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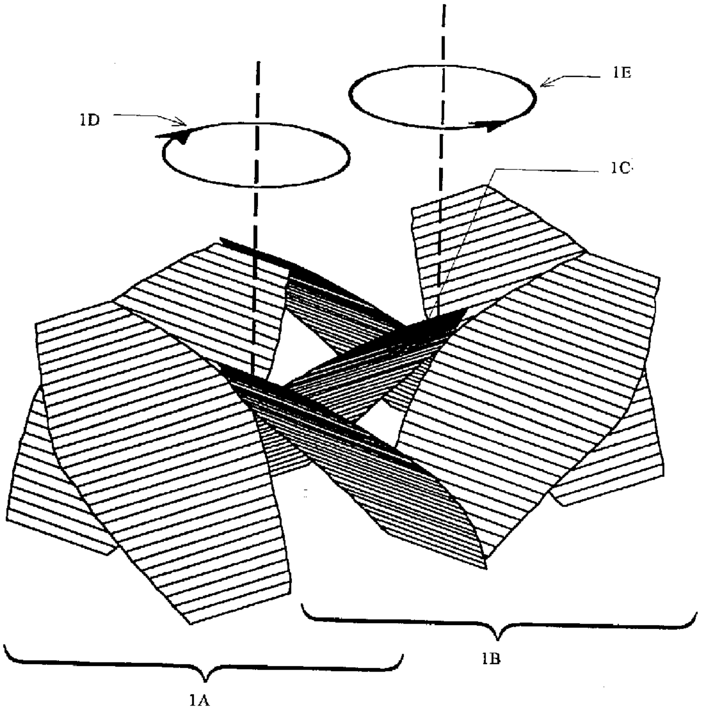
(54) **ECHANGEUR DE MASSE ET DE CHALEUR**
(54) **MASS- AND HEAT-EXCHANGE DEVICE**



(57) Échangeur de chaleur et de masse pour une colonne de distillation, en particulier une colonne de distillation cryogénique. L'échangeur comprend plusieurs rangées horizontales de ventilateurs stationnaires (1A, 1B). Les ventilateurs sont superposés en rangées horizontales successives à l'intérieure desquelles chaque déflecteur fait partie de deux ventilateurs adjacents tournant dans des directions opposées. Les rangées sont formées par la juxtaposition de bandes obtenues de feuilles coupées, et repliées ou pliées ou torsadées et leur fabrication est particulièrement simple.

(57) A mass- and heat-exchange device for a distillation column, in particular a cryogenic distillation column, comprises several horizontal layers of stationary ventilators (1A, 1B). The ventilators are stacked in successive horizontal layers within which each deflector forms part of two adjacent ventilators rotating in opposite directions. The layers are formed by the juxtaposition of strips obtained from sheets by cutting and folding and/or bending and/or twisting and are particularly simple to manufacture.

PATENT APPLICATION

For:
"MASS- AND HEAT-EXCHANGE DEVICE"
In the name of:
L'AIR LIQUIDE, SOCIETE ANONYME POUR L'ETUDE ET L'EXPLOITATION DES PROCEDES GEORGES CLAUDE

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ABSTRACT

A mass- and heat-exchange device for a distillation column, in particular a cryogenic distillation column, comprises several horizontal layers of stationary ventilators (1A, 1B). The ventilators are stacked in successive horizontal layers within which each deflector forms part of two adjacent ventilators rotating in opposite directions.

The layers are formed by the juxtaposition of strips obtained from sheets by cutting and folding and/or bending and/or twisting and are particularly simple to manufacture.

Figure to be reproduced: Figure 1

The present invention relates to a mass- and heat-exchange device and, in particular, a mass- and heat-exchange device intended to serve as packing in distillation columns having a high number of theoretical plates, typically in columns for the distillation of air or of mixtures of carbon monoxide, nitrogen, hydrogen or hydrocarbons, or in isotope separation columns. It may also serve for isotope distillation. Typically, it will be installed in distillation columns having a high number of theoretical plates.

The packings ordinarily used comprise corrugated strips having parallel alternating corrugations arranged against each other, each one lying in a general vertical plane, the corrugations being oblique and descending in opposite directions from one strip to the next. The degree of perforation is approximately 10% for these so-called crossed-corrugated packings.

GB-A-1,004,046 discloses packings of the crossed-corrugated type.

CA-A-1,095,827 proposes an improvement of this type of packing by adding a dense perforation of small diameter in order to allow the liquid to pass right through the crossed-corrugated strips.

WO-A-94/12258 proposes an improvement of this type of packing, based on positioning the strips precisely with respect to each other in a vertical plane by means of an interlocking system. The object of this device is to house a greater packing surface area in the same volume, since the interlocking allows interpenetration of the strips.

WO-A-86/06296 and WO-A-90/10497 disclose a packing composed of horizontal and superposed layers, each layer comprising a row of pyramids.

In WO-A-86/06296, the structure comprises open-based pyramids having side faces which are alternately open and closed, connected by their tips so as to constitute a multitude of ventilator blades which rotate the gas in order to intensify contact between the gas and the liquid. A fundamental characteristic of this structure is that it can be obtained by the assembly of perforated and folded metal sheets. This time, the perforation is no longer only designed to optimize the flow of the liquid but also to enable the gas to pass through the crossed folded strips, the degree of perforation being about 50%.

Paradoxically, it is just at this moment when crossed-corrugated packing is starting to be radically debated that this type of packing is beginning to be used for separating the gases in air. This relatively late application may be partly explained by the high-performance characteristics of cryogenic plates compared to other plates on the market (an HETP, or height equivalent to a theoretical plate, of about 10 cm and a low pressure drop).

In WO-A-90/10497, the structure obtained above is improved by making the faces of the pyramids of two successive layers coincide, thereby creating transverse channels with respect to the strips and promoting transverse mixing. It clearly mentions the advantage of double perforation: a checker-board-type perforation (therefore having 50% of the surface area perforated) for the gas and a secondary perforation in the "closed faces" in order to organize the trickling of the liquid.

The latter patent application has given rise to the Sulzer product "Optiflow™" which represents the first construction of a new-product generation, making it possible to achieve performance characteristics which are in particular superior to those of the now classical crossed-corrugated packings (an HETP reduced by about 25 to 30% for a constant vapour rate, or a flooding rate increased by about 25 to 30% for a constant HETP).

This patent and these patent applications make it possible to identify two major lines of research. The objective of the first line of research is to optimize the flow of the liquid so that the wetted surface area is as great as possible and so that the liquid is distributed in all directions, being remixed in the course of trickling in the packing. The objective of the second line of research is to optimize the flow of the gas, i.e. to obtain as turbulent a vertical flow as possible, without preferential flow channels or regions of low circulation.

Up to now, the flow of the liquid phase has been studied on structures of the crossed-corrugated type. It has been discovered that small-diameter perforations (approximately 10%) promote passage of the liquid on each side of the strips. Several improvements have been proposed: CA-A-1,095,827 claims precise positioning of the holes with respect to the folds and WO-A-94/12258 claims relative positioning of the strips, by interpenetration of the strips. In fact, it seems that the positioning of the holes does not appreciably increase the effectiveness of the packing since the main function of the holes is to allow the liquid to pass from one side of the strip to the other. Only the degree of perforation and the diameter of the holes therefore influence the efficiency.

The idea of pyramids, introduced in WO-A-86/06296 and WO-A-90/10497, introduces a novel type of perforation - perforations for passage of the gas (representing approximately 50% of the surface area). These perforations make it possible to reduce the pressure drop and to create ventilators promoting stirring of the gas. These documents are silent with regard to the flow of the liquid.

The fact of joining the pyramids by the tips ("vertices" and "corners" - by "corners" are meant the points lying on the base) has a major disadvantage: because of the fact that there is little material remaining at these points, the mechanical integrity of the assembly means that these "tips" have to be physically linked using a mechanical process of the stapling, binding, stitching, welding or soldering type, which requires complex and expensive tools and therefore results in quite a high cost. It may furthermore be pointed out that the number of these fastenings varies as the number of pyramids, i.e. as the inverse cube of their size, thereby limiting the economically accessible specific surface area of this type of packing. Moreover, the principle of the checker-board perforation leads to scrap rates of about 50%; this is particularly detrimental when the material of the packing is very costly, for example a woven fabric.

It also appears that this structure is highly aerated and that the HETP could be even further reduced if some of the scrap were to be lodged in the structure without degrading the turbulence of the gas or the degree of wetting of the surface.

The object of the present invention is to create a heat- and mass-exchange device having good properties with regard to flow of the gas, which incorporates a series of improvements relating to the spreading, distribution and mixing of the liquid, and being simpler to manufacture than those of the prior art, and therefore to make it practically possible to produce packings which are very fine and therefore have an even smaller HETP.

One subject of the invention is a heat- and/or mass-exchange device consisting of a stack of stationary ventilators so as to promote gas mixing, each ventilator consisting of four deflectors whose mid-perpendiculars are inclined and approximately derived from each other by rotation about vertical axes, the sum of the four angles of rotation being 360° and the ventilators being stacked in successive horizontal layers within which each deflector forms part of two adjacent ventilators rotating in opposite directions and in such a way that there is enough space between two adjacent deflectors for the gas to pass through them.

The deflectors of the ventilators may be planar or non-planar, symmetrical or non-symmetrical, and derived by rotation about a vertical or non-vertical axis.

The structure thus described makes it possible to create the swirling flow of the gas which improves the exchange between the liquid film trickling over the deflectors and the gas. It has the advantage of providing great design freedom in order to define the shape of and the connections between the deflectors. This freedom should be used in order better to provide the other functions of the product and to reduce its cost.

It may be pointed out that the open-pyramid structure of Patent Applications WO-A-86/06296 and WO-A-90/10497 is a very special case of the general structure which just been described when the following conditions are simultaneously fulfilled:

1. the deflectors of the ventilators are rhombuses, one diagonal of which is horizontal, or triangles, the base of which is horizontal;
2. the angles of rotation of the deflectors are 90°;
3. the axes of rotation pass through the ends of the horizontal diagonals of the rhombic deflectors or through the ends of the horizontal bases of the triangular deflectors;
4. the upper vertices of the rhombuses or of the triangles of one layer coincide with a vertex of a rhombus or of a triangle of the layer immediately above.

According to another aspect of the invention:

- the deflectors of the ventilators are neither rhombuses, one diagonal of which is horizontal, nor triangles, the base of which is horizontal; or
- the angles of rotation of the deflectors are not 90°; or

- the axes of rotation do not pass through the ends of the horizontal diagonals of the rhombic deflectors; or
- the axes of rotation do not pass through the ends of the horizontal bases of the triangular deflectors; or
- the upper vertices of the rhombuses or of the triangles of one layer do not coincide with a vertex of a rhombus or of a triangle of the layer immediately above.

According to another aspect of the invention, a device is provided in which:

- the lower part of some or all of the deflectors is unsymmetrical;
- the upper part of some or all of the deflectors is symmetrical with respect to the line of greatest slope and has substantially the shape of an inverted V, so as to promote spreading of the liquid;
- some or all of the deflectors are drilled with one or more holes, with or without vertical axis symmetry, so as to encourage the liquid to pass under the deflectors;
- some or all of the deflectors are connected to several of their neighbours in the same horizontal plane by a common edge segment which is rounded, flattened or depressed, so as to allow lateral partition of the liquid between deflectors;
- some or all of the deflectors penetrate into the space lying in the vertical of an adjacent deflector;
- some or all of the deflectors are designed so as to feed another deflector with liquid, generally with the aid of a tip, or to collect the liquid from another deflector;
- the lower part of some or all of the deflectors is at least partly widened, so as to maintain as high as possible a trickling surface area for the liquid;

- one end of at least two deflectors forms a projection; and
- one or each projection interlocks with another projection or a notch, so as to fasten the layers of ventilators together.

It may also be pointed out that Patent Application WO-A-94/12258 describes a structure in which each interpenetration point is the centre of four deflectors which are not derived from each other by rotation. However, the deflectors are fastened in such a way that the gas can no longer pass between the two deflectors of vertically superimposed ventilators. The concept of a ventilator, as conceived, disappears because of the absence of perforations for the gas.

In the device proposed here, the positioning of the strips with respect to each other is governed by the gas perforations which must be positioned precisely with respect to each other.

Another subject of the invention is a process for manufacturing a heat- and/or mass-exchange device consisting of a stack of stationary ventilators, so as to promote gas mixing, each ventilator consisting of four deflectors whose mid-perpendiculars are inclined and approximately derived from each other by rotation about vertical axes, the sum of the four angles of rotation being 360° and the ventilators being stacked in successive horizontal layers within which each deflector forms part of two adjacent ventilators rotating in opposite directions and in such a way that there is enough space between two adjacent deflectors for the gas to pass through them, in which flat sheets of metal or of another material are cut and folded and/or bent, twisted or stamped in order to form concertinaed sheets, with or without projections, the solid surfaces forming flat, folded, curved or twisted deflectors.

The flat product may be rolled, woven or knitted.

According to other aspects of the invention, a manufacturing processes is provided in which:

- the concertinaed sheets are placed side by side, parallel to a vertical plane;
- the concertinaed sheets are at least 45% drilled before folding;
- the structure consists of approximately identical concertinaed sheets and the concertinaed sheets of odd row are turned upside down with respect to the sheets of even row about a vertical or horizontal axis lying in the mid-plane of the concertinaed sheet;
- the concertinaed sheets are positioned by means of a bearing region enabling the sheets to be interlocked and also, once they have been locked against each other, ensuring that the concertinaed sheets are stable. The interlocking may be designed so as to prevent the two degrees of translational freedom at certain points of contact or at all of them. Or else it may be designed so as to prevent one degree of translational freedom of certain points of contact and the other degree of freedom at other points of contact;
- the concertinaed sheets are drilled and folded so as to connect the solid surfaces by fold lines, which may or may not be curved, allowing liquid exchange between adjacent deflectors;
- the fold lines are not continuous so as create projections outside the region lying between the two planes containing the folds;
- the bearing region is formed by a local depression;
- the bearing region is formed by cutting and folding and/or bending or twisting;
- projections enable the concertinaed sheets to be positioned by projection and/or notch interlocking;
- projections enable distributors or collectors to be created for the deflectors of an adjacent layer; and

- the degree of perforation of the concertinaed sheets enables wide trickling surfaces to be created.

Another subject of the invention is a process for the separation of gases from air or of hydrocarbons, or of carbon monoxide, or of isotopes in a distillation column comprising at least one heat- and/or mass-exchange device consisting of a stack of stationary ventilators, so as to promote gas mixing, each ventilator consisting of four deflectors whose mid-perpendiculars are inclined and approximately derived from each other by rotation about vertical axes, the sum of the four angles of rotation being 360° and the ventilators being stacked in successive horizontal layers within which each deflector forms part of two adjacent ventilators rotating in opposite directions and such that there is enough space between two adjacent deflectors for the gas to pass through them.

Another subject of the invention is a plant for the separation of gases from air or of hydrocarbons, or of carbon monoxide, or of isotopes in a distillation column comprising at least one heat- and/or mass-exchange device consisting of a stack of stationary ventilators, so as to promote gas mixing, each ventilator consisting of four deflectors whose mid-perpendiculars are inclined and approximately derived from each other by rotation about vertical axes, the sum of the four angles of rotation being 360° and the ventilators being stacked in successive horizontal layers within which each deflector forms part of two adjacent ventilators rotating in opposite directions and such that there is enough space between two adjacent deflectors for the gas to pass through them.

Other aspects of the invention will now be described with reference to the following drawings, in which:

- Figure 1 shows the perspective view of two ventilators of alternate directions of a device according to the invention;

- Figure 2 shows the flow of the liquid over the deflectors of a device according to the invention;
- Figure 3 shows the diagrammatic representation of the cutting of a metal sheet according to the invention;
- Figure 4 shows two diagrammatic representations of the metal sheet of Figure 3 folded into a concertina: 4.1 shows a perspective view and 4.2 shows a view along the axis of the folds;
- Figure 5 shows two diagrammatic representations of two metal sheets of Figure 4 joined together: 5.1 shows a perspective view and 5.2 shows a view along the axis of the folds of one of the sheets;
- Figure 6 shows the industrial-scale cutting of a metal sheet according to the invention;
- Figure 7 shows the structure obtained by joining together two cut and folded sheets according to Figure 6;
- Figure 8 shows several details of the structure in Figure 7: 8.1 shows the four blades which participate in a bearing region, 8.2 shows a plan view of 8.1 and 8.3 shows the two superimposed ventilators created by the structure;
- Figure 9 shows an enlargement of the region 7B of Figure 7 over which the flow of the liquid has been shown;
- Figure 10 shows the manufacture of a bearing point by cutting, folding and interlocking of two layers;
- Figure 11 shows several ways of folding which enable the layers to be interlocked on each other; and
- Figure 12 shows a column shell with structured packings consisting of the device of the present invention.

Figure 1 shows two adjacent stationary ventilators (1A and 1B) in a horizontal layer. The deflectors are not necessarily derived from each other by rotation. These two ventilators stir the gas flow in opposite directions (vortex 1D and 1E), thus creating the maximum turbulence. It may be pointed out that the deflector 1C is common to the two ventilators. The complete structure is obtained by repeating this pattern in the three directions, with or without variations in the geometry of the deflectors. The documents mentioned above are silent with regard to the flow of liquid in the structure.

Figure 2 shows the liquid spreading out over the deflectors. The manner in which the deflectors are connected together between two horizontal layers will be seen later. Let us merely assume that each deflector is fed via its apex (2C) with the trickling liquid. Of course, the maximum amount of the surface has to be wetted. This remark suffices to sketch the best shape to give the deflectors.

The upper part (2A) must be "pointed" so as to follow the spreading of the liquid from its feed point. On the other hand, once this spreading has been achieved, the deflector may keep its maximum width over a certain distance in order to increase the trickling surface area (2B). Collecting is thus easier and can take place on low-slope edges with a slightly inclined contour. This leads to a "bulging" shape.

The optimum distribution of the liquid on both sides of deflectors results in a hole (2D) being drilled close to the vertex (2C), allowing some of the liquid to pass through to the other side.

In order for there not to be a preferential path for the liquid, it is expedient to make sure that the same stream of liquid is distributed in several directions and constantly remixed. Thus, an edge segment (2E) common to the two deflectors divides the liquid flowing over the deflector into two and creates a mixing region (2F).

For cost reasons, the deflectors have to be able to be manufactured from a sheet material. Unfortunately, the technique of drilling-folding and/or drilling-bending used hitherto for manufacturing structured packings does not make it possible to obtain the rich variety of shapes to the level of requirement of the architecture described above.

However, a method exists which does make it possible to obtain a very rich variety of shapes from a flat product: cutting-folding. To be convinced of this, one has only to look at certain "pop-up books" or certain packages made of board. Folding is well-known for manufacturing polyhedra. This process has, to our knowledge, never been used to manufacture structured packings. It is also possible to combine it with stamping, so as to obtain surfaces which cannot be opened out flat. Although very many options are possible, this process can be particularly economic since the successive operations of cutting, folding and even stamping may be integrated into the same press tool.

Figure 3 shows the diagrammatic cutting of a sheet before folding, in which the deflectors are "solid" quadrilaterals (3E). The sheet cut in this way is then folded into a concertina along the dotted lines. The bold dotted lines (3A) are "valley" folds while the fine dots (3B) mark "peak" folds. It should be clearly noted that these fold lines are discontinuous since the dark-grey parts (3C) are not folded with the rest and therefore, after folding, form projections which stand out from the two planes containing the peak and valley folds. In fact, the folding only occurs along the regions shown symbolically by black spots (3D) which form both a connection between the deflectors and a bearing and/or interlocking point serving for stacking and positioning, when stacking the concertinaed sheets. It will be seen later which devices may be used to form these regions.

Figure 4 shows two diagrammatic representations of a sheet of Figure 3 folded into a concertina. 4.1 is a perspective view of the folded sheet. 4.2 is a top view of the sheet along the axis of the folds, in which the concertina formed by the sheet (4G) may be clearly seen. The folding creates two plane orientations which are characterized by the areas of different grey of the deflectors (4A and 4B). The projections (4C and 4D), which stick out from the region lying between the two planes containing the fold lines, may be seen. It is therefore seen that the deflectors, once they have been folded, offer the liquid a "pointed" spreading surface (4E), which is symmetrical with respect to the line of greatest slope, and then a widened trickling surface (4F).

Figure 5 shows two diagrammatic representations of the structure obtained by joining together two strips folded as in Figure 4. 5.1 is a perspective view of the structure. 5.2 is a view from above, along the axis of the folds of the sheet in the front plane, in which the two stacked strips 5F and 5G may be seen. The concertinaed sheet of Figure 4 may again be seen in the front plane of 5.1 and 5F. In the rear plane of 5.1 and at 5G there is an identical sheet turned over through 180° with respect to a vertical axis. Two superimposed ventilators are created by this structure (5A and 5B). It will be noticed that these ventilators are of two different types: 5A is a ventilator which is "closed" with respect to the centre of rotation; that is to say that the widening of the trickling surface is housed on the side of the centre of rotation, thus offering a narrower passage for the gas. On the other hand, 5B is an "open" ventilator. Along the same vertical, there is an alternation of the two types of ventilator. In order to obtain ventilators rotating in opposite directions, it would be necessary to add an additional concertinaed sheet. The structure obtained at 5C indicates why the bottom of the deflectors does not have a symmetrical trickling surface. This is because, if the base of the deflectors were rectangularly symmetric it would no doubt have a greater trickling surface area, but a junction of the edges of the two deflectors forming a kind of horizontal gutter would be obtained in 5C. Such a structure would be highly disadvantageous, both with respect to the gas flow and with respect to the liquid flow. Finally, it may be pointed out that the projections of the concertinaed sheet in the first plane (5D) fit in exactly between two consecutive folds of the sheet in the second plane. Likewise, the projections of the sheet in the rear plane (5E) fit in between the folds of the sheet in the front plane. The sheets are thus positioned relative to each other in all directions and simply locking them together ensures that the structure is stable.

The purpose of all the previous figures, which are intentionally diagrammatic, is to show the main characteristics of the structure. It is quite clear that the structure in Figure 5 has no mechanical integrity since there is no material at the connection points between deflectors. The cutting-folding principle, optionally combined with stamping, makes it possible to obtain a very wide variety of shapes, from which it may be necessary to draw in order to improve the structure, both with respect to its performance characteristics and manufacturing simplicity. The figures which follow describe a structure which has been validated on an industrial scale, having good mechanical integrity and incorporating several improvements with respect to the liquid flow and to the manufacture.

Figure 6 shows the cutting of a non-folded sheet. The fold lines (6A) are shown by dotted lines; it may clearly be seen that they are discontinuous. In order to obtain good mechanical integrity, there remains, at the connection points, one third of the material which would be folded if there were no cutting. In order to keep a structure as close as possible to the ideal case, this material has been distributed unequally over the various connection points. At 6B, adding a vertical edge is a good way of obtaining a long fold while losing the minimum amount of open surface. On the other hand, it is necessary to avoid introducing a horizontal edge on which the liquid accumulates; a fold line has therefore been designed which constitutes an edge segment (6C) allowing lateral partition of the liquid. The projection at the point 6D serves both for distributing the liquid and for fastening the strips together. Finally, a hole (6E), allowing the liquid to pass from one side of the sheet to the other, may be drilled in each deflector.

Figure 7 shows two sheets of Figure 6 which are folded and joined together. The series of stacked ventilators (7A) may be seen. Figure 5 had shown that the strips were positioned perfectly by the projections. The fold lines introduce into this positioning an imprecision equal to the length of the fold line. In order to compensate for this, it is possible when folding to create a local depression on the fold line so that the point inserted furthest is centred on the bearing point. Thus, when assembling the structure, the latter is held in position simply by the strips being locked against each other. A bearing point, where the projection of the strip in the rear plane is provided with a tip constituting both a kind of attachment for fastening the strips and a liquid distributor for remixing, may be seen at 7B.

Figure 8 shows several enlargements of Figure 7. Figure 8.1 shows an enlargement of the bearing region 7B. Figure 8.2 shows a top view of 8.1 with no concealed faces, in which it may be seen that the deflectors penetrate the space lying along the vertical of the adjacent deflectors so as to create a wide trickling surface (8.2A) and a liquid feed from another deflector (8.2B). Figure 8.3 shows two types of superimposed ventilators created by the structure: an "open" ventilator (8.3A) and a "closed" ventilator (8.3B).

Figure 9 shows a detail of Figure 7, lying around 7B. The deflectors 9D and 9F belong to the concertinaed sheet in the rear plane while 9C and 9E belong to the sheet in the front plane. The black arrows depict the flow of the liquid over the deflectors. The structure is symmetrical with respect to the bearing point (9A). The way in which the tip (9B) and its symmetry form attachments, which stabilize the structure, may be seen. When the two concertinaed sheets are placed face to face, the structure deforms a little and resumes its position due to elasticity when the tip has adopted its final position. At 9C there is a region which causes lateral partition of the liquid followed by remixing. The liquid which flows over the deflector in the rear plane divides into two parts (9D). Part of the liquid, after undergoing free fall (9G), will wet the deflector in the front plane (9E) via the distributor formed by the projection at the tip (9B) and therefore mixes with the liquid flowing over the adjacent concertinaed sheet. The other part of the liquid remains on the same concertinaed sheet and will wet the underside of the deflector 9F.

Figure 10 shows one possible way of interlocking the sheets at a bearing point, which may replace the local depression at a common point 6C, i.e. the centre of a ventilator. In order to make the figures more understandable, they are projected in such a way that the top-down direction goes towards the rear of the sheet. Figure 10.1 shows just the detail of the cutting at the bearing point. The cutting line is 10.1A. Next, the sheets are folded at 10.1C and at 10.1B. Figure 10.2 shows the two folded sheets face to face before they are interlocked and Figure 10.3 shows them interlocked. The interlocking forms the centre of a ventilator and the four orientations of the deflectors in Figure 10.3 may be seen, provided the figure is straightened.

The interlocking may be designed so as to prevent the two degrees of translational freedom at certain points of contact or at all of them. Alternatively, it may be designed so as to prevent one degree of translational freedom at certain points of contact and the other degree of freedom at other points of contact.

Figure 11 shows the sheets 11 according to the invention, in which a bearing face is flat and bounded by two folds (11.2) or is curved (11.3) or involves more than two folds (11.4). In these three cases, the cutting allows the edges of the deflectors to form projections (11A). Figure 11.1 shows simple concertina folding. Figure 11.2 shows the case in which the facet (11B) lying inside a pair of folds is flat, as in Figure 10. In Figure 11.3, there is a curved surface (11C) instead of folds. Finally, in Figure 11.4 there is an additional fold (11D).

Figure 12 shows a shell 100 of a distillation column containing two structured packing units 200 consisting of a heat- and/or mass-exchange device according to the present invention.

The folded sheets 300 are joined together obliquely with respect to the axis of the shell 100.

The heat- and mass-exchange device of the present invention can be installed in any column of an air separation apparatus, for example the medium-pressure column, the low-pressure column, the argon column or the nitrogen-removal column.

Each column may contain heat- and mass-exchange devices according to the present invention, as well as the conventional structured packings (of the crossed-corrugated type, for example) and/or loose packings and/or plates.

The specific surface area of the heat- and mass-exchange device of the present invention may vary from one section of a column to another.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. Heat- and/or mass-exchange device consisting of a stack of stationary ventilators (1A, 1B, 5A, 5B, 7A, 8.3A, 8.3B), so as to promote gas mixing, each ventilator consisting of four deflectors (1C, 3E, 4A, 4B, 9C, 9D, 9E, 9F) whose mid-perpendiculars are inclined and approximately derived from each other by rotation about vertical axes, the sum of the four angles of rotation being 360° and the ventilators being stacked in successive horizontal layers within which each deflector forms part of two adjacent ventilators rotating in opposite directions and in such a way that there is enough space between two adjacent deflectors for the gas to pass through them.

2. Device according to Claim 1, in which:

- the deflectors (1C, 3E, 4A, 4B, 9C, 9D, 9E, 9F) of the ventilators (1A, 1B, 5A, 5B, 7A, 8.3A, 8.3B) are neither rhombuses, one diagonal of which is horizontal, nor triangles, the base of which is horizontal; or
- the angles of rotation of the deflectors are not 90°; or
- the axes of rotation do not pass through the ends of the horizontal diagonals of the rhombic deflectors; or
- the axes of rotation do not pass through the ends of the horizontal bases of the triangular deflectors; or
- the upper vertices of the rhombuses or of the triangles of one layer do not coincide with a vertex of a rhombus or of a triangle of the layer immediately above.

3. Device according to Claim 1 or 2, in which the lower part of some or all of the deflectors (1C, 3E, 4A, 4B, 9C, 9D, 9E, 9F) is unsymmetrical.

4. Device according to Claim 1, 2 or 3, in which the upper part (2A, 4E) of some or all of the deflectors (1C, 3E, 4A, 4B, 9C, 9D, 9E, 9F) is

symmetrical with respect to the line of greatest slope and is substantially in the shape of an inverted V, so as to promote spreading of the liquid.

5. Device according to one of the preceding claims, in which some or all of the deflectors are drilled with one or more holes (2D, 6E), with or without vertical axis symmetry, so as to encourage the liquid to pass under the deflectors.

6. Device according to one of the preceding claims, in which some or all of the deflectors are connected to one or more of their neighbours in the same horizontal plane by a common edge segment (2E, 6C) which is rounded, flattened or depressed, so as to allow lateral partition of the liquid between deflectors.

7. Device according to one of the preceding claims, in which some or all of the deflectors are connected to one or more of their neighbours by a common edge segment (2E, 6A, 6C) which is rounded, flattened or depressed, so as to fasten the deflectors together.

8. Device according to one of the preceding claims, in which some or all of the deflectors penetrate the space lying in the vertical of an adjacent deflector.

9. Device according to one of the preceding claims, in which some or all of the deflectors are designed so as to feed another deflector with liquid, generally with the aid of a tip (6D, 8.2B, 9B), or to collect the liquid from another deflector.

10. Device according to one of the preceding claims, in which some or all of the pairs of neighbouring deflectors have projections (6D, 8.2B, 9B, 11A) and/or notches allowing mutual interlocking so as to fasten the deflectors together.

11. Device according to one of the preceding claims, in which the lower part of some or all of the deflectors is at least partly widened, so as to

maintain as high as possible a trickling surface area (2B, 4F, 8.2A) for the liquid.

12. Device according to one of the preceding claims, in which one end of at least two deflectors (1C, 3E, 4A, 4B, 9C, 9D, 9E, 9F) forms a projection (3C, 4C, 4D, 5D, 5E, 6D, 9B, 11A).

13. Device according to Claim 12, in which one or each projection (3C, 4C, 4D, 5D, 5E, 6D, 9B, 11A) interlocks with another projection or a notch so as to fasten the layers of ventilators.

14. Process for manufacturing a device according to one of the preceding claims, in which flat sheets of metal or of another material are cut and folded and/or bent, twisted or stamped in order to form concertinaed sheets (4G, 5F, 5G, 300), with or without projections, the solid surfaces (3E) forming flat, folded, curved or twisted deflectors.

15. Manufacturing process according to Claim 14, in which the concertinaed sheets (4G, 5F, 5G, 300) are placed side by side, parallel to a vertical plane.

16. Manufacturing process according to Claim 14 or 15, in which the concertinaed sheets (4G, 5F, 5G, 300) are at least 45% drilled before folding.

17. Manufacturing process according to one of Claims 14 to 16, in which the structure consists of approximately identical concertinaed sheets (4G, 5F, 5G, 300) and in which the concertinaed sheets of odd row (5F) are turned upside down with respect to the sheets of even row (5G) about a vertical or horizontal axis lying in the mid-plane of the concertinaed sheets.

18. Manufacturing process according to one of Claims 14 to 17, in which the concertinaed sheets (4G, 5F, 5G, 300) are positioned by means of a bearing region (3D, 7B) enabling the sheets to be interlocked and also, once they have been locked against each other, ensuring that the concertinaed sheets are stable.

19. Manufacturing process according to Claim 18, in which the bearing region (3D, 7B) is formed by a local depression.

20. Manufacturing process according to Claim 18 or 19, in which the bearing region (3D, 7B) is formed by cutting and folding and/or bending or twisting.

21. Manufacturing process according to one of Claims 14 to 20, combined with Claim 6, in which the concertinaed sheets are drilled and folded so as to connect the solid surfaces by fold lines (6C), which may or may not be curved, allowing liquid exchange between adjacent deflectors.

22. Manufacturing process according to one of Claims 14 to 21, in which the fold lines (3A, 3B, 6A, 6C) are not continuous so as to create projections (3C, 4C, 4D, 5D, 5E, 6D, 11A) outside the region lying between the two planes containing the folds.

23. Manufacturing process according to one of Claims 14 to 22, in which projections (3C, 4C, 4D, 5D, 5E, 6D, 9B, 11A) enable the concertinaed sheets to be positioned by projection and/or notch interlocking.

24. Manufacturing process according to one of Claims 14 to 23, in which projections (3C, 4C, 4D, 5D, 5E, 6D, 9B, 11A) enable distributors (6D, 8.2B, 9B) or collectors to be created for the deflectors of an adjacent layer.

25. Manufacturing process according to one of Claims 14 to 24, combined with Claim 11, in which the at least 45% degree of perforation of the concertinaed sheets (4G, 5F, 5G) enables wide trickling surfaces (2B, 4F, 8.2A) to be created.

26. Process for the separation of gases from air or of hydrocarbons, or of carbon monoxide, or of isotopes in a distillation column comprising at least one device according to one of Claims 1 to 13.

27. Plant for the separation of gases from air or of hydrocarbons, or of carbon monoxide, or of isotopes in a distillation column comprising at least one device according to one of Claims 1 to 13.

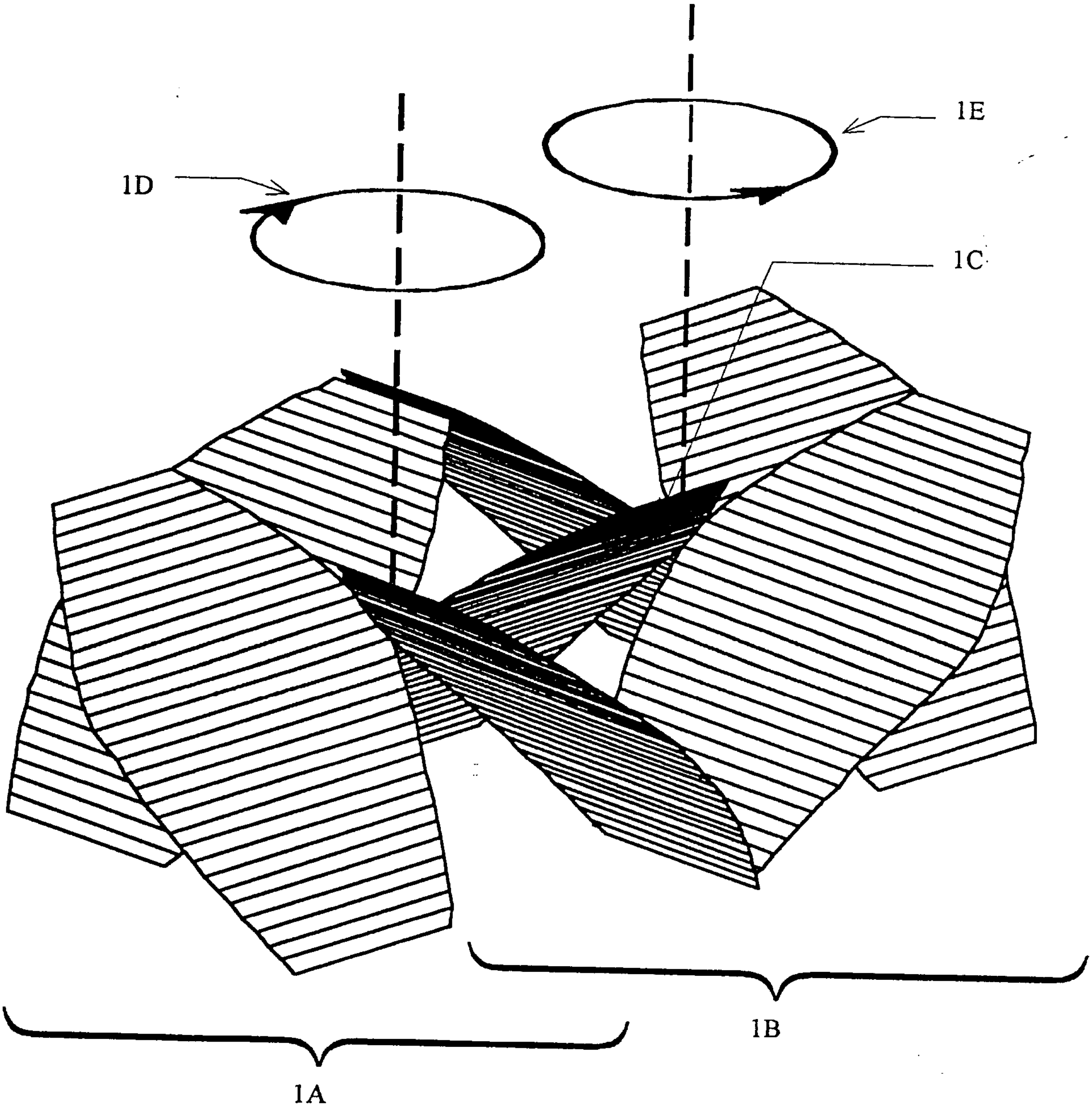


Fig. 1

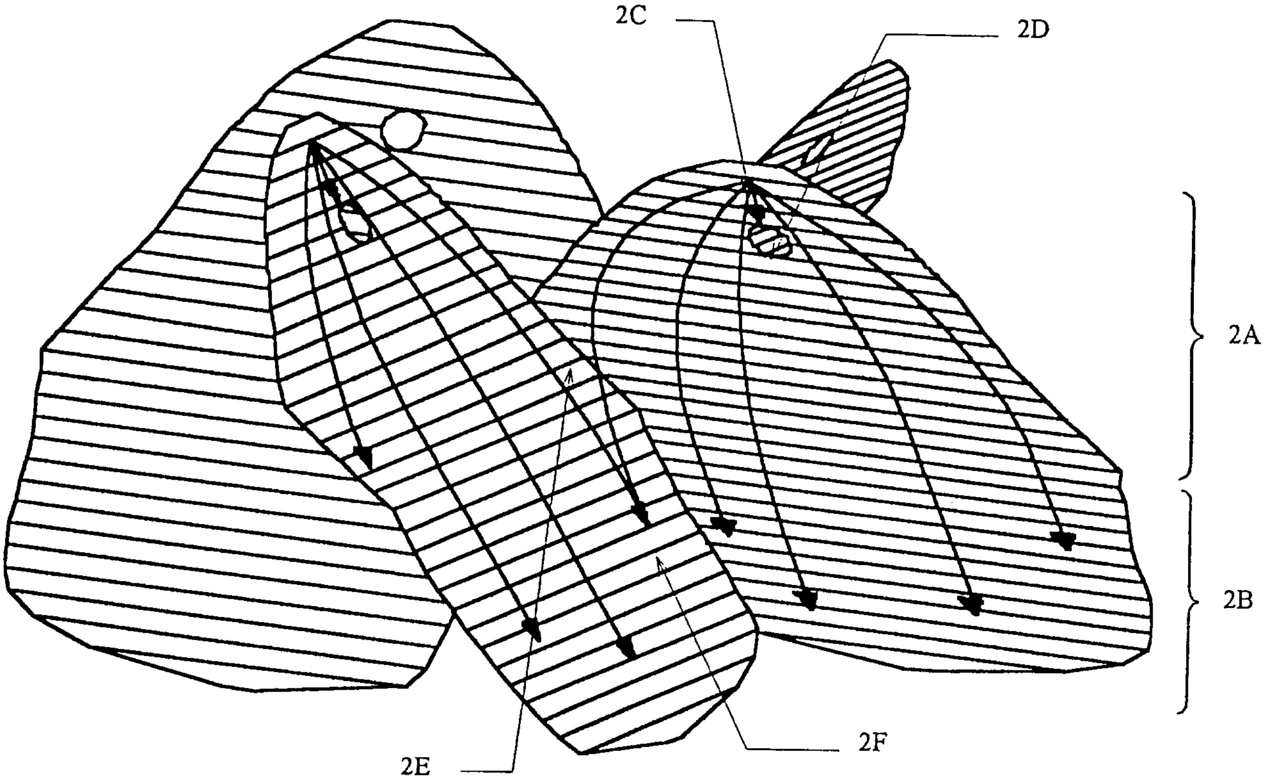


Fig. 2

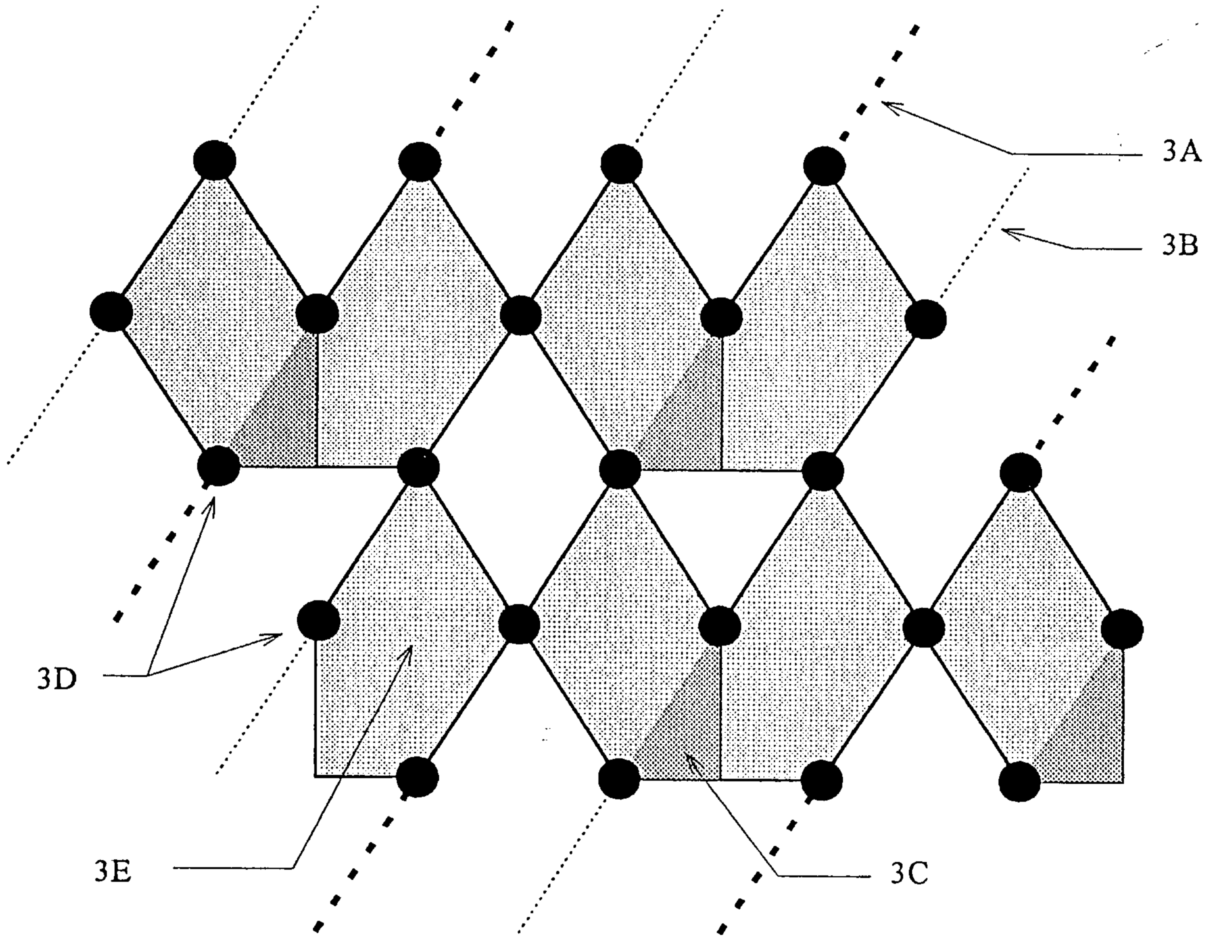
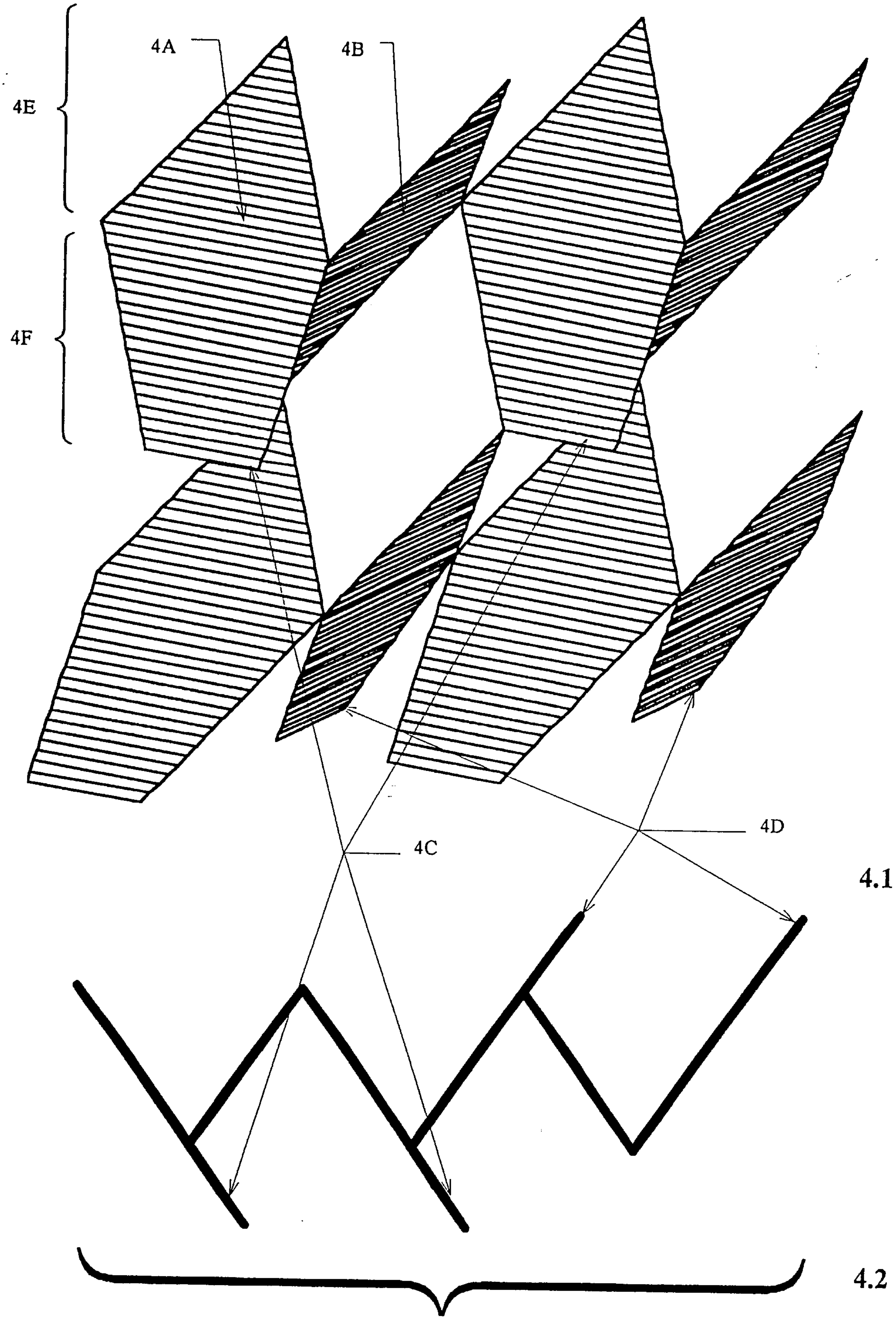


Fig. 3



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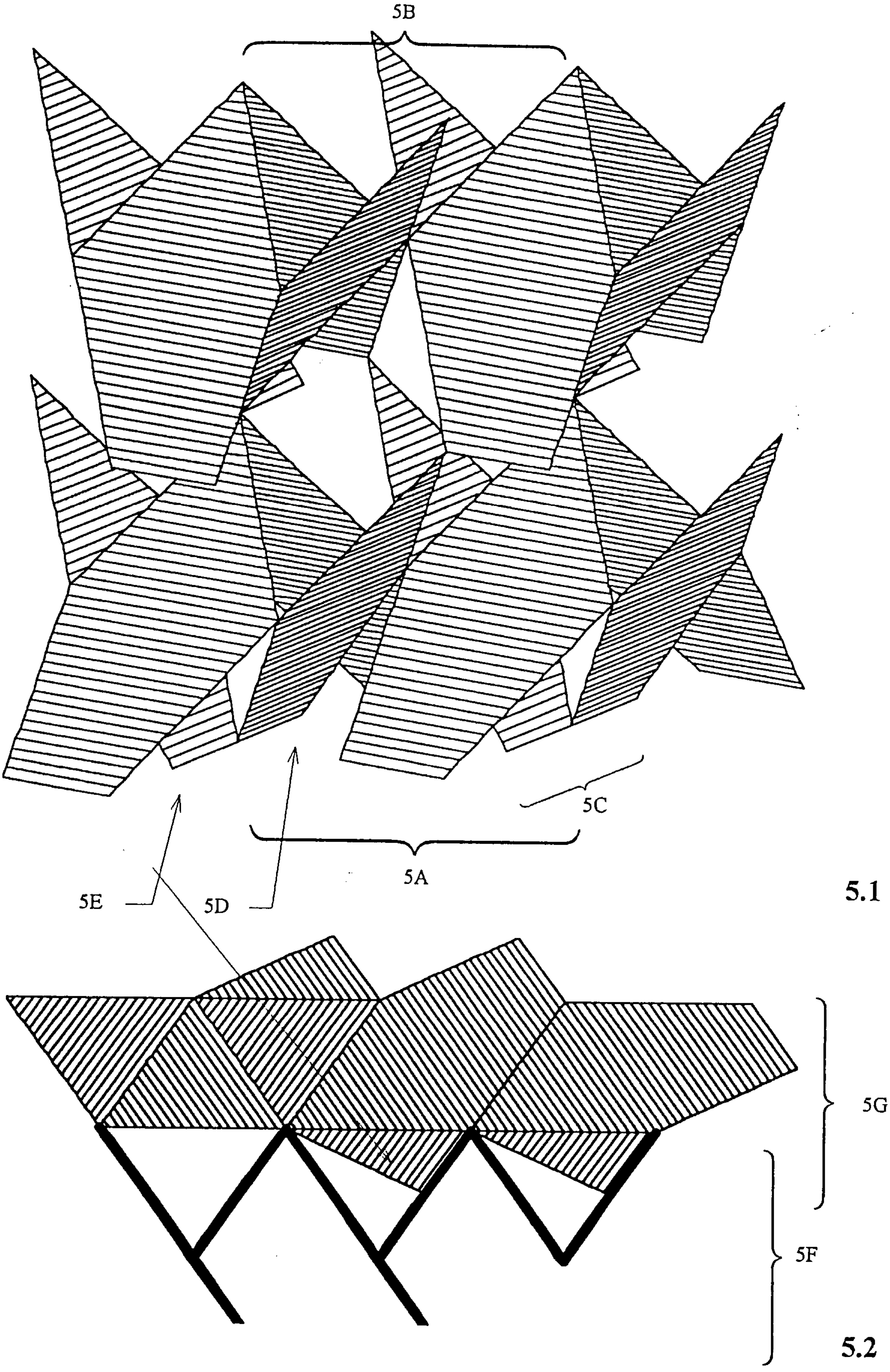


Fig. 5

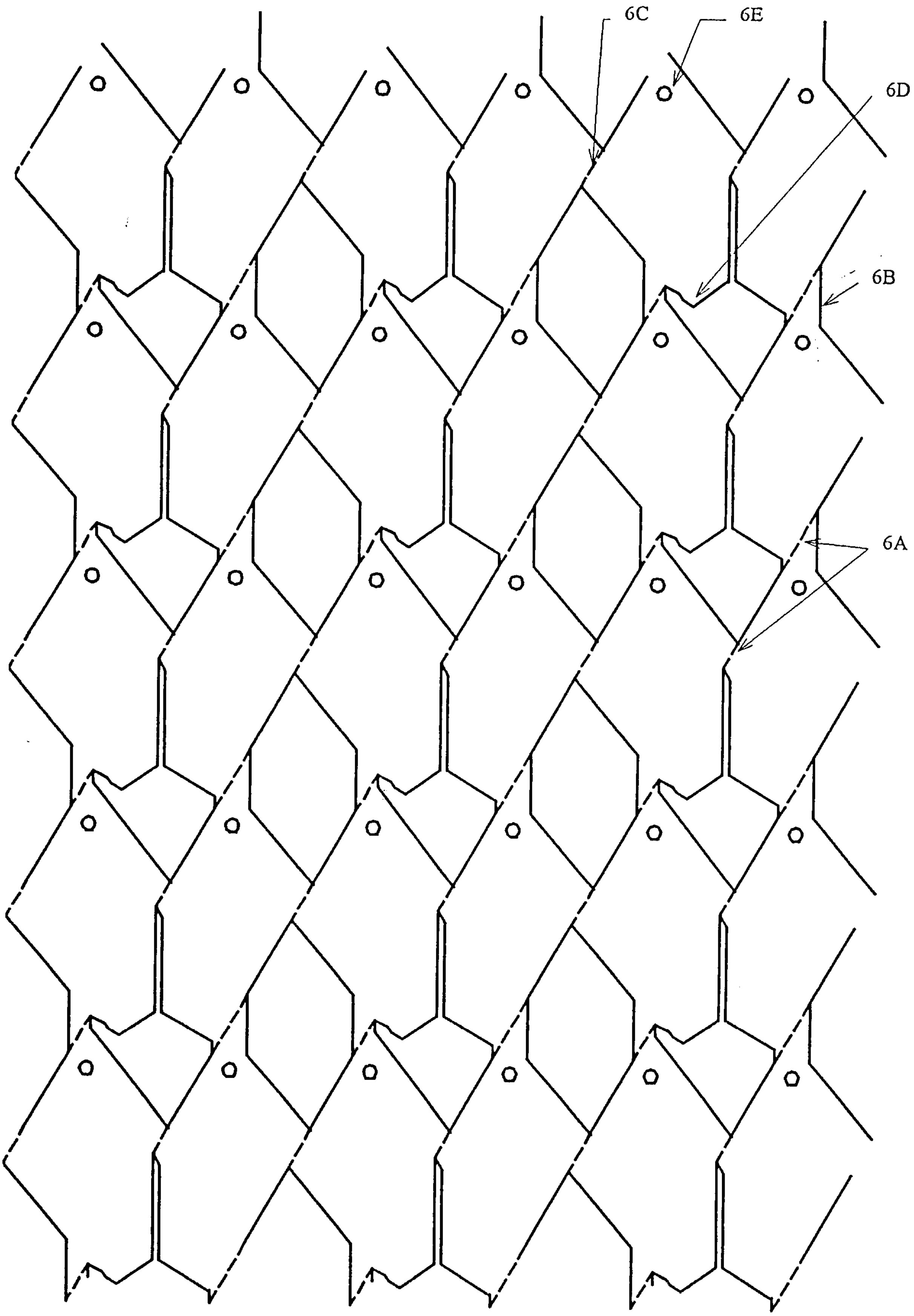


Fig. 6

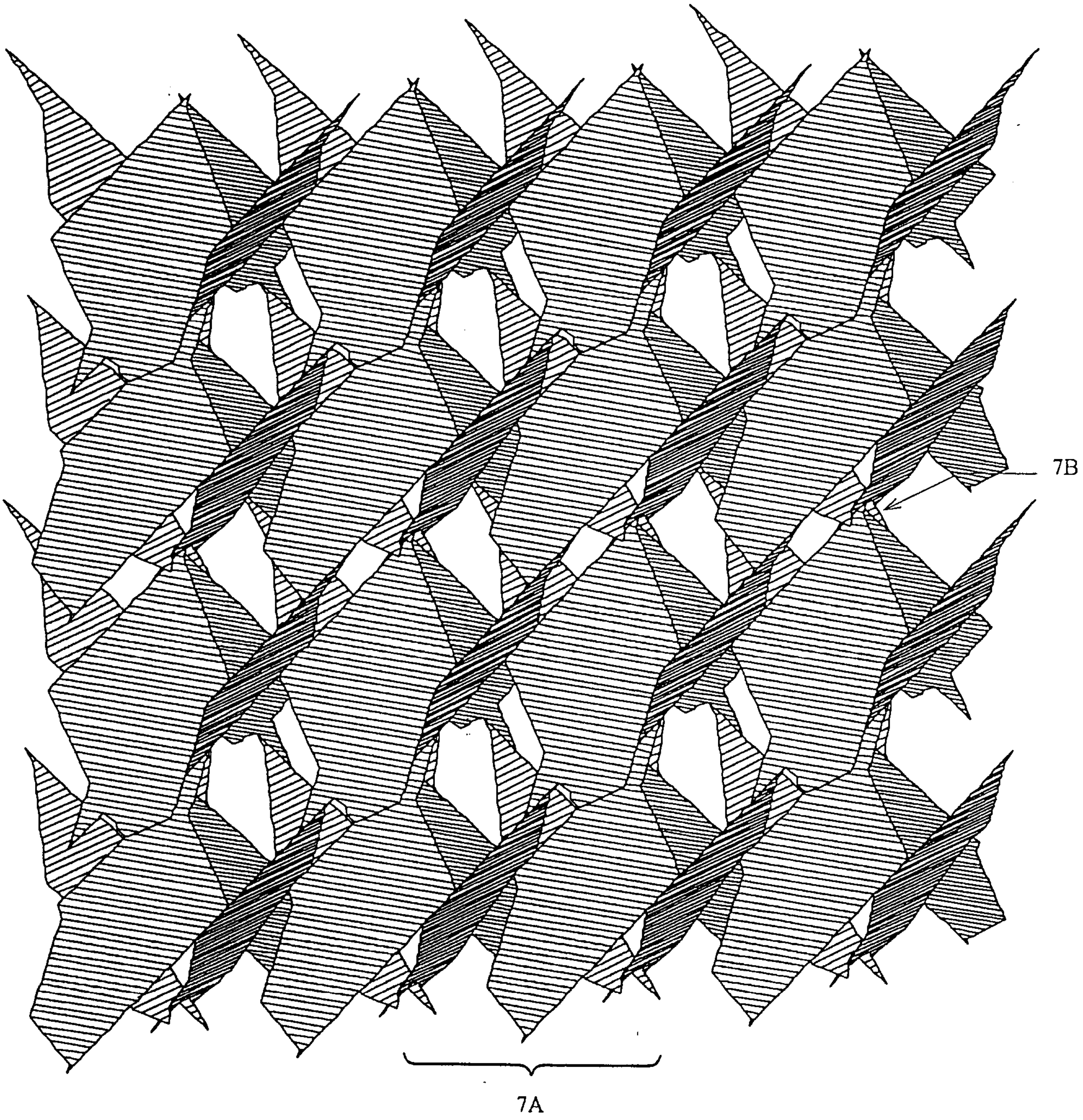
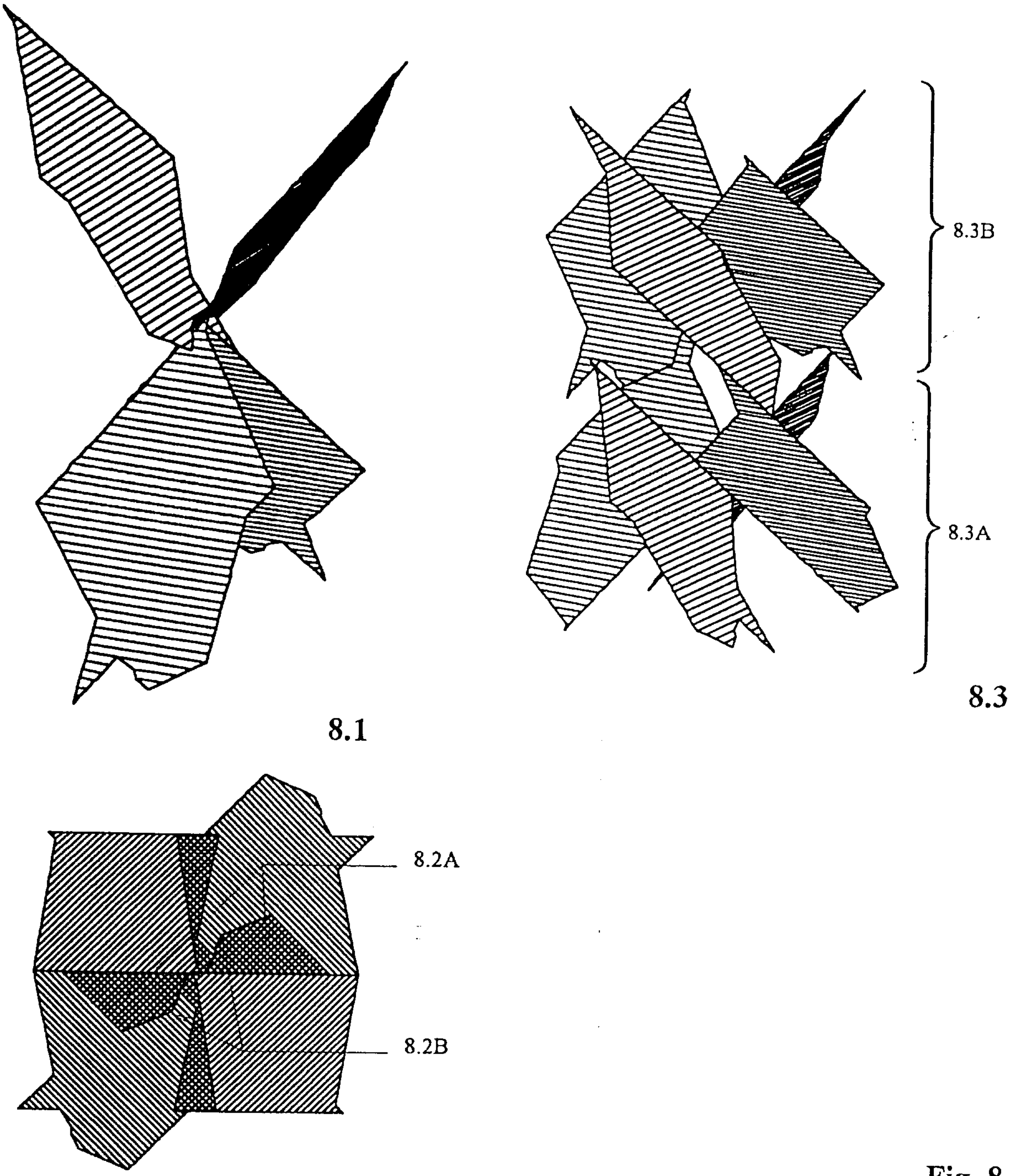


Fig. 7



8.1

8.3

8.2

Fig. 8

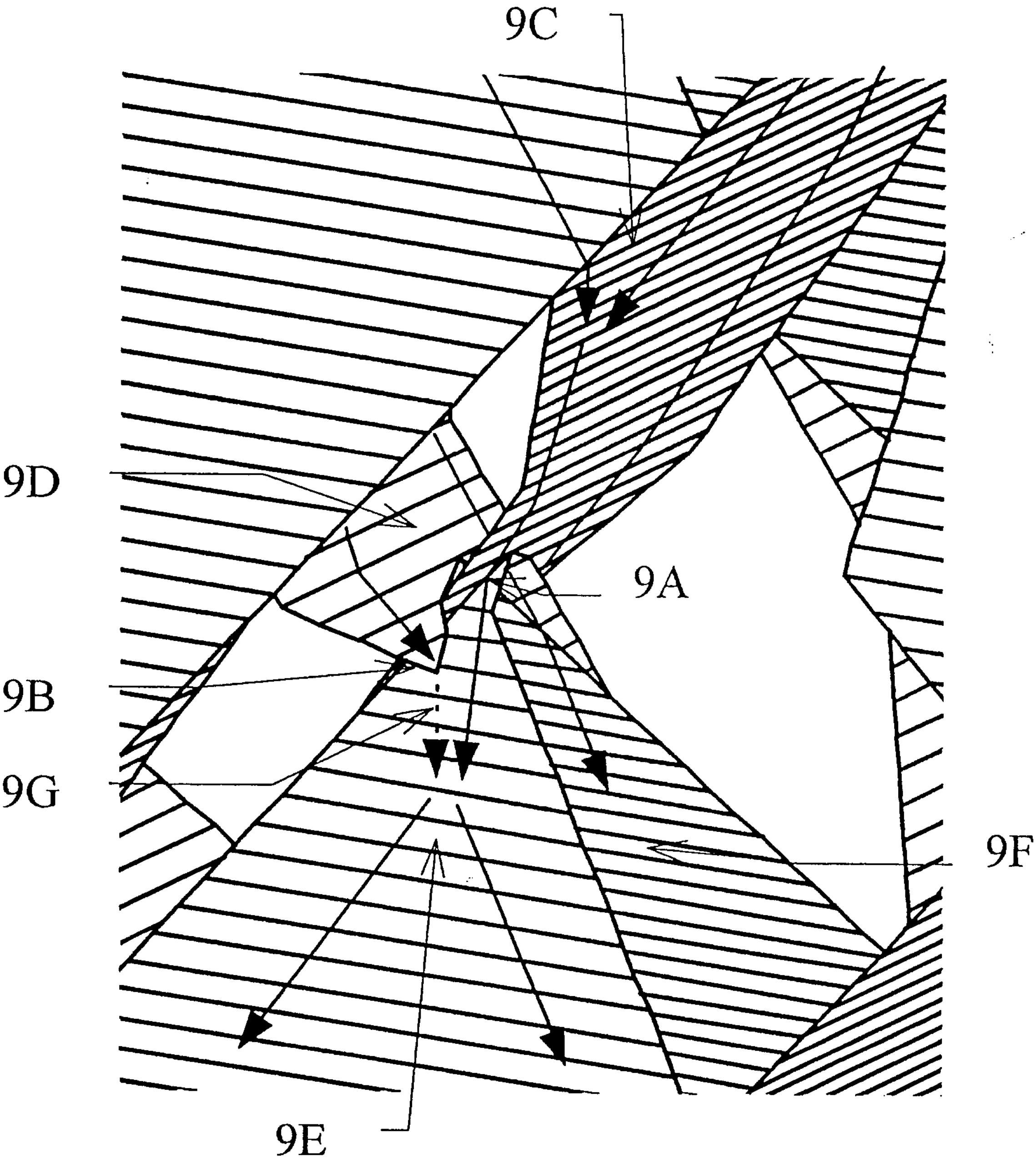
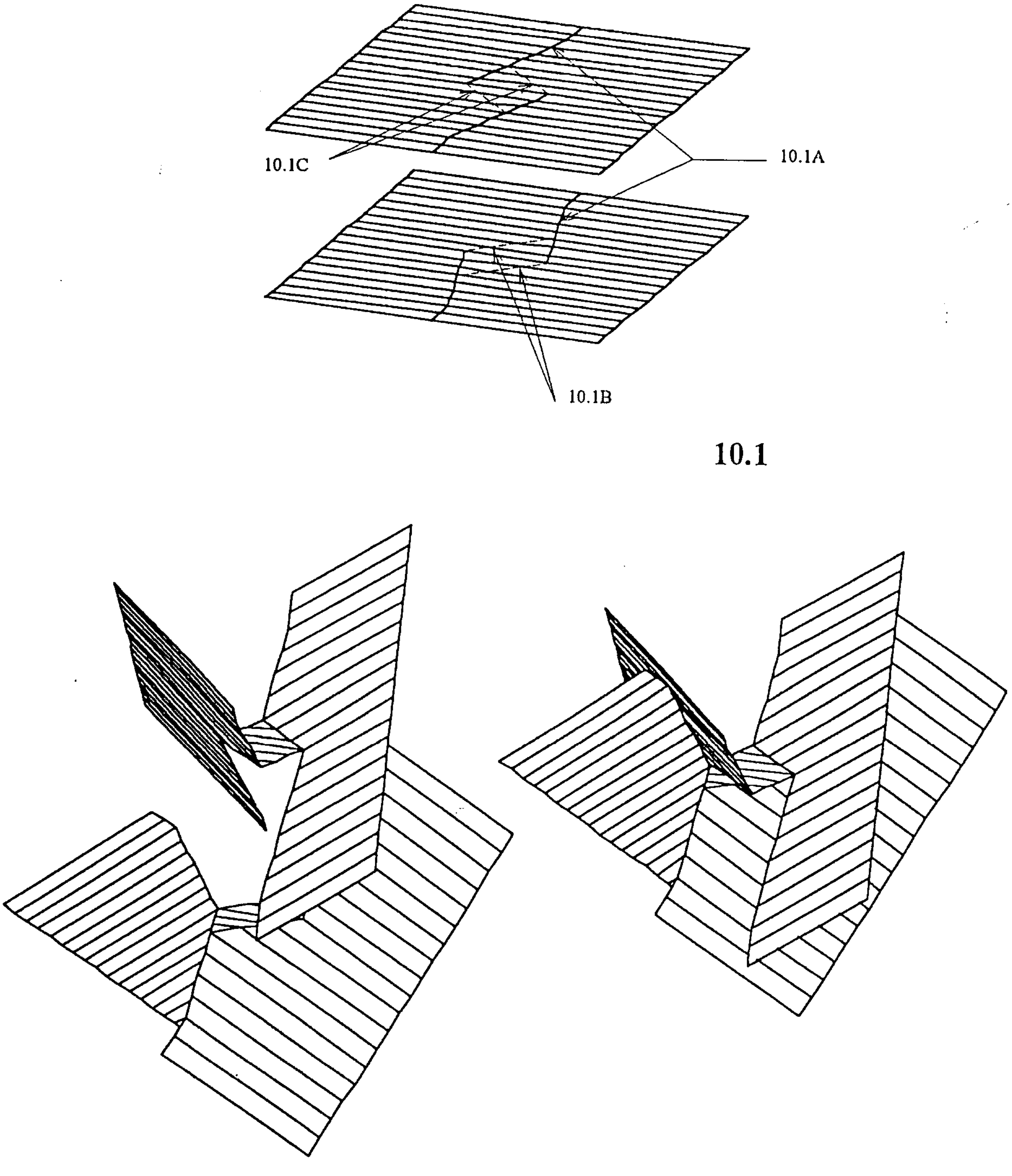


Fig. 9



10.1

10.2

10.3

Fig. 10

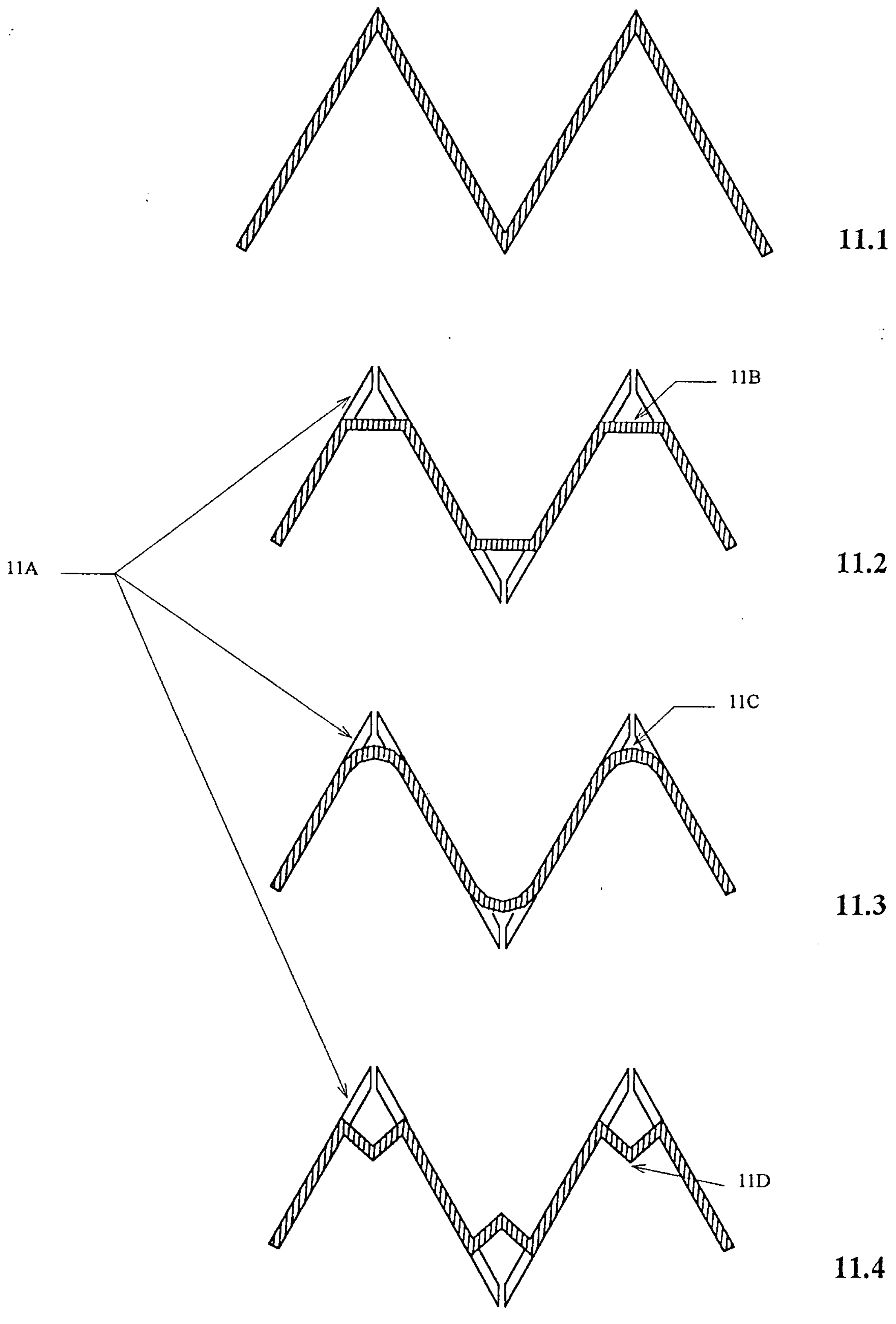


Fig. 11

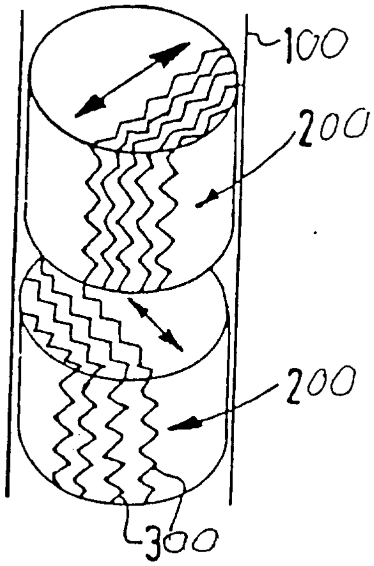
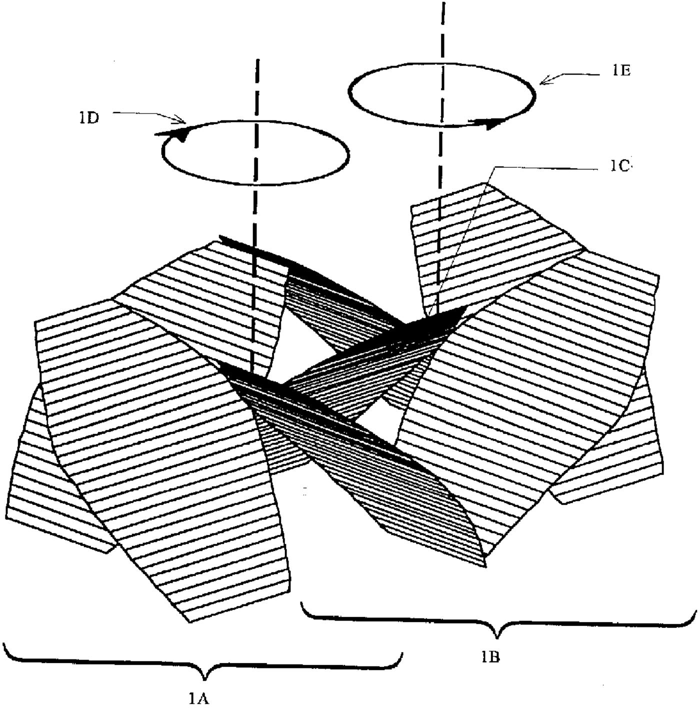


Fig. 12


1D
1E
1C
1A
1B