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(54) OSCILLATOR FOR GENERATING TWO OR MORE PULSATING FLUID FLOWS FROM A CONSTANT FLUID FLOW AND A METHOD OF GENERATING FLUID BUBBLES IN A LIQUID

(57) Oscillator (1b, 1c) for generating two or more pulsating fluid flows from a constant fluid flow, whereby the oscillator (1b, 1c) comprises a first fluid inlet (6) for receiving a fluid flow and a first fluid outlet (2) and a second fluid outlet (2) for each outputting a said pulsating fluid flow, whereby the oscillator (1b, 1c) comprises a bistable fluidic amplifier (6,7,8,9) for amplifying a control signal, whereby the fluidic amplifier (6,7,8,9) is placed between the first fluid inlet (6) and the fluid outlets (2,3), whereby the oscillator (1b, 1c) comprises a piezo-electric actuator (15) for generating said control signal. Also a method of generating fluid bubbles (40) in a liquid, using such an oscillator (1b, 1c) according to any of the previous claims is used, whereby a pulsating fluid flow from the fluid outlets (2,3) is used to generate fluid bubbles (40) in the liquid.

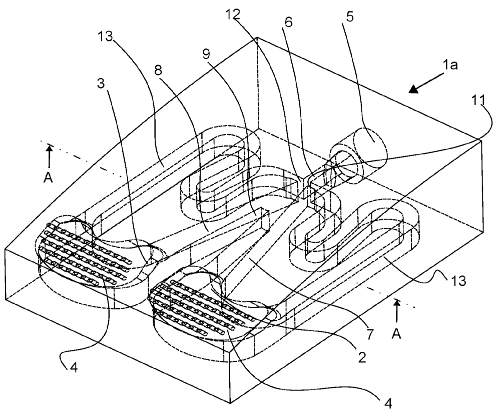

Fig. 1

EP 3 895 792 A1

Description

[0001] The present invention concerns an oscillator for generating two or more pulsating fluid flows from a constant fluid flow and a method of generating fluid bubbles in a liquid using such an oscillator.

[0002] More specifically the fluid is a gas. However, due to the nature of fluidic technology, the invention can equally be used with a liquid instead of a gas. Because of the prevalence of gas-related uses, the invention is described below with reference to a gas but is not limited to a gas.

[0003] From the technical field of fluidics, oscillators are known to enable switching of gases for generating two or more pulsating gas flows from a constant gas flow. A typical example of such an oscillator is the well known standard bistable two-loop fluidic oscillator, such as for instance shown in fig. 1 of 'Taxonomic trees of fluidic oscillators. Tesař, Vaclav. (2017). EPJ Web of Conferences. 143. 02128. 10.1051/epjconf/201714302128.'

[0004] Traditional oscillators however have the disadvantage that they are designed with certain geometric characteristics, which determine the oscillation frequency at which they operate. Usually, the oscillation frequency can be varied to a limited degree by varying the inlet pressure of gas into the oscillator, but this is usually only over a relatively small range and will also strongly influence the total flow rate of gas through the oscillator, which is often undesirable.

[0005] There is therefore a need for oscillators of which the oscillation frequency can be adjusted independently of the gas pressure or gas flow rate

[0006] The invention therefore provides for an oscillator for generating two or more pulsating gas flows from a constant gas flow, whereby the oscillator comprises a first gas inlet for receiving a gas flow and a first gas outlet and a second gas outlet for each outputting said gas flow, whereby the oscillator comprises a bistable fluidic amplifier for amplifying a control signal, whereby the fluidic amplifier is placed between the first gas inlet and the gas outlets, whereby the oscillator comprises a piezo-electric actuator for generating said control signal.

[0007] The term fluidic amplifier also comprises an amplifier with an amplification factor of 1, which can also be considered a fluidic switch.

[0008] The control signal can be any type of mechanical energy based control signal.

[0009] It will be clear that the piezo-electric actuator needs to be connected to a voltage source to generate a displacement as a control signal, and to a source of alternating voltage to generate one or more periodic control signals. Such periodic control signals are in general a train of mechanical pulses, so in other words a wave, whereby the wave may have any known wave shape, such as sinusoidal, saw-tooth, or block.

[0010] The advantage of this is that the frequency of the control signals generated by a piezo-electric actuator can be very easily controlled and modulated, resulting in control of the oscillation frequency of the oscillator, so the pulsation frequency of the pulsating gas flows, independently of the inlet gas pressure or the gas flow rate.

[0011] As such piezo-electric actuators are widely available commercially and require only low voltages and currents to operate, this is an easy, cheap and safe way of generating such a control signal. The invention therefore allows reliably controlling and modulating large gas flows using small, industry-standard control circuits.

[0012] Due to the fact that the fluidic amplifier amplifies the control signal generated by the piezo-electric element, this can be achieved with a very low consumption of electrical energy.

[0013] In a preferred embodiment the oscillator comprises one piezo-electric actuator or two or more piezo-electric actuators which are arranged to actuate at the same frequency, whereby the piezo-electric actuator is or the piezo-electric actuators are arranged to alternately act in two opposite directions and generate a said control signal during action in both opposite directions.

[0014] In case there are several piezo-electric actuators, they can actuate in phase with each other. This means that they actuate in the same direction at the same time. However, it is also conceivable that, depending on the response speed of the gas flow to a control signal that is required for specific applications, they are arranged to actuate out of phase with each other, but nevertheless in a coordinated fashion.

[0015] In a preferred embodiment, the piezo-electric actuator is, or the piezo-electric actuators are, arranged to generate a first said control signal by acting in a first of said directions and to generate a second said control signal by acting in the second of said directions.

[0016] Hereby, preferably, when the oscillator is in use, the first control signal causes a gas flow flowing from the first inlet to the first outlet to switch to the second outlet, and the second control signal causes a gas flow flowing from the first inlet to the second outlet to switch to the first outlet.

[0017] In a preferred embodiment the piezo-electric actuator is a bender actuator which actuates by bending in a direction perpendicular to a direction in which the bender actuator extends.

[0018] In a preferred embodiment the oscillator comprises a source of alternating voltage, whereby the source of alternating voltage is electrically connected to the piezo-electric actuator.

[0019] In a preferred embodiment at least one of the gas outlets is provided with a perforated plate having a plurality of holes. Preferably all of the gas outlets are provided with such a plate. Preferably the plates have at least three, and more preferably at least six, holes each. Preferably the holes in the plate or plates have the same cross-sectional area. These measures ensure that the oscillator is particularly suited for generating relatively small gas bubbles in a liquid, whereby the gas bubbles that are produced have a narrow size distribution.

[0020] Within the general invention there are two main groups of preferred embodiments related to the configuration of the piezo-electric element in relation to the fluidic amplifier.

[0021] In the first main group of preferred embodiments the fluidic amplifier comprises a gas inlet channel which is connected to the first gas inlet, whereby the piezo-electric element is placed in or around the gas inlet channel of the fluidic amplifier.

[0022] In this first group, the oscillator can act alone to generate pulsating airflows that are used directly for an intended application. However, the outlet channels can also be connected to the control ports of a traditional fluidic amplifier second, so that the oscillator acts as a master, generating gas pressure waves in the outlet channel, whereby these gas pressure waves are then amplified by the other fluidic amplifier acting as slave.

[0023] Note that in such a configuration the outlet channels can also be split and connected to the control ports of several different traditional fluidic amplifiers, so that a single master-multiple slaves configuration is obtained, whereby the master is the oscillator according to the invention and the slaves are the traditional fluidic amplifiers.

[0024] Preferably, the oscillator comprises at least two of said bender actuators which are placed in a spaced-apart, parallel, side by side configuration. This ensures that the control signal is transferred more reliably to a gas flow fed into the gas inlet channel because the bender actuators provide a degree of containment of the air flow lines.

[0025] In a preferred embodiment in the first main group at least a part of the wall of the gas inlet channel is formed by a said piezo-electric actuator. This ensures that the control signal is fully and efficiently transferred to a gas flow fed into the gas inlet channel.

[0026] In a preferred embodiment in the first main group the piezo-electric actuator extends, when no voltage is applied to it, in the direction in which the gas inlet channel extends.

[0027] An alternative way of defining this is that the piezo-electric actuator extends in the flow direction of the gas in the gas inlet channel when the oscillator is in use.

[0028] In a preferred embodiment in the first main group the gas inlet channel has a smallest dimension, whereby those two bender actuators of the at least two said bender actuators that are the furthest apart have a maximum mutual distance, whereby this maximum mutual distance is at least 50% of the smallest dimension of the gas inlet channel.

[0029] As a result, a major part of the gas flowing through the gas inlet channel will flow between the two bender actuators, so that a good transfer of energy is obtained from the bender actuators to the flowing gas, leading to efficient amplification.

[0030] In the second main group of preferred embodiments the fluidic amplifier comprises at least two control ports, whereby the oscillator comprises a second gas inlet which is connected to at least two control channels, whereby the control signal is a gas pressure wave control signal, whereby the piezo-electric actuator is arranged to generate a said gas pressure wave control signal in the at least two control channels, whereby a first of the control channels is connected to a first of the control ports and a second of the control channels is connected to a second of the control ports.

[0031] Generating said gas pressure wave control signals can clearly easily be done by applying an alternating voltage to the piezo-electric actuator, which can be modulated as required.

[0032] In this second group, the second gas inlet and the control channels, in combination with the piezo-electric element, act as a master, generating gas pressure waves in the control channels, whereby these gas pressure waves are then amplified by the fluidic amplifier acting as slave.

[0033] Note that in such a configuration the control channels can also be split and connected to the control ports of several different fluidic amplifiers, so that a single master-multiple slaves configuration is obtained.

[0034] In a preferred embodiment in the second main group the piezo-electric actuator or a valve member attached to the piezo-electric element is configured to partly or completely block, when the piezo-electric actuator is electrically activated, the connection between the second gas inlet and at least one of the control channels while keeping the connection between the second gas inlet and another of the control channels open.

[0035] Preferably the oscillator comprises exactly two control channels, whereby said piezo-electric actuator or said valve member is configured, when the piezo-electric actuator is electrically connected to a source of alternating voltage, to partly or completely block alternatively the connection between the second gas inlet and exactly one of the control channels or the connection between the second gas inlet and the other of the control channels.

[0036] By imposing an alternating voltage on the piezo-electric actuator, a pressure wave is thereby generated in one or more of the control channels.

[0037] Two separate control waves, phase shifted by half a period, are thereby obtained, one in each of the control channels.

[0038] The invention further concerns the use of an oscillator according to the invention for generating a pulsating flow of gas, whereby the piezo-electric element is supplied with a alternating voltage of a single, but preferably adjustable frequency, whereby preferably the pulsating flow of gas has a single, but preferably adjustable, pulsation frequency.

[0039] The invention further concerns a method of generating gas bubbles in a liquid, whereby an oscillator according to the invention is used, whereby the piezo-electric actuator is supplied with an alternating voltage, whereby the first gas inlet is connected to a source of pressurized gas, whereby a pulsating gas flow from at least one of the gas outlets is used to generate gas bubbles, whereby the size of the bubbles is adjustable by adjusting the frequency of the alternating voltage.

[0040] Preferably these gas bubbles are air bubbles and are used to form a bubble screen under water to attenuate the sound energy of underwater sound from a source of undesirable underwater sound and thereby reduce the propagation of such sound. This is advantageous because the abortion and scattering of sound waves under water is dependent on the bubble size distribution, which can be controlled by controlling the oscillator frequency.

[0041] In order to illustrate the invention, exemplary embodiments are explained below, with reference to the following figures, wherein:

Fig. 1 shows a perspective view of an oscillator not according to the invention;

Fig. 2 shows a cross-section of the oscillator of fig. 1 according to line A-A;

Fig. 3 shows a cross-section of the oscillator of figs. 1 and 2 according to line B-B;

Fig. 4 shows a cross-section in an analogous view as fig. 2, of an oscillator according to the invention, in a first state of use;

Fig. 5 shows the oscillator of fig. 4, in a second state of use;

Fig. 6 shows a cross-section in an analogous view as fig. 2, of another oscillator according to the invention, in a first state of use;

Fig. 7 shows the oscillator of fig. 6, in a second state of use;

Fig. 8 shows a schematic side view of a method of using an oscillator according to the invention;

Fig. 9 shows a schematic top view of the same method of using the oscillator.

Fig. 10 shows a cross-section according to line C-C of a component used in the same method of using the oscillator.

[0042] In the explanation below the invention is described with reference to air and water. It should be noted that the invention can equally be used with other gasses instead of air, and even with liquids instead of air, and with other other liquids than water.

[0043] The oscillator 1a of figures 1 to 3 is a traditional fluidic oscillator, of which the air outlets 2,3 are provided with perforated plates 4 with fifty round holes of 1.7mm diameter each. This oscillator 1a is further called the first oscillator.

[0044] The first oscillator 1a comprises a first air inlet 5 and an air inlet channel 6 leading away from the first air inlet 5. The air inlet channel 6 widens and diverges into two air outlet channels, more specifically a first outlet channel 7 and a second outlet channel 8 which lead to the two aforementioned air outlets 2,3, more specifically to a first air outlet 2 and to a second air outlet 3, which are provided with said perforated plates 4.

[0045] The two outlet channels 7, 8 are separated by a splitter 9 with a concave nose 10.

[0046] The splitter 9 and the air inlet channel 6 and the outlet channels 7, 8 jointly constitute a bistable fluidic amplifier arranged to amplify control signals, whereby in this case the control signals are fed to the fluidic amplifier via a first control port 11 and a second control port 12.

[0047] From each of the air outlets 2,3, a feedback channel 13 leads back to the control ports at the point where the air inlet channel 6 widens.

[0048] The first oscillator 1a works as follows: A constant airflow is established at the first air inlet 5 and through the air inlet channel 6. This airflow will either flow through the first outlet channel 7 or through the second outlet channel 8, but not through both at the same time. If undisturbed, the air will continue to flow this way because of the Coanda-effect, which enhances the tendency for a fluid to follow a curved surface. The transition from the air inlet channel 6 to each of the outlet channels 7, 8 is such a curved surface. The concave nose 10 of the splitter 9 helps to create an induced secondary airflow that further stabilises the airflow through that particular outlet channel 7,8.

[0049] Most of the air flowing through this outlet channel 7,8 will then exit at the corresponding air outlet 2,3. However, this airflow also generates a pressure pulse which is sent back via the corresponding feedback channel 13 to the corresponding control port 11, 12, and which cause the airflow to switch to the other outlet channel 7,8.

[0050] If left undisturbed, a stable airflow through the other outlet channel 7, 8 will now be established. However, also at the other air outlet 2,3, a pressure wave is generated, which will be fed back via the feedback channel 13 to the corresponding control port 11,12, so that the airflow switches to the other outlet channel 7,8 again.

[0051] This way, a sequence of pressure control signals, in other words a pressure control wave, is established at both control ports 11, 12, every time switching the airflow from the first outlet channel 7 to the second outlet channel 8 and back, thereby generating two pulsating airflows, one in each of the outlet channels 7, 8, each pulsating with the same oscillation frequency and phase shifted by half a wave period.

[0052] These sequences of control signals are thereby amplified by the fluidic amplifier

[0053] The oscillation frequency of the first oscillator 1a is more or less fixed, depending on the exact design of the first oscillator 1a. A change in air pressure at the first air inlet 5, resulting in a change in the total air flow rate through the first oscillator 1a, will influence the oscillation frequency to a relatively small degree, but the oscillation frequency can not be controlled independently of the air flow rate

[0054] A first embodiment of an oscillator according to the invention, further to be called the second oscillator 1b, as shown in figures 4 and 5, differs mainly from the traditional oscillator in that there are no feedback channels 13 and no control ports 11, 12. Consequently, the outer contours of the housing of the second oscillator 1b can be much smaller.

[0055] It is noted that, although they are no perforated plates 4 indicated in the figures 4 and 5 because this is not important for showing the difference with the first oscillator 1a, the air outlets 2,3 of the second oscillator 1b can easily be provided with such perforated plates 4, and usually are provided with such perforated plates 4.

[0056] In order to generate a control signal, the second oscillator 1b is instead provided with two piezo-electric bender actuators 15, which are extending in the length direction of the air inlet channel 6 and which are fixedly attached at one of their extremes 17a, near the first air inlet 5.

[0057] The actuators 15 are each connected to a source of alternating voltage, with a controllable frequency, via electrical wires which are not shown in the figures, but which run via wire channels 16 provided in the housing of the second oscillator 1b.

[0058] The actuators 15 can bend in two directions, depending on whether a positive or a negative voltage is applied to them. This results in a movement of the free extreme 17b of the actuators 15, so that the actuators 15 can adopt two working positions, one of which is shown in figure 4, and the other of which is shown in figure 5.

[0059] It will be clear that in case no voltage is applied, the actuators 15 adopt a neutral position, intermediate between these two working positions.

[0060] In order to accommodate the actuators 15 in their working positions, the housing of the second oscillator 1b is provided with matching recesses 18.

[0061] As can be seen in figures 4 and 5, the actuators 15 constitute at least part of the wall of the air inlet channel 6.

[0062] The second oscillator 1b works as follows:
Like for the first oscillator 1a, a constant airflow is established at the first air inlet 5 and through the air inlet channel 6, with the actuators 15 in their neutral position. This airflow through the air inlet channel 6 establishes itself in a stable flow pattern into either the first outlet channel 7 or the second outlet channel 8, and then onward towards the corresponding air outlet 2,3.

[0063] Oscillation of the airflow through the second oscillator 1b is induced by applying an alternating voltage to the actuators 15. These actuators 15 will then alternatingly switch between the two working positions. A movement of the actuators 15 in one direction, eg from the working position shown in fig.4 to the working position shown in fig. 5, will then cause the airflow to switch from the first outlet channel 7 to the second outlet channel 8, and therefore constitutes a first mechanical control signal for such a switch.

[0064] A movement of the actuators 15 the other direction, so from the working position shown in fig. 5 to the working position shown in fig. 4, will cause the airflow to switch from the second outlet channel 8 to the first outlet channel 7, and therefore constitutes a second mechanical control signal for an opposite switch of the airflow.

[0065] A repeated movement of the actuators 15 thereby generates a control wave of a mechanical-energy signal, which is amplified by the fluidic amplifier, every time switching the airflow from the first outlet channel 7 to the second outlet channel 8 and back, thereby generating two pulsating airflows, one in each of the outlet channels 7, 8, each pulsating with the same oscillation frequency and phase-shifted by half a wave period.

[0066] Even though it may appear from figures 4 and 5 that the actuators 15 are directing the airflow from the first air inlet 5 channel towards one of the two outlet channels 7, 8, once the airflow is established in one of two outlet channels 7, 8, the actuators 15 are not needed anymore to maintain this airflow. Due to the Coanda-effect this airflow will remain stable even if the actuators 15 would be absent.

[0067] In order to obtain a reliable oscillation behaviour of the second oscillator 1b, both actuators 15 should be actuating at the same frequency. They do not necessarily need to operate exactly in phase, as, depending on the situation, a faster or slower switch from an airflow in one outlet channel 7,8 to an airflow in the other outlet channel 7,8 may be required and can be obtained by making one of the actuators 15 move slightly earlier than the other actuator 15.

[0068] It will be clear that the oscillation frequency of the second oscillator 1b will be the same as the frequency of the alternating voltage. This oscillation frequency can therefore be easily controlled by electronically altering the frequency of the alternating voltage. This can be done independently of the actual airflow through the second oscillator 1b.

[0069] A second embodiment of an oscillator according to the invention, further to be called the third oscillator 1c, differs from the first oscillator 1a in that the feedback channels are absent. There are however, like in the first oscillator 1a, two control ports 11, 12 present in the air inlet channel 6. This part of the third oscillator 1c is essentially a traditional bistable fluidic amplifier with control ports 11, 12, and is not shown separately.

[0070] Different to the first oscillator 1a, the third oscillator 1c comprises a pressure wave generator 19, shown in figs. 6 and 7, for generating a control signal. This pressure wave generator 19 comprises a second air inlet 20, which splits at a junction 21 into a first control channel 22 and a second control channel 23.

[0071] On the opposite side of the junction 21, compared to the second air inlet 20, a cavity 24 is present. In this cavity 24 a single piezo-electric bender actuator 15 is fixedly attached at one of its extremes 17a. The other, free, extreme 17b of the actuator 15 extends into the junction 21, and is provided with an approximately triangular valve member 25.

[0072] The first control channel 22 is connected to the first control port 11 and the second control channel 23 is connected to the second control port 12 of the bistable fluidic amplifier.

[0073] The actuator 15 is connected to a source of alternating voltage with a controllable frequency, via electrical wires which are not shown in the figures, but which run via a wire channel 16 provided in the housing of the pressure wave generator 19.

[0074] The actuator 15 can bend in two directions, depending on whether a positive or a negative voltage is applied to it, and can thereby adopt two working positions, one of which is shown in figure 6, and the other of which is shown in figure 7. It will be clear that in case no voltage is applied, the actuator 15 adopts a neutral position, intermediate between these two working positions.

[0075] The third oscillator 1c works as follows:
Like for the first oscillator 1a, a constant airflow is established at the first air inlet 5 and through the air inlet channel 6. This airflow through the air inlet channel 6 then establishes itself, like in the first oscillator 1a, in a stable flow pattern into either the first outlet channel 7 or the second outlet channel 8 due to the Coanda-effect, and then onward towards the corresponding air outlet 2,3.

[0076] A constant airflow is also established at the second air inlet 20, which is the air inlet of the pressure wave generator 9. This constant airflow is much smaller than the airflow through the air inlet channel 6 and is less than 10% of the airflow through the air inlet channel 6. This second airflow will be used to generate two control pressure wave signals which are fed to the control ports 11, 12.

[0077] In order to obtain this, an alternating voltage is applied to the actuator 15.

[0078] This actuator 15 will then alternatingly switch between the two working positions. A movement of the actuator 15 in one direction, eg from the working position shown in fig.6 to the working position shown in fig. 7, will cause the second control channel 23 to become blocked at the junction 21, so that the the airflow from the second air inlet 20 will exclusively flow into the first control channel 22 and thereby cause a pressure signal in the first control channel 22.

[0079] A movement of the actuators 15 the opposite direction, so from the working position shown in fig.7 to the working position shown in fig. 6, will cause the first control channel 22 to become blocked at the junction 21, so that the the airflow from the second air inlet 20 will exclusively flow into the second control channel 23 and thereby cause a pressure signal in the second control channel 23.

[0080] It is noted that the control channels 22, 23 do not necessarily need to become totally blocked. Partial blocking of the control channels 22, 23, so that the majority, preferably at least 67%, of the air will flow into the other control channel 22,23, is sufficient, although not optimal.

[0081] A repeated movement of the actuator 15 thereby generates two pressure wave control signals, one in the first control channel 22 and one in the second control channel 23, whereby these pressure waves are phase-shifted by half a wave period.

[0082] Because the first control channel 22 is connected to the first control port 11 and the second control channel 23 is connected to the second control port 12, a pressure signal in the first control channel 22 causes the airflow in the air inlet channel 6 to flow into the second outlet channel 8 and so towards the second air outlet 3. Likewise. a pressure signal in the second control channel 23 causes the airflow in the first air inlet 5 channel to flow into first outlet channel 7 and so towards the first air outlet 2.

[0083] This means that the control waves of pressure signals in the control channels 22, 23 are amplified by the fluidic amplifier in the third oscillator 1c, every time switching the airflow from the first outlet channel 7 to the second outlet channel 8 and back, thereby generating two pulsating airflows, one in each of the outlet channels 7, 8, each pulsating with the same oscillation frequency and phase-shifted by half a wave period.

[0084] It will be clear that the oscillation frequency of the third oscillator 1c will be the same as the frequency of the alternating voltage. This oscillation frequency can therefore be easily controlled by electronically altering the frequency of the alternating voltage. This can be done independently of the actual airflow through the third oscillator 1c.

[0085] An advantageous way of using the first, second and third oscillators is in a method of generating a bubble screen to reduce the propagation of underwater sound by attenuating the sound energy of this sound, which is desirable to limit the effects of construction works on animals in the water.

[0086] This will be described below for the second oscillator 1b, referring to figures 8 to 10. Note that a third oscillator 1c can also be used instead of the second oscillator 1b without adaptations. Note that a first oscillator 1a can also be used with some limitations, as will be described below. Note that figures 8 and 9 are schematic representations and are not to scale.

[0087] In these figures a device 30 is shown for attenuation of sound energy, in other words for reducing underwater sound propagation, originating from a source 29 of underwater sound,eg offshore/inland water construction activities, such as pile driving for building constructions or platforms.

[0088] The device 30 comprises a flexible air hose 31, to which bubble generation units 32 are connected. The air hose 31 is connected to a source 33 of pressurized air.

[0089] The bubble generation units 32 are arranged in a circle with a radius of circa 50 m around a source 29 of underwater sound, for instance a pile-driving activity.

[0090] The bubble generation units 32 have a footprint of circa 50 cm by 100 cm, and contain two parallel rows 34a, 34b, on either side of the air hose 31, of eight identical oscillators 1b per row 34a, 34b.

[0091] A cross-section of the bubble generation units 32 is shown in figure 10. As can be seen, each of the bubble generation units 32 comprises a bubble generation unit body 35, typically made of rubber, in which for each oscillator a channel 36, running from close to the base of the bubble generation unit body 35 to the top of the bubble generation unit body 35, is provided.

[0092] Inside the bubble generation unit body 35, two rows 34a, 34b of second oscillators 1b are provided. These oscillators 1b are indicated schematically in figure 10. The first air inlet 5, and second air inlet 20 if present, of these oscillators 1b are connected to the air hose 31, whereby the air outlets 2,3 of the oscillators 1b debouch in said channel 36.

[0093] The device further comprises a control unit 37. The control unit 37 will usually be mounted on a ship, which is not shown in the figures. The control unit 37 is connected to the piezo-electric actuators 15 of the oscillators and is arranged to supply an alternating voltage to these actuators 15, via a cable channel 38.

[0094] The device 30 is set up such that separate connections for applying an alternating voltage from the control unit 37 to the separate rows of oscillators are present, so that an alternating voltage with a different frequency can be supplied to the piezo-electric actuators 15 of the oscillators in the respective rows.

[0095] The device 30 further comprises a hydrophone 39 which is connected to the control unit 37 and which is positioned outside the circle formed by the air hose 31. The control unit 37 is programmed to analyse a sound frequency spectrum captured by the hydrophone 39 and to determine the dominant frequency or frequencies in this sound frequency spectrum.

[0096] The use of the device 30 in a method for attenuating sound energy or reducing sound propagation under water is as follows.

[0097] When the source 29 of underwater sound, eg. a pile driving activity, is active, pressurized air is supplied to the air hose 31 and an alternating voltage with a certain starting frequency is supplied by the control unit 37 to the oscillators 1b.

[0098] As a results the oscillators 1b will oscillate at that same frequency, and generate air pulses at the air outlets 2,3. At their air outlets 2,3, in this case provided with perforated plates 4, air bubbles 40 are thereby generated in the channels 36. The air bubbles 40 will start to move up, acting as an air pump and establishing an upward water flow in the channels 36, as indicated by the arrows A in figure 10. This water flow will effectively remove newly forming air bubbles 40 at the holes in the perforated plates 4, so that an equilibrium situation with a constant air bubble 40 size is quickly established. These air bubbles 40 are released from the channels 36 in the bubble generation unit body 35, so that these channels 36 in effect become a bubble outlet channel 36.

[0099] Due to the fact that many bubble generation units 32 are present, a circular air bubble screen is thereby formed. This bubble screen is effective in reflecting and absorbing sound, so that the long range effect of sound coming from the source 29 of underwater sound is limited.

[0100] At the same time, the hydrophone 39 captures the sound spectrum of the underwater sound outside the circle, so the sound spectrum of the underwater sound not absorbed or reflected by the air bubbles 40 in the bubble screen. This sound spectrum which is analysed by the control unit 37 by means of fast fourier transform so that the sound frequency or frequencies having the highest sound pressure can be established.

[0101] Accordingly, the control unit 37 can actively adapt the frequency of the alternating voltage supplied to the oscillators 1b, and thereby the oscillation frequencies of the oscillators 1b, and thereby the size of the air bubbles 40 generated, in order to achieve a maximum reduction of the propagation of the underwater sound.

[0102] It is particularly advantageous that two rows 34a, 34b of separately controllable oscillators 1b are provided in the same bubble generation units 32, so that two dominant frequencies or frequency ranges can be efficiently absorbed and reflected.

[0103] Hereby, a higher oscillation frequency will lead to smaller air bubbles 40, whereby smaller air bubbles 40 are effective in absorbing and reflecting sound of a higher frequency, compared to larger air bubbles 40.

[0104] Note that also a first oscillator 1a is usable in the bubble generation units 32. The air bubble size will then not be controllable and adjustable, but the advantage of obtaining a constant and stable flow of air bubbles 40 of a constant size out of such a bubble generation unit 32 is nevertheless present, compared to air bubbles created by random phenomena, such as occur when air is pressed out of a standard hole or nozzle, which will vary in size and in mutual distance.

[0105] A bubble generation unit 32 having a first oscillator 1a can firstly be better designed than traditional bubble generation units to generate air bubble sizes matching the sound frequency spectrum expected from specific underwater noise-generating activities. Secondly, such air bubbles 40 will coalesce less compared to air bubbles coming out of traditional bubble generation units, so that they remain active and effective longer, in other words over a greater vertical distance as they rise through the water.

[0106] Clearly, two, or even more, of such devices 30 can be used together, either or not supplied with pressurized air from the same source 33.

[0107] In such a case, a second device 30 is placed in a circle around a first device 30.

[0108] As a consequence, two concentric bubble screens are formed.

[0109] Since the sound frequency spectra of a first sound, generated by the source 29 of underwater sound, and a second sound on the outside of the inner bubble screen, which sound results from partial absorption and reflection of the first sound, will usually have different frequencies which have the highest sound pressure, the oscillators 1b in the bubble generation units 32 of the second second device 30 will usually work at a different oscillation frequency than the oscillators 1b in the bubble generation units 32 of the first device 30, thereby generating different bubble sizes in the inner bubble screen than in the outer bubble screen.

[0110] It is noted that both devices 30 comprise a separate hydrophone located on the other side of the respective bubble screen compared to the source of underwater sound, so that the performance of both devices 30 can be optimized independently for greater overall performance.

[0111] Another useful application of the first, second and third oscillators 1a,1b,1c is the generation of gas or liquid bubbles of an optimal and constant size in the chemical industry, either for optimising physical phenomena, such as gas-liquid or liquid-liquid material transfer, eg. by diffusion, or chemical phenomena, such as gas-liquid or liquid-liquid chemical reactions.

Claims

1. Oscillator (1b, 1c) for generating two or more pulsating fluid flows from a constant fluid flow, whereby the oscillator (1b, 1c) comprises a first fluid inlet (6) for receiving a fluid flow and a first fluid outlet (2) and a second fluid outlet (2) for each outputting a said pulsating fluid flow, whereby the oscillator (1b, 1c) comprises a bistable fluidic amplifier (6,7,8,9) for amplifying a control signal, whereby the fluidic amplifier (6,7,8,9) is placed between the first fluid inlet (6) and the fluid outlets (2,3), **characterized in that** the oscillator (1b, 1c) comprises a piezo-electric actuator (15) for generating said control signal.

2. Oscillator (1b, 1c) according to claim 1, **characterized in that** the oscillator (1b, 1c) comprises one piezo-electric actuator (15) or two or more piezo-electric actuators (15) which are arranged to actuate at the same frequency, whereby the piezo-electric actuator (15) is, or whereby the piezo-electric actuators (15) are, arranged to alternately act in two opposite directions and generate a said control signal during action in both opposite directions.

3. Oscillator (1b, 1c) according to claim 2, **characterized in that** the piezo-electric actuator (15) is, or the piezo-electric actuators (15) are, arranged to generate a first said control signal by acting in a first of said directions and to generate a second said control signal by acting in the second of said directions.

4. Oscillator (1b) according to any of the previous claims, whereby the fluid is a gas.

5. Oscillator (1b, 1c) according to any of the previous claims, **characterized in that** the piezo-electric actuator is a bender actuator (15).

6. Oscillator (1b) according to claim 5, **characterized in that** the fluidic amplifier (6,7,8,9) comprises a fluid inlet channel (6) which is connected to the first fluid inlet (6), whereby the oscillator (1b) comprises at least two of said bender actuators 15 which are placed in a spaced-apart, parallel, side by side configuration.

7. Oscillator (1b) according to claim 6, **characterized in that** at least a part of the wall of the fluid inlet channel (6) is formed by said piezo-electric actuator 15 or actuators 15.

8. Oscillator (1b) according to claim 6 or 7, **characterized in that** the piezo-electric actuator (15) is placed in the fluid inlet channel (6) of the fluidic amplifier (6,7,8,9), whereby the piezo-electric actuator (15) extends in the direction in which the fluid inlet channel (6) extends.

9. Oscillator (1c) according to any of claims 1 to 5, **characterized in that** the fluidic amplifier (6,7,8,9) comprises at least two control ports (11,12), whereby the oscillator (1c) comprises a second fluid inlet (20) which is connected to at least two control channels (22, 23) whereby the control signal is a fluid pressure wave or fluid pressure pulse control signal, whereby the piezo-electric actuator (15) is arranged to generate a said control signal in the at least two control channels (22, 23), whereby a first control channel (22) of the control channels (22, 23) is connected to a first control port (11) of the control ports (11,12) and a second control channel (23) of the control channels (22, 23) is connected to a second control port (12) of the control ports (12,13).

10. Oscillator (1c) according to claim 9, **characterized in that** the piezo-electric actuator (15) or a valve member (25) attached to the piezo-electric actuator (15) is configured to partly or completely block, when the piezo-electric actuator (15) is electrically activated, the connection between the second fluid inlet (20) and at least one of the control channels (22, 23) while keeping the connection between the second fluid inlet (20) and another of the control channels (22, 23) open.

11. Oscillator (1c) according to claim 10, **characterized in that** the oscillator (1c) comprises exactly two control channels (22, 23), whereby said piezo-electric actuator (15) or said valve member (25) is configured, when the piezo-electric actuator (15) is electrically connected to a source of alternating voltage, to partly or completely block alternatively the connection between the second fluid inlet (20) and exactly one of the control channels (22, 23) or the connection between the second fluid inlet (20) and the other of the control channels (22, 23).

12. Oscillator (1b, 1c) according to any of the previous claims, **characterized in that** the oscillator (1b, 1c) comprises a source of alternating voltage, whereby

the source of alternating voltage is electrically connected to the piezo-electric actuator (15) or actuators (15).

13. Oscillator (1b, 1c) according to any of the previous claims, **characterized in that** at least one of the fluid outlets (2,3) is provided with a perforated plate (4) having a plurality of holes.

14. Method of generating fluid bubbles (40) in a liquid, **characterized in that** an oscillator (1b, 1c) according to any of the previous claims is used, whereby the piezo-electric actuator (15) is connected to a source of alternating voltage, whereby the first fluid inlet (6) is connected to a source (33) of pressurized fluid, whereby a pulsating fluid flow from at least one of the fluid outlets (2,3) is used to generate fluid bubbles (40) in the liquid, whereby preferably the size of the bubbles (40) is adjustable by adjusting the frequency of the alternating voltage.

15. Method according to claim 14, **characterized in that** the fluid bubbles (40) are air bubbles (40) and are used to form a bubble screen under water to attenuate the sound energy of underwater sound coming from a source of undesirable underwater sound.

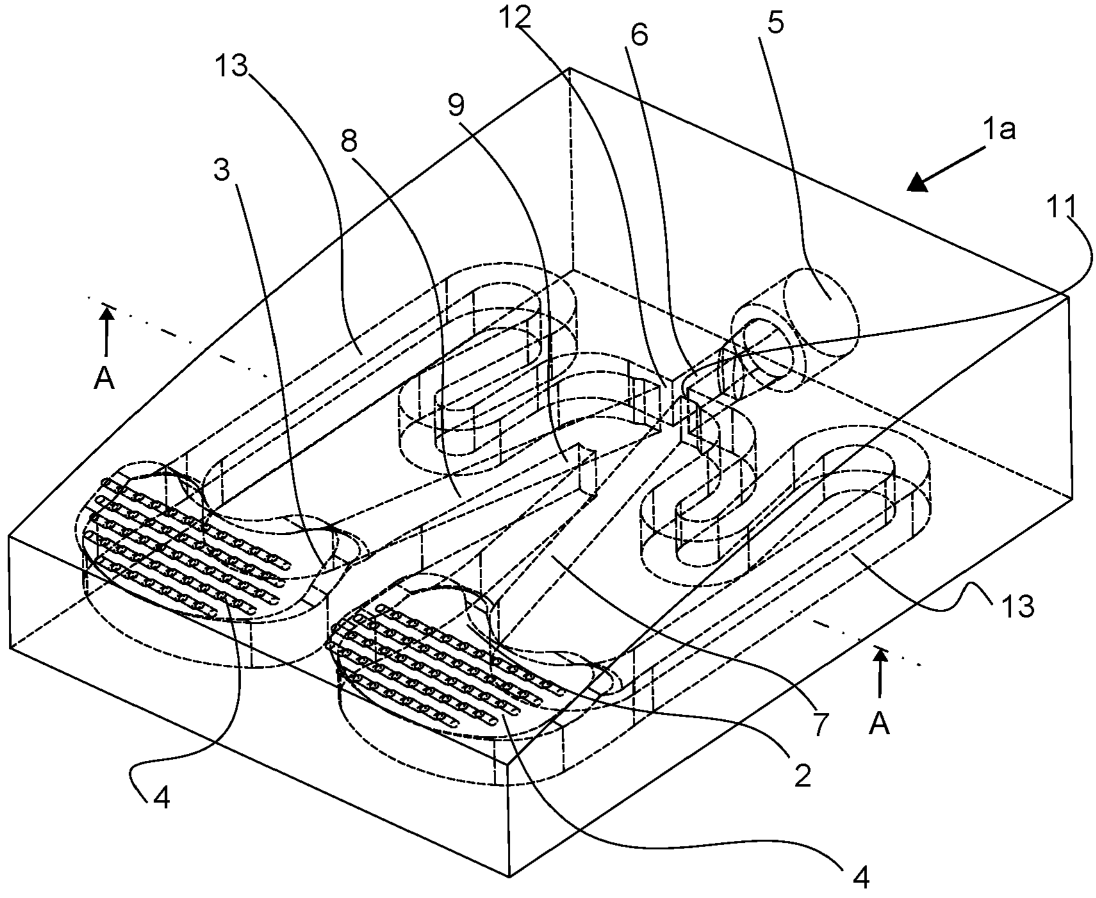

Fig. 1

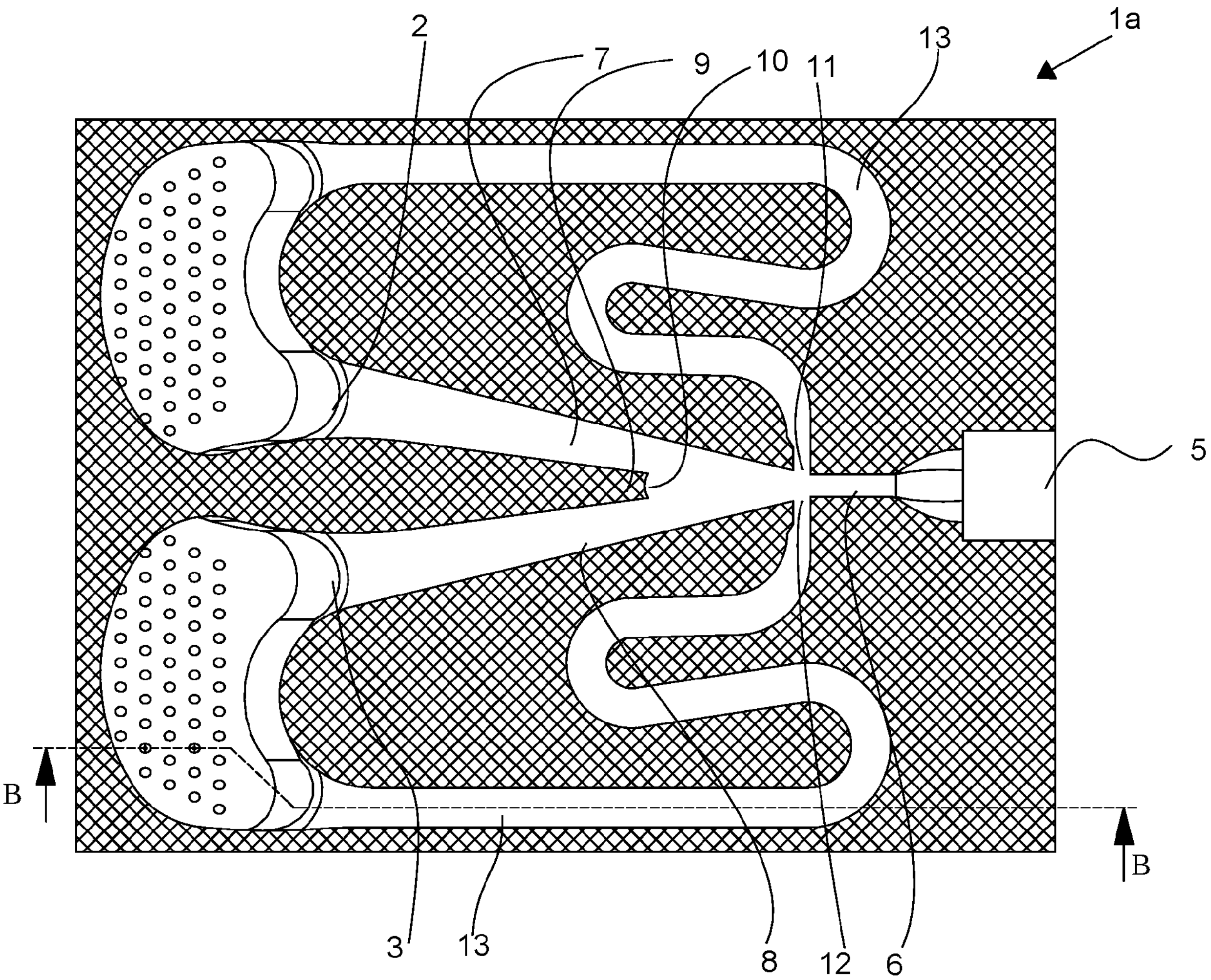

Fig. 2

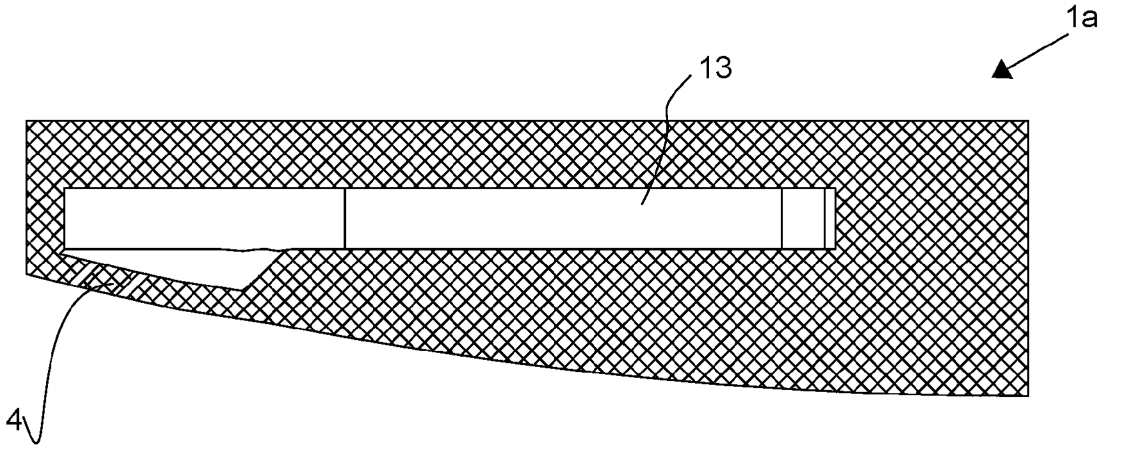

Fig. 3

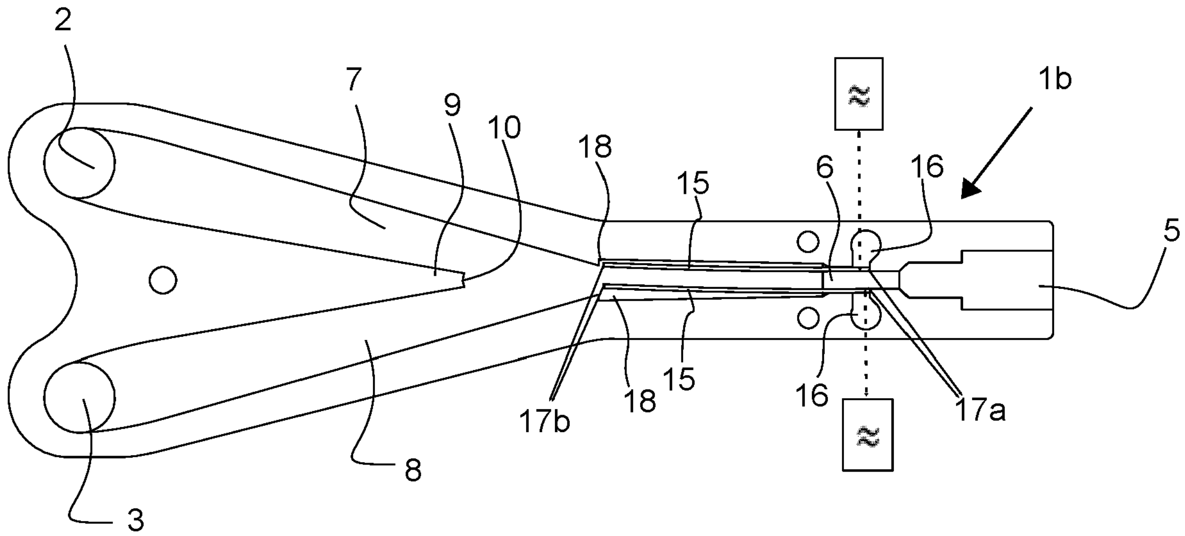
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Fig. 4

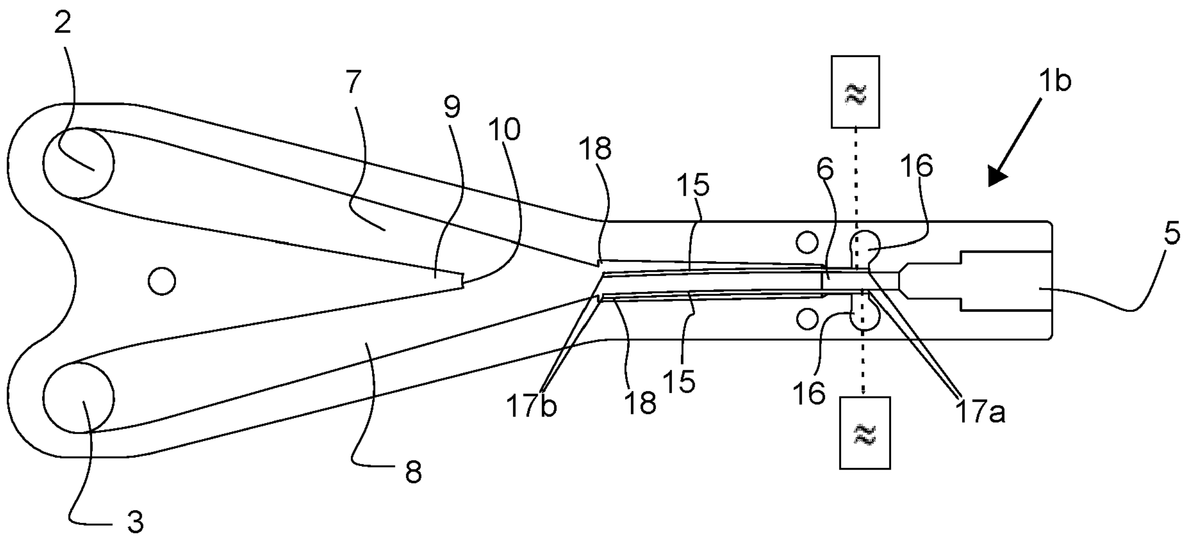
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Fig. 5

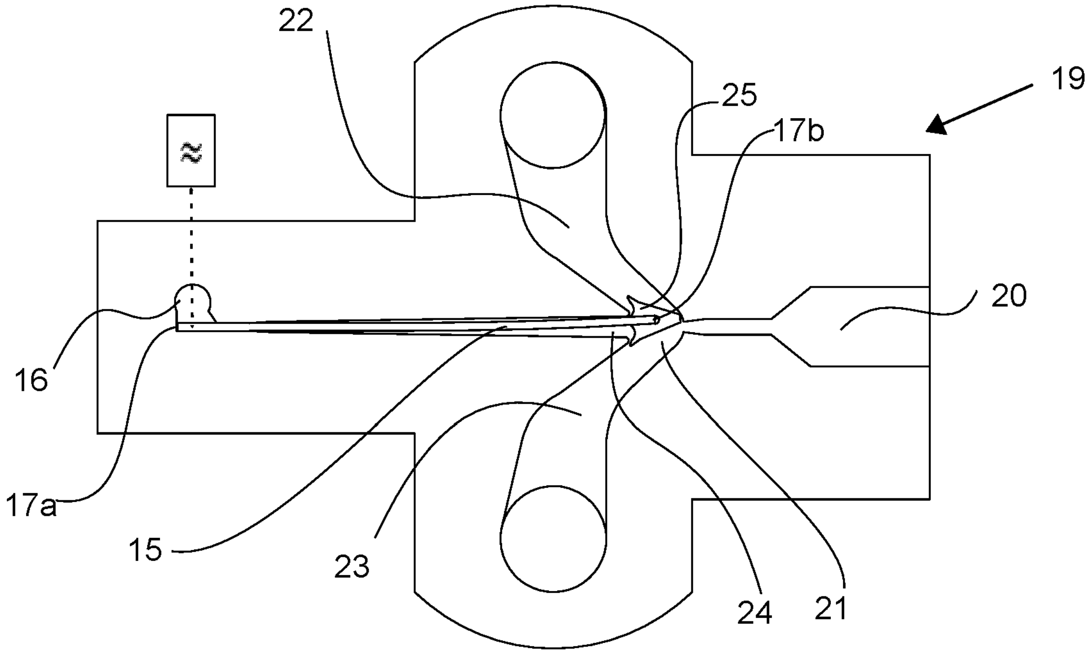

Fig. 6

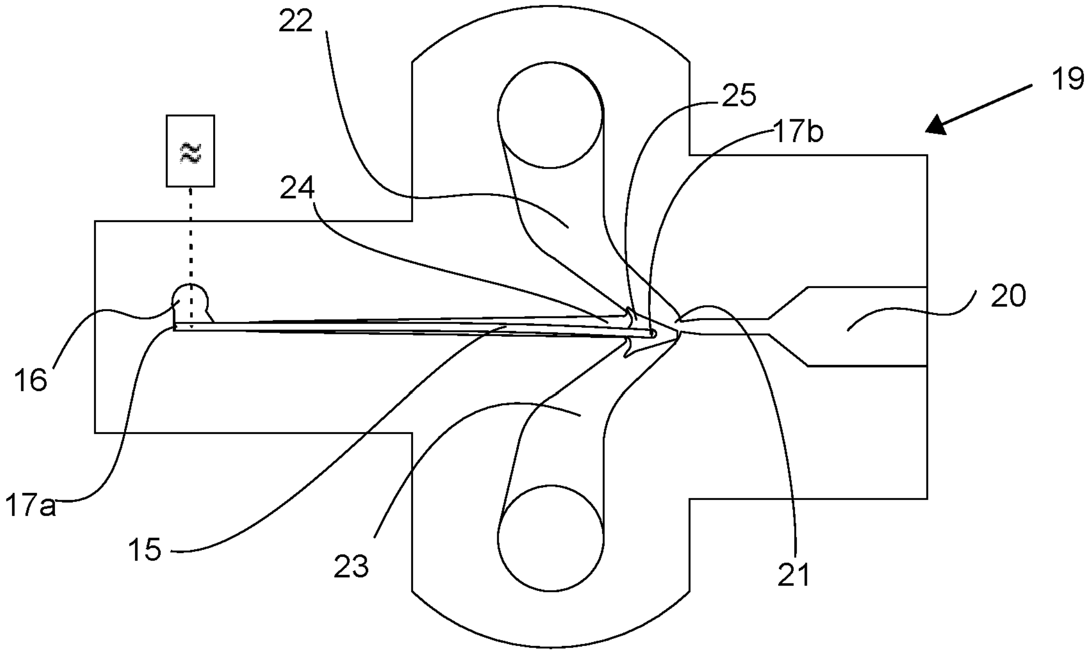

Fig. 7

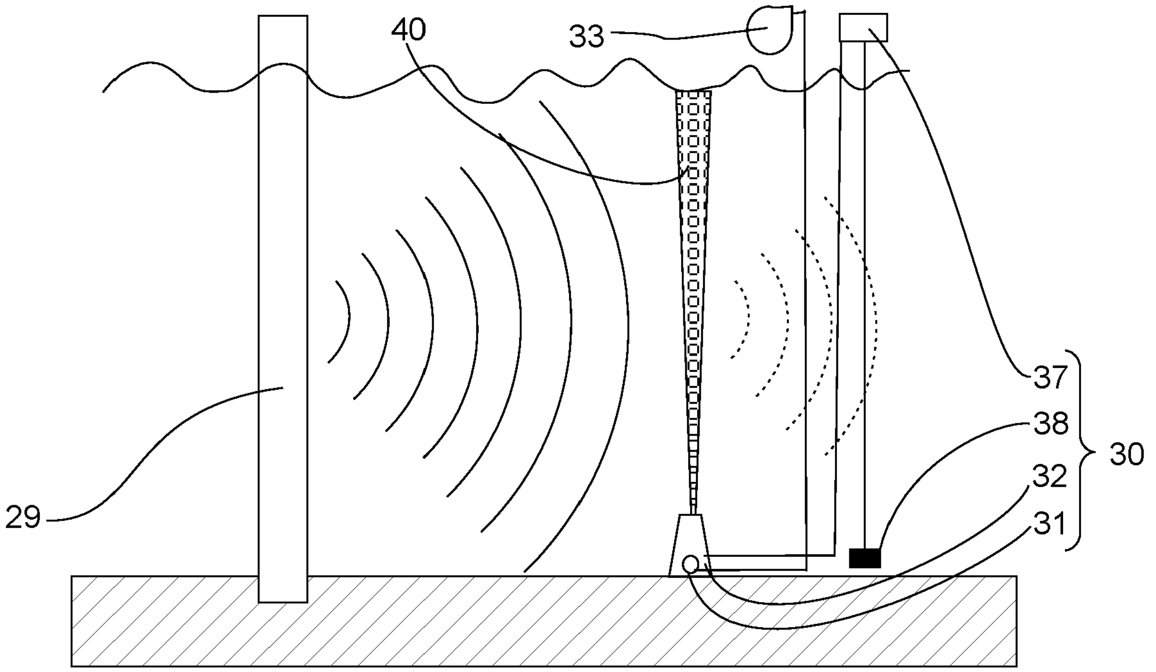

Fig. 8

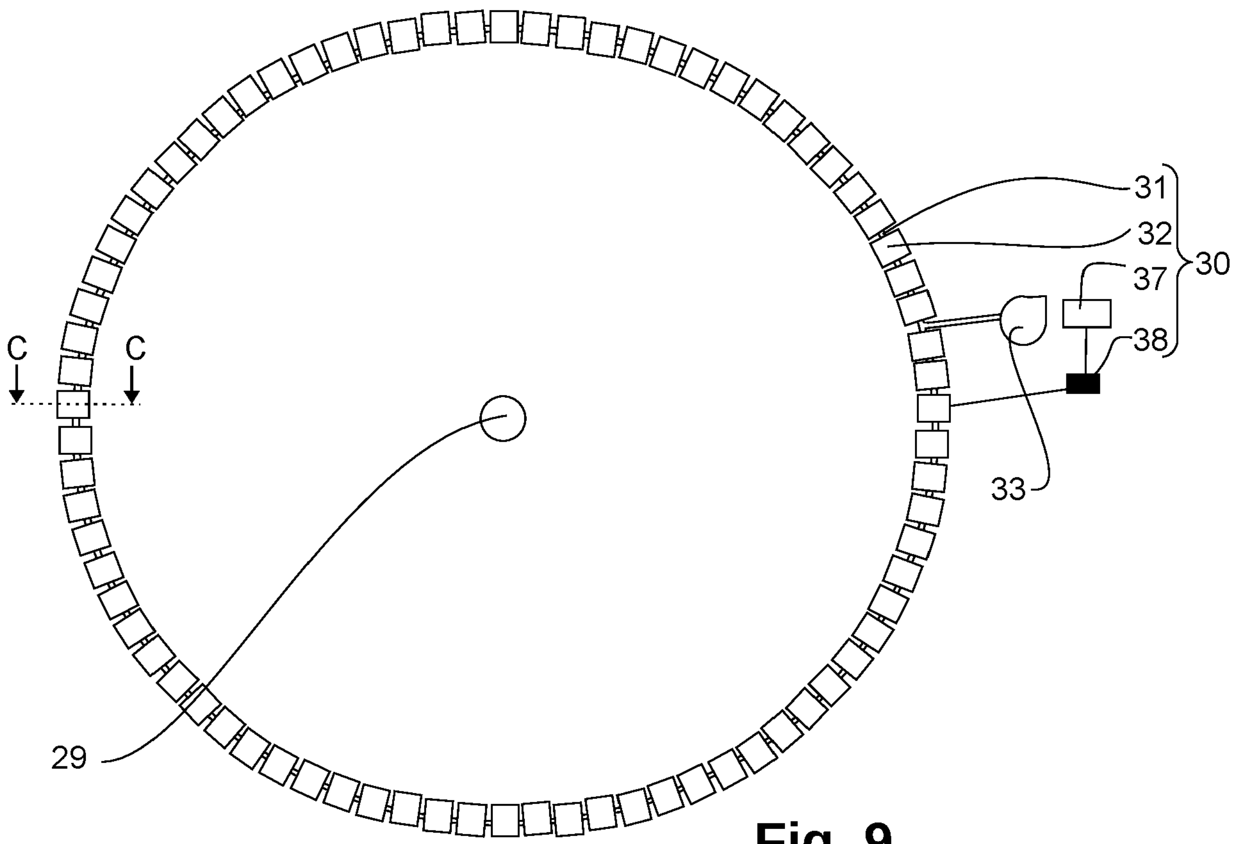

Fig. 9

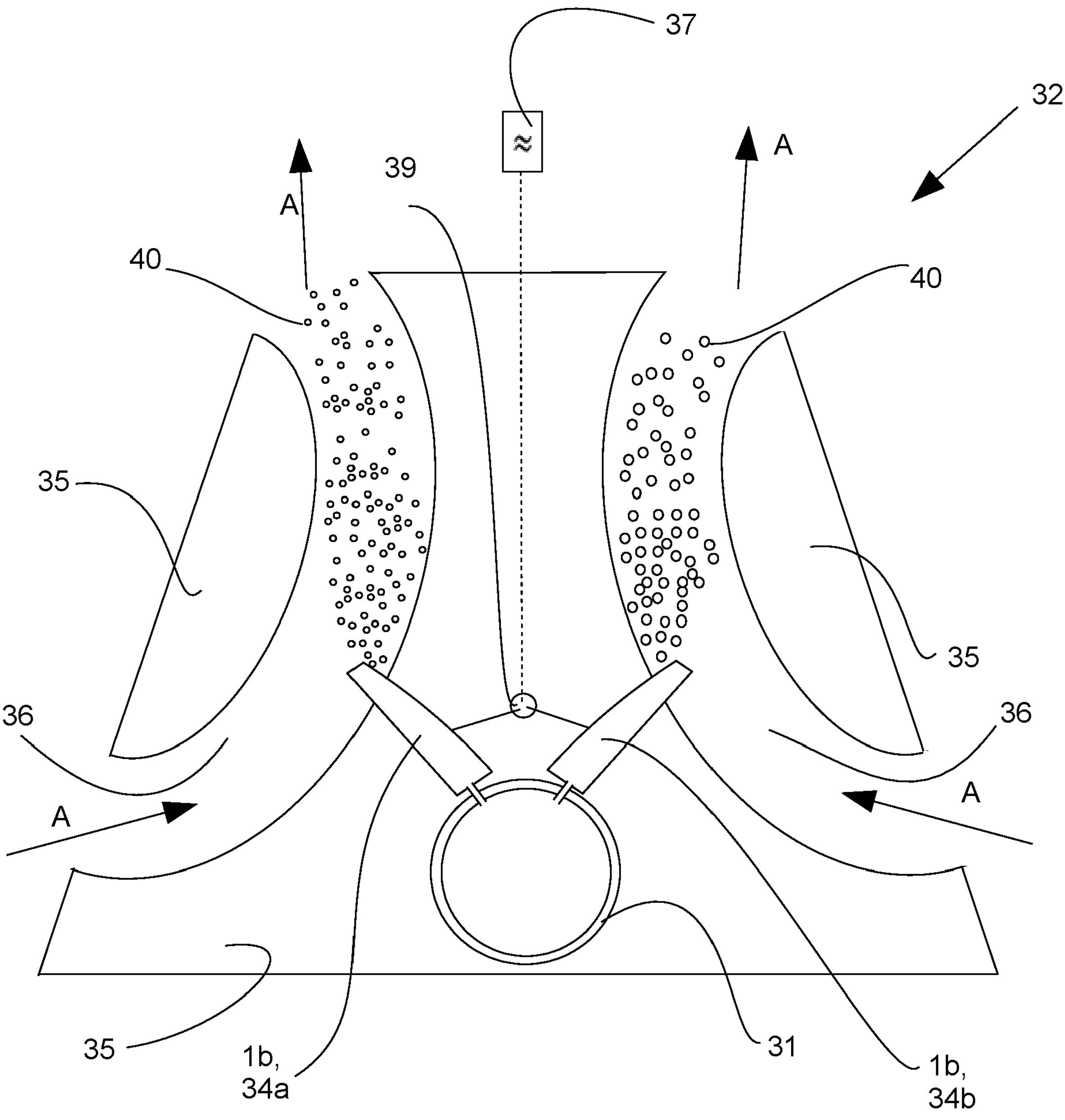

Fig. 10

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EUROPEAN SEARCH REPORT

Application Number
EP 20 17 0173

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B01F
F15D
F15C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	6 October 2020	Frego, Maria Chiara

CATEGORY OF CITED DOCUMENTS

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