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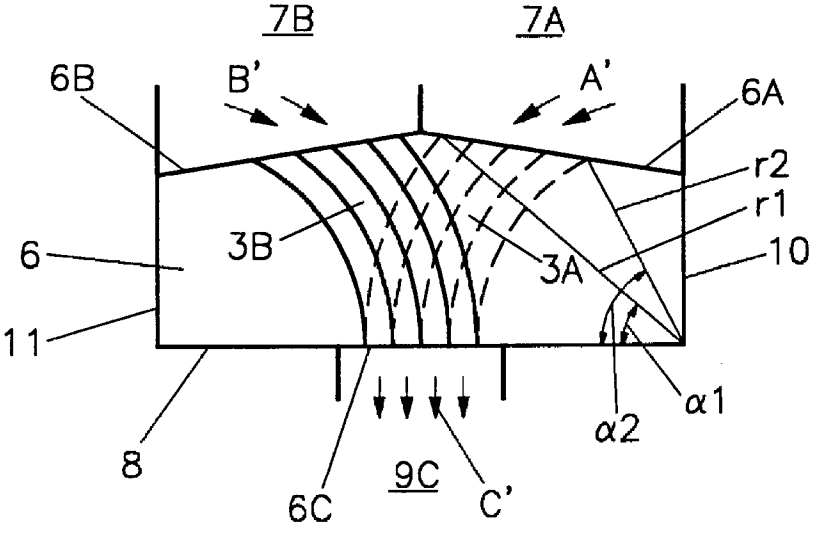
(54) **MICROMELANGEUR STATIQUE**
(54) **STATIC MICROMIXER**



(57) Cette invention concerne un micromélangeur statique comportant une enceinte de mélange et, en amont de celle-ci, un élément de canalisation servant à charger séparément dans ladite enceinte les fluides à mélanger ou à disperser. Cette invention a pour objet de réaliser un élément de canalisation d'alimentation d'un mélangeur statique de ce type, qui permettra de rehausser l'efficacité du procédé de mélange. L'objet de l'invention présente les caractéristiques suivantes : a) les éléments gaufrés A et B de l'élément de canalisation se composent chacun de pellicules minces ayant une épaisseur comprise entre 10 et 1000 micromètres, de

(57) Disclosed is a static micromixer with a mixing chamber and a duct component upstream of the former for separate feeding to the mixing chamber of the fluids to be mixed or dispersed. The aim of the invention is to design the duct component in a static mixer of this generic type in such a way as to improve the efficiency of the mixing process in the mixing chamber. The invention is characterised by the following features: a) the wafer-like elements A and B for the duct component each consist of thin films with a thickness of 10-1000 microns, preferably < 250 microns, the lateral dimension being of the order of millimetres, a family of adjacent

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préférence supérieure à 250 micromètres, et une largeur de l'ordre du millimètre, lesdits éléments gaufrés comportant une série de gorges adjacentes formées de façon à définir, une fois lesdits éléments superposés, des séries séparées de canaux servant à acheminer dans l'enceinte les fluides A' et B' à mélanger; b) les gorges ont une profondeur inférieure à 1000 micromètres, de préférence inférieure à 250 micromètres, une largeur comprise entre 1 micromètre et 1 millimètre, mais de préférence inférieure à 1000 micromètres, l'épaisseur de paroi des flancs et du fond des gorges étant inférieure à 1000 micromètres et de préférence à 250 micromètres; c) chaque série de gorges ménagées dans les pellicules superposées suit un arc menant alternativement de l'enceinte de mélange à une enceinte d'alimentation en fluides A' et B', toutes les gorges étant parallèles et débouchant dans l'enceinte de mélange.

grooves being formed in each wafer-like element such that when the foils are superposed one on top of the other a separate series of channels is formed for feeding the fluids A' and B' to be mixed; b) the grooves have depths of less than 1000 microns, preferably less than 250 microns, widths of between 1 micron and the millimetre range but preferably less than 1000 microns, the wall thickness of the intermediate ridges and groove floors being less than 1000 microns and preferably less than 250 microns; c) each family of grooves in the stacked films follows an arc and lead alternately from the mixing chamber to a feed chamber for the fluid A' or B' in such a way that all families of grooves in the films are aligned parallel to one another and discharge into the mixing chamber.

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(54) Title: STATIC MICROMIXER

(54) Bezeichnung: STATISCHER MIKROVERMISCHER

(57) Abstract

Disclosed is a static micromixer with a mixing chamber and a duct component upstream of the former for separate feeding to the mixing chamber of the fluids to be mixed or dispersed. The aim of the invention is to design the duct component in a static mixer of this generic type in such a way as to improve the efficiency of the mixing process in the mixing chamber. The invention is characterised by the following features: a) the wafer-like elements A and B for the duct component each consist of thin films with a thickness of 10-1000 microns, preferably < 250 microns, the lateral dimension being of the order of millimetres, a family of adjacent grooves being formed in each wafer-like element such that when the foils are superposed one on top of the other a separate series of channels is formed for feeding the fluids A' and B' to be mixed; b) the grooves have depths of less than 1000 microns, preferably less than 250 microns, widths of between 1 micron and the millimetre range but preferably less than 1000 microns, the wall thicknesses of the intermediate ridges and groove floors being less than 1000 microns and preferably less than 250 microns; c) each family of grooves in the stacked films follows an arc and lead alternately from the mixing chamber to a feed chamber for the fluid A' or B' in such a way that all families of grooves in the films are aligned parallel to one another and discharge into the mixing chamber.

(57) Zusammenfassung

Die Erfindung betrifft einen statischen Mikrovermischer mit einer Mischkammer und einem vorgeschalteten Führungsbauteil für die getrennte Zufuhr von zu mischenden oder zu dispergierenden Fluiden zu der Mischkammer. Die Erfindung hat zur Aufgabe, bei einem statischen Vermischer der gattungsgemäßen Bauart das Führungsbauteil für die getrennte Zufuhr der zu mischenden Fluide zur Mischkammer so zu gestalten, daß eine erhöhte örtliche und zeitliche Effektivität der Vermischung in der Mischkammer erzielt wird. Die Erfindung ist durch die folgenden Merkmale gekennzeichnet: a) die platternartigen Elemente A und B für das Führungsbauteil bestehen jeweils aus dünnen Folien mit einer Dicke von 10 bis 1000 μm, vorzugsweise < 250 μm, bei einer lateralen Ausdehnung im Millimeterbereich, in die je eine Schar benachbarter Nuten eingearbeitet ist, so daß beim Übereinanderschichten der Folien je eine Reihe von Kanälen für die Führung der zu mischenden Fluide A' und B' entsteht; b) die Nuten haben Tiefen von < 1000 μm, vorzugsweise < 250 μm, Breiten von 1 μm bis in den Millimeterbereich, vorzugsweise jedoch < 1000 μm, bei Wanddicken der Zwischenstege und Nutböden von < 1000 μm, vorzugsweise < 250 μm; c) die jeweiligen Scharen von Nuten in den übereinandergeschichteten Folien verlaufen jeweils bogenförmig gekrümmt und abwechselnd von der Mischkammer zu je einer Zufuhrkammer für das Fluid A' bzw. B' in der Weise, daß alle Scharen von Nuten der Folien parallel zueinander ausgerichtet in die Mischkammer ausmünden.

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STATIC MICROMIXER

The invention relates to a static micromixer with a mixing chamber and a guide structure arranged upstream of the mixing chamber for the separate admission of the fluids to be mixed or to be dispersed to the mixing chamber in accordance with the preamble of claim 1.

WO 91/16970 A1 discloses a mixing arrangement in a column with mixing-, catalyst- and guide elements arranged in various layers. Adjacent elements within one layer are arranged inclined with respect to the main flow direction. For this purpose, the elements may have the shape of an oblique prism through which parallel passages of square cross-section extend and which may be made by the combination of structured plates. With such an arrangement, a uniform flow resistance of the fluids to be mixed is obtained; however, the mixing efficiency decreases from the center to the peripheral zones of the column space at the downstream end of the elements adjacent the mixing chamber.

DE 31 14 195 C2 discloses such a mixing apparatus for the mixing of flowing media with at least two inlet channels, with a passage structure arranged adjacent the inlet channels and with an outlet channel connected to the common outlet end of the passage structure. The passage structure through which the individual passages extend and which serves to admit the fluids to be mixed separately consists of individual plate units dis-

posed on top of one another and consisting each of a separation wall and a corrugated sheet. The individual passages of each unit are formed by the corrugations of the corrugated sheet and the adjacent separating wall. The units are so disposed on top of one another that the individual passages of adjacent units are inclined with respect to each other at predetermined angles. In one embodiment, the arrangement is such that the passage structure includes parallel individual passages of equal length wherein the individual passages of the respective units are in communication alternately with two supply channels, but have outlets disposed on top of one another at the outlet end of the passage structure. Since the respective fluid can enter only every second individual passage - taken in the height extension of the passage structure - the inlet to the intermediate unit must be closed (see column 6, lines 26 to 33 in connection with Figs. 7a, 7b), whereby unused clearance volumes are generated. But also with this arrangement, optimal mixing occurs only in the middle of the outlet end of the passage structure; the mixing effectiveness decreases toward the outside end areas. Also, in this case, providing the required inlet blocking structures is relatively complicated and generates manufacturing problems particularly with small passage cross-sections.

Based on the state of the art discussed above, it is the object of the present invention to provide, for this type of a static micromixer, a flow guide structure for the separate admission of the fluids to be mixed in a mixing chamber in such a way that the local and time effectiveness of the mixing step in the mixing chamber is increased. In addition, the mixer should, with regard to the passages in the guide structure, be vacuum and pressure tight so that it can be used particularly in chemical engineering applications.

This object is solved by the characterizing features of patent claim 1. The subclaims referring thereto comprise advantageous embodiments of this solution.

With the arc-like curved parallel passages of the flow guide structure A and B, which lead the fluid into the mixing chamber in the general flow direction, a uniform mixing is obtained over the whole outlet area while there are no unused clearance volumes in the guide structure. Because of the microstructuring of the rows of passages, the fluids to be mixed or to be dispersed are divided into a multitude of fine neighboring flow filaments or lamellas which, upon entering the mixing chamber, mix rapidly and in a short distance or are divided into a dispersing phase which forms droplets or bubbles and an enveloping phase forming a continuous phase. The density of the passage openings and consequently of the flow filaments at the entrance into the mixing chamber is several thousand openings or flow filaments per cm^2.

An embodiment of the micromixer according to the invention and a method of making such a micromixer will be described on the basis of the accompanying drawings.

Fig. 1 shows a, greatly enlarged, perspective view of two grooved foils and a cover plate disposed on top of one another,

Fig. 2 is a schematic top view of a micromixer, and

Fig. 3 explains the method of manufacturing the grooved foils.

As shown in Fig. 1, the plate-like elements, which are alternately disposed on top of one another consist of thin foils 1A and 1B having a thickness of 30 to 1000 µm, preferably <250 µm and a lateral extension in the mm range. A series of curved arc-like grooves 2A, 2B is formed into the foils 1A, 1B so as to be arranged closely adjacent one another so that, when the

foils are disposed on top of one another, alternately, rows of passages 3A and 3B are formed (see Fig. 2).

The grooves have depths of <1000 µm preferably <250 µm, widths of 10 µm up to a mm size, preferably however <500 µm, a wall thickness of the webs 4a between the grooves and also of the bottoms 5A, 5B of <1000 µm, preferably <250 µm. The set of grooves 2B extends from the left rear face 6B in the shape of an arc to the center area 6C of the front face 8B of the foil 1B; the set of grooves 2A extends in the shape of an arc from the right rear face 6A to the center area 6C of the front face 8B of the foil 1A, both types of foils having the same outline. The outline has the geometric shape of a pentagon formed by a rectangle with an equilateral triangle connected thereto, wherein one side of the rectangle forms the base of the equilateral triangle.

If a plurality of the foils 1A and 1B are placed, in an alternate array and coinciding fashion, on top of one another, a guide structure 6 is provided as it is shown schematically in Fig. 2, in a top view. At both face areas 6A, 6B formed by the legs of the triangle, fluid admission chambers 7A, 7B for the fluid A′ and B′ are arranged. The mixing chamber 9C is disposed adjacent the center area of the opposite face 8, the end portions of the passages 3A, 3B leading to the mixing chamber 9C being in a parallel alignment so that the fluids A′, B′, to be mixed, or respectively, the reaction products C′ to be dispersed enter the mixing chamber 9C in a common flow direction from where they are conducted away.

The leg face areas 6A, 6B are inclined with respect to the face area 8 or, respectively, the side surfaces 10, 11 of the guide structure 6 such that the series of arc-like curved passages 3A and 3B leading alternately from the admission chambers 7A and 7B to the mixing chamber 9C have approximately all the same length.

For the circular grooves or passages consequently the arc length should be constant:

$$L = \frac{2\pi r \cdot \alpha}{360} = \text{constant}$$

wherein r is the respective radius of curvature and α is the respective arc angle of the particular grooves or passages. Such a requirement would lead to curved face areas 6A and 6B. However, approximated flat face areas are substituted using, for example, the approximation rule:

$$\frac{\alpha_2}{\alpha_1} = \frac{r_1}{r_2}$$

wherein r_1 represents the largest and r_2 represents the smallest radius and α_1 and α_2 represent the corresponding arc angles of the outermost and the innermost grooves.

After the foils 1A, 1B are stacked on top of one another, they are provided with cover plates 15 and interconnected in a vacuum and pressure-tight manner, for example, by diffusion welding so that the guide structure 6 formed thereby becomes a homogeneous microstructure body which is then connected to the chambers 7A, 7B and 9C.

For the manufacture of the foils 1A, 1B, a rotatable sinter metal plate 12 with a ground surface can be used, on which a raw foil 13 of a metal such as copper or silver is disposed and held in place by vacuum (see Fig. 3). By a shaped diamond (not shown), a number of concentric circular grooves 14 are cut into the center area of the foil between a center point of rotation M and the periphery of the foil 13. Then the raw foil 13 is divided into four individual foils 1A, 1B in such a way that four longitudinal sides 8 equal to the average diame-

ter of the concentric set of grooves from whose center area the circular set of grooves 14 starts out, on each end two, that is, all together, eight small sides 10, 11 and on each side two pairs of legs 6A, 6B are formed, wherein the series of grooves 14 extend each between the legs 6A and 6B, respectively. The four segments - taken apart- form the earlier mentioned congruent pentagons. The grooves are preferably rectangular in cross-section.

A number of grooved foils can be placed on top of one another and can be cut into the pentagons in a single cutting step.

List of Reference Numerals

1A	foil
1B	foil
2A	grooves
2B	grooves
3A	passages
3B	passages
4A	intermediate webs
4B	intermediate webs
5A	groove bottoms
5B	groove bottoms
6	guide structure
6A	rear face
6B	rear face
6C	center area
7A	admission chamber
7B	admission chamber
8	front face
9C	mixing chamber
10	side surfaces
11	side surfaces
12	sinter metal plate
13	raw foil
14	grooves
15	cover plate
A′	fluids
B′	fluids
C′	reaction product
r_1	radius of curvature
r_2	radius of curvature
α_1	arc angle
α_2	arc angle
M	center point of rotation

Patent Claims

1. Static micromixer with a mixing chamber and a guide structure for the separate admission of fluids to be mixed or to be dispersed to the mixing chamber, wherein

the guide structure consists of several plate-like elements stacked on top of one another through which a series of elongated adjacent passages extend;

at least two types of elements A and B are provided, which are alternately stacked on top of one another and whose series of passages have their discharge openings adjacent the mixing chamber disposed on top of one another and form there a common cross-section wherein alternately the series of passages of the element type A lead to a supply chamber of a fluid A′ and the series of passages of the element type B lead to a supply chamber of a fluid B′, characterized by the following features:

a) the plate-like elements A and B for the guide element consist each of thin foils (1A, 1B) with a thickness of 30 to 1000 µm, preferably < 250 µm, with a lateral extension in the millimeter range, into which a series of adjacent grooves (2A, 2B) are cut so that, upon stacking the foils (1A, 1B) on top of one another, a series of passages (3A, 3B) is provided for guiding the fluids A′ and B′ to be mixed,

b) the grooves (2A, 2B) have a depth of < 1000 µm, preferably < 250 µm, widths of 10 µm to the millimeter range, pref-

erably however <500 µm with wall thicknesses of the intermediate webs (4A, 5B) of <1000 µm, preferably <250 µm;

c) the respective series of grooves (2A, 2B) in the stacked foils 1A, 1B extend in a curved, arc-like shape and alternately from the mixing chamber (9C) to an admission chamber (7A, 7B) for the fluid A', or respectively, B' in such a way that all series grooves (2A, 2B) of the foils 1A, 1B lead into the mixing chamber (9C) in a parallel array.

2. Static micromixer according to claim 1, characterized by the following features:

a) the foils 1A, 1B stacked on top of one another have, in a top view, the geometric shape of a pentagon which is formed by a rectangle with an equilateral triangle connected thereto wherein one side of the rectangle forms the base of the equilateral triangle;

b) the admission chambers (7A, 7B) for the fluids A' and, respectively, B' are connected to the surfaces (6A, 6B) formed by the two legs of the triangle and the mixing chamber (9C) is connected to the surface (8) formed by the opposite longitudinal side of the rectangle,

c) the legs (6A, 6B) of the triangle are inclined with respect to its base such that the arc-shaped grooves (2A, 2B) extending from the mixing chamber (9C) of the foil (1A) and foil (1B) and leading alternately to the admission chamber (7A) and, respectively, the admission chamber (7B) have approximately the same length.

3. Static micromixer according to claim 1, characterized in that the foils (1A, 1B) stacked on top of one another are interconnected, for example by diffusion welding, to form a vacuum-tight and pressure resistant micro structure body (6), which is connected to admission chamber (7A and, respectively, 7B) and the mixing chamber (9C).

4. Method for the manufacture of foils according to claim 2, characterized by the following steps:

a) a raw foil (13) is engaged, by vacuum, with a rotatable ground metal sinter plate (12);

b) a series of concentric grooves (14) is cut into the rotating raw foil (13), by means of a shaped diamond, in an intermediate area of the raw foil (13) between its centerpoint of rotation (M) and its periphery;

c) the raw foil is divided into four individual foils (1A, 1B) in such a way that:

four segments are produced by two cuts extending normal to each other and intersecting in the centerpoint of rotation (M) and that by additional cuts on each segment form congruent pentagons according to claim 2 are formed.

Fig. 1

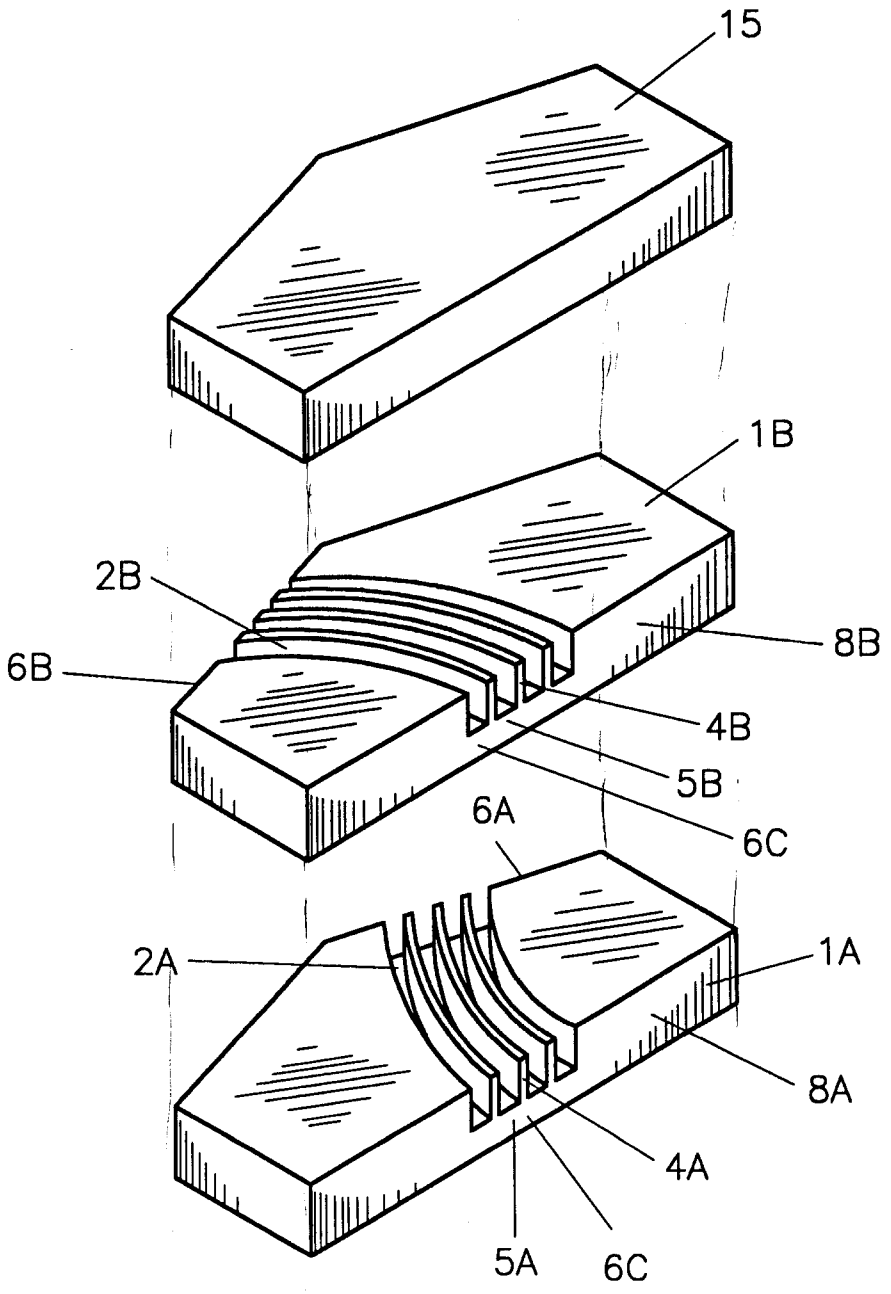


Fig. 2

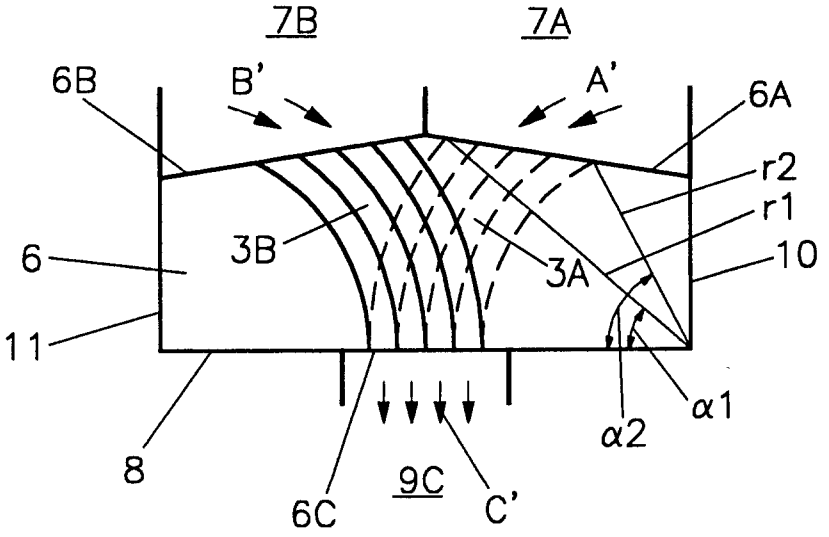
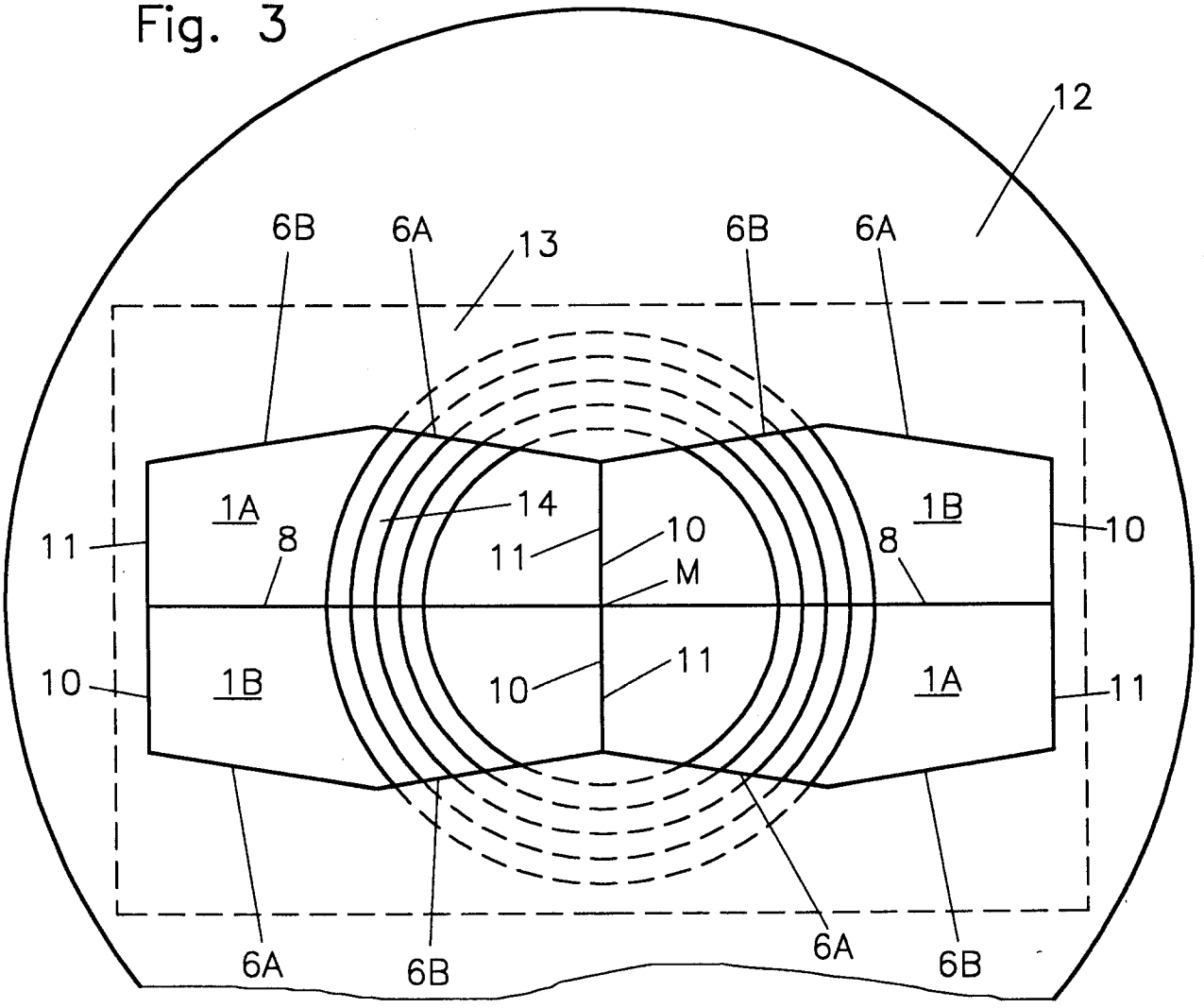
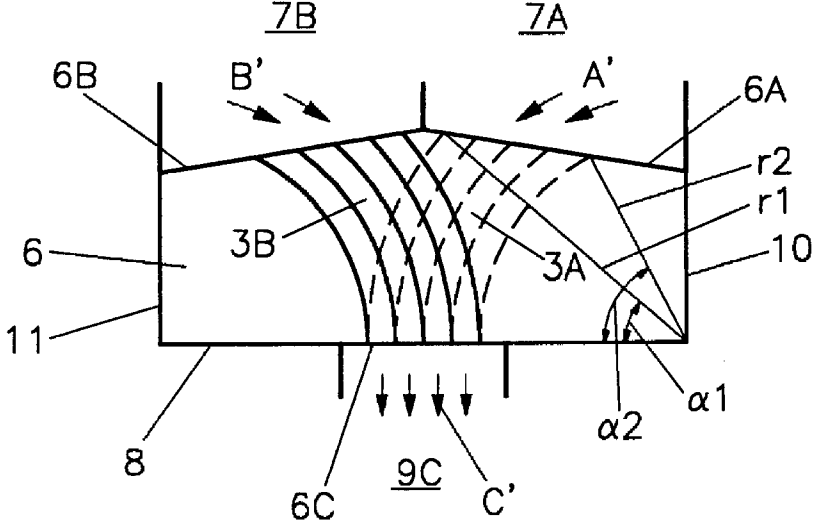

7B
7A
6B
B'
A'
6A
r2
r1
10
6
3B
3A
11
α1
α2
8
6C
9C
C'

Fig. 3


12
6B
6A
13
6B
6A
1A
14
1B
11
8
10
11
M
8
10
10
1B
11
1A
11
6A
6B
6A
6B


7B
7A
6B
B'
A'
6A
r2
r1
6
3B
3A
10
11
α1
α2
8
6C
9C
C'