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(72) Inventor: **Toffoletto, Sandro**
1752 VILLARS-SUR-GLANE (CH)

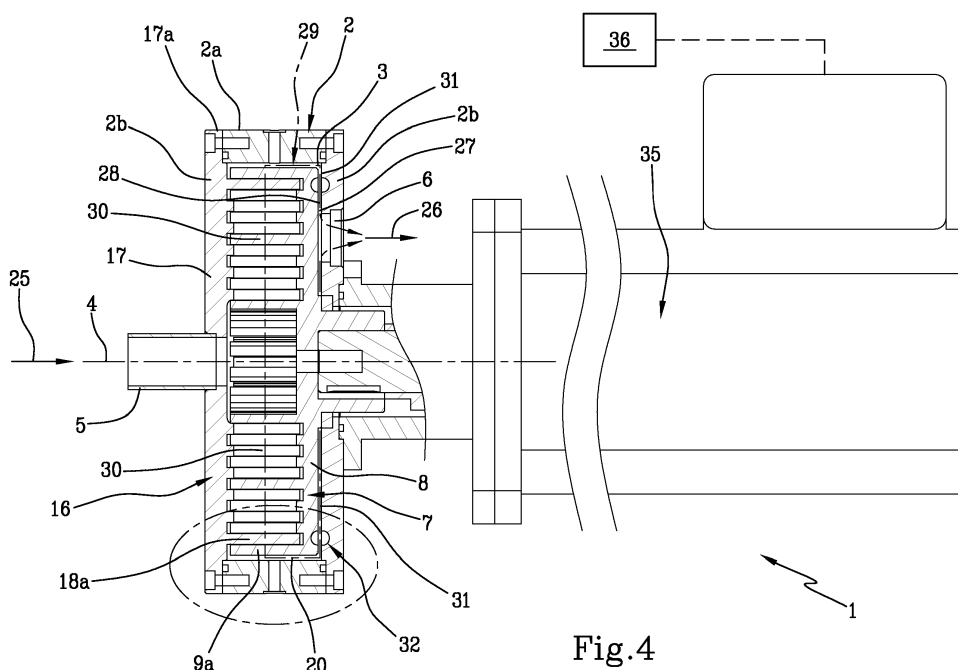
(74) Representative: **Vittorangeli, Lucia**
Bugnion S.p.A.
Viale Lancetti, 17
20158 Milano (IT)

(71) Applicant: **Nanotechlab S.A.**
1752 Villars-Sur-Glane (CH)

(54) Multi-stage mixer

(57) A multi-stage mixer (1) comprises a casing (2) defining a chamber (3). A rotor (7) rotates inside the chamber (3) and is provided with circular rows (9a-9g) of cutting elements (10) arranged concentrically in a radially inward position relative to one another. A stator (16) comprises circular rows (18a-18f) of cutting elements (10') arranged concentrically in a radially inward position relative to one another. Each row (9a-9g; 18a-18f) of the rotor and stator comprises a circumferential sequence of cutting elements (10, 10') having a given radial thickness (14, 14') and interspersed with recesses

(15, 15') which extend for the entire radial thickness (14, 14') of the cutting elements (10, 10'). The rotor (7) and stator (16) are mutually facing, so that the circular rows (9a-9g) of cutting elements (10) of the rotor (7) are inserted between the circular rows (18a-18f) of cutting elements (10') of the stator (16) inside the chamber (3). Two adjacent recesses (15, 15') disposed in consecutive rows of cutting elements (10, 10') of the rotor (7) or stator (16) extend along a respective median direction (19, 19'), whose extensions are unaligned within a circular crown defined by the two consecutive rows of cutting elements.

**Fig.4****EP 2 810 703 A1**

Description

[0001] The present invention relates to a multi-stage mixer.

[0002] In particular, the present invention relates to a multi-stage high shear mixer capable of obtaining stable compounds even from normally immiscible substances (for example, suspensions, dispersions or emulsions).

[0003] Mixers are used to mix substances for example in the adhesives, cosmetics, food and pharmaceutical industries, etc. In particular, the present invention relates to a multi-stage high shear mixer capable of creating emulsions of water in hydrocarbons such as, for example, diesel or biodiesel fuel, dense combustible oil and the like.

[0004] Such an application is suitable for use in endothermic engines, in particular diesel engines, both of vehicles or ships and stationary electric power plants, or else in turbines or boilers, and makes it possible to obtain a decrease in unburned substances (NOx), fumes and particulate matter (PM) and an increase in fuel efficiency and average engine lifespan, with resulting cost savings. However, this application requires high stability of the emulsion over time.

[0005] In known mixers, in order to create the shear effect use is made of a rotor associated with a stator in such a way as to create a difference in velocity between adjacent areas of the fluid to be mixed. In particular, the velocity of the fluid at the outside diameter of the rotor is greater than that at the centre of the rotor itself and this difference in velocity generates the so-called shear effect.

[0006] The stator and the rotor are coaxial and respectively comprise at least one row of cutting elements (teeth) arranged circumferentially. The teeth of the rotor internally abut those of the stator in such a way as to create a narrow passage for the fluid.

[0007] In the case of multi-stage mixers the rotor and stator comprise two or more rows of teeth disposed in concentric circles. The rows of teeth mutually abut and in particular the rows of teeth of the rotor internally engage the rows of teeth of the stator.

[0008] During the rotation of the rotor, the substances to be mixed enter centrally and are accelerated outwards due to centrifugal force. During the various passes between the stages of the rotor-stator assembly, the material is subjected to a succession of cuts which decrease the size of the particles (micelles).

[0009] The quality of the mixture obtained, and its stability in particular, depend both on the final particle size and the uniformity of the particle size in the mixture. In particular, the stability of the mixture (emulsion) increases with decreasing micelle sizes and increasing uniformity of the micelle size in the mixture (emulsion).

[0010] Most known mixers require a considerable volume and numerous bypasses before reaching micelle sizes that are in any event not smaller than 1 μm .

[0011] Moreover, in the case of emulsions, and in par-

ticular water-in-hydrocarbon emulsions for the above-mentioned applications, known mixers are not capable of emulsifying more than 8-10 % of water.

[0012] In this context, the technical task of the present invention is to overcome one or more of the aforesaid limitations.

[0013] In particular, it is an object of the present invention to provide a multi-stage mixer that is capable of obtaining mixtures whose particles (micelles) have final sizes which are very small and preferably uniformly distributed in the mixture.

[0014] A further object of the present invention is to provide a multi-stage mixer that is capable of obtaining emulsions with a high content of the dispersed phase relative to the continuous phase. In particular, in the case of water-in-hydrocarbon emulsions, one object of the present invention is to provide a multi-stage mixer capable of emulsifying at least 20% of water in the hydrocarbon.

[0015] The stated technical task and specified object are substantially achieved by a multi-stage mixer comprising the technical features set forth in one or more of the appended claims. The dependent claims correspond to possible embodiments of one of the aspects of the invention.

[0016] In particular, according to a first aspect, the present invention relates to a multi-stage mixer comprising a casing defining a chamber which extends along a longitudinal axis. The chamber comprises an inlet for the substances to be mixed and an outlet for the mixture. A rotor is designed to rotate in the chamber around the longitudinal axis. The rotor comprises a supporting wall which is set perpendicular to the longitudinal axis and laterally extending from which there are at least two circular rows of cutting elements arranged concentrically relative to the longitudinal axis, in a radially inward position relative to one another and separated by an air space. Each row comprises a circumferential sequence of cutting elements having a given radial thickness and interspersed with recesses which extend for the entire radial thickness of the cutting elements so as to be placed in communication with the air space. A stator comprises a supporting wall, laterally extending from which, in an axial direction inside the chamber, there are at least two circular rows of cutting elements arranged concentrically relative to the longitudinal axis, in a radially inward position relative to one another and separated by an air space. Each row comprises a circumferential sequence of cutting elements having a given radial thickness and interspersed with recesses which extend for the entire radial thickness of the cutting elements so as to be placed in communication with the air space. The rotor and the stator are mutually facing so that the circular rows of cutting elements of the rotor are inserted between the circular rows of cutting elements of the stator inside the chamber. In a section perpendicular to the longitudinal axis, each recess of the rotor and/or each recess of the stator extends for the entire radial thickness of the re-

spective cutting elements along a respective median direction. The extensions of the median directions of two adjacent recesses disposed in consecutive rows of cutting elements of the rotor or stator are unaligned within a circular crown defined by the two consecutive rows of cutting elements.

[0017] Such features make it possible to subject the substances to be mixed to a high shear action while avoiding bypasses or preferential routes in the passage through the rows of cutting elements.

[0018] Preferably, in a section perpendicular to the longitudinal axis, each recess of the rotor and/or stator extends for the entire radial thickness of the cutting elements along a median direction extending radially relative to the longitudinal axis.

[0019] This feature makes it possible to obtain a particularly effective unalignment which causes an abrupt change of direction in the passage of substances through the rows of cutting elements.

[0020] Preferably, the number of cutting elements in a row of the rotor is different from the number of cutting elements in the consecutive row. Preferably, the number of cutting elements in a row of the stator is different from the number of cutting elements in the consecutive row.

[0021] This feature ensures an optimal unalignment between the recesses of adjacent rows of the rotor or stator.

[0022] Preferably, the number of cutting elements in a row of the rotor is greater than the number of cutting elements in the radially inward consecutive row. Preferably, the number of cutting elements in a row of the stator is greater than the number of cutting elements in the radially inward consecutive row. This feature enables the recesses to be distributed unevenly along the different circumferences.

[0023] Preferably, the number of cutting elements in a row of the rotor and/or the number of cutting elements of the stator increases starting from a radially inner row and proceeding outward in a centrifugal direction. In particular, at least one row of the stator and at least one immediately consecutive row of the rotor have the same number of cutting elements. Preferably, at least one row of the stator and at least one immediately consecutive row of the rotor in a centrifugal direction have the same number of cutting elements. These features make it possible to define one or more stages of advancement of the liquid along the mixer corresponding to a pair of rows of cutting elements respectively of the rotor and stator having an identical number of cutting elements. Consequently, two pairs of consecutive rows have a number of cutting elements that increases in a centrifugal direction. Preferably, the rotor comprises a radially outer row disposed externally to a radially outer row of the stator.

[0024] This feature makes it possible to add to the shear effect a further cavitation effect given by the rotation of the radially outer row of the rotor relative to the cylindrical wall of the casing.

[0025] Preferably, the rotor comprises one more circu-

lar row of cutting elements than the circular rows of cutting elements of the stator.

[0026] This feature ensures a symmetrical structure in which the rotor externally and internally embraces the stator, so that the incoming substances immediately encounter a radially inner row of the rotor and leave the rotor/stator assembly at the radially outer row of the rotor.

[0027] Preferably, the casing comprises the stator disposed so as to close off the chamber; in particular, the supporting wall of the stator defines a bottom wall of the casing.

[0028] This feature enables the structure to be simplified as the stator also incorporates the function of closing off the chamber.

[0029] Preferably, the recesses of the rotor and/or the recesses of the stator are open at a respective projecting end of the cutting elements.

[0030] This feature amplifies the shear effect, which can be delivered for the entire height of the recesses.

[0031] Preferably, each circular row of cutting elements of the rotor and/or each circular row of cutting elements of the stator comprises an annular foot that extends respectively from the supporting wall of the rotor or the supporting wall of the stator in a section where recesses are not present. Preferably, the air space comprises a recessed portion within the supporting wall of the rotor or the supporting wall of the stator, respectively, which is delimited by two consecutive annular feet.

[0032] This feature simplifies the formation of the recesses, renders the cutting elements more stable and enables a recessed portion to be formed which positively influences the shear effect.

[0033] Preferably, a projecting end of the cutting elements of the rotor is disposed inside a respective recessed portion of an air space of the stator and/or vice versa.

[0034] This feature makes it possible to avoid any bypasses in the path of the substances in the area subject to the shear effect given by the interaction between rotor and stator. In particular, this feature obliges the substances to follow a tortuous path within the rotor/stator coupling (i.e. in a centrifugal portion of the path of the substances to be mixed), so that the passage between rows of cutting elements substantially takes place only through the recesses.

[0035] Preferably, the outlet is disposed in a radially intermediate portion between the longitudinal axis and a radially outer portion of the rotor and generates an outflow that is preferably axially disposed.

[0036] This feature makes it possible to divert the path of the substances to be mixed, thus generating a centrifugal portion and a centripetal portion of said path.

[0037] Preferably, the inlet and the outlet are disposed on opposite sides of the chamber relative to the rows of cutting elements.

[0038] This feature enables the structure of the mixer to be simplified.

[0039] Preferably, the inlet, preferably axially dis-

posed, is fashioned in the supporting wall of the stator, for example in a bottom wall of the casing. This feature enables the structure to be simplified by limiting the number of necessary components.

[0040] Preferably, the outlet is disposed in a bottom wall of the casing directly facing a rear surface of the rotor opposite the rows of cutting elements. Preferably, one path of the substances and of the mixture inside the multi-stage mixer comprises a centrifugal portion between the rows of cutting elements of the rotor and of the stator and a centripetal portion disposed between the rotor and the bottom wall of the casing.

[0041] This feature enables the mixing to be optimized by distinguishing different paths in which additional shear/cavitation effects can be applied. Preferably, cavitation means are provided, in particular blind cavities fashioned in the rotor and/or in the bottom wall of the casing and preferably disposed in the centripetal portion of the path.

[0042] This feature makes it possible to further decrease the size of the micelles and increase the uniformity thereof within the mixture.

[0043] Preferably, there is provided a motor, preferably a brushless one operatively connected to the rotor so as to drive it in rotation around the longitudinal axis, and a programmed control unit to regulate the rotation speed of the rotor depending on the substances to be mixed and/or the cavitation means, in particular the number and shape of the blind cavities, so as to generate a cavitation frequency that is close to or coincides with the molecular resonance frequency of at least one of the substances to be mixed, in particular the dispersed phase in the case of emulsions.

[0044] This feature makes it possible to further decrease the size of the micelles and increase the uniformity thereof within the mixture also when there is a change in the substances used, for example following the addition of antifreeze additives to the fuel in the wintertime.

[0045] In accordance with a further aspect, the present invention relates to a method for mixing substances in a multi-stage mixer, the method comprising regulating the rotation speed of the rotor so as to generate a cavitation frequency that is close to or coincides with the molecular resonance frequency of at least one of the substances to be mixed, in particular the dispersed phase in the case of emulsions.

[0046] This feature makes it possible to further decrease the size of the micelles and increase the uniformity thereof within the mixture also when there is a change in the substances used, for example following the addition of antifreeze additives to the fuel in the wintertime.

[0047] In accordance with a further aspect, the present invention relates to a method for mixing substances in a multi-stage mixer comprising one or more among:

subjecting the substances to be mixed to a shear action along a centrifugal portion of a path of the substances inside the multi-stage mixer;

subjecting the substances to at least a cavitation effect in the passage between the centrifugal portion and a centripetal portion of the path of the substances inside the multi-stage mixer;

subjecting the substances to at least a further cavitation effect along a centripetal portion of the path of the substances inside the multi-stage mixer;

regulating the rotation speed of the rotor so as to generate, in the centripetal portion of the path, a cavitation frequency that is close to or coincides with the molecular resonance frequency of at least one of the substances to be mixed, in particular the dispersed phase in the case of emulsions.

[0048] Such features enable the micelle size to be reduced thanks to the synergetic cooperation of several effects. This contributes to increasing stability, also by virtue of the greater uniformity of the micelle size in the mixture. Finally, this aspect makes it possible to emulsify at least 20% of water in the case of water-in-hydrocarbon emulsions.

[0049] Additional features and advantages of the invention will become more apparent from the description that follows of a multi-stage mixer according to the invention, given by way of illustration and not by way of limitation with reference to the appended drawings, in which:

- figures 1a and 1b schematically illustrate an exploded perspective view of a multi-stage mixer in accordance with the present invention, respectively from two different angles;
- figure 2 schematically illustrates a sectional view of an element of the multi-stage mixer of figure 1;
- figure 3 schematically illustrates a sectional view of an element of the multi-stage mixer of figure 1;
- figure 4a schematically illustrates a view from above of the multi-stage mixer of figure 1, assembled;
- figure 4 schematically illustrates a sectional view along the line IV-IV corresponding to an axial plane of the multi-stage mixer of figure 4a;
- figure 5 schematically illustrates an enlarged view of a detail of figure 4;
- figure 6 schematically illustrates an enlarged view of a detail of figure 3.

[0050] With reference to the figures, 1 indicates a multi-stage mixer for mixing substances. In a possible application, the multi-stage mixer according to the present invention can be used to produce emulsions, in particular water-in-hydrocarbon emulsions. 2 indicates a casing defining a chamber 3, in particular a cylindrical chamber, which extends along a longitudinal axis 4. In particular, the casing 2 is cylindrical in shape, internally hollow where the chamber 3 is located, and comprises a cylindrical wall 2a closed off at each end by a respective bottom wall 2b. According to the illustrated example, each bottom wall preferably has a discoid shape and comprises an outer flange for coupling with the cylindrical wall,

for example by means of threaded connections.

[0051] The chamber comprises an inlet 5 for the substances to be mixed and an outlet 6 for the mixture. 7 indicates a rotor designed to rotate in the chamber 3 around the longitudinal axis 4. The rotor 7 comprises a supporting wall defining, for example, a discoid element 8 disposed perpendicularly and symmetrically relative to the longitudinal axis 4. In particular, the rotor 7 and the respective discoid element 8 are disposed inside the chamber 3. In particular, the discoid element 8 is disposed parallel to one of the bottom surfaces 2b of the casing 2.

[0052] Figure 2 illustrates a section of the rotor cut through a plane perpendicular to the longitudinal axis 4. 9a-9g indicate circular rows of cutting elements 10 of the rotor arranged concentrically relative to the longitudinal axis 4, in a radially inward position relative to one another. In the illustrated example, the rotor 7 comprises seven circular rows of cutting elements 10. In general the rotor 7 comprises at least two circular rows of cutting elements 10.

[0053] The circular rows 9a-9g extend laterally from the discoid element 8, i.e. in an axial direction. In particular, the circular rows extend between an end 11 that is proximal relative to the discoid element 8 and an end that is distal relative to the discoid element 8 or a projecting end 12.

[0054] The term "consecutive" means two successive rows in a radial direction relative to the longitudinal axis 4. Rows 9a and 9b are consecutive, for example, irrespective of whether the travel direction is centrifugal or centripetal.

[0055] Two consecutive rows of the rotor 7 are separated by a ring-shaped air space 13 coaxially disposed relative to the longitudinal axis 4. The term "air space" means the empty space between two consecutive rows of cutting elements.

[0056] Each row 9a-9g of the rotor 7 comprises a circumferential sequence of cutting elements 10 having a given radial thickness 14. The cutting elements 10 of a row are interspersed with recesses 15 which extend for the entire radial thickness 14 of the cutting elements in such a way as to be placed in communication with the air space 13. 16 indicates a stator which extends inside the chamber 3.

[0057] In the following description of the stator, terms analogous to those used for the rotor are used, in particular when identical or similar structures are involved. These terms are associated with different numerical references, in some cases characterized by a prime symbol. Alternatively, the identical terms used for the rotor can be referred to as "first", whereas the identical terms used for the stator can be referred to as "second".

[0058] The stator 16 comprises a supporting wall 17, preferably of a discoid shape.

[0059] Preferably, the casing 2 comprises the stator 16 disposed so as to close off the chamber 3, in particular in the supporting wall 17. In such a case the supporting

wall 17 coincides with one of the bottom walls 2b of the casing 2 and preferably comprises an outer flange 17a for coupling, for example by means of threaded connections, with the cylindrical wall 2a of the casing 2.

[0060] The supporting wall 17 is disposed perpendicularly and symmetrically relative to the longitudinal axis 4. In particular, the supporting wall 17 is disposed parallel to the discoid element 8 of the rotor 7.

[0061] Figure 3 illustrates a section of the stator cut through a plane perpendicular to the longitudinal axis 4. 18a-18f indicate circular rows of cutting elements 10' of the stator arranged concentrically relative to the longitudinal axis 4, in a radially inward position relative to one another. In the illustrated example, the stator 16 comprises six circular rows of cutting elements 10'. In general, the stator 16 comprises at least two circular rows of cutting elements 10'.

[0062] The circular rows 18a-18f extend laterally from the supporting wall 17, i.e. in an axial direction, inside the chamber 3. In particular, the circular rows extend between an end 11' that is proximal relative to the supporting wall 17 and an end that is distal relative to the supporting wall or a projecting end 12'.

[0063] As in the case of the rotor 7, the term "consecutive" means two successive rows in a radial direction relative to the longitudinal axis 4. Rows 18a and 18b are consecutive, for example, irrespective of whether the travel direction is centrifugal or centripetal.

[0064] Two consecutive rows of the stator are separated by a ring-shaped air space 13' disposed coaxially with the longitudinal axis 4. The term "air space" means the empty space between two consecutive rows of cutting elements.

[0065] Each row 18a-18f of the stator 16 comprises a circumferential sequence of cutting elements 10' having a given radial thickness 14'. The cutting elements 10' of a row are interspersed with recesses 15' which extend for the entire radial thickness 14' of the cutting elements 10' in such a way as to be placed in communication with the air space 13'.

[0066] In the assembled configuration of the mixer, the rotor 7 and stator 16 are mutually facing so that the circular rows 9a-9g of cutting elements 10 of the rotor 7 are inserted between the circular rows 18a-18f of cutting elements 10' of the stator 16 inside the chamber 3.

[0067] In particular, the projecting ends 12 of the rows 9a-9g of the rotor 7 are inserted in the respective air spaces 13' of the stator 16 so that they are directly facing the supporting wall 17 of the stator. Analogously, the projecting ends 12' of the rows 18a-18f of the stator 16 are inserted in the respective air spaces 13 of the rotor 7 so that they are directly facing the discoid element 8 of the rotor 7.

[0068] Considering a section perpendicular to the longitudinal axis 4, for example illustrated in figure 2 with reference to the rotor, each recess 15 of the rotor 7 extends for the entire radial thickness 14 of the cutting elements 10 along a median direction 19.

[0069] Considering a section perpendicular to the longitudinal axis 4, for example illustrated in figure 3 with reference to the stator, each recess 15' of the stator 16 extends for the entire radial thickness 14' of the cutting elements 10' along a median direction 19'.

[0070] Considering the extensions of the median directions 19 of two adjacent recesses disposed in consecutive rows of cutting elements of the rotor, said extensions are unaligned within a circular crown defined by the two consecutive rows of cutting elements.

[0071] Considering the extensions of the median directions 19' of two adjacent recesses disposed in consecutive rows of cutting elements of the stator, said extensions are unaligned within a circular crown defined by the two consecutive rows of cutting elements.

[0072] The term "extension" means the extension in the median direction beyond the radial thickness 14, 14' of the cutting elements 10, 10'.

[0073] The term "adjacent" means two successive recesses disposed in consecutive rows in a circumferential or tangential direction relative to the longitudinal axis 4. For the sake of clarity, two adjacent recesses of the rotor are indicated as 15a and 15b in figure 2 and two adjacent recesses of the stator are indicated as 15'a and 15'b in figure 3.

[0074] In other words, the recesses 15 of two consecutive rows of the rotor 7 or recesses 15' of two consecutive rows of the stator 16 are not aligned either along a radial direction or along a continuous inclined or arcuate direction relative to the longitudinal axis 4 and thus a staggering is defined between adjacent recesses of two consecutive rows of the rotor or of the stator so as to avoid direct linear paths of the substances to be mixed in a centrifugal portion of a path of the substances to be mixed inside the chamber 3.

[0075] The rotor 7 and/or stator 16 are for example constructed by cutting the respective air spaces 13, 13' and respective recesses 15, 15'. With reference to this method of construction, two adjacent recesses of two consecutive rows are obtained via the motion of a tool relative to the workpiece which follows a broken line given by the connection of the median directions 19, 19' of the adjacent recesses.

[0076] Preferably, two extensions of median directions 19, 19' of adjacent recesses of the rotor or stator are connected by a tangential portion 19a, 19'a corresponding to the air space between two circular rows.

[0077] With reference to a possible embodiment, in a section perpendicular to the longitudinal axis 4, each recess 15 of the rotor 7 and/or each recess 15' of the stator 16 extends for the entire radial thickness 14, 14' of the cutting elements 10, 10' along a median direction 19, 19', for example formed by a straight line, extending radially relative to the longitudinal axis 4.

[0078] With reference to figure 2 or 3, the union of the median directions 19, 19' of adjacent recesses and connecting portions 19a and 19'a form a broken line, with an orientation that is preferably radial in the portion corre-

sponding to the median directions and preferably tangential in the connecting portion.

[0079] Advantageously, also independently of the above-described features, the number of cutting elements 10 of a row of the rotor 7 is different from the number of cutting elements 10 of the consecutive row. In particular, the number of cutting elements 10 of a row of the rotor 7 is greater than the number of cutting elements 10 of the radially inward consecutive row. Advantageously, also independently of the above-described features, the number of cutting elements 10' of a row of the stator 16 is different from the number of cutting elements 10' of the consecutive row. In particular, the number of cutting elements 10' of a row of the stator 16 is greater than the number of cutting elements 10' of the radially inward consecutive row. According to one possible embodiment, also independently of what was described previously, the number of cutting elements in a row of the rotor and/or the stator increases as one proceeds outwards from a radially inner row in a centrifugal direction. In particular, at least one row of the stator and at least one immediately consecutive row of the rotor have the same number of cutting elements. Preferably, at least one row of the stator and at least one row that is immediately consecutive in a centrifugal direction have the same number of cutting elements.

[0080] Such features make it possible to define one or more stages of advancement of the liquid along the mixer corresponding to a pair of rows of cutting elements respectively of the stator and rotor having an identical number of cutting elements. Consequently, two pairs of consecutive rows have a number of cutting elements which increases in the centrifugal direction.

[0081] Between the rows of the rotor 7 and stator 16, a radially outer row of the rotor 7 has been indicated as 9a and a radially outer row of the stator 16 as 18a. Advantageously, the radially outer row 9a of the rotor 7 is disposed externally to the radially outer row 18 of the stator 16. In other words, in an assembled configuration of the multi-stage mixer, the radially outer row 9a of the rotor 7 is inserted between the radially outer row 18a of the stator 16 and the casing 2, in particular the cylindrical wall 2a of the casing 2. This arrangement generates an annular section 20 for the passage of the substances to be mixed, delimited by the rotor and casing, in particular by the cylindrical wall 2a of the casing.

[0082] Preferably, the rotor 7 comprises one more circular row of cutting elements 10 compared to the circular rows of cutting elements 10' of the stator 16. In other words, the rotor 7 embraces the stator 16 both internally and externally relative to the longitudinal axis 4.

[0083] According to one possible embodiment, illustrated for example in the figures, the recesses 15 of the rotor 7 are open at the projecting end 12 of the cutting elements 10. Alternatively, according to an unillustrated embodiment, the recesses 15 of the rotor 7 are closed off at the projecting end 12 of the cutting elements 10.

[0084] In accordance with one possible embodiment,

illustrated for example in the figures, the recesses 15' of the stator 16 are open at the projecting end 12' of the cutting elements 10'. Alternatively, according to an unillustrated embodiment, the recesses 15' of the stator 16 are closed off at the projecting end 12' of the cutting elements 10'.

[0085] In accordance with one possible embodiment, also independently of what was described previously, each circular row of cutting elements 10 of the rotor 7 comprises an annular foot 21, which extends from the discoid element 8 of the rotor 7 in a portion where the recesses 15 are not present.

[0086] Advantageously, the air space 13 comprises a recessed portion 22 inside the discoid element 8 of the rotor 7. The recessed portion 22 is delimited by two consecutive annular feet 21.

[0087] In accordance with one possible embodiment, also independently of what was described previously, each circular row of cutting elements 10' of the stator 16 comprises an annular foot 21' which extends from the supporting wall 17 of the stator 16 in a portion where the recesses 15' are not present.

[0088] Advantageously, the air space 13' comprises a recessed portion 22' inside the supporting wall 17 of the stator 16. The recessed portion 22' is delimited by two consecutive annular feet 21'.

[0089] Preferably, the projecting end 12 of the cutting elements 10 of the rotor 7 is disposed inside a respective recessed portion 22' of an air space 13' of the stator 16.

[0090] Preferably, the projecting end 12' of the cutting elements 10' of the stator 16 is disposed inside a respective recessed portion 22 of an air space 13 of the rotor 7.

[0091] Figure 6 illustrates an enlarged portion of the rotor 7 or of the stator 16 corresponding to a section containing the longitudinal axis 4. In this section, each air space 13, 13' comprises at least one portion 23, 23' directly facing the recesses 15, 15' and extending up to the projecting end 12, 12' of the cutting elements. In the same section containing the longitudinal axis 4, each air space 13, 13' further comprises the recessed portion 22, 22' directly facing the annular feet 21, 21' of the rows of cutting elements.

[0092] Advantageously, each recess 15 of the rotor is delimited by at least a bottom surface 24 perpendicular to the longitudinal axis 4 and disposed proximal to the discoid element 8. The axial position of the bottom surface 24 defines the axial extent of the respective annular foot 21. Advantageously, each recess 15' of the stator is delimited by at least a bottom surface 24' perpendicular to the longitudinal axis 4 and disposed proximal to the supporting wall 17. The axial position of the bottom surface 24' defines the axial extent of the respective annular foot 21'.

[0093] According to one possible embodiment, illustrated for example in the figures, the inlet 5 is disposed on the longitudinal axis 4, thus defining an inflow 25 axially disposed and substantially coinciding with the longitudinal axis 4. The inlet 5 is fashioned, for example, in

the supporting wall 17 of the stator 16, in particular when the supporting wall 17 defines a bottom wall 2b of the casing 2.

[0094] According to one possible embodiment, also independently of what was described previously, the outlet 6 is disposed in a portion that is radially intermediate between the longitudinal axis 4 and a radially outer portion of the rotor 7. In particular, the outlet is disposed in such a way as to generate an outflow 26 axially disposed, i.e. parallel to the longitudinal axis 4, preferably at a given radial distance from the longitudinal axis. In particular, this radial distance is smaller than the radial extent of the rotor/stator.

[0095] According to one possible embodiment, illustrated for example in the figures, the outlet 6 is disposed on a bottom wall 2b of the casing 2, for example a bottom wall opposite the stator, in particular the supporting wall 17, relative to the chamber 3. According to one possible embodiment, illustrated for example in the figures, the outlet 6 is disposed on a bottom wall 2b of the casing 2 defining a bottom surface 27 parallel to and directly facing a rear surface 28 of the rotor 7 opposite the rows of cutting elements 10.

[0096] Preferably, the inlet 5 and outlet 6 are disposed on opposite sides of the chamber 3 relative to the paired rows of cutting elements of the rotor and stator.

[0097] Advantageously, with 29 indicating a path of the substances to be mixed and of the mixture inside the mixer, disposed between the inlet 5 and the outlet 6, said path comprises a centrifugal portion 30 disposed between the rows of cutting elements 10, 10' of the rotor 7 and stator 16 and a centripetal portion 31 disposed between the rotor 7 (rear surface 28) and bottom surface 27 of the casing 2. This feature can also be envisaged independently of what was described previously.

[0098] Also independently of the previously described features, there can be advantageously provided cavitation means 32 disposed in the centripetal portion 31 of the path 29. Preferably, the cavitation means 32 comprise blind cavities 33 fashioned in the rotor 7 (rear surface 28) and/or blind cavities 34 fashioned in the bottom surface 27 of the casing 2 directly facing the rear surface 28. In particular, the blind cavities 33, 34 of the rotor and/or stator have a hemispherical or spherical cap shape. Preferably, the blind cavities 33 fashioned in the rotor 7 (rear surface 28) are disposed in at least two rows that are concentric relative to the longitudinal axis 4, one disposed radially inside the other. Preferably, the blind cavities in a row are staggered relative to the blind cavities of the consecutive row (see the definition used for the rows of cutting elements). Preferably, the blind cavities 34 fashioned in the bottom surface 27 of the casing 2 are disposed in at least two rows that are concentric relative to the longitudinal axis 4, one disposed radially inside the other. Preferably, the blind cavities of a row are staggered relative to the blind cavities of the consecutive row (see the definition used for the rows of cutting elements). In accordance with one possible embodiment,

35 indicates a motor, preferably a brushless one operatively connected to the rotor so as to drive it in rotation around the longitudinal axis 4. 36 schematically indicates a programmed control unit for regulating the rotation speed of the rotor according to the substances and/or cavitation means, in particular the number and shape of the blind cavities, in order to generate a cavitation frequency that is close to or coincides with the molecular resonance frequency of at least one of the substances to be mixed, in particular the dispersed phase in the case of emulsions (for example water). Advantageously, it is envisaged that the rotation speed of the rotor can be changed in the event of a change in the dispersed phase (and thus of its molecular resonance frequency, for example when passing from pure water to water to which an antifreeze or something else has been added) or depending on the entity of the shear to which the liquid must be subjected in the centrifugal portion of the path.

[0099] According to a further aspect, the present invention relates to a method for mixing substances in a multi-stage mixer comprising, in particular, one or more of the above-described features. This method envisages adjusting the rotation speed of the rotor so as to generate, for example, a cavitation frequency that is close to or coincides with the molecular resonance frequency of at least one of the substances to be mixed, in particular the dispersed phase (water - water and antifreeze) in the case of emulsions. In particular, cavitation is generated at the site of the cavitation means disposed in the centripetal portion 31 of the path followed by the substances inside the mixer.

[0100] Advantageously, it can be envisaged to subject the substances to be mixed to a shear action along the centrifugal portion 31 of the path 29 of the substances inside the multi-stage mixer.

[0101] Optionally, it can be envisaged to subject the substances to at least a cavitation effect in the passage between the centrifugal portion 30 and the centripetal portion 31 of the path 29 of the substances inside the multi-stage mixer. In the example illustrated, the cavitation effect is given by the interaction of the radially outer row 9a of the rotor disposed externally to the radially outer row 18a of the stator and facing the cylindrical wall 2a of the casing 2.

[0102] Optionally, it can be envisaged to subject the substances to at least a further cavitation effect in the centripetal portion 31 of the path of the substances inside the multi-stage mixer. In the illustrated example, this further cavitation effect is given by the effect of the cavitation means 32, in particular the effect of the blind cavities 33, 34 disposed between the rear surface 28 of the rotor 7 and the bottom surface 27 of the casing 2.

[0103] In this latter case, it is advantageously envisaged to regulate the rotation speed of the rotor to generate, in the centripetal portion 31 of the path 29, a cavitation frequency that is close to or coincides with the molecular resonance frequency of at least one of the substances to be mixed, in particular of the dispersed phase

in the case of emulsions.

[0104] During use, the multi-stage mixer according to the present invention makes it possible to mix, and in particular to emulsify, two substances introduced inside the mixer through the inlet 5.

[0105] In passing between the inlet 5 and outlet 6, the substances to be mixed are conveyed through the rows of cutting elements, in particular in a centrifugal direction. In a section that is transverse to the longitudinal axis 4, the path of the substances through the rows of cutting elements is tortuous and winds among the recesses and an opening 37 which remains between a row of the stator and a row adjacent to the rotor. Thanks to the arrangement of cutting elements and recesses according to the invention, the effectiveness of the passage is particularly high, since possible bypasses or direct connections between the recesses are avoided.

[0106] In passing between the recesses of the rotor and stator, the substances to be mixed are subjected to a first cavitation effect due to the relative rotation and operating according to a cavitation frequency correlated with the speed of the rotor.

[0107] In a radially outer portion of the rotor, the substances to be mixed can be subjected to a cavitation effect given by the interaction of the radially outer row 9a of the rotor disposed externally to the radially outer row 18a of the stator and facing the cylindrical wall 2a of the casing 2. This further cavitation effect is advantageously envisaged in the passage between the centrifugal portion 30 and the centripetal portion 31 of the path 29 of the substances inside the multi-stage mixer.

[0108] As they proceed towards the outlet, the substances to be mixed are subjected to yet a further cavitation effect generated thanks to the presence of the cavitation means in the portion of the path disposed between the rotor and the casing, in particular in the centripetal portion 31 of the path of the substances inside the multi-stage mixer.

Claims

1. A multi-stage mixer (1) comprising:

a casing (2) defining a chamber (3) which extends along a longitudinal axis (4), said chamber (3) comprising an inlet (5) for the substances to be mixed and an outlet (6) for the mixture;
a rotor (7) designed to rotate in said chamber (3) around said longitudinal axis (4), said rotor (7) comprising a supporting wall (8), disposed perpendicular to said longitudinal axis (4), laterally extending from which there are at least two circular rows (9a-9g) of cutting elements (10) arranged concentrically relative to said longitudinal axis (4), in a radially inward position relative to one another and separated by an air space (13),

wherein each row (9a-9g) comprises a circumferential sequence of cutting elements (10) having a given radial thickness (14), interspersed by recesses (15) which extend for the entire radial thickness (14) of the cutting elements (10) so as to be placed in communication with said air space (13);

a stator (16) comprising a supporting wall (17) laterally extending from which, in an axial direction inside said chamber (3), there are at least two circular rows (18a-18f) of cutting elements (10') arranged concentrically relative to said longitudinal axis (4), in a radially inward position relative to one another and separated by an air space (13'), wherein each row (18a-18f) comprises a circumferential sequence of cutting elements (10') having a given radial thickness (14'), interspersed by recesses (15') which extend for the entire radial thickness (14') of the cutting elements (10') so as to be placed in communication with said air space (13');

wherein said rotor (7) and said stator (16) are mutually facing so that the circular rows (9a-9g) of cutting elements (10) of the rotor (7) are inserted between the circular rows (18a-18f) of cutting elements (10') of the stator (16) inside said chamber (3),

wherein in a section perpendicular to said longitudinal axis (4), each recess (15) of the rotor (7) and/or each recess (15') of the stator (16) extends for the entire radial thickness (14, 14') of the respective cutting elements (10, 10') along a respective median direction (19, 19') and wherein the extensions of the median directions (19, 19') of two adjacent recesses (15, 15') disposed in consecutive rows of cutting elements (10, 10') of the rotor (7) or stator (16) are unaligned inside a circular crown defined by two consecutive rows of cutting elements.

2. The multi-stage mixer according to claim 1, wherein in a section perpendicular to said longitudinal axis (4), each recess (15, 15') of the rotor (7) and/or of the stator (16) extends for the entire radial thickness (14, 14') of the cutting elements (10, 10') along a median direction (19, 19') extending radially relative to said longitudinal axis (4).
3. The multi-stage mixer, in particular according to claim 1, wherein the number of cutting elements (10) in a row (9a-9g) of the rotor (7) is different from the number of cutting elements (10) in the consecutive row and/or wherein the number of cutting elements (10') in a row (18a-18f) of the stator (16) is different from the number of cutting elements (10') in the consecutive row.
4. The multi-stage mixer according to claim 3, wherein

the number of cutting elements (10) in a row (9a-9g) of the rotor (7) is greater than the number of cutting elements (10') in the radially inward consecutive row and/or wherein the number of cutting elements (10') in a row (18a-18f) of the stator (16) is greater than the number of cutting elements (10') in the radially inward consecutive row.

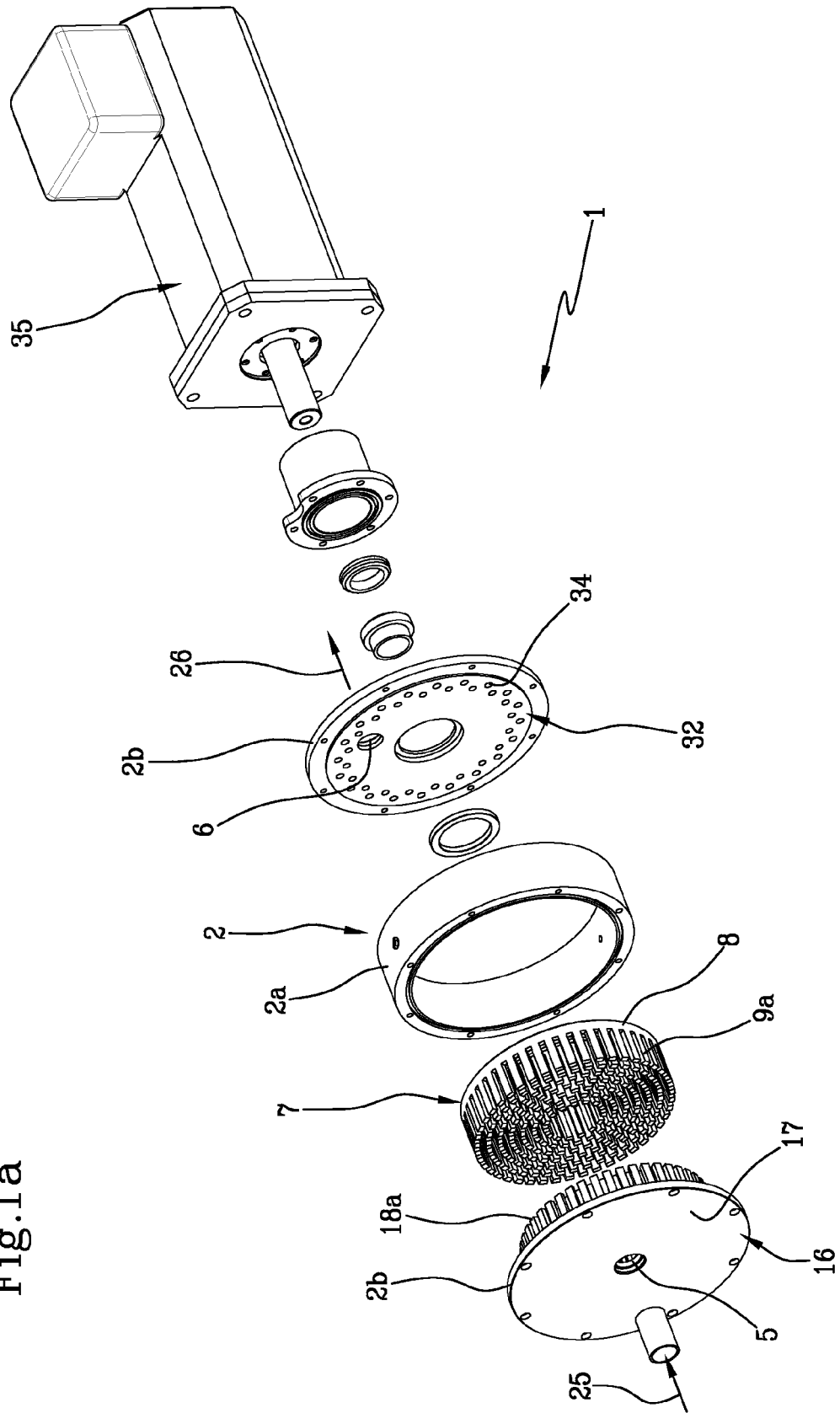
5. The multi-stage mixer in particular according to claim 1, wherein the number of cutting elements (10) in a row of the rotor (7) and/or the number of cutting elements (10') of the stator (16) increases proceeding outward from a radially inner row in a centrifugal direction; in particular, at least one row of the stator and at least one row of the rotor which is immediately consecutive, for example, in a centrifugal direction, have the same number of cutting elements.
6. The multi-stage mixer according to claim 1, wherein said rotor (7) comprises a radially outer row (9a) which is disposed externally to the radially outer row (18a) of the stator (16), and/or wherein said rotor (7) comprises one more circular row of cutting elements (10) compared to the circular rows of cutting elements (10') of the stator (16).
7. The multi-stage mixer according to claim 1, wherein said casing (2) comprises said stator (16) disposed so as to close off said chamber (3), in particular said supporting wall (17) defining a bottom wall (2a) of the casing (2).
8. The multi-stage mixer according to claim 1, wherein said recesses (15) of the rotor (7) and/or wherein said recesses (15') of the stator (16) are open at a respective projecting end (12, 12') of the cutting elements (10, 10').
9. The multi-stage mixer according in particular to claim 1, wherein each circular row (9a-9g) of cutting elements (10) of the rotor (7) and/or wherein each circular row (18a-18f) of cutting elements (10') of the stator (16) comprises an annular foot (21, 21'), which extends respectively from the supporting wall (8) of the rotor (7) or the supporting wall (17) of the stator (16) in a portion where the recesses (15, 15') are not present, and wherein said air space (13, 13') comprises a recessed portion (22, 22') respectively within the supporting wall (8) of the rotor (7) or the supporting wall (17) of the stator (16), delimited by two consecutive annular feet.
10. The multi-stage mixer according to claim 9, wherein a projecting end (12) of the cutting elements (10) of the rotor (7) is disposed inside a respective recessed portion (22') of an air space (13') of the stator (16) and/or vice versa.

11. The multi-stage mixer according to claim 1, wherein said outlet (6) is disposed in a radially intermediate portion between said longitudinal axis (4) and a radially outer portion of said rotor (7), generating an outflow (26) that is preferably axially disposed, and/or wherein said inlet (5) and said outlet (6) are disposed on opposite sides of the chamber (3) relative to said rows of cutting elements (10, 10'). 5
12. The multi-stage mixer according to claim 1, wherein said inlet (5), preferably axially disposed, is fashioned in said supporting wall (17) of said stator (16), for example a bottom wall (2b) of the casing (2). 10
13. The multi-stage mixer according in particular to claim 1, wherein said outlet (6) is disposed in a bottom wall (2b) of said casing (2) directly facing a rear surface (28) of said rotor (7) which is opposite said rows of cutting elements (10) and wherein a path (29) of said substances and said mixture inside the multi-stage mixer (1) comprises a centrifugal portion (30) between the rows (9a-9g; 18a-18f) of cutting elements (10, 10') of the rotor (7) and stator (16) and a centripetal portion (31) disposed between the rotor (7) and said bottom wall (2b) of the casing (2). 15 20 25
14. The multi-stage mixer according to claim 13, comprising cavitation means (32) preferably disposed in said centripetal portion (31) of said path (29), in particular blind cavities (33, 34) fashioned in the rotor (7) and/or in the bottom wall (2b) of the casing (2). 30
15. The multi-stage mixer according to claim 14, comprising a motor (35), preferably a brushless one operatively connected to said rotor (7) in order to drive its rotation around said longitudinal axis (4) and a control unit (36) programmed to regulate the rotation speed of the rotor depending on the substances and/or cavitation means (32), in particular the number and shape of the blind cavities (33, 34), in order to generate a cavitation frequency that is close to or coincides with the molecular resonance frequency of at least one of the substances to be mixed, in particular the dispersed phase in the case of emulsions. 35 40 45
16. The method for mixing substances in a multi-stage mixer, in particular according to one or more of the preceding claims, comprising: 50
- regulating the rotation speed of the rotor (7) so as to generate a cavitation frequency that is close to or coincides with the molecular resonance frequency of at least one of the substances to be mixed, in particular the dispersed phase in the case of emulsions. 55
17. The method for mixing substances in a multi-stage

mixer, in particular according to claim 16, comprising:

subjecting the substances to be mixed to a shear action along a centrifugal portion (30) of a path (29) of said substances inside the multi-stage mixer (1);
 subjecting the substances to at least a cavitation effect in the passage between said centrifugal portion (30) and a centripetal portion (31) of the path (29) of said substances inside the multi-stage mixer (1);
 subjecting the substances to at least a further cavitation effect along a centripetal portion (31) of the path (29) of said substances inside the multi-stage mixer (1);
 regulating the rotation speed of the rotor (7) so as to generate, in the centripetal portion (31) of the path (29) a cavitation frequency that is close to or coincides with the molecular resonance frequency of at least one of the substances to be mixed, in particular the dispersed phase in the case of emulsions.

Fig.1a



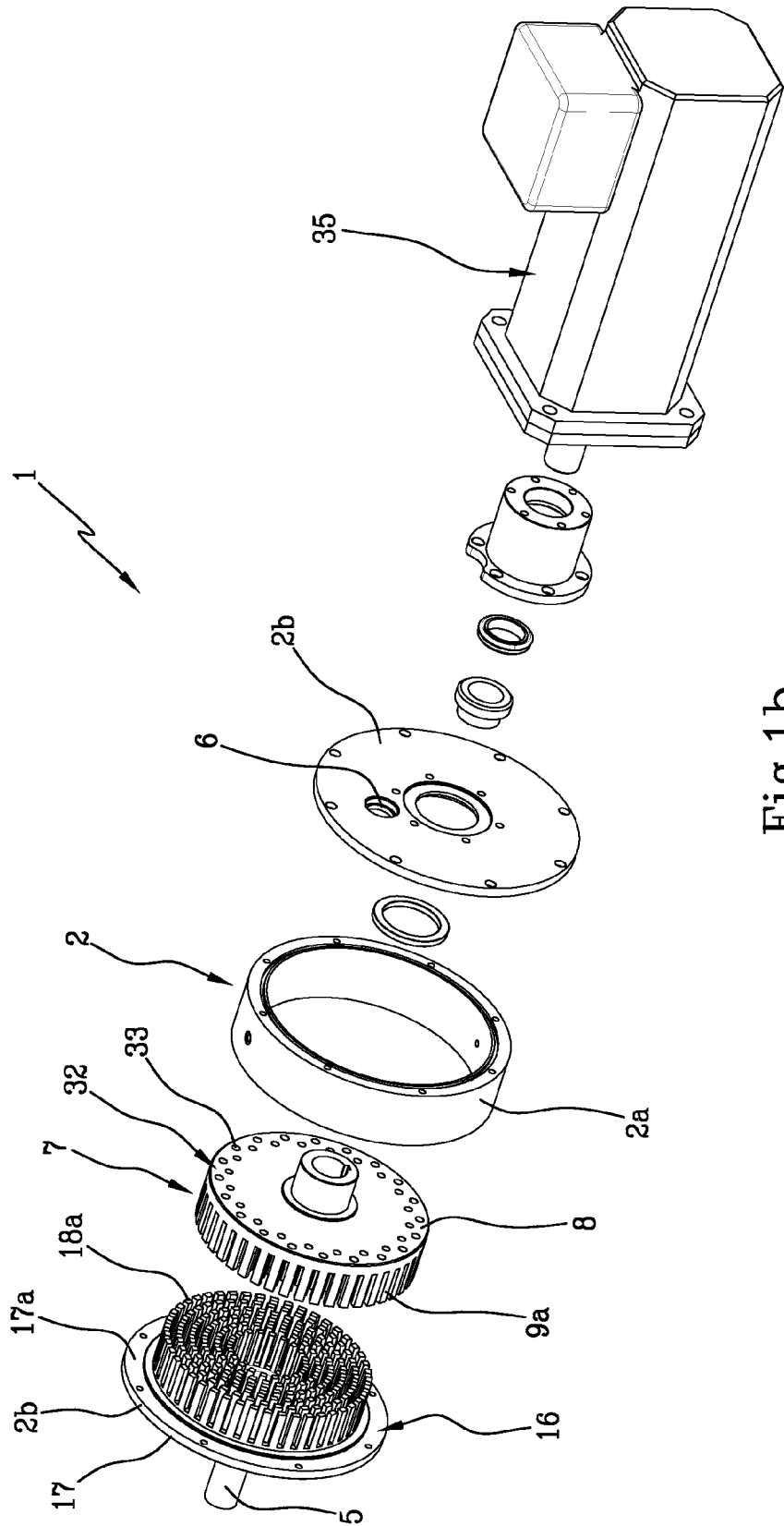


Fig.1b

Fig.2

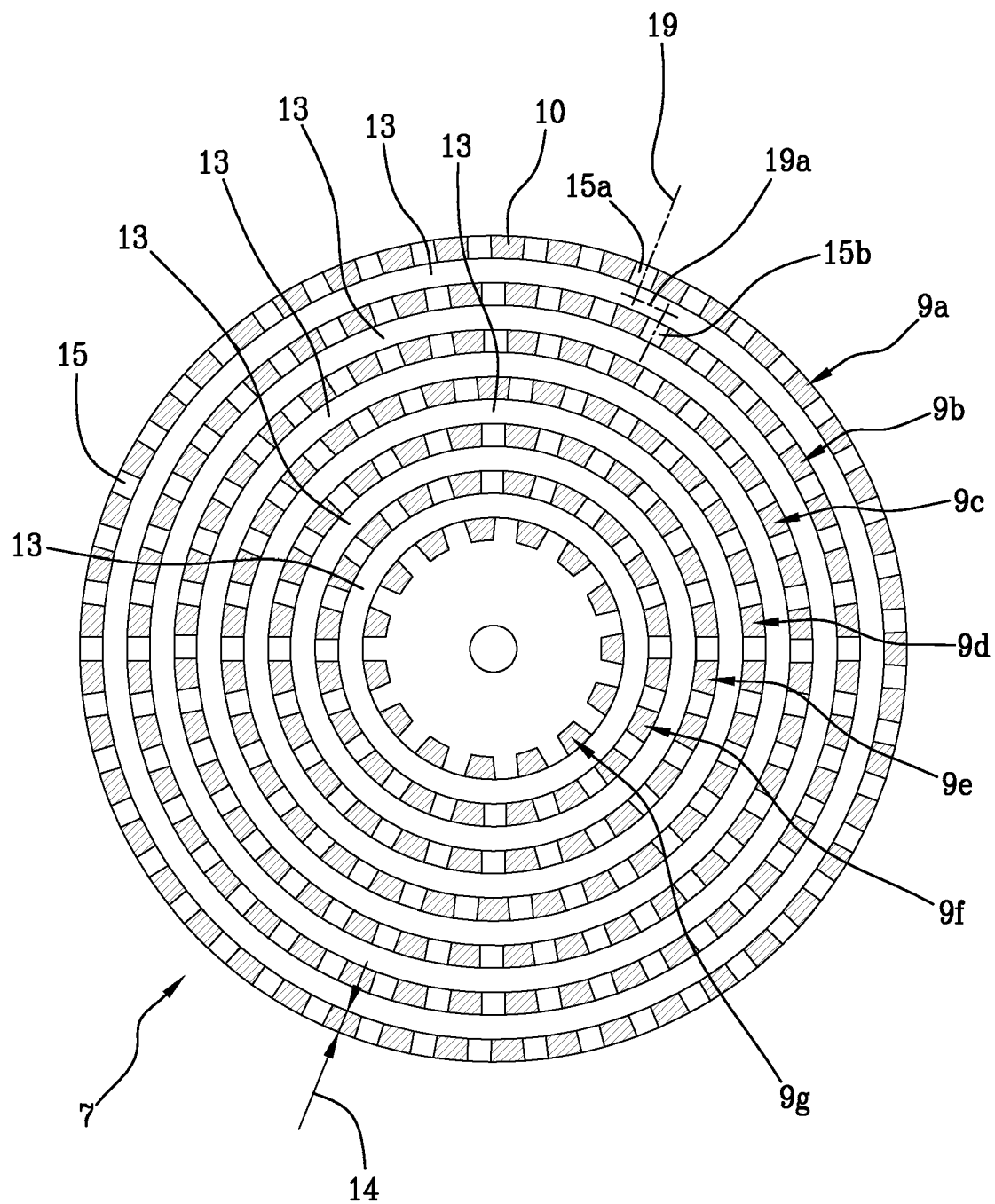
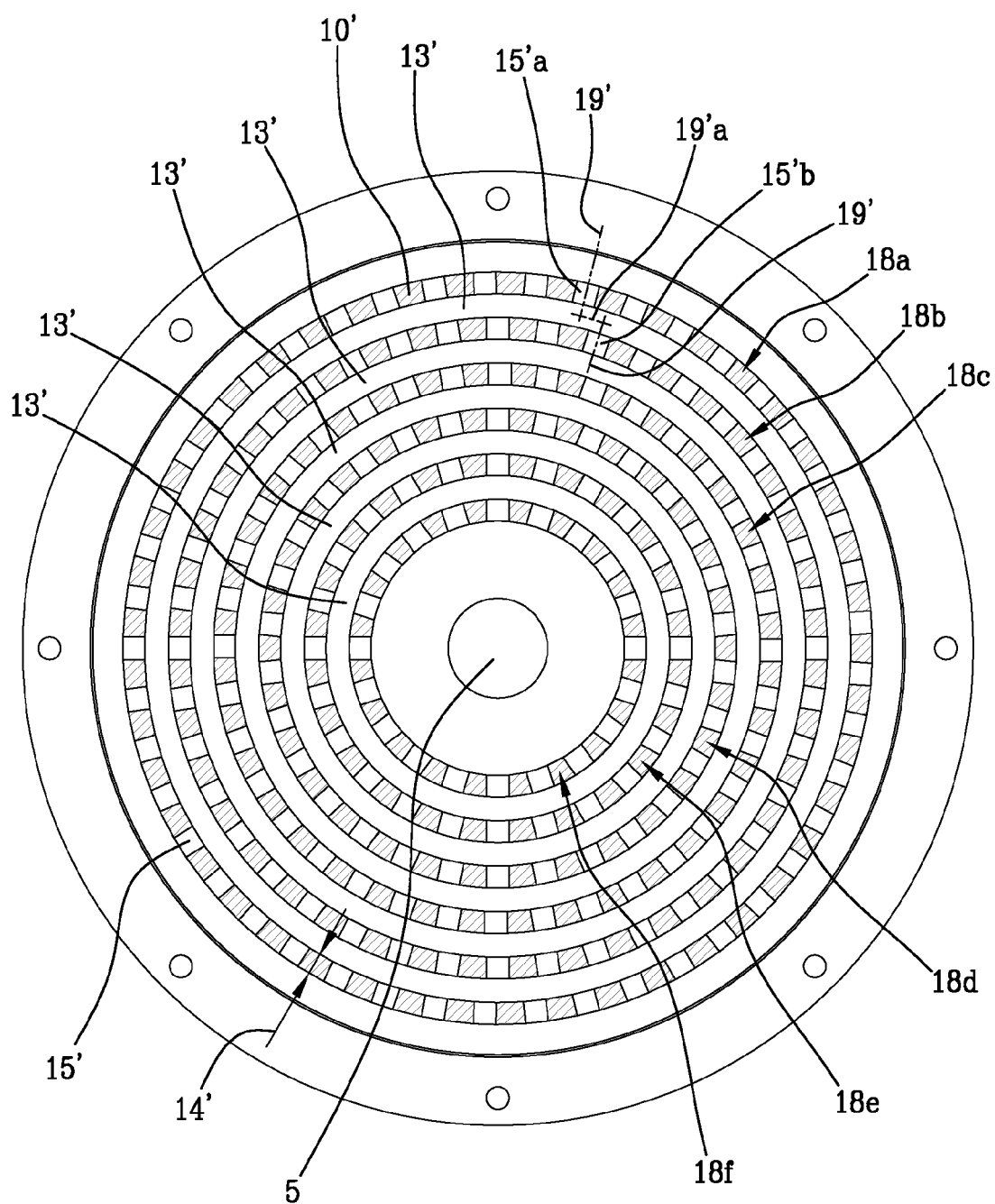
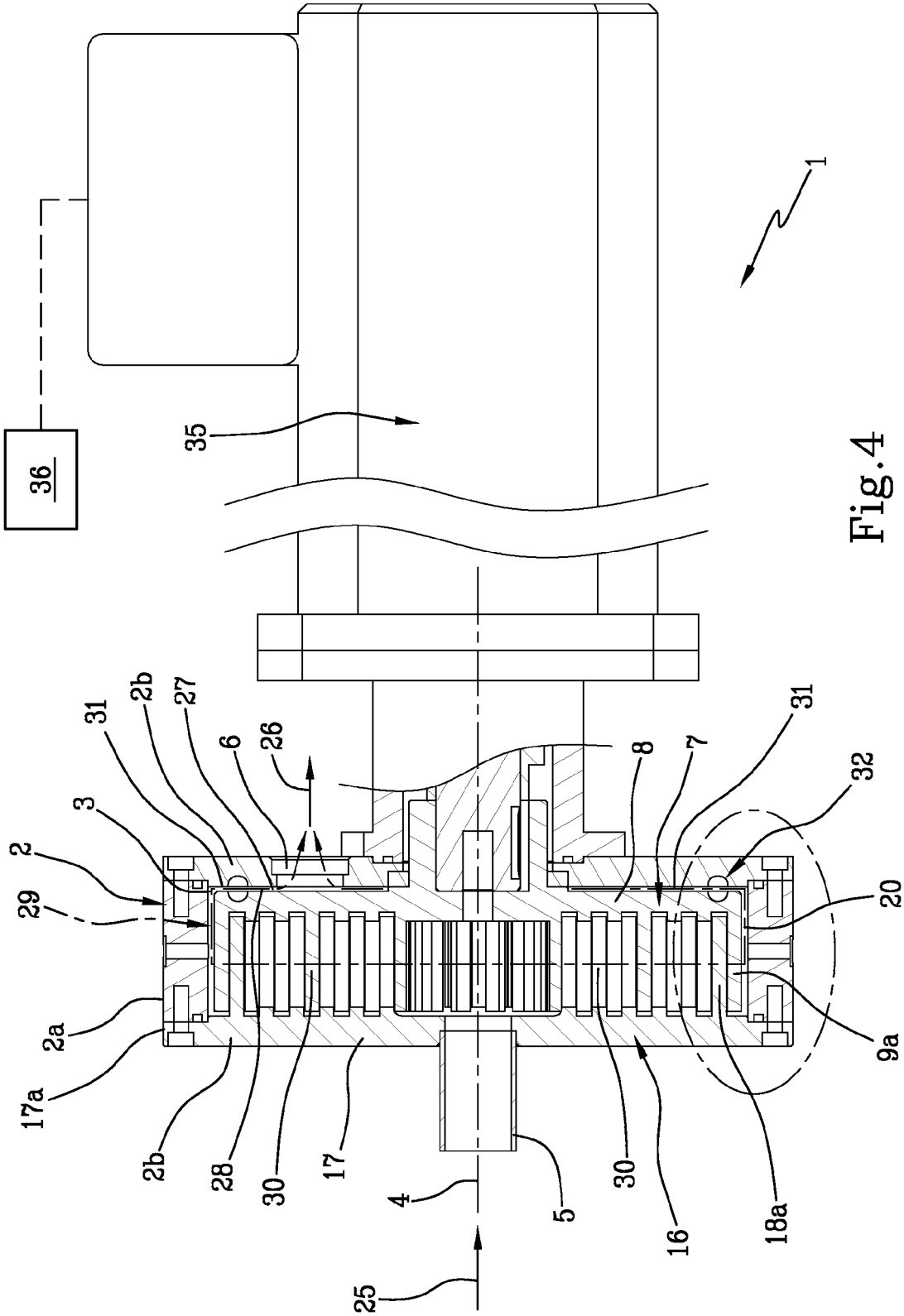


Fig.3





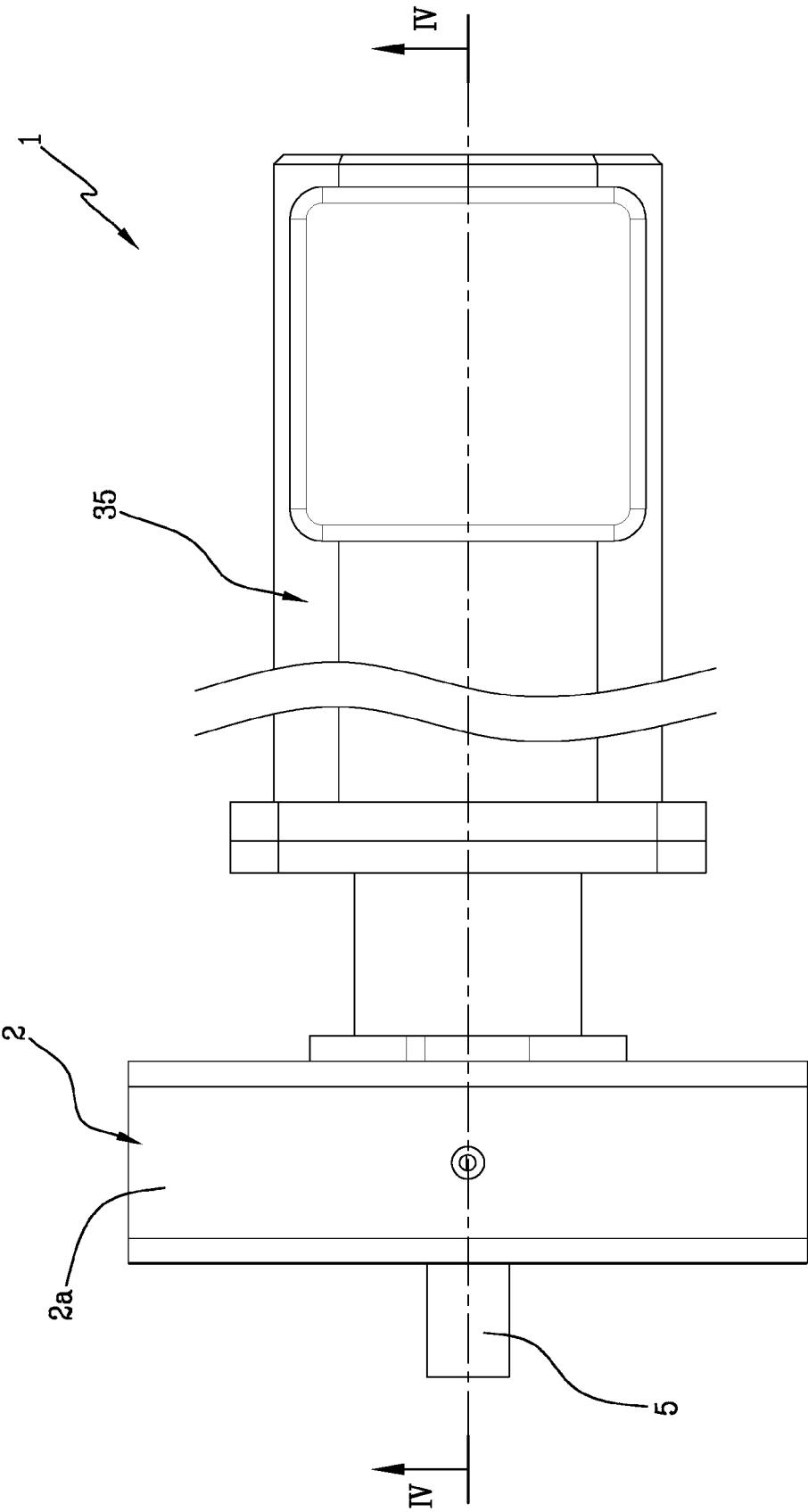
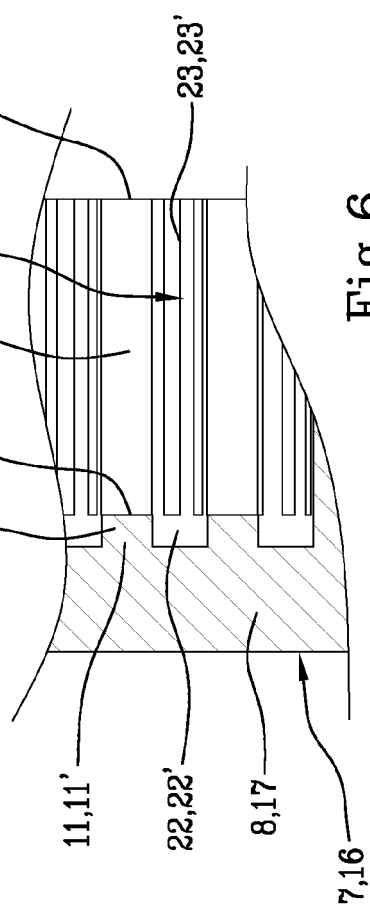
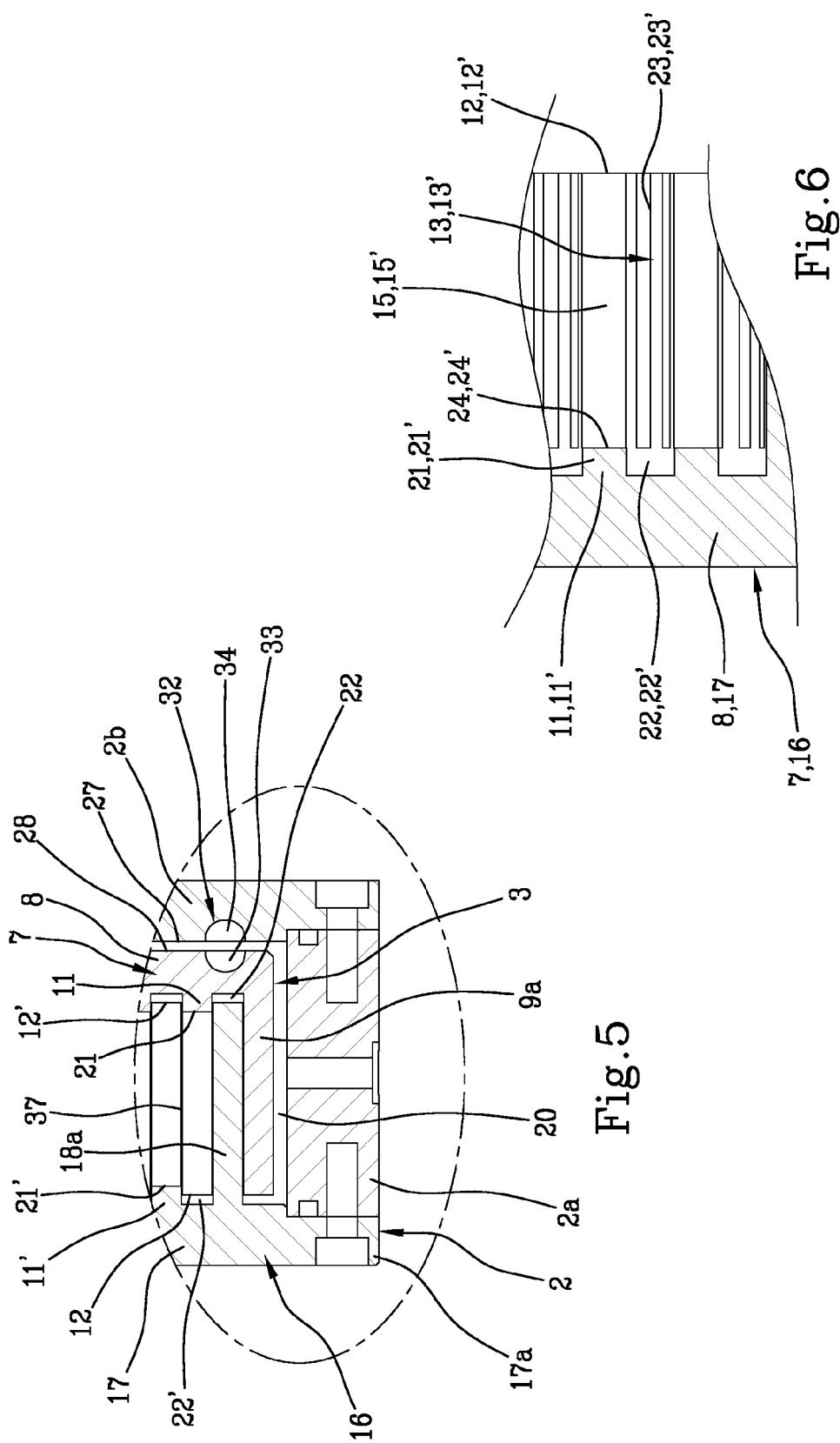


Fig. 4a





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Application Number
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Place of search		Date of completion of the search	Examiner
The Hague		4 November 2013	Zattoni, Federico
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