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(54) FLUIDIC DISPENSING DEVICE

(57) The disclosure provides a fluidic dispensing device (110), including a housing (112) and a stir bar (132). The housing (112) has an exterior wall (140-1) and a fluid reservoir (136). The exterior wall (140-1) has a first opening (140-3) in fluid communication with the fluid reservoir (136). The stir bar (132) is moveably confined within the fluid reservoir (136). The stir bar (132) has a plurality of paddles (132-1-132-4) and a rotational axis (165), with each of the plurality of paddles (132-1-132-4) that intermittently faces toward the first opening (140-3).

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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to fluidic dispensing devices.

2. Description of the Related Art

[0002] One type of microfluidic dispensing device, such as an ink jet printhead, is designed to include a capillary member, such as foam or felt, to control backpressure. In this type of printhead, the only free fluid is present between a filter and the ejection device. If settling or separation of the fluid occurs, it is almost impossible to re-mix the fluid contained in the capillary member.

[0003] Another type of printhead is referred to in the art as a free fluid style printhead, which has a movable wall that is spring loaded to maintain backpressure at the nozzles of the printhead. One type of spring loaded movable wall uses a deformable deflection bladder to create the spring and wall in a single piece. An early printhead design by Hewlett-Packard Company used a circular deformable rubber part in the form of a thimble shaped bladder positioned between a lid and a body that contained ink. The deflection of the thimble shaped bladder collapsed on itself. The thimble shaped bladder maintained backpressure by deforming the bladder material as ink was delivered to the printhead chip.

[0004] In a fluid tank where separation of fluids and particulate may occur, it is desirable to provide a mixing of the fluid. For example, particulate in pigmented fluids tend to settle depending on particle size, specific gravity differences, and fluid viscosity. U.S. Patent Application Publication No. 2006/0268080 discloses a system having an ink tank located remotely from the fluid ejection device, wherein the ink tank contains a magnetic rotor, which is rotated by an external rotary plate, to provide bulk mixing in the remote ink tank.

[0005] It has been recognized, however, that a microfluidic dispensing device having a compact design, which includes both a fluid reservoir and an on-board fluid ejection chip, presents particular challenges that a simple agitation in a remote tank does not address. For example, it has been determined that not only does fluid in the bulk region of the fluid reservoir need to be re-mixed, but remixing in the ejection chip region also is desirable, and in some cases, may be necessary, in order to prevent the clogging of the region near the fluid ejection chip with settled particulate.

[0006] Further, it has been recognized that even with remixing, there is a potential for stagnation zones to be created in a fluid channel of a fluidic dispensing device, wherein settled particulate is not affected by the fluid flow through the fluid channel and/or a fluid flow through the fluid channel may result in an unintentional depositing of particulate. Such stagnation zones may be created, for example, at locations in the fluid channel where there are abrupt changes in the surface features, such as in a corner defined by orthogonal planar surfaces.

[0007] What is needed in the art is a fluidic dispensing device having a moveable stir bar that provides for both bulk fluid remixing and fluid remixing in the vicinity of the fluid ejection chip, or a fluidic dispensing device having multiple stir bars that provide for both bulk fluid remixing and fluid remixing in the vicinity of the fluid ejection chip.

[0008] In addition, what is needed in the art is a method of operating a stir bar that includes stir bar feedback, so as to facilitate efficient fluid re-mixing and redistribution of particulate in the fluid within a fluid reservoir, or a fluidic dispensing device having features to reduce stagnation zones in a fluid channel in the vicinity of the ejection chip.

SUMMARY OF THE INVENTION

[0009] The present invention provides a fluidic dispensing device having a moveable stir bar that facilitates both bulk fluid remixing and fluid remixing in the vicinity of the fluid ejection chip. The present invention provides a fluidic dispensing device having multiple stir bars that facilitate both bulk fluid remixing and fluid remixing in the vicinity of the fluid ejection chip.

[0010] The present invention provides a method of operating a stir bar that includes stir bar feedback, so as to facilitate efficient fluid re-mixing and redistribution of particulate in the fluid within a fluid reservoir. The present invention provides a fluidic dispensing device having features to reduce stagnation zones in a fluid channel in the vicinity of the ejection chip.

[0011] The invention, in one form, is directed to a fluidic dispensing device that includes a housing and a stir bar. The housing has an exterior wall and a fluid reservoir. The exterior wall has a first opening in fluid communication with the fluid reservoir. The stir bar is moveably confined within the fluid reservoir. The stir bar has a plurality of paddles and a rotational axis, with each of the plurality of paddles that intermittently faces toward the first opening.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The above-mentioned and other features and advantages of this invention, and the manner of attaining them, will become more apparent and the invention will be better understood by reference to the following description of embodiments of the invention taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a perspective view of an embodiment of a microfluidic dispensing device in accordance with the present invention, in an environment that includes an external magnetic field generator.

FIG. 2 is another perspective view of the microfluidic dispensing device of FIG. 1.

FIG. 3 is a top orthogonal view of the microfluidic dispensing device of FIGs. 1 and 2.

FIG. 4 is a side orthogonal view of the microfluidic dispensing device of FIGs. 1 and 2.

FIG. 5 is an end orthogonal view of the microfluidic dispensing device of FIGs. 1 and 2.

FIG. 6 is an exploded perspective view of the microfluidic dispensing device of FIGs. 1 and 2, oriented for viewing into the chamber of the body in a direction toward the ejection chip.

FIG. 7 is another exploded perspective view of the microfluidic dispensing device of FIGs. 1 and 2, oriented for viewing in a direction away from the ejection chip.

FIG. 8 is a section view of the microfluidic dispensing device of FIG. 1, taken along line 8-8 of FIG. 5.

FIG. 9 is a section view of the microfluidic dispensing device of FIG. 1, taken along line 9-9 of FIG. 5.

FIG. 10 is a perspective view of the microfluidic dispensing device of FIG. 1, with the end cap and lid removed to expose the body/diaphragm assembly.

FIG. 11 is a perspective view of the depiction of FIG. 10, with the diaphragm removed to expose the guide portion and stir bar contained in the body, in relation to first and second planes and to the fluid ejection direction.

FIG. 12 is an orthogonal view of the body/guide portion/stir bar arrangement of FIG. 11, as viewed in a direction into the body of the chamber toward the base wall of the body.

FIG. 13 is an orthogonal end view of the body of FIG. 11, which contains the guide portion and stir bar, as viewed in a direction toward the exterior wall and fluid opening of the body.

FIG. 14 is a section view of the body/guide portion/stir bar arrangement of FIGs. 12 and 13, taken along line 14-14 of FIG. 13.

FIG. 15 is an enlarged section view of the body/guide portion/stir bar arrangement of FIGs. 12 and 13, taken along line 15-15 of FIG. 13.

FIG. 16 is an enlarged view of the depiction of FIG. 12, with the guide portion removed to expose the stir bar residing in the chamber of the body.

FIG. 17 is a top view of another embodiment of a microfluidic dispensing device in accordance with the present invention.

FIG. 18 is a section view of the microfluidic dispensing device of FIG. 17, taken along line 18-18 of FIG. 17.

FIG. 19 is an exploded perspective view of the microfluidic dispensing device of FIG. 17, oriented for viewing into the chamber of the body in a direction toward the ejection chip.

FIG. 20 is another perspective view of the microfluidic dispensing device of FIG. 17, with the end cap, lid and diaphragm removed to expose the guide portion and stir bar contained in the body, shown in relation to first and second planes and the fluid ejection direction.

FIG. 21 is an orthogonal top view corresponding to the perspective view of FIG. 20, showing the body having a chamber that contains the guide portion and the stir bar.

FIG. 22 is a side orthogonal view of the body of the microfluidic dispensing device of FIG. 17, wherein the body contains the guide portion and the stir bar.

FIG. 23 is a section view taken along line 23-23 of FIG. 22.

FIG. 24 is a perspective view of an embodiment of the stir bar of the microfluidic dispensing device of FIG. 17, as further depicted in FIGs. 18-21 and 23.

FIG. 25 is a top view of the stir bar of FIG. 24.

FIG. 26 is a side view of the stir bar of FIG. 24.

FIG. 27 is a section view of the stir bar taken along line 27-27 of FIG. 25.

FIG. 28 is a perspective view of another embodiment of a stir bar suitable for use in the microfluidic dispensing device of FIG. 17.

FIG. 29 is a top view of the stir bar of FIG. 28.

FIG. 30 is a side view of the stir bar of FIG. 28.

FIG. 31 is a section view of the stir bar taken along line 31-31 of FIG. 29.

FIG. 32 is an exploded perspective view of another embodiment of a stir bar suitable for use in the microfluidic dispensing device of FIG. 17.

FIG. 33 is a top view of the stir bar of FIG. 32.

FIG. 34 is a side view of the stir bar of FIG. 32.

FIG. 35 is a section view of the stir bar taken along line 35-35 of FIG. 33.

FIG. 36 is an exploded perspective view of another embodiment of a stir bar suitable for use in the microfluidic dispensing device of FIG. 17.

FIG. 37 is a top view of the stir bar of FIG. 36.

FIG. 38 is a side view of the stir bar of FIG. 36.

FIG. 39 is a section view of the stir bar taken along line 39-39 of FIG. 37.

FIG. 40 is an exploded perspective view of another embodiment of a stir bar suitable for use in the microfluidic dispensing device of FIG. 17.

FIG. 41 is a top view of the stir bar of FIG. 40.

FIG. 42 is a side view of the stir bar of FIG. 40.

FIG. 43 is a section view of the stir bar taken along line 43-43 of FIG. 41.

FIG. 44 is a top view of another embodiment of a stir bar suitable for use in the microfluidic dispensing device of FIG. 17.

FIG. 45 is a side view of the stir bar of FIG. 45.

FIG. 46 is a section view of the stir bar taken along line 46-46 of FIG. 44.

FIG. 47 is an x-ray image of a microfluidic dispensing device configured in accordance with FIGs. 17-23, which depicts an appropriate particulate suspension in the fluid, such as a newly filled microfluidic dispensing device, or after implementation of a method of the present invention to re-mix the fluid in the fluid reservoir.

FIG. 48 is an x-ray image of a microfluidic dispensing device configured in accordance with FIGs. 17-23 having a longitudinal extent of the housing arranged along a vertical axis, and showing an accumulation of settled particulate at a gravitational low region of the fluid reservoir.

FIG. 49 is an x-ray image of the microfluidic dispensing device of FIG. 48, which is tilted off-axis from the vertical axis to depict how settled particulate migrates to a new gravitational low region of the fluid reservoir based on the change of orientation.

FIG. 50 is an x-ray image of a microfluidic dispensing device configured in accordance with FIGs. 17-23, wherein the ejection chip faces vertically downward and settled particulate has accumulated over the channel inlet and the channel outlet of the fluid channel that feeds fluid to the ejection chip.

FIG. 51 is a perspective view of the microfluidic dispensing device of FIGs. 17-23, shown in a Cartesian space having X, Y, and Z axes, with the longitudinal extent of the housing on the positive Z-axis and the lateral extent of the housing lying on the X-Y plane.

FIG. 52 shows the microfluidic dispensing device depicted in FIG. 18 at an orientation wherein the fluid ejection direction is pointing upwardly at 135 degrees, and with an exterior of the dome portion of the diaphragm facing upwardly and with an exterior of the base wall facing downwardly.

FIG. 53 shows the microfluidic dispensing device depicted in FIG. 18 at an orientation wherein the fluid ejection direction is at 45 degrees, and with the exterior of the dome portion of the diaphragm facing downwardly at 45 degrees from vertical, and with the exterior of the base wall facing upwardly at an angle of 45 degrees from vertical.

FIG. 54 is a block diagram of an external magnetic field generator used to rotate the stir bar in the various embodiments of the present invention, and having a sensor.

FIG. 55 is a diagrammatic illustration of an angular rotational position of a stir bar (with magnet) relative to the angular rotational position of a rotating magnetic field.

FIG. 56 is a diagrammatic illustration and graphical depiction of a scenario wherein the torque required to rotate a stir bar is too high to begin stir bar rotation, i.e., the stir bar is stuck and prevented from rotation.

FIG. 57 is a diagrammatic illustration and graphical depiction of a scenario wherein there is a phase lag of approximately 45 degrees between the angular rotational position of a stir bar and an angular rotational position of a rotating magnetic field.

FIG. 58 is a diagrammatic illustration and graphical depiction of a scenario wherein there is a phase lag of approximately 90 degrees, represented by an arced arrowed line, between the angular rotational position of a stir bar and an angular rotational position of a rotating magnetic field.

FIG. 59 is a flowchart of a method of operating a stir bar in a fluidic dispensing device, in accordance with an aspect of the present invention.

FIG. 60 is a further enlargement of a portion of the depiction of FIG. 23, illustrating the locations of stagnation zones in the fluid channel.

FIG. 61 is a bottom view of an enlargement of a portion of the guide portion of FIG. 21, showing the flow control portion having an inlet flow director member and an outlet flow director member.

FIG. 62 is an enlarged bottom perspective view of the guide portion of FIG. 21, at an orientation that shows the flow control portion and the several surfaces of the inlet flow director member.

FIG. 63 is an enlarged bottom perspective view of the guide portion of FIG. 21, at an orientation that shows the flow control portion and the several surfaces of the outlet flow director member.

FIG. 64 is a side orthogonal view of another embodiment of a microfluidic dispensing device having features to reduce the occurrence of stagnation zones in the fluid channel.

FIG. 65 is a top orthogonal view of the microfluidic dispensing device of FIG. 51.

FIG. 66 is a section view of the microfluidic dispensing device taken along line 66-66 of FIG. 64.

FIG. 67 is a section view of the microfluidic dispensing device taken along line 67-67 of FIG. 64.

FIG. 68 is an enlargement of a portion of the depiction of FIG. 67.

FIG. 69 is a section view of the microfluidic dispensing device taken along line 69-69 of FIG. 65.

FIG. 70 is a section view of the microfluidic dispensing device taken along line 70-70 of FIG. 65.

FIG. 71 is an enlargement of a portion of the depiction of FIG. 70.

FIG. 72 is a perspective view of the microfluidic dispensing device of FIG. 1, with the end cap and lid removed to expose the body/diaphragm assembly, in relation to first and second planes and to the fluid ejection direction, and with a portion of the diaphragm broken away to illustrate the fluid reservoir.

FIG. 73 is a top orthogonal view of the body/diaphragm assembly of FIG. 72.

FIG. 74 is a section view of the body/diaphragm assembly of FIG. 72, taken along line 74-74 of FIG. 73, to expose the multiple stir bars located in the fluid reservoir.

FIG. 75 is a perspective view of the depiction of FIG. 72, with the diaphragm removed to expose the multiple stir bar contained in the body, and with the ejection chip removed to expose the fluid opening in the exterior wall.

FIG. 76 is another perspective view of the depiction of FIG. 75, in an orientation to show the channel inlet and channel outlet of a fluid channel.

FIG. 77 is a top orthogonal view of the body/stir bar components of FIGs. 75 and 76.

FIG. 78 is a diagrammatic depiction of the two stir bars depicted in FIGs. 73-77, illustrating an overlap of a first rotational area of a first stir bar with a second rotational area of a second stir bar.

FIG. 79 is a perspective view of an alternative body having a separation wall, which may be substituted for the body depicted in FIGs. 1-5 and 72-77.

FIG. 80 is another perspective view of the depiction of FIG. 79, in an orientation to show the channel inlet and channel outlet of a fluid channel in relation to the separation wall.

FIG. 81 is a perspective view corresponding to the depiction of the alternative body of FIGs. 79 and 80, with the two stir bars inserted on opposite sides of the separation wall.

FIG. 82 is a top orthogonal view of the alternative body and stir bar components of FIG. 81.

FIG. 83 is a section view of the alternative body of FIGs. 79-82, taken along line 83-83 of FIG. 82.

FIG. 84 is the section view of FIG. 83, modified to include a section view of the diaphragm of FIGs. 72-74 installed on the alternative body of FIGs. 79-83.

FIG. 85 is an enlarged portion of the depiction of FIG. 82, illustrating the separation wall separating a first rotational area of a first stir bar from a second rotational area of a second stir bar.

FIG. 86 is a perspective view of the depiction of FIG. 72, with the diaphragm removed to expose the stir bar contained in the body, and the ejection chip removed to expose the fluid opening in the exterior wall.

FIG. 87 is another perspective view of the depiction of FIG. 72, in an orientation to show the channel inlet and channel outlet of a fluid channel.

FIG. 88 is an orthogonal view of the body/stir bar arrangement of FIGs. 86 and 87, as viewed in a direction into the body of the chamber toward the base wall of the body.

FIG. 89 is a section view of the body/stir bar arrangement of FIG. 88, taken along line 89-89 of FIG. 88.

FIG. 90 is a top view of another embodiment of a microfluidic dispensing device in accordance with the present invention.

FIG. 91 is a section view of the microfluidic dispensing device of FIG. 90, taken along line 91-91 of FIG. 90.

FIG. 92 is another perspective view of the microfluidic dispensing device of FIG. 90, with the end cap, lid and diaphragm removed to illustrate a range of motion of the moveable stir bar with respect to the guide portion.

FIG. 93 is another perspective view of the microfluidic dispensing device of FIG. 90, with the end cap, lid and diaphragm removed to expose the guide portion and the moveable stir bar contained in the body, shown in relation to first and second planes and the fluid ejection direction.

FIG. 94 is an orthogonal top view corresponding to the perspective view of FIG. 93, showing the body having a chamber that contains the guide portion and the moveable stir bar, and illustrating the range of motion of the moveable stir bar with respect to the guide portion.

FIG. 95 is a side orthogonal view of the body of the microfluidic dispensing device of FIG. 90, wherein the body contains the guide portion and the moveable stir bar.

FIG. 96 is a section view taken along line 96-96 of FIG. 95.

FIG. 97 is a perspective view of an embodiment of the stir bar of the microfluidic dispensing device of FIG. 90, as further depicted in FIGs. 91-94 and 96.

FIG. 98 is a top view of the stir bar of FIG. 97.

FIG. 99 is a side view of the stir bar of FIG. 97.

FIG. 100 is a section view of the stir bar of FIG. 97 taken along line 100-100 of FIG. 98.

[0013] Corresponding reference characters indicate corresponding parts throughout the several views. The exemplifications set out herein illustrate embodiments of the invention, and such exemplifications are not to be construed as limiting the scope of the invention in any manner.

DETAILED DESCRIPTION OF THE INVENTION

[0014] Referring now to the drawings, and more particularly to FIGs. 1-16, there is shown a fluidic dispensing device, which in the present example is a microfluidic dispensing device 110 in accordance with an embodiment of the present invention.

[0015] Referring to FIGs. 1-5, microfluidic dispensing device 110 generally includes a housing 112 and a tape automated bonding (TAB) circuit 114. Microfluidic dispensing device 110 is configured to contain a supply of a fluid, such as a fluid containing particulate material, and TAB circuit 114 is configured to facilitate the ejection of the fluid from housing 112. The fluid may be, for example, cosmetics, lubricants, paint, ink, etc.

[0016] Referring also to FIGs. 6 and 7, TAB circuit 114 includes a flex circuit 116 to which an ejection chip 118 is mechanically and electrically connected. Flex circuit 116 provides electrical connection to an electrical driver device (not shown), such as an ink jet printer, configured to operate ejection chip 118 to eject the fluid that is contained within housing 112. In the present embodiment, ejection chip 118 is configured as a plate-like structure having a planar extent formed generally as a nozzle plate layer and a silicon layer, as is well known in the art. The nozzle plate layer of ejection chip 118 has a plurality of ejection nozzles 120 oriented such that a fluid ejection direction 120-1 is substantially orthogonal to the planar extent of ejection chip 118. Associated with each of the ejection nozzles 120, at the silicon layer of ejection chip 118, is an ejection mechanism, such as an electrical heater (thermal) or piezoelectric (electromechanical) device. The operation of such an ejection chip 118 and driver is well known in the micro-fluid ejection arts, such as in ink jet printing.

[0017] As used herein, each of the terms substantially orthogonal and substantially perpendicular is defined to mean an angular relationship between two elements of 90 degrees, plus or minus 10 degrees. The term substantially parallel is defined to mean an angular relationship between two elements of zero degrees, plus or minus 10 degrees.

[0018] As best shown in FIGs. 6 and 7, housing 112 includes a body 122, a lid 124, an end cap 126, and a fill plug 128 (e.g., ball). Contained within housing 112 is a diaphragm 130, a stir bar 132, and a guide portion 134. Each of the housing 112 components, stir bar 132, and guide portion 134 may be made of plastic, using a molding process. Diaphragm 130 is made of rubber, using a molding process. Also, in the present embodiment, fill plug 128 may be in the form of a stainless steel ball bearing.

[0019] Referring also to FIGs. 8 and 9, in general, a fluid (not shown) is loaded through a fill hole 122-1 in body 122 (see also FIG. 6) into a sealed region, i.e., a fluid reservoir 136, between body 122 and diaphragm 130. Back pressure in fluid reservoir 136 is set and then maintained by inserting, e.g., pressing, fill plug 128 into fill hole 122-1 to prevent air from leaking into fluid reservoir 136 or fluid from leaking out of fluid reservoir 136. End cap 126 is then placed onto an end of the body 122/lid 124 combination, opposite to ejection chip 118. Stir bar 132 resides in the sealed fluid reservoir 136 between body 122 and diaphragm 130 that contains the fluid. An internal fluid flow may be generated within fluid reservoir 136 by rotating stir bar 132 so as to provide fluid mixing and redistribution of particulate in the fluid within the sealed region of fluid reservoir 136.

[0020] Referring now also to FIGs. 10-16, body 122 of housing 112 has a base wall 138 and an exterior perimeter wall 140 contiguous with base wall 138. Exterior perimeter wall 140 is oriented to extend from base wall 138 in a direction that is substantially orthogonal to base wall 138. Lid 124 is configured to engage exterior perimeter wall 140. Thus, exterior perimeter wall 140 is interposed between base wall 138 and lid 124, with lid 124 being attached to the open free end of exterior perimeter wall 140 by weld, adhesive, or other fastening mechanism, such as a snap fit or threaded union. Attachment of lid 124 to body 122 occurs after installation of diaphragm 130, stir bar 132, and guide portion 134 in body 122.

[0021] Exterior perimeter wall 140 of body 122 includes an exterior wall 140-1, which is a contiguous portion of exterior perimeter wall 140. Exterior wall 140-1 has a chip mounting surface 140-2 that defines a plane 142 (see FIGs. 11 and 12), and has a fluid opening 140-3 adjacent to chip mounting surface 140-2 that passes through the thickness of exterior wall 140-1. Ejection chip 118 is mounted, e.g., by an adhesive sealing strip 144 (see FIGs. 6 and 7), to chip mounting surface 140-2 and is in fluid communication with fluid opening 140-3 (see FIG. 13) of exterior wall 140-1. Thus, the planar extent of ejection chip 118 is oriented along plane 142, with the plurality of ejection nozzles 120 oriented such that the fluid ejection direction 120-1 is substantially orthogonal to plane 142. Base wall 138 is oriented along a plane 146 (see FIG. 11) that is substantially orthogonal to plane 142 of exterior wall 140-1. As best shown in FIGs. 6, 15 and 16, base wall 138 may include a circular recessed region 138-1 in the vicinity of the desired location of stir bar 132.

[0022] Referring to FIGs. 11-16, body 122 of housing 112 also includes a chamber 148 located within a boundary defined by exterior perimeter wall 140. Chamber 148 forms a portion of fluid reservoir 136, and is configured to define an interior space, and in particular, includes base wall 138 and has an interior perimetrical wall 150 configured to have rounded corners, so as to promote fluid flow in chamber 148. Interior perimetrical wall 150 of chamber 148 has an extent bounded by a proximal end 150-1 and a distal end 150-2. Proximal end 150-1 is contiguous with, and may form a transition radius with, base wall 138. Such an edge radius may help in mixing effectiveness by reducing the number of sharp corners. Distal end 150-2 is configured to define a perimetrical end surface 150-3 at a lateral opening 148-1 of chamber 148. Perimetrical end surface 150-3 may include a plurality of perimetrical ribs, or undulations, to provide an effective sealing surface for engagement with diaphragm 130. The extent of interior perimetrical wall 150 of chamber 148 is substantially orthogonal to base wall 138, and is substantially parallel to the corresponding extent of exterior perimeter wall 140 (see FIG. 6).

[0023] As best shown in FIGs. 15 and 16, chamber 148 has an inlet fluid port 152 and an outlet fluid port 154, each of which is formed in a portion of interior perimetrical wall 150. The terms "inlet" and "outlet" are terms of convenience that are used in distinguishing between the multiple ports of the present embodiment, and are correlated with a particular rotational direction of stir bar 132. However, it is to be understood that it is the rotational direction of stir bar 132 that dictates whether a particular port functions as an inlet port or an outlet port, and it is within the scope of this invention to reverse the rotational direction of stir bar 132, and thus reverse the roles of the respective ports within chamber 148.

[0024] Inlet fluid port 152 is separated a distance from outlet fluid port 154 along a portion of interior perimetrical wall 150. As best shown in FIGs. 15 and 16, considered together, body 122 of housing 112 includes a fluid channel 156 interposed between the portion of interior perimetrical wall 150 of chamber 148 and exterior wall 140-1 of exterior perimeter wall 140 that carries ejection chip 118.

[0025] Fluid channel 156 is configured to minimize particulate settling in a region of ejection chip 118. Fluid channel 156 is sized, e.g., using empirical data, to provide a desired flow rate while also maintaining an acceptable fluid velocity for fluid mixing through fluid channel 156.

[0026] In the present embodiment, referring to FIG. 15, fluid channel 156 is configured as a U-shaped elongated passage having a channel inlet 156-1 and a channel outlet 156-2. Fluid channel 156 dimensions, e.g., height and width, and shape are selected to provide a desired combination of fluid flow and fluid velocity for facilitating intra-channel stirring.

[0027] Fluid channel 156 is configured to connect inlet fluid port 152 of chamber 148 in fluid communication with outlet fluid port 154 of chamber 148, and also connects fluid opening 140-3 of exterior wall 140-1 of exterior perimeter wall 140 in fluid communication with both inlet fluid port 152 and outlet fluid port 154 of chamber 148. In particular, channel inlet 156-1 of fluid channel 156 is located adjacent to inlet fluid port 152 of chamber 148 and channel outlet 156-2 of fluid channel 156 is located adjacent to outlet fluid port 154 of chamber 148. In the present embodiment, the structure of inlet fluid port 152 and outlet fluid port 154 of chamber 148 is symmetrical.

[0028] Fluid channel 156 has a convexly arcuate wall 156-3 that is positioned between channel inlet 156-1 and channel outlet 156-2, with fluid channel 156 being symmetrical about a channel mid-point 158. In turn, convexly arcuate wall 156-3 of fluid channel 156 is positioned between inlet fluid port 152 and outlet fluid port 154 of chamber 148 on the opposite side of interior perimetrical wall 150 from the interior space of chamber 148, with convexly arcuate wall 156-3 positioned to face fluid opening 140-3 of exterior wall 140-1 and ejection chip 118.

[0029] Convexly arcuate wall 156-3 is configured to create a fluid flow through fluid channel 156 that is substantially parallel to ejection chip 118. In the present embodiment, a longitudinal extent of convexly arcuate wall 156-3 has a radius that faces fluid opening 140-3 and that is substantially parallel to ejection chip 118, and has transition radii 156-4, 156-5 located adjacent to channel inlet 156-1 and channel outlet 156-2, respectively. The radius and transition radii 156-4, 156-5 of convexly arcuate wall 156-3 help with fluid flow efficiency. A distance between convexly arcuate wall 156-3 and fluid ejection chip 118 is narrowest at the channel mid-point 158, which coincides with a mid-point of the longitudinal extent of ejection chip 118, and in turn, with a mid-point of the longitudinal extent of fluid opening 140-3 of exterior wall 140-1.

[0030] Each of inlet fluid port 152 and outlet fluid port 154 of chamber 148 has a beveled ramp structure configured such that each of inlet fluid port 152 and outlet fluid port 154 converges in a respective direction toward fluid channel 156. In particular, inlet fluid port 152 of chamber 148 has a beveled inlet ramp 152-1 configured such that inlet fluid port 152 converges, i.e., narrows, in a direction toward channel inlet 156-1 of fluid channel 156, and outlet fluid port 154 of chamber 148 has a beveled outlet ramp 154-1 that diverges, i.e., widens, in a direction away from channel outlet 156-2 of fluid channel 156.

[0031] Referring again to FIGs. 6-10, diaphragm 130 is positioned between lid 124 and perimetrical end surface 150-3 of interior perimetrical wall 150 of chamber 148. The attachment of lid 124 to body 122 compresses a perimeter of diaphragm 130 thereby creating a continuous seal between diaphragm 130 and body 122. More particularly, diaphragm 130 is configured for sealing engagement with perimetrical end surface 150-3 of interior perimetrical wall 150 of chamber 148 in forming fluid reservoir 136. Thus, in combination, chamber 148 and diaphragm 130 cooperate to define fluid reservoir 136 having a variable volume.

[0032] Referring particularly to FIGs. 6, 8 and 9, an exterior surface of diaphragm 130 is vented to the atmosphere through a vent hole 124-1 located in lid 124 so that a controlled negative pressure can be maintained in fluid reservoir 136. Diaphragm 130 is made of rubber, and includes a dome portion 130-1 configured to progressively collapse toward base wall 138 as fluid is depleted from microfluidic dispensing device 110, so as to maintain a desired negative pressure in chamber 148, and thus changing the effective volume of the variable volume of fluid reservoir 136.

[0033] Referring to FIGs. 8 and 9, for sake of further explanation, below, the variable volume of fluid reservoir 136, also referred to herein as a bulk region, may be considered to have a proximal continuous 1/3 volume portion 136-1, and a continuous 2/3 volume portion 136-4 that is formed from a central continuous 1/3 volume portion 136-2 and a distal continuous 1/3 volume portion 136-3, with the central continuous 1/3 volume portion 136-2 separating the proximal continuous 1/3 volume portion 136-1 from the distal continuous 1/3 volume portion 136-3. The proximal continuous 1/3 volume portion 136-1 is located closer to ejection chip 118 than the continuous 2/3 volume portion 136-4 that is formed from the central continuous 1/3 volume portion 136-2 and the distal continuous 1/3 volume portion 136-3.

[0034] Referring to FIGs. 6-9 and 16, stir bar 132 resides in the variable volume of fluid reservoir 136 and chamber 148, and is located within a boundary defined by the interior perimetrical wall 150 of chamber 148. Stir bar 132 has a rotational axis 160 and a plurality of paddles 132-1, 132-2, 132-3, 132-4 that radially extend away from the rotational axis 160. Stir bar 132 has a magnet 162 (see FIG. 8), e.g., a permanent magnet, configured for interaction with an external magnetic field generator 164 (see FIG. 1) to drive stir bar 132 to rotate around the rotational axis 160. The principle of stir bar 132 operation is that as magnet 162 is aligned to a strong enough external magnetic field generated by external magnetic field generator 164, then rotating the external magnetic field generated by external magnetic field generator 164 in a controlled manner will rotate stir bar 132. The external magnetic field generated by external magnetic field generator 164 may be rotated electronically, akin to the operation of a stepper motor, or may be rotated via a rotating shaft. Thus, stir bar 132 is effective to provide fluid mixing in fluid reservoir 136 by the rotation of stir bar 132 around the rotational axis 160.

[0035] Fluid mixing in the bulk region relies on a flow velocity caused by rotation of stir bar 132 to create a shear stress at the settled boundary layer of the particulate. When the shear stress is greater than the critical shear stress (empirically determined) to start particle movement, remixing occurs because the settled particles are now distributed in the moving fluid. The shear stress is dependent on both the fluid parameters such as: viscosity, particle size, and density; and mechanical design factors such as: container shape, stir bar 132 geometry, fluid thickness between moving and stationary surfaces, and rotational speed.

[0036] Also, a fluid flow is generated by rotating stir bar 132 in a fluid region, e.g., the proximal continuous 1/3 volume portion 136-1 and fluid channel 156, associated with ejection chip 118, so as to ensure that mixed bulk fluid is presented to ejection chip 118 for nozzle ejection and to move fluid adjacent to ejection chip 118 to the bulk region of fluid reservoir 136 to ensure that the channel fluid flowing through fluid channel 156 mixes with the bulk fluid of fluid reservoir 136, so as to produce a more uniform mixture. Although this flow is primarily distribution in nature, some mixing will occur if the flow velocity is sufficient to create a shear stress above the critical value.

[0037] Stir bar 132 primarily causes rotation flow of the fluid about a central region associated with the rotational axis 160 of stir bar 132, with some axial flow with a central return path as in a partial toroidal flow pattern.

[0038] Referring to FIG. 16, each paddle of the plurality of paddles 132-1, 132-2, 132-3, 132-4 of stir bar 132 has a respective free end tip 132-5. To reduce rotational drag, each paddle may include upper and lower symmetrical pairs of chamfered surfaces, forming leading beveled surfaces 132-6 and trailing beveled surfaces 132-7 relative to a rotational direction 160-1 of stir bar 132. It is also contemplated that each of the plurality of paddles 132-1, 132-2, 132-3, 132-4 of stir bar 132 may have a pill or cylindrical shape. In the present embodiment, stir bar 132 has two pairs of diametrically opposed paddles, wherein a first paddle of the diametrically opposed paddles has a first free end tip 132-5 and a second paddle of the diametrically opposed paddles has a second free end tip 132-5.

[0039] In the present embodiment, the four paddles forming the two pairs of diametrically opposed paddles are equally spaced at 90 degree increments around the rotational axis 160. However, the actual number of paddles of stir bar 132 may be two or more, and preferably three or four, but more preferably four, with each adjacent pair of paddles having the same angular spacing around the rotational axis 160. For example, a stir bar 132 configuration having three paddles may have a paddle spacing of 120 degrees, having four paddles may have a paddle spacing of 90 degrees, etc.

[0040] In the present embodiment, and with the variable volume of fluid reservoir 136 being divided as the proximal continuous 1/3 volume portion 136-1 and the continuous 2/3 volume portion 136-4 described above, with the proximal continuous 1/3 volume portion 136-1 being located closer to ejection chip 118 than the continuous 2/3 volume portion 136-4, the rotational axis 160 of stir bar 132 may be located in the proximal continuous 1/3 volume portion 136-1 that is closer to ejection chip 118. Stated differently, guide portion 134 is configured to position the rotational axis 160 of stir bar 132 in a portion of the interior space of chamber 148 that constitutes a 1/3 of the volume of the interior space of chamber 148 that is closest to fluid opening 140-3.

[0041] Referring again also to FIG. 11, the rotational axis 160 of stir bar 132 may be oriented in an angular range of perpendicular, plus or minus 45 degrees, relative to the fluid ejection direction 120-1. Stated differently, the rotational axis 160 of stir bar 132 may be oriented in an angular range of parallel, plus or minus 45 degrees, relative to the planar extent (e.g., plane 142) of ejection chip 118. In combination, the rotational axis 160 of stir bar 132 may be oriented in both an angular range of perpendicular, plus or minus 45 degrees, relative the fluid ejection direction 120-1, and an angular range of parallel, plus or minus 45 degrees, relative to the planar extent of ejection chip 118.

[0042] More preferably, the rotational axis 160 has an orientation substantially perpendicular to the fluid ejection direction 120-1, and thus, the rotational axis 160 of stir bar 132 has an orientation that is substantially parallel to plane 142, i.e., planar extent, of ejection chip 118 and that is substantially perpendicular to plane 146 of base wall 138. Also, in the present embodiment, the rotational axis 160 of stir bar 132 has an orientation that is substantially perpendicular to plane 146 of base wall 138 in all orientations around rotational axis 160 and is substantially perpendicular to the fluid ejection direction 120-1.

[0043] Referring to FIGs. 6-9, 11, and 12, the orientations of stir bar 132, described above, may be achieved by guide portion 134, with guide portion 134 also being located within chamber 148 in the variable volume of fluid reservoir 136 (see FIGs. 8 and 9), and more particularly, within the boundary defined by interior perimetrical wall 150 of chamber 148. Guide portion 134 is configured to confine stir bar 132 in a predetermined portion of the interior space of chamber 148 at a predefined orientation, as well as to split and redirect the rotational fluid flow from stir bar 132 towards channel inlet 156-1 of fluid channel 156. On the return flow side, guide portion 134 helps to recombine the rotational flow received from channel outlet 156-2 of fluid channel 156 in the bulk region of fluid reservoir 136.

[0044] For example, guide portion 134 may be configured to position the rotational axis 160 of stir bar 132 in an angular range of parallel, plus or minus 45 degrees, relative to the planar extent of ejection chip 118, and more preferably, guide portion 134 is configured to position the rotational axis 160 of stir bar 132 substantially parallel to the planar extent of ejection chip 118. In the present embodiment, guide portion 134 is configured to position and maintain an orientation of the rotational axis 160 of stir bar 132 to be substantially parallel to the planar extent of ejection chip 118 and to be substantially perpendicular to plane 146 of base wall 138 in all orientations around rotational axis 160.

[0045] Guide portion 134 includes an annular member 166, a plurality of locating features 168-1, 168-2, offset members 170, 172, and a cage structure 174. The plurality of locating features 168-1, 168-2 are positioned on the opposite side of annular member 166 from offset members 170, 172, and are positioned to be engaged by diaphragm 130, which keeps offset members 170, 172 in contact with base wall 138. Offset members 170, 172 maintain an axial position (relative to the rotational axis 160 of stir bar 132) of guide portion 134 in fluid reservoir 136. Offset member 172 includes a retention feature 172-1 that engages body 122 to prevent a lateral translation of guide portion 134 in fluid reservoir 136.

[0046] Referring again to FIGs. 6 and 7, annular member 166 of guide portion 134 has a first annular surface 166-1, a second annular surface 166-2, and an opening 166-3 that defines an annular confining surface 166-4. Opening 166-3 of annular member 166 has a central axis 176. Annular confining surface 166-4 is configured to limit radial movement of stir bar 132 relative to the central axis 176. Second annular surface 166-2 is opposite first annular surface 166-1, with first annular surface 166-1 being separated from second annular surface 166-2 by annular confining surface 166-4. Referring also to FIG. 9, first annular surface 166-1 of annular member 166 also serves as a continuous ceiling over, and between, inlet fluid port 152 and outlet fluid port 154. The plurality of offset members 170, 172 are coupled to annular member 166, and more particularly, the plurality of offset members 170, 172 are connected to first annular surface 166-1 of annular member 166. The plurality of offset members 170, 172 are positioned to extend from annular member 166 in a first axial direction relative to the central axis 176. Each of the plurality of offset members 170, 172 has a free end configured to engage base wall 138 of chamber 148 to establish an axial offset of annular member 166 from base wall 138. Offset member 172 also is positioned and configured to aid in preventing a flow bypass of fluid channel 156.

[0047] The plurality of offset members 170, 172 are coupled to annular member 166, and more particularly, the plurality of offset members 170, 172 are connected to second annular surface 166-2 of annular member 166. The plurality of offset members 170, 172 are positioned to extend from annular member 166 in a second axial direction relative to the central axis 176, opposite to the first axial direction.

[0048] Thus, when assembled, each of locating features 168-1, 168-2 has a free end that engages a perimetrical portion of diaphragm 130, and each of the plurality of offset members 170, 172 have a free end that engages base wall 138.

[0049] Cage structure 174 of guide portion 134 is coupled to annular member 166 opposite to the plurality of offset members 170, 172, and more particularly, the cage structure 174 has a plurality of offset legs 178 connected to second annular surface 166-2 of annular member 166. Cage structure 174 has an axial restraint portion 180 that is axially displaced by the plurality of offset legs 178 (three, as shown) from annular member 166 in the second axial direction opposite to the first axial direction. As shown in FIG. 12, axial restraint portion 180 is positioned over at least a portion of the opening 166-3 in annular member 166 to limit axial movement of stir bar 132 relative to the central axis 176 in the second axial direction. Cage structure 174 also serves to prevent diaphragm 130 from contacting stir bar 132 as diaphragm displacement (collapse) occurs during fluid depletion from fluid reservoir 136.

[0050] As such, in the present embodiment, stir bar 132 is confined within the region defined by opening 166-3 and annular confining surface 166-4 of annular member 166, and between axial restraint portion 180 of the cage structure 174 and base wall 138 of chamber 148. The extent to which stir bar 132 is movable within fluid reservoir 136 is determined by the radial tolerances provided between annular confining surface 166-4 and stir bar 132 in the radial direction, and by the axial tolerances between stir bar 132 and the axial limit provided by the combination of base wall 138 and axial restraint portion 180. For example, the tighter the radial and axial tolerances provided by guide portion 134, the less variation of the rotational axis 160 of stir bar 132 from perpendicular relative to base wall 138, and the less side-to-side motion of stir bar 132 within fluid reservoir 136.

[0051] In the present embodiment, guide portion 134 is configured as a unitary insert member that is removably attached to housing 112. Guide portion 134 includes retention feature 172-1 and body 122 of housing 112 includes a second retention feature 182. First retention feature 172-1 is engaged with second retention feature 182 to attach guide portion 134 to body 122 of housing 112 in a fixed relationship with housing 112. The first retention feature 172-1/second retention feature 182 may be, for example, in the form of a tab/slot arrangement, or alternatively, a slot/tab arrangement, respectively.

[0052] Referring to FIGs. 7 and 15, guide portion 134 may further include a flow control portion 184, which in the present embodiment, also serves as offset member 172. Referring to FIG. 15, flow control portion 184 has a flow separator feature 184-1, a flow rejoining feature 184-2, and a concavely arcuate surface 184-3. Concavely arcuate surface 184-3 is coextensive with, and extends between, each of flow separator feature 184-1 and flow rejoining feature 184-2. Each of flow separator feature 184-1 and flow rejoining feature 184-2 is defined by a respective angled, i.e., beveled, wall. Flow separator feature 184-1 is positioned adjacent inlet fluid port 152 and flow rejoining feature 184-2 is positioned adjacent outlet fluid port 154.

[0053] The beveled wall of flow separator feature 184-1 positioned adjacent to inlet fluid port 152 of chamber 148 cooperates with beveled inlet ramp 152-1 of inlet fluid port 152 of chamber 148 to guide fluid toward channel inlet 156-1 of fluid channel 156. Flow separator feature 184-1 is configured such that the rotational flow is directed toward channel inlet 156-1 instead of allowing a direct bypass of fluid into the outlet fluid that exits channel outlet 156-2. Referring also to FIGs. 9 and 14, positioned opposite beveled inlet ramp 152-1 is the fluid ceiling provided by first annular surface 166-1 of annular member 166. Flow separator feature 184-1 in combination with the continuous ceiling of annular member 166 and beveled ramp wall provided by beveled inlet ramp 152-1 of inlet fluid port 152 of chamber 148 aids in directing a fluid flow into channel inlet 156-1 of fluid channel 156.

[0054] Likewise, referring to FIGs. 9, 14 and 15, the beveled wall of flow rejoining feature 184-2 positioned adjacent to outlet fluid port 154 of chamber 148 cooperates with beveled outlet ramp 154-1 of outlet fluid port 154 to guide fluid away from channel outlet 156-2 of fluid channel 156. Positioned opposite beveled outlet ramp 154-1 is the fluid ceiling provided by first annular surface 166-1 of annular member 166.

[0055] In the present embodiment, flow control portion 184 is a unitary structure formed as offset member 172 of guide portion 134. Alternatively, all or a portion of flow control portion 184 may be incorporated into interior perimetrical wall 150 of chamber 148 of body 122 of housing 112.

[0056] In the present embodiment, as best shown in FIGs. 15 and 16, stir bar 132 is oriented such that the plurality of paddles 132-1, 132-2, 132-3, 132-4 periodically face the concavely arcuate surface 184-3 of the flow control portion 184 as stir bar 132 is rotated about the rotational axis 160. Stir bar 132 has a stir bar radius from rotational axis 160 to the free end tip 132-5 of a respective paddle. A ratio of the stir bar radius and a clearance distance between the free end tip 132-5 and flow control portion 184 may be 5:2 to 5:0.025. More particularly, guide portion 134 is configured to confine stir bar 132 in a predetermined portion of the interior space of chamber 148. In the present example, a distance between the respective free end tip 132-5 of each of the plurality of paddles 132-1, 132-2, 132-3, 132-4 and concavely arcuate surface 184-3 of flow control portion 184 is in a range of 2.0 millimeters to 0.1 millimeters, and more preferably, is in a range of 1.0 millimeters to 0.1 millimeters, as the respective free end tip 132-5 faces concavely arcuate surface 184-3. Also, it has been found that it is preferred to position stir bar 132 as close to ejection chip 118 as possible so as to maximize flow through fluid channel 156.

[0057] Also, guide portion 134 is configured to position the rotational axis 160 of stir bar 132 in a portion of fluid reservoir 136 such that the free end tip 132-5 of each of the plurality of paddles 132-1, 132-2, 132-3, 132-4 of stir bar 132 rotationally ingresses and egresses a proximal continuous 1/3 volume portion 136-1 that is closer to ejection chip 118. Stated differently, guide portion 134 is configured to position the rotational axis 160 of stir bar 132 in a portion of the interior space such that the free end tip 132-5 of each of the plurality of paddles 132-1, 132-2, 132-3, 132-4 rotationally ingresses and egresses the continuous 1/3 volume portion 136-1 of the interior space of chamber 148 that includes inlet fluid port 152 and outlet fluid port 154.

[0058] More particularly, in the present embodiment, wherein stir bar 132 has four paddles, guide portion 134 is configured to position the rotational axis 160 of stir bar 132 in a portion of the interior space such that the first and second free end tips 132-5 of each the two pairs of diametrically opposed paddles 132-1, 132-3 and 132-2, 132-4 alternatingly and respectively are positioned in the proximal continuous 1/3 volume portion 136-1 of the volume of the interior space of chamber 148 that includes inlet fluid port 152 and outlet fluid port 154 and in the continuous 2/3 volume portion 136-4 having the distal continuous 1/3 volume portion 136-3 of the interior space that is furthest from ejection chip 118.

[0059] FIGs. 17-27 depict another embodiment of the invention, which in the present example is in the form of a microfluidic dispensing device 210. Elements common to both microfluidic dispensing device 110 and microfluidic dispensing device 210 are identified using common element numbers, and for brevity, are not described again below in full detail.

[0060] Microfluidic dispensing device 210 generally includes a housing 212 and TAB circuit 114, with microfluidic dispensing device 210 configured to contain a supply of a fluid, such as a particulate carrying fluid, and with TAB circuit 114 configured to facilitate the ejection of the fluid from housing 212.

[0061] As best shown in FIGs. 17-19, housing 212 includes a body 214, a lid 216, an end cap 218, and a fill plug 220 (e.g., ball). Contained within housing 212 is a diaphragm 222, a stir bar 224, and a guide portion 226. Each of housing 212 components, stir bar 224, and guide portion 226 may be made of plastic, using a molding process. Diaphragm 222 is made of rubber, using a molding process. Also, in the present embodiment, fill plug 220 may be in the form of a stainless steel ball bearing.

[0062] Referring to FIG. 18, in general, a fluid (not shown) is loaded through a fill hole 214-1 in body 214 (see FIG. 6) into a sealed region, i.e., a fluid reservoir 228, between body 214 and diaphragm 222. Back pressure in fluid reservoir 228 is set and then maintained by inserting, e.g., pressing, fill plug 220 into fill hole 214-1 to prevent air from leaking into fluid reservoir 228 or fluid from leaking out of fluid reservoir 228. End cap 218 is then placed onto an end of the body 214/lid 216 combination, opposite to ejection chip 118. Stir bar 224 resides in the sealed fluid reservoir 228 between body 214 and diaphragm 222 that contains the fluid. An internal fluid flow may be generated within fluid reservoir 228 by rotating stir bar 224 so as to provide fluid mixing and redistribution of particulate within the sealed region of fluid reservoir 228.

[0063] Referring now also to FIGs. 20 and 21, body 214 of housing 212 has a base wall 230 and an exterior perimeter wall 232 contiguous with base wall 230. Exterior perimeter wall 232 is oriented to extend from base wall 230 in a direction that is substantially orthogonal to base wall 230. Referring to FIG. 19, lid 216 is configured to engage exterior perimeter wall 232. Thus, exterior perimeter wall 232 is interposed between base wall 230 and lid 216, with lid 216 being attached to the open free end of exterior perimeter wall 232 by weld, adhesive, or other fastening mechanism, such as a snap fit or threaded union.

[0064] Referring also to FIGs. 18, 22 and 23, exterior perimeter wall 232 of body 214 includes an exterior wall 232-1, which is a contiguous portion of exterior perimeter wall 232. Exterior wall 232-1 has a chip mounting surface 232-2 and a fluid opening 232-3 adjacent to chip mounting surface 232-2 that passes through the thickness of exterior wall 232-1.

[0065] Referring again also to FIG. 20, chip mounting surface 232-2 defines a plane 234. Ejection chip 118 is mounted to chip mounting surface 232-2 and is in fluid communication with fluid opening 232-3 of exterior wall 232-1. An adhesive sealing strip 144 holds ejection chip 118 and TAB circuit 114 in place while a dispensed adhesive under ejection chip 118, and the encapsulant to protect the electrical leads, is cured. After the cure cycle, the liquid seal between ejection chip 118 and chip mounting surface 232-2 of body 214 is the die bond adhesive.

[0066] The planar extent of ejection chip 118 is oriented along the plane 234, with the plurality of ejection nozzles 120 (see e.g., FIG. 1) oriented such that the fluid ejection direction 120-1 is substantially orthogonal to the plane 234. Base wall 230 is oriented along a plane 236 that is substantially orthogonal to the plane 234 of exterior wall 232-1, and is substantially parallel to the fluid ejection direction 120-1.

[0067] As best illustrated in FIG. 20, body 214 of housing 212 includes a chamber 238 located within a boundary defined by exterior perimeter wall 232. Chamber 238 forms a portion of fluid reservoir 228, and is configured to define an interior space, and in particular, includes base wall 230 and has an interior perimetrical wall 240 configured to have rounded corners, so as to promote fluid flow in chamber 238. Referring to FIG. 19, interior perimetrical wall 240 of chamber 238 has an extent bounded by a proximal end 240-1 and a distal end 240-2. Proximal end 240-1 is contiguous with, and preferably forms a transition radius with, base wall 230. Distal end 240-2 is configured to define a perimetrical end surface 240-3 at a lateral opening 238-1 of chamber 238. Perimetrical end surface 240-3 may include a plurality of ribs, or undulations, to provide an effective sealing surface for engagement with diaphragm 222. The extent of interior perimetrical wall 240 of chamber 238 is substantially orthogonal to base wall 230, and is substantially parallel to the corresponding extent of exterior perimeter wall 232.

[0068] As best shown in FIG. 19, chamber 238 has an inlet fluid port 242 and an outlet fluid port 244, each of which is formed in a portion of interior perimetrical wall 240. Inlet fluid port 242 is separated a distance from outlet fluid port 244 along the portion of interior perimetrical wall 240. The terms "inlet" and "outlet" are terms of convenience that are used in distinguishing between the multiple ports of the present embodiment, and are correlated with a particular rotational direction 250-1 of stir bar 224. However, it is to be understood that it is the rotational direction of stir bar 224 that dictates whether a particular port functions as an inlet port or an outlet port, and it is within the scope of this invention to reverse the rotational direction of stir bar 224, and thus reverse the roles of the respective ports within chamber 238.

[0069] As best shown in FIG. 23, body 214 of housing 212 includes a fluid channel 246 interposed between a portion of interior perimetrical wall 240 of chamber 238 and exterior wall 232-1 of exterior perimeter wall 232 that carries ejection chip 118. Fluid channel 246 is configured to minimize particulate settling in a region of fluid opening 232-3, and in turn, ejection chip 118.

[0070] In the present embodiment, fluid channel 246 is configured as a U-shaped elongated passage having a channel inlet 246-1 and a channel outlet 246-2. Fluid channel 246 dimensions, e.g., height and width, and shape are selected to provide a desired combination of fluid flow and fluid velocity for facilitating intra-channel stirring.

[0071] Fluid channel 246 is configured to connect inlet fluid port 242 of chamber 238 in fluid communication with outlet fluid port 244 of chamber 238, and also connects fluid opening 232-3 of exterior wall 232-1 of exterior perimeter wall 232 in fluid communication with both inlet fluid port 242 and outlet fluid port 244 of chamber 238. In particular, channel inlet 246-1 of fluid channel 246 is located adjacent to inlet fluid port 242 of chamber 238 and channel outlet 246-2 of fluid channel 246 is located adjacent to outlet fluid port 244 of chamber 238. In the present embodiment, the structure of inlet fluid port 242 and outlet fluid port 244 of chamber 238 is symmetrical.

[0072] Fluid channel 246 has a convexly arcuate wall 246-3 that is positioned between channel inlet 246-1 and channel outlet 246-2, with fluid channel 246 being symmetrical about a channel mid-point 248. In turn, convexly arcuate wall 246-3 of fluid channel 246 is positioned between inlet fluid port 242 and outlet fluid port 244 of chamber 238 on the opposite side of interior perimetrical wall 240 from the interior space of chamber 238, with convexly arcuate wall 246-3 positioned to face fluid opening 232-3 of exterior wall 232-1 and fluid ejection chip 118.

[0073] Convexly arcuate wall 246-3 is configured to create a fluid flow substantially parallel to ejection chip 118. In the present embodiment, a longitudinal extent of convexly arcuate wall 246-3 has a radius that faces fluid opening 232-3, is substantially parallel to ejection chip 118, and has transition radii 246-4, 246-5 located adjacent to channel inlet 246-1 and channel outlet 246-2 surfaces, respectively. The radius and radii of convexly arcuate wall 246-3 help with fluid flow efficiency. A distance between convexly arcuate wall 246-3 and fluid ejection chip 118 is narrowest at the channel mid-point 248, which coincides with a mid-point of the longitudinal extent of fluid ejection chip 118, and in turn, with at a mid-point of the longitudinal extent of fluid opening 232-3 of exterior wall 232-1.

[0074] Referring again also to FIG. 19, each of inlet fluid port 242 and outlet fluid port 244 of chamber 238 has a beveled ramp structure configured such that each of inlet fluid port 242 and outlet fluid port 244 converges in a respective direction toward fluid channel 246. In particular, inlet fluid port 242 of chamber 238 has a beveled inlet ramp 242-1 configured such that inlet fluid port 242 converges, i.e., narrows, in a direction toward channel inlet 246-1 of fluid channel 246, and outlet fluid port 244 of chamber 238 has a beveled outlet ramp 244-1 that diverges, i.e., widens, in a direction away from channel outlet 246-2 of fluid channel 246.

[0075] Referring again to FIG. 18, diaphragm 222 is positioned between lid 216 and perimetrical end surface 240-3 of interior perimetrical wall 240 of chamber 238. The attachment of lid 216 to body 214 compresses a perimeter of diaphragm 222 thereby creating a continuous seal between diaphragm 222 and body 122, and more particularly, diaphragm 222 is configured for sealing engagement with perimetrical end surface 240-3 of interior perimetrical wall 240 of chamber 238 in forming fluid reservoir 228. Thus, in combination, chamber 148 and diaphragm 222 cooperate to define fluid reservoir 228 having a variable volume.

[0076] Referring particularly to FIGs. 18 and 19, an exterior surface of diaphragm 222 is vented to the atmosphere through a vent hole 216-1 located in lid 216 so that a controlled negative pressure can be maintained in fluid reservoir 228. Diaphragm 222 is made of rubber, and includes a dome portion 222-1 configured to progressively collapse toward base wall 230 as fluid is depleted from microfluidic dispensing device 210, so as to maintain a desired negative pressure in chamber 238, and thus changing the effective volume of the variable volume of fluid reservoir 228.

[0077] Referring to FIG. 18, for sake of further explanation, below, the variable volume of fluid reservoir 228, also referred to herein as a bulk region, may be considered to have a proximal continuous 1/3 volume portion 228-1, a central continuous 1/3 volume portion 228-2, and a distal continuous 1/3 volume portion 228-3, with the central continuous 1/3 volume portion 228-2 separating the proximal continuous 1/3 volume portion 228-1 from the distal continuous 1/3 volume portion 228-3. The proximal continuous 1/3 volume portion 228-1 is located closer to ejection chip 118 than either of the central continuous 1/3 volume portion 228-2 and the distal continuous 1/3 volume portion 228-3.

[0078] Referring to FIGs. 18 and 19, stir bar 224 resides in the variable volume of fluid reservoir 228 and in chamber 238, and is located within a boundary defined by interior perimetrical wall 240 of chamber 238. Referring also to FIGs. 24-27, stir bar 224 has a rotational axis 250 and a plurality of paddles 252, 254, 256, 258 that radially extend away from the rotational axis 250. Stir bar 224 has a magnet 260 (see FIGs. 18, 23, and 27), e.g., a permanent magnet, configured for interaction with external magnetic field generator 164 (see FIG. 1) to drive stir bar 224 to rotate around the rotational axis 250. In the present embodiment, stir bar 224 has two pairs of diametrically opposed paddles that are equally spaced at 90 degree increments around rotational axis 250. However, the actual number of paddles of stir bar 224 is two or more, and preferably three or four, but more preferably four, with each adjacent pair of paddles having the same angular spacing around the rotational axis 250. For example, a stir bar 224 configuration having three paddles would have a paddle spacing of 120 degrees, having four paddles would have a paddle spacing of 90 degrees, etc.

[0079] In the present embodiment, as shown in FIGs. 24-27, stir bar 224 is configured in a stepped, i.e., two-tiered, cross pattern with chamfered surfaces which may provide the following desired attributes: quiet, short, low axial drag, good rotational speed transfer, and capable of starting to mix with stir bar 224 in particulate sediment. In particular, referring to FIG. 26, each of the plurality of paddles 252, 254, 256, 258 of stir bar 224 has an axial extent 262 having a first tier portion 264 and a second tier portion 266. Referring also to FIG. 25, first tier portion 264 has a first radial extent 268 terminating at a first distal end tip 270. Second tier portion 266 has a second radial extent 272 terminating in a second distal end tip 274. The first radial extent 268 is greater than the second radial extent 272, such that a first rotational velocity of first distal end tip 270 of first tier portion 264 is higher than a second rotational velocity of second distal end tip 274 of second tier portion 266.

[0080] Also, in the present embodiment, the first radial extent 268 is not limited by a cage containment structure, as in the previous embodiment, such that first distal end tip 270 advantageously may be positioned closer to the surrounding portions of interior perimetrical wall 240 of chamber 238, particularly in the central continuous 1/3 volume portion 228-2 and the distal continuous 1/3 volume portion 228-3. By reducing the clearance between first distal end tip 270 and interior perimetrical wall 240 of chamber 238, mixing effectiveness is improved. Stir bar 224 has a stir bar radius (first radial extent 268) from rotational axis 250 to the distal end tip 270 of first tier portion 264 of a respective paddle. A ratio of the stir bar radius and a clearance distance between the distal end tip 270 and its closest encounters with interior perimetrical wall 240 may be 5:2 to 5:0.025. In the present example, such clearance at each of the closest encounters may be in a range of 2.0 millimeters to 0.1 millimeters, and more preferably, is in a range of 1.0 millimeters to 0.1 millimeters.

[0081] First tier portion 264 has a first tip portion 270-1 that includes first distal end tip 270. First tip portion 270-1 may be tapered in a direction from the rotational axis 250 toward first distal end tip 270. First tip portion of 270-1 of first tier portion 264 has symmetrical upper and lower surfaces, each having a beveled, i.e., chamfered, leading surface and a beveled trailing surface. The beveled leading surfaces and the beveled trailing surfaces of first tip portion 270-1 are configured to converge at first distal end tip 270.

[0082] Also, in the present embodiment, first tier portion 264 of each of the plurality of paddles 252, 254, 256, 258 collectively form a convex surface 276. As shown in FIG. 18, convex surface 276 has a drag-reducing radius positioned to contact base wall 230 of chamber 238. The drag-reducing radius may be, for example, at least three times greater than the first radial extent 268 of first tier portion 264 of each of the plurality of paddles 252, 254, 256, 258.

[0083] Referring again to FIG. 26, second tier portion 266 has a second tip portion 274-1 that includes second distal end tip 274. Second distal end tip 274 may have a radial blunt end surface. Second tier portion 266 of each of the plurality of paddles 252, 254, 256, 258 has an upper surface having a beveled, i.e., chamfered, leading surface and a beveled trailing surface.

[0084] Referring to FIGs. 19-27, the rotational axis 250 of stir bar 224 may be oriented in an angular range of perpendicular, plus or minus 45 degrees, relative to the fluid ejection direction 120-1. Stated differently, the rotational axis 250 of stir bar 224 may be oriented in an angular range of parallel, plus or minus 45 degrees, relative to the planar extent (e.g., plane 234) of ejection chip 118. Also, rotational axis 250 of stir bar 224 may be oriented in an angular range of perpendicular, plus or minus 45 degrees, relative to the planar extent of base wall 230. In combination, the rotational axis 250 of stir bar 224 may be oriented in both an angular range of perpendicular, plus or minus 45 degrees, relative the fluid ejection direction 120-1 and/or the planar extent of base wall 230, and an angular range of parallel, plus or minus 45 degrees, relative to the planar extent of ejection chip 118.

[0085] More preferably, the rotational axis 250 has an orientation that is substantially perpendicular to the fluid ejection direction 120-1, an orientation that is substantially parallel to the plane 234, i.e., planar extent, of ejection chip 118, and an orientation that is substantially perpendicular to the plane 236 of base wall 230. In the present embodiment, the rotational axis 250 of stir bar 224 has an orientation that is substantially perpendicular to the plane 236 of base wall 230 in all orientations around rotational axis 250 and/or is substantially perpendicular to the fluid ejection direction 120-1 in all orientations around rotational axis 250.

[0086] The orientations of stir bar 224, described above, may be achieved by guide portion 226, with guide portion 226 also being located within chamber 238 in the variable volume of fluid reservoir 228, and more particularly, within the boundary defined by interior perimetrical wall 240 of chamber 238. Guide portion 226 is configured to confine and position stir bar 224 in a predetermined portion of the interior space of chamber 238 at one of the predefined orientations, described above.

[0087] Referring to FIGs, 18-21, for example, guide portion 226 may be configured to position the rotational axis 250 of stir bar 224 in an angular range of parallel, plus or minus 45 degrees, relative to the planar extent of ejection chip 118, and more preferably, guide portion 226 is configured to position the rotational axis 250 of stir bar 224 substantially parallel to the planar extent of ejection chip 118. In the present embodiment, guide portion 226 is configured to position and maintain an orientation of the rotational axis 250 of stir bar 224 to be substantially perpendicular to the plane 236 of base wall 230 in all orientations around rotational axis 250 and to be substantially parallel to the planar extent of ejection chip 118 in all orientations around rotational axis 250.

[0088] Referring to FIGs. 19-21 and 23, guide portion 226 includes an annular member 278, and a plurality of mounting arms 280-1, 280-2, 280-3, 280-4 coupled to annular member 278. Annular member 278 has an opening 278-1 that defines an annular confining surface 278-2. Opening 278-1 has a central axis 282. Second tier portion 266 of stir bar 224 is received in opening 278-1 of annular member 278. Annular confining surface 278-2 is configured to contact the radial extent of second tier portion 266 of the plurality of paddles 252, 254, 256, 258 to limit radial movement of stir bar 224 relative to the central axis 282. Referring to FIGs. 18-20 and 23, annular member 278 has an axial restraint surface 278-3 positioned to be axially offset from base wall 230 of chamber 238, for axial engagement with first tier portion 264 of stir bar 224.

[0089] Referring to FIGs. 20 and 21, the plurality of mounting arms 280-1, 280-2, 280-3, 280-4 are configured to engage housing 212 to suspend annular member 278 in the interior space of chamber 238, separated from base wall 230 of chamber 238, with axial restraint surface 278-3 positioned to face, and to be axially offset from, base wall 230 of chamber 238. A distal end of each of mounting arms 280-1, 280-2, 280-3, 280-4 includes respective locating features 280-5, 280-6, 280-7, 280-8 that have free ends to engage a perimetrical portion of diaphragm 222.

[0090] In the present embodiment, base wall 230 limits axial movement of stir bar 224 relative to the central axis 282 in a first axial direction and axial restraint surface 278-3 of annular member 278 is located to axially engage at least a portion of first tier portion 264 of the plurality of paddles 252, 254, 256, 258 to limit axial movement of stir bar 224 relative to the central axis 282 in a second axial direction opposite to the first axial direction.

[0091] As such, in the present embodiment, stir bar 224 is confined within the region defined by opening 278-1 and annular confining surface 278-2 of annular member 278, and between axial restraint surface 278-3 of annular member 278 and base wall 230 of chamber 238. The extent to which stir bar 224 is movable within fluid reservoir 228 is determined by the radial tolerances provided between annular confining surface 278-2 and stir bar 224 in the radial direction, and by the axial tolerances between stir bar 224 and the axial limit provided by the combination of base wall 230 and axial restraint surface 278-3 of annular member 278. For example, the tighter the radial and axial tolerances provided by guide portion 226, the less variation of the rotational axis 250 of stir bar 224 from perpendicular relative to base wall 230, and the less side-to-side motion of stir bar 224 within fluid reservoir 228.

[0092] In the present embodiment, guide portion 226 is configured as a unitary insert member that is removably attached to housing 212. Referring to FIG. 23, guide portion 226 includes a first retention feature 284 and body 214 of housing 212 includes a second retention feature 214-2. First retention feature 284 is engaged with second retention feature 214-2 to attach guide portion 226 to body 214 of housing 212 in a fixed relationship with housing 212. First retention feature 284/second retention feature 214-2 combination may be, for example, in the form of a tab/slot arrangement, or alternatively, a slot/tab arrangement, respectively.

[0093] As best shown in FIG. 23 with respect to FIG. 19, guide portion 226 may further include a flow control portion 286 having a flow separator feature 286-1, a flow rejoining feature 286-2, and a concavely arcuate surface 286-3. Flow control portion 286 provides an axial spacing between axial restraint surface 278-3 and base wall 230 in the region of inlet fluid port 242 and outlet fluid port 244. Concavely arcuate surface 286-3 is coextensive with, and extends between, each of flow separator feature 286-1 and flow rejoining feature 286-2. Flow separator feature 286-1 is positioned adjacent inlet fluid port 242 and flow rejoining feature 286-2 is positioned adjacent outlet fluid port 244. Flow separator feature 286-1 has a beveled wall that cooperates with beveled inlet ramp 242-1 (see FIG. 19) of inlet fluid port 242 of chamber 238 to guide fluid toward channel inlet 246-1 of fluid channel 246. Likewise, flow rejoining feature 286-2 has a beveled wall that cooperates with beveled outlet ramp 244-1 (see FIG. 19) of outlet fluid port 244 to guide fluid away from channel outlet 246-2 of fluid channel 246.

[0094] It is contemplated that all, or a portion, of flow control portion 286 may be incorporated into interior perimetrical wall 240 of chamber 238 of body 214 of housing 212.

[0095] In the present embodiment, as is best shown in FIG. 23, stir bar 224 is oriented such that the free ends of the plurality of paddles 252, 254, 256, 258 periodically face concavely arcuate surface 286-3 of flow control portion 286 as stir bar 224 is rotated about the rotational axis 250. A ratio of the stir bar radius and a clearance distance between the distal end tip 270 of first tier portion 264 of a respective paddle and flow control portion 286 may be 5:2 to 5:0.025. More particularly, guide portion 226 is configured to confine stir bar 224 in a predetermined portion of the interior space of chamber 238. In the present example, a distance between first distal end tip 270 and concavely arcuate surface 286-3 of flow control portion 286 is in a range of 2.0 millimeters to 0.1 millimeters, and more preferably, is in a range of 1.0 millimeters to 0.1 millimeters.

[0096] Also referring to FIG. 18, guide portion 226 is configured to position the rotational axis 250 of stir bar 224 in a portion of fluid reservoir 228 such that first distal end tip 270 of each of the plurality of paddles 252, 254, 256, 258 of stir bar 224 rotationally ingresses and egresses a proximal continuous 1/3 volume portion 228-1 of fluid reservoir 228 that is closer to ejection chip 118. Stated differently, guide portion 226 is configured to position the rotational axis 250 of stir bar 224 in a portion of the interior space such that first distal end tip 270 of each of the plurality of paddles 252, 254, 256, 258 rotationally ingresses and egresses the continuous 1/3 volume portion 228-1 of the interior space of chamber 238 that includes inlet fluid port 242 and outlet fluid port 244.

[0097] More particularly, in the present embodiment wherein stir bar 224 has four paddles, guide portion 226 is configured to position the rotational axis 250 of stir bar 224 in a portion of the interior space of chamber 238 such that first distal end tip 270 of each the two pairs of diametrically opposed paddles alternatingly and respectively are positioned in the proximal continuous 1/3 volume portion 228-1 of the volume of the interior space of chamber 238 that includes inlet fluid port 242 and outlet fluid port 244 and in the distal continuous 1/3 volume portion 228-3 of the interior space that is furthest from ejection chip 118. More particularly, in the present embodiment wherein stir bar 224 has two sets of diametrically opposed paddles, guide portion 226 is configured to position the rotational axis 250 of stir bar 224 in a portion of the interior space of chamber 238 such that first distal end tip 270 of each of diametrically opposed paddles, e.g., 252, 256 or 254, 258, as shown in FIG. 23, alternatingly and respectively are positioned in the proximal continuous 1/3 volume portion 228-1 and the distal continuous 1/3 volume portion 228-3 as stir bar 224 is rotated.

[0098] FIGs. 28-31 show a configuration for a stir bar 300, which may be substituted for stir bar 224 of microfluidic dispensing device 210 discussed above with respect to the embodiment of FIGs. 17-27 for use with guide portion 226.

[0099] Stir bar 300 has a rotational axis 350 and a plurality of paddles 352, 354, 356, 358 that radially extend away from the rotational axis 350. Stir bar 300 has a magnet 360 (see FIG. 31), e.g., a permanent magnet, configured for interaction with external magnetic field generator 164 (see FIG. 1) to drive stir bar 300 to rotate around the rotational axis 350. In the present embodiment, stir bar 300 has two pairs of diametrically opposed paddles that are equally spaced at 90 degree increments around rotational axis 350.

[0100] In the present embodiment, as shown, stir bar

300 is configured in a stepped, i.e., two-tiered, cross pattern with chamfered surfaces. In particular, each of the plurality of paddles 352, 354, 356, 358 of stir bar 300 has an axial extent 362 having a first tier portion 364 and a second tier portion 366. First tier portion 364 has a first radial extent 368 terminating at a first distal end tip 370. Second tier portion 366 has a second radial extent 372 terminating in a second distal end tip 374. The first radial extent 368 is greater than the second radial extent 372, such that a first rotational velocity of first distal end tip 370 of first tier portion 364 of stir bar 300 is higher than a second rotational velocity of second distal end tip 374 of second tier portion 366 of stir bar 300.

[0101] First tier portion 364 has a first tip portion 370-1 that includes first distal end tip 370. First tip portion 370-1 may be tapered in a direction from the rotational axis 350 toward first distal end tip 370. First tip portion 370-1 of first tier portion 364 has symmetrical upper and lower surfaces, each having a beveled, i.e., chamfered, leading surface and a beveled trailing surface. The beveled leading surfaces and the beveled trailing surfaces of first tip portion 370-1 are configured to converge at first distal end tip 370. Also, in the present embodiment, first tier portion 364 of each of the plurality of paddles 352, 354, 356, 358 collectively form a flat surface 376 for engaging base wall 230.

[0102] Second tier portion 366 has a second tip portion 374-1 that includes second distal end tip 374. Second distal end tip 374 may have a radially blunt end surface. Second tier portion 366 has two diametrical pairs of upper surfaces, each having a beveled, i.e., chamfered, leading surface and a beveled trailing surface. However, in the present embodiment, the two diametrical pairs have different configurations, in that the area of the upper beveled leading surface and upper beveled trailing surface for diametrical pair of paddles 352, 356 is greater than the area of bevel of the upper beveled leading surface and upper beveled trailing surface for diametrical pair of paddles 354, 358. As such, adjacent angularly spaced pairs of the plurality of paddles 352, 354, 356, 358 alternatingly provide less and more aggressive agitation, respectively, of the fluid in fluid reservoir 228.

[0103] FIGs. 32-35 show a configuration for a stir bar 400, which may be substituted for stir bar 224 of microfluidic dispensing device 210 discussed above with respect to the embodiment of FIGs. 17-27 for use with guide portion 226.

[0104] Stir bar 400 has a rotational axis 450 and a plurality of paddles 452, 454, 456, 458 that radially extend away from the rotational axis 450. Stir bar 400 has a magnet 460 (see FIGs. 32 and 35, e.g., a permanent magnet), configured for interaction with external magnetic field generator 164 (see FIG. 1) to drive stir bar 400 to rotate around the rotational axis 450. In the present embodiment, stir bar 400 has two pairs of diametrically opposed paddles that are equally spaced at 90 degree increments around rotational axis 450.

[0105] In the present embodiment, as shown, stir bar 400 is configured in a stepped, i.e., two-tiered, cross pattern. In particular, each of the plurality of paddles 452, 454, 456, 458 of stir bar 400 has an axial extent 462 having a first tier portion 464 and a second tier portion 466. First tier portion 464 has a first radial extent 468 terminating at a first distal end tip 470. Second tier portion 466 has a second radial extent 472 terminating in a second distal end tip 474 having a wide radial end shape. The first radial extent 468 is greater than the second radial extent 472, such that a first rotational velocity of first distal end tip 470 of first tier portion 464 of stir bar 400 is higher than a second rotational velocity of second distal end tip 474 of second tier portion 466 of stir bar 400.

[0106] First tier portion 464 has a first tip portion 470-1 that includes first distal end tip 370. First tip portion 470-1 may be tapered in a direction from the rotational axis 450 toward first distal end tip 470. First tip portion 470-1 of first tier portion 464 has symmetrical upper and lower surfaces, each having a beveled, i.e., chamfered, leading surface and a beveled trailing surface. The beveled leading surfaces and the beveled trailing surfaces of first tip portion 470-1 are configured to converge at first distal end tip 470. Also, in the present embodiment, first tier portion 464 of each of the plurality of paddles 452, 454, 456, 458 collectively form a flat surface 476 for engaging base wall 230.

[0107] Second tier portion 466 has a second tip portion 474-1 that includes second distal end tip 474. Second tip portion 474-1 has a radially blunt end surface. Second tier portion 466 has two diametrical pairs of upper surfaces. However, in the present embodiment, the two diametrical pairs have different configurations, in that the diametrical pair of paddles 452, 456 have upper beveled leading surfaces and upper beveled trailing surfaces, and the diametrical pair of paddles 454, 458 do not, i.e., provide a blunt lateral surface substantially parallel to rotational axis 450.

[0108] Referring again to FIGs. 32 and 35, stir bar 400 includes a void 478 that radially intersects the rotational axis 450, with void 478 being located in the diametrical pair of paddles 454, 458. Magnet 460 is positioned in void 478 with the north pole of magnet 460 and the south pole of magnet 460 being diametrically opposed with respect to the rotational axis 450. A film seal 480 is attached, e.g., by ultrasonic welding, heat staking, laser welding, etc., to stir bar 400 to cover over void 478. It is preferred that film seal 480 have a seal layer material that is chemically compatible with the material of stir bar 400. Film seal 480 has a shape that conforms to the shape of the upper surface of second tier portion 466 of diametrical pair of paddles 454, 458. The present configuration has an advantage over a stir bar insert that is molded around the magnet, since insert molding may slightly demagnetize the magnet from the insert mold process heat.

[0109] FIGs. 36-39 show a configuration for a stir bar 400-1, having substantially the same configuration as stir bar 400 discussed above with respect to FIGs. 32-35, with the sole difference being the shape of the film seal used to seal void 478. Stir bar 400-1 has a film seal 480-1 having a circular shape, and which has a diameter that forms an arcuate web between adjacent pairs of the plurality of paddles 452, 454, 456, 458. The web features serve to separate the bulk mixing flow in the region between stir bar 400-1 and diaphragm 222, and the regions between adjacent pairs of the plurality of paddles 452, 454, 456, 458.

[0110] FIGs. 40-43 show a configuration for a stir bar 500, which may be substituted for stir bar 224 of microfluidic dispensing device 210 discussed above with respect to the embodiment of FIGs. 17-27 for use with guide portion 226.

[0111] Stir bar 500 has a cylindrical hub 502 having a rotational axis 550, and a plurality of paddles 552, 554, 556, 558 that radially extend away from cylindrical hub 502. Stir bar 500 has a magnet 560 (see FIGs. 40 and 43), e.g., a permanent magnet, configured for interaction with external magnetic field generator 164 (see FIG. 1) to drive stir bar 500 to rotate around the rotational axis 550.

[0112] In the present embodiment, as shown, the plurality of paddles 552, 554, 556, 558 of stir bar 500 are configured in a stepped, i.e., two-tiered, cross pattern with chamfered surfaces. In particular, each of the plurality of paddles 552, 554, 556, 558 of stir bar 500 has an axial extent 562 having a first tier portion 564 and a second tier portion 566. First tier portion 564 has a first radial extent 568 terminating at a first distal end tip 570. Second tier portion 566 has a second radial extent 572 terminating in a second distal end tip 574.

[0113] First tier portion 564 has a first tip portion 570-1 that includes first distal end tip 570. First tip portion 570-1 may be tapered in a direction from the rotational axis 550 toward first distal end tip 570. First tip portion 570-1 of first tier portion 564 has symmetrical upper and lower surfaces, each having a beveled, i.e., chamfered, leading surface and a beveled trailing surface. The beveled leading surfaces and the beveled trailing surfaces of first tip portion 570-1 are configured to converge at first distal end tip 570. First tier portion 564 of each of the plurality of paddles 552, 554, 556, 558, and cylindrical hub 502, collectively form a convexly curved surface 576 for engaging base wall 230.

[0114] The second tier portion 566 has a second tip portion 574-1 that includes second distal end tip 574. Second distal end tip 574 may have a radially blunt end surface. Second tier portion 566 has an upper surface having a chamfered leading surface and a chamfered trailing surface.

[0115] Referring again to FIGs. 40 and 43, stir bar 500 includes a void 578 that radially intersects the rotational axis 550, with void 578 being located in cylindrical hub 502. Magnet 560 is positioned in void 578 with the north pole of magnet 560 and the south pole of magnet 560 being diametrically opposed with respect to the rotational axis 550. A film seal 580 has a shape that conforms to the circular shape of the upper surface of cylindrical hub 502. Film seal 580 is attached, e.g., by ultrasonic welding, heat staking, laser welding, etc., to the upper surface of cylindrical hub 502 of stir bar 500 to cover over void 578. It is preferred that film seal 580 have a seal layer material that is chemically compatible with the material of stir bar 500.

[0116] FIGs. 44-46 show a configuration for a stir bar 500-1, having substantially the same configuration as stir bar 500 discussed above with respect to FIGs. 40-43, with the sole difference being that film seal 580 used to seal void 578 has been replaced with a permanent cover 580-1. In this embodiment, cover 580-1 is unitary with the stir bar body, which are formed around magnet 560 during the insert molding process.

[0117] While the stir bar embodiments of FIGs. 24-46 have been described as being for use with microfluidic dispensing device 210 having guide portion 226, those skilled in the art will recognize that stir bar 132 described above in relation to microfluidic dispensing device 110 having guide portion 134 may be modified to also include a two-tiered stir bar paddle design for use with guide portion 134.

[0118] When fluid is first introduced into the respective microfluidic dispensing device, e.g., microfluidic dispensing device 210, the fluid is at a desired state of particulate suspension having a mixed viscosity. This ideal condition is illustrated in FIG. 47. In particular, FIG. 47 is an x-ray image of an implementation of microfluidic dispensing device 210 of FIGs. 17-23 having a longitudinal extent of housing 212 arranged along a vertical axis 600. FIG. 47 illustrates fluid 602 having suspended particulate content, and with no accumulation of settled particulate, i.e., in an ideal state for use.

[0119] However, over time, the particulate portion of the fluid tends to separate from the bulk liquid portion of the fluid. In turn, over time, the particulate portion tends to accumulate as a settled particulate portion formed as a settled layer of particles. In order to achieve coverage uniformity of the ejected fluid, it is desirable to maintain the fluid at the desired state of particulate suspension in the fluid liquid by performing fluid re-mixing operations.

[0120] It has been observed that the density of the bulk fluid liquid portion of the fluid is less than the density of the settled particulate portion. Also, the dense settled layer of the settled particulate portion will have a greater viscosity than the viscosity of the desired mixed fluid. The separated fluid may also create re-mixing challenges because the higher density of the settled particulate portion will tend to inhibit the rotational motion of the stir bar.

[0121] FIG. 48 is an x-ray image of an implementation of microfluidic dispensing device 210 having the longitudinal extent of housing 212 arranged along a vertical axis 600, with housing 212 oriented such that ejection chip 118 faces vertically upward and with the planar extent of ejection chip 118 being substantially perpendicular to vertical axis 600. Contained in housing 212 is stir bar 500 having magnet 560. Fluid reservoir 228 of microfluidic dispensing device 210 is shown to contain fluid 602 that includes settled particulate 604 at a gravitational low region 606 of fluid reservoir 228. In the orientation shown, ejection chip 118 is facing vertically upward, and the settled particulate 604 has accumulated at the gravitational low region 606 of fluid reservoir 228 on the opposite end of housing 212 relative to ejection chip 118.

[0122] FIG. 49 is an x-ray image of an implementation of microfluidic dispensing device 210 tilted off-axis from vertical axis 600 by an angular amount 608 of about 20 to 25 degrees, and depicts how settled particulate 604 migrates to a new gravitational low region 610 of fluid reservoir 228 based on the change of orientation of housing 212 relative to vertical axis 600. Also, it can be seen that the particulate layer adjacent to the walls of fluid reservoir 228 do not tend to move easily by changing the orientation of microfluidic dispensing device 210.

[0123] FIG. 50 is an x-ray image of an implementation of microfluidic dispensing device 210 (containing stir bar 224 having magnet 260; see also FIGs. 18 and 23) that illustrates an undesirable orientation, wherein housing 212 is oriented such that ejection chip 118 faces vertically downward with the planar extent of ejection chip 118 being substantially perpendicular to vertical axis 600. As shown, settled particulate 604 migrates to a new gravitational low region 612 of fluid reservoir 228 based on the change of orientation of housing 212, such that settled particulate 604 has accumulated over channel inlet 246-1 and channel outlet 246-2 of fluid channel 246. Thus, without sufficient mixing of fluid 602, settled particulate 604 would render microfluidic dispensing device 210 inoperable, by completely blocking fluid channel 246, which in turn, would prevent fluid from reaching ejection chip 118.

[0124] Referring to FIG. 51, microfluidic dispensing device 210 is shown in a Cartesian space having X, Y, and Z axes, with the longitudinal extent of housing 212 lying on the positive Z-axis and the lateral extent of housing 212 lying on the X-Y-plane. In the X-Z plane, the positive X-axis represents 0 degrees; the Z-axis represents vertical, with the upper Z-axis (positive) labeled as 90 degrees, corresponding to vertical axis 600 discussed above; and the X-axis (negative) represents 180 degrees. An orientation of the longitudinal extent of housing 212 of microfluidic dispensing device 210 is represented by fluid ejection direction 120-1, and which also represents the direction that ejection chip 118 and fluid channel 246 is facing.

[0125] In preparation for mixing, microfluidic dispensing device 210 may be positioned such that fluid ejection direction 120-1 does not face downward. The term "not face downward" means that the arrow of fluid ejection direction 120-1 does not point below the X-Y plane, i.e., is never less than horizontal. Thus, in the orientation of the present example, microfluidic dispensing device 210 may be rotated in the X-Z plane about the Y-axis, in a range of upward vertical (Z+ at 90 degrees) plus or minus 90 degrees, i.e., upward vertical to horizontal without the fluid ejection direction 120-1 being pointed downward.

[0126] It is noted that the planar extent of ejection chip 118 is substantially perpendicular to fluid ejection direction 120-1 in all orientations around fluid ejection direction 120-1, and the planar extent of base wall 230 of housing 212 of microfluidic dispensing device 210 is substantially parallel to fluid ejection direction 120-1. Thus, the direction of tilt of housing 212 (X+ or X-) in the X-Z plane (e.g., base wall 230 facing upwardly or facing downwardly) may determine the extent to which particulate settlement may accumulate around stir bar 224.

[0127] In the illustration of FIG. 52, microfluidic dispensing device 210 is shown with fluid ejection direction 120-1 pointing upwardly at 135 degrees (i.e., positive 45 degrees offset from 90 degrees (upward vertical)), and with microfluidic dispensing device 210 oriented with an exterior 222-2 of dome portion 222-1 of diaphragm 222 facing upwardly and with an exterior 230-1 of base wall 230 facing downwardly. The angle at which each of the exterior 222-2 of diaphragm 222 and the exterior 230-1 of base wall 230 is considered to face corresponds to the angle at which rotational axis 250 of stir bar 224 intersects the upward vertical portion of the Z-axis, with the exception of when rotational axis 250 of stir bar 224 is parallel to the Z-axis. In the example of FIG. 52, the exterior 222-2 of dome portion 222-1 of diaphragm 222 is facing upwardly at 45 degrees and the exterior 230-1 of base wall 230 is facing downwardly at 45 degrees. At the 135 degree orientation of fluid ejection direction 120-1 depicted in FIG. 52, any particulate settled or settling along base wall 230 will start to migrate toward a gravitational low point in fluid reservoir 228 and away from stir bar 224 (see also FIG. 49).

[0128] Referring to FIG. 53, alternatively, an orientation of fluid ejection direction 120-1 may be in a range of 40 degrees to 90 degrees, and wherein when the orientation is not vertical, i.e., not 90 degrees, the exterior 230-1 of base wall 230 is positioned to face upwardly and the exterior 222-2 of diaphragm 222 is positioned to face downwardly. In the specific example of FIG. 53, the orientation of microfluidic dispensing device 210 has the benefit of the nozzles-up orientation for ejection chip 118, but has the exterior 222-2 of dome portion 222-1 of diaphragm 222 switched to face downwardly at 45 degrees from vertical, and thus the exterior 230-1 of base wall 230, and correspondingly, convex surface 276 of stir bar 224 that contacts base wall 230, now faces upwardly at an angle of 45 degrees from vertical. The 45 degree orientation of microfluidic dispensing device 210 will still move the particles away from ejection chip 118 and fluid channel 26, but also will cause the particulate to settle in a region spaced away from the plurality of paddles 252, 254, 256, 258 (see also FIG. 24) of stir bar 224 and towards the dome portion 222-1 of diaphragm 222. However, if stir bar 224 can be rotated, i.e., is not blocked from rotation by particulate sediment, then the orientation depicted in FIG. 52 is preferred over the orientation depicted in FIG. 53, because in the orientation depicted in FIG. 52, the higher tip velocity of stir bar 224 will be closer to the settled particulate than in the orientation of FIG. 53.

[0129] As a general observation, the longer the time between uses of the microfluidic dispensing device or between re-mixing within the microfluidic dispensing device, the longer the mixing time that will be required to re-mix the fluid in the microfluidic dispensing device to achieve an acceptable level of particulate suspension, e.g., preferably, a level within the tolerances of an initial filling of the microfluidic dispensing device, as depicted in FIG. 47.

[0130] Referring to FIG. 54, there is shown a block diagram of external magnetic field generator 164 in accordance with an aspect of the present invention. External magnetic field generator 164 includes a microcontroller 164-1, an electromagnetic field rotator 164-2, an electromagnetic field generator 164-3, and a sensor 164-4. Microcontroller 164-1 includes a microprocessor, on-board non-transitory electronic memory 164-5, and interface circuitry, e.g., input/output circuits, a universal asynchronous receiver/transmitter (UART), analog-to-digital (A-to-D) converter, etc., as is known in the art. Microcontroller 164-1 is configured to execute program instructions to control the rotation of the magnetic field generated by external magnetic field generator 164, and in turn, to control the rotation of a stir bar, such as stir bar 224 having magnet 260.

[0131] More particularly, electromagnetic field generator 164-3 generates an external magnetic field, which is coupled to magnet 260 of stir bar 224. Microcontroller 164-1 executes program instructions to generate control signals that are supplied to electromagnetic field rotator 164-2 to control a rotational speed and rotational direction of the magnetic field generated by electromagnetic field generator 164-3, and in turn, to control the rotational speed and rotational direction of stir bar 224. During normal mixing operation, the rotational speed of stir bar 224 may be in a range, for example, of 100 to 1000 revolutions per minute. As discussed above, the external magnetic field generated by external magnetic field generator 164 may be rotated electronically, akin to operation of a stepper motor, by positioned discrete electromagnets that are selectively turned on and off to produce a virtual rotation of the magnetic field and which can switch directions, or alternatively, may be physically rotated via a magnetic plate, e.g., a permanent magnet, connected to a rotatable motor shaft.

[0132] In accordance with the present invention, sensor 164-4 has an electrical output that provides a feedback signal, which is used to determine whether or not the stir bar, e.g., stir bar 224, is rotating properly and efficiently within the fluid reservoir of the microfluidic dispensing device, e.g., microfluidic dispensing device 210. Sensor 164-4 may be, for example, a Hall-effect sensor, which generates and supplies a composite magnetic signal, in electrical form, based on the relative angular rotational position of magnet 260 of stir bar 224 and the position of the rotating magnetic field generated by electromagnetic field rotator 164-2 and electromagnetic field generator 164-3 of external magnetic field generator 164.

[0133] In the present embodiment, the control of the rotation of stir bar 224 is equivalent to driving a stepper motor. The angular rotational velocity of stir bar 224 must match the average angular rotational velocity magnetic field generated electromagnetic field rotator 164-2 and electromagnetic field generator 164-3, or else the rotational motion of stir bar 224 will "break phase" with the rotating magnetic field generated by electromagnetic field rotator 164-2 and electromagnetic field generator 164-3. As used herein, each of the terms "break phase", "breaking phase" and "broken phase" refers to a condition wherein the angular rotational velocity of the rotating magnetic field exceeds the angular rotational velocity of the stir bar, e.g., stir bar 224 having magnet 260.

[0134] In accordance with the present invention, the rotating magnetic field may be analog, as in a continuous rotation, or may be digital, as in predefined incremental angular positions.

[0135] To illustrate these concepts, please refer also to FIGs. 55-58. In each of FIGs. 55-58, both the rotational direction of a rotating magnetic field 700 generated by electromagnetic field rotator 164-2 and electromagnetic field generator 164-3 of external magnetic field generator 164, and the rotational direction of magnet 260 of stir bar 224, is in rotational direction 250-1, i.e., a counterclockwise as shown. Magnet 260 includes a north pole (N) and a south pole (S). Also, the rotating magnetic field 700 generated by electromagnetic field generator 164-3 and electromagnetic field rotator 164-2 has a north pole (N) and a south pole (S).

[0136] FIG. 55 illustrates stir bar 224 having magnet 260 relative to the angular rotational position of magnetic field 700 generated by electromagnetic field generator 164-3 and electromagnetic field rotator 164-2 of external magnetic field generator 164. In the present example, magnetic field 700 is depicted at four discrete angular rotational positions, individually identified as Position 1, Position 2, Position 3, and Position 4. While in the present example only four angular rotational positions are identified for ease of illustration, those skilled in the art will recognize that in practice, the number of angular rotational positions may be increased, if desired, and may correspond in number to 2 x n, wherein n is a positive integer. In FIG. 55, an initial occurrence of Position 1 is identified as position P1(A), and it is to be understood that the respective N, S depictions of the angular rotational position of magnetic field 700 of position P1(A) and position P1 are identical. As the angular rotational position of magnetic field 700 generated by electromagnetic field generator 164-3 and electromagnetic field rotator 164-2 is rotated, the angular rotational position of magnet 260 of stir bar 224 attempts to follow, since unlike poles attract and like poles repel.

[0137] Referring to FIG. 55, position P1(A), if magnetic field 700 of electromagnetic field generator 164-3 is stationary and stir bar 224 is not obstructed from rotation, magnet 260 of stir bar 224 will lock onto the angular rotational position of magnetic field 700 generated by electromagnetic field generator 164-3, e.g., the north pole (N) of magnet 260 of stir bar 224 will be attracted to the south pole (S) of magnetic field 700 generated by electromagnetic field generator 164-3 of external magnetic field generator 164.

[0138] In FIG. 55, for example, positions P1(A), P2, P3, P4, and P1 depict a complete rotation of magnetic field 700 of electromagnetic field generator 164-3 and electromagnetic field rotator 164-2 from the stationary position P1(A), and a complete rotation of stir bar 224, at discrete sample times. As depicted in positions P1, P2, P3, and P4, the angular rotational position of magnet 260 of stir bar 224 may lag in phase from the angular rotational position of the rotating magnetic field 700 generated by electromagnetic field generator 164-3 and electromagnetic field rotator 164-2 of external magnetic field generator 164. Some phase lag is expected.

[0139] In the present embodiment, a range of normal phase lag (e.g., determined empirically) is defined, wherein the amount of phase lag does not adversely affect the rotational/stirring efficiency of stir bar 224. In the present example, the range of normal phase lag may be defined as a range of 0 degrees through 140 degrees. As such, a phase lag that is not normal is considered to be an abnormal phase lag, which in the present example, is a phase lag of more than 140 degrees. The abnormal phase lag will include the condition of breaking phase, and also is inclusive of the special case of breaking phase of a stuck stir bar.

[0140] In the present example of FIG. 55, the phase lag is approximately 30 degrees. As used herein, the term "approximately" means the indicated amount plus or minus 10 percent. Continuous rotation of stir bar 224 by the rotation of magnetic field 700 may be recognized by the repetition of the sequential positions P1, P2, P3, and P4.

[0141] FIG. 56 illustrates a scenario wherein the torque required to rotate stir bar 224 is too high to begin rotation, i.e., stir bar 224 is stuck and prevented from rotation, such as for example, by an accumulation of settled particulate around stir bar 224. As such, as illustrated at the sequence of positions P1-4, representing a completed rotation of magnetic field 700, stir bar 224 is stationary while magnetic field 700 of external magnetic field generator 164 is rotating. Thus, FIG. 56 illustrates one example wherein stir bar 224 has broken phase from the rotation of magnetic field 700 generated by electromagnetic field generator 164-3 of external magnetic field generator 164.

[0142] Another possible case where stir bar 224 would break phase from the rotating magnetic field 700 is when the acceleration rate of the angular rotational velocity of the rotation of magnetic field 700 provided by electromagnetic field rotator 164-2 and electromagnetic field generator 164-3 is faster than can be obtained by stir bar 224. In such a case, for example, the present angular rotational velocity of magnetic field 700 must be decreased such that an acceptable phase lag relationship may be obtained.

[0143] FIG. 57 illustrates a scenario wherein there is a phase lag of approximately 45 degrees between the angular rotational position of stir bar 224 and the angular rotational position of magnetic field 700 at each of the plurality of positions P1-P4 of the rotating magnetic field 700.

[0144] FIG. 58 illustrates a scenario wherein there is a phase lag of approximately 90 degrees, represented by an arced arrowed line, between the angular rotational position of stir bar 224 and the angular rotational position of magnetic field 700 at each of the plurality of positions P1-P4 of the rotating magnetic field 700. Also, FIG. 58 demonstrates a plurality of rotational cycles, with each rotational cycle including a respective set of positions P1-P4. It is noted that for purposes of illustration clarity, only magnet 260 of stir bar 224 is shown in FIG. 58, and due to size restrictions in FIG. 58, the north pole (N) of magnet 260 is represented by a bold dot.

[0145] Referring again to FIGs. 56-58, each of FIGs. 56-58 include three graphs, including a stir bar magnet strength (top graph), a magnetic field strength (middle graph) of magnetic field 700, and a composite magnetic strength (lower graph), relative to the four angular rotational positions P1, P2, P3 and P4 of magnetic field 700 under the various scenarios of FIGs. 56-58. The vertical axis of each of the graphs represents a magnetic strength amplitude and the horizontal axis represents an angular rotational position, wherein the scale 0 to 1 on the horizontal axis represents one complete revolution (cycle) of magnetic field 700, corresponding to positions P1-P4 of magnetic field 700. FIG. 58 depicts multiple revolutions (cycles) of magnetic field 700, wherein each of the ranges 0-1, 1-2, 2-3, 3-4 represents one revolution of magnetic field 700. The composite magnetic strength (bottom graph) is an algebraic sum of the stir bar magnet strength (top graph) and the magnetic field strength (middle graph) at any point along the horizontal axis, and is representative of the electrical output of sensor 164-4, as a Hall Effect sensor, which receives magnetic contributions from both of the stir bar magnet 260 and magnetic field 700 during operation.

[0146] In general, it is noted that in FIGs. 56-58, the magnetic field strength profile (curve) of the magnetic field strength (middle) graph is a square wave, and will have the same profile shape, regardless of the angular rotational velocity of magnetic field 700, due to the fixed location of sensor 164-4 with respect to the rotating magnetic field 700. As such, variations in the respective shapes of the composite magnetic strength profile of the composite magnetic strength (bottom) graph as between FIGs. 56-58 are due to differences in the amount that the angular rotational position of magnet 260 of stir bar 224 lags the angular rotational position of magnetic field 700. Thus, by comparing the present output of sensor 164-4 representing a present composite magnetic strength profile with a previously stored profile database, i.e., an electronic library, of composite magnetic strength profiles, a determination may be made as to whether the stir bar is stuck, whether operating normally, i.e., within a predefined range of lag, or whether the stir has broken phase with the rotating magnetic field.

[0147] As introduced above, FIG. 56 depicts a scenario wherein stir bar 224, and in turn magnet 260, are stuck, i.e., blocked from rotation. FIG. 56 includes the three graphs described above, including a stir bar magnet strength profile 702 of magnet 260, a magnetic field strength profile 704 of magnetic field 700, and a composite magnetic strength profile 706. If desired, the stir bar magnet strength profile 702, representing a stuck stir bar, may be generated at the sensor output of sensor 164-4, for example, by taking a magnetic reading in the absence of magnetic field 700, e.g., magnetic field 700 of external magnetic field generator 164 is turned OFF. Also, if desired, the magnetic field strength profile 704 having a constant square wave shape, may be generated at the sensor output of sensor 164-4, for example, in the absence of microfluidic dispensing device 210 or in the presence of microfluidic dispensing device 210 with stir bar 224 blocked from rotation.

[0148] The composite magnetic strength profile 706 is the algebraic sum of the stir bar magnet strength profile 702 and the magnetic field strength profile 704. Since the stir bar magnet strength profile 702 (stuck stir bar) is a constant at unity, representing a non-rotation of stir bar magnet 260, then the shape of the composite magnetic strength profile 706 is the same as that of the magnetic field strength profile 704 of magnetic field 700 but for a vertical shift of unity on the vertical axis. Moreover, the composite magnetic strength profile 706 may be generated at the sensor output of sensor 164-4 by rotating magnetic field 700 while rotation of magnet 260 of stir bar 224 is blocked.

[0149] As such, referring again also to FIG. 54, the composite magnetic strength profile 706 generated by sensor 164-4 is supplied as a composite electrical signal to microcontroller 164-1, which in turn processes the composite electrical signal, e.g., through an analog-to-digital converter, and stores digital data representative of the composite magnetic strength profile 706, stuck stir bar, in a profile database 164-6 formed in electronic memory 164-5 of microcontroller 164-1 of external magnetic field generator 164. Thus, the digital representation of the composite magnetic strength profile 706 may be retrieved from the profile database 164-6 of electronic memory 164-5 for future reference as being representative of a stuck stir bar condition of stir bar 224 of microfluidic dispensing device 210. Accordingly, the composite magnetic strength profile 706 may be used by microcontroller 164-1 to aid in determining the operational status (e.g., stuck, normal, breaking phase, etc.) of stir bar 224 relative to the rotation of the rotating magnetic field 700 generated by external magnetic field generator 164.

[0150] Similarly, an electrical signal generated by sensor 164-4 representative of the magnetic field strength profile 704 may be processed by microcontroller 164-1, e.g., through an analog-to-digital converter, which in turn stores digital data representative of the magnetic field strength profile 704 in profile database 164-6 formed in electronic memory 164-5 of microcontroller 164-1 for future reference.

[0151] As introduced above, FIG. 57 illustrates a scenario wherein there is a phase lag of approximately 45 degrees between the angular rotational position of magnet 260 of stir bar 224 and the angular rotational position of magnetic field 700 at each of the plurality of positions P1-P4 of the rotating magnetic field 700. FIG. 57 includes the three types of graphs described above, including a stir bar magnet strength profile 708 of magnet 260, the magnetic field strength profile 704 of magnetic field 700, and a composite magnetic strength profile 710.

[0152] To establish the composite magnetic strength profile 710 representing a 45 degree lag, the 45 degree lag condition may be simulated in a lab setting, and then a reading of the sensor output of sensor 164-4 is taken to acquire the composite electrical signal representative of the composite magnetic strength profile 710. In particular, referring also to FIG. 54, the composite magnetic strength profile 710 generated by sensor 164-4 is supplied as a composite electrical signal to microcontroller 164-1, which in turn processes the composite electrical signal, e.g., through an analog-to-digital converter, and stores digital data representative of the composite magnetic strength profile 710, 45 degree lag, in profile database 164-6 formed in electronic memory 164-5 of microcontroller 164-1 of external magnetic field generator 164. Thus, the digital representation of the composite magnetic strength profile 710 also may be retrieved from the profile database 164-6 of electronic memory 164-5 for future reference as being representative of a 45 degree lag of magnet 260 of stir bar 224 of microfluidic dispensing device 210 relative to the rotating magnetic field 700. In turn, the composite magnetic strength profile 710 may be used by microcontroller 164-1 in determining the operational status (e.g., stuck, normal, breaking phase, etc.) of stir bar 224 relative to the rotation of the rotating magnetic field 700 generated by external magnetic field generator 164.

[0153] If desired, the stir bar magnet strength profile 708 of magnet 260 may most easily be derived by subtracting the magnetic field strength profile 704 of magnetic field 700, having the constant square wave shape, from the composite magnetic strength profile 710. This mathematical operation may be carried out by program instructions executed by microcontroller 164-1, which in turn may also store the stir bar magnet strength profile 708 of magnet 260 in profile database 164-6 formed in electronic memory 164-5 of microcontroller 164-1.

[0154] As introduced above, FIG. 58 illustrates a scenario wherein there is a phase lag of approximately 90 degrees between the angular rotational position of stir bar 224 and the angular rotational position of magnetic field 700 at each of the plurality of positions P1-P4 of the rotating magnetic field 700. FIG. 58 includes the three types of graphs described above, including a stir bar magnet strength profile 712 of magnet 260, the magnetic field strength profile 704 of magnetic field 700, and a composite magnetic strength profile 714. As a general observation, as the angular rotational velocity of stir bar 224 is increased, there will be an increase in the amount of phase lag between the angular rotational position of stir bar 224 and the angular rotational position of magnetic field 700.

[0155] To establish the composite magnetic strength profile 714 representing a 90 degree lag, the 90 degree lag condition may be simulated in a lab setting, and then a reading of the sensor output of sensor 164-4 is taken to acquire the composite electrical signal representative of the composite magnetic strength profile 714. In particular, referring also to FIG. 54, the composite magnetic strength profile 714 generated by sensor 164-4 is supplied as a composite electrical signal to microcontroller 164-1, which in turn processes the composite electrical signal, e.g., through an analog-to-digital converter, and stores digital data representative of the composite magnetic strength profile 714, having a 90 degree lag, in profile database 164-6 formed in electronic memory 164-5 of microcontroller 164-1 of external magnetic field generator 164.

[0156] Thus, the digital representation of the composite magnetic strength profile 714 also may be retrieved from the profile database 164-6 of electronic memory 164-5 for future reference as being representative of a 90 degree lag of magnet 260 of stir bar 224 of microfluidic dispensing device 210 relative to the rotating magnetic field 700. In turn, the composite magnetic strength profile 714 may be used by microcontroller 164-1 in determining the operational status (e.g., stuck, normal, breaking phase, etc.) of stir bar 224 relative to the rotation of the rotating magnetic field 700 generated by external magnetic field generator 164.

[0157] If desired, the stir bar magnet strength profile 712 of magnet 260 may most easily be derived by subtracting the magnetic field strength profile 704 of magnetic field 700, having the constant square wave shape, from the composite magnetic strength profile 714. This mathematical operation may be carried out by program instructions executed by microcontroller 164-1, which in turn may also store the stir bar magnet strength profile 712 of magnet 260 in profile database 164-6 formed in electronic memory 164-5 of microcontroller 164-1.

[0158] In accordance with the above description, composite magnetic strength profiles are stored in profile database 164-6 of electronic memory 164-5, which may be representative of a normal condition and a stuck stir bar condition. The stuck stir bar condition may be represented by a single composite magnetic strength profile, such as composite magnetic strength profile 706 of FIG. 56. The normal condition may be represented by a plurality of composite magnetic strength profiles that are in the preestablished range of normal phase lag, such as for example, a range of 0 degrees through 140 degrees.

[0159] In the example of FIGs. 57 and 58, the composite magnetic strength profile 710 representing a phase lag of 45 degrees and the composite magnetic strength profile 714 representing a phase lag of 90 degrees may be two of the plurality of composite magnetic strength profiles that are representative of a normal phase lag. For example, the normal phase lag may be represented by any number of composite magnetic strength profiles that are in the designated normal lag range. For example, the plurality of composite magnetic strength profiles representative of the normal phase lag may be established at angular increments, such as 1 degree increments, 5 degrees increments, or 10 degree increments, or other such types of increments, and stored in the profile database 164-6 of electronic memory 164-5.

[0160] Any composite magnetic strength profile read by sensor 164-4 that does not fall into the normal phase lag range by default is an abnormal phase lag, wherein a stuck stir bar is a special case of an abnormal lag condition. Thus, the normal phase lag range (representative of a normal condition) and the abnormal phase lag (representative of an abnormal condition) are mutually exclusive.

[0161] FIG. 59 is a flowchart of a method of operating a stir bar in a fluidic dispensing device, in accordance with an aspect of the present invention, with further reference to the embodiment of FIGs. 17-27, including stir bar 224. The method of FIG. 59, except for any manual intervention at step S810, may be performed by program instructions executed by microcontroller 164-1, depicted in FIG. 54.

[0162] At step S800, it is determined whether the present phase lag between the angular rotational position of the magnet 260 of stir bar 224 and the angular rotational position of magnetic field 700 generated by electromagnetic field rotator 164-2 and electromagnetic field generator 164-3 of external magnetic field generator 164 is in a range of normal phase lag.

[0163] In particular, in real time, sensor 164-4 provides electronic signals representative of a present composite magnetic strength of magnet 260 and magnetic field 700. Microcontroller 164-1 processes the electronic signals representative of a present composite magnetic strength to acquire a present composite magnetic strength. Microcontroller 164-1 then accesses profile database 164-6 of electronic memory 164-5 to compare the present composite magnetic strength to the stored plurality of composite magnetic strength profiles. If the comparison results in a match, or if the present composite magnetic strength, e.g., curve, falls between two of the stored composite magnetic strength profiles in the range of normal phase lag, then the phase lag between the angular rotational position of the magnet 260 of stir bar 224 and the angular rotational position of magnetic field 700 is in a range of normal phase lag, and stir bar 224 is considered to be operating in a normal condition, resulting in a determination of YES. Otherwise, the phase lag between the angular rotational position of the magnet 260 of stir bar 224 and the angular rotational position of magnetic field 700 is not in a range of normal phase lag, resulting in a determination of NO, and is considered an abnormal condition.

[0164] If the determination of step S800 is YES, then the process proceeds to step S802. Steps S802, S804, and S806 are directed to improving the stirring efficiency of stir bar 224 under the scenario that the phase lag is in a range of normal phase lag.

[0165] At step S802, it is determined whether the phase lag between the angular rotational position of the magnet 260 of stir bar 224 and the angular rotational position of magnetic field 700 is stable over time. As used herein, the phase lag is "stable" if a group of consecutive readings of the present composite magnetic strength from sensor 164-4 do not deviate from one another by more than a predetermined deviation, such as for example, by more than 5 percent.

[0166] If the determination at step S802 is YES, i.e., that the phase lag is stable, then at step S804, the angular rotational velocity of stir bar 224 is increased by increasing the angular rotational velocity of the rotating magnetic field 700. To help avoid a positive overshoot in angular rotational velocity, the increase will be gradual, and may be incremental, e.g., in speed increase increments of one percent. In particular, microcontroller 164-1 executes program instructions to determine whether the phase lag is stable, and if so, then sends a signal to electromagnetic field rotator 164-2 to increase the angular rotational velocity of magnetic field 700 by the specified amount. The process then returns to step S800.

[0167] If the determination at step S802 is NO, i.e., that the phase lag is not stable, then at step S806 the angular rotational velocity of the rotating magnetic field 700 is decreased. To help avoid a negative overshoot in angular rotational velocity, the decrease in the angular rotational velocity will be gradual, and may be incremental, e.g., in speed decrease increments of one percent. In particular, microcontroller 164-1 executes program instructions to determine whether the phase lag is stable, and if not, then sends a signal to electromagnetic field rotator 164-2 to decrease the angular rotational velocity of magnetic field 700 by the specified amount. The process then returns to step S800.

[0168] If the determination at step S800 is NO, i.e., the phase lag between the angular rotational position of the magnet 260 of stir bar 224 and the angular rotational position of magnetic field 700 is not in a range of normal phase lag, i.e., the phase lag is abnormal, then the process proceeds to step S808.

[0169] Steps S808, S810, and S812 are invoked under the scenario that the phase lag is not a range of normal phase lag, i.e., the phase lag is abnormal.

[0170] At step S808, it is determined whether stir bar 224 is stuck, i.e., stir bar 224 will not rotate.

[0171] In particular, in real time, sensor 164-4 provides electronic signals representative of a present composite magnetic strength of magnet 260 and magnetic field 700. Microcontroller 164-1 processes the electronic signals representative of a present composite magnetic strength to acquire a present composite magnetic strength. Microcontroller 164-1 then accesses the stuck stir bar composite magnetic strength profile, e.g., composite magnetic strength profile 706, from profile database 164-6 of electronic memory 164-5 to compare the present composite magnetic strength to the stored stuck stir bar composite magnetic strength profile.

[0172] If the comparison results in a match, then the result at step S808 is YES, indicating a stuck stir bar, i.e., the special case of an abnormal phase lag between the angular rotational position of the magnet 260 of stir bar 224 and the angular rotational position of magnetic field 700. If the comparison does not result in a match, then the result at step S808 is NO, and the phase lag is considered to be a general case of abnormal phase lag, and the process proceeds to step S812.

[0173] If the determination at step S808 is YES, that stir bar 224 is stuck, then the process proceeds to S810, wherein a user intervention may be invoked to unstick the stuck stir bar. It has been observed that changing the orientation of microfluidic dispensing device to use gravity to move the particulate and break up the layer formed by settled particulate, such as settled particulate 604 of FIGs. 48-50, may be used to free a stir bar, such as stir bar 224, which is stuck from rotation by the accumulated settled particulate 604. In this regard, please see the discussion above with respect to FIGs. 47-53. It is noted that shallow ejection chip angles will not be able to use gravity as effectively in moving sediment that may have settled in the ejection chip region including the fluid channel, such as for example, during a shipping condition.

[0174] A further option in attempting to break up the layer formed by settled particulate, such as settled particulate 604 depicted in FIG. 50, may be obtained by vibrating microfluidic dispensing device 210. Such haptic vibration may also help to clear the fluid channel, e.g., fluid channel 246 of FIGs. 48-50, and may be induced automatically upon occurrence of the YES determination at step S808. The frequency and intensity of the haptic vibration may be determined empirically, and may be dependent, at least in part, on the amount of particulate in the fluid.

[0175] Following intervention at step S810, the process is returns to step S800.

[0176] If the determination at step S808 is NO, that stir bar 224 is not stuck, then the assumption is made that the abnormal phase lag is due to some other cause, such as due to the magnet 260 of stir bar 224 breaking phase with the rotating magnetic field 700 provided by electromagnetic field rotator 164-2 and electromagnetic field generator 164-3, and the process proceeds to step S812.

[0177] At step S812, the angular rotational velocity of rotating magnetic field 700 is decreased. To help avoid a negative overshoot in the correction of the angular rotational velocity of rotating magnetic field 700, the decrease in angular rotational velocity will be gradual, and may be incremental, e.g., in speed decrease increments of one percent. In particular, microcontroller 164-1 executes program instructions to decrease the angular rotational velocity of magnetic field 700 by the specified amount. For example, the angular rotational velocity of the rotating magnetic field 700 is decreased until the normal phase lag associated with steps S800 through S804 is again achieved. Following step S812, the process returns to step S800.

[0178] It is contemplated that the determination made at step S800 may be simplified to a predefined number of conditions, such as for example, a normally operating stir bar, a stuck stir bar, and a stir bar that has broken phase with the rotating magnetic field, wherein steps S800 and S808 may be essentially combined into a single step having three possible outcomes.

[0179] Also, from the information obtained above, an estimate of viscosity of the mixed or unmixed fluid is possible by correlating the phase lag or peak angular rotational velocity of stir bar 224 with various levels of viscosity, e.g., by empirically establishing a viscosity curve, and comparing the present phase lag or peak angular rotational velocity of stir bar 224 with the viscosity curve. For a digitally changing magnetic field 700, a step response signal, e.g., step-wise increasing the angular rotational velocity of magnetic field 700, may also be used to determine an estimate of fluid viscosity in microfluidic dispensing device 210.

[0180] Further, it is contemplated that additional sensors, like sensor 164-4, e.g., additional Hall Effect sensors, may be used to further improve signal detection and profile generation. Also, it is noted that for the more analog rotating magnetic fields, a digital Hall Effect sensor can be used to look at the time periods instead of amplitudes in generating the composite magnetic strength profiles.

[0181] As an alternative to the above method using a Hall Effect sensor as sensor 164-4, it is contemplated that sensor 164-4 may be a vibration sensor. A vibration sensor will generate different signal signatures from the composite magnetic strength profile generated by a Hall Effect sensor, and rather, the vibration sensor directly generates an electronic vibration profile that may be substituted for the composite magnetic strength profile in the method described above. In such a case, the vibration sensor (acceleration, velocity, or positional) measures the differences caused by changes in magnetic attraction and repulsion between magnet 260 of stir bar 224 and the rotating magnetic field 700.

[0182] For example, if magnet 260 of stir bar 224 is rotating normally, the phase lag between magnet 260 of stir bar 224 and magnetic field 700 results in sensor 164-4, as a vibration sensor, generating a fairly uniform vibration signal because the magnet attraction, and thus the phase lag, during rotation is stable (see also step S802 described above).

[0183] In an abnormal phase lag condition of a loss of phase, there is a periodic repulsion of magnet 260 of stir bar 224 and magnetic field 700 that results in sensor 164-4, as a vibration sensor, generating a corresponding vibration pulse parallel to the axis of rotation, e.g., is strongest each time a pole of magnet 260 of stir bar 224 coincides with a like pole of magnetic field 700. In this condition, the stir bar is rotating erratically and inefficiently.

[0184] In a stir bar stuck condition, there the periodic repulsion of magnet 260 of stir bar 224 and magnetic field 700 occurs once per revolution, sensor 164-4 (as a vibration sensor) will generate the strongest signal parallel to the axis of rotation.

[0185] Notwithstanding the use of a stir bar to generate a fluid flow within a fluidic dispensing device to produce a remixing of the fluid contained in the fluidic dispensing device, it has been recognized that in a fluid channel of a fluidic dispensing device there is a potential for stagnation zones to be created, wherein settled particulate is not affected by the fluid flow through the fluid channel and/or a fluid flow through the fluid channel may result in an unintentional depositing of particulate. Such stagnation zones may be created, for example, at locations in the fluid channel where there are abrupt changes in the surface features, such as in a corner defined by orthogonal planar surfaces.

[0186] FIG. 60 is a further enlarged portion of the view depicted in FIG. 23. As shown in FIG. 60, fluid channel 246 defines a passage 246-6, represent by a dashed arrowed line, which extends between channel inlet 246-1 and channel outlet 246-2. Stir bar 224, when rotated, generates a fluid flow into channel inlet 246-1, through passage 246-6, and out of channel outlet 246-2.

[0187] Passage 246-6 has an outer wall structure 246-7 and an inner wall structure 246-3, 246-4, 246-5 formed by convexly arcuate wall 246-3 and transition radii 246-4, 246-5. Outer wall structure 246-7 is spaced away from inner wall structure 246-3, 246-4, 246-5.

[0188] Outer wall structure 246-7 includes an inlet side wall 650, an outlet side wall 652, and a distal wall portion 654. Outlet side wall 652 is spaced away from inlet side wall 650. Distal wall portion 654 is interposed between inlet side wall 650 and outlet side wall 652. Inlet side wall 650 is substantially perpendicular to distal wall portion 654 to define a first corner structure 246-8 that forms a first stagnation zone 656 of passage 246-6. Outlet side wall 652 is substantially perpendicular to distal wall portion 654 to define a second corner structure 246-9 that forms a second stagnation zone 658 of passage 246-6. Referring also to FIG. 18, fluid opening 232-3 extends through exterior wall 232-1 to distal wall portion 654 of fluid channel 246 between first corner structure 246-8, i.e., the first stagnation zone 656 and second corner structure 246-9, i.e., the second stagnation zone 658.

[0189] Referring to FIGs. 60-63, flow control portion 286, as a unitary component having flow separator feature 286-1, flow rejoining feature 286-2, and concavely arcuate surface 286-3, further includes an inlet flow director member 660 positioned adjacent to channel inlet

246-1 and an outlet flow director member 652 positioned adjacent to channel outlet 246-2. Inlet flow director member 660 is a portion of inlet fluid port 242 of chamber 238 and outlet flow director member 662 is a portion of outlet fluid port 244 of chamber 238.

[0190] More particularly, inlet fluid port 242 of chamber 238 is defined by an interior perimetrical wall portion 240-4 of interior perimetrical wall 240 in opposed combination with an inlet port wall portion 286-4 of flow separator feature 286-1 and inlet flow director member 6600. Interior perimetrical wall portion 240-4 of interior perimetrical wall 240 and inlet flow director member 660 are oriented to laterally converge in a direction toward channel inlet 246-1 of fluid channel 246. Conversely, outlet fluid port 244 of chamber 238 is defined by an interior perimetrical wall portion 240-5 of interior perimetrical wall 240 in opposed combination with an outlet port wall portion 286-5 of flow rejoining feature 286-2 of flow control portion 286 and outlet flow director member 662. Interior perimetrical wall portion 240-5 of interior perimetrical wall 240 and outlet flow director member 662 are oriented to laterally diverge in a fluid flow direction away from channel outlet 246-2.

[0191] Referring also to FIGs. 61-63, inlet port wall portion 286-4 of flow separator feature 286-1 of flow control portion 286 has a proximal end 664-1, a distal end 664-2, and a first height 664-3 (FIG. 62). The proximal end 664-1 of inlet port wall portion 286-4 is located to intersect concavely arcuate surface 286-3 at an acute angle to form a first apex 664-4 (see FIG. 61). Likewise, outlet port wall portion 286-5 of flow rejoining feature 286-2 of flow control portion 286 has a proximal end 666-1, a distal end 666-2, and a height 666-3 (FIG. 63). The proximal end 666-1 of the outlet port wall portion 286-5 is located to intersect concavely arcuate surface 286-3 at a second acute angle to form a second apex 666-4 (see FIG. 61). The entire curvature of concavely arcuate surface 286-3 extends between first apex 664-4 and second apex 666-4.

[0192] Inlet flow director member 660 has a surface structure having an inlet deflection wall portion 660-1 that directs a portion of the fluid flow toward first corner structure 246-8, i.e., the first stagnation zone 656, in passage 246-6. Inlet deflection wall portion 660-1 has a proximal end 660-2, a distal end 660-3, and a height 660-4. The proximal end 660-2 of inlet deflection wall portion 660-1 is located to intersect inlet port wall portion 286-4 of flow separator feature 286-1 at an obtuse angle.

[0193] As shown in FIG. 62, height 614-3 of inlet port wall portion 286-4 of flow separator feature 286-1 is greater than the height 660-4 of inlet deflection wall portion 660-1 to further define the surface structure of inlet flow director member 660 to include a first inlet ceiling portion 660-5 having a triangular shape and a second inlet ceiling portion 660-6 having a trapezoidal shape. First inlet ceiling portion 660-5 is positioned to laterally extend from inlet deflection wall portion 660-1 to inlet port wall portion 286-4 of flow control portion 286. Second inlet ceiling portion 660-6 is positioned to laterally extend from inlet deflection wall portion 660-1 of inlet flow director member 660 to inlet port wall portion 286-4 of flow control portion 286. Second inlet ceiling portion 660-6 is positioned to distally extend from first inlet ceiling portion 660-5, and with second inlet ceiling portion 660-6 and first inlet ceiling portion 660-5 positioned to intersect at an obtuse angle.

[0194] Referring again to FIGs. 61-63, outlet flow director member 662 has a second surface structure that facilitates generation of one or more eddy currents at second corner structure 246-9, i.e., the second stagnation zone 668, near channel outlet 246-2. In the present embodiment, the second surface structure of outlet flow director member 662 is symmetrical with the first surface structure of inlet flow director member 660 structure with respect to chamber 238, as well as with respect to channel mid-point 248. Outlet flow director member 662 has a second outlet wall portion 662-1 having a proximal end 662-2, a distal end 662-3, and height 662-4. The proximal end 662-2 of second outlet wall portion 662-1 is located to intersect the outlet port wall portion 286-5 of flow rejoining feature 286-2 at a second obtuse angle.

[0195] As shown in FIG. 63, height 666-3 of outlet port wall portion 286-5 of flow separator feature 286-1 is greater than the height 612-4 of second outlet deflection wall portion 662-1 to further define the surface structure of outlet flow director member 662 to include a first outlet ceiling portion 662-5 having a triangular shape and a second outlet ceiling portion 662-6 having a trapezoidal shape. The first outlet ceiling portion 662-5 of outlet flow director member 662 is positioned to laterally extend from the second outlet wall portion 662-1 to the outlet port wall portion 286-5 of flow rejoining feature 286-2. The second outlet ceiling portion is positioned to laterally extend from the second outlet wall portion to the outlet port wall portion 286-5. The second outlet ceiling portion is positioned to distally extend from the first outlet ceiling portion and with the second outlet ceiling portion and the first outlet ceiling portion positioned to intersect at an obtuse angle.

[0196] FIGs. 64-71 are directed to still another embodiment for reducing the potential for stagnation zones in a fluid channel of a fluidic dispensing device, such as a microfluidic dispensing device 750. The present embodiment utilizes modifications to the wall structure of the chamber so as to reduce the occurrence of abrupt changes in the surface features and/or reducing the lateral extent of any orthogonal walls in the fluid channel region of the fluidic dispensing device.

[0197] Microfluidic dispensing device 750 generally includes a housing 752 and a TAB circuit which includes ejection chip 118, such as TAB circuit 114 described above, and which for brevity will not be repeated here. Microfluidic dispensing device 750 is configured to contain a supply of a fluid, such as a fluid containing particulate material. The fluid may be, for example, cosmetics, lubricants, paint, ink, etc.

[0198] Referring to FIGs. 64 and 65, housing 752 includes a body 754 and a lid 756. Referring also to FIGs. 67, 69, and 70, contained within housing 752 is a diaphragm 758 and a stir bar 760 (see also FIG. 66). Each of the housing 752 components (body 754 and lid 756) and stir bar 760 may be made of plastic, using a molding process. Diaphragm 758 is made of rubber, using a molding process.

[0199] In general, a fluid (not shown) is contained in a sealed region, i.e., a fluid reservoir 762, between body 754 and diaphragm 758. Stir bar 760 resides in the sealed fluid reservoir 762 between body 754 and diaphragm 758 that contains the fluid. An internal fluid flow may be generated within fluid reservoir 762 by rotating stir bar 760 so as to provide fluid mixing and redistribution of particulate in the fluid within the sealed region of fluid reservoir 762.

[0200] Referring now also to FIGs. 66-70, body 704 of housing 752 has a base wall 764 and an exterior perimeter wall 766 contiguous with base wall 764. Exterior perimeter wall 766 is oriented to extend from base wall 764 in a direction that is substantially orthogonal to base wall 764. As best shown in FIGs. 67, 69, and 70, lid 756 is configured to engage exterior perimeter wall 766. Thus, exterior perimeter wall 766 is interposed between base wall 764 and lid 756, with lid 756 being attached to the open free end of exterior perimeter wall 766 by weld, adhesive, or other fastening mechanism, such as a snap fit or threaded union. Attachment of lid 756 to body 754 occurs after installation of stir bar 760 and diaphragm 758.

[0201] Referring to FIGs. 69-71, exterior perimeter wall 766 of body 754 includes an exterior wall 766-1, which is a contiguous portion of exterior perimeter wall 766. Exterior wall 766-1 has a chip mounting surface 766-2 that defines a plane, and has a fluid opening 766-3 adjacent to chip mounting surface 766-2 that passes through the thickness of exterior wall 766-1. Ejection chip 118 is mounted to chip mounting surface 766-2 and is in fluid communication with fluid opening 766-3 of exterior wall 766-1. Thus, ejection chip 118 and its associated ejection nozzles are oriented such that the fluid ejection direction 120-1 is substantially orthogonal to the plane of chip mounting surface 766-2. Base wall 764 is oriented along a plane that is substantially orthogonal to the plane of chip mounting surface 766-2 of exterior wall 766-1.

[0202] Referring to FIGs. 66, 68, and 71, body 754 of housing 752 also includes a chamber 768 located within a boundary defined by exterior perimeter wall 766. Chamber 768 forms a portion of fluid reservoir 762, and is configured to define an interior space, and in particular, includes base wall 764 and has an interior perimetrical wall 770 configured to have a rounded perimeter so as to promote fluid flow in chamber 768. Referring also to FIG. 67, interior perimetrical wall 770 of chamber 768 has a height extent bounded by a proximal end 770-1 and a distal end 770-2. Proximal end 770-1 is contiguous with, and may form a transition radius with, base wall 764. Such an edge radius may help in mixing effectiveness by reducing the number of sharp corners. Distal end 770-2 has a perimetrical end surface 770-3 to define a lateral opening of chamber 768. Perimetrical end surface 770-3 may be flat, or may include a plurality of perimetrical ribs, or undulations, to provide an effective sealing surface for engagement with diaphragm 758. Thus, in combination, chamber 768 and diaphragm 758 cooperate to define fluid reservoir 762 having a variable volume. The height extent of interior perimetrical wall 770 of chamber 768 is substantially orthogonal to base wall 764, and is substantially parallel to the corresponding extent of exterior perimeter wall 766.

[0203] Referring to FIGs. 66, 69 and 70, stir bar 760 resides in the variable volume of fluid reservoir 762. More particularly, in the orientation shown, stir bar 760 is located in chamber 768, and is located within a boundary defined by the interior perimetrical wall 770 of chamber 768. Stir bar 760 has a rotational axis 772 and a plurality of paddles 760-1, 760-2, 760-3, 760-4 that radially extend away from rotational axis 772. The actual number of paddles of stir bar 760 may be two or more, and preferably three or four, but more preferably four, with each adjacent pair of paddles having the same angular spacing around the rotational axis 772.

[0204] Stir bar 760 has a magnet (not shown), e.g., a permanent magnet, configured for interaction with an external magnetic field generator 164 (see FIG. 1) to drive stir bar 760 to rotate around the rotational axis 772, using the drive principles described above. In the present embodiment, stir bar 760 is free-floating with chamber 768, and will be attracted into contact with base wall 764 by the application of the electromagnetic filed generated by external magnetic field generator 164. Stir bar 760 primarily causes rotation flow of the fluid about a central region associated with the rotational axis 772 of stir bar 760, with some axial flow with a central return path as in a partial toroidal flow pattern.

[0205] As best shown in FIGs. 66-71, chamber 768 has an inlet fluid port 776 and an outlet fluid port 778, each of which is formed in a portion of interior perimetrical wall 770, with inlet fluid port 776 being separated a distance from outlet fluid port 778 along a portion of interior perimetrical wall 770. In particular, interior perimetrical wall 770 includes a divider wall 770-4 (see FIGs. 66 and 67) located between inlet fluid port 776 and outlet fluid port 778 of the chamber 768. In the present embodiment, the structure of inlet fluid port 776 and outlet fluid port 778 of chamber 768 is symmetrical with respect to chamber 768, and with respect to channel mid-point 782.

[0206] The terms "inlet" and "outlet" are terms of convenience that are used in distinguishing between the multiple ports of the present embodiment, and are correlated with a particular rotational direction of stir bar 760. However, it is to be understood that it is the rotational direction of stir bar 760 that dictates whether a particular port functions as an inlet port or an outlet port, and it is within the scope of this invention to reverse the rotational direction of stir bar 760, and thus reverse the roles of the respective ports within chamber 768.

[0207] As best shown in FIGs. 66 and 69-71, body 754 of housing 752 includes a fluid channel 780 interposed between a portion (e.g., divider wall 770-4) of interior perimetrical wall 770 of chamber 768 and exterior wall 766-1 of exterior perimeter wall 766 that carries ejection chip 118. Fluid channel 780 has a channel inlet 780-1 and a channel outlet 780-2. Fluid channel 780 dimensions, e.g., height, width, and shape, are selected to facilitate a desired combination of fluid flow and fluid velocity for facilitating intra-channel stirring. Fluid channel 780 is in fluid communication with each of inlet fluid port 776 of chamber 768, outlet fluid port 778 of chamber 768, and fluid opening 766-3 of exterior wall 766-1 that mounts ejection chip 118.

[0208] Fluid channel 780 defines a passage 780-3, represented by a dashed arrowed line in FIG. 66, which extends between channel inlet 780-1 and channel outlet 780-2. Fluid channel 780 has an interior wall 780-4 that is positioned between channel inlet 780-1 and channel outlet 780-2, with fluid channel 780 being symmetrical about a channel mid-point 782, and with interior wall 780-4 positioned to face fluid opening 766-3 of exterior wall 766-1 and ejection chip 118. Likewise, the structure of channel inlet 780-1 and channel outlet 780-2 of fluid channel 780 is symmetrical with respect to the channel mid-point 782. Passage 780-3 is in fluid communication with fluid opening 766-3 in the exterior wall 766-1.

[0209] Referring also to FIGs. 67 and 68, channel inlet 780-1 of fluid channel 780 is in fluid communication with inlet fluid port 776 of chamber 768 via an inlet transition passage 784. Inlet transition passage 784 is oriented to extend from inlet fluid port 776 of the chamber 768 and into the channel inlet 780-1 of fluid channel 780. Inlet transition passage 784 has a plurality of surfaces 788, 789, 790, 792, 794 that converge in a direction 786 (see FIGs. 66, 67, and 70) from the chamber 768 toward fluid opening 766-3 in the exterior wall 766-1, such that the cross-sectional area of inlet transition passage 784 diminishes in a direction toward fluid channel 780.

[0210] Referring to FIGs. 66-71, the plurality of surfaces 788, 789, 790, 792, 794 of the inlet transition passage 784 includes a ramp floor 788, an inner wall 789, a tapered ceiling 790, an angled ceiling portion 792, and a beveled side wall 794. The ramp floor 788 is located between inner wall 789 and beveled side wall 794, and is located to extend from base wall 764 at inlet fluid port 776 of the chamber 768 to the channel inlet 780-1 of fluid channel 780. Each of the tapered ceiling 790 and the beveled side wall 794 is located to extend from the interior perimetrical wall at inlet fluid port 776 of the chamber 768 and into fluid channel 780 to an interior surface 795 of the exterior wall 766-1. The angled ceiling portion 792 transitions from the tapered ceiling 790 to the beveled side wall 794.

[0211] Referring also to FIG. 66, in the present embodiment, ramp floor 788 has a first transition ramp portion 788-1 and a second transition ramp portion 788-2. As best shown in FIG. 71, the second transition ramp portion 788-2 is located closer to channel inlet 780-1 of fluid channel 780 than the first transition ramp portion 788-1. The first transition ramp portion 788-1 has a first slope relative to base wall 764 and the second transition ramp portion 788-2 has a second slope relative to base wall 764. The second slope of the second transition ramp portion 788-2 is steeper than the first slope of the first transition ramp portion 788-1.

[0212] Referring to FIGs. 66 and 67, channel outlet 780-2 of fluid channel 780 is in fluid communication with outlet fluid port 778 of the chamber 768 via an outlet transition passage 796. Outlet transition passage 796 is oriented to extend from outlet fluid port 778 of the chamber 768 and into the channel outlet 780-2 of fluid channel 780. Outlet transition passage 796 has a plurality of surfaces 798, 799, 800, 802, 804 that diverge in a direction 786-1 away from fluid opening 766-3 in the exterior wall 766-1 and toward chamber 768. Stated differently, the plurality of surfaces 798, 799, 800, 802, 804 of outlet transition passage 796 converge in a direction toward fluid opening 766-3 in the exterior wall 766-1 and away from chamber 768, such that the cross-sectional area of outlet transition passage 796 diminishes in a direction toward fluid channel 780.

[0213] In the present embodiment, outlet transition passage 796 is constructed identical to the inlet transition passage 784. At chamber 768, outlet transition passage 796 is separated from inlet transition passage 784 by divider wall 770-4. Also, in the present embodiment, inlet transition passage 784 and the outlet transition passage 796 are symmetrical with respect to the chamber 768, and are symmetrical with respect to channel mid-point 782. The terms "inlet" transition passage and "outlet" transition passage are terms of convenience that are used in distinguishing between the two transition passages of the present embodiment, and are correlated with a particular rotational direction of stir bar 760 as to performing one of an inlet or an outlet function. However, it is to be understood that it is the rotational direction of stir bar 760 that dictates whether a particular transition passage functions as an inlet transition passage or an outlet transition passage, and it is within the scope of this invention to reverse the rotational direction of stir bar 760, and thus reverse the roles of the respective transition passages.

[0214] The plurality of surfaces 794, 799, 800, 802, 804 of outlet transition passage 796 includes a ramp floor 798, an inner wall 799, a tapered ceiling 800, an angled ceiling portion 802, and a beveled side wall 804. The ramp floor 798 is located between inner wall 799 and beveled side wall 804, and is located to extend from the base wall 764 at outlet fluid port 778 of the chamber 768 to the channel outlet 780-2 of fluid channel 780. Each of the tapered ceiling 800 and the beveled side wall 804 is located to extend from the interior perimetrical wall at outlet fluid port 778 of the chamber 768 and into fluid channel 780 to interior surface 795 of exterior wall 766-1.

Angled ceiling portion 802 transitions from tapered ceiling 800 to beveled side wall 804.

[0215] In the present embodiment, ramp floor 798 has a first transition ramp portion 798-1 and a second transition ramp portion 798-2. The second transition ramp portion 798-2 is located closer to channel outlet 780-2 of fluid channel 780 than the first transition ramp portion 798-1. The first transition ramp portion 798-1 has a first slope relative to base wall 764 and the second transition ramp portion 788-2 has a second slope relative to the base wall 764. The second slope of the second transition ramp portion 798-2 is steeper than the first slope of the first transition ramp portion 798-1.

[0216] Referring to FIGs. 1-5, housing 112 includes a body 122, a lid 124, and an end cap 126. Referring to FIGs. 72 and 74, body 122 includes a fill hole 122-1 and a fill plug 128 (e.g., ball). In the present embodiment, fill plug 128 may be in the form of a stainless steel ball bearing. Referring to FIGs. 72-76 in relation to FIG. 1, contained within housing 112 is a diaphragm 130 and a plurality of stir bars 132, 135. In the present embodiment, there are two stir bars that are individually identified as stir bar 132 and stir bar 135. Each of the housing 112 components and the plurality of stir bars 132, 135 may be made of plastic, using a molding process. Diaphragm 130 is made of rubber, using a molding process.

[0217] In general, a fluid (not shown) is loaded through a fill hole 122-1 in body 122 (see FIGs. 72-74) into a sealed region, i.e., a fluid reservoir 136, between body 122 and diaphragm 130. Back pressure in fluid reservoir 136 is set and then maintained by inserting, e.g., pressing, fill plug 128 into fill hole 122-1 to prevent air from leaking into fluid reservoir 136 or fluid from leaking out of fluid reservoir 136. Referring again to FIGs. 1-5, end cap 126 is then placed onto an end of the body 122/lid 124 combination, opposite to ejection chip 118. The plurality of stir bars 132, 135 reside in the sealed fluid reservoir 136 between body 122 and diaphragm 130 that contains the fluid. An internal fluid flow may be generated within fluid reservoir 136 by rotating each of stir bar 132 and stir bar 135, so as to provide fluid mixing and redistribution of particulate in the fluid within the sealed region of fluid reservoir 136. In the present embodiment, as will be discussed in more detail below, the rotational direction of stir bar 135 is opposite to the rotational direction of stir bar 132.

[0218] Referring to FIGs. 72-76, body 122 of housing 112 has a base wall 138 and an exterior perimeter wall 140 contiguous with base wall 138. Exterior perimeter wall 140 is oriented to extend from base wall 138 in a direction that is substantially orthogonal to base wall 138. Referring again to FIGs. 1-5, lid 124 is configured to engage exterior perimeter wall 140. Thus, exterior perimeter wall 140 is interposed between base wall 138 and lid 124, with lid 124 being attached to the open free end of exterior perimeter wall 140 by weld, adhesive, or other fastening mechanism, such as a snap fit or threaded union. Attachment of lid 124 to body 122 occurs after the insertion of the plurality of stir bars 132, 135 (see FIG. 74) in body 122 and after the installation of diaphragm 130 (see FIGs. 72-74) on body 122.

[0219] Referring to FIGs. 72-76, exterior perimeter wall 140 of body 122 includes an exterior wall 140-1, which is a contiguous portion of exterior perimeter wall 140. As best shown in FIG. 75, exterior wall 140-1 has a chip mounting surface 140-2 that defines a plane 142 (see also FIG. 72), and has a fluid opening 140-3 adjacent to chip mounting surface 140-2 that passes through the thickness of exterior wall 140-1. Ejection chip 118 is mounted, e.g., by an adhesive, to chip mounting surface 140-2 and is in fluid communication with fluid opening 140-3 (see FIG. 74) of exterior wall 140-1. Thus, referring to FIGs. 1, 72 and 73, the planar extent of ejection chip 118 is oriented along plane 142, with the plurality of ejection nozzles 120 oriented such that the fluid ejection direction 120-1 is substantially orthogonal to plane 142. Base wall 138 is oriented along a plane 146 (see FIGs. 72 and 74) that is substantially orthogonal to plane 142 of exterior wall 140-1.

[0220] Referring to FIGs. 74-77, body 122 of housing 112 also includes a chamber 148 located within a boundary defined by exterior perimeter wall 140. Chamber 148 forms a portion of fluid reservoir 136, and is configured to define an interior space, and in particular, includes base wall 138 and has an interior perimetrical wall 150 configured to have rounded corners, so as to promote fluid flow in chamber 148. Each of the plurality of stir bars 132, 135 is rotatable, and moveable laterally and longitudinally along base wall 138, within the confining limits defined by interior perimetrical wall 150 of fluid reservoir 136. In the present embodiment, stir bar 132 of the plurality of stir bars 132, 135 is located closer to inlet fluid port 152 and an outlet fluid port 154 than is stir bar 135. Stated differently, as illustrated in FIG. 76, for example, stir bar 132 is interposed between fluid ports 152, 154 and stir bar 135, and in turn, as illustrated in FIG. 75, stir bar 132 is interposed between fluid opening 140-3 and stir bar 135.

[0221] Interior perimetrical wall 150 of chamber 148 has an extent bounded by a proximal end 150-1 and a distal end 150-2. Proximal end 150-1 is contiguous with, and may form a transition radius with, base wall 138. Such an edge radius may help in mixing effectiveness by reducing the number of sharp corners. Distal end 150-2 is configured to define a perimetrical end surface 150-3 at an open end 148-2 of chamber 148. Perimetrical end surface 150-3 may include a plurality of perimetrical ribs, or undulations, to provide an effective sealing surface for engagement with diaphragm 130 (see FIGs. 72-77). The extent of interior perimetrical wall 150 of chamber 148 is substantially orthogonal to base wall 138, and is substantially parallel to the corresponding extent of exterior perimeter wall 140 (see FIGs. 75 and 76).

[0222] As best shown in FIG. 76, chamber 148 has an inlet fluid port 152 and an outlet fluid port 154, each of which is formed in a portion of interior perimetrical wall

150. The terms "inlet" and "outlet" are terms of convenience that are used in distinguishing between the multiple ports of the present embodiment, and are correlated with a particular rotational direction of the stir bar of the plurality of stir bars 132, 135 that is located closer to inlet fluid port 152 and an outlet fluid port 154, which as illustrated in FIG. 76, for example, is stir bar 132. In other words, it is the rotational direction of the closer stir bar that dictates whether a particular port functions as an inlet port or an outlet port, and it is within the scope of this invention to reverse the rotational direction of the plurality of stir bars 132, 135, and thus reverse the roles of the respective ports within chamber 148.

[0223] As shown in FIG. 76, inlet fluid port 152 is separated a distance from outlet fluid port 154 along a portion of interior perimetrical wall 150. Referring also to FIG. 74, body 122 of housing 112 includes a fluid channel 156 interposed between the portion of interior perimetrical wall 150 of chamber 148 and exterior wall 140-1 of exterior perimeter wall 140 that carries ejection chip 118.

[0224] Fluid channel 156 is configured to minimize particulate settling in a region of ejection chip 118. Fluid channel 156 is sized, e.g., using empirical data, to provide a desired flow rate while also maintaining an acceptable fluid velocity for fluid mixing through fluid channel 156. In the present embodiment, fluid channel 156 is configured as a U-shaped elongated passage. Fluid channel 156 dimensions, e.g., height and width, and shape are selected to provide a desired combination of fluid flow and fluid velocity for facilitating intra-channel stirring. Fluid channel 156 is configured to connect inlet fluid port 152 of chamber 148 in fluid communication with outlet fluid port 154 of chamber 148, and also connects fluid opening 140-3 (see FIG. 75) of exterior wall 140-1 of exterior perimeter wall 140 in fluid communication with both inlet fluid port 152 and outlet fluid port 154 (see FIG. 76) of chamber 148.

[0225] Referring again to FIGs. 1, 72, and 73, diaphragm 130 is positioned between lid 124 and perimetrical end surface 150-3 of interior perimetrical wall 150 of chamber 148. The attachment of lid 124 to body 122 compresses a perimeter of diaphragm 130 thereby creating a continuous seal between diaphragm 130 and body 122. More particularly, diaphragm 130 is configured for sealing engagement with perimetrical end surface 150-3 of interior perimetrical wall 150 of chamber 148 in forming fluid reservoir 136. Thus, in combination, chamber 148 and diaphragm 130 cooperate to define fluid reservoir 136 having a variable volume.

[0226] Referring particularly to FIGs. 1 and 72, an exterior surface of diaphragm 130 is vented to the atmosphere through a vent hole 124-1 located in lid 124 so that a controlled negative pressure can be maintained in fluid reservoir 136. Diaphragm 130 is made of rubber, and includes a dome portion 130-1 configured to progressively collapse toward base wall 138 as fluid is depleted from microfluidic dispensing device 110, so as to maintain a desired negative pressure in chamber 148, and thus changing the effective volume of the variable volume of fluid reservoir 136, also referred to herein as a bulk region.

[0227] Referring to FIGs. 72-77, stir bar 132 moveably resides in, and is confined within, the variable volume of fluid reservoir 136 and chamber 148, and is located within a boundary defined by the interior perimetrical wall 150 of chamber 148.

[0228] Referring also to FIG. 78, stir bar 132 has a rotational axis 160 and a plurality of paddles 132-1, 132-2, 132-3, 132-4 that radially extend away from rotational axis 160 to rotate about rotational axis 160 in a rotational direction 160-1 to define a rotational area 160-2 of stir bar 132. While rotational area 160-2 is depicted as being circular as to a single revolution of stir bar 132 about rotational axis 160, it is to be understood that within a single revolution of stir bar 132 it is possible that the location of rotational axis 160 relative to fluid reservoir 136, base wall 138, and chamber 148 may shift radially, thus resulting in a non-circular, e.g., oval, shape for rotational area 160-2 of stir bar 132. As depicted in FIG. 77, stir bar 132 has a magnet 162, e.g., a permanent bar magnet having opposed poles, i.e., a North pole and a South pole.

[0229] Likewise, referring again to FIG. 78, stir bar 135 has a rotational axis 165 and a plurality of paddles 135-1, 135-2, 135-3, 135-4 that radially extend away from rotational axis 165 to rotate about rotational axis 165 in a rotational direction 165-1 to define a rotational area 165-2 of stir bar 135. While rotational area 165-2 is depicted as being circular as to a single revolution of stir bar 135 about rotational axis 165, it is to be understood that within a single revolution of stir bar 135 it is possible that the location of rotational axis 165 relative to fluid reservoir 136, base wall 138, and chamber 148 may shift radially, thus resulting in a non-circular, e.g., oval, shape for rotational area 165-2 of stir bar 135. As depicted in FIG. 77, stir bar 135 has a magnet 167, e.g., a permanent bar magnet having opposed poles, i.e., a North pole and a South pole.

[0230] In the present example, with reference to FIGs. 74-78, the plurality of paddles 132-1, 132-2, 132-3, 132-4 of stir bar 132 are in-mesh with the plurality of paddles 135-1, 135-2, 135-3, 135-4 of stir bar 135, and as such, rotational direction 160-1 of stir bar 132 is opposite to the rotational direction 165-1 of stir bar 135. Also, in the present embodiment, an in-mesh timing sequence of the plurality of paddles 132-1, 132-2, 132-3, 132-4 of stir bar 132 with the plurality of paddles 135-1, 135-2, 135-3, 135-4 is such that the like poles of magnet 162 of stir bar 132 and magnet 167 of stir bar 135 repel to aid in opposed rotational directions of stir bar 132 and stir bar 135. As depicted in FIG. 78, the in-mesh relationship of the plurality of paddles 132-1, 132-2, 132-3, 132-4 of stir bar 132 with the plurality of paddles 135-1, 135-2, 135-3, 135-4 of stir bar 135 results in an overlap of the rotational area 160-2 of stir bar 132 with the rotational area 165-2 of stir bar 135.

[0231] In operation, each of magnet 162 of stir bar 132 and magnet 167 of stir bar 135 interact with an external magnetic field generator 168 (see FIG. 1) to cause the plurality of stir bars 132, 135 to rotate around their respective rotational axes 160, 165. The principle of operation of the plurality of stir bars 132, 135 is that as magnets 162, 167 are aligned to a strong enough external magnetic field generated by external magnetic field generator 168, then rotating the external magnetic field generated by external magnetic field generator 168 in a controlled manner will rotate the plurality of stir bars 132, 135 in a chaotic, somewhat erratic, manner due to the interaction of the magnetic fields of magnets 162, 167, wherein like poles repel and unlike poles attract, and/or due to impact of stir bars 132, 135 with each other or with interior perimetrical wall 150 of body 122. The external magnetic field generated by external magnetic field generator 168 may be electronically rotated, akin to operation of a stepper motor, or may be rotated via a rotating shaft. Thus, the plurality of stir bars 132, 135 are effective to provide fluid mixing in fluid reservoir 136 by the rotation of stir bar 132 around rotational axis 160 and by the rotation of stir bar 135 around rotational axis 165.

[0232] While in the present embodiment, each of stir bar 132 and 135 has a respective magnet, 162, 167, those skilled in the art will recognize that due to the in-mesh relationship of the plurality of paddles 132-1, 132-2, 132-3, 132-4 of stir bar 132 with the plurality of paddles 135-1, 135-2, 135-3, 135-4 of stir bar 135, it is possible to include a magnet in only one of stir bars 132, 135. For example, assume that stir bar 132 includes magnet 162, but stir bar 135 does not. As such, stir bar 132 will interact with the rotating external magnetic field generated by external magnetic field generator 168, but stir bar 135 will not. However, due to the overlap of the rotational area 160-2 of stir bar 132 with the rotational area 165-2 of stir bar 135 that results in the in-mesh relationship, stir bar 135 will be driven to rotate by the rotation of stir bar 132.

[0233] Fluid mixing in the bulk region relies on a flow velocity caused by rotation of the plurality of stir bars 132, 135 to create a shear stress at the settled boundary layer of the particulate. When the shear stress is greater than the critical shear stress (empirically determined) to start particle movement, remixing occurs because the settled particles are now distributed in the moving fluid. The shear stress is dependent on both the fluid parameters such as: viscosity, particle size, and density; and mechanical design factors such as: container shape, stir bar geometry, fluid thickness between moving and stationary surfaces, and rotational speed.

[0234] A fluid flow is generated by rotating the plurality of stir bars 132, 135 in a fluid region, e.g., fluid reservoir 136, and fluid channel 156 associated with ejection chip 118, so as to ensure that mixed bulk fluid is presented to ejection chip 118 for nozzle ejection and to move fluid adjacent to ejection chip 118 to the bulk region of fluid reservoir 136 to ensure that the channel fluid flowing through fluid channel 156 mixes with the bulk fluid of fluid reservoir 136, so as to produce a more uniform mixture. Although this flow is primarily distribution in nature, some mixing will occur if the flow velocity is sufficient to create a shear stress above the critical value.

[0235] The combination of the rotation of stir bar 132 and the counter rotation of stir bar 135 results in a rotational flow of the fluid about a central region associated with each of rotational axis 160 of stir bar 132 and rotational axis 165 of stir bar 135. In the present embodiment, rotational axis 160 of stir bar 132 and rotational axis 165 of stir bar 135 are moveable within the confinement range defined by fluid reservoir 136, and within chamber 148.

[0236] Referring to FIGs. 74-78, each paddle of the plurality of paddles 132-1, 132-2, 132-3, 132-4 of stir bar 132 has a respective free end tip 132-5. Referring to FIG. 74, so as to reduce rotational drag, each paddle may include upper and lower symmetrical pairs of chamfered surfaces, forming leading beveled surfaces 132-6 and trailing beveled surfaces 132-7 relative to a rotational direction 160-1 of stir bar 132. It is also contemplated that each of the plurality of paddles 132-1, 132-2, 132-3, 132-4 of stir bar 132 may have a pill or cylindrical shape. In the present embodiment, stir bar 132 has two pairs of diametrically opposed paddles, wherein a first paddle of the diametrically opposed paddles has a first free end tip 132-5 and a second paddle of the diametrically opposed paddles has a second free end tip 132-5.

[0237] Likewise, referring to FIGs. 74-78, each paddle of the plurality of paddles 135-1, 135-2, 135-3, 135-4 of stir bar 135 has a respective free end tip 135-5. Referring to FIG. 74, so as to reduce rotational drag, each paddle may include upper and lower symmetrical pairs of chamfered surfaces, forming leading beveled surfaces 135-6 and trailing beveled surfaces 135-7 relative to a rotational direction 165-1 of stir bar 135. It is also contemplated that each of the plurality of paddles 135-1, 135-2, 135-3, 135-4 of stir bar 135 may have a pill or cylindrical shape. In the present embodiment, stir bar 135 has two pairs of diametrically opposed paddles, wherein a first paddle of the diametrically opposed paddles has a first free end tip 135-5 and a second paddle of the diametrically opposed paddles has a second free end tip 135-5.

[0238] In the present embodiment, for each of the stir bars 132, 135, the four paddles forming the two pairs of diametrically opposed paddles are equally spaced at 90 degree increments around the respective rotational axis of rotational axes 160, 165. However, the actual number of paddles may be two or more, and preferably three or four, but more preferably four, with each adjacent pair of paddles having the same angular spacing around the respective rotational axis of rotational axes 160, 165. For example, a stir bar configuration having three paddles may have a paddle spacing of 120 degrees, having four paddles may have a paddle spacing of 90 degrees, etc.

[0239] Referring to FIGs. 72-76, the plurality of stir bars 132, 135 are located for movement within the variable volume of fluid reservoir 136 (see FIG. 72 and 74), and more particularly, within the boundary defined by interior perimetrical wall 150 of chamber 148 (see also FIGs. 75-77).

[0240] As such, in the present embodiment, the plurality of stir bars 132, 135 are confined within fluid reservoir 136 by the confining surfaces provided by fluid reservoir 136, e.g., by chamber 148 and diaphragm 130. The extent to which the respective stir bars 132, 135 are movable within fluid reservoir 136 is determined by the radial tolerances provided between each of the stir bars 132, 135 and the interior perimetrical wall 150 of chamber 148 in the radial (lateral/longitudinal) direction, and by the axial tolerances between each of the stir bars 132, 135 and the axial limit provided by the combination of base wall 138 of chamber 148 and diaphragm 130.

[0241] Thus, referring to FIGs. 73-76, the rotational axes 160, 165 of the plurality of stir bars 132, 135 are free to move radially and axially, e.g., longitudinally, laterally, and/or vertically, within fluid reservoir 136 to the extent permitted by the confining surfaces, e.g., interior surfaces of chamber 148 and diaphragm 130, of fluid reservoir 136. Such confining surfaces also limit the canting of the rotational axes 160, 165 of the plurality of stir bars 132, 135 to be within a predefined angular range, e.g., perpendicular, plus or minus 45 degrees, relative to plane 146 of base wall 138 of chamber 148 and/or to the fluid ejection direction 120-1 (see also FIG. 73). Stated differently, the rotational axes 160, 165 of the plurality of stir bars 132, 135 are moveable radially and axially within fluid reservoir 136, and may be canted in an angular range of perpendicular, plus or minus 45 degrees, relative to plane 146 of base wall 138 of chamber 148 and/or to the fluid ejection direction 120-1.

[0242] In the present embodiment, referring to FIGs. 74-77, the plurality of stir bars 132, 135 are moveably confined within fluid reservoir 136, and the confining surfaces of fluid reservoir 136 maintain an orientation of stir bar 132 such that the free end tip 132-5 of a respective paddle of the plurality of paddles 132-1, 132-2, 132-3, 132-4 periodically and intermittently face inlet and outlet fluid ports 152, 154; fluid channel 156; fluid opening 140-3; and ejection chip 118, as stir bar 132 is rotated about rotational axis 160, and permits movement of the plurality of stir bars 132, 135 toward or away from inlet and outlet fluid ports 152, 154; fluid channel 156; fluid opening 140-3; and ejection chip 118.

[0243] In accordance with an aspect of the present embodiment, to effect movement of the location of the plurality of stir bars 132, 135 within fluid reservoir 136, first, external magnetic field generator 168 (see FIG. 1) is energized to interact with each of magnet 162 (see FIG. 77) of stir bar 132 and magnet 167 of stir bar 135. If the magnetic field generated by external magnetic field generator 168 is rotating, then the plurality of stir bars 132, 135 will tend to rotate with the magnetic field. Next, housing 112 of microfluidic dispensing device 110 may be moved relative to external magnetic field generator 168, or vice versa.

[0244] In other words, magnets 162, 167 of the plurality of stir bars 132, 135 are attracted to the magnetic field generated by external magnetic field generator 168, such that rotational axis 160 and rotational area 160-2 of stir bar 132, and rotational axis 165 and rotational area 165-2 of stir bar 135, will be relocated within fluid reservoir 136 and chamber 148 with a change of location of external magnetic field generator 168 relative to the location of housing 112 of microfluidic dispensing device 110. The attraction of the plurality of stir bars 132, 135 to the magnetic field generated by external magnetic field generator 168 can cause rotational axis 160 of stir bar 132 and rotational axis 165 of stir bar 135 to attempt to occupy the same space, which is not possible, thus resulting in erratic radial movement of stir bar 132 relative to stir bar 135 that causes stir bars 132, 135 to sweep a larger area. Also, such an attempt to occupy the same space may result in an intermittent radial impact of stir bar 132 with stir bar 135, resulting in a vibratory effect that may be beneficial in loosening settled particulate in fluid reservoir 136.

[0245] Referring to FIGs. 79-84, there is shown an alternative body 200, which may be substituted for the body 122 depicted in FIGs. 1-5 and 72-77. Body 200 is identical in all respects to body 122 except for the inclusion of a separation wall 202. As such, the description set forth above as to features common to body 122 and to body 200 also will apply to body 200, and thus, for brevity, the full description of such features common to body 122 and to body 200 will not be repeated here although such common features will be identified in FIGs. 79-84. In particular, the difference between body 200 and body 122 is that of the inclusion of separation wall 202 in body 200, which will be described in detail below.

[0246] Referring to FIG. 84, separation wall 202 is positioned in fluid reservoir 136 between base wall 138 and diaphragm 130 to divide fluid reservoir 136, and in turn chamber 148, into a first region 204 and a second region 206 (see also FIG. 83). Referring also to FIGs. 79-82, separation wall 202 has at least one transverse opening 208, and in the present embodiment, includes a plurality of transverse openings 208, which are individually identified as transverse opening 208-1, transverse opening 208-2, transverse opening 208-3, transverse opening 208-4 and transverse opening 208-5. Each of the plurality of transverse openings 208 connects the first region 204 in fluid communication with the second region 206. Referring also to FIG. 83, separation wall 202 is interposed between the stir bar 132 and the stir bar 135 of the plurality of stir bars 132, 135, such that stir bar 132 is located in its entirety in the first region 204 and stir bar 135 is located in its entirety in the second region 206.

[0247] As best shown in FIGs. 79-81, with reference to FIG. 84, separation wall 202 has a profile shape selected to facilitate a collapse of diaphragm 130 toward base wall 138 as fluid is depleted from fluid reservoir 136 and chamber 148. In addition, the shape, e.g., height, of separation wall 202 is selected to prevent contact of diaphragm 130 with either of the plurality of stir bars 132,

135. In the present embodiment, separation wall 202 may include two or more spaced posts 211. In the present example, referring also to FIG. 82, there are four posts that are individually identified as post 211-1, post 211-2, post 211-3, and post 211-4. Each of the posts 211 extend from base wall 138 in a direction substantially perpendicular to base wall 138 to a respective free end tip 212-1, free end tip 212-2, free end tip 212-3, and free end tip 212-4. In other words, in the present embodiment, each of the posts 211 of separation wall 202 extends in a cantilever manner from base wall 138.

[0248] Thus, referring to FIGs. 83 and 84, at least a portion of separation wall 202 is taller than a height of each of the stir bars 132, 135. In the present embodiment, referring to FIGs. 79-82, in the present embodiment, the outer posts 211-1, 211-4 of posts 211 are the same length as measured from base wall 138, the central posts 211-2, 211-3 of posts 211 are the same length as measured from base wall 138, and the central posts 211-2, 211-3 are longer than the outer posts 211-1, 211-4. In the present embodiment, an extent of each of the central posts 211-2, 211-3 of posts 211 from base wall 138 to its respective free end tip is longer than a height of each of the stir bars 132, 135 (see FIGs. 81, 83 and 84).

[0249] As identified in FIGs. 79, 80, and 82, a respective transverse opening of the plurality of transverse openings 208 is present between any two adjacent posts of the plurality of spaced posts 211 to facilitate fluid communication between the first region 204 and the second region 206. Referring to FIG. 82, for example, in the present embodiment the transverse opening 208-1 is located between interior perimetrical wall 150 and post 211-1; transverse opening 208-2 is located between post 211-1 and post 211-2; transverse opening 208-3 is located between post 211-2 and post 211-3; transverse opening 208-4 is located between post 211-3 and post 211-4; and transverse opening 208-5 is located between post 211-4 and interior perimetrical wall 150.

[0250] As depicted in FIG. 85, rotational area 160-2 of stir bar 132 is located in its entirety in first region 204. Likewise, rotational area 165-2 of stir bar 135 is located in its entirety in second region 206. Thus, in contrast to the non-separated embodiment depicted in FIGs. 77-78, body 200 having separation wall 202 separates the first rotational area 160-2 of stir bar 132 from the second rotational area 165-2 of the stir bar 135. The separation wall 202 prevents first rotational area 160-2 of stir bar 132 from overlapping, i.e., intersecting, the second rotational area 165-2 of stir bar 135. In turn, the plurality of paddles 132-1, 132-2, 132-3, 132-4 of stir bar 132 are prevented from being in-mesh with the plurality of paddles 135-1, 135-2, 135-3, 135-4 of stir bar 135. As such, in the embodiment of FIGs. 79-85, the respective rotational direction of each of stir bar 132 and stir bar 135 may be in opposite rotational directions, may be in the same rotational direction, or may periodically change between the same rotational direction and opposite rotational directions.

[0251] In general, a fluid (not shown) is loaded through a fill hole 122-1 in body 122 (see FIGs. 72 and 86-88) into a sealed region, i.e., a fluid reservoir 136, between body 122 and diaphragm 130. Back pressure in fluid reservoir 136 is set and then maintained by inserting, e.g., pressing, fill plug 128 into fill hole 122-1 to prevent air from leaking into fluid reservoir 136 or fluid from leaking out of fluid reservoir 136. Referring again to FIGs. 1-5, end cap 126 is then placed onto an end of the body 122/lid 124 combination, opposite to ejection chip 118. Stir bar 132 resides in the sealed fluid reservoir 136 between body 122 and diaphragm 130 that contains the fluid. An internal fluid flow may be generated within fluid reservoir 136 by rotating stir bar 132 so as to provide fluid mixing and redistribution of particulate in the fluid within the sealed region of fluid reservoir 136.

[0252] Referring to FIGs. 72 and 86-89, body 122 of housing 112 has a base wall 138 and an exterior perimeter wall 140 contiguous with base wall 138. Exterior perimeter wall 140 is oriented to extend from base wall 138 in a direction that is substantially orthogonal to base wall 138. Referring again to FIGs. 1-5, lid 124 is configured to engage exterior perimeter wall 140. Thus, exterior perimeter wall 140 is interposed between base wall 138 and lid 124, with lid 124 being attached to the open free end of exterior perimeter wall 140 by weld, adhesive, or other fastening mechanism, such as a snap fit or threaded union. Attachment of lid 124 to body 122 occurs after installation of diaphragm 130 (see FIG. 72) and stir bar 132 (see FIG. 86) in body 122.

[0253] Referring to FIGs. 72 and 86-89, exterior perimeter wall 140 of body 122 includes an exterior wall 140-1, which is a contiguous portion of exterior perimeter wall 140. As best shown in FIG. 86, exterior wall 140-1 has a chip mounting surface 140-2 that defines a plane 142 (see also FIG. 72), and has a fluid opening 140-3 adjacent to chip mounting surface 140-2 that passes through the thickness of exterior wall 140-1. Ejection chip 118 is mounted, e.g., by an adhesive, to chip mounting surface 140-2 and is in fluid communication with fluid opening 140-3 (see FIG. 86) of exterior wall 140-1. Thus, the planar extent of ejection chip 118 is oriented along plane 142, with the plurality of ejection nozzles 120 oriented such that the fluid ejection direction 120-1 is substantially orthogonal to plane 142. Base wall 138 is oriented along a plane 146 (see FIGs. 72 and 86) that is substantially orthogonal to plane 142 of exterior wall 140-1.

[0254] Referring to FIGs. 86-89, body 122 of housing 112 also includes a chamber 148 located within a boundary defined by exterior perimeter wall 140. Chamber 148 forms a portion of fluid reservoir 136, and is configured to define an interior space, and in particular, includes base wall 138 and has an interior perimetrical wall 150 configured to have rounded corners, so as to promote fluid flow in chamber 148. Stir bar 132 is moveable laterally and longitudinally along base wall 138 within the confining limits defined by interior perimetrical wall 150 of fluid reservoir 136.

[0255] Interior perimetrical wall 150 of chamber 148 has an extent bounded by a proximal end 150-1 and a distal end 150-2. Proximal end 150-1 is contiguous with, and may form a transition radius with, base wall 138. Such an edge radius may help in mixing effectiveness by reducing the number of sharp corners. Distal end 150-2 is configured to define a perimetrical end surface 150-3 at an open end 148-2 of chamber 148. Perimetrical end surface 150-3 may include a plurality of perimetrical ribs, or undulations, to provide an effective sealing surface for engagement with diaphragm 130 (see FIG. 72). The extent of interior perimetrical wall 150 of chamber 148 is substantially orthogonal to base wall 138, and is substantially parallel to the corresponding extent of exterior perimeter wall 140 (see FIG. 86).

[0256] As best shown in FIG. 87, chamber 148 has an inlet fluid port 152 and an outlet fluid port 154, each of which is formed in a portion of interior perimetrical wall 150. The terms "inlet" and "outlet" are terms of convenience that are used in distinguishing between the multiple ports of the present embodiment, and are correlated with a particular rotational direction of stir bar 132. However, it is to be understood that it is the rotational direction of stir bar 132 that dictates whether a particular port functions as an inlet port or an outlet port, and it is within the scope of this invention to reverse the rotational direction of stir bar 132, and thus reverse the roles of the respective ports within chamber 148.

[0257] Inlet fluid port 152 is separated a distance from outlet fluid port 154 along a portion of interior perimetrical wall 150. As best shown in FIG. 89, body 122 of housing 112 includes a fluid channel 156 interposed between the portion of interior perimetrical wall 150 of chamber 148 and exterior wall 140-1 of exterior perimeter wall 140 that carries ejection chip 118.

[0258] Fluid channel 156 is configured to minimize particulate settling in a region of ejection chip 118. Fluid channel 156 is sized, e.g., using empirical data, to provide a desired flow rate while also maintaining an acceptable fluid velocity for fluid mixing through fluid channel 156. In the present embodiment, fluid channel 156 is configured as a U-shaped elongated passage. Fluid channel 156 dimensions, e.g., height and width, and shape are selected to provide a desired combination of fluid flow and fluid velocity for facilitating intra-channel stirring. Fluid channel 156 is configured to connect inlet fluid port 152 of chamber 148 in fluid communication with outlet fluid port 154 of chamber 148, and also connects fluid opening 140-3 (see FIG. 86) of exterior wall 140-1 of exterior perimeter wall 140 in fluid communication with both inlet fluid port 152 and outlet fluid port 154 (see FIG. 87) of chamber 148.

[0259] Referring again to FIGs. 1, 72, and 86, diaphragm 130 is positioned between lid 124 and perimetrical end surface 150-3 of interior perimetrical wall 150 of chamber 148. The attachment of lid 124 to body 122 compresses a perimeter of diaphragm 130 thereby creating a continuous seal between diaphragm 130 and body 122. More particularly, diaphragm 130 is configured for sealing engagement with perimetrical end surface 150-3 of interior perimetrical wall 150 of chamber 148 in forming fluid reservoir 136. Thus, in combination, chamber 148 and diaphragm 130 cooperate to define fluid reservoir 136 having a variable volume.

[0260] Referring particularly to FIGs. 1 and 72, an exterior surface of diaphragm 130 is vented to the atmosphere through a vent hole 124-1 located in lid 124 so that a controlled negative pressure can be maintained in fluid reservoir 136. Diaphragm 130 is made of rubber, and includes a dome portion 130-1 configured to progressively collapse toward base wall 138 as fluid is depleted from microfluidic dispensing device 110, so as to maintain a desired negative pressure in chamber 148, and thus changing the effective volume of the variable volume of fluid reservoir 136, also referred to herein as a bulk region.

[0261] Referring to FIGs. 72 and 86-89, stir bar 132 moveably resides in, and is confined within, the variable volume of fluid reservoir 136 and chamber 148, and is located within a boundary defined by the interior perimetrical wall 150 of chamber 148. In the present embodiment, stir bar 132 has a rotational axis 160 and a plurality of paddles 132-1, 132-2, 132-3, 132-4 that radially extend away from the rotational axis 160. Stir bar 132 has a magnet 162 (see FIG. 88), e.g., a permanent magnet, configured for interaction with an external magnetic field generator 164 (see FIG. 1) to drive stir bar 132 to rotate around the rotational axis 160. The principle of stir bar 132 operation is that as magnet 162 is aligned to a strong enough external magnetic field generated by external magnetic field generator 164, then rotating the external magnetic field generated by external magnetic field generator 164 in a controlled manner will rotate stir bar 132. The external magnetic field generated by external magnetic field generator 164 may be rotated electronically, akin to operation of a stepper motor, or may be rotated via a rotating shaft. Thus, stir bar 132 is effective to provide fluid mixing in fluid reservoir 136 by the rotation of stir bar 132 around the rotational axis 160.

[0262] Fluid mixing in the bulk region relies on a flow velocity caused by rotation of stir bar 132 to create a shear stress at the settled boundary layer of the particulate. When the shear stress is greater than the critical shear stress (empirically determined) to start particle movement, remixing occurs because the settled particles are now distributed in the moving fluid. The shear stress is dependent on both the fluid parameters such as: viscosity, particle size, and density; and mechanical design factors such as: container shape, stir bar geometry, fluid thickness between moving and stationary surfaces, and rotational speed.

[0263] A fluid flow is generated by rotating stir bar 132 in a fluid region, e.g., fluid reservoir 136, and fluid channel 156 associated with ejection chip 118, so as to ensure that mixed bulk fluid is presented to ejection chip 118 for nozzle ejection and to move fluid adjacent to ejection chip 118 to the bulk region of fluid reservoir 136 to ensure that the channel fluid flowing through fluid channel 156 mixes with the bulk fluid of fluid reservoir 136, so as to produce a more uniform mixture. Although this flow is primarily distribution in nature, some mixing will occur if the flow velocity is sufficient to create a shear stress above the critical value.

[0264] Stir bar 132 primarily causes rotation flow of the fluid about a central region associated with the rotational axis 160 of stir bar 132, with some axial flow with a central return path as in a partial toroidal flow pattern. Advantageously, in the present embodiment, the rotational axis 160 of stir bar 132 is moveable within the confinement range defined by fluid reservoir 136.

[0265] Referring to FIGs. 86-89, each paddle of the plurality of paddles 132-1, 132-2, 132-3, 132-4 of stir bar 132 has a respective free end tip 132-5. Referring to FIGs. 87-89, so as to reduce rotational drag, each paddle may include upper and lower symmetrical pairs of chamfered surfaces, forming leading beveled surfaces 132-6 and trailing beveled surfaces 132-7 relative to a rotational direction 160-1 of stir bar 132. It is also contemplated that each of the plurality of paddles 132-1, 132-2, 132-3, 132-4 of stir bar 132 may have a pill or cylindrical shape. In the present embodiment, stir bar 132 has two pairs of diametrically opposed paddles, wherein a first paddle of the diametrically opposed paddles has a first free end tip 132-5 and a second paddle of the diametrically opposed paddles has a second free end tip 132-5.

[0266] In the present embodiment, the four paddles forming the two pairs of diametrically opposed paddles are equally spaced at 90 degree increments around the rotational axis 160. However, the actual number of paddles of stir bar 132 may be two or more, and preferably three or four, but more preferably four, with each adjacent pair of paddles having the same angular spacing around the rotational axis 160. For example, a stir bar 132 configuration having three paddles may have a paddle spacing of 120 degrees, having four paddles may have a paddle spacing of 90 degrees, etc.

[0267] Referring to FIGs. 72 and 86-89, stir bar 132 is located for movement within the variable volume of fluid reservoir 136 (see FIG. 72), and more particularly, within the boundary defined by interior perimetrical wall 150 of chamber 148 (see FIGs. 86-89).

[0268] As such, in the present embodiment, stir bar 132 is confined within fluid reservoir 136 by the confining surfaces provided by fluid reservoir 136, e.g., by chamber 148 and diaphragm 130. The extent to which stir bar 132 is movable within fluid reservoir 136 is determined by the radial tolerances provided between stir bar 132 and interior perimetrical wall 150 of chamber 148 in the radial (lateral/longitudinal) direction, and by the axial tolerances between stir bar 132 and the axial limit provided by the combination of base wall 138 of chamber 148 and diaphragm 130.

[0269] Thus, referring to FIGs. 86-89, the rotational axis 160 of stir bar 132 is free to move radially and axially, e.g., longitudinally, laterally, and/or vertically, within fluid reservoir 136 to the extent permitted by the confining surfaces, e.g., interior surfaces of chamber 148 and diaphragm 130, of fluid reservoir 136. Such confining surfaces also limit the canting of the rotational axis 160 of stir bar 132 to be within a predefined angular range, e.g., perpendicular, plus or minus 45 degrees, relative to plane 146 of base wall 138 of chamber 148 and/or to the fluid ejection direction 120-1. Stated differently, the rotational axis 160 of stir bar 132 is moveable radially and axially within fluid reservoir 136, and may be canted in an angular range of perpendicular, plus or minus 45 degrees, relative to plane 146 of base wall 138 of chamber 148 and/or to the fluid ejection direction 120-1.

[0270] In the present embodiment, referring to FIGs. 72 and 86-89, stir bar 132 is moveably confined within fluid reservoir 136, and the confining surfaces of fluid reservoir 136 maintain an orientation of stir bar 132 such that the free end tip 132-5 of a respective paddle of the plurality of paddles 132-1, 132-2, 132-3, 132-4 periodically face fluid channel 156, and in turn, intermittently face toward fluid opening 140-3 that is in fluid communication with ejection chip 118, as stir bar 132 is rotated about the rotational axis 160, and permits movement of stir bar 132 toward or away from inlet and outlet fluid ports 152, 154; fluid channel 156; fluid opening 140-3; and ejection chip 118.

[0271] In accordance with the present invention, to effect movement of the location of stir bar 132 within fluid reservoir 136, first, external magnetic field generator 164 (see FIG. 1) is energized to interact with magnet 162 (see FIG. 87), e.g., a permanent magnet, of stir bar 132. If the magnetic field generated by external magnetic field generator 164 is rotating, then stir bar 132 will tend to rotate in unison with the rotation of the magnetic field. Next, housing 112 of microfluidic dispensing device 110 is moved relative to external magnetic field generator 164, or vice versa. In other words, magnet 162 of stir bar 132 is attracted to the magnetic field generated by external magnetic field generator 164, such that the rotational axis 160 of stir bar 132 will be relocated within fluid reservoir 136 with a change of location of external magnetic field generator 164 relative to the location of housing 112 of microfluidic dispensing device 110.

[0272] It is contemplated that the movement pattern of the rotational axis 160 of stir bar 132 may be linear, e.g., longitudinal, lateral, diagonal, X-shaped, Z-shaped, etc., or may be non-linear, such as curved, circular, elliptical, a figure 8 pattern, etc.

[0273] FIGs. 90-100 depict another embodiment of the invention, which in the present example is in the form of a microfluidic dispensing device 210. Elements common to both microfluidic dispensing device 110 and microfluidic dispensing device 210 are identified using common element numbers, and for brevity, are not described again below in full detail.

[0274] Microfluidic dispensing device 210 generally includes a housing 212 and TAB circuit 114, with microfluidic dispensing device 210 configured to contain a supply of a fluid, such as a particulate carrying fluid, and with TAB circuit 114 configured to facilitate the ejection of the fluid from housing 212.

[0275] As best shown in FIGs. 90-92, housing 212 includes a body 214, a lid 216, an end cap 218, and a fill plug 220 (e.g., ball). Contained within housing 212 is a diaphragm 222, a stir bar 224, and a guide portion 226. Each of housing 212 components, stir bar 224, and guide portion 226 may be made of plastic, using a molding process. Diaphragm 222 is made of rubber, using a molding process. Also, in the present embodiment, fill plug 220 may be in the form of a stainless steel ball bearing.

[0276] Referring to FIG. 91, in general, a fluid (not shown) is loaded through a fill hole 214-1 in body 214 into a sealed region, i.e., a fluid reservoir 228, between body 214 and diaphragm 222. Back pressure in fluid reservoir 228 is set and then maintained by inserting, e.g., pressing, fill plug 220 into fill hole 214-1 to prevent air from leaking into fluid reservoir 228 or fluid from leaking out of fluid reservoir 228. End cap 218 is then placed onto an end of the body 214/lid 216 combination, opposite to ejection chip 118. Stir bar 224 resides in the sealed fluid reservoir 228 between body 214 and diaphragm 222 that contains the fluid. An internal fluid flow may be generated within fluid reservoir 228 by rotating stir bar 224 so as to provide fluid mixing and redistribution of particulate within the sealed region of fluid reservoir 228.

[0277] Referring now also to FIGs. 93 and 94, body 214 of housing 212 has a base wall 230 and an exterior perimeter wall 232 contiguous with base wall 230. Exterior perimeter wall 232 is oriented to extend from base wall 230 in a direction that is substantially orthogonal to base wall 230. Referring also to FIGs. 91 and 92, lid 216 is configured to engage exterior perimeter wall 232. Thus, exterior perimeter wall 232 is interposed between base wall 230 and lid 216, with lid 216 being attached to the open free end of exterior perimeter wall 232 by weld, adhesive, or other fastening mechanism, such as a snap fit or threaded union.

[0278] Referring to FIGs. 91-94, exterior perimeter wall 232 of body 214 includes an exterior wall 232-1, which is a contiguous portion of exterior perimeter wall 232. Exterior wall 232-1 has a chip mounting surface 232-2 and a fluid opening 232-3 adjacent to chip mounting surface 232-2 that passes through the thickness of exterior wall 232-1.

[0279] Referring to FIGs. 92-94, chip mounting surface 232-2 defines a plane 234. Ejection chip 118 is mounted, e.g., via an adhesive, to chip mounting surface 232-2 and is in fluid communication with fluid opening 232-3 of exterior wall 232-1. The planar extent of ejection chip 118 is oriented along the plane 234, with the plurality of ejection nozzles 120 (see e.g., FIG. 1) oriented such that the fluid ejection direction 120-1 is substantially orthogonal to the plane 234. Base wall 230 is oriented along a plane 236 that is substantially orthogonal to the plane 234 of exterior wall 232-1, and is substantially parallel to the fluid ejection direction 120-1 (see FIGs. 90 and 93).

[0280] As illustrated in FIGs. 91-94, body 214 of housing 212 includes a chamber 238 located within a boundary defined by exterior perimeter wall 232. Chamber 238 forms a portion of fluid reservoir 228, and is configured to define an interior space, and in particular, includes base wall 230 and has an interior perimetrical wall 240 configured to have rounded corners, so as to promote fluid flow in chamber 238. Stir bar 224 is laterally and longitudinally located by guide portion 226 within fluid reservoir 228 and within a boundary defined by interior perimetrical wall 240, wherein guide portion 226 facilitates movement of stir bar 224 in at least one direction substantially perpendicular to the rotational axis 250 of stir bar 224.

[0281] Referring to FIGs. 92-94, interior perimetrical wall 240 of chamber 238 has an extent bounded by a proximal end 240-1 and a distal end 240-2. Proximal end 240-1 is contiguous with, and preferably forms a transition radius with, base wall 230. Distal end 240-2 is configured to define a perimetrical end surface 240-3 at an open end 238-1 of chamber 238. Perimetrical end surface 240-3 may include a plurality of ribs, or undulations, to provide an effective sealing surface for engagement with diaphragm 222. The extent of interior perimetrical wall 240 of chamber 238 is substantially orthogonal to base wall 230, and is substantially parallel to the corresponding extent of exterior perimeter wall 232.

[0282] Referring to FIGs. 95 and 96, chamber 238 has an inlet fluid port 242 and an outlet fluid port 244, each of which is formed in a portion of interior perimetrical wall 240. Inlet fluid port 242 is separated a distance from outlet fluid port 244 along the portion of interior perimetrical wall 240. The terms "inlet" and "outlet" are terms of convenience that are used in distinguishing between the multiple ports of the present embodiment, and are correlated with a particular rotational direction 250-1 of stir bar 224. However, it is to be understood that it is the rotational direction of stir bar 224 that dictates whether a particular port functions as an inlet port or an outlet port, and it is within the scope of this invention to reverse the rotational direction of stir bar 224, and thus reverse the roles of the respective ports within chamber 238.

[0283] As best shown in FIG. 96, body 214 of housing 212 includes a fluid channel 246 interposed between a portion of interior perimetrical wall 240 of chamber 238 and exterior wall 232-1 of exterior perimeter wall 232 that carries ejection chip 118. Fluid channel 246 is configured to minimize particulate settling in a region of fluid opening 232-3, and in turn, ejection chip 118.

[0284] In the present embodiment, fluid channel 246 is configured as a U-shaped elongated passage having a channel inlet 246-1 and a channel outlet 246-2. Fluid channel 246 dimensions, e.g., height and width, and shape are selected to provide a desired combination of fluid flow and fluid velocity for facilitating intra-channel stirring.

[0285] Fluid channel 246 is configured to connect inlet fluid port 242 of chamber 238 in fluid communication with outlet fluid port 244 of chamber 238, and also connects fluid opening 232-3 of exterior wall 232-1 of exterior perimeter wall 232 in fluid communication with both inlet fluid port 242 and outlet fluid port 244 of chamber 238. In particular, channel inlet 246-1 of fluid channel 246 is located adjacent to inlet fluid port 242 of chamber 238 and channel outlet 246-2 of fluid channel 246 is located adjacent to outlet fluid port 244 of chamber 238. In the present embodiment, the structure of inlet fluid port 242 and outlet fluid port 244 of chamber 238 is symmetrical. Each of inlet fluid port 242 and outlet fluid port 244 of chamber 238 may have a beveled ramp structure configured such that each of inlet fluid port 242 and outlet fluid port 244 converges in a respective direction toward fluid channel 246.

[0286] Fluid channel 246 has a convexly arcuate wall 246-3 that is positioned between channel inlet 246-1 and channel outlet 246-2, with fluid channel 246 being symmetrical about a channel mid-point 248. In turn, convexly arcuate wall 246-3 of fluid channel 246 is positioned between inlet fluid port 242 and outlet fluid port 244 of chamber 238 on the opposite side of interior perimetrical wall 240 from the interior space of chamber 238, with convexly arcuate wall 246-3 positioned to face fluid opening 232-3 of exterior wall 232-1 and fluid ejection chip 118.

[0287] Convexly arcuate wall 246-3 is configured to create a fluid flow substantially parallel to ejection chip 118. In the present embodiment, a longitudinal extent of convexly arcuate wall 246-3 has a radius that faces fluid opening 232-3, is substantially parallel to ejection chip 118, and has transition radii 246-4, 246-5 located adjacent to channel inlet 246-1 and channel outlet 246-2 surfaces, respectively. The radius and radii of convexly arcuate wall 246-3 help with fluid flow efficiency. A distance between convexly arcuate wall 246-3 and fluid ejection chip 118 is narrowest at the channel mid-point 248, which coincides with a mid-point of the longitudinal extent of fluid ejection chip 118, and in turn, with at a mid-point of the longitudinal extent of fluid opening 232-3 of exterior wall 232-1.

[0288] Referring again to FIG. 91, diaphragm 222 is positioned between lid 216 and perimetrical end surface 240-3 of interior perimetrical wall 240 of chamber 238. The attachment of lid 216 to body 214 compresses a perimeter of diaphragm 222 thereby creating a continuous seal between diaphragm 222 and body 214, and more particularly, diaphragm 222 is configured for sealing engagement with perimetrical end surface 240-3 of interior perimetrical wall 240 of chamber 238 in forming fluid reservoir 228. Thus, in combination, chamber 238 and diaphragm 222 cooperate to define fluid reservoir 228 having a variable volume.

[0289] An exterior surface of diaphragm 222 is vented to the atmosphere through a vent hole 216-1 located in lid 216 so that a controlled negative pressure can be maintained in fluid reservoir 228. Diaphragm 222 is made of rubber, and includes a dome portion 222-1 configured to progressively collapse toward base wall 230 as fluid is depleted from microfluidic dispensing device 210, so as to maintain a desired negative pressure in chamber 238, and thus changing the effective volume of the variable volume of fluid reservoir 228.

[0290] Referring to FIG. 91, stir bar 224 resides, and is confined within, in the variable volume of fluid reservoir 228 and in chamber 238, and is located within a boundary defined by interior perimetrical wall 240 of chamber 238. Referring also to FIGs. 92-94 and 96-100, stir bar 224 has a rotational axis 250 and a plurality of paddles 252, 254, 256, 258 that radially extend away from the rotational axis 250. Stir bar 224 has a magnet 260 (see FIGs. 91, 96, and 100), e.g., a permanent magnet, configured for interaction with external magnetic field generator 164 (see FIG. 1) to drive stir bar 224 to rotate around the rotational axis 250. In the present embodiment, stir bar 224 has two pairs of diametrically opposed paddles that are equally spaced at 90 degree increments around rotational axis 250. However, the actual number of paddles of stir bar 224 is two or more, and preferably three or four, but more preferably four, with each adjacent pair of paddles having the same angular spacing around the rotational axis 250. For example, a stir bar 224 configuration having three paddles would have a paddle spacing of 120 degrees, having four paddles would have a paddle spacing of 90 degrees, etc.

[0291] In the present embodiment, as shown in FIGs. 91-94 and 97-100, stir bar 224 is configured in a stepped, i.e., two-tiered, cross pattern with chamfered surfaces which may provide the following desired attributes: quiet, short, low axial drag, good rotational speed transfer, and capable of starting to mix with stir bar 224 in particulate sediment. In particular, referring to FIG. 99, each of the plurality of paddles 252, 254, 256, 258 of stir bar 224 has an axial extent 262 having a first tier portion 264 and a second tier portion 266. Referring also to FIG. 98, first tier portion 264 has a first radial extent 268 terminating at a first distal end tip 270. Second tier portion 266 has a second radial extent 272 terminating in a second distal end tip 274. The first radial extent 268 is greater than the second radial extent 272, such that a first rotational velocity of first distal end tip 270 of first tier portion 264 is higher than a second rotational velocity of second distal end tip 274 of second tier portion 266, while the angular velocity of first distal end tip 270 of first tier portion 264 is the same as the angular velocity of second distal end tip 274 of second tier portion 266.

[0292] First tier portion 264 has a first tip portion 270-1 that includes first distal end tip 270. First tip portion 270-1 may be tapered in a direction from the rotational axis 250 toward first distal end tip 270. First tip portion of 270-1 of first tier portion 264 has symmetrical upper and lower surfaces, each having a beveled, i.e., chamfered, leading surface and a beveled trailing surface. The beveled leading surfaces and the beveled trailing surfaces of first tip portion 270-1 are configured to converge at first distal end tip 270.

[0293] Also, in the present embodiment, first tier portion 264 of each of the plurality of paddles 252, 254, 256, 258 collectively form a convex surface 276 (see FIGs. 91, 99 and 100). As shown in FIG. 91, convex surface 276 has a drag-reducing radius positioned to contact base wall 230 of chamber 238. The drag-reducing radius may be, for example, at least three times greater than the first radial extent 268 of first tier portion 264 of each of the plurality of paddles 252, 254, 256, 258.

[0294] Referring again to FIG. 99, second tier portion 266 has a second tip portion 274-1 that includes second distal end tip 274. Second distal end tip 274 may have a radial blunt end surface. Second tier portion 266 of each of the plurality of paddles 252, 254, 256, 258 has an upper surface having a beveled, i.e., chamfered, leading surface and a beveled trailing surface.

[0295] Referring to FIGs. 91-94, the orientation of stir bar 224 is achieved by guide portion 226, with guide portion 226 also being located within chamber 238 in the variable volume of fluid reservoir 228, and more particularly, within the boundary defined by interior perimetrical wall 240 of chamber 238. Guide portion 226 is configured to confine and position stir bar 224 for movement in a predetermined portion of the interior space of chamber 238.

[0296] Referring to FIGs. 91-94 and 96, guide portion 226 includes a confining member 279, and a plurality of mounting arms 280-1, 280-2, 280-3, 280-4 coupled to confining member 279. Confining member 279 has a guide opening 279-1, which in the present embodiment is in the form of an elongated opening 279-1, that defines an interior radial confining surface 279-2 that limits, yet facilitates, radial movement of stir bar 224 in a direction substantially perpendicular to rotational axis 250. While in the present embodiment the longitudinal extent of elongated opening 279-1 is linear, those skilled in the art will recognize that the longitudinal extent of elongated opening 279-1 may have other non-linear shapes, such as S-shaped or C-shaped.

[0297] Referring particularly to FIGs. 92 and 94, elongated opening 279-1 has a longitudinal extent 283-1 and a lateral extent 283-2 perpendicular to longitudinal extent 283-1. Longitudinal extent 283-1 is greater, i.e., longer, than lateral extent 283-2. In the present embodiment, longitudinal extent 283-1 is in a direction toward inlet and outlet fluid ports 242, 244; fluid channel 246; and fluid opening 232-3 of exterior wall 232-1 of body 214 of housing 212, so as to facilitate movement of stir bar 224 toward or away from inlet and outlet fluid ports 242, 244; fluid channel 246; fluid opening 232-3; and ejection chip 118.

[0298] In particular, second tier portion 266 of stir bar 224 is received in elongated opening 279-1 of confining member 279. Interior radial confining surface 279-2 of elongated opening 279-1 is configured to contact the radial extent of second tier portion 266 of the plurality of paddles 252, 254, 256, 258 of stir bar 224 to limit, yet facilitate, radial (e.g., lateral and/or longitudinal) movement of stir bar 224 relative to rotational axis 250 of stir bar 224. A maximum distance 283-3 between stir bar 224 and interior radial confining surface 279-2 along the longitudinal extent 283-1 of elongated opening 279-1 defines the longitudinal limit of motion of stir bar 224 within chamber 238.

[0299] In the present example, the lateral extent 283-2 of interior radial confining surface 279-2 of elongated opening 279-1 is only slightly larger (e.g., 0.5 to 5 percent) than the diameter across the radial extent of second tier portion 266 of stir bar 224, whereas the longitudinal extent 283-1 of interior radial confining surface 279-2 of elongated opening 279-1 is substantially larger (e.g., greater than 10 percent) than the diameter across the radial extent of second tier portion 266 of stir bar 224, so as to facilitate radial movement of stir bar 224 in a direction substantially perpendicular to rotational axis 250 of stir bar 224 along the longitudinal extent 283-1 of interior radial confining surface 279-2 of elongated opening 279-1. In other words, in the present example, stir bar 224 is permitted to slide back and forth along the longitudinal extent 283-1 of interior radial confining surface 279-2 of elongated opening 279-1.

[0300] Referring to FIGs. 91 and 96, confining member 279 has an axial confining surface 279-3 positioned to be axially offset from base wall 230 of chamber 238, for axial engagement with first tier portion 264 of stir bar 224.

[0301] Referring to FIGs. 93-96, the plurality of mounting arms 280-1, 280-2, 280-3, 280-4 are configured to engage body 214 of housing 212 to position, e.g., suspend, confining member 279 in the interior space of chamber 238, separated from base wall 230 of chamber 238, with axial confining surface 279-3 positioned to face, and to be axially offset from, base wall 230 of chamber 238. A distal end of each of mounting arms 280-1, 280-2, 280-3, 280-4 includes respective locating features 280-5, 280-6, 280-7, 280-8 that have free ends to engage a perimetrical portion of diaphragm 222 (see also FIG. 91).

[0302] In the present embodiment, referring to FIGs. 91 and 96, base wall 230 limits axial movement of stir bar 224 relative to the rotational axis 250 in a first axial direction and axial confining surface 279-3 of confining member 279 is located to axially engage at least a portion of first tier portion 264 of the plurality of paddles 252, 254, 256, 258 to limit axial movement of stir bar 224 relative to the rotational axis 250 in a second axial direction opposite to the first axial direction.

[0303] As such, in the present embodiment, stir bar 224 is radially confined within the region defined by interior radial confining surface 279-2 of elongated opening 279-1 of confining member 279, and is axially confined between axial confining surface 279-3 of confining member 279 and base wall 230 of chamber 238. The portion of chamber 238 and fluid reservoir 228 in which stir bar 224 is moveable is determined by the location of elongated opening 279-1 of guide portion 226 in chamber 238. The extent to which stir bar 224 is moveable within chamber 238 and fluid reservoir 228 is determined by the radial tolerances provided between interior radial confining surface 279-2 of elongated opening 279-1 of guide portion 226 and stir bar 224 in a radial direction perpendicular to rotational axis 250, and by the axial tolerances between stir bar 224 and the axial limit provided by the combination of base wall 230 and axial confining surface 279-3 of confining member 279. For example, the tighter the radial and axial tolerances provided by guide portion 226, the less variation of the rotational axis 250 of stir bar 224 from perpendicular relative to base wall 230, and the less side-to-side motion of stir bar 224 within fluid reservoir 228.

[0304] Notwithstanding, the longitudinal extent 283-1 of elongated opening 279-1 of confining member 279 facilitates radial movement of stir bar 224 in a direction substantially perpendicular to rotational axis 250 of stir bar 224 in at least one direction, e.g., in at least a longitudinal direction corresponding to the longitudinal extent 283-1 of elongated opening 279-1. Referring to FIGs. 92 and 94, a maximum distance 283-3 between stir bar 224 and interior radial confining surface 279-2 along the longitudinal extent 283-1 of elongated opening 279-1 defines the longitudinal limit of motion of stir bar 224 within chamber 238.

[0305] In view of the above, those skilled in the art will recognize that lateral motion of stir bar 224 may be facilitated by increasing lateral extent 283-2 of elongated opening 279-1 of guide portion 226, such that a gap is present between stir bar 224 and interior radial confining surface 279-2 along the lateral extent 283-2 of elongated opening 279-1 of confining member 279 of guide portion 226. As such, in addition to linear movement of rotational axis 250 of stir bar 224 being facilitated, other movement patterns, such as other linear patterns, e.g., diagonal, X-shaped, Z-shaped, etc., or non-linear, such as curved, circular, elliptical, a figure 8 pattern, etc., may be realized.

[0306] In accordance with the present invention, to effect movement of the location of stir bar 224 within fluid reservoir 228, first, external magnetic field generator 164 (see FIG. 1) is energized to interact with magnet 260 (see FIGs. 91 and 96), e.g., a permanent magnet, of stir bar 224. If the magnetic field generated by external magnetic field generator 164 is rotating, then stir bar 224 will tend to rotate in unison with the rotation of the magnetic field. Next, housing 212 of microfluidic dispensing device 210 is moved relative to external magnetic field generator 164, or vice versa. In other words, magnet 260 of stir bar 224 is attracted to the magnetic field generated by external magnetic field generator 164, such that the rotational axis 250 of stir bar 224 will be relocated within fluid reservoir 228 with a change of location of external magnetic field generator 164 relative to the location of housing 212 of microfluidic dispensing device 210.

[0307] In the present embodiment, guide portion 226 is configured as a unitary insert member that is removably received in housing 212. Referring to FIG. 96, guide portion 226 includes a first retention feature 284 and body 214 of housing 212 includes a second retention feature 214-2. First retention feature 284 is engaged with second retention feature 214-2 to attach guide portion 226 to body 214 of housing 212 in a fixed relationship with housing 212. First retention feature 284/second retention feature 214-2 combination may be, for example, in the form of a tab/slot arrangement, or alternatively, a slot/tab arrangement, respectively.

[0308] Referring to FIG. 96, guide portion 226 may further include a flow control portion 286 having a flow separator feature 286-1, a flow rejoining feature 286-2, and a concavely arcuate surface 286-3. Flow control portion 286 provides an axial spacing between axial confining surface 279-3 and base wall 230 in the region of inlet fluid port 242 and outlet fluid port 244. Concavely arcuate surface 286-3 is coextensive with, and extends between, each of flow separator feature 286-1 and flow rejoining feature 286-2. Flow separator feature 286-1 is positioned adjacent inlet fluid port 242 and flow rejoining feature 286-2 is positioned adjacent outlet fluid port 244. Flow separator feature 286-1 has a beveled wall that cooperates with inlet fluid port 242 of chamber 238 to guide fluid toward channel inlet 246-1 of fluid channel 246. Likewise, flow rejoining feature 286-2 has a beveled wall that cooperates with outlet fluid port 244 to guide fluid away from channel outlet 246-2 of fluid channel 246.

[0309] It is contemplated that all, or a portion, of flow control portion 286 may be incorporated into interior perimetrical wall 240 of chamber 238 of body 214 of housing 212.

[0310] In the present embodiment, as is best shown in FIG. 96, stir bar 224 is oriented such that the free ends of the plurality of paddles 252, 254, 256, 258 periodically face concavely arcuate surface 286-3 of flow control portion 286 as stir bar 224 is rotated about the rotational axis 250. More particularly, guide portion 226 is configured to confine stir bar 224 in a predetermined portion of the interior space of chamber 238. In the present example, elongated opening 279-1 of confining member 279 of guide portion 226 facilitates radial movement of stir bar 224 in a direction toward, or away from, concavely arcuate surface 286-3 of flow control portion 286 and toward, or away from, inlet and outlet fluid ports 242, 244; fluid channel 246; and fluid opening 232-3 in at least a longitudinal direction corresponding to the longitudinal extent 283-1 of elongated opening 279-1 (see FIGs. 92 and 94).

[0311] More particularly, in the present embodiment wherein stir bar 224 has four paddles, guide portion 226 is configured to position the rotational axis 250 of stir bar 224 in a portion of the interior space of chamber 238 such that first distal end tip 270 of each the two pairs of diametrically opposed paddles alternatingly and intermittently are positioned to face in a direction toward inlet and outlet fluid ports 242, 244; fluid channel 246; and fluid opening 232-3, as stir bar 224 is rotated.

[0312] Those skilled in the art will recognize that the actual configuration of stir bar 224 may be modified in various ways, without departing from the scope of the present invention. For example, it is contemplated that shape and/or size of the plurality of paddles of stir bar

224 may be varied from the express example set forth herein. Also, it is contemplated that second tier portion 266 of stir bar 224 (see FIG. 99) may be formed as a continuous circular hub.

[0313] While this invention has been described with respect to at least one embodiment, the present invention can be further modified within the spirit and scope of this disclosure. This application is therefore intended to cover any variations, uses, or adaptations of the invention using its general principles. Further, this application is intended to cover such departures from the present disclosure as come within known or customary practice in the art to which this invention pertains and which fall within the limits of the appended claims.

Claims

1. A fluidic dispensing device (110), **characterized in that** the fluidic dispensing device (110) comprises:

   a housing (112), configured to have an exterior wall (140-1) and a fluid reservoir (136), the exterior wall (140-1) being configured to have a first opening (140-3) in fluid communication with the fluid reservoir (136); and
   a stir bar (132), configured to be moveably confined within the fluid reservoir (136), the stir bar (132) being configured to have a plurality of paddles (132-1~132-4) and a rotational axis (165), with each of the plurality of paddles (132-1~132-4) that intermittently faces toward the first opening (140-3).

2. The fluidic dispensing device (110) of claim 1, **characterized in that** the rotational axis (165) is configured to have an orientation that is substantially perpendicular to a fluid ejection direction (120-1).

3. The fluidic dispensing device (110) of claim 1 or 2, **characterized in that** the fluid reservoir (136) is configured to have a chamber (148) having an interior perimetrical wall (150) having at least one port in fluid communication with the first opening (140-3), the stir bar (132) is configured to be laterally and longitudinally located within the fluid reservoir (136) within a boundary defined by the interior perimetrical wall (150).

4. The fluidic dispensing device (110) of claim 1 or 2, **characterized in that** the fluid reservoir (136) is configured to have a chamber (148) having an interior perimetrical wall (150) and a base wall (138), the interior perimetrical wall (150) of the chamber (148) is configured to have an extent bounded by a proximal end (150-1) and a distal end (150-2), the proximal end (150-1) is configured to be contiguous with the base wall (138) and the distal end (150-2) is configured to define a perimetrical end surface (150-3) at a lateral opening of the chamber (148).

5. The fluidic dispensing device (110) of claim 4, **characterized in that** the fluid reservoir (136) further includes a diaphragm (130) configured to be engaged in sealing engagement with the perimetrical end surface (150-3),
   the chamber (148) and the diaphragm (130) is configured to cooperate to define a fluid reservoir (136) having a variable volume, and
   the chamber (146) and the diaphragm (130) is configured to define confining surfaces (166-4) of the fluid reservoir (136), the stir bar (132) is configured to be confined for movement within the variable volume confined by the chamber (146) and the diaphragm (130).

6. The fluidic dispensing device (110) any one of claims 1 to 5, **characterized in that** the fluidic dispensing device (110) comprises a guide portion (134) located in the fluid reservoir (136), the guide portion (134) is configured to have a confining member (279) having a guide opening (279-1) that facilitates radial movement of the stir bar (132) in a direction substantially perpendicular to the rotational axis (165).

7. The microfluidic dispensing device (110) of claim 5, **characterized in that** the guide opening (279-1) is an elongated opening that has a longitudinal extent and a lateral extent perpendicular to the longitudinal extent, the longitudinal extent is configured to be greater than the lateral extent.

8. The microfluidic dispensing device (110) of claim 5, **characterized in that** the guide opening (279-1) is an elongated opening that has a longitudinal extent in a direction toward the first opening (140-3) of the exterior wall (140-1).

9. The fluidic dispensing device (110) of claim 5, **characterized in that** the guide opening (279-1) is an elongated opening that has a longitudinal extent in a direction toward the first opening (140-3) of the exterior wall (140-1) to facilitate movement of the stir bar (132).

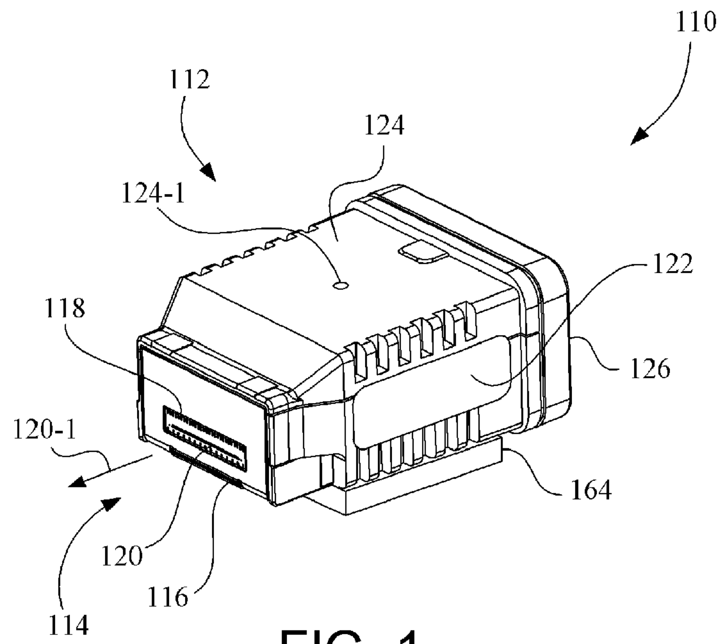
10. The fluidic dispensing device (110) of any one of claims 1 to 5, **characterized in that** the housing (112) is configured to have a base wall (132), and further comprises a guide portion (134) located in the fluid reservoir (136), the guide portion (134) is configured to includes a confining member (279) having a guide opening (279-1) and an axial confining surface (279-3), the guide opening (279-1) is configured to define an interior radial confining surface (279-2) that engages the stir bar (132), the guide opening (279-1) is configured to facilitate radial

movement of the stir bar (132) in a direction substantially perpendicular to the rotational axis (165), the axial confining surface (279-3) is configured to be axially displaced from the base wall (138) along the rotational axis (165), at least a portion of the stir bar (132) is configured to be positioned between the axial confining surface (279-3) and the base wall (138).

11. The fluidic dispensing device (110) of any one of claims 6-10, **characterized in that** the guide portion (134) further includes a plurality of mounting arms (280-1~280-4) that are configured to engage the housing (112) to position the confining member (279).

12. The fluidic dispensing device (110) of claim 1 or 2, **characterized in that** the fluid reservoir (136) is configured to be defined by a chamber (146) and a diaphragm (130), the diaphragm (130) is configured to be in sealing engagement with the chamber (146) to define a variable volume of the fluid reservoir (136), the stir bar (132) is configured to be located in the variable volume, and
the fluid reservoir (136) comprises a guide portion (134) configured to be located within the variable volume to confine the stir bar (132) for movement within a predefined portion of the variable volume, wherein the guide portion (134) is configured to facilitate movement of the stir bar (132) in at least one direction substantially perpendicular to the rotational axis (165) of the stir bar (132).

13. The fluidic dispensing device (110) of any of claims 1-12, **characterized in that** the fluidic dispensing device (110) comprises an ejection chip (118) configured to be mounted to a chip mounting surface (140-2) of the housing (112), the ejection chip (118) is configured to be in fluid communication with the first opening (140-3), the ejection chip (118) is configured to have a plurality of ejection nozzles (120) oriented such that a fluid ejection direction is substantially orthogonal to the chip mounting surface (140-2).


110
112
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124-1
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120-1
164
120
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114

FIG. 1

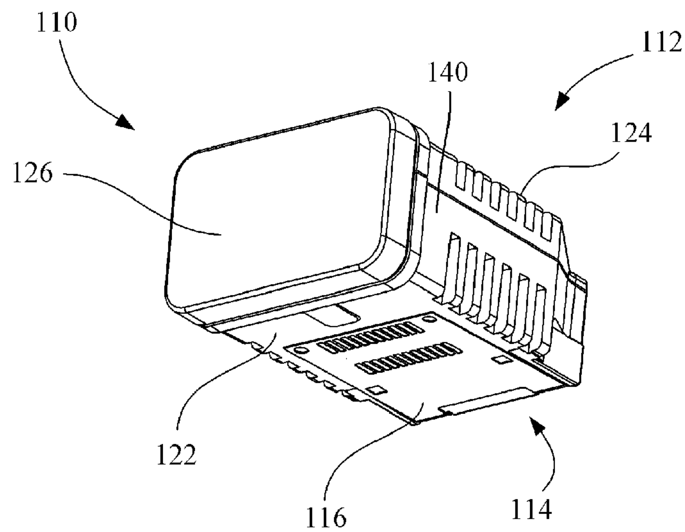
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FIG. 2

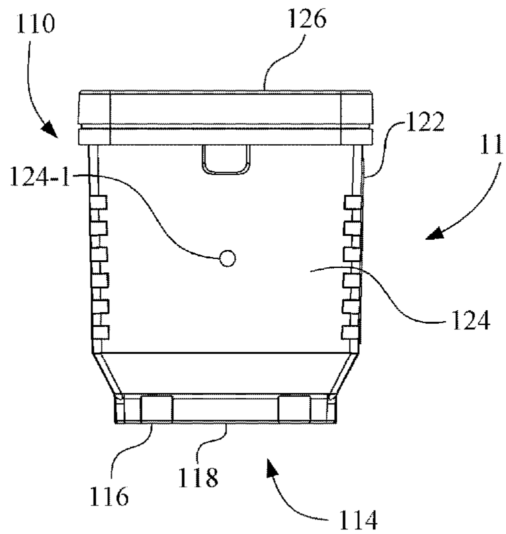


FIG. 3

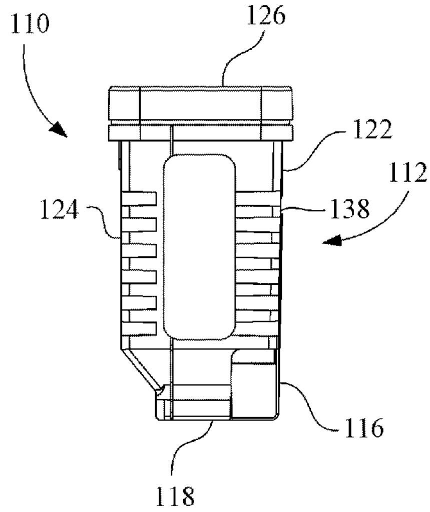


FIG. 4

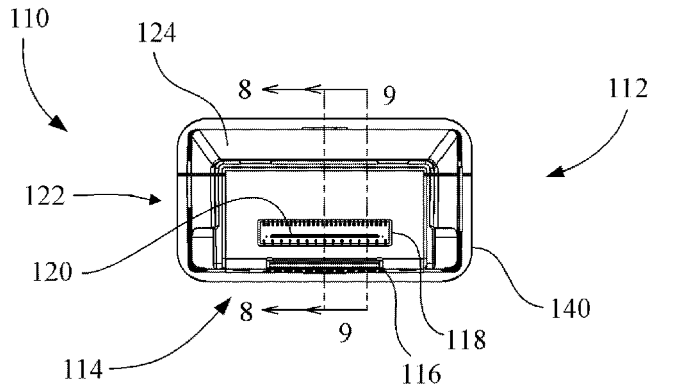
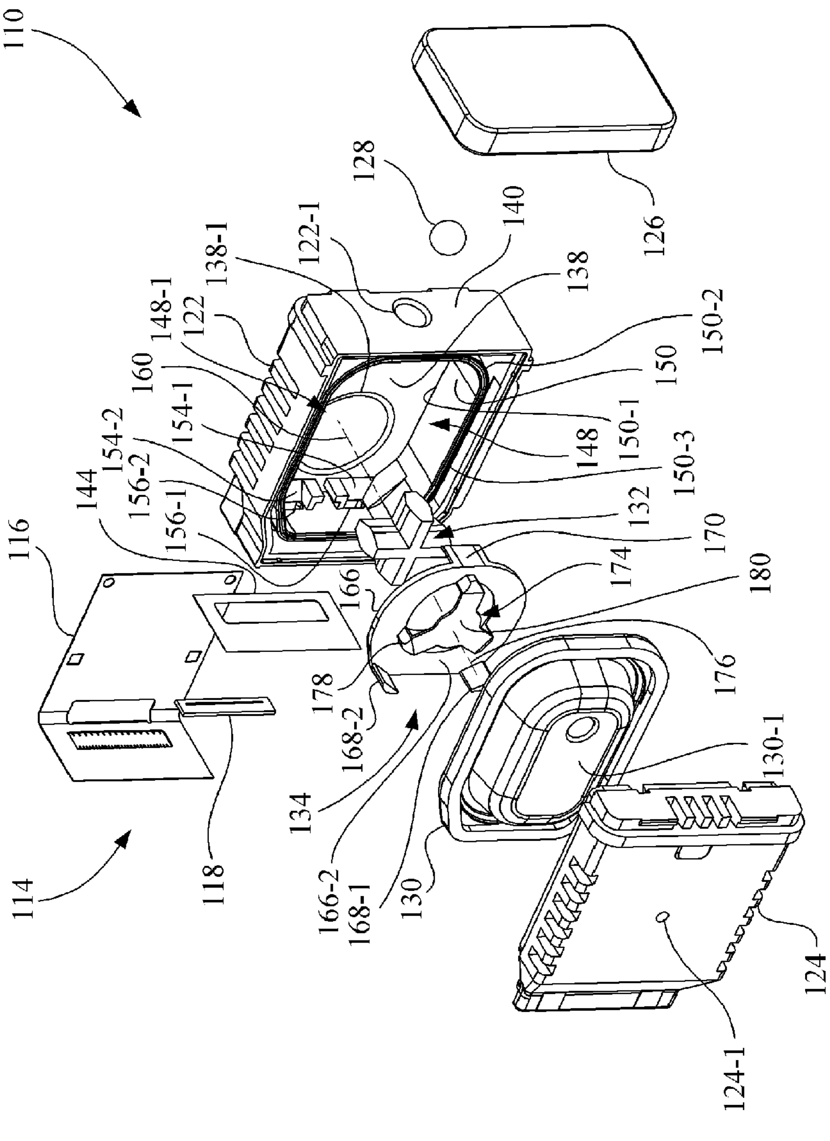


FIG. 5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122-1
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138
148-1
122
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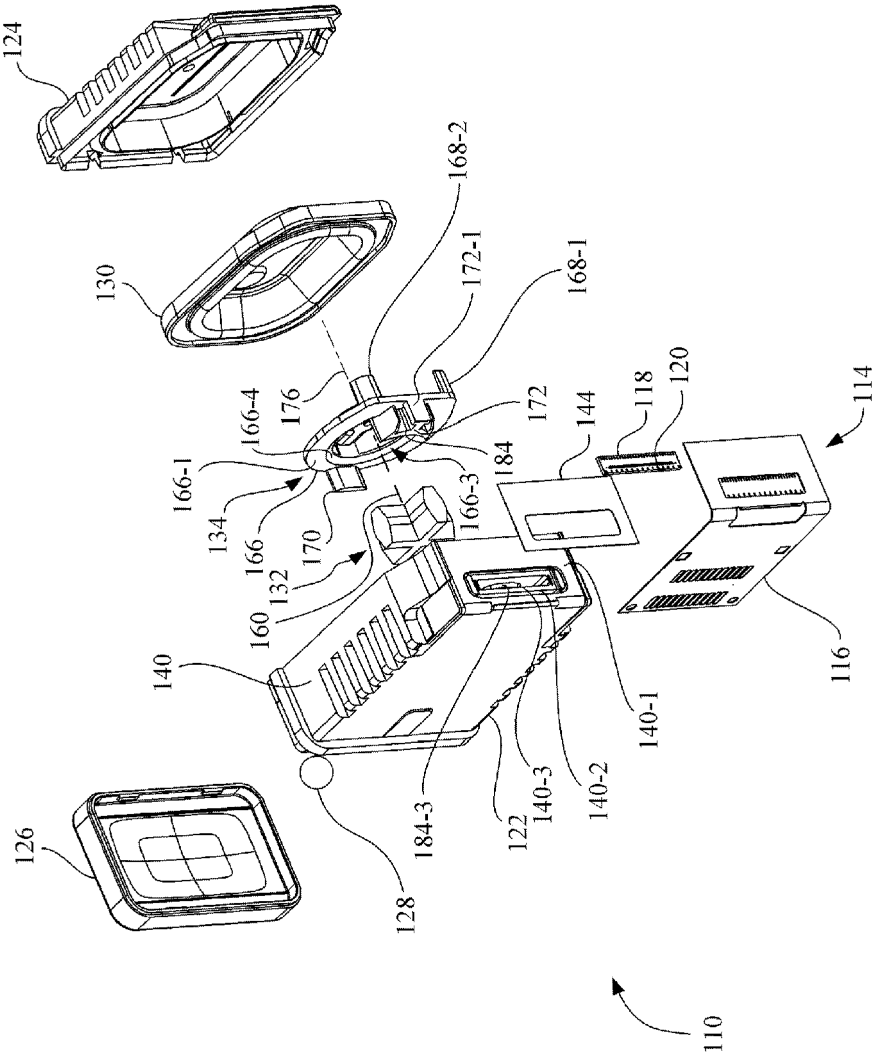
150
154-2
154-1
148
150-1
150-3
144
156-2
156-1
132
170
116
166
174
180
178
176
168-2
134
130-1
114
118
166-2
168-1
130
124
124-1

FIG. 6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166-4
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120
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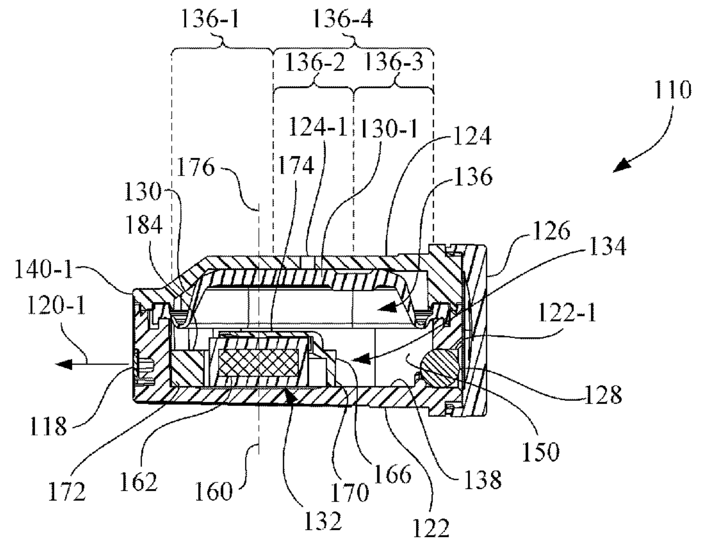
122
184-3
126
128
110

FIG. 7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132
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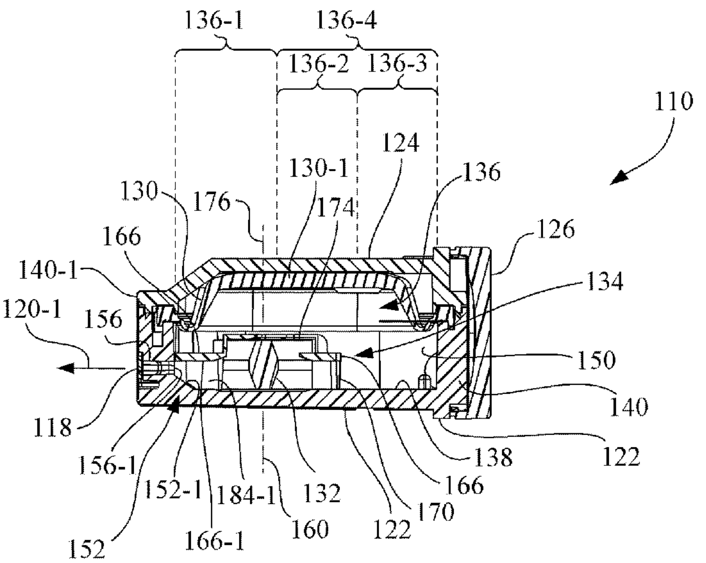
166
138
122

FIG. 8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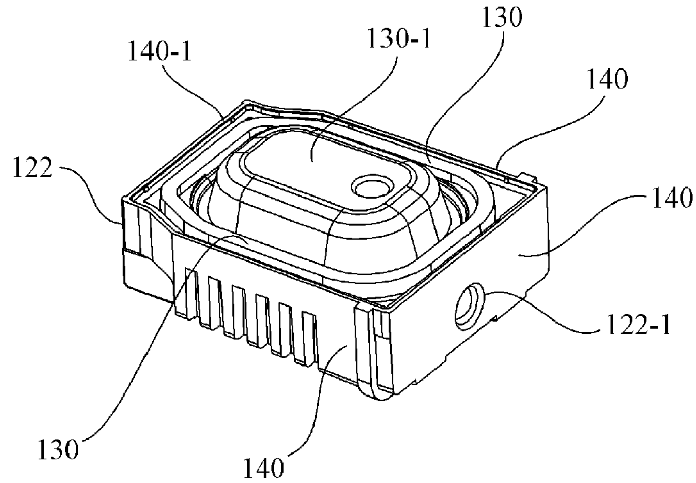
152
166-1
160
122
170

FIG. 9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140
122
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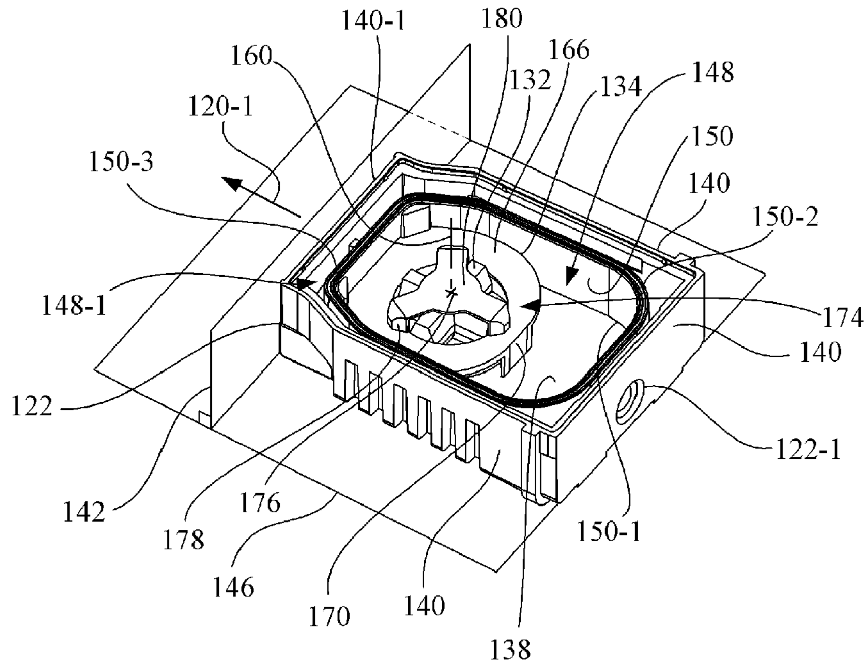
122-1
130
140

FIG. 10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146
170
140
138

FIG. 11

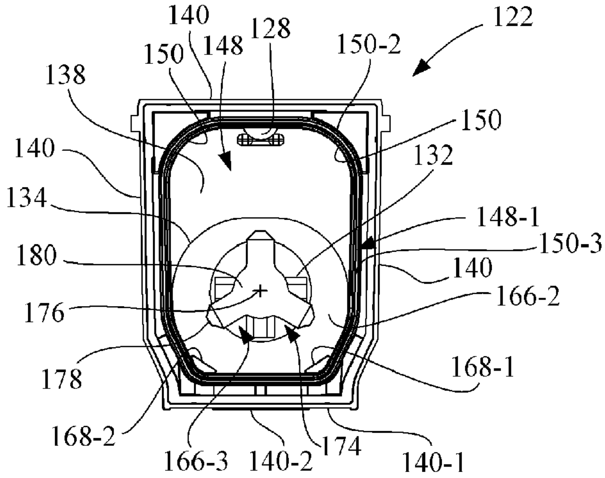


FIG. 12

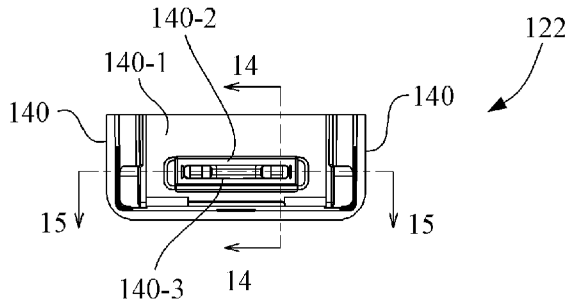


FIG. 13

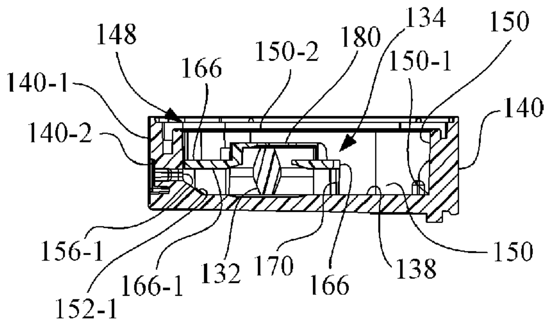
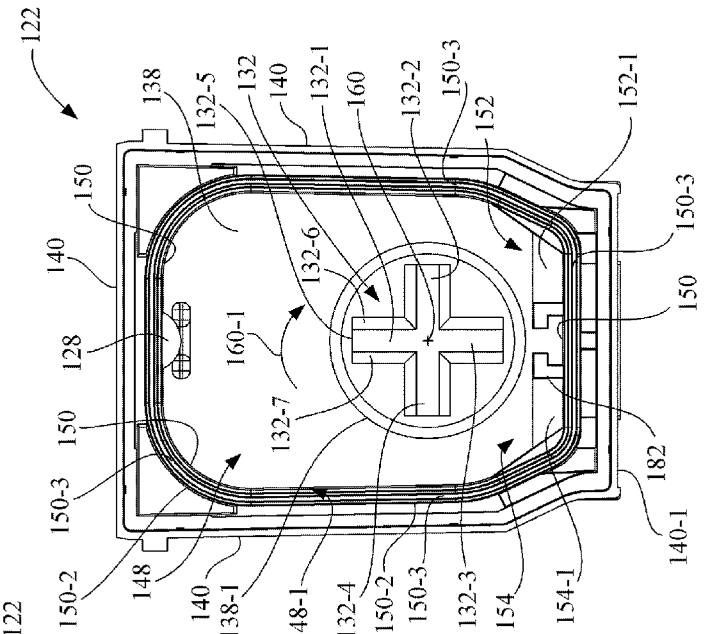


FIG. 14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140
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150-3
150
150-3
150
182
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140
138-1
148-1
132-4
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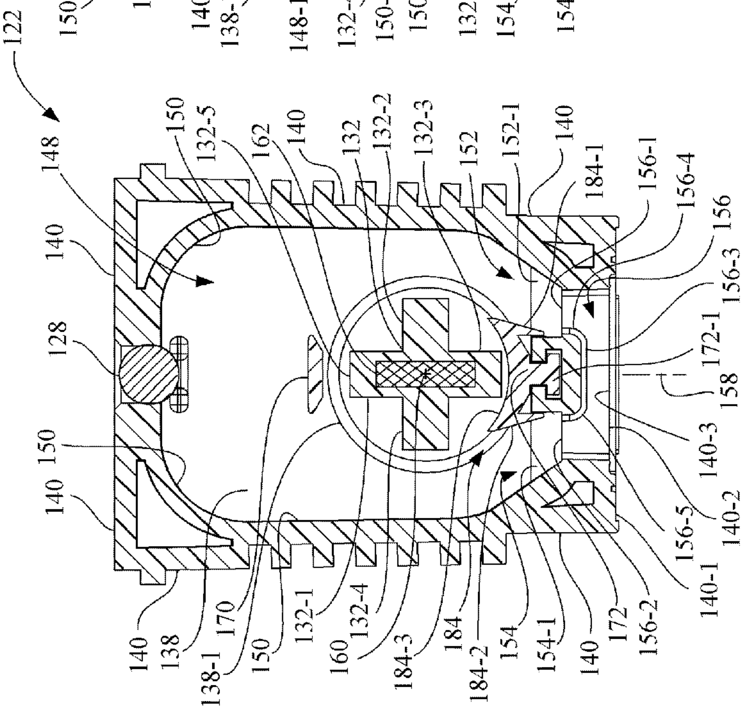
150-3
132-3
154
154-1

FIG. 16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140
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156-5
140-1
138
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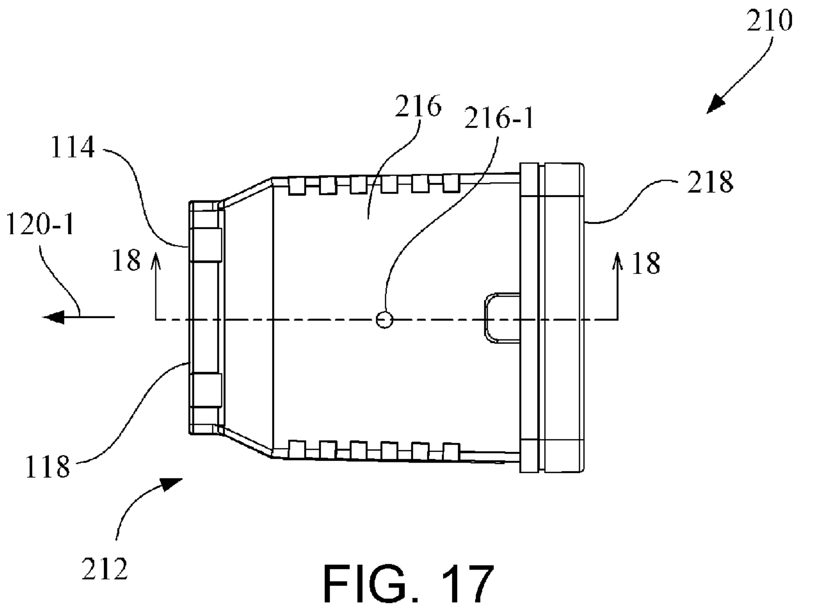
156-2

FIG. 15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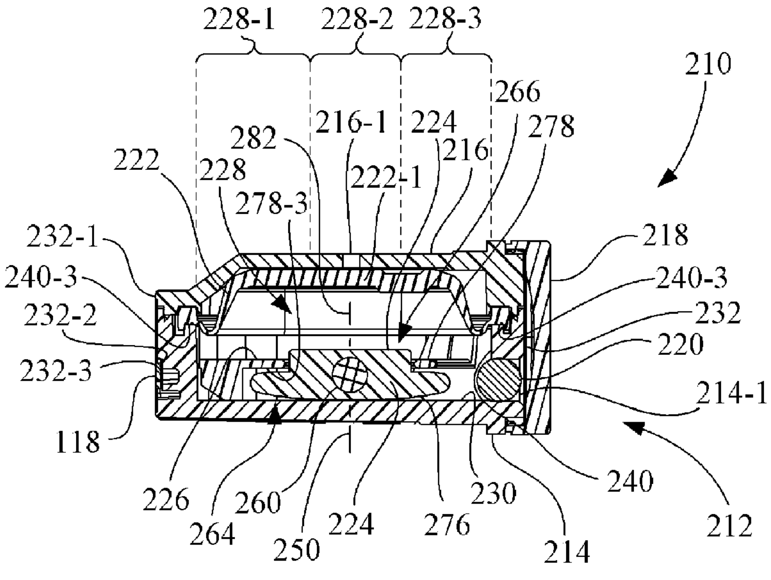
118
212

FIG. 17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240-3
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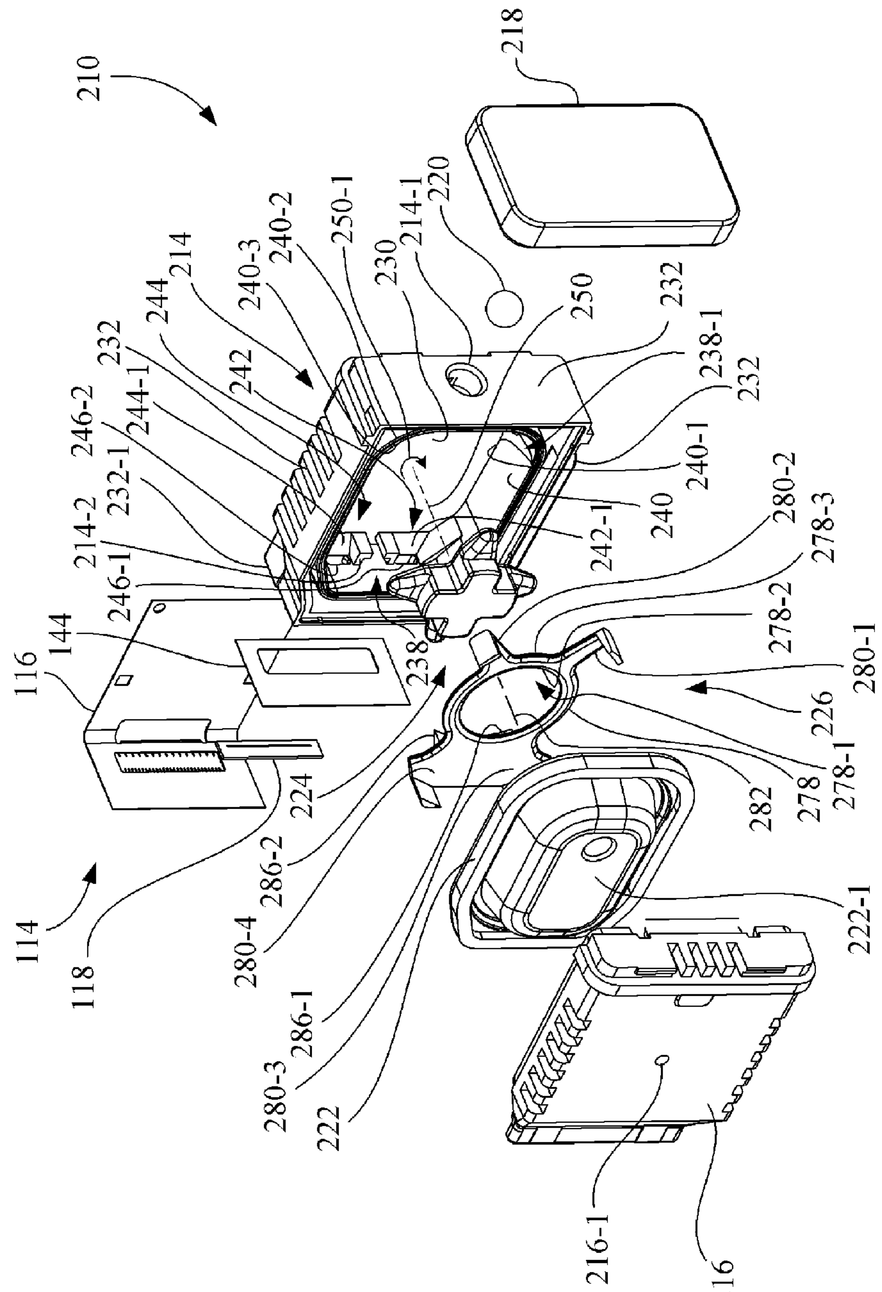
FIG. 18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280-4
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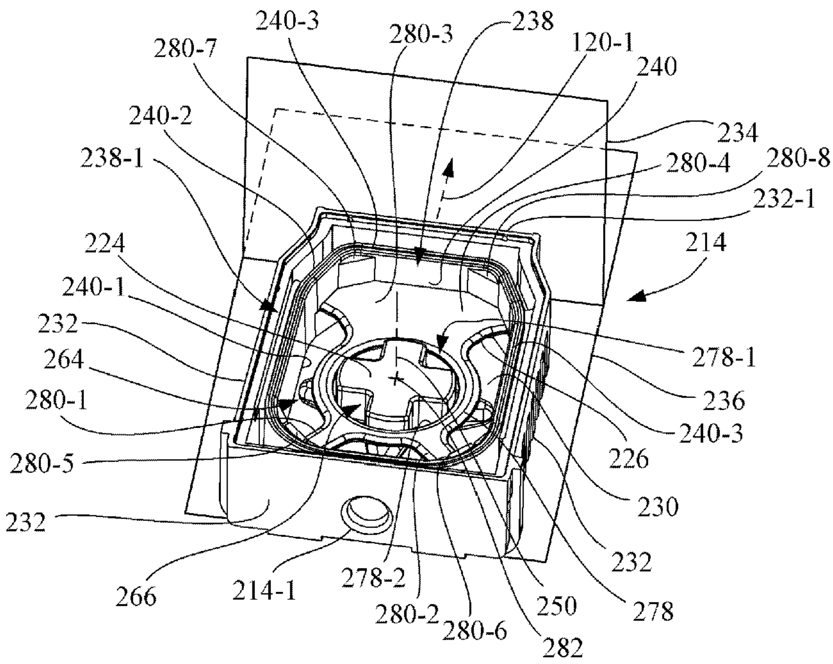
FIG. 19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236
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280-2
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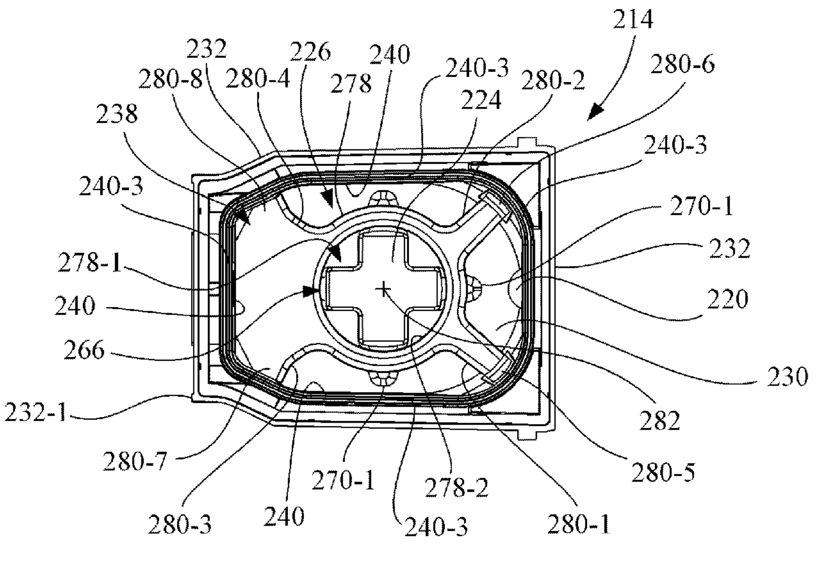
278
280-6
282

FIG. 20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232
240
220
266
230
232-1
282
280-7
280-5
270-1
278-2
280-3
240
240-3
280-1

FIG. 21

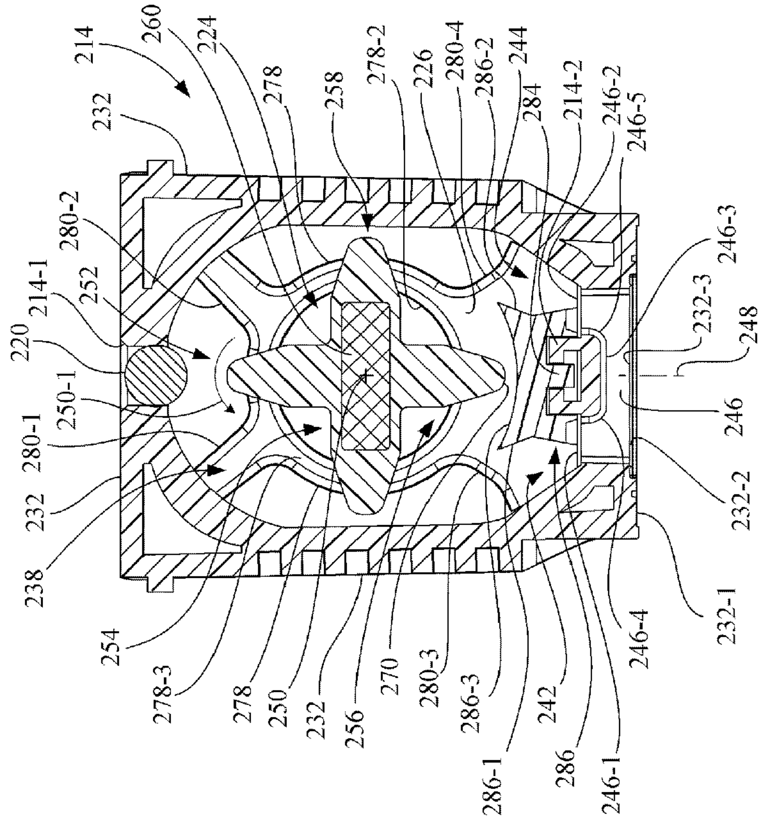


FIG. 23

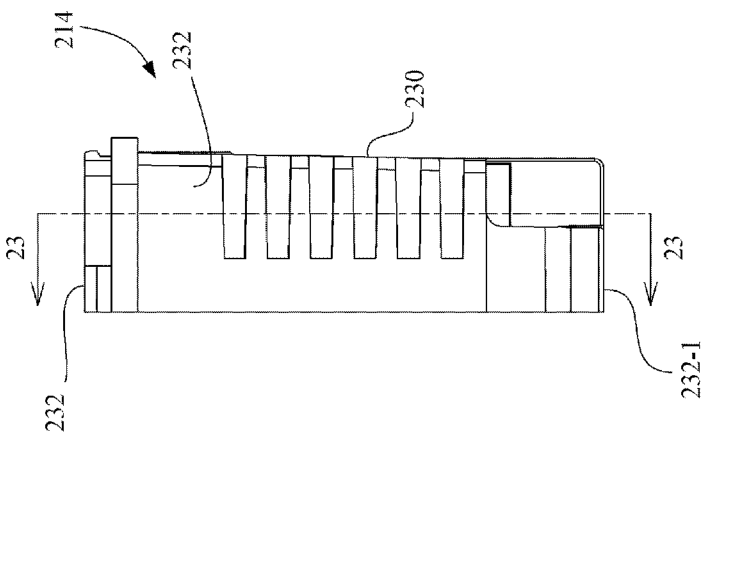


FIG. 22

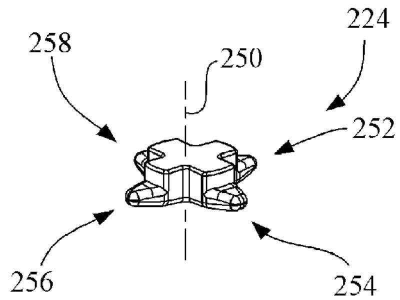


FIG. 24

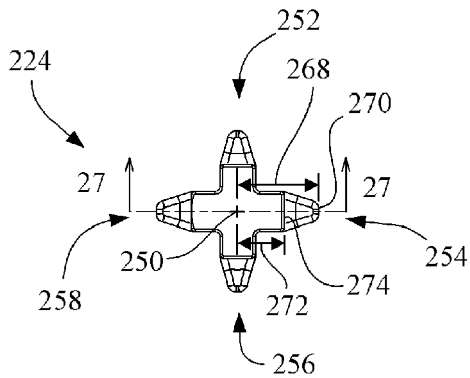


FIG. 25

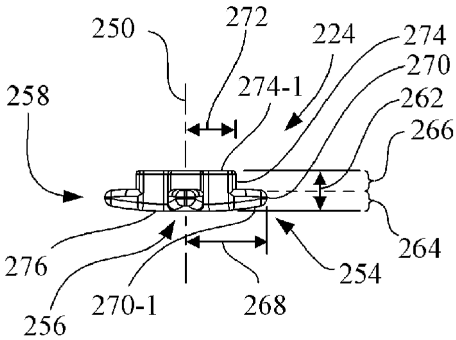


FIG. 26

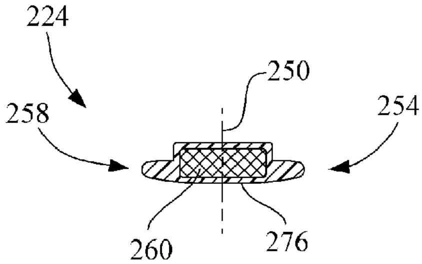


FIG. 27

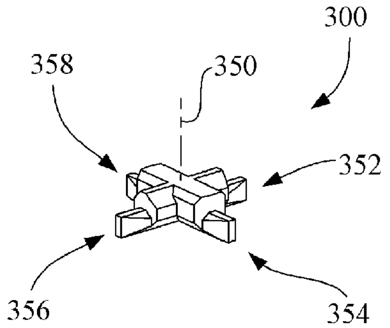


FIG. 28

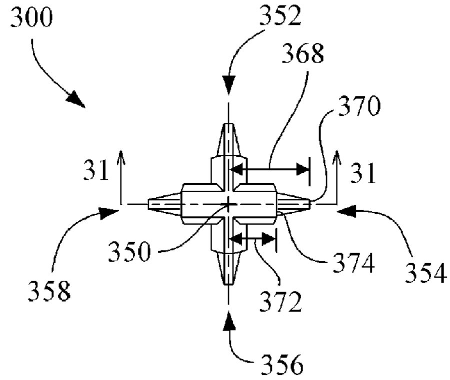


FIG. 29

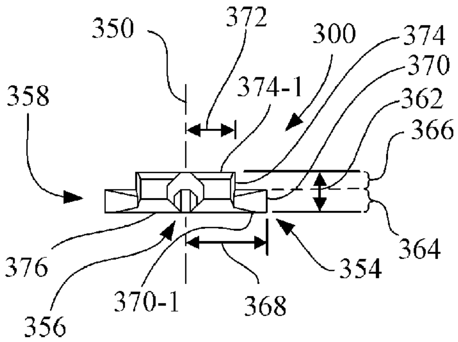


FIG. 30

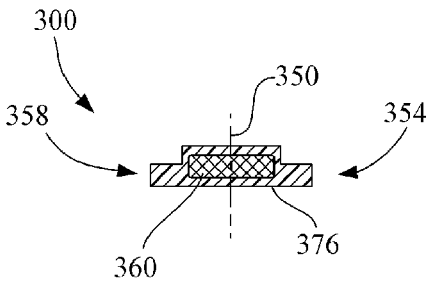


FIG. 31

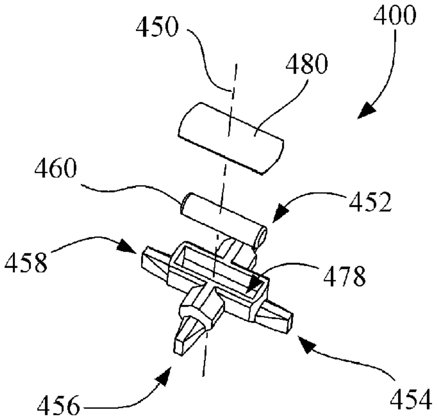


FIG. 32

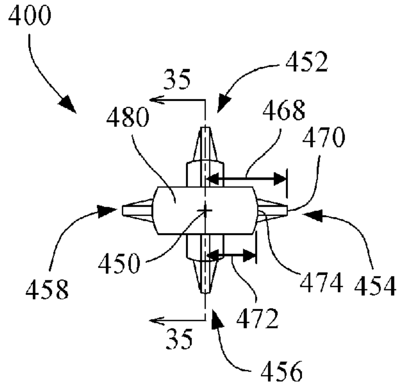


FIG. 33

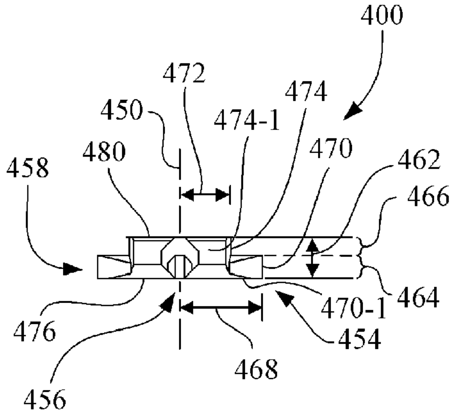


FIG. 34

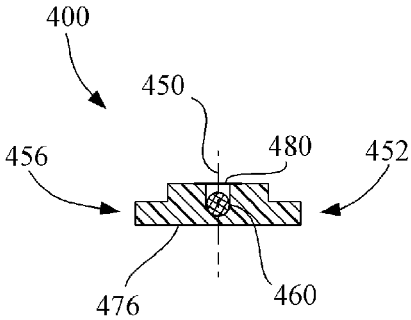


FIG. 35

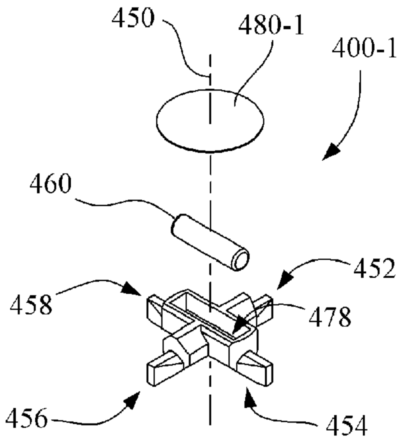


FIG. 36

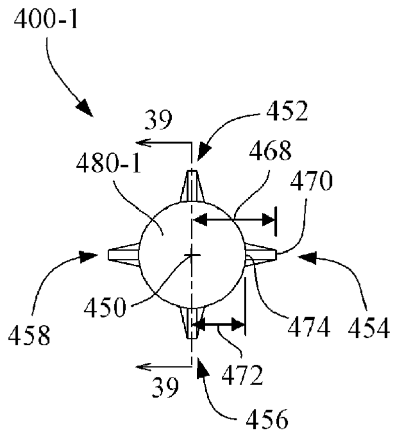


FIG. 37

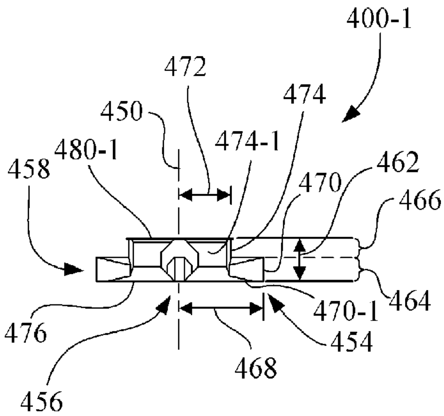


FIG. 38

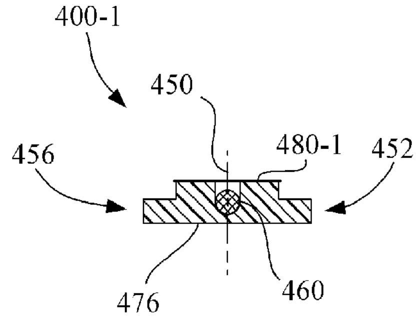


FIG. 39

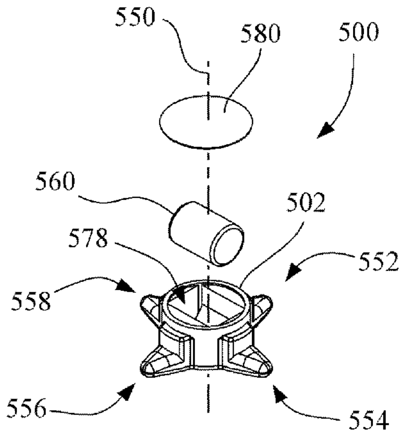


FIG. 40

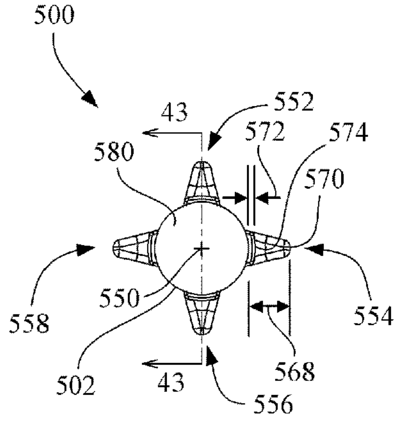


FIG. 41

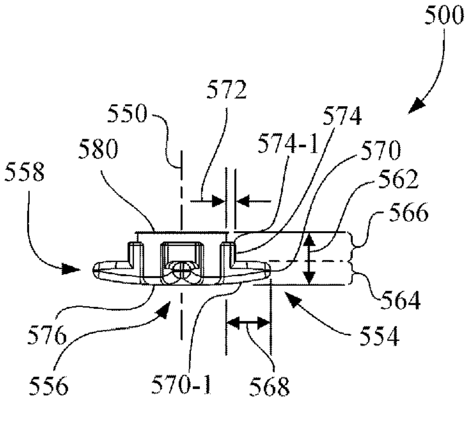


FIG. 42

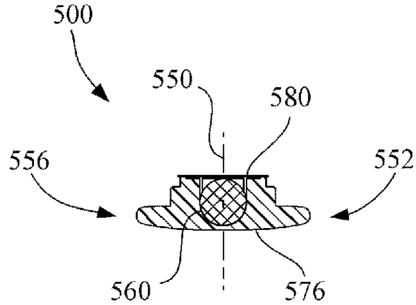


FIG. 43

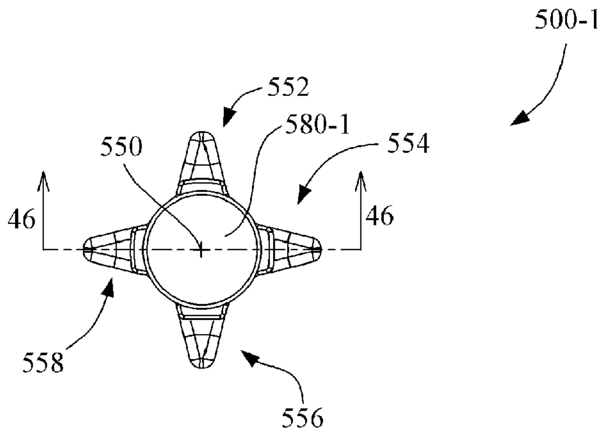


FIG. 44

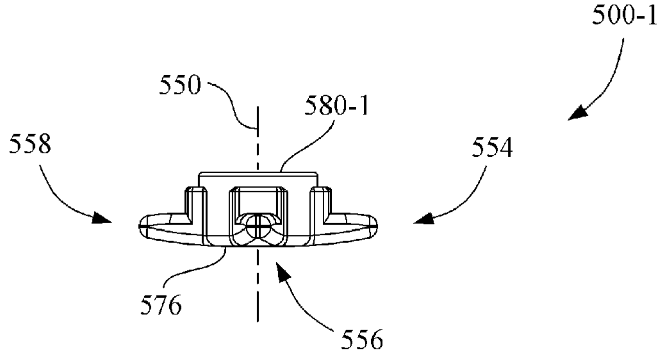


FIG. 45

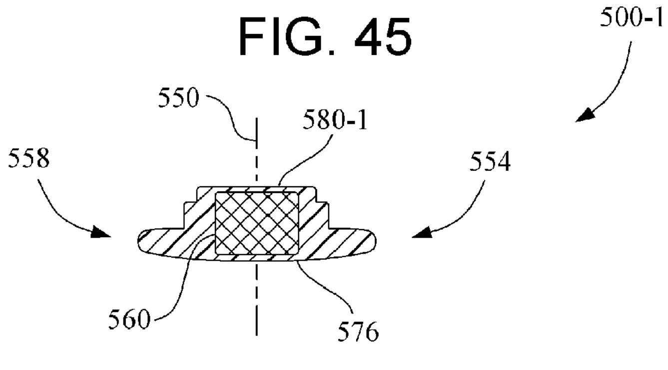


FIG. 46

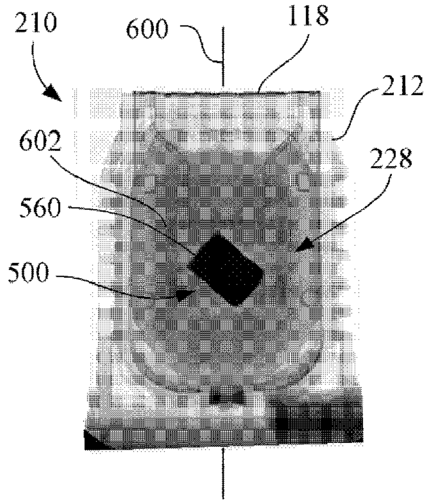


FIG. 47

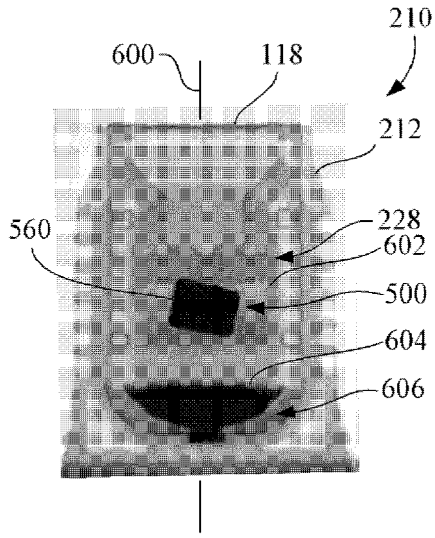


FIG. 48

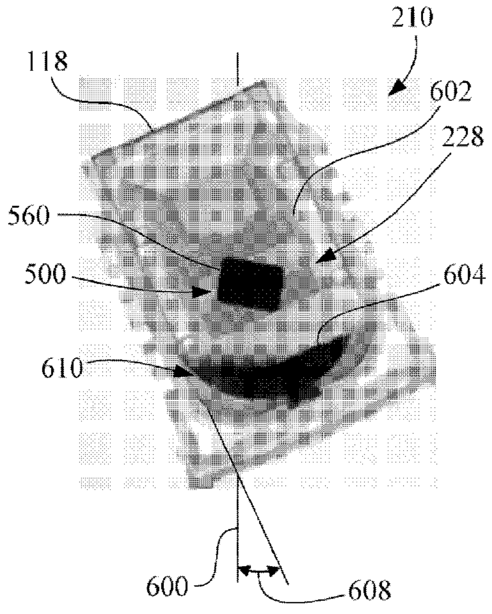


FIG. 49

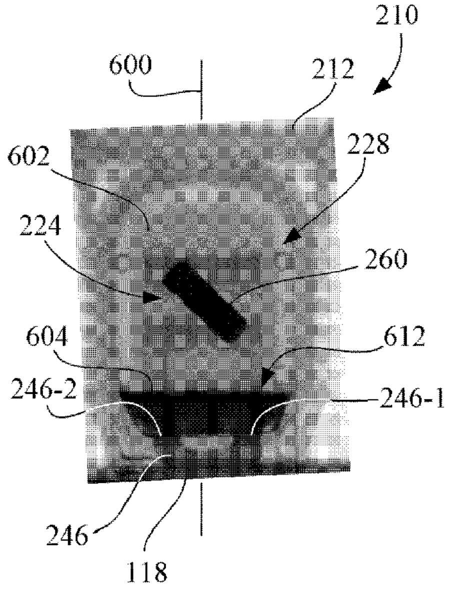


FIG. 50

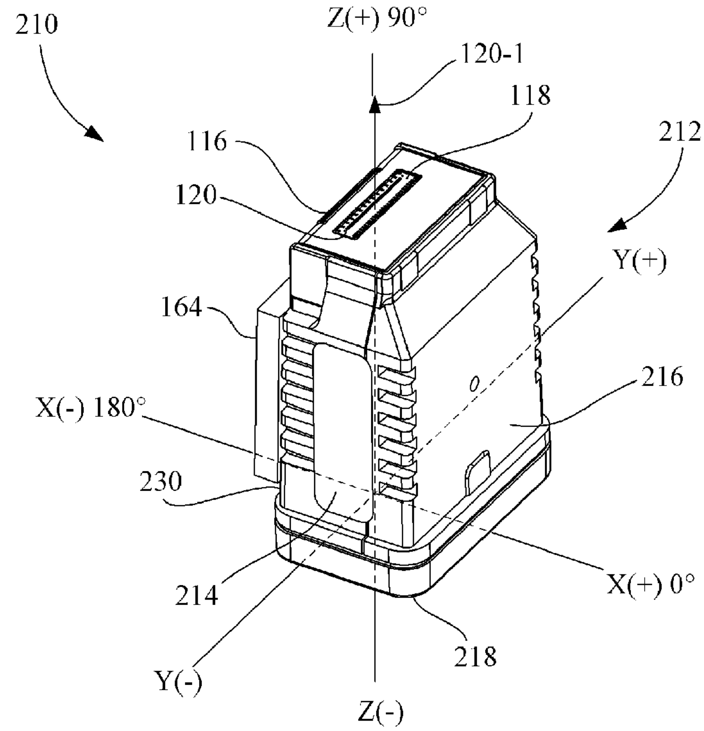

210
Z(+) 90°
120-1
118
116
212
120
Y(+)
164
216
X(-) 180°
230
214
X(+) 0°
218
Y(-)
Z(-)

FIG. 51

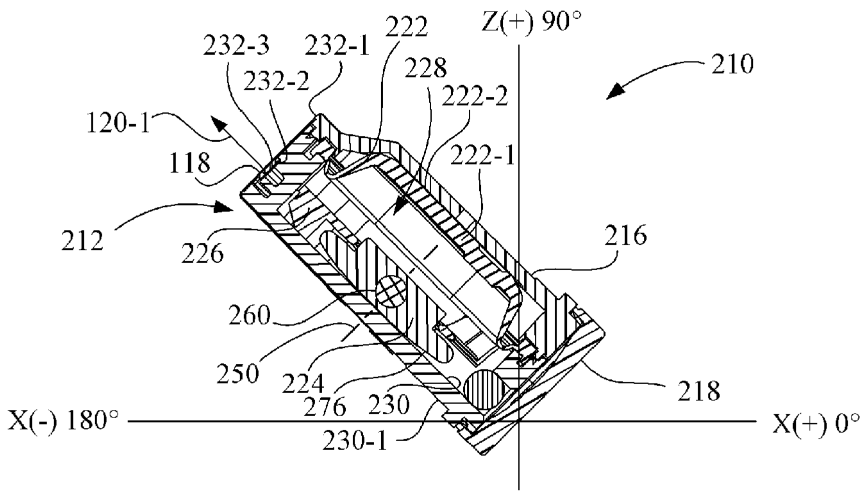

232-3
232-1
222
Z(+) 90°
232-2
228
210
222-2
120-1
222-1
118
212
226
216
260
250
224
218
276
230
X(-) 180°
230-1
X(+) 0°

FIG. 52

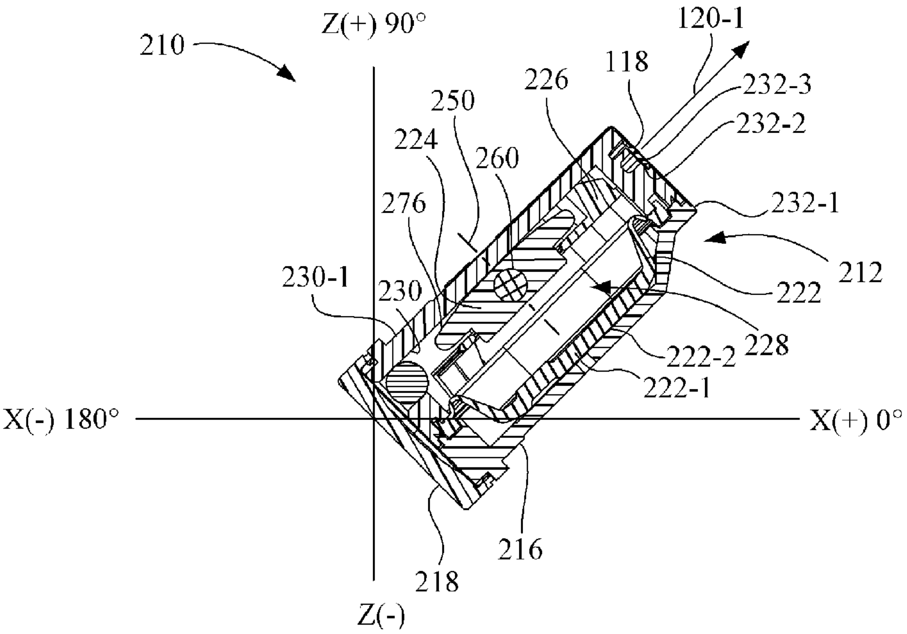

210
Z(+) 90°
120-1
118
226
232-3
232-2
250
224
260
276
232-1
212
230-1
230
222
228
222-2
222-1
X(-) 180°
X(+) 0°
216
218
Z(-)

FIG. 53

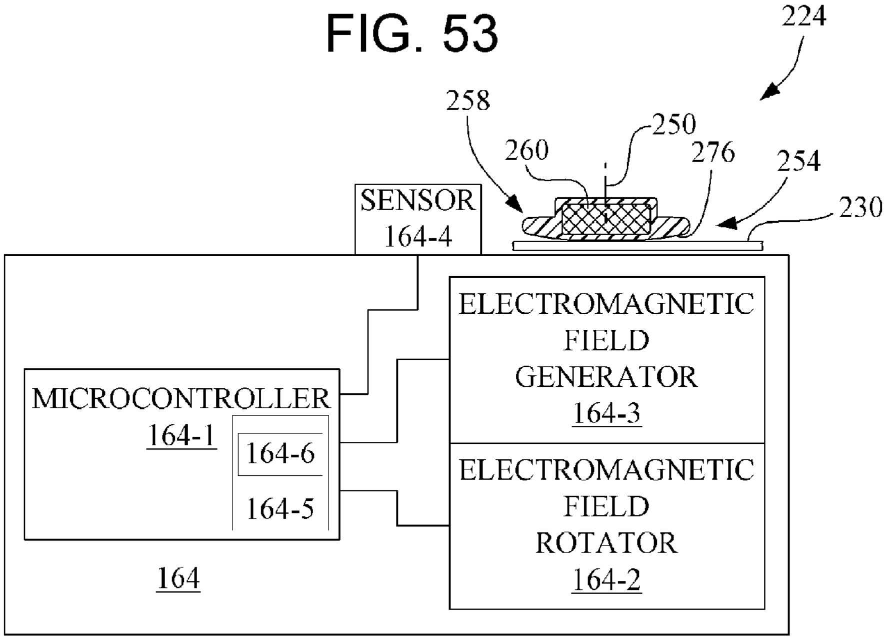

224
258
250
260
276
254
230
SENSOR
164-4
ELECTROMAGNETIC
FIELD
GENERATOR
164-3
MICROCONTROLLER
164-1
164-6
164-5
ELECTROMAGNETIC
FIELD
ROTATOR
164-2
164

FIG. 54

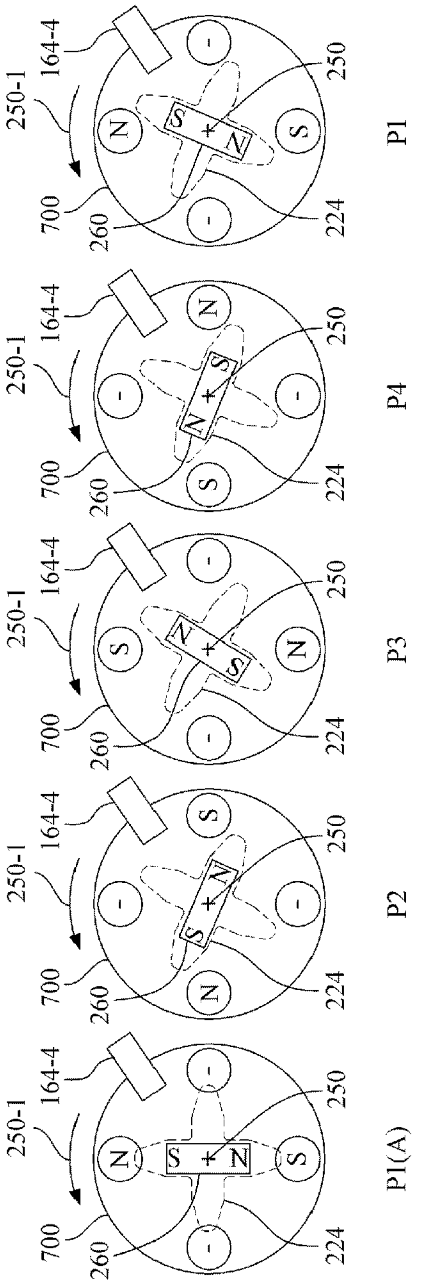


FIG. 55

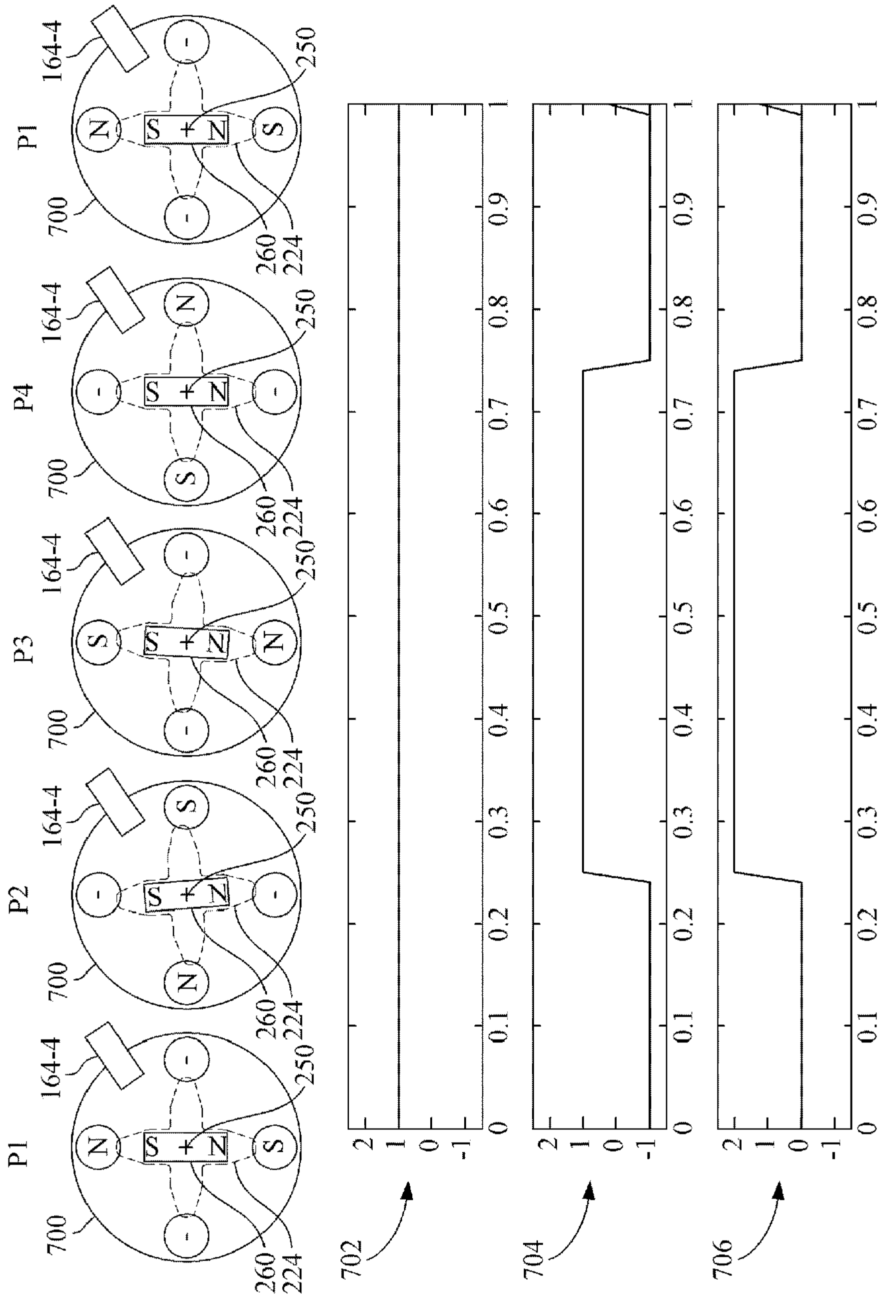


FIG. 56

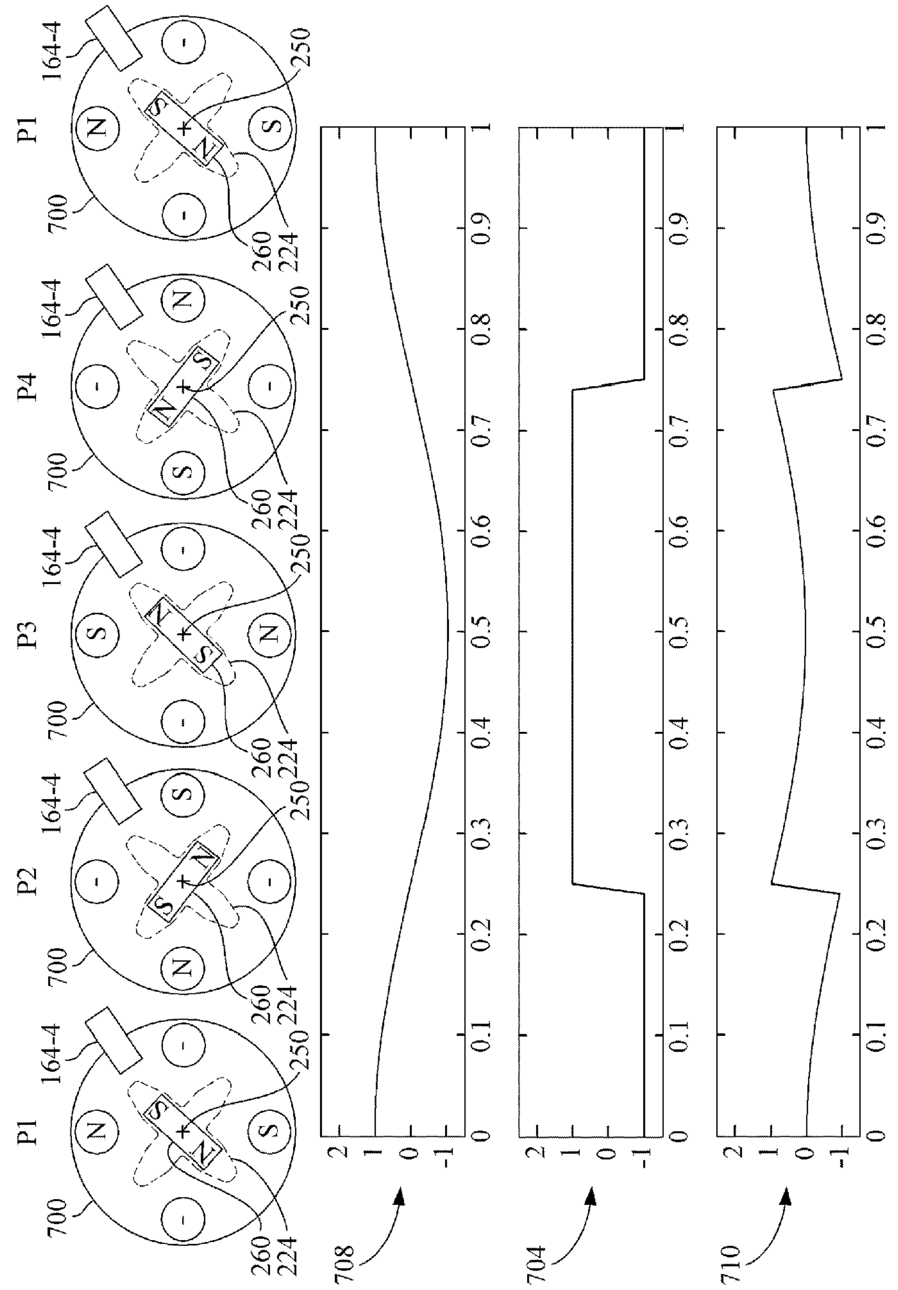

P1
P2
P3
P4
P1
164-4
700
250
260
224
N
S
708
704
710
2
1
0
-1
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

FIG. 57

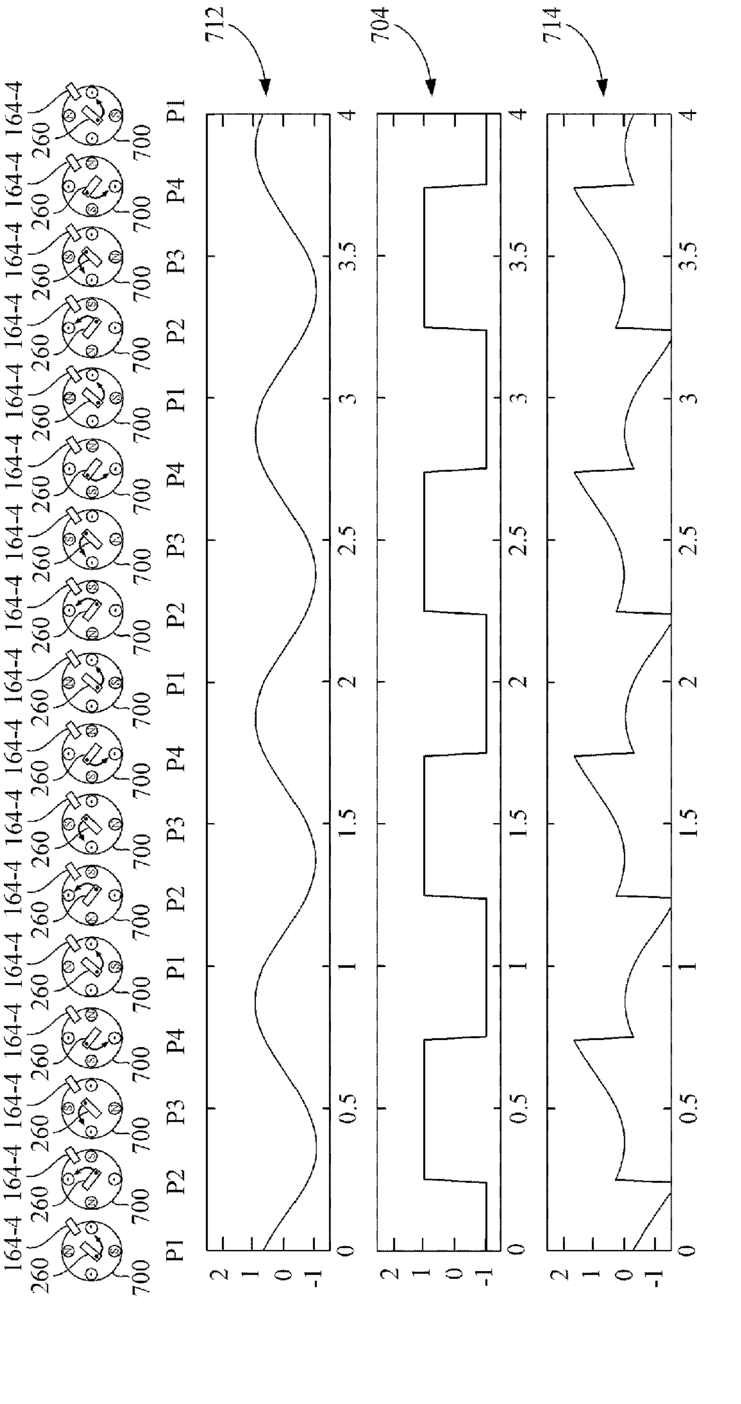


FIG. 58

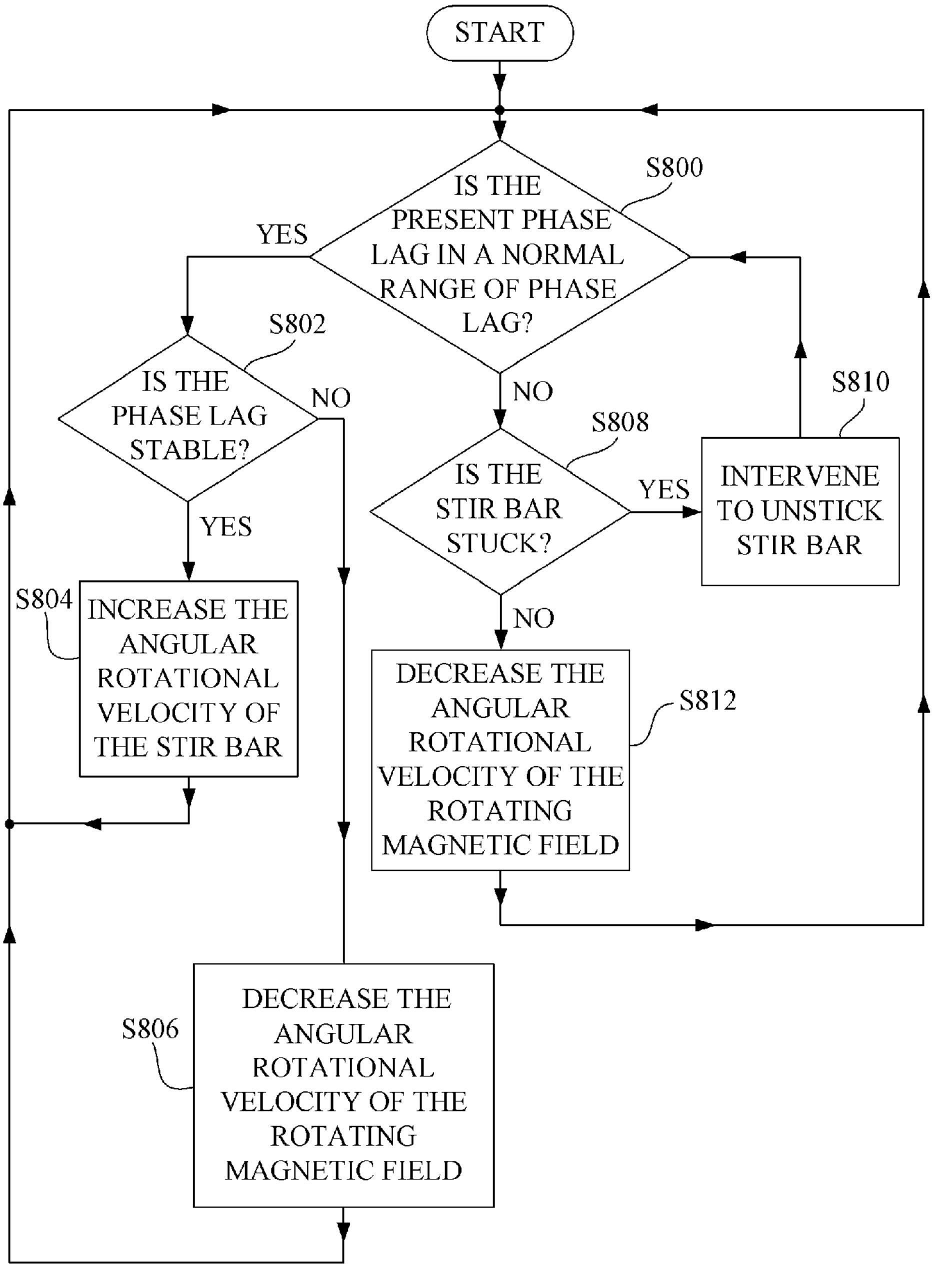

START
IS THE PRESENT PHASE LAG IN A NORMAL RANGE OF PHASE LAG?
S800
YES
NO
S802
IS THE PHASE LAG STABLE?
NO
YES
S804
INCREASE THE ANGULAR ROTATIONAL VELOCITY OF THE STIR BAR
S806
DECREASE THE ANGULAR ROTATIONAL VELOCITY OF THE ROTATING MAGNETIC FIELD
S808
IS THE STIR BAR STUCK?
YES
NO
S810
INTERVENE TO UNSTICK STIR BAR
S812
DECREASE THE ANGULAR ROTATIONAL VELOCITY OF THE ROTATING MAGNETIC FIELD

FIG. 59

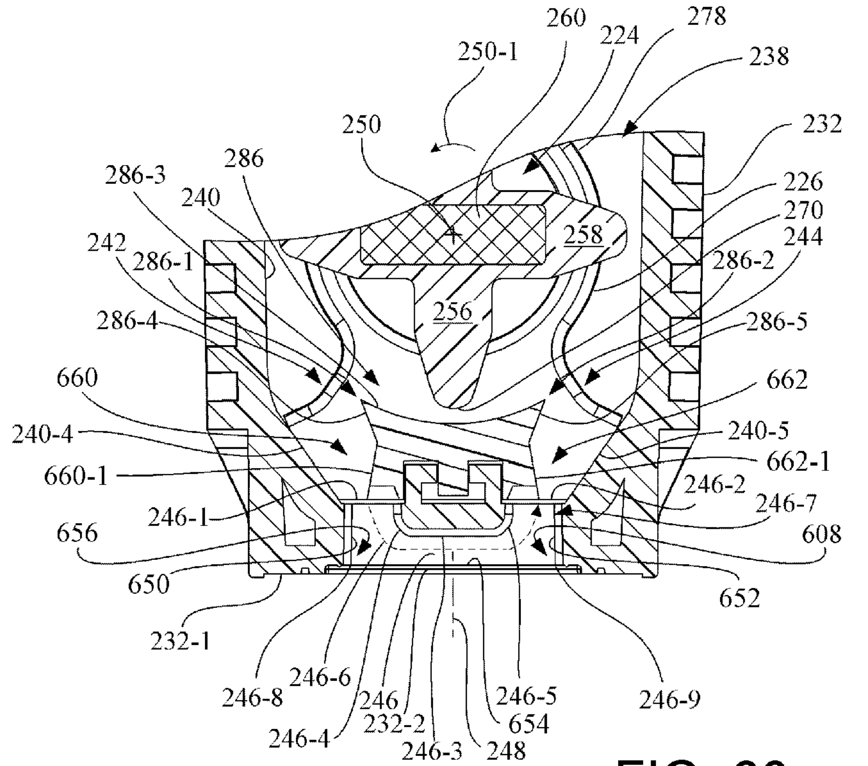

260
278
250-1
224
238
250
232
286-3
286
226
240
270
258
242
244
286-1
286-2
256
286-4
286-5
660
662
240-4
240-5
660-1
662-1
246-2
246-1
246-7
656
608
650
652
232-1
246-8
246-6
246-5
246-9
246
654
232-2
246-4
246-3
248

FIG. 60

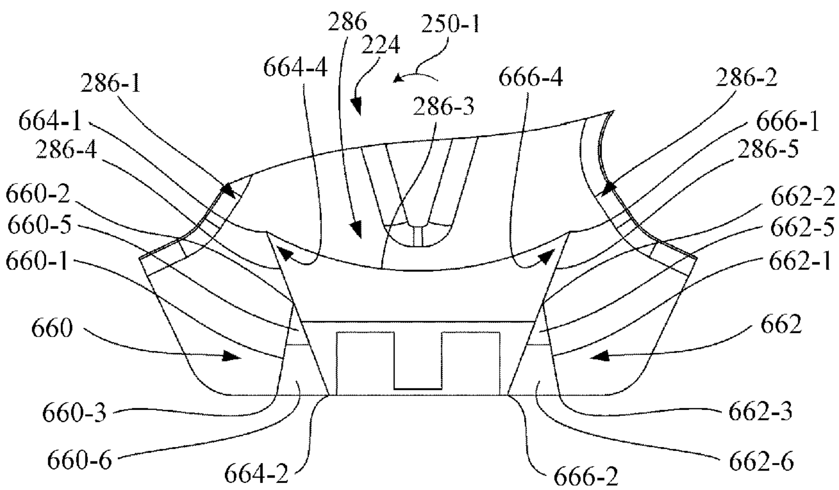

286
250-1
224
664-4
666-4
286-1
286-2
286-3
664-1
666-1
286-4
286-5
660-2
662-2
660-5
662-5
660-1
662-1
660
662
660-3
662-3
660-6
662-6
664-2
666-2

FIG. 61

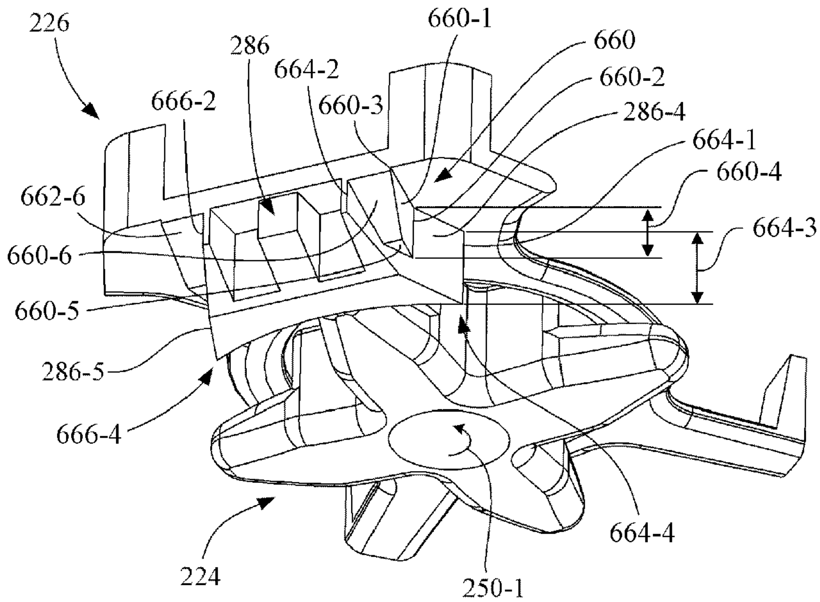

226
286
660-1
660
664-2
660-2
666-2
660-3
286-4
664-1
660-4
662-6
664-3
660-6
660-5
286-5
666-4
664-4
224
250-1

FIG. 62

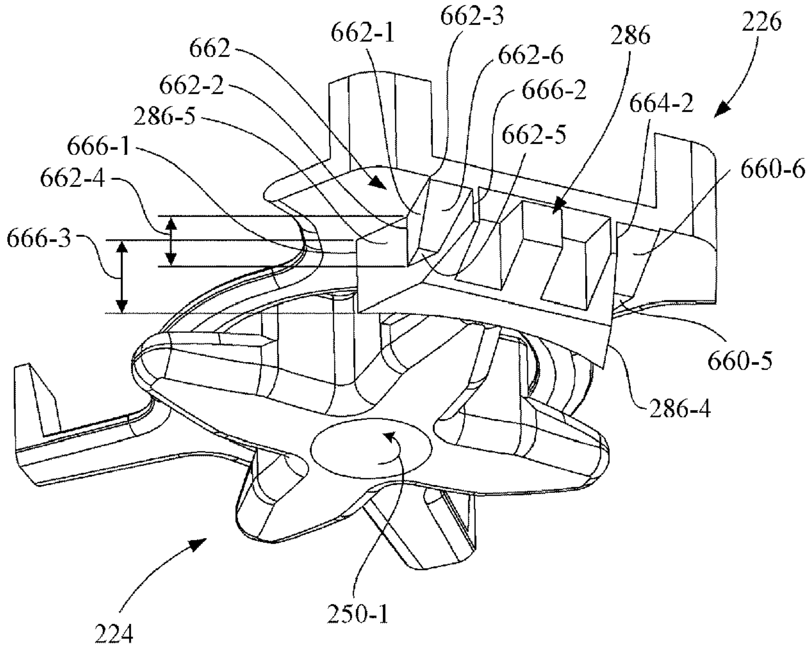

662-3
662-1
226
662
286
662-6
662-2
666-2
664-2
286-5
662-5
666-1
660-6
662-4
666-3
660-5
286-4
224
250-1

FIG. 63

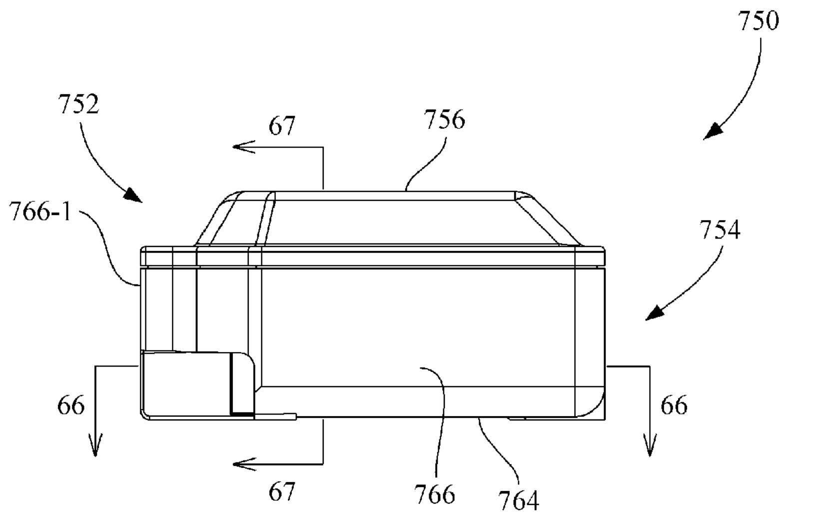

750
752
67
756
766-1
754
66
66
67
766
764

FIG. 64

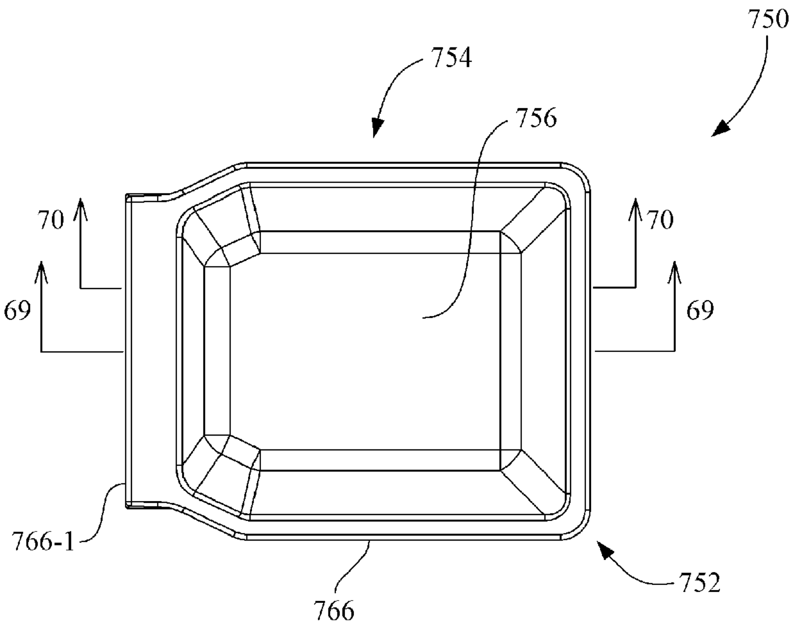

750
754
756
70
70
69
69
766-1
766
752

FIG. 65

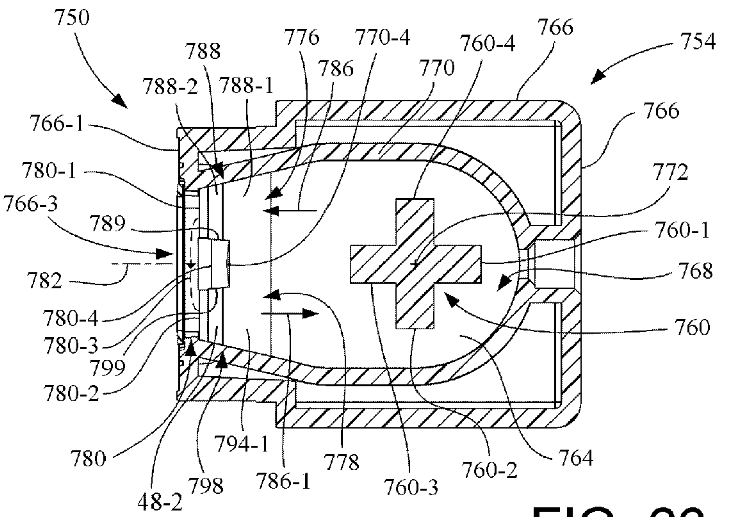


FIG. 66

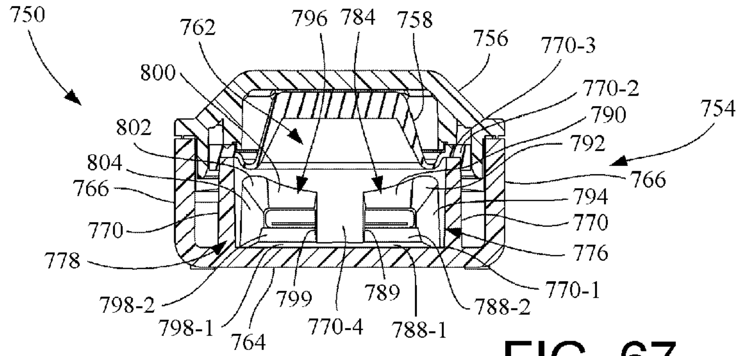


FIG. 67

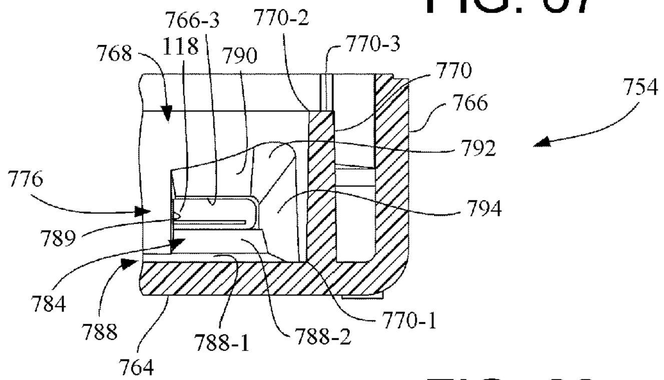


FIG. 68

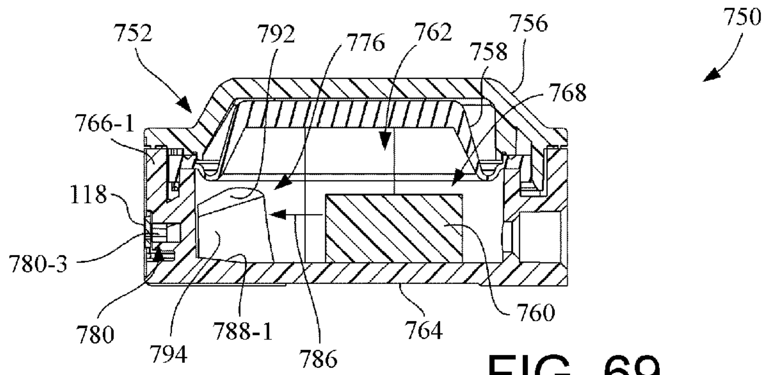


FIG. 69

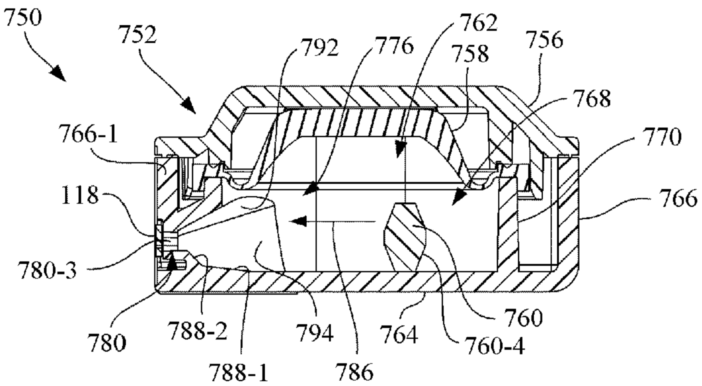


FIG. 70

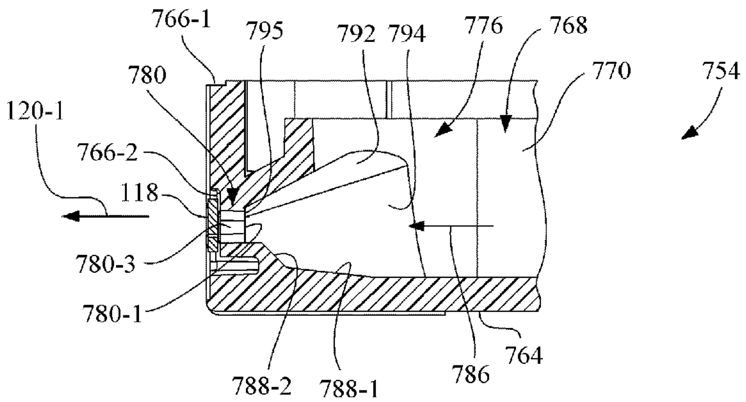


FIG. 71

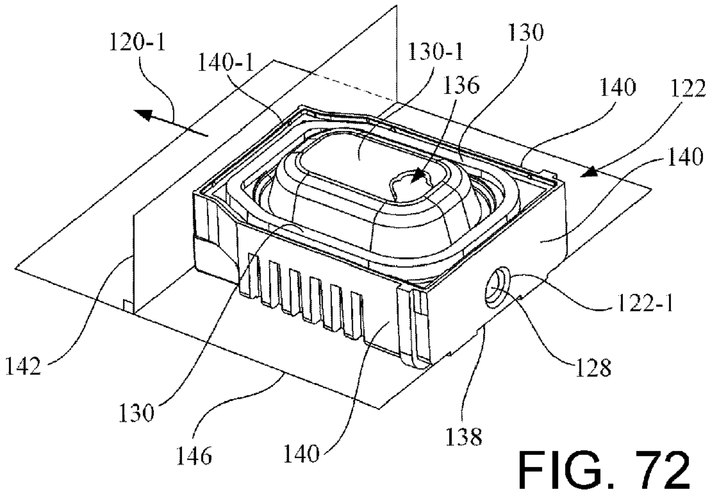


FIG. 72

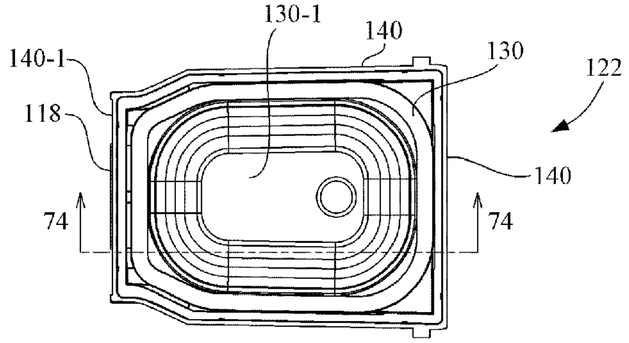


FIG. 73

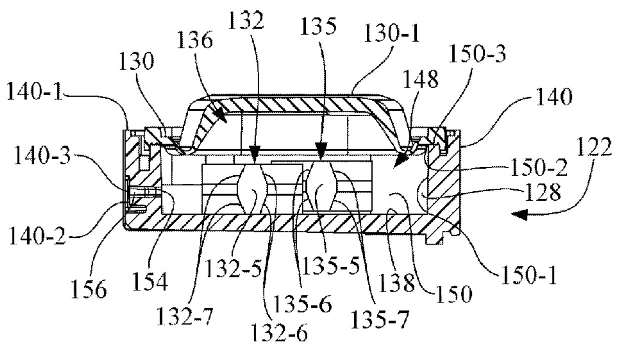


FIG. 74

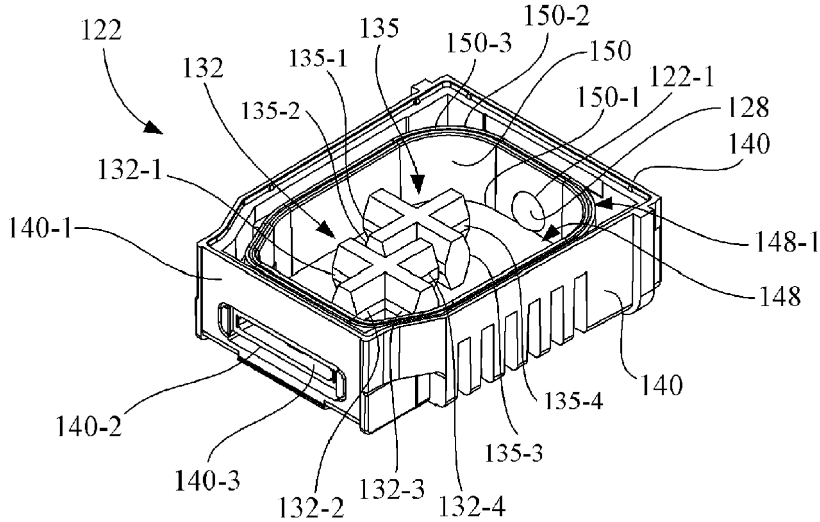

122
132
135-1
135
150-3
150-2
150
122-1
150-1
128
140
135-2
132-1
140-1
148-1
148
140
135-4
140-2
135-3
140-3
132-3
132-2
132-4

FIG. 75

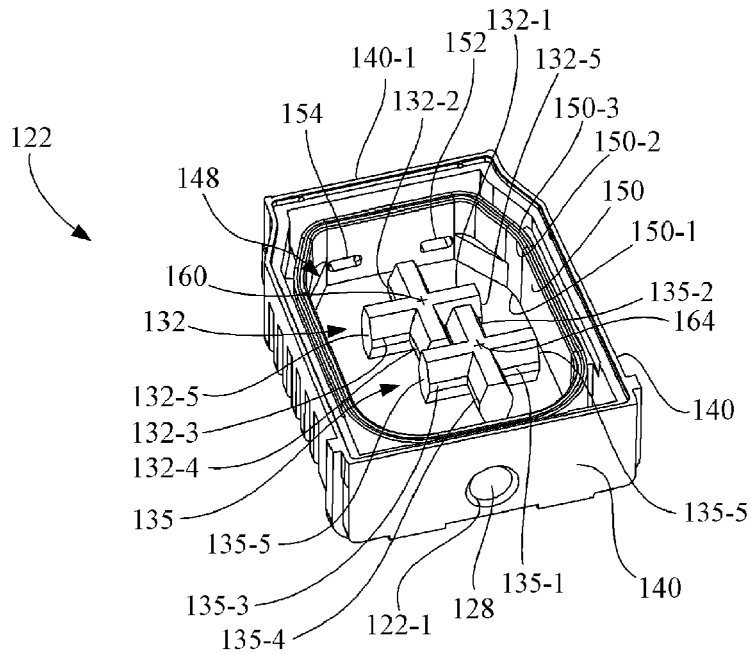

132-1
152
140-1
132-5
132-2
150-3
154
150-2
122
148
150
150-1
160
135-2
132
164
132-5
140
132-3
132-4
135
135-5
135-5
135-1
140
135-3
128
122-1
135-4

FIG. 76

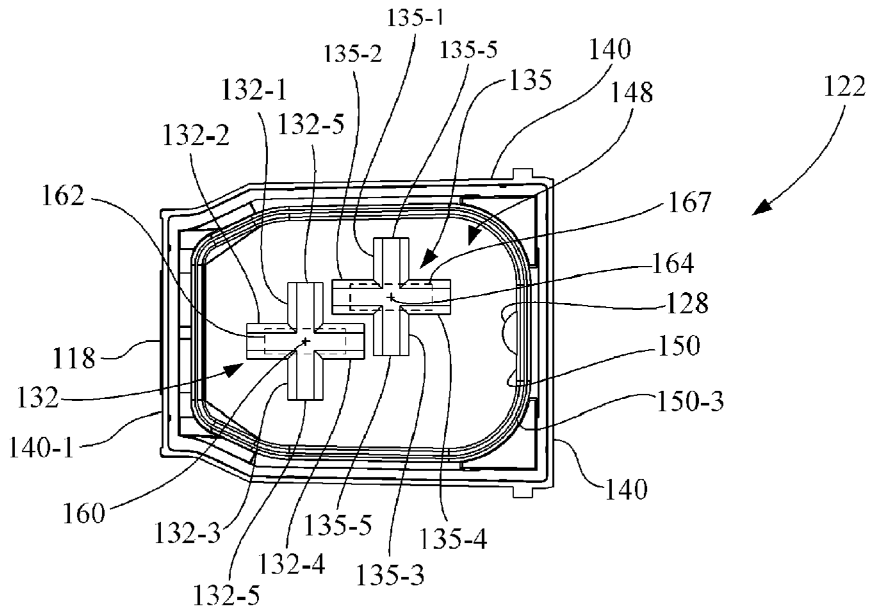

135-1
135-2
135-5
140
135
148
122
132-1
132-5
132-2
162
167
164
128
118
150
132
150-3
140-1
140
160
132-3
135-5
135-4
132-4
135-3
132-5

FIG. 77

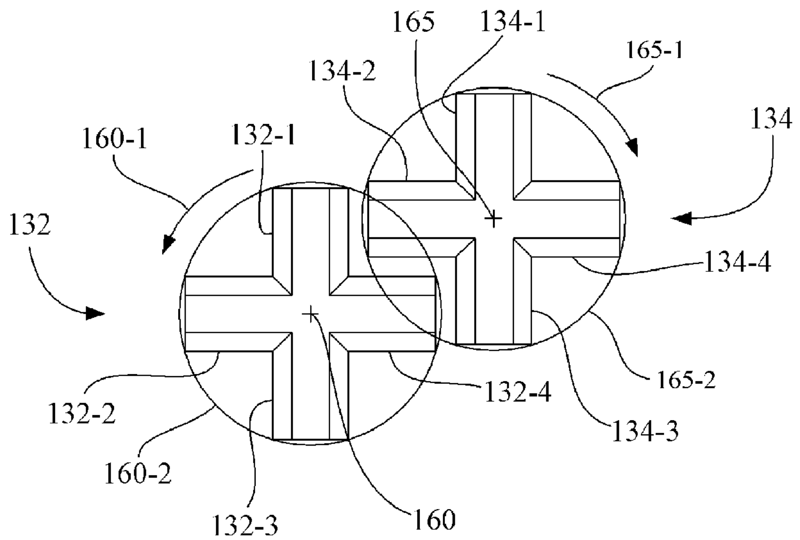

165
134-1
165-1
134-2
134
160-1
132-1
132
134-4
165-2
132-4
132-2
134-3
160-2
132-3
160

FIG. 78

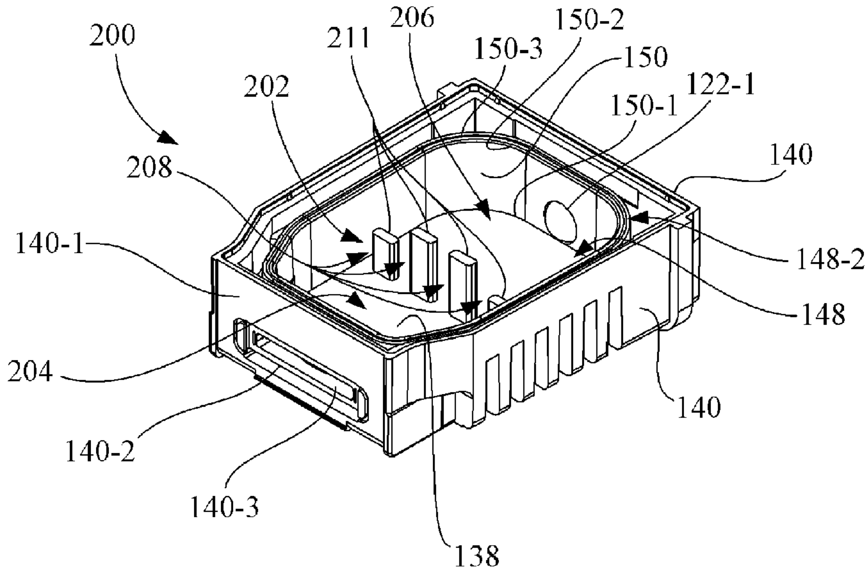
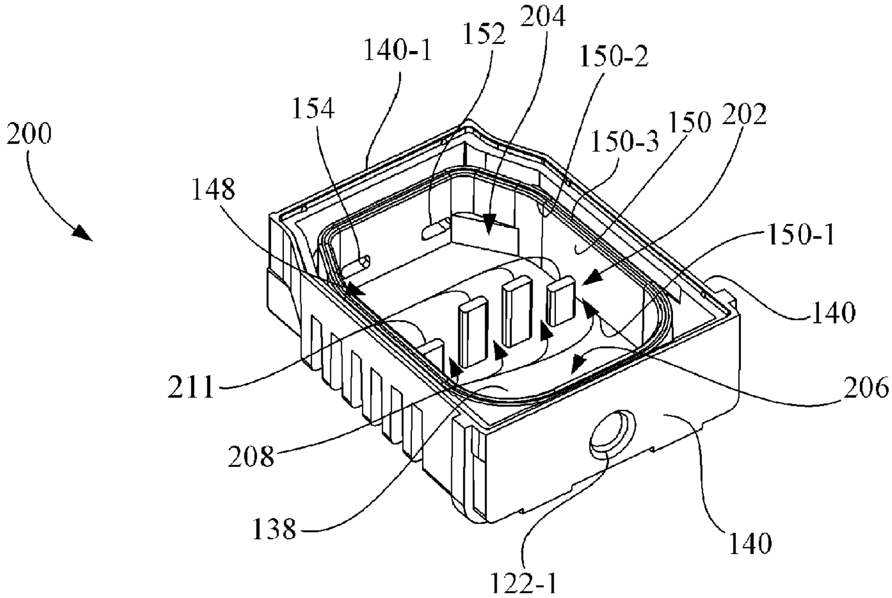

200
211
206
150-2
150-3
150
122-1
150-1
202
140
208
140-1
148-2
148
204
140
140-2
140-3
138

FIG. 79


204
140-1
152
150-2
154
150
202
200
150-3
148
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211
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140
122-1

FIG. 80

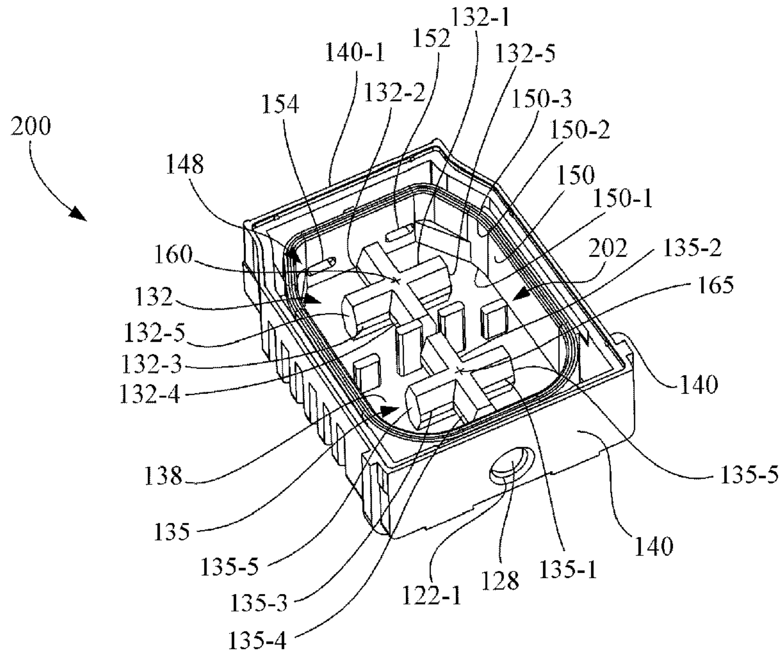
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FIG. 81

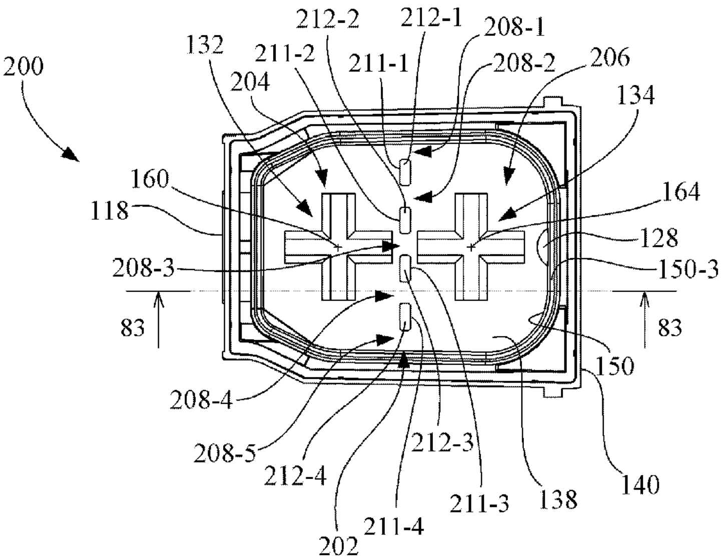
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FIG. 82

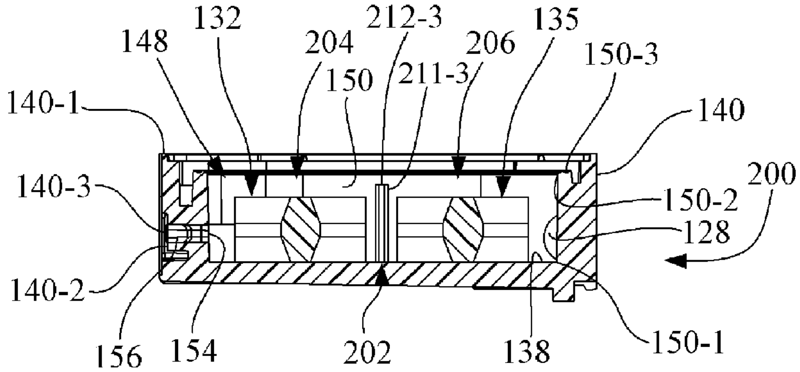
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FIG. 83

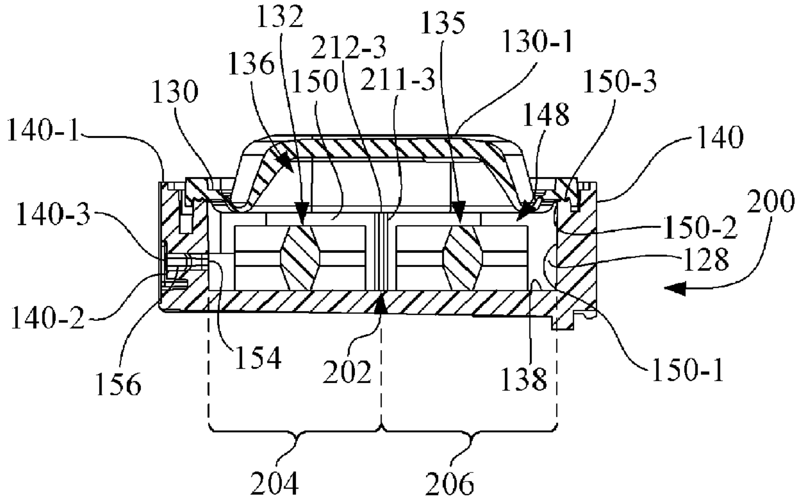
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FIG. 84

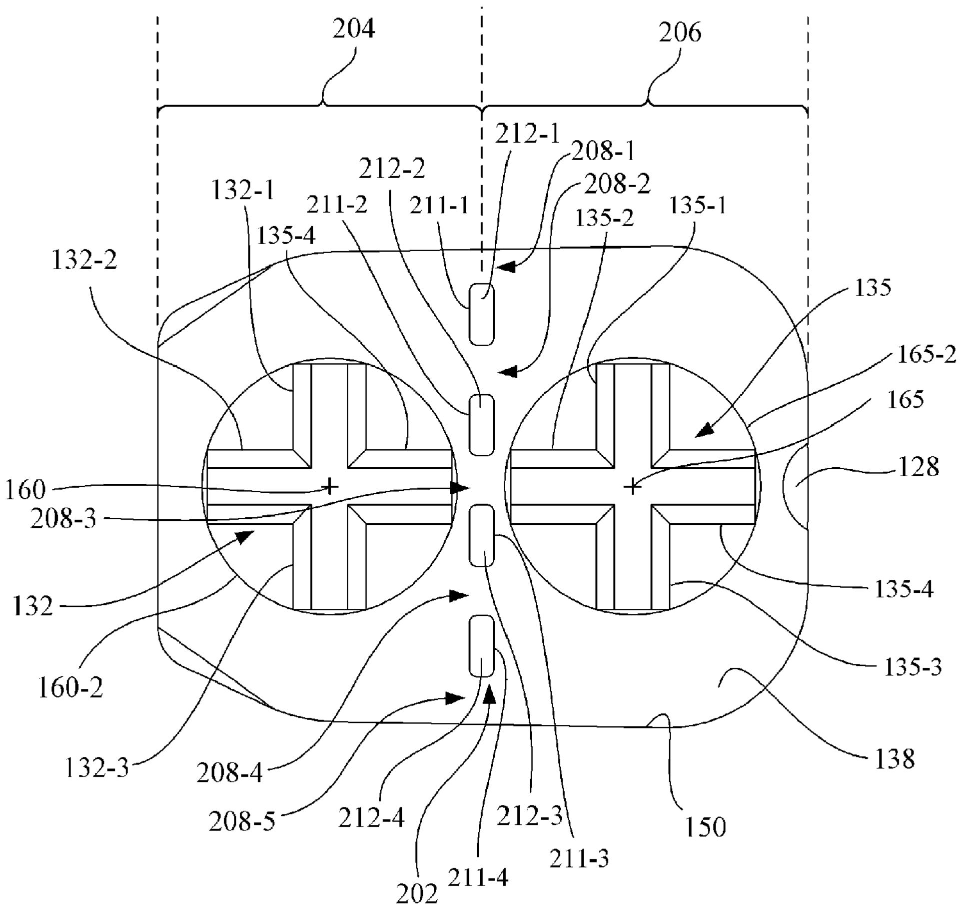
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FIG. 85

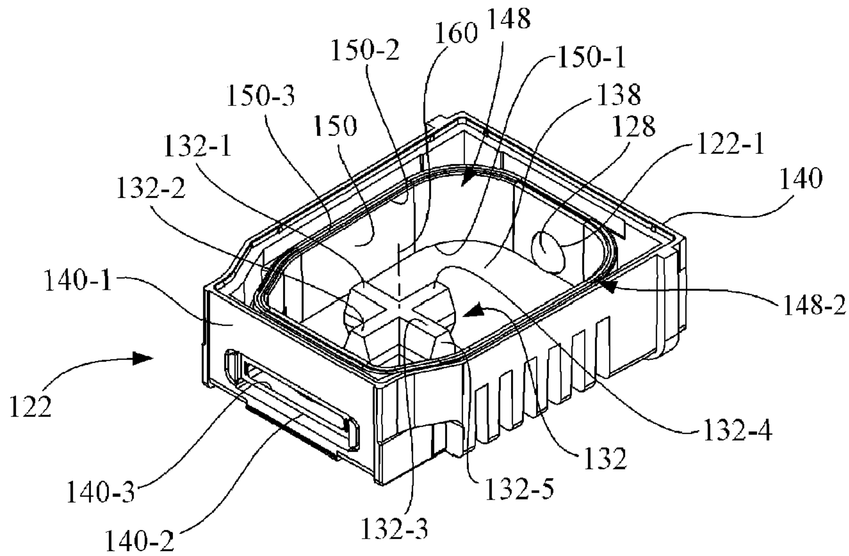
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FIG. 86

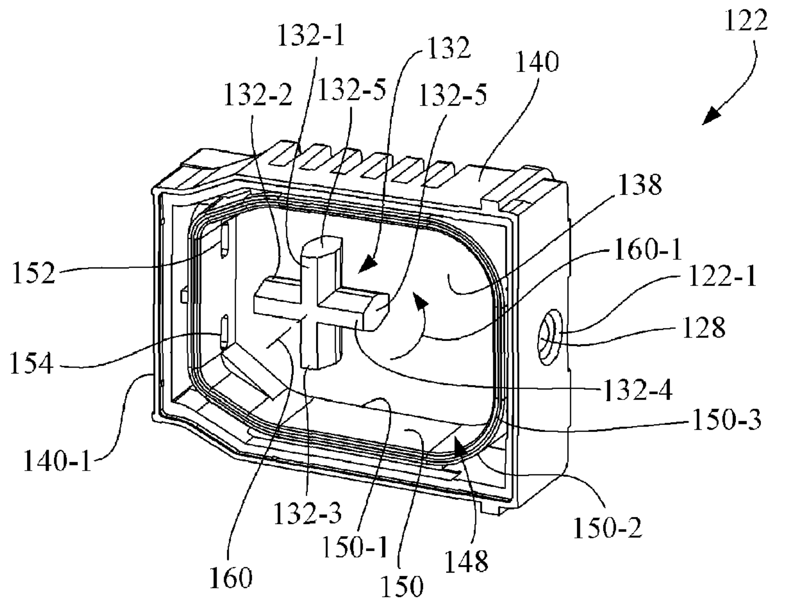
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FIG. 87

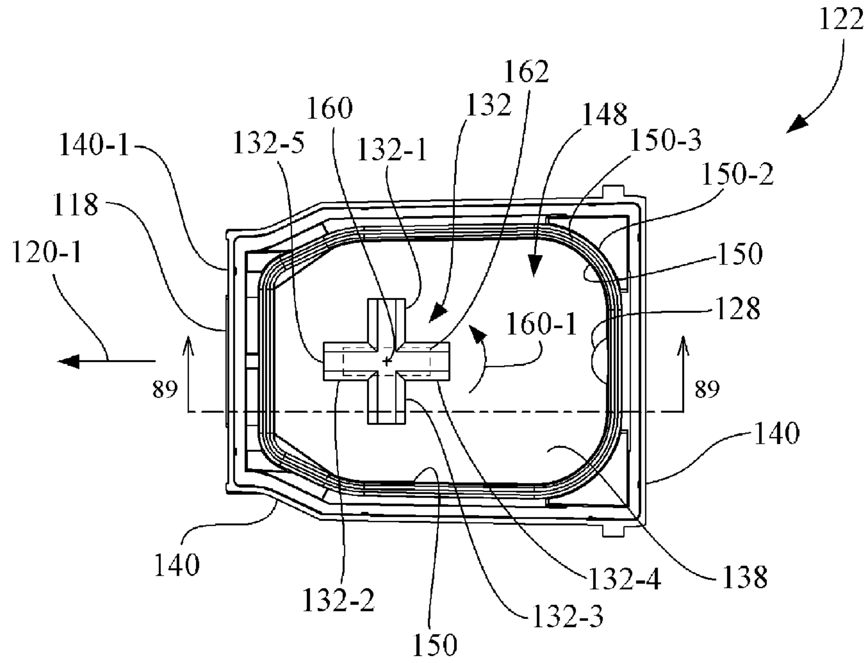
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FIG. 88

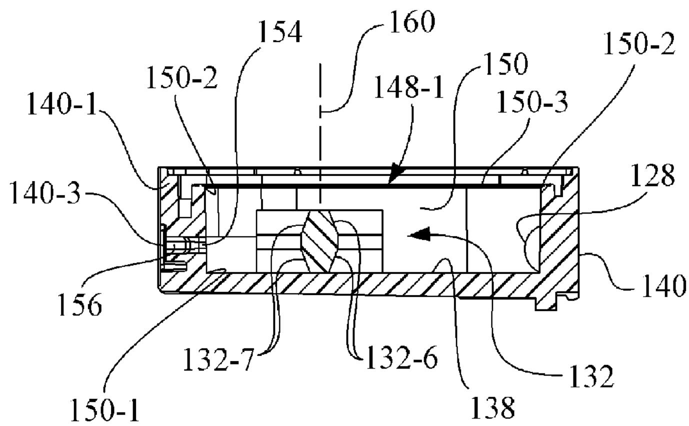
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FIG. 89

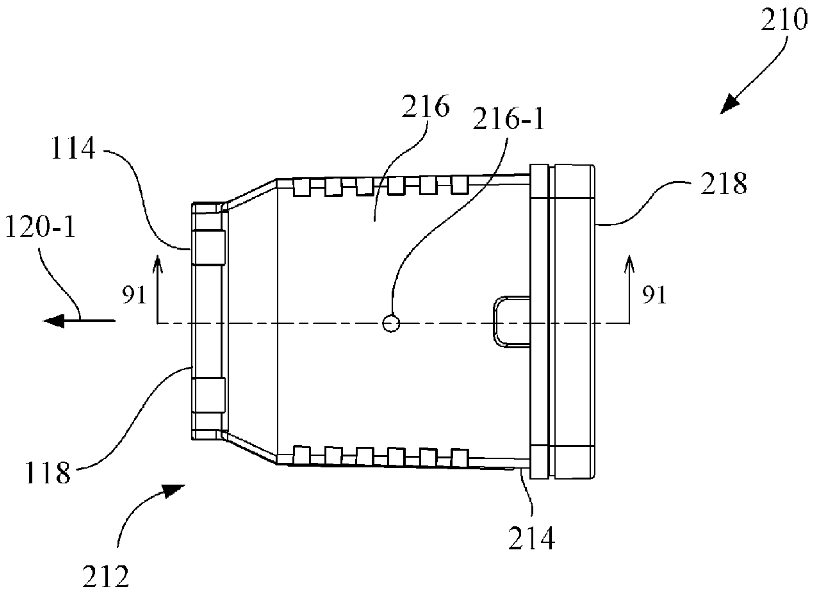
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FIG. 90

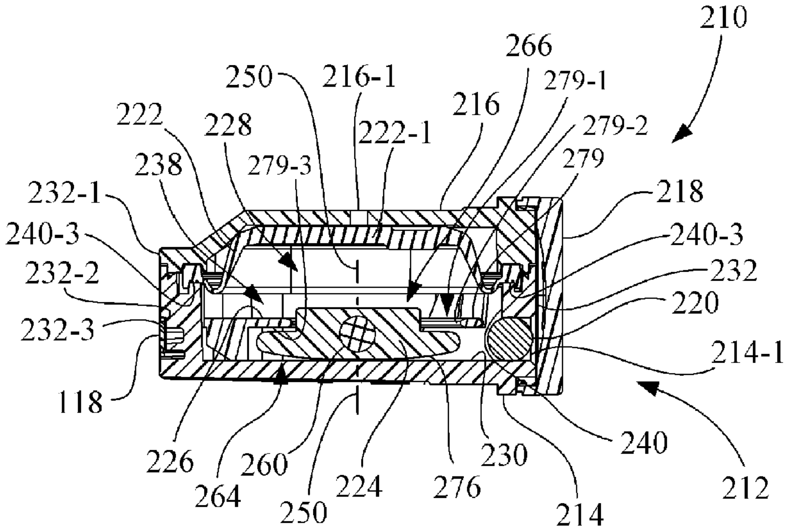
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FIG. 91

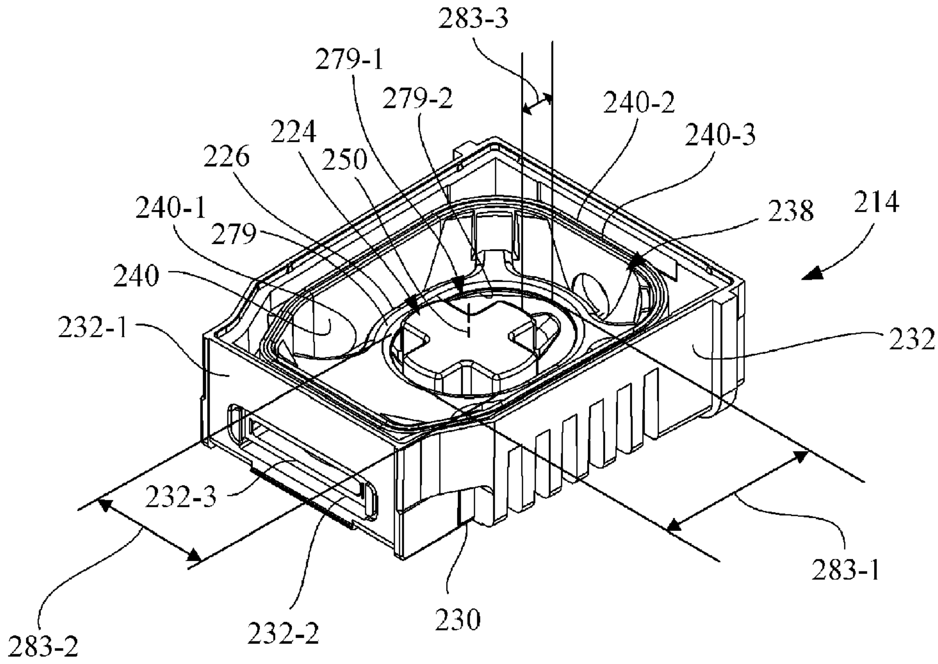
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FIG. 92

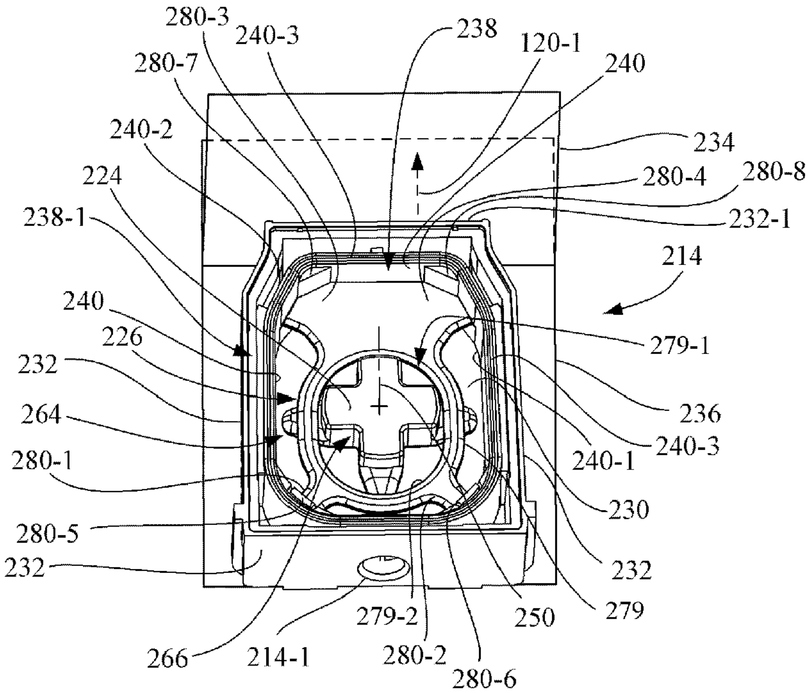
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FIG. 93

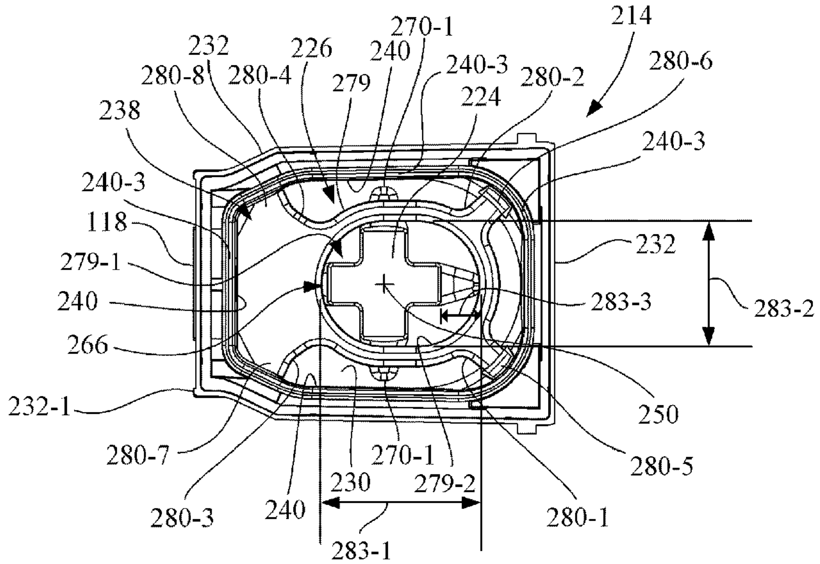
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FIG. 94

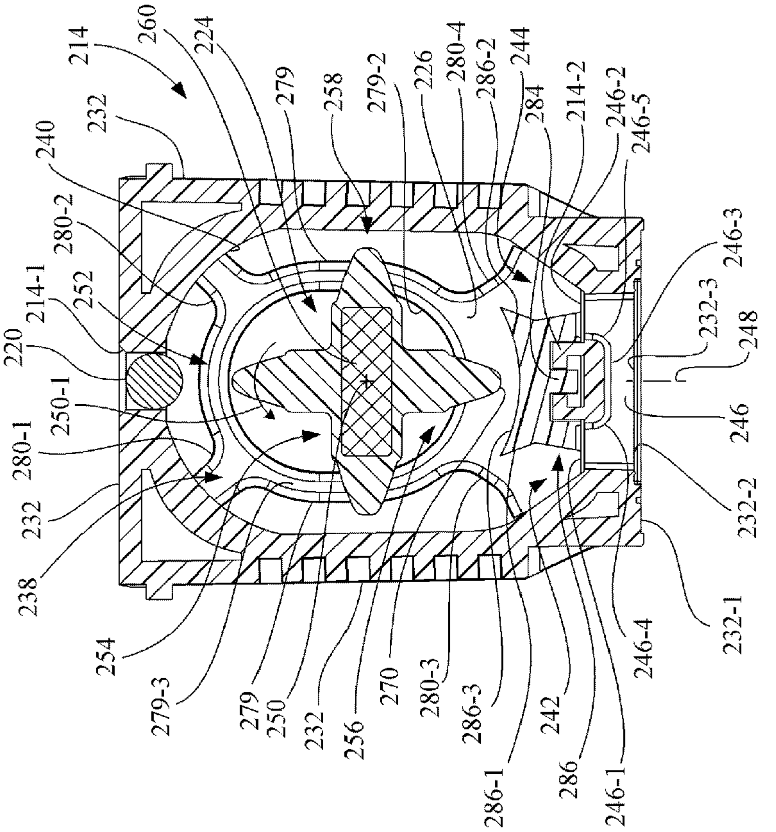
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FIG. 96

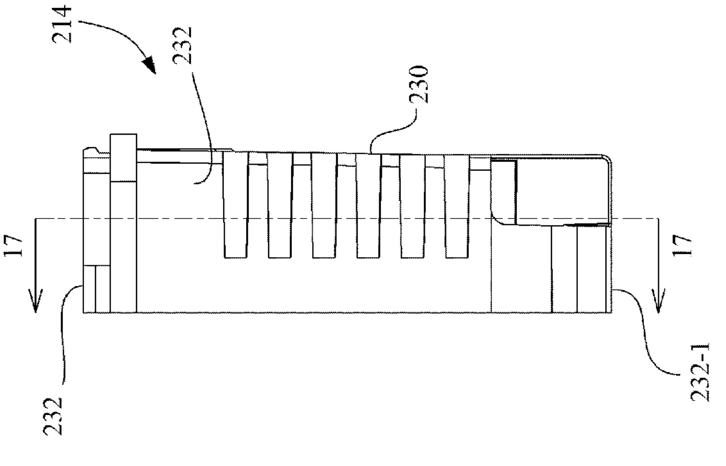
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FIG. 95

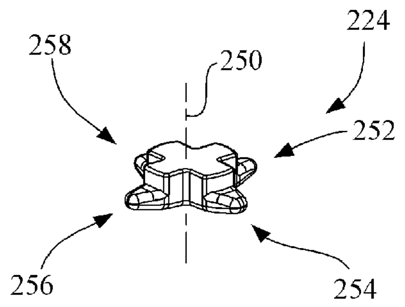

FIG. 97

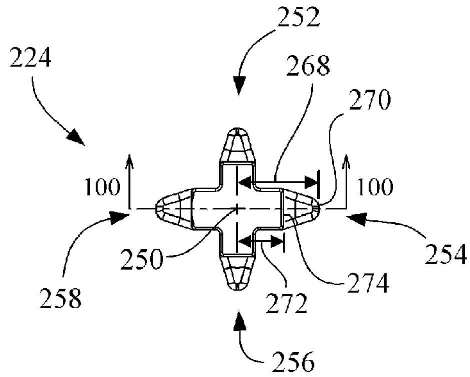

FIG. 98

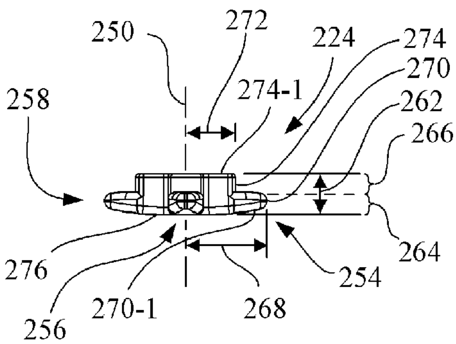

FIG. 99

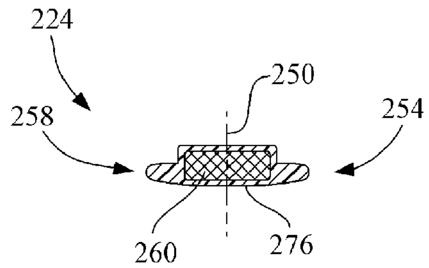

FIG. 100

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EUROPEAN SEARCH REPORT

Application Number
EP 17 18 2097

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y A	EP 2 919 072 A1 (RICOH CO LTD [JP]) 16 September 2015 (2015-09-16) * paragraphs [0023], [0024], [0031] - [0033], [0035]; figures 2A-B, 3, 4 *	1-5 13 6-12	INV. B41J2/17 B41J2/175 B41J2/195
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TECHNICAL FIELDS SEARCHED (IPC)

B41J

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	27 November 2017	Bitane, Rehab

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