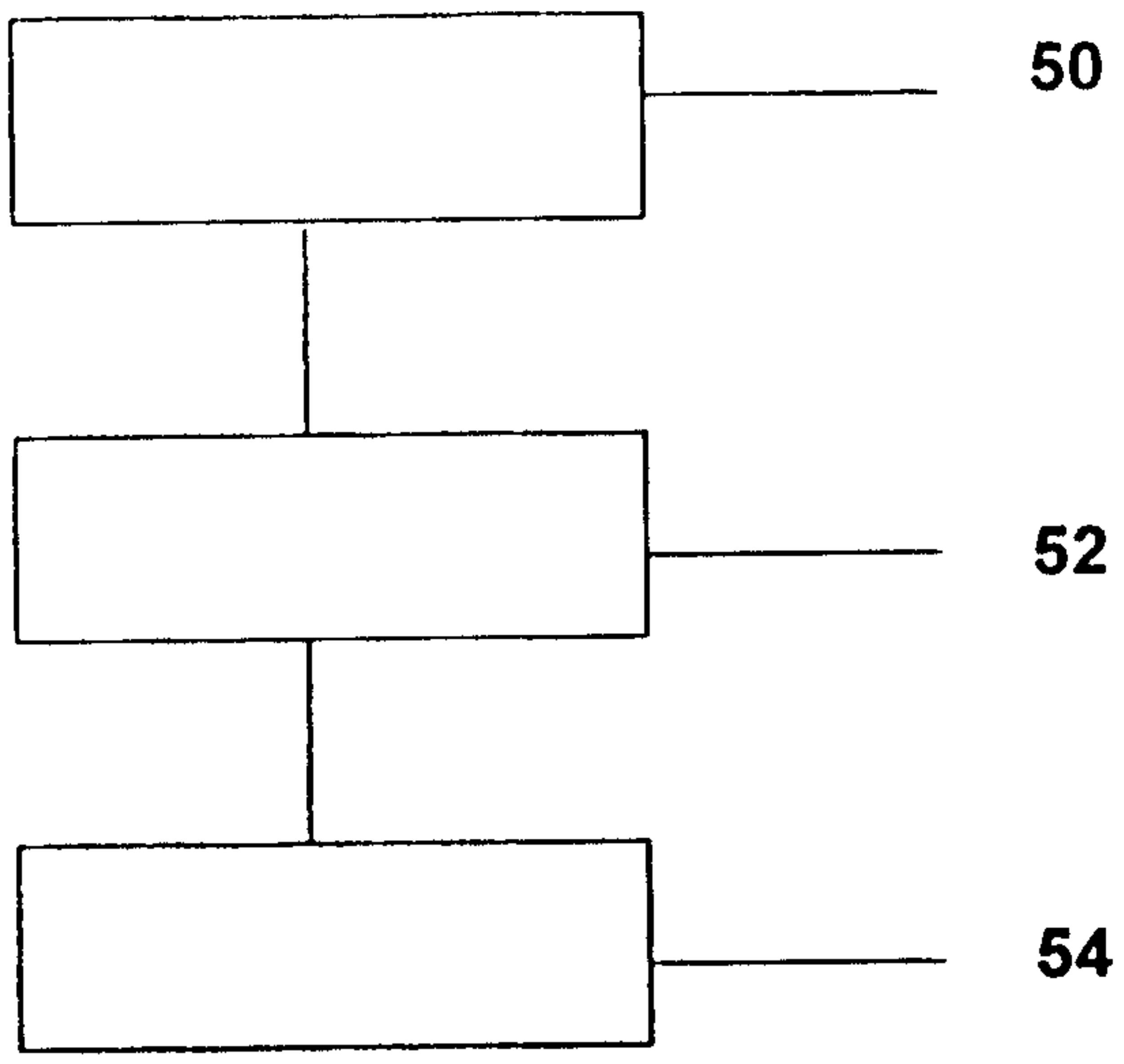


Fig. 4

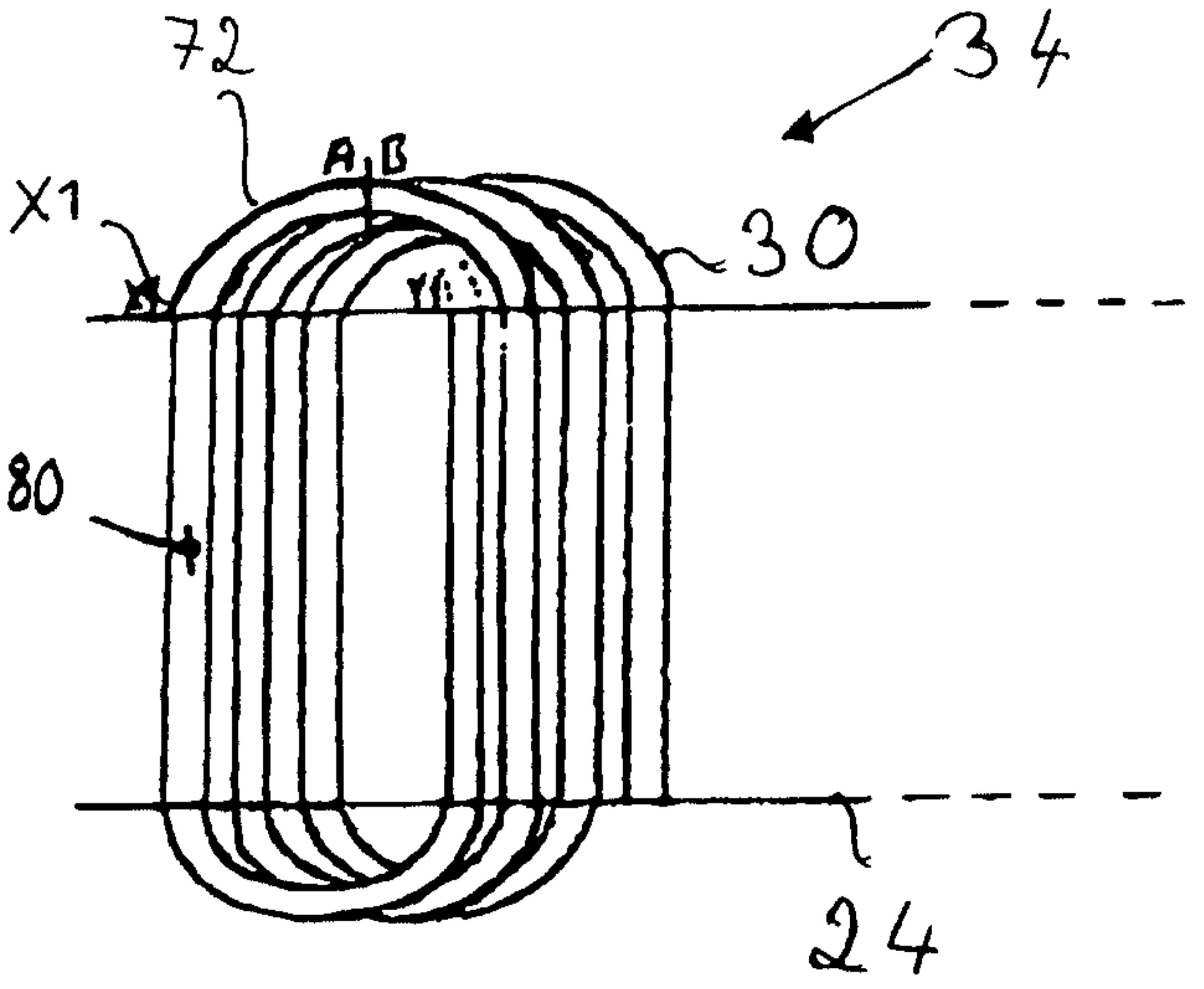


Fig. 5

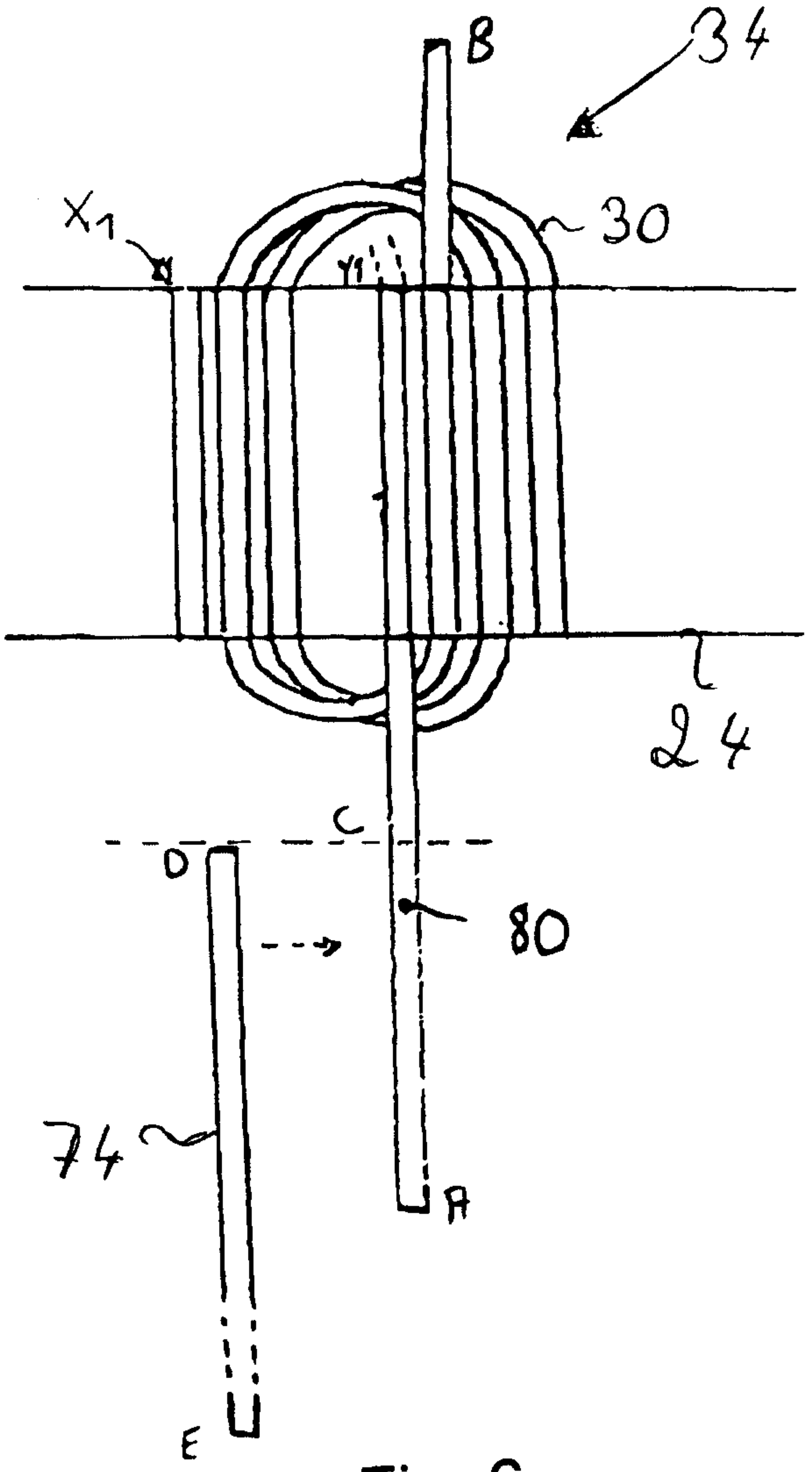


Fig. 6

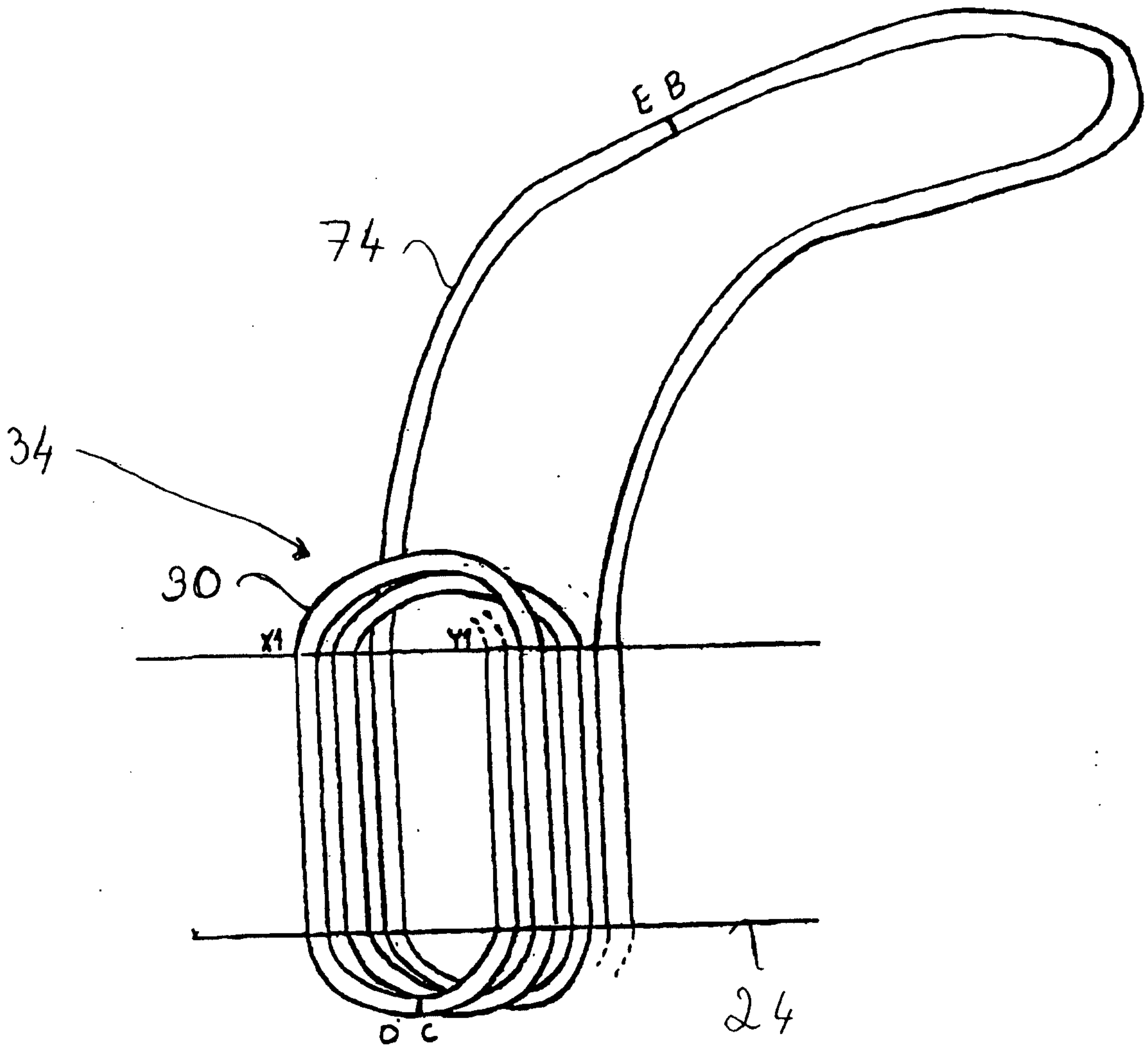


Fig. 7

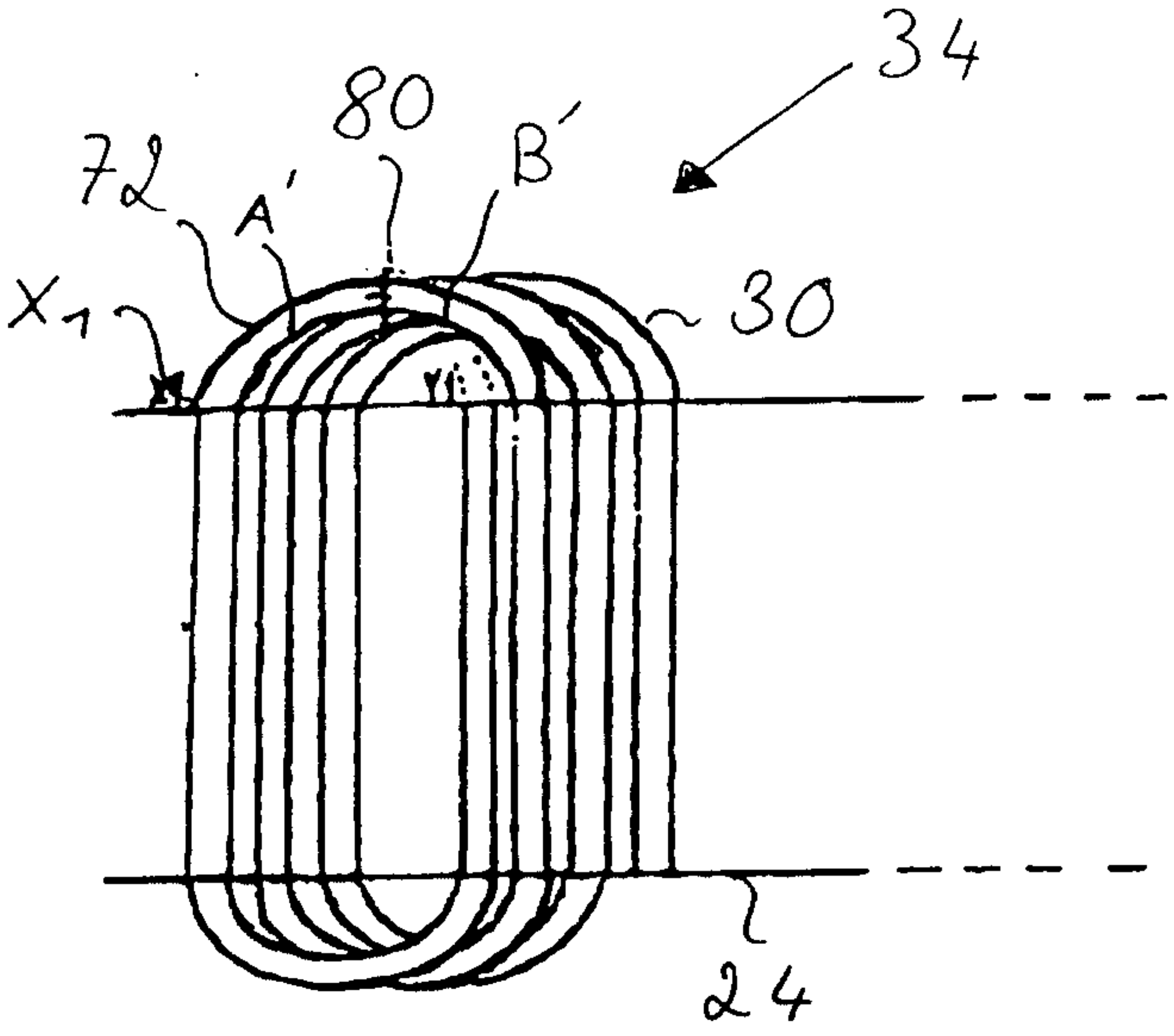


Fig. 8

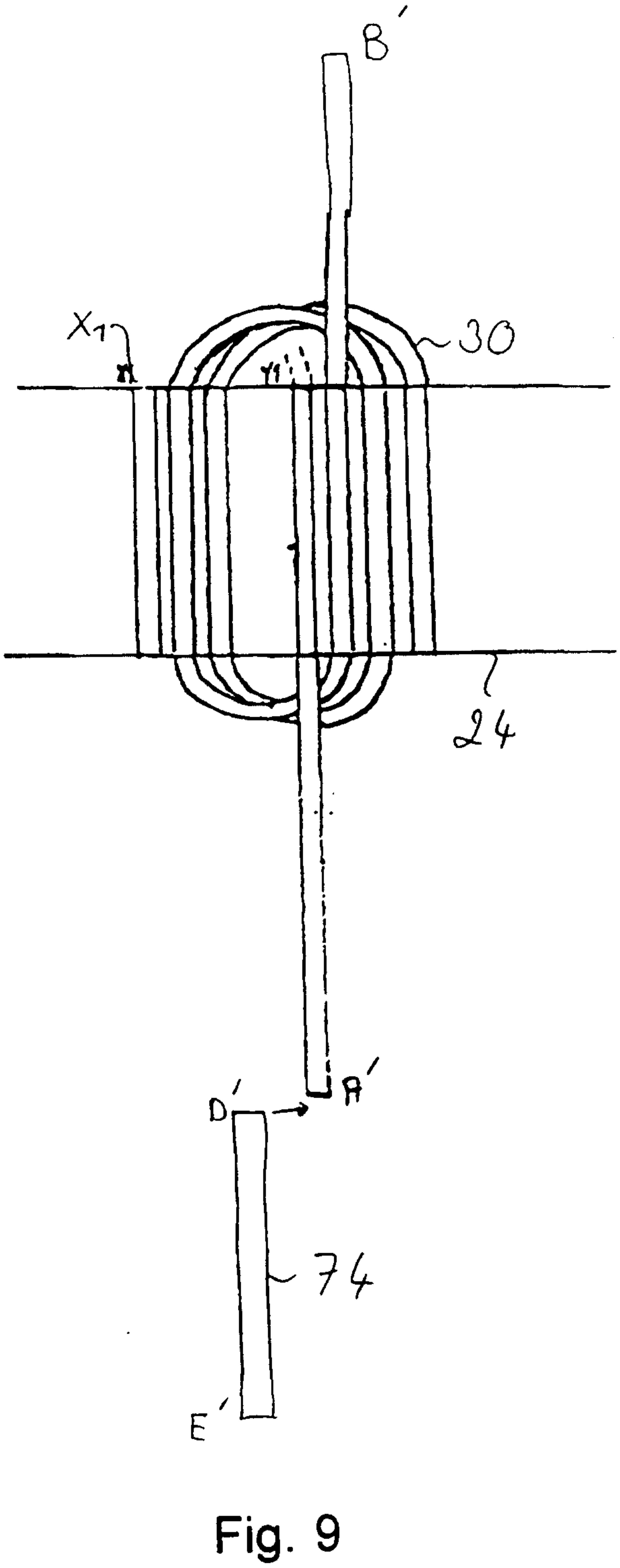


Fig. 9

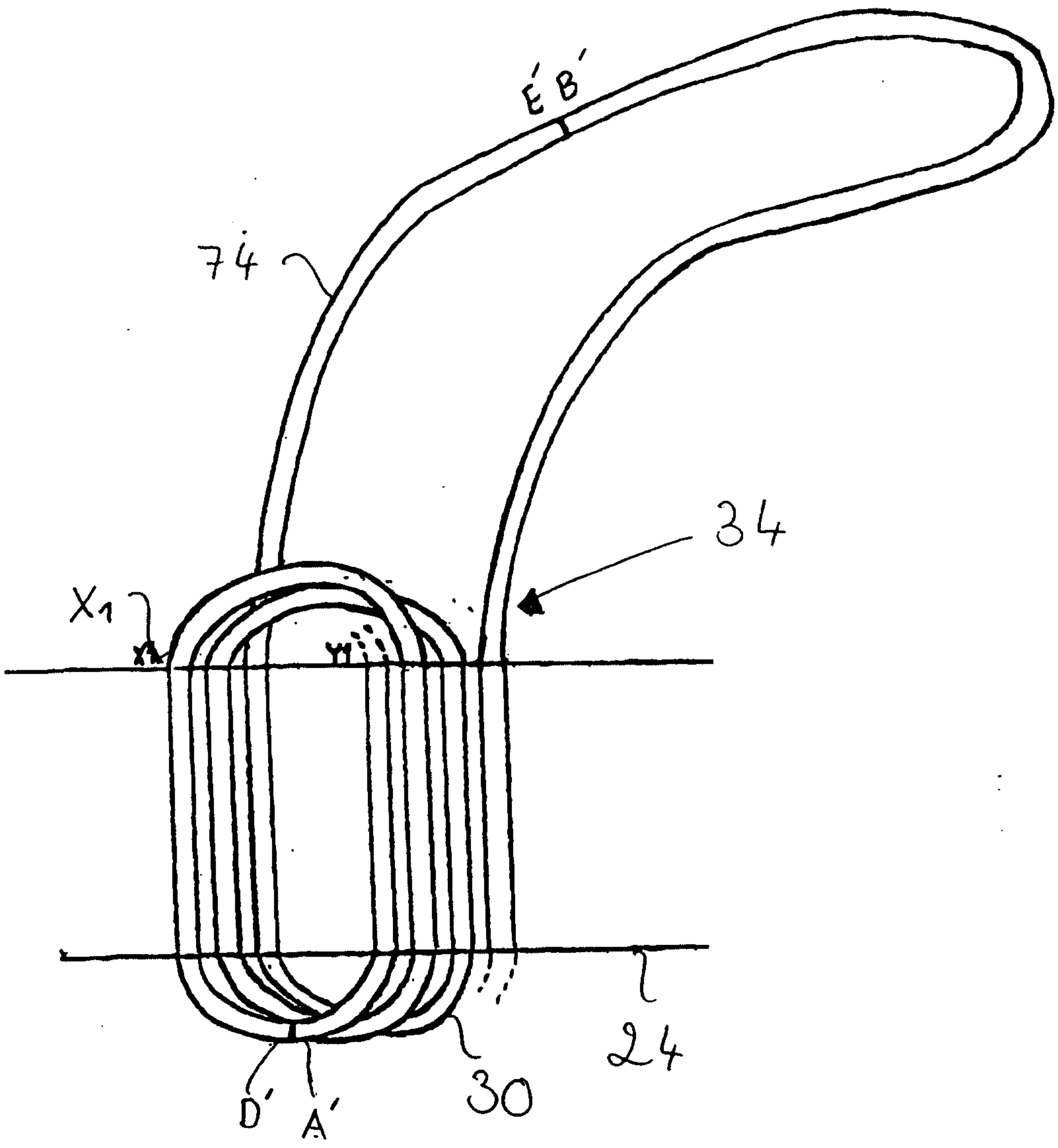


Fig. 10