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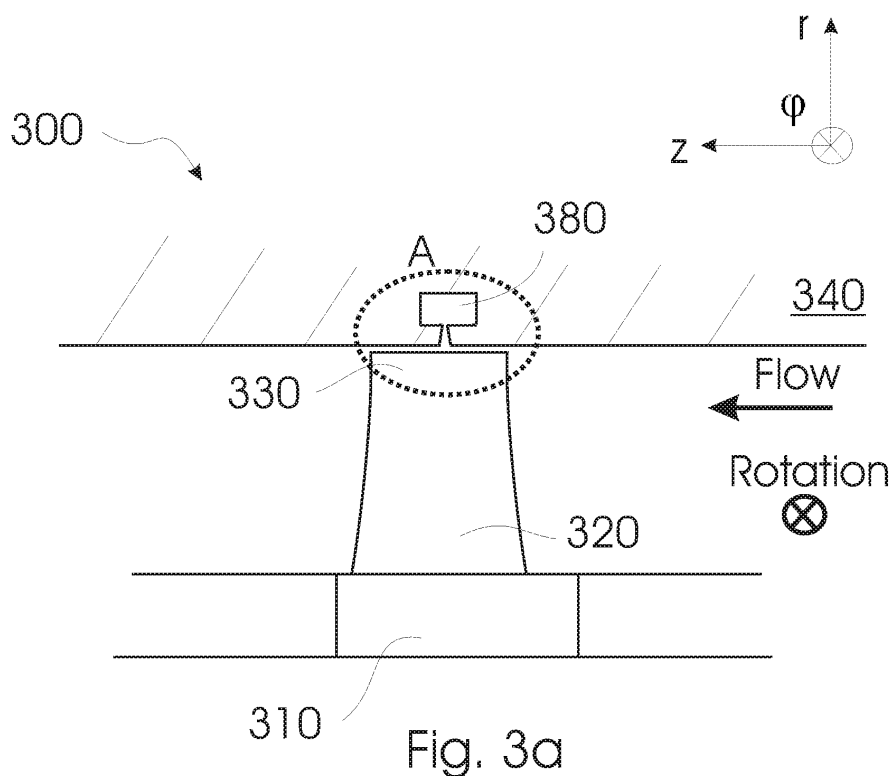
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(54) **Compressor and method for controlling the fluid flow in a compressor**

(57) The present invention relates to a compressor and method for controlling a fluid in the tip region of a compressor. More specifically, the present invention relates to a compressor having a fluidic oscillator and a method of controlling the fluid flow in the compressor. Specifically, a method for controlling a fluid flow in an axial, unshrouded radial or mixed flow compressor is pro-

vided, said method comprises providing an oscillating stream of a fluid from the exterior side of the compressor into the fluid flow. Further, a compressor is provided having a multitude of compressor blades (320) and a housing (340), the compressor comprises at least one fluidic oscillator (380) in the housing for providing an oscillating stream of fluid.



Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a compressor and method for controlling the flow within the compressor. More specifically, the present invention relates to an axial or radial compressor having a fluidic oscillator and a method of controlling the fluid flow in the compressor tip region.

[0002] Turbomachineries typically consist of at least one rotating blade row having a multitude of rotor blades connected to a shaft. In the case of the compressor, the rotor shaft is driven and the blades transfer the mechanical energy to the fluid passing through it.

[0003] The role of the compressor is to increase the pressure of the gas passing through it. Typically, they are used for a wide range of gases and in a number of different applications. Turbomachinery compressors are typically referred to as axial, mixed or radial flow depending on the nature of the flow path. In an axial compressor the flow path remains primarily axial whilst in a radial compressor the flow path transitions from axial at inlet to the rotor blade row to radial at exit.

[0004] Axial and radial compressors operate over a limited set of mass flows commonly referred to as the operating range. At a given rotational speed the operating range of a compressor is limited by choke at high mass flows and the initiation of large scale flow field instability at low mass flows appears. There are two distinct, yet related forms of flow field instability that occur at low mass flows. These are commonly referred to as rotating stall and surge. It has been shown that the initiation of rotating stall generally precedes the initiation of surge. Whether surge occurs is dependent on the nature of the system the compressor is an element of. The occurrence of either phenomenon drastically reduces the pressure rise of the compressor. These phenomena also pose severe, mechanical risks with potentially disastrous implications for the system they are a component of.

[0005] Rotating stall, and hence surge, may be initiated at the tip of the rotating component. It is believed that this form of initiation is particularly prevalent in high speed axial compressors and that it is related to the tip vortex. Further, this form of initiation has proven to be both difficult to predict and to detect. This difficulty associated with predicting the initiation of rotating stall forces designers to maintain a significant margin (commonly referred to as the stall or surge margin) between the working line (the locus of points the compressor operates on during normal operation) and the stall/surge line (the stalling mass flow as a function of given rotational speed).

BRIEF DESCRIPTION OF THE INVENTION

[0006] In view of the above, a method for influencing a tip vortex of a compressor and a compressor as described herein is provided.

[0007] Further aspects, advantages and features of the present invention are apparent from the dependent claims, the description and the accompanying drawings.

[0008] According to a first aspect of the invention, a method for influencing a tip vortex in a fluid flow of a compressor having a multitude of blades is presented, wherein each of the blades has a blade tip and a tip clearance. The method comprises providing an oscillating stream of a fluid from the exterior of the compressor into the fluid flow.

[0009] According to a further aspect of the invention, a compressor having a multitude of rotor blades and a housing is provided. The compressor includes at least one fluidic oscillator in the housing for providing an oscillating stream of a fluid.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] A full and enabling disclosure of the present invention, including the best mode thereof, to one of ordinary skill in the art, is set forth more particularly in the remainder of the specification, including reference to the accompanying figures wherein:

[0011] Fig. 1 shows a perspective view of a rotor with fluid passing through;

[0012] Fig. 2a shows a view in the r-z-plane of a rotor as known in the prior art;

[0013] Fig. 2b shows an enlarged view of the rotor of Fig. 2a;

[0014] Fig. 3a shows a view in the r-z-plane of a rotor according to embodiments described herein;

[0015] Fig. 3b shows an enlarged view of the rotor of Fig. 3a according to embodiments described herein

[0016] Fig. 4a shows a view in the r-z-plane of a rotor according to embodiments described herein;

[0017] Fig. 4b shows an enlarged view of the rotor of Fig. 4a according to embodiments described herein;

[0018] Fig. 5a shows a view in the r-z-plane of a rotor according to further embodiments described herein;

[0019] Fig. 5b shows an enlarged view of the rotor of Fig. 5a according to embodiments described herein;

[0020] Fig. 6a shows an arrangement of fluidic oscillators according to embodiments described herein;

[0021] Fig. 6b shows an enlarged view of the arrangement of Fig. 6a according to embodiments described herein;

[0022] Fig. 6c shows a further arrangement of a fluidic oscillator according to embodiments described herein;

[0023] Fig. 7a shows position 1 of a fluidic actuator using a "flip-flop"-device according to embodiments described herein;

[0024] Fig. 7b shows position 2 of a fluidic actuator using a "flip-flop"-device according to embodiments described herein;

[0025] Fig. 8a shows a fluidic oscillator according to embodiments described herein;

[0026] Fig. 8b shows a fluidic oscillator according to further embodiments described herein; and

[0027] Fig. 8c shows a fluidic oscillator according to yet further embodiments described herein.

DETAILED DESCRIPTION OF THE INVENTION

[0028] Reference will now be made in detail to the various embodiments of the invention, one or more examples of which are illustrated in the figures. Each example is provided by way of explanation of the invention, and is not meant as a limitation of the invention. For example, features illustrated or described as part of one embodiment can be used on or in conjunction with other embodiments to yield yet a further embodiment. It is intended that the present invention includes such modifications and variations.

[0029] According to embodiments described herein, a method is provided to delay the onset of the initiation of stall via disruption, or stabilization, of the tip leakage vortex. Thus, the stability (and possibly efficiency) of the compressor is increased. Further, a compressor is provided having a higher efficiency compared to compressors known in the art and having a reduced risk for the appearance of stall and/or surge phenomenon.

[0030] There are a number of means of attempting to control the onset of stall phenomena. These include the use of variable inlet guide vanes (in essence a variable stator row) at inlet to a stage, magnetic bearings for manipulating the rotor shaft and thus deliberately reducing or increasing the clearance of the tip gap between the rotor tip and the housing, and the injection of high momentum air, in either a steady or unsteady manner, ahead of the tip of the rotor leading edge. The addition of inlet guide vanes or magnetic bearings adds complexity to the compressor and leads to significant issues concerning robustness. The injection of air ahead of the leading edge of a blade may not be sufficiently localized, or be tailored sufficiently, to achieve optimal control of the vortex.

[0031] According to one aspect of the present invention, it is thought, that stall initiated at the tip of the rotor is linked to the movement of the tip leakage vortex in the rotor blade row passage. This movement of the vortex may for instance be caused by the throttling of the compressor towards lower mass flows at a given rotational speed. The movement of the vortex may also be linked to the inherent stability of the vortex. The movement of the tip vortex may include an upstream movement, a downstream movement, a movement in other directions and/or even a change in size. The change in position and behaviour of the vortex as the stall point is approached is believed to be linked to the stall initiation. Once the vortex reaches for instance a more upstream position it may cause a spike initiation. To counter this, a method is provided for influencing stall initiation that delays the initiation of the phenomena by directly influencing the vortex.

[0032] Furthermore, using the provided method and the rotor according to embodiments described herein, it is possible to influence and/or stabilise the tip leakage

vortex and/or its movement and the associated flows between the blade tip and the casing in order to stabilize the compressor and improve rotor performance. It is hypothesised, that the stabilising and the influencing of the movement of this vortex can delay the onset of spike stall initiation. To achieve this influence of the tip leakage vortex, a fluidic oscillator is used to achieve delay of the initiation of the rotating stall phenomenon.

[0033] In the following description, the term rotor should be understood as a rotor assembly, which may include a rotation axis with a multitude of attached rotor blades, and a housing, surrounding the rotor blades and the axis. According to some embodiments, the rotor may be a compressor. Although, for convenience, the following description and the figures refer to axial compressors, the present application can also be applied to mixflow or radial compressors.

[0034] Furthermore, the direction "axial" indicates the averaged main path the flow takes on passing through the rotor, also indicated by the direction z of the coordinate system. This is also marked as "flow" in the figures. The direction "circumferential" is labelled by the rotation arrow that refers to the ϕ -direction in the figures. The radial direction is perpendicular to the axial direction and runs from the centre of rotation to the exterior, e.g. from hub to tip, also indicated by the r -direction of the coordinate system. In this context, in general words, the "exterior side" describes the side as being in a more positive, radial direction than the point of view, when seen from a rotating coordinate system rotating with the rotation axis of the rotor. In more detail, the term "exterior" may exemplarily mean a location beyond the tip of the rotor blade. Therefore, this location may be between the tip of the blade and the housing or in the housing itself.

[0035] Further, the term "toward" means in this context "in the direction of", or "along a course leading to".

[0036] In the description, the same features are indicated by the same reference numbers and the figures are described with respect to the differences compared to the preceding figures without repetition of the already described reference numbers.

[0037] The directions with their notation can easily be seen in the coordinate system of Fig. 1. Therein, the rotation direction, or circumferential direction is indicated by coordinate ϕ , the radial direction is denoted by the coordinate r and the flow direction or axial direction is given by the coordinate z .

[0038] Fig. 1 shows a schematic drawing of a section of a rotor 100 as known in the art. The rotor includes a rotation axis, which a shaft 110 is centered on. The shaft 110 provides or passes the rotational energy of the rotor 100. In case of a compressor, the rotation axis 110 provides the energy, which is converted into fluid energy. On the rotation axis 110, a plurality of rotor blades 120 is added. In Fig. 1, exemplarily three rotor blades are shown in the displayed section. This number is not limiting and can also be less than or greater than three. Typically, the number of blades is not limiting. Each rotor

blade has a rotor blade tip 130 in the exterior radial direction (i.e. largest r-direction) of the blade.

[0039] Further, in Fig. 1 the flow and the rotation are shown by respective arrows. For the sake of simplicity and a better view, a housing is not shown in Fig. 1, but an exemplarily depicted tip leakage vortex 150 indicates the interaction of the fluid between the rotor blade tip 130 and the housing.

[0040] The rotor blades 120 have a predetermined geometry according to their desired function. For instance, each blade has a 3-dimensional geometry having a different shape and extension in each direction. The geometry of the blades in the figures is exemplarily and is not limiting to the present invention. The respective geometry of the blades is not shown in the merely schematic figures, but the blades are generally curved in dependence of their desired function. For instance, a compressor has blades with a curved surface, which allows for compressing the passing fluid.

[0041] Typically, turbomachinery compressors include a rotation axis, a shaft, a set of one or more rotating blade rows (rotor blade row or impeller), a set of one or more stationary blade row (stator or diffuser) and a stationary housing (commonly referred to as a casing). In Fig. 1, only one rotating blade row 101 is exemplarily shown. For the sake of simplicity and demonstration purposes, neither the housing nor a stationary blade row is shown in Fig. 1. The pairing of an individual rotor and stator blade row is referred to as a stage. The rotor blades 120 are driven by an external source (e.g. motor or turbine, not shown) and convert the mechanical (rotational energy) into an increase in enthalpy and pressure. Typically, a given compressor will operate at a range of rotational speeds with the pressure rise directly proportional to this parameter. The requirement for a moving blade row and a stationary casing generally leads to a clearance between the tip 130 of the rotating component and the casing (this is not the case for a shrouded impeller in a radial compressor). This clearance is generally small and has been demonstrated to have important implications in terms of both the pressure rise and operating range of the machine.

[0042] Typically, the function of a rotor as shown in Fig. 1 can be described as follows. Typically, the shaft 110 spins the rotor blades 120. The rotor blades 120 do work on the flow passing through them thus transferring mechanical energy into an enthalpy and pressure rise of the gas.

[0043] Fig. 2a shows a schematic view of a rotor 100 as known in the art in the r-z-plane. The rotor blade 120 with a blade tip 130 is mounted on the rotation axis or shaft 110. A housing 140 surrounds the rotor blades and the axis along the axial direction. The flow and the rotation are indicated according to Fig. 1.

[0044] Fig. 2b shows a detail view from section A as indicated by the dashed circle in Fig. 2a. The vortex 150 in the gap 170 between housing and the blade tip is e.g. generated from the flow originating from the pressure

side of the rotor airfoil, flowing through the gap between the tip 130 of the blade 120 and the casing and emerging on the suction side. This flow, driven by the pressure gradient between the two sides of the airfoil, interacts with the main flow passing through the rotor and results in the formation of a vortex.

[0045] The tip leakage vortex 150 of the shown embodiment increases over the width of the blade 120 in axial direction and may further increase even if it reaches beyond the blade width.

[0046] The figures show schematic drawings of the arrangement and the vortex. However, the skilled person will know that the vortex has components in the axial, the radial and the tangential direction. Although the drawings may convey the impression that the exemplarily shown vortex has only an axial component, it should be understood that the vortex has generally components in a wide range of directions.

[0047] In certain cases, the behavior of the tip leakage vortex has been linked to the initiation of rotating stall. The embodiments described herein consider the use of a fluidic oscillator for influencing the behaviour of the tip vortex. The embodiments further consider the use of fluidic oscillators to control the tip leakage vortex in a compressor as stall is approached with the intention of delaying the initiation of the rotating stall phenomenon. This typically increases the operating range of compressors. Furthermore, by providing oscillating fluid, it is possible to provide a fluid with a high energy, while the amount of the fluid is decreased compared to a continuous stream. Moreover, a defined amount of oscillating gas can be provided by using fluidic oscillators.

[0048] According to embodiments described herein, a rotor is provided having a fluidic oscillator device. The fluidic oscillator device is typically positioned in the housing. In Fig. 3a, a rotor 300 according to embodiments of the present invention is shown. As can be seen, a fluidic oscillator 380 is positioned axially just ahead or over the tip 330 of the rotor blade in the housing 340 of the rotor 300.

[0049] Typically, the fluidic oscillator device provides a pulsated stream of gas. According to embodiments described herein, a "fluidic oscillator" or a "fluidic oscillator device" referred to herein is a device which is able to provide a fluid stream in a repetitive variation in time, varying about a central value or between two or more different states. According to some embodiments, the oscillator has a certain frequency, which can be continuous and constant. According to some embodiments described herein, the frequency may also be transient and may change over the time.

[0050] According to embodiments described herein, the fluidic oscillator 380 provides a pulsating stream of a fluid in different directions. This may be only one direction of the z-, r-, or φ -direction. Alternatively, the oscillating fluid may be directed in more than one direction, for instance in a direction, which is composed of two or three of the z-, r-, or φ -directions. The fluidic oscillator 380 in-

jects high momentum fluid, e.g. air/gas in either the axial direction, in the tangential direction, radially toward the tip of the blade or in a combination of the three at one or a number of circumferential locations. This will be described in more detail below with regard to Figs. 3 to 5.

[0051] Referring to Fig. 3b, a section A of the rotor shown in Fig. 3a is represented in more detail. In a gap 370 of the rotor 300 a tip leakage vortex 350 develops. According to embodiments described herein, a fluidic oscillator 380 is located in the housing 340 of the rotor. The fluidic oscillator comprises an outlet 385, which is positioned so that the outlet is directed toward the blade tip 330. The fluidic oscillator 380 provides a pulsating stream 390 of a fluid towards the blade tip 330.

[0052] According to embodiments described herein, the outlet may have an angular shape in order to allow the fluid to be spread over a certain range.

[0053] According to embodiments described herein, the outlet may be split in more than one, for instance two outlet parts providing alternately the pulsating stream. For the sake of simplicity, only one outlet is shown in the Figs. 3 to 5. According to embodiments, which can be combined with other embodiments described herein, the pulsating stream 390 is injected in a substantially radial direction toward the blade tip 330. When the pulsating fluid exits the fluidic port 385, the fluid may spread according to the flow conditions in the gap 370 in different directions.

[0054] The term "substantially" in this context means that there may occur a deviation from the attribute labeled with "substantially". Typically, the term "substantially" includes a deviation from less than 15%, more typically less than 10% and even more typically less than 5%. For instance, the term "in a substantially axial direction", resp. "in a substantially circumferential direction" comprises deviations of +/- 20% from the axial resp. circumferential direction.

[0055] However, as the pulsating fluid 390 has a high energy, the spread of the pulsating fluid 390 may be small compared to the deviation from the radial direction. According to some embodiments, the spread width may be large, if the flow conditions in the gap 370 are strong enough to influence the pulsating stream 390. Typically, the spread angle is between 5° and 45°, more typically between 10° and 30°, and even more typically between 15° and 30°.

[0056] Typically, the pulsating fluid 390 is the same fluid as in the main flow (substantially in the z-direction) of the rotor, which may be, for instance, air. Alternatively, the pulsating fluid 390 may be different from the fluid in the main flow. According to embodiments described herein, the interaction between the fluid in the gap 370 and the pulsating fluid 390 may be influenced not only by the energy of both fluids, but also by the type of fluid.

[0057] As in Fig. 3b the fluid spreads, the fluid may be provided to the tip vortex 350 in the tip region in all three directions (the axial, the radial and the circumferential direction), even if the predominant direction is the radial

direction. According to some embodiments, none of the three directions is predominant and the oscillating fluid 390 is provided to the blade tip 330 in substantially equal parts.

[0058] Fig. 4a shows a rotor 300 having a fluidic oscillator 380 located in the housing 340. In this embodiment, the fluidic oscillator 380 provides pulsating fluid 390 in the gap 370 between the blade tip 330 and the housing 340 in a radial direction, as can be seen in Fig. 4b. Typically, the energy of the oscillating fluid 390 may be high enough, so that the oscillating stream 390 is not spread in other directions and maintains its substantially radial direction when entering in the gap 370 toward the rotor blade tip 330. Thereby, the oscillating fluid 390 may influence the tip vortex 350 by limiting the tip leakage flow.

[0059] According to some embodiments described herein, the fluidic oscillator 380 may also be located in the housing 340 of rotor 300, such that the fluid is provided in a substantially axial direction. Therefore, the outlet of the fluidic oscillator 380 is arranged so that the outlet 385 directs the pulsating stream 390 in a certain direction, as exemplarily shown in Figs. 5a and 5b, the z-direction or a combination including the z- as well as the r-direction. Thereby, the vortex 350 may be influenced in a manner different from that in Figs. 3 to 4.

[0060] Typically, the direction of the fluid stream is substantially towards the centre of the rotor. However, according to some embodiments, the direction may vary in the z-, as well as in the φ -direction to a certain degree. Such a variation can for instance be seen in Fig. 5b.

[0061] According to some embodiments, the outlet of the oscillating fluid may be arranged in any angular manner and may be inclined in almost any direction that produces a positive result in terms of performance.

[0062] According to some embodiments, the oscillating fluid stream is not limited to the combinations described herein. The direction of the oscillating fluid stream may be achieved by the geometry, by the arrangement or by the controlling of the oscillator device.

[0063] According to some embodiments, the fluidic oscillator 380 can be arranged in any manner and is not limited to the above, exemplarily described embodiments.

[0064] According to some embodiments, which can be combined with any other embodiments described herein, there may be more than one fluidic oscillator located in the rotor over the tip 330 of the rotor blade, as shown in Figs. 6a to 6c. For instance, in Fig. 6a, an arrangement of three fluidic oscillators distributed along the axial direction is shown. According to some embodiments, a multitude of fluidic oscillators may be arranged in circumferential direction in the housing around the rotor. The three fluidic oscillators 380, 381, and 382 are typically positioned in any manner over the blade 380. According to some embodiments, there can be more than three fluidic oscillators be positioned over the length (chord) of the blade 380. Typically, a multitude of fluidic oscillators is provided.

[0065] In Fig. 6b, a detailed view of section A of Fig. 6a is given. Therein, the fluidic oscillators 380, 381, and 382 provide streams of oscillating fluid 390, 391, and 392 toward the tip of the blade in the gap 370 between the blade tip 330 and the housing 340. The direction of the oscillating streams 390, 391, and 392 is substantially radial, but the fluid spreads in all direction when leaving the fluidic oscillator. According to some embodiments, the oscillating fluid stream 390, 391, and 392 can also be directed in only one direction, such as the circumferential direction or the axial direction. Oscillating fluid, which is directed in one direction, can be seen from Figs. 4a to 5b and can be combined with the arrangement shown in Fig. 6.

[0066] By providing a multitude of fluidic oscillator devices, the influence on the tip leakage vortex may be improved. According to some embodiments, the influence can be achieved more efficiently by providing oscillating fluid to a multitude of locations in the gap between the blade tip and the housing. Therefore, different vortex movements and/or changes can be prevented by providing e.g. more fluid in one direction than in the other directions.

[0067] Alternatively, a multitude of fluidic oscillators may be arranged in axial direction along the length of the rotor. According to some embodiments, the multitude of fluidic oscillators may be arranged around the rotor housing 340. Typically, the multitude of fluidic oscillators may be arranged at regular distances. Alternatively, the fluidic oscillators may be arranged at irregular distances. According to some embodiments described herein, the multitude of fluidic oscillators is arranged in a circumferential and an axial direction.

[0068] According to some embodiments described herein, a fluidic oscillator as shown in Fig. 6c is provided. The fluidic oscillator 380 includes several outlets 385, 386, and 387. According to some embodiment, which can be combined with other embodiments described herein, the oscillating fluid passes to either one of the different outlets or through all outlets at different or equal amounts.

[0069] According to some embodiments, the fluidic oscillator can be controlled by means of a computer, which is, for instance, coupled to a pressure sensor. According to other embodiments, the fluidic oscillator may be controlled by a computer, which is coupled to a velocity sensor, which may be positioned at the inlet of the rotor. According to some embodiments, the computer is adapted for calculating the necessary measures to prevent the tip leakage vortex to change beyond a predetermined range. Therefore, the computer may be fed with experimental or numerical simulation data as a reference for the controlling measures. If a multitude of fluidic oscillators is provided, the computer may control them dependently from one another. If a fluidic oscillator with more than one outlet is provided, the computer may control the actual used outlet or the amount of use of the single outlets.

[0070] According to embodiments described herein, by providing a fluidic oscillator the operating range of a compressor can be extended. Further, the performance of the rotor may be improved and stall initiation can be avoided as explained in more detail below.

[0071] According to embodiments, which can be combined with any embodiments described herein, the fluidic oscillator(s) as mentioned above may be fluidic actuators providing a stream of pulsating fluid.

[0072] According to some embodiments, the fluidic actuator employs a so called "flip-flop" diverted valve. The fluidic "flip-flop" device, where fluid, e.g. air is blown from a nozzle onto the wedge connecting two bifurcating channels open to the environment, is illustrated in Fig. 7a and 7b. The fluidic "flip-flop device" is also labelled as a fluidic switch.

[0073] In Fig. 7a and 7b, a fluidic switch is shown in different switching positions. According to some embodiments described herein, the fluidic switch includes a supply 610, two inputs 620 (also labelled as control inputs 620), an interaction region 630, and two channels 641 and 642. In a first switching position, as shown in Fig. 7a, the supply flow 615 is passed from the supply 610 to a wedge in an interaction region 630 from which the two bifurcating channels 641, 642 depart. Due to the wall-attachment effect (Coanda effect) the supply flow 615 will stabilize itself into either one of the two channels 641, 642. In Fig. 7a, the flow is stabilized in the channel 641 and departs from the fluidic switch 600 in an output stream 645. The fluidic switch 600 can e.g. be used as fluidic oscillator 380 as shown in Figs. 3 to 6.

[0074] By applying a proper pressure to the control ports 620 (the control flow 625 is shown in dashed lines) it is possible to divert the flow to the other channel, and vice versa. The second switching position is shown in Fig. 7b, where the fluid flow is stabilized in channel 642. By switching the position of the stabilized flow between the two channels 641, 642 by means of the control flow 625, a pulsating stream is produced and can be released in form of an output stream 645. These output streams form the pulsating stream 390 as described above are directed to the gap between the blade tip and the housing toward the blade tip.

[0075] According to some embodiments, the control flow 625 is controlled by means of a computer in order to adjust parameters of the fluidic switch, such as released fluid amount, pressure in the released outlet stream or frequency of the oscillating stream. Therefore, the control flow may be provided in different manners. For instance, the control flow 625 may be provided by separate, independent channels or by some kind of feedback mechanism.

[0076] When the control ports are connected through some feedback mechanism, a fluidic oscillator is provided as can be seen in Figs. 8a to 8c. Three examples are shown in Figs. 8a to 8c. All three of them have a feedback system, which enables them to be passively controlled that is by the fluid flow itself without the need of external

control, as described in more detail below. According to embodiments described herein, the fluid devices may also be actively controlled.

[0077] The term "feedback system" in this context describes a part of an oscillator device, which provides a control flow for controlling the oscillation of the fluid. According to some embodiments, the feedback system uses a certain amount of the oscillating fluid stream and recycles it as control flow to the oscillating fluid stream in a more upstream position. Thereby, the control of the flow in the oscillator can be described as being self-regulating using the wall-attachment-effect.

[0078] In Fig. 8a, a "direct feedback" actuator is shown. The two output channels 641, 642 are connected directly to the control ports 661, 662 by means of a feedback line. When the supply flow 615 stabilizes in either one of the two output channels 641, 642 (in Fig. 8a exemplarily channel 642), some portion of it will recirculate in the feedback line and will create an overpressure at the control flow 625 (indicated by the dashed arrows). When this pressure reaches a critical value, switching will occur and the flow will divert to the other channel 641. Once the flow has switched, a similar process will ensue and the flow will then repeatedly switch between the two outputs of channels 641, 642 with the control flow 625 initiating the switching of the flow direction, thereby generating two pulsating output streams 645, which leave alternately the outlets at 90-degree phase with one another.

[0079] According to some embodiments, the oscillating fluid stream, which can be air, may be fed to the gap in only one outlet as exemplarily shown in Fig. 3 to 5. Therefore, in this embodiment, the outlet 385 may comprise two output channels 641, 642.

[0080] In Fig. 8b a "coupled control" actuator is shown. In this embodiment, two control ports 661, 662 are connected to one another. When the supply flow 615 stabilizes in either one of the two output channels 641, 642 (here again exemplarily 642), it will induce an expansion wave to travel to the other control port. This creates a relative overpressure and switching will occur. Again, once the flow has switched, a repetitive process will ensue process will ensue generating two pulsating flow outlets at 90 degree phase with one another.

[0081] In Fig. 8c an "internal feedback" oscillator is shown. The two output channels 641, 642 are connected to a cavity 670, which acts as a Helmholtz resonator and provides the oscillating pressure needed for the switching. When a fluid is forced into a cavity, such as cavity 670, flow from the nozzle impinges on the wedge to produce vortices. These propagate back to the orifice to induce jet oscillations transverse to the flow direction. Thus, the fluid inside of the cavity will flow out alternatively through channels 641, 642, thereby generating two pulsating output streams which leave alternately the outlets at a 90-degree phase with one another.

[0082] According to embodiments described herein, the frequency of injection of the oscillating fluid stream is set by the volume/length of the feedback or control

loops, and it is tuned to the blade passing frequency by means of a passive pressure sensor and actuator, which is mounted flush to the engine casing and connected to the oscillator control port area. According to some embodiments, the frequency of the oscillating fluid stream can change in time. Typically, the timing of the injection can either be achieved actively or passively. The term passively is used to describe a system which is controlled only by the fluid flow, i.e. by the wall-attachment effect (Coanda-effect) and the control flow through the feedback/control loops, which forces the fluid to switch from one channel to the other dependent on the fluid characteristics and the characteristics of the geometry of the oscillator. Therefore, the oscillator makes use of the wall attachment effect and the fluid-fluid interaction for controlling the switching of the fluid stream. The word active is used to describe a control system in which the switching of the fluid is maintained by some external control parameters, such as flow direction of the inlet flow, active variation of the control flow etc.

[0083] According to some embodiments described herein, a method for controlling a fluid flow in a rotor is provided. According to some embodiments described herein, an oscillating stream of a fluid is provided toward the blade tip between the blade tip and an exterior side of the blade. For instance, the oscillating stream may be provided in a gap between the blade tip and the housing toward the blade tip.

[0084] A vortex develops during operation of a rotor, typically in compressors, at the blade tip as the tip leakage flow interacts with the mainstream flow. The influence of the vortex has been linked to the initiation of stall. Thereby, the vortex may change energetically and/or interact with the geometry of the blades and it has been found, that this may cause stall and surge phenomena.

[0085] According to an aspect described herein, an oscillating stream of fluid is provided by a fluidic oscillator, such as a fluidic switch or a fluidic "flip-flop" device used to influence the tip leakage flow. This in turn influences the tip leakage vortex and hence the stability of the compressor. The vortex can be prevented from moving upstream or increasing its size up to a critical size. Thereby, the efficiency can be increased in two ways: first, the risk for the stall phenomenon to occur is decreased and second, the oscillating fluid as described above is very energy saving due to the passive or active switching manner and the limited need of fluid. Hence, the overall-energy-yield of the rotor can be improved without disturbing the main fluid flow. Further, the method for controlling a fluid flow in a rotor is used for stall control.

[0086] According to some embodiment, which can be combined with other embodiments described herein, the vortex can be stabilised by the pulsating stream of fluid. Stabilisation in this context means that one or more characteristics of the vortex are influences and/or balanced. Typically, not only the vortex but other flow phenomena in a tip region of the rotor blade can be influenced.

[0087] According to yet another embodiment, the

above described method is a method of stall control that influences the role of the tip region flow phenomenon on the stall initiation process. For instance, among these flow phenomena may be the behaviour of the tip vortex. The control of such phenomena is achieved by the utilisation of flow control via the employment of passive actuators to influence such flow phenomena in a certain manner. According to other embodiments, active actuators may also be employed, if proven necessary.

[0088] According to some embodiments described herein, the oscillating stream oscillates in a substantially 90-degree phase. Thereby, two streams of a fluid are provided and leave the oscillator alternately in a substantially regular manner, so that the two alternating fluid streams have a 90-degree phase with one another.

[0089] According to some embodiments, which can be combined with other embodiments described herein, the oscillating fluid stream may be directed toward the tip of a rotor blade of a compressor in a substantially radial manner. According to other embodiments, the oscillating stream may be directed toward the tip of a rotor blade in a substantially axial manner. According to yet other embodiments, the oscillating stream may be directed toward the tip of a rotor blade in a substantially circumferential manner. Typically, the direction of the oscillating stream is not only one of the three coordinate directions, but is composed by at least two of the three directions, or even by components of all three directions.

[0090] Typically, the fluid in the oscillating stream is the same fluid as the fluid in the main stream of the rotor, e.g. air. According to some embodiments, the fluid in the oscillating stream may be different from the fluid in the main stream.

[0091] According to some embodiments described herein, a multitude of oscillating streams is emitted from a multitude of different locations.

[0092] According to some embodiments, the frequency of the oscillating stream is determined by measuring at least one characteristic of the fluid between the exterior side of the rotor and the tip of a rotor blade. According to other embodiments, the frequency of the oscillating fluid is determined by characteristics of the main fluid, for instance the velocity at the rotor inlet. With a given blade geometry, the appearance and the characteristics of a vortex between the housing and the blade tip can be predicted.

[0093] According to some embodiments, the amount of oscillating fluid stream can be controlled to influence the characteristics of the fluidic oscillator. This may be done by controlling and regulating the control flow, by geometry conditions and/or by regulating the pressure of the oscillating stream. By controlling the amount of the oscillating stream, it is further possible to control the pressure of the output stream of the fluidic oscillator. When the pressure of the oscillating stream is controlled, the influence of the oscillating stream on the vortex can be affected. According to some embodiments described herein, the frequency of the oscillating stream can be

controlled in order to improve the influence on the vortex according to determined needs.

[0094] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the described subject-matter, including making and using any devices or systems and performing any incorporated methods. While various specific embodiments have been disclosed in the foregoing, those skilled in the art will recognize that the spirit and scope of the claims allows for equally effective modifications. Especially, mutually non-exclusive features of the embodiments described above may be combined with each other. The patentable scope is defined by the claims, and may include such modifications and other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

Claims

1. A method for influencing a tip vortex of a compressor having a housing, a multitude of blades, each having a blade tip, a tip clearance being between the housing and each of the blade tips, the method comprises providing an oscillating stream of a fluid from the exterior side of the compressor into the fluid flow.
2. The method according to claim 1, wherein the oscillating stream is directed toward the tip of a blade of the compressor.
3. The method according to any of the preceding claims, wherein the oscillating stream is provided such that the flow characteristics in an area between the exterior side of the compressor and the tip of a blade of the compressor are influenced by the oscillating stream.
4. The method according to any of the preceding claims, wherein the oscillating stream stabilises the tip vortex.
5. The method according to any of the preceding claims, wherein the oscillating stream is emitted in a substantially radial direction.
6. The method according to any of the preceding claims, wherein the oscillating stream is emitted in a non-perpendicular manner with respect to one or more of the axial, tangential and radial direction.
7. The method according to any of the preceding claims, wherein the oscillating stream oscillates in a

changing frequency.

8. The method according to any of the preceding claims, wherein the oscillating stream is passively controlled. 5
9. A compressor having at least a multitude of rotor blades and a housing, the compressor comprising:

at least one fluidic oscillator in the housing for providing an oscillating stream of a fluid. 10
10. The compressor according to claim 9, further comprising at least one outlet of the at least one fluidic oscillator, the outlet being directed toward the tip of at least one of the rotor blades. 15
11. The compressor according to any of claims 9 to 10, wherein the fluidic oscillator directs the oscillating stream of a fluid in a substantially radial direction. 20
12. The compressor according to any of claims 9 to 11, further comprising a multitude of fluidic oscillators.
13. The compressor according to any of claims 9 to 12, wherein the oscillator comprises a feedback system. 25
14. The compressor according to any of claims 9 to 13, wherein the oscillator is actively controlled. 30
15. The compressor according to any of claims 9 to 14, wherein the oscillator is passively controlled.

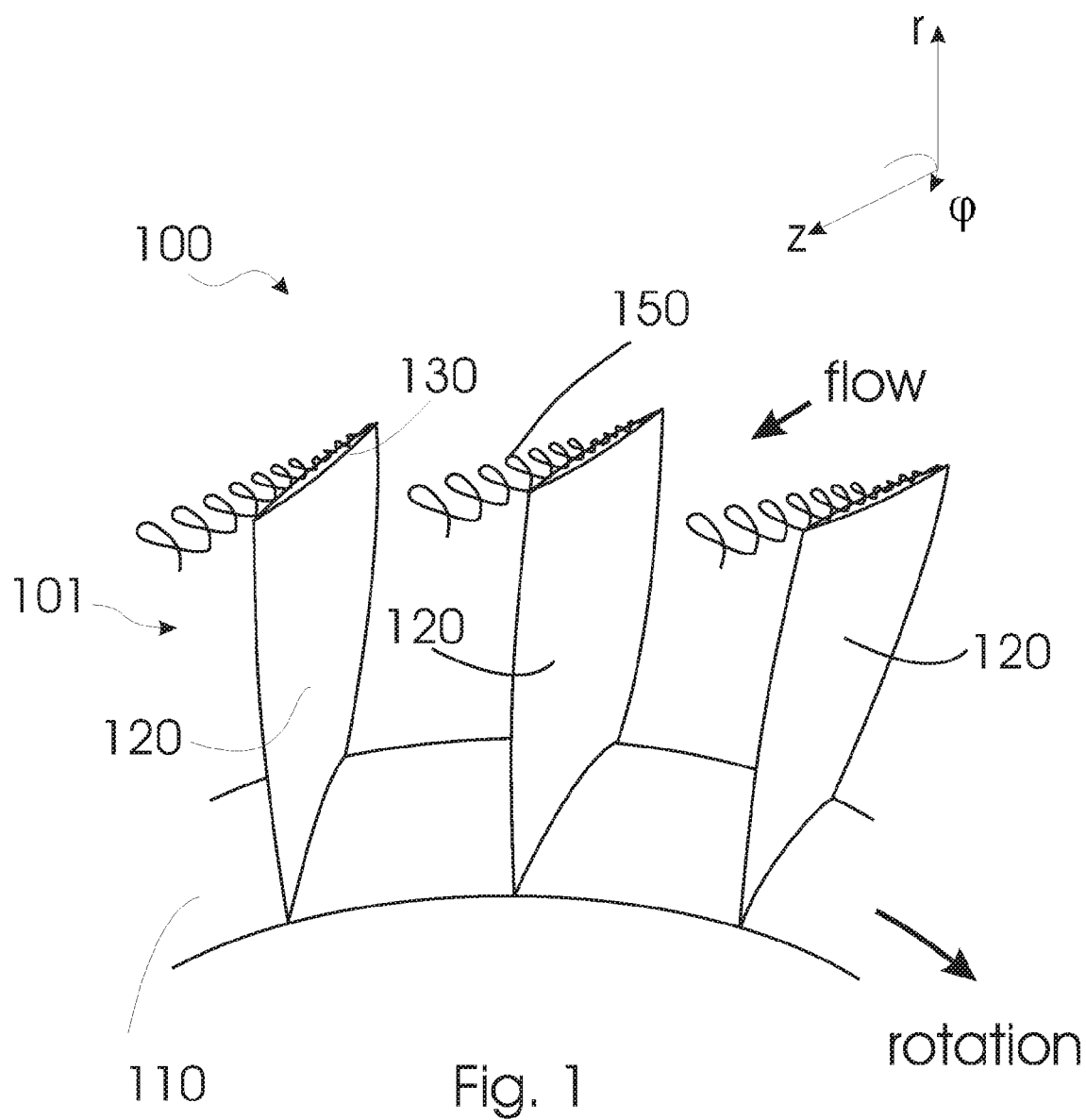
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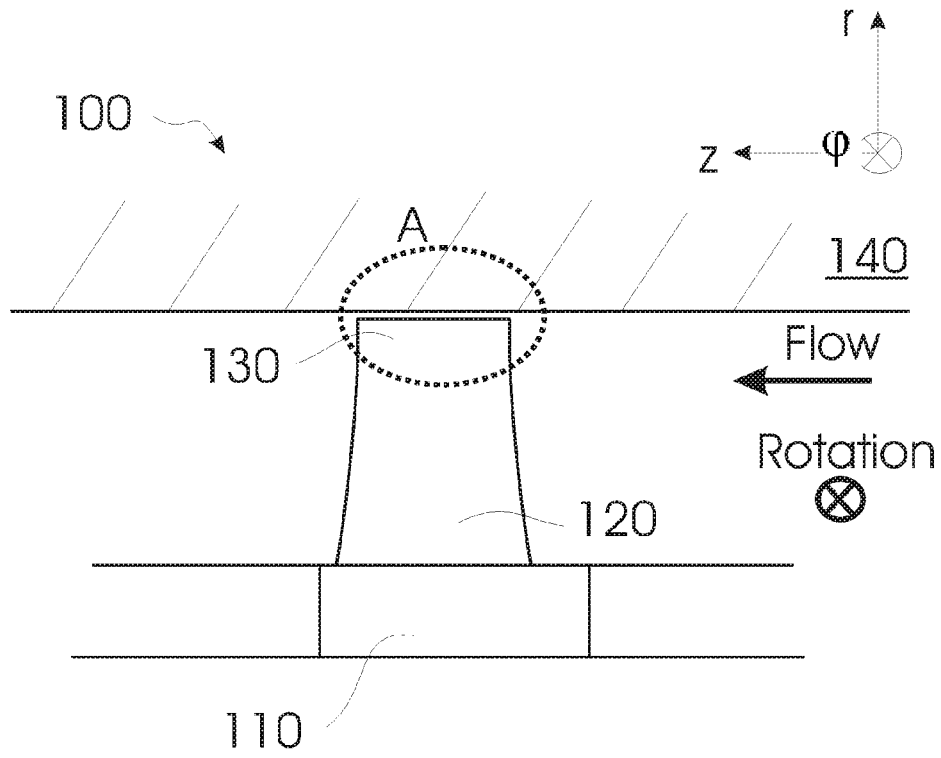


Fig. 2a

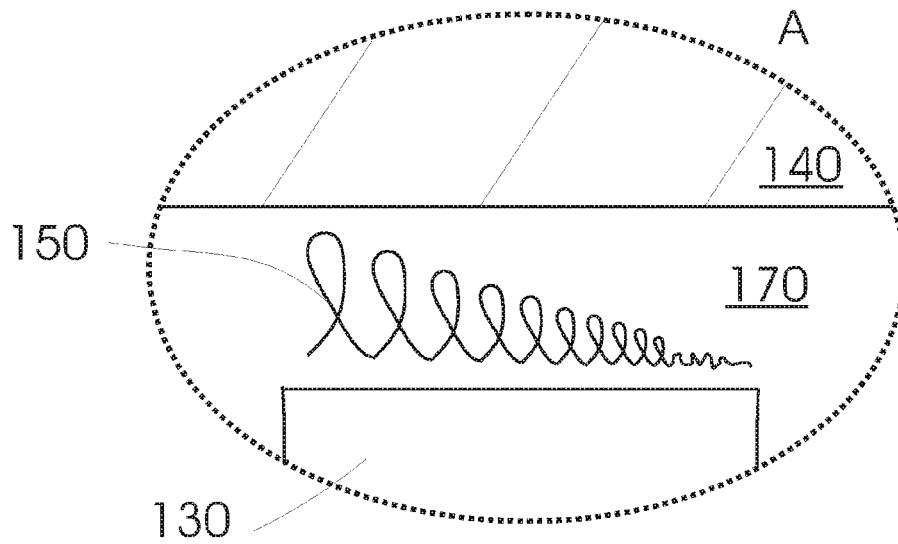
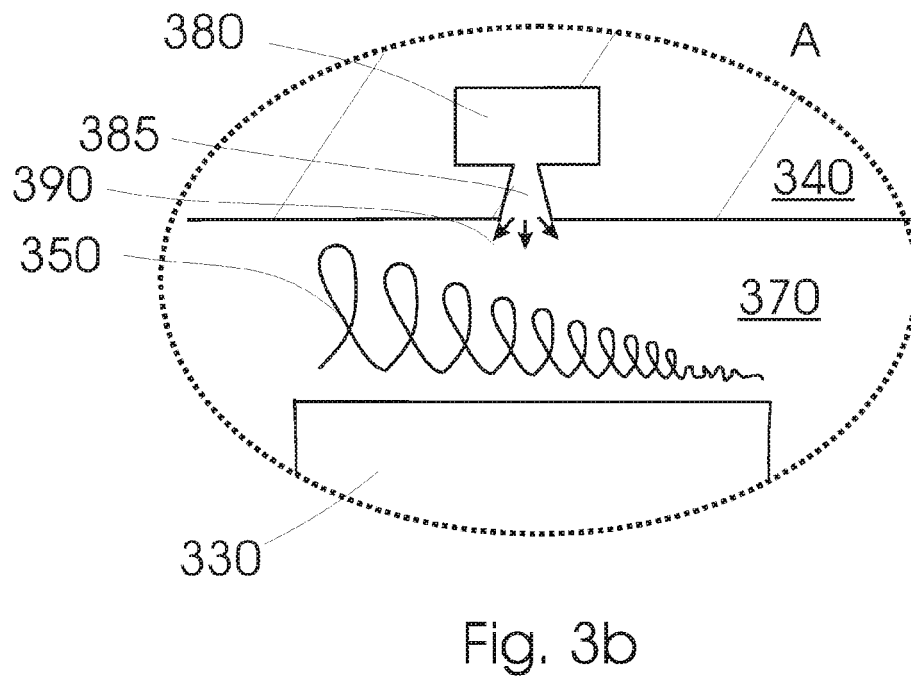
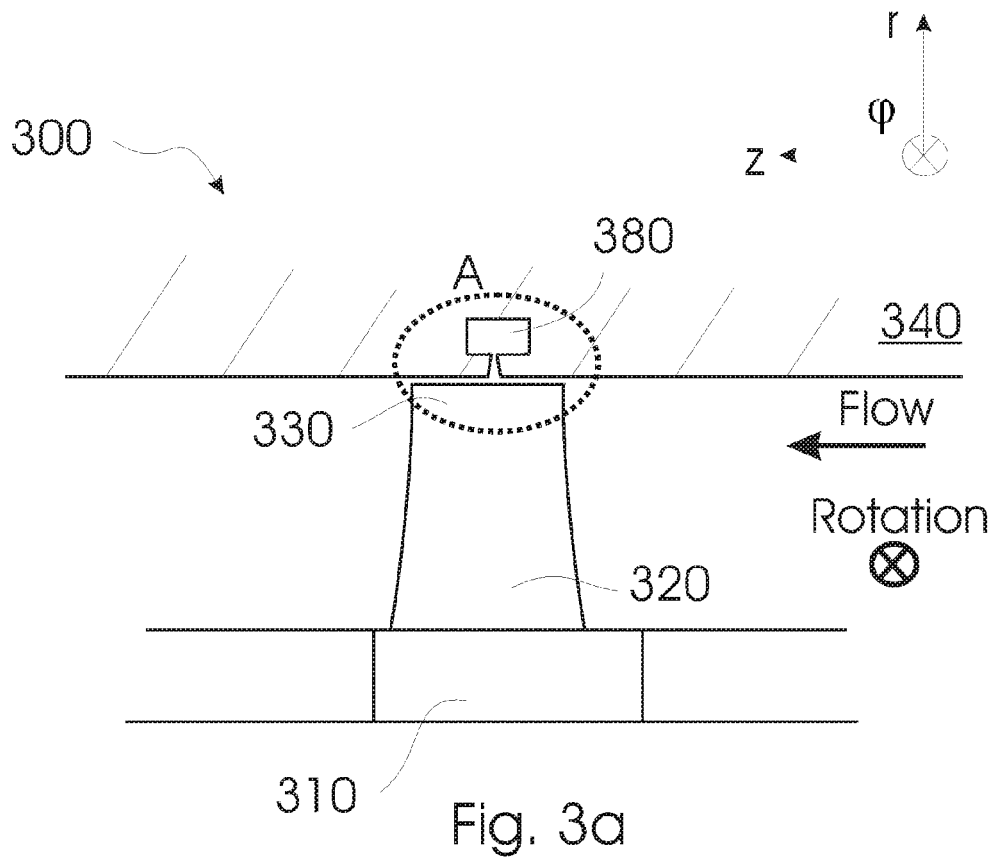
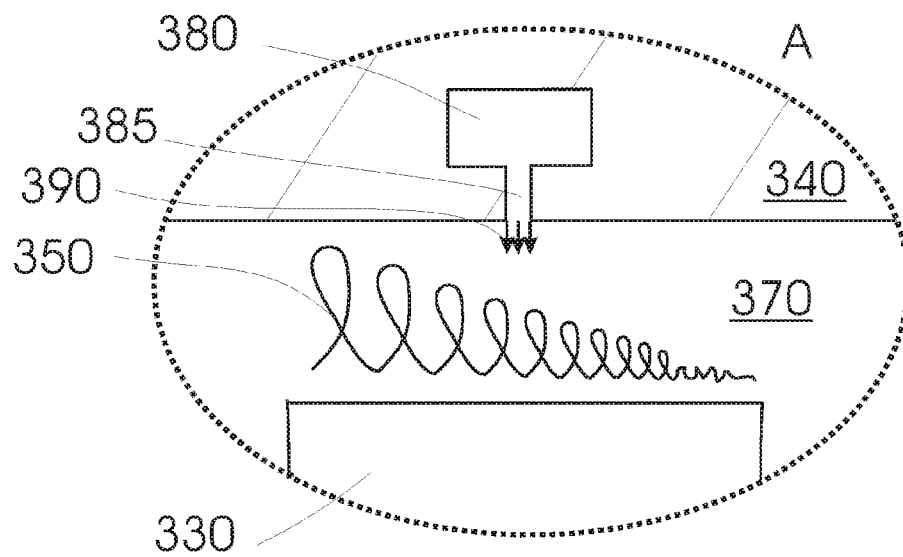
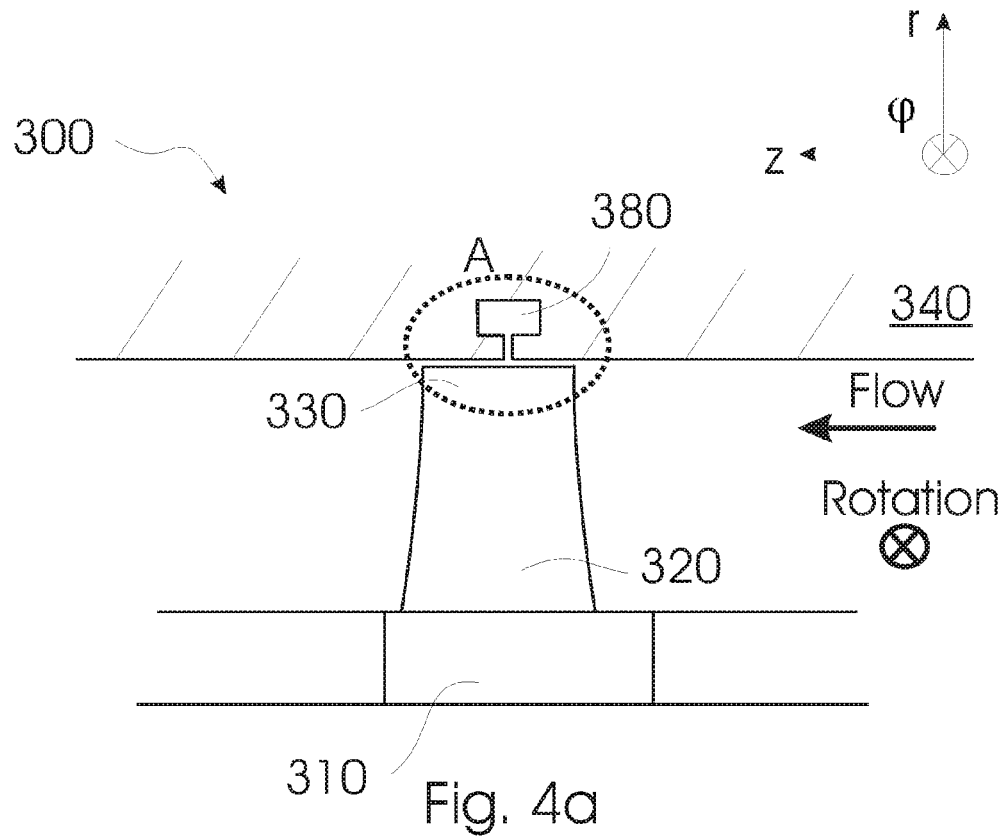
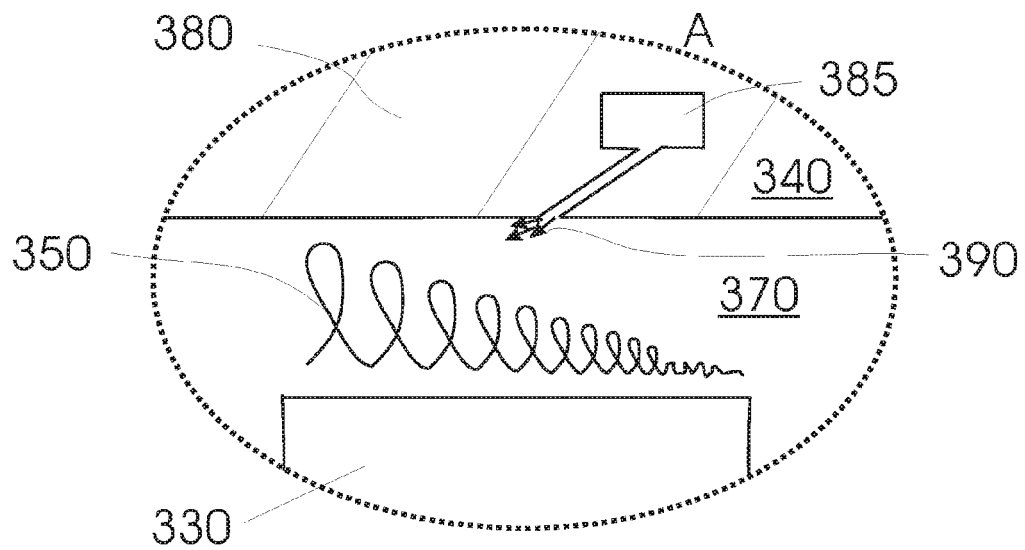
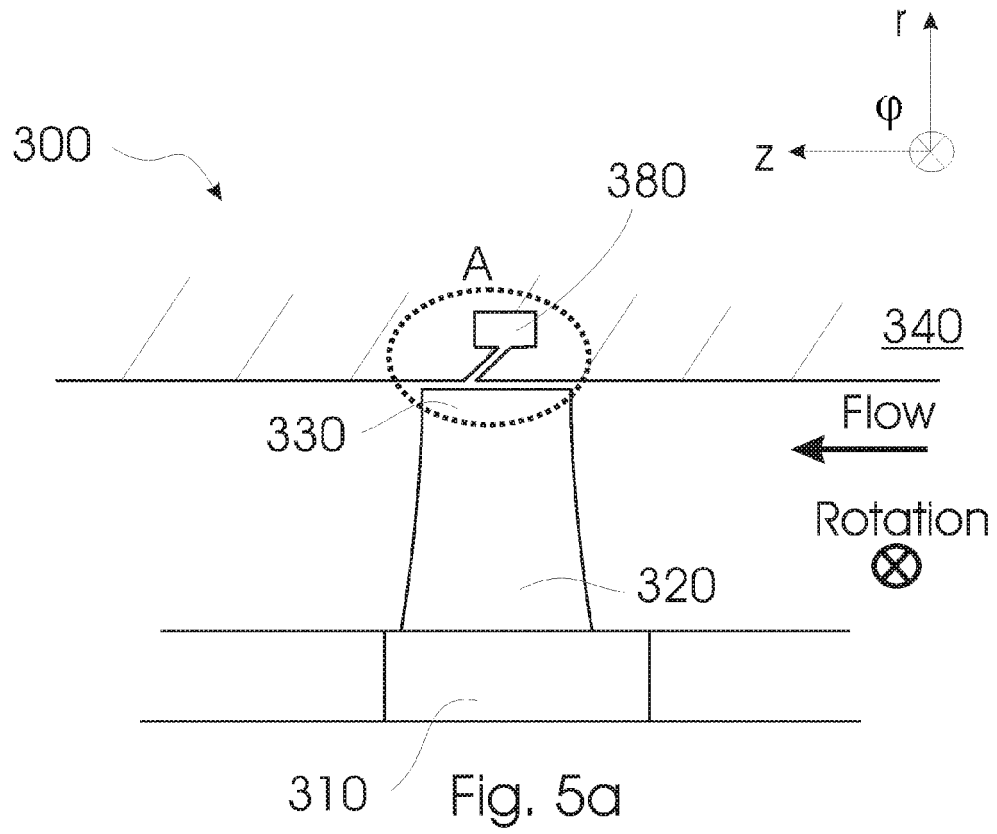
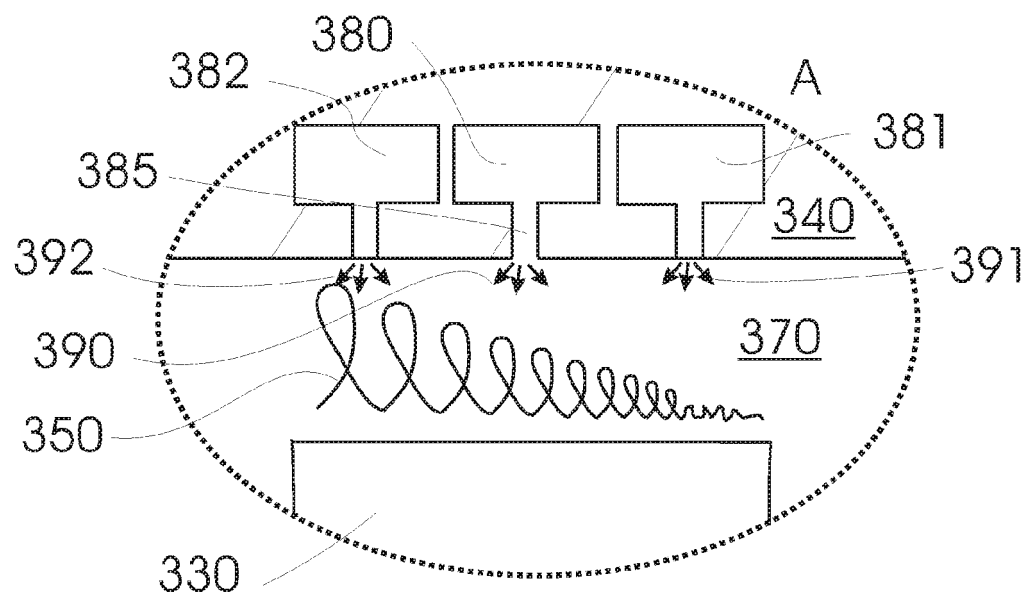
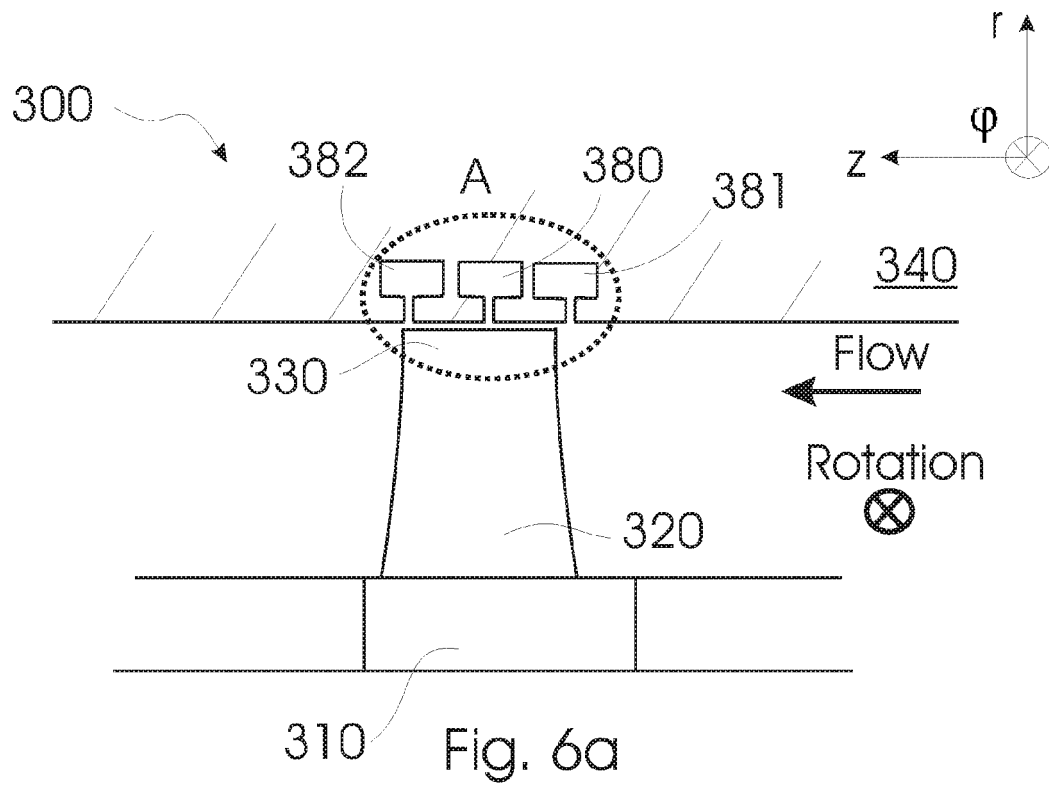


Fig. 2b









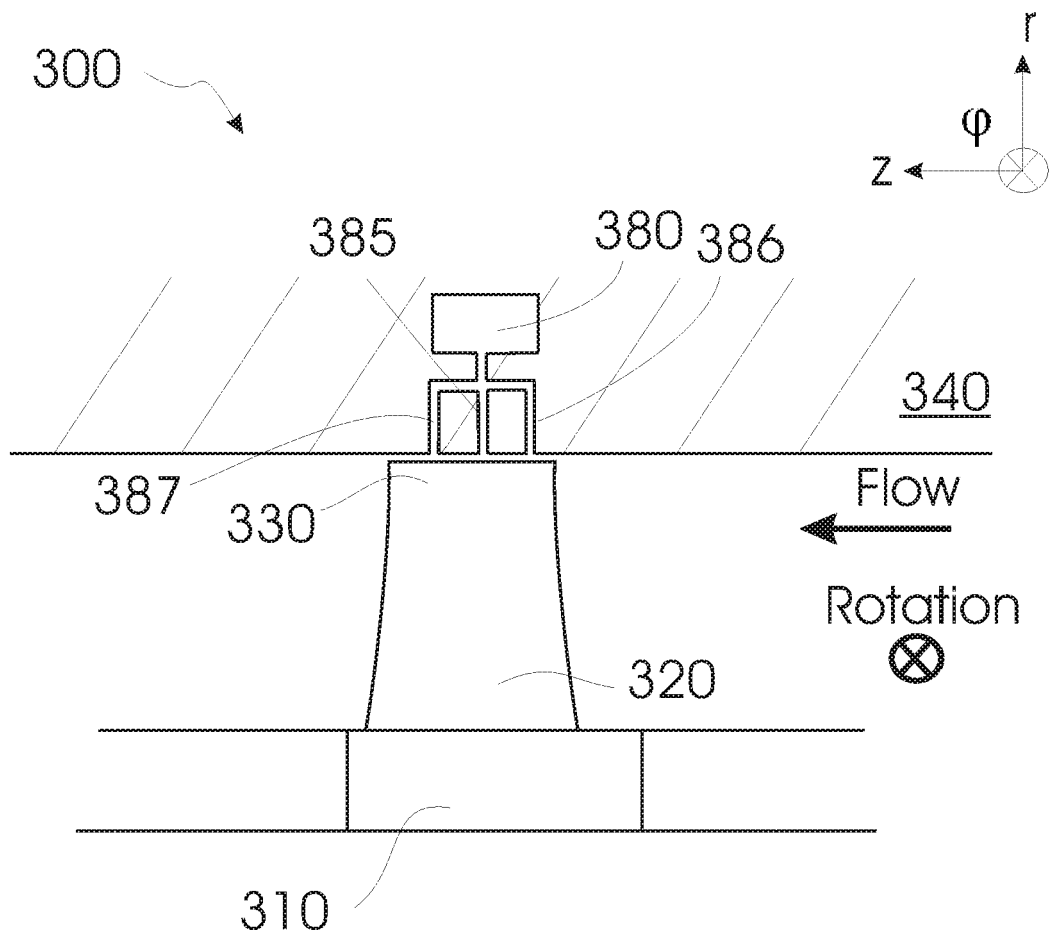


Fig. 6c

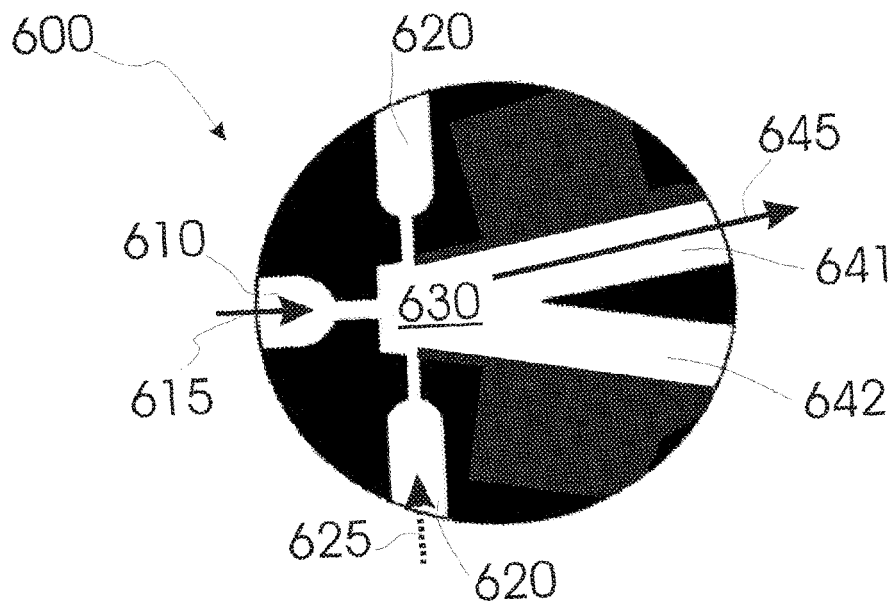


Fig. 7a

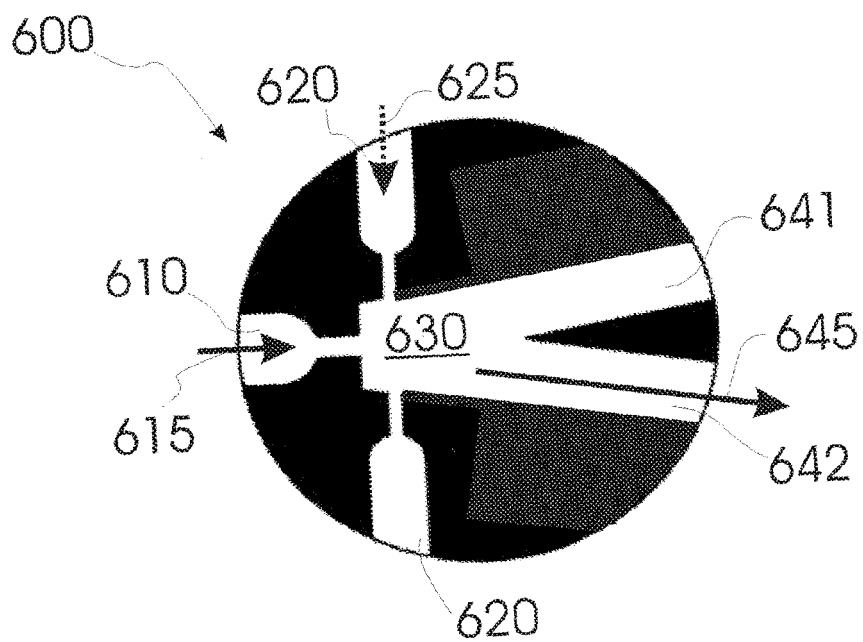


Fig. 7b

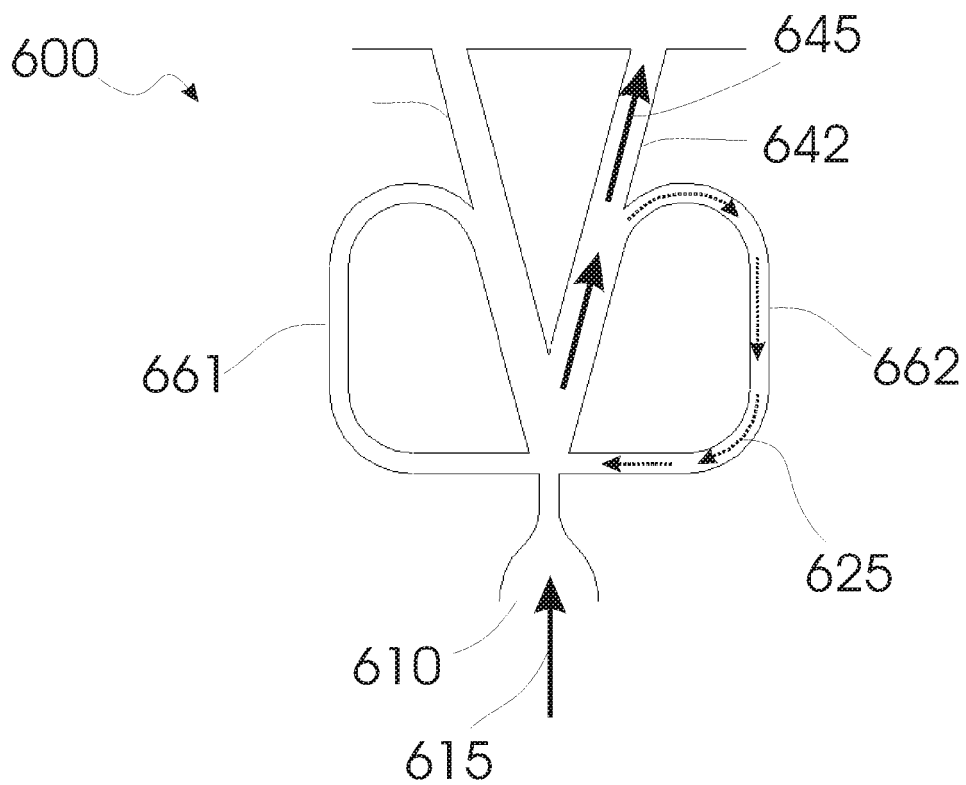


Fig. 8a

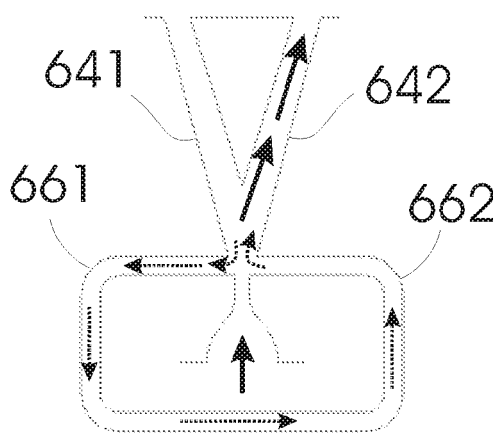


Fig. 8b

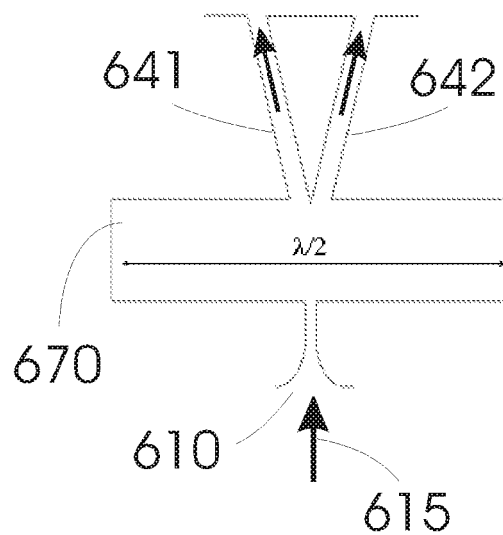


Fig. 8c



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Application Number
EP 09 17 1535

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