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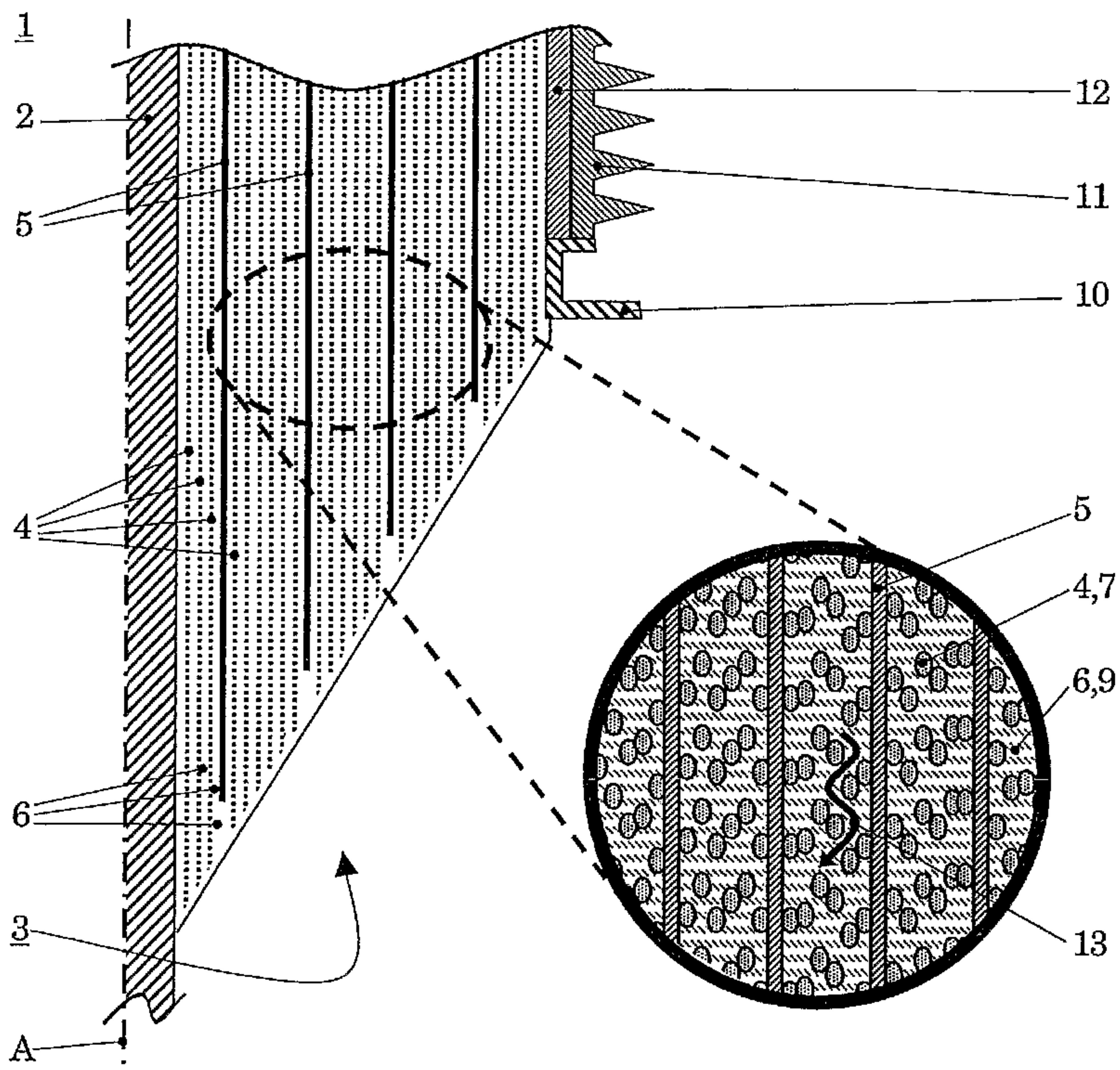
(54) Title: HIGH-VOLTAGE BUSHING



(57) Abrégé/Abstract:
The high-voltage bushing (1) has a conductor (2) and a core (3) surrounding the conductor (2), wherein the core (3) comprises a sheet-like spacer(4), which spacer (4) is impregnated with an electrically insulating matrix material (6). It is characterized in that the spacer (4) has a multitude of holes (9) that are fillable with the matrix material (6). Preferably, the spacer (4) is net-shaped or meshed. It can be a net of fibers. The bushing (1) can be a fine-graded bushing (1) with equalizing plates (5) within the core. As a matrix material (6), a particle-filled resin (6) can be used.

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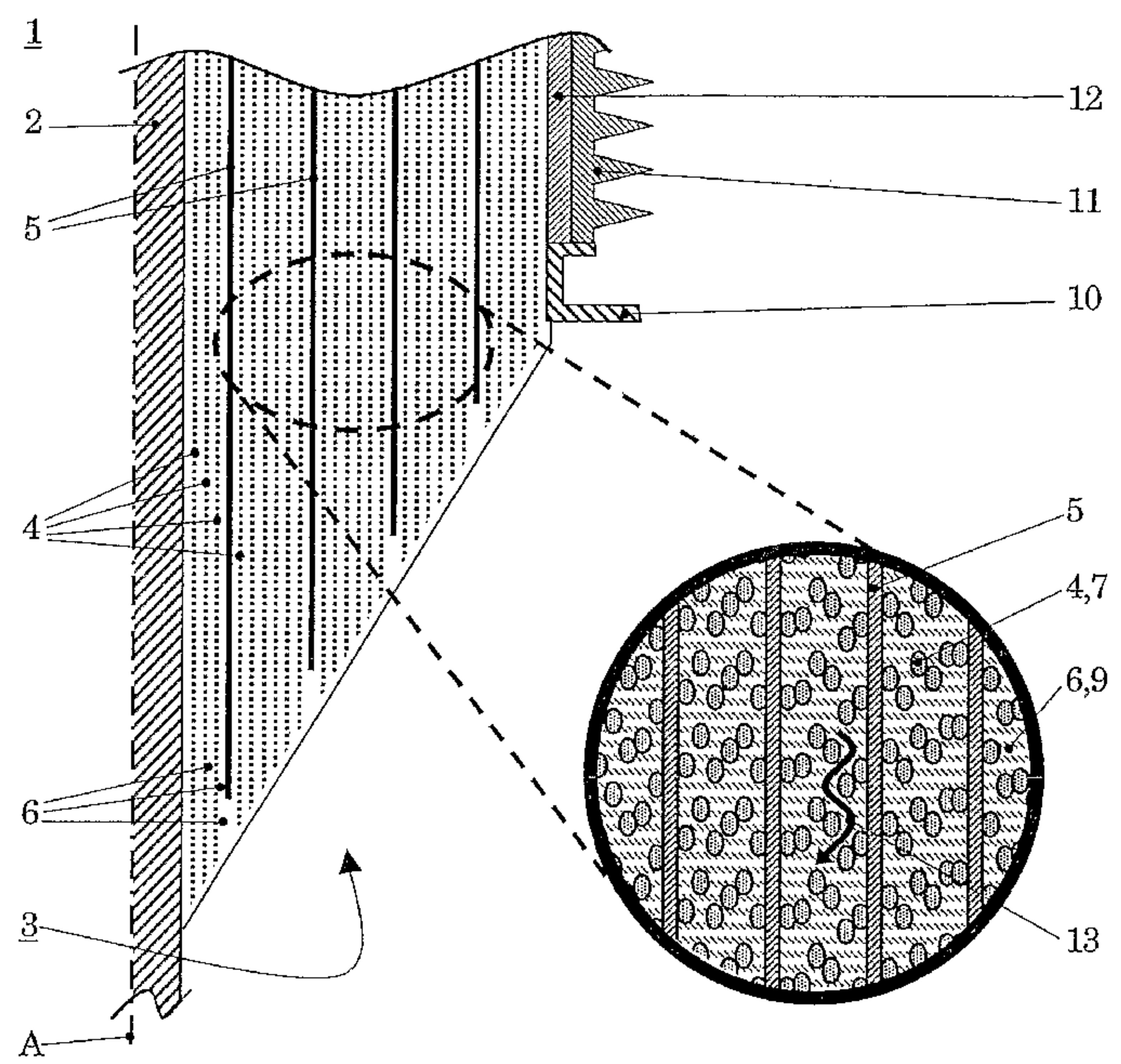

(57) Abstract: The high-voltage bushing (1) has a conductor (2) and a core (3) surrounding the conductor (2), wherein the core (3) comprises a sheet-like spacer(4), which spacer (4) is impregnated with an electrically insulating matrix material (6). It is characterized in that the spacer (4) has a multitude of holes (9) that are fillable with the matrix material (6). Preferably, the spacer (4) is net-shaped or meshed. It can be a net of fibers. The bushing (1) can be a fine-graded bushing (1) with equalizing plates (5) within the core. As a matrix material (6), a particle-filled resin (6) can be used.

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HIGH-VOLTAGE BUSHING

DESCRIPTION

Technical Field

The invention relates to the field of high-voltage technology. It relates to a bushing and a method of production of a bushing and the use of a sheet-like material according to the opening clause of the independent claims. Such bushings find application, e.g., in transformers, gas-insulated switchgears, generators or as test bushings.

State of the Art

Bushings are devices that are usually used to carry current at high potential through a grounded barrier, e.g., a transformer tank. In order to decrease and control the electric field near the bushing, condenser bushings have been developed, also known as (fine-) graded bushings. Condenser bushings facilitate electrical stress control through insertion of floating equalizer (electrode) plates, which are incorporated in the core of the bushing. The condenser core decreases the field gradient and distributes the field along the length of the insulator, which provides for low partial discharge readings well above nominal voltage readings.

The condenser core of a bushing is typically wound from kraft paper or creped kraft paper as a spacer. The equalization plates are constructed of either metallic (typically aluminium) inserts or nonmetallic (ink, graphite paste) patches. These plates are located coaxially so as to achieve an optimal balance between external flashover and internal puncture strength. The paper spacer ensures a defined position of the electrodes plates and provides for mechanical stability.

The condenser cores of today's bushings are impregnated either with oil (OIP, oil impregnated paper) or with resin (RIP, resin impregnated paper). RIP bushings have the advantage that they are dry (oil free) bushings. The core of an RIP bushing is wound from paper, with the electrode plates being inserted in appropriate places between neighboring paper windings. The resin is then introduced during a heating and vacuum process of the core.

A disadvantage of impregnated paper bushings is that the process of impregnating the paper with oil or with a resin is a slow process. It would be desirable to be able to accelerate the production of high voltage bushings, which bushings nevertheless should be void-free and safe in operation.

Summary of the invention

Therefore, the goal of the invention is to create a high voltage bushing and a method of production of such a bushing that do not have the disadvantages mentioned above. The production process shall be accelerated, in particular, the impregnation process shall be shortened.

The problem is solved by the apparatusses and the method with the characteristics of the claims.

According to the invention, the bushing has a conductor and a core surrounding the conductor, wherein the core comprises a sheet-like spacer, which spacer is impregnated with an electrically insulating matrix material. It is characterized in that the spacer has a multitude of holes that are fillable with the matrix material.

The conductor typically is a rod or a tube or a wire. The core provides for electrical insulation of the conductor and may (but does not have to) contain equalization plates. Typically, the core is substantially rotationally symmetric and concentric with the conductor. The flat spacer can be impregnated with a polymer (resin) or with oil or with some other matrix material. The flat spacer can be paper or, preferably, a different material, which is typically wound, in spiral form, thus forming a multitude of neighboring layers.

The spacer is interspersed with holes. The holes facilitate and accelerate the penetration of the wound spacer (core) with the matrix material. With unpierced paper, as in the state of the art, the matrix material has to creep through one paper layer in order to move radially from between a pair of two neighboring spacer layers to a neighboring pair of two neighboring spacer layers. If the spacer comprises a multitude of holes, the exchange of matrix material in radial direction is strongly facilitated, and also the penetration of the core of wound spacer material in axial direction is strongly facilitated, since there is less flow resistance due to more space.

If the holes are large enough and the winding is done accordingly, channels will form within the core, that will quickly guide the matrix material through the core during impregnation.

The holes penetrate the sheet-like spacer substantially in the direction of the short dimension of the sheet-like spacer.

Another major advantage of the use of a spacer that has a multitude of holes is, that it allows the use of alternative materials. One great advantage is that the paper can be replaced by other materials, like polymers or organic or anorganic fibers. A disadvantage of the use of paper as spacer is, that before impregnation the paper must be dried thoroughly, which is a slow process. Water that would remain in the core due to a too short or otherwise insufficient drying process would destroy the bushing, when it is used at elevated temperature. Another, at least as important advantage is, that the use of a wide variety of matrix materials is possible. With unpierced paper, as in the state of the art, only liquid, unfilled, low-viscosity polymers could be used as matrix materials. These restrictions do not apply to a bushing according to the invention. This can result in a considerable reduction of the time needed for curing the matrix material. In particular, particle-filled polymers can be used as matrix materials, which results in several thermomechanical advantages and in an improved (accelerated) bushing produceability.

In a preferred embodiment the spacer is net-shaped or meshed. Preferably, the spacer has a grid of openings. The grid, and the distribution of the openings, respectively, may be regular or irregular. Also the shape of the openings may be constant or may vary throughout the grid.

In another preferred embodiment the spacer comprises a multitude of fibers, and in particular, the spacer can substantially consist of fibers. Suitable fibers can, e.g., be glass fibers. Various materials can be used in the spacer, which also can be used in form of fibers. For example organic fibers, like polyethylene and polyester, or inorganic fibers, like alumina or glass, or other fibers, like fibers from silicone. Fibers of different materials can also be used in combination in a spacer. Single fibers or bundles of fibers can used as warp and woof of a fabric. It is of great advantage to use fibers that have a low or vanishing water uptake, in particular a water uptake that is small compared to the water uptake of cellulose fibers, which are used in the bushings known from the state of the art.

In another preferred embodiment the spacer is wound around an axis, which axis is defined through the shape of the conductor. In appropriate radial distances to the axis equalization plates of metallic or semiconducting material are provided within the core.

Such a bushing is a graded or a fine-graded bushing. Typically, one single layer of the spacer material is wound around the conductor or around a mandrel so as to form a spiral of spacer material. In particular in the case of very long bushings, two or more axially shifted strips of spacer material may be wound in parallel. It is also possible to wind a spiral of double-layer or even thicker spacer material; such a double- or triple-layer could then nevertheless be considered as the one layer of spacer material, which spacer material in that case would happen to be double- or triple-layered.

The equalization plates can be a metallic foil, e.g., of aluminium, which are inserted into the core after certain numbers of windings, so that the equalization plates are arranged and fixed in a well-defined, prescribable radial distance to the axis. The metallic or semiconducting material for the equalization plates can also be provided for through application of such material to the spacer, e.g., through spraying, printing, coating, plasma spraying or chemical vapor deposition or the like.

In particular in the case that fibers form the major part of the spacer, the equalization plates can be formed through spacer fibers, which are at least partially metallic or semiconducting. Such special fibers can, e.g., be metallically or semiconductingly coated over certain lengths of their axial extension.

In another advantageous embodiment the spacer is coated and/or surface treated for an improved adhesion between the spacer and the matrix material. Depending on the spacer material, it can be advantageous to brush, etch, coat or otherwise treat the surface of the spacer, so as to achieve an improved interaction between the spacer and the matrix material. This will provide for an enhanced thermomechanical stability of the core.

In another advantageous embodiment the spacer is wound around an axis, which axis is defined through the shape of the conductor, and the size of the holes in the spacer varies along the direction parallel to the axis and/or along the direction perpendicular to that. The impregnation capability can be enhanced through that. If the spacer is, e.g., a rectangular piece of a glass fiber net, which has a short side, which is aligned parallel to the axis, whereas the long side will be wound up to a spiral around the conductor, the size of the holes in the glass fiber net may vary along the short side and/or along the long side. Also the shape of the holes in the spacer material may be varied in such a way.

In a particularly preferred embodiment the matrix material comprises filler particles. Preferably, it comprises a polymer and filler particles. The polymer can for example be an epoxy resin, a polyester resin, a polyurethane resin, or another electrically insulating polymer. Preferably, the filler particles are electrically insulating or semiconducting. The filler particles can, e.g., be particles of SiO_2, Al_2O_3, BN, AlN, BeO, TiB_2, TiO_2, SiC, Si_3N_4, B_4C or the like, or mixtures thereof. It is also possible to have a mixture of various such particles in the polymer. Preferably, the physical state of the particles ist solid.

Compared to a core with un-filled expoxy as matrix material, there will be less epoxy in the core, if a matrix material with a filler is used. Accordingly, the time needed to cure the epoxy can be considerably reduced, which reduces the time needed to manufacture the bushing.

It is very advantageous if the thermal conductivity of the the filler particles is higher than the thermal conductivity of the polymer. And it is also very advantageous if the coefficient of thermal expansion (CTE) of the filler particles is smaller than the CTE of the polymer. If the filler material is chosen accordingly, the thermomechanical properties of the bushing are considerably enhanced.

A higher thermal conductivity of the core through use of a matrix material with a filler will allow for an increased current rating of the bushing or for a reduced weight and size of the bushing at the same current rating. Also the heat distribution within the bushing under operating conditions is more uniform when filler particles of high thermal conductivity are used.

A lower CTE of the core due to the use of a matrix material with a filler will lead to a reduced total chemical shrinkage during curing. This enables the production of (near) end-shape bushings (machining free), and therefore considerably reduces the production time. In addition, the CTE mismatch between core and conductor (or mandrel) can be reduced.

Furthermore, due to a filler in the matrix material, the water uptake of the core can be largely reduced, and an increased fracture toughness (higher crack resistance) can be achieved (higher crack resistance). Using a filler can significantly reduce the brittleness of the core (higher fracture toughness), thus enabling to enhance the thermomechanical properties (higher glass transition temperature) of the core.

Further preferred embodiments and advantages emerge from the dependent claims and the figures.

Brief Description of the Drawings

Below, the invention is illustrated in more detail by means of possible embodiments, which are shown in the included drawings. The figures show schematically:

Fig. 1	cross-section of a fine-graded bushing, partial view;
Fig. 1A	enlarged detail of Fig. 1;
Fig. 2	partial view of a spacer in form of a net of fibers;
Fig. 3	partial view of a spacer.

The reference symbols used in the figures and their meaning are summarized in the list of reference symbols. Generally, alike or alike-functioning parts are given the same reference symbols. The described embodiments are meant as examples and shall not confine the invention.

Ways to implement the invention

Fig. 1 schematically shows a partial view of a cross-section of a fine-graded bushing 1. The bushing is substantially rotationally symmetric with a symmetry axis A. In the center of the bushing 1 is a solid metallic conductor 2, which also could be a tube or a wire. The conductor 2 is partially surrounded by a core 3, which also is substantially rotationally symmetric with the symmetry axis A. The core 3 comprises a spacer 4, which is wound around a core and impregnated with a curable epoxy 6 as a matrix material 6. In prescribable distances from the axis A pieces of aluminium foil 5 are inserted between neighboring windings of the spacer 4, so as to function as equalizing plates 5. On the outside of the core, a flange 10 is provided, which allows to fix the bushing to a grounded housing of a transformer or a switchgear or the like. The bushing can be part of a transformer or a switchgear or of another high-voltage installation or high-voltage apparatus, e.g., of a generator. Under operation conditions the conductor 1 will be on high potential, and the core provides for the electrical insulation between the conductor 2 and the flange 10 on ground potential. On that side of the bushing 2, which usually is located outside of the housing, a insulating envelope 11 surrounds the core 3. The envelope 11 can be a hollow composite made of, e.g., porcellain, silicone or an epoxy. The envelope may be provided with sheds or, as shown in Fig. 1, provide sheds. The envelope has some sheds, that's actually the reason why we need it. The envelope 11 shall protect the core 3 from ageing (UV radiation, weather) and maintain good electrical insulating properties during the entire life of the bushing 1. The shape of the sheds is designed such, that it has a self-cleaning surface when it is exposed to rain. This avoids dust or pollution accumulation on the surface of the sheds, which could affect the insulating properties and lead to electrical flashover.

In case that there is an intermediate space between the core 3 and the envelope 11, an insulating medium 12, e.g., an insulating liquid 12 like silicone gel or polyurethane gel, can be provided to fill that intermediate space.

The enlarged partial view Fig. 1A of Fig. 1 shows the structure of the core 3 in greater detail. The spacer 4 is sheet-like and has a multitude of holes 9, which are filled with matrix material 6. The spacer 4 is substantially a net 4 of interwoven bundles 7 of glass fibers.

Fig. 2 schematically shows such a spacer 4. The bundles 7 of fibers form bridges 8 or cross-pieces 8, through which openings 9 or holes 9 are defined. In a cross-section through such a net, when wound to a spiral, fiber bundles and holes between these are visible, like shown in Fig. 1A.

In Fig. 1A also the equalizing plates 5 are shown, which are inserted in certain distances from the axis between neighboring spacer windings. In Fig. 1A there are five spacer windings between neighboring equalizing plates 5. Through the number (integer or non-integer) of spacer windings between neighboring equalizing plates 5 the (radial) distance between neighboring equalizing plates 5 can be chosen. Theradial distance between neighboring equalizing plates 5 may be varied from equalizing plate to equalizing plate.

The holes 9 of neighboring spacer windings overlap, as shown in Fig. 1A, so that channels 13 are formed, into which and through which the matrix material 6 can flow during impregnation. In a core wound from a spacer material without holes, as they are known from the state of the art, channels 13, which radially extend from one side of a spacer windin to the other side of the spacer winding, cannot be formed.

Typically, there are between 3 and 9 spacer windings (layers) between neighboring equalizing plates 5. It is also possible to have only one spacer layer between neighboring equalizing plates 5, in which case the spacer material, which forms the brigdes 8, should be penetratable by matrix material 6 and/or the height of the spacer 4 at the bridges (measured perpendicular to the sheet plane of the sheet-like spacer) should vary, so as to allow matrix material 6 to flow through (radially extending) spaces left between a bridge and a neighboring solid equilization plate 5. This way, a void-free impregnation of the spacer 4 with matrix material 6 is possible. In case of a net of interwoven bundles of fibers, the is brigdes 8 are penetrable by matrix material 6, since a fiber bundle is not solid, but leaves space between the fibers forming a bundle. And, in case of a net of interwoven bundles of fibers, there is a non-constant height of the spacer bridges, since the diameter of a bundle of fibers is not constant, and since the thickness of the spacer is in such a net larger in places, where warp and woof overlap, than in the places in between.

Typically, two or more layers of spacer material are arranged between neighboring equalization plates 5. In that case, channels 13 can be formed through some overlap of holes 9 from neighboring spacer layers.

Instead of bundles 7 of fibers, a net-like spacer 5 can also be formed from single fibers (not shown).

The spacer 4 can also be structured from a solid piece of material, instead of from fibers. Fig. 3 shows an example. A sheet-like paper or polymer comprises holes 9, which are separated from each other by bridges 8. The shape of the holes can be square, as shown in Fig. 3, but any shape is possible, e.g., rectangular or round or oval.

The matrix material 6 of the core 3 in Fig. 1 is preferably a particle-filled polymer. For example an epoxy resin or a polyurethane filled with particles of Al_2O_3. Typical filler particle sizes are of the order of 10 nm to 300 µm. The spacer is shaped such that the filler particles can distribute throughout the core 3 during impregnation. In conventional bushings with (hole-free) paper as spacer, the paper would function as a filter for such particles. It can easily be provided for channels 13, that are large enough for a flowing through of a particle-filled matrix material 6, as shown in Fig. 1A.

The thermal conductivity of a standard RIP-core with pure (not particle-filled) resin is typically about 0.15 W/mK to 0.25 W/mK. When a particle-filled resin is used, values of at least 0.6 W/mK to 0.9 W/mK or even above 1.2 W/mK or 1.3 W/mK for the thermal conductivity of the bushing core can readily be achieved.

In addition, the coefficient of thermal expansion (CTE) can be much smaller when a particle-filled matrix material 6 is used instead of a matrix material without filler particles. This results in less thermomechanical stress in the bushing core.

The production process of a bushing as described in conjuntion with Fig. 1 typically comprises the steps of winding the spacer 4 (in one or more strips or pieces) onto the conductor 2, adding the equalization electrodes 5 during winding, applying a vacuum and applying the matrix material 6 to the vacuumized core 3 until the core 3 is fully impregnated. The impregnation under vacuum takes place at temperatures of typically between 50°C and 90°C. Then the epoxy matrix material 6 is cured (hardened) at a temperature of typically between 100°C and 140°C and eventually post-cured in order to reach the desired thermomechanical properties. Then the core is cooled down, machined, and the flange 10, the insulating envelope 11 and other parts are applied.

In general, the spacer should have a grid of holes. The grid does not necessarily have to be evenly spaced in any direction. And the shape and the area of the holes does not necessarily have to be evenly spaced in any direction. In particular, it can be advantageous to vary the size (area) of the holes along the axial direction and/or perpendicular to the axial direction, such that a void-free impregnation of the core is facilitated.

The openings 9 in a spacer can have a lateral extension of the order of typically 0.5 mm to 5 cm, in particular 2 mm to 2 cm, whereas the thickness of the spacer 4 and the width of the bridges 8 typically is of the order of 0.03 mm to 3 mm, in particular 0.1 mm to 0.6 mm. The area consumed by the holes 9 is usually at least as large as the area consumed by the bridges. Typically, in the plane of the spacer sheet, the area consumed by the holes 9 is between 1 and 5 orders of magnitude, in particular 2 to 4 orders of magnitude larger than the area consumed by the bridges.

The use of a spacer 4 with a multitude of holes can allow the production of a paperless dry (oil-free) bushing. This is advantageous, because the process of drying the spacer before impregnation can be quickened or even skipped.

Instead of inserting pieces of metallic foil between the spacer windings, equalization plates 5 may also be formed through application of conductive of semiconducting material directly to the spacer 4. In case that the spacer 4 is made from fibers, it is possible to incorporate conductive or semiconducting fibers in the spacer net.

Typical voltage ratings for high voltage bushings are between about 50 kV to 800 kV, at rated currents of 1 kA to 50 kA.

List of Reference Symbols

1	bushing, condenser bushing
2	conductor
3	core
4	spacer, net, grid of meshes
5	equalizing plate, aluminium foil
6	matrix material, epoxy
7	bundle of fibers
8	cross-piece, bar, bridge
9	hole, opening
10	flange
11	insulating envelope (with sheds), hollow core composite
12	insulating medium, gel
13	channel
A	axis

CLAIMS

1. Bushing (1) with a conductor (2) and a core (3) surrounding the conductor (2), the core (3) comprising a sheet-like spacer (4), which spacer (4) is impregnated with an electrically insulating matrix material (6), and which spacer is wound, in spiral form, thus forming a multitude of neighboring layers, **characterized in that** the spacer (4) has a multitude of holes (9) that are fillable with the matrix material (6).

2. Bushing (1) according to claim 1, characterized in that the spacer (4) is net-shaped or meshed.

3. Bushing (1) according to one of the preceding claims, characterized in that the spacer (4) comprises a multitude of fibers (7).

4. Bushing (1) according to one of the preceding claims, characterized in that the spacer (4) is wound around an axis (A), which axis (A) is defined through the shape of the conductor (2), and that in appropriate radial distances to the axis (A) equalization plates (5) of metallic or semiconducting material are provided within the core (3).

5. Bushing (1) according to claim 3 and claim 4, characterized in that the equalization plates (5) are formed through fibers (7) of the spacer (4), which are at least partially metallic or semiconducting.

6. Bushing (1) according to claim 4 or claim 5, characterized in that the equalization plates (5) are formed by applying a metallic or

semiconducting material to the spacer (4).

7. Bushing (1) according to one of the preceding claims, characterized in that the spacer (4) is coated and/or surface treated for an improved adhesion between the spacer (4) and the matrix material (6).

8. Bushing (1) according to one of the preceding claims, characterized in that the spacer (4) is wound around an axis (A), which axis (A) is defined through the shape of the conductor (2), and that the size of the holes (9) in the spacer (4) varies along the direction parallel to the axis (A) and/or along the direction perpendicular to that direction.

9. Bushing (1) according to one of the preceding claims, characterized in that the matrix material (6) comprises filler particles.

10. Bushing (1) according to one of the preceding claims, characterized in that the filler particles are electrically insulating or semiconducting.

11. Bushing (1) according to claim 10, characterized in that the thermal conductivity of the the filler particles is higher than the thermal conductivity of the polymer and/or that the coefficient of thermal expansion of the the filler particles is smaller than the coefficient of thermal expansion of the polymer.

12. Method of production of a bushing (1), wherein a sheet-like spacer (4) is wound, in spiral form, around a conductor (2) or around a mandrel, thus forming a multitude of neighboring layers, and then impregnated with an electrically insulating matrix material (6),
characterized in that
a spacer (4) comprising a multitude of holes (9) is used.

13. Use of a sheet-like material (4) with a multitude of holes (9) as a spacer (4), wound, in spiral form, thus forming a multitude of neighboring layers, in a core (3) of a bushing (1).

14. Transformer comprising a bushing (1) according to one of the claims 1-11.

15. Switchgear comprising a bushing (1) according to one of the claims 1-11.

16. High-voltage apparatus or high-voltage installation, in particular a generator, comprising a bushing (1) according to one of the claims 1-11.

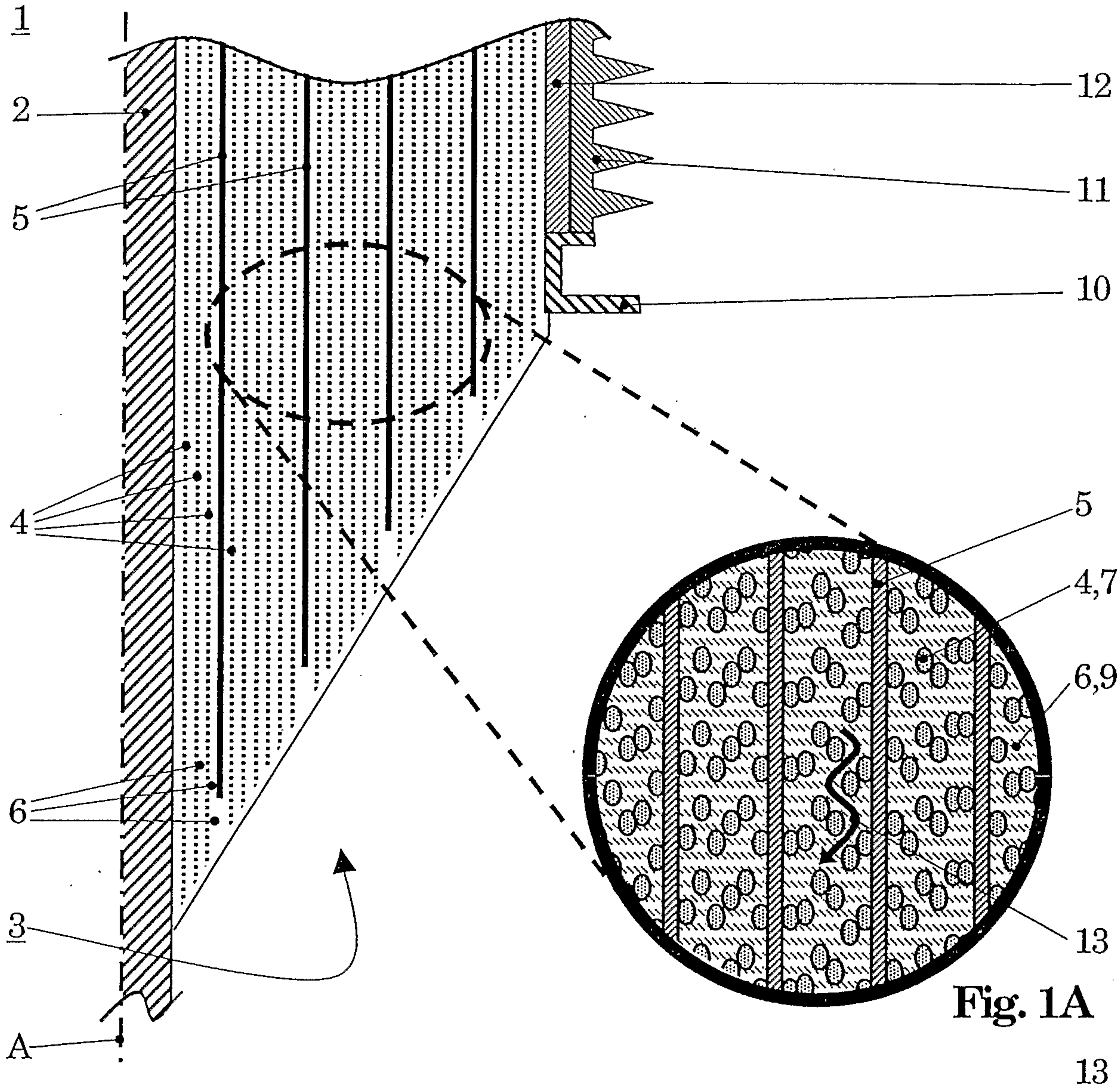


Fig. 1

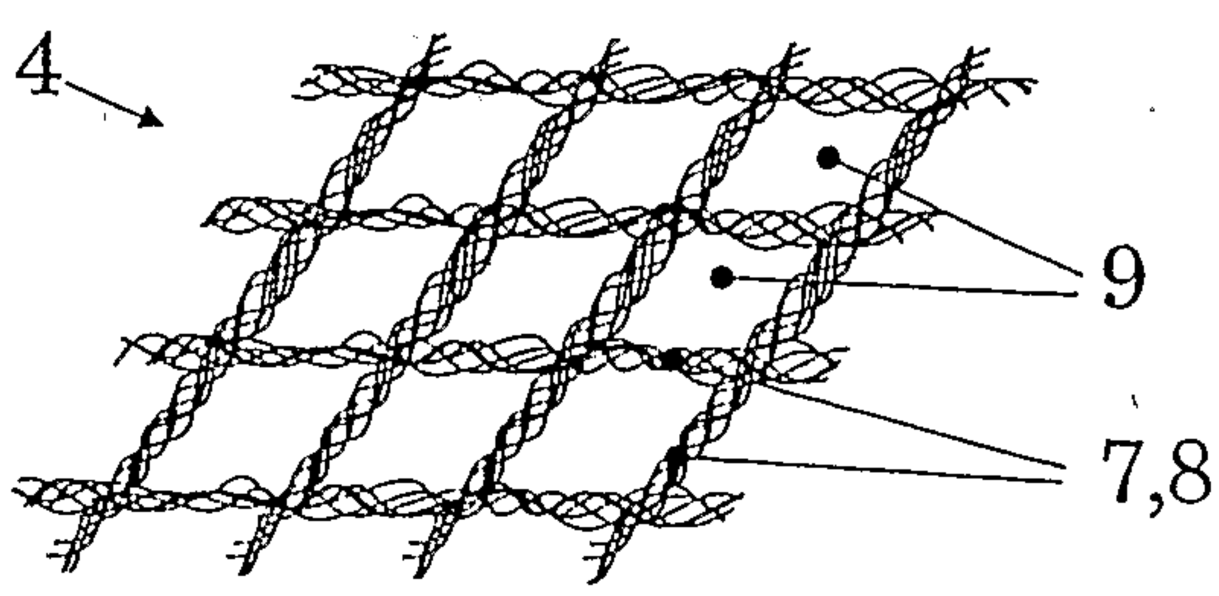


Fig. 2

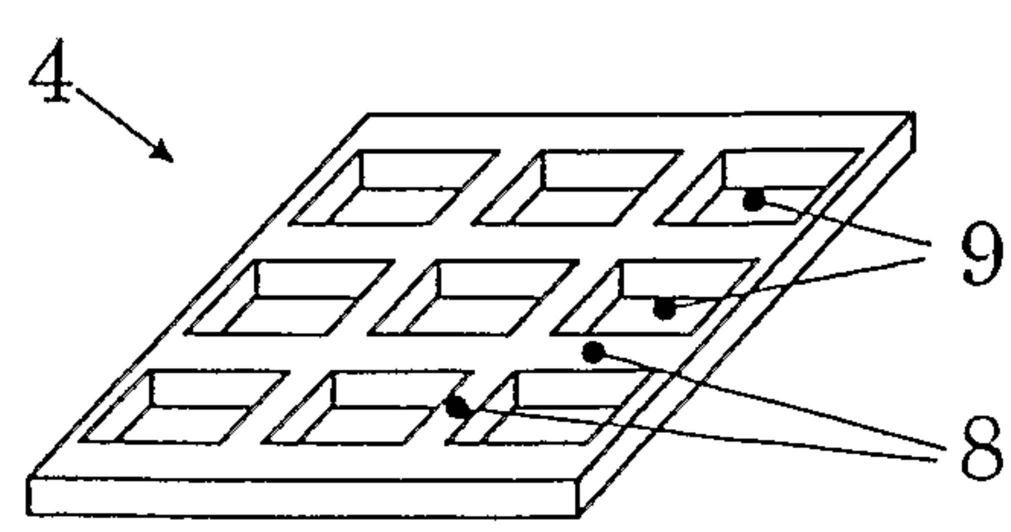
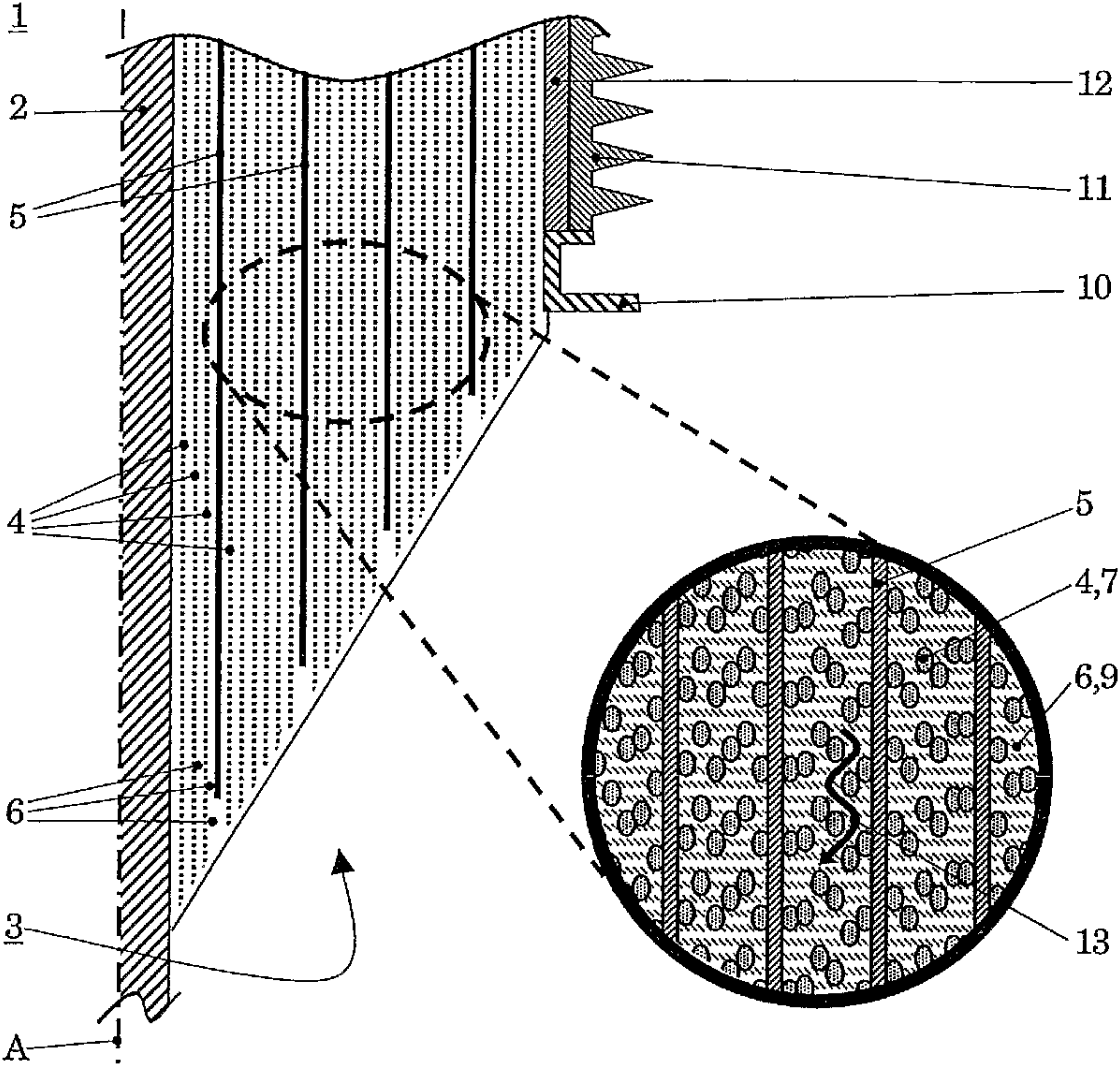


Fig. 3



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