Fluidic oscillator with bistable jet-type amplifier

Subject of this invention is a new version of fluidic oscillators with a bistable amplifier (10) of jet-type, used in particular for control of fluid flow on the surface of a body exposed to fluid flow, where in place of the so far known feedback channels the oscillation generation is based on employing propagation and reflection of compression and expansion waves in a resonance channel (1) connected to the control nozzle (11) of the jet-type bistable amplifier (10).
Description

Technical field

[0001] The subject of this invention is a device generating periodic unsteady pressure and/or flow processes in the fluid that passes through it. It can find application in all those areas of technology that work with flows of fluids (in particular gases), for example in aeronautics and building turbomachines - such as steam, gas, or wind turbines.

Background art

[0002] Fluidic oscillators generating periodic unsteady pressure and/or flow processes in the fluid passing through it. Typically, the fluidic oscillator is formed by a system of mutually interconnected cavities in which the overall hydrodynamic instability gives rise to self-excited oscillation. These oscillators have been nowadays developed for a number of uses, of which it is particularly proper to mention the control of fluid flow past bodies. The generated oscillating fluid flow from the oscillator output terminal acts on the external flow past the body and influences such phenomena as the flow separation from the surface of the body. In this application, the flow from the oscillator cavity, usually located inside the body, is lead into an actuator nozzle positioned by its exit in such locations on the body surface in which the boundary layer formed on the body is particularly sensitive to acting disturbances. As a result, it is possible by relatively small input power to influence the boundary layer so as to suppress its tendency towards separation from the body - the tendency that is often found when the angle of attack of the body relative to the direction of the outer flow reaches a certain limit value. Of course, the fluid passing through the oscillator may be, with advantage, the same fluid as the one that flows past the body. On the other hand, it is also possible, using the fluidic oscillator, to produce a premature separation at small attack angles. It is therefore possible to remove the operating limits that are otherwise caused by the behaviour of boundary layer. For example, a wind turbine blade may be kept operating in a regime where otherwise the boundary layer separation would stall it. Thus the flow control with the oscillatory control flow leads to a wider freedom for design and operation of fluid handling machinery - in the above example the wind turbine may be used in a wider range of wind velocities. An important fact that has been demonstrated by a number of investigators is the pulsating jet issuing from the actuator nozzle acts on the boundary layer more effectively than if it were a steady, non-oscillatory jet.

[0003] Known versions of fluidic oscillator applicable to the above mentioned purposes contain a jet-type bistable fluidic amplifier and at least one channel, called feedback channel, that is connected to the control nozzle(s) of the amplifier and carry into it a feedback signal. The bistable amplifiers are usually based on applying the Coanda effect of jet attachment to a solid wall. The knowledge about these amplifiers is not widespread, nevertheless there is sufficient information about them - their working principles, layouts, and functioning - in available literature. For example, they are the subject of Section 4.4. named " Switching valves based on the Coanda effect" in the monograph "Pressure-Driven Microfluidics", published by ArtechHouse, Inc., Norwood, MA, U.S.A.

[0004] Current versions of bistable jet-type fluidic amplifiers are almost invariably of planar layout. This means the cavities forming the oscillator are made in a planar plate by removal of material - for example by a photo-chemical method (etching according to a photographically transferred mask) - into the same depth. The cavities made this way are then closed by being covered with planar cover-plates.

[0005] The fluid in which the oscillation is generated is brought into the supply nozzle of the amplifier. From the exit of the supply nozzle it issues as a jet. To obtain the bistability, on both sides of the said supply nozzle are positioned attachment walls, symmetrically facing one another. The jet has therefore an equal opportunity to attach by means of the Coanda effect of jet attachment to either one of them. The attachment walls are inclined so that the attachment causes a change the jet flow direction. One attachment wall guides the attached jet to the first output terminal - while the other attachment wall would lead it to the second output terminal. In the use of the oscillator for the above mentioned control of an outer fluid flow, both output terminals are connected to actuator nozzles. Of course in its other uses the oscillator co-operates with other connected devices instead of the attachment nozzles. The flow inside the amplifier is controlled by control nozzles. These are positioned so that they oppose each other, with their exits positioned in the locations between the attachment walls and the exit of the supply nozzle. By a flow from the suitable control nozzle it is thus possible to switch the jet from one attachment wall to the opposite one and thus, as a result, from one output terminal into the other one. Fluidic oscillators known so far use for generating the oscillation a feedback connected to the control nozzles. Two basic types of the feedback are used, both invented by R. W. Warren in the U.S.A. The classical version, known from the US Patent 3,158,166, "Negative feedback oscillator", filed 7th Aug. 1962, is characterised by two feedback loops. Each of them guides separately on the opposite sides of the amplifier, the feedback flow from the output terminal of the amplifier to the same-side control nozzle. A simpler version of the feedback is characterised by a single feedback channel connecting the two control nozzles. This layout was first used by E.C. Spyropoulos and published a conference contribution on this subject on page 27 in Proceedings of the Fluid Amplification Symposium, organised in 1964 by Harry Diamond Laboratories in Washington D.C. A related oscillator with a single feedback channel is the subject of the US Patent Nr. 4...
An important property of both versions of the so far known oscillators is the frequency of generated oscillation being practically directly proportional to the intensity (i.e. flow rate) of the fluid through the oscillator. In many applications, in particular in the above mentioned use to the control of boundary layer separation, there is a demand for high oscillation frequency. This requirement leads not only to high velocity flows inside the actual oscillator, but also to high flow velocity in the connected loads - such as the above mentioned actuator nozzles. This mutual dependence of the velocities is due to the oscillator and its load being mutually bound by matching conditions. A detailed description of these conditions is available in the paper "Fluidic control of reactor flow - pressure drop matching" published in Chemical Engineering Research and Design, Vol. 87, p. 817, 2009. This paper actually solves the matching problem for the particular situation in which the load connected to the output terminal of a fluidic amplifier is a chemical reactor. Nevertheless the character of the load is unimportant from the point of view of the matching and conditions analogous to those described there apply to any load, including the actuator nozzles.

The high flow velocities in the actuator nozzles, resultant from the requirement of high frequency, however, cause troubles. One of the obvious disadvantages are the high dissipative losses - because the magnitude of energetic losses in flowing fluid rapidly increases with the flow velocity, very roughly with the second power of the velocity magnitude. Another problem in many situations is the non-availability of a suitable high pressure fluid source, the high pressure being necessary for generating the high velocity. Finally, a very important disadvantage of high-velocity flows in actuator nozzles is the less effective action on the controlled boundary layer - the high-velocity jet is said to "pierce" through the boundary layer instead of the desirable pushing action on it.

Disclosure of the invention

The disadvantages described above are removed by the device according to the present invention. It is a fluidic oscillator with a bistable jet-type fluidic amplifier having cavities that include including the supply nozzle, first control nozzle, second control nozzle, a cavity with the first attachment wall and the second attachment wall, the first output exit and second output exit, where on one side of the supply nozzle is located the first control nozzle while on the opposite side of the supply nozzle there is a second control nozzle and the first control nozzle as well as the second control nozzle are located with their mouths against each other, and downstream from the first control nozzle is positioned the second attachment wall and downstream from this there is the second output exit, while downstream from the second control nozzle is positioned the first attachment wall downstream from which there is the first output exit and the first attachment wall is facing the second attachment wall, characterised by presence of the resonance channel which is connected to the first control nozzle while its other, free end is open into space and the second control nozzle open into the same or a different space.

The space mentioned above is the atmosphere or a closed cavity, with an advantage the inner space of a pressure tank. The dimensions of this space are assumed to be large - so large that the outlets from the fluidic oscillator do not mutually influence one another. In practice this means that these dimensions are larger many times (for example at least twice) than the linear dimensions of the fluidic amplifier. Of course, if the free end of the resonance channel and the second control nozzle are open into different spaces, then the size of the spaces is not limited by these conditions.

Between the entrances into the first outlet terminal and the second outlet terminal may be positioned variously shaped splitter, usually of the wedge shape.

The resonance channel is with advantage positioned in the same plate as the cavities of the jet-type bistable amplifier and is made by removal of plate material into the same depth as the cavities of the jet-type bistable amplifier. In the next manufacturing operation after this removal, the cavities are separated from the atmosphere by cover plate placed on the plate. The cavities may be also made in a thin flat plate by removal of the plate material along the line that represent the outer circumference of the cavities. The advantage of this possibility is the necessity to remove a smaller total amount of the plate material so that the manufacture may be faster and/or less expensive. In this case, to cover the cavities and separate them from the atmosphere there are to be two cover plates, one positioned above and the other below the plate in which the cavities were made. The cover plate may contain a separate part covering the bistable amplifier and another part covering the resonance channel, or all the cavities may be covered by a single common cover plate. There are also known methods of manufacturing the cavities in which the produced oscillator body is made in one piece (it may be, e.g. the method of the "lost wax") in which case no cover plates are needed.

The fluidic oscillator may also involve an inlet for another (second) gas. With an advantage, such a second gas inlet may be made up of at least one inclined nozzle open by its exit into the resonance channel. The inclined nozzle serves for introduction of the second gas so that it fills the resonance channel - up to such an extent that the second gas flow out from the free end of the resonance channel. In that case the frequency of generated oscillation is determined by the properties of the second gas. It is obvious the if this change of the properties due to the presence of the second gas is to have the largest possible effect, the exit of the inclined nozzle into the resonance channel must be positioned as near as possible to the first control nozzle of the bistable jet-
type amplifier.

It may be useful for the oscillator to contain also a sensor making possible sensing and/or measurement of the frequency of the generated oscillation. This is particularly advantageous is the case of the oscillator having the second gas inlet, because the frequency of the generated oscillation depends on the character and state of the second gas and the oscillator according to this invention may then have the useful function of a meter for measurement of either the composition of binary gas mixture or a detector of concentration changes. Also, either with the second gas inlet or without it, the oscillator may assume the role of a temperature meter. The sensor may be placed anywhere next to the cavities of the fluidic oscillator in positions where the oscillation causes periodic changes of the flow. Nevertheless, positioning at or near to the output terminal is particularly advantageous because the changes in the course of each oscillation period are there the highest and this makes easier meeting or overcoming the sensitivity limits of the sensor.

The inlet of the second gas may be, however, connected with the supply nozzle - as long as there is a supply of another cold gas into the oscillator cavities somewhere between the sensor and an upstream from it located cold gas inlet. This possibility is advantageous in those cases where the oscillator is to serve as a temperature meter - utilising its generated frequency dependence on temperature - with a sensor that cannot operate at a too high temperature, in particular the temperature of hot gas supplied into the supply nozzle. By properly positioned inlet of the cold gas the sensor temperature is decreased to an acceptable level. In an alternative version, the oscillator may contain two bistable jet-type amplifiers connected so that the upstream bistable jet-type amplifier is used in generation of the oscillation while the downstream amplifier serves for amplifying the oscillation signal. The sensor is then positioned in or near the cavities of the downstream bistable jet-type amplifier. In the use for the temperature measurements, the hot gas, the temperature of which is measured, is fed into the supply nozzle of the upstream amplifier while the downstream amplifies, fed with cold gas, decreases the temperature in the vicinity of the sensor.

The fluidic oscillator may be characterised by the presence of a sensor for evaluation of the frequency of the generated oscillation and this sensor is positioned inside the oscillator cavities where a periodic fluid flow takes place, with advantage in the first output exit or in the second output exit.

The fluidic oscillator used for control of boundary layer on the surface of a body exposed to fluid flow has at least one of its output terminals connected to an actuator nozzle for generation of pulsatory flow-controlling jet.

The resonance channels may be straight or curved. Its length may be adjustable or even continuously variable during the oscillator operation. Often requested property is compactness of the whole oscillator including the resonance channel. To achieve the compactness, the resonance channel may be meandering or shaped as a spiral. The curvature radii of these versions should not be small - for example the radius should be not smaller than roughly one half of the total length dimension of the bistable fluidic amplifier, because too small radius would lead to deformation of the spatial shape of the pressure waves propagating in the channel and this might lead to irregular oscillator functioning.

It is important that the fluidic oscillator according to this invention is constituted of two parts. It is, on one hand, a known fluidic bistable jet-type amplifier, and on the other hand the resonance channel.

Bistable jet-type amplifier contains cavities, such as in particular the supply nozzle, first control nozzle, second control nozzle, the cavity for flow issuing from the supply nozzle with the first attachment wall and opposite to it positioned second attachment wall, the first output terminal and the second output terminal.

The spatial arrangement of the bistable amplifier is such that there is, on one side of the supply nozzle, the first control nozzle and on the other, opposite side of the supply nozzle there is the second control nozzle, where the first as well as the second control nozzles are mutually arranged so that their exits are directed against each other. Downstream from the first control nozzle is positioned the second attachment wall and further downstream from it there is the second output terminal. On the other side, downstream from the first control nozzle there is the first attachment wall downstream from which there is the first output terminal. The first attachment wall and the second attachment wall are located opposing each other symmetrically relative to the axis of the supply nozzle. Positioned between the two entrances into the first output terminal and the second output terminal may be a variously shaped splitter, usually shaped more or less as a wedge. The second basic component of the oscillator according to this invention is a resonance channel, which is connected to the first control nozzle of the bistable amplifier while its opposite free end is open into a stagnant space. The second control nozzle of the bistable amplifier is open into the same or another stagnant space. This stagnant space may be the atmosphere. In the usual planar version all parts of the amplifier are made for example by removal of the material on the surface of a flat plate. All the cavities are then separated from the surrounding atmosphere by a cover plate. The stagnant space may be any other large space containing a fluid such as air, gas or liquid or a gaseous or liquid mixture. Operating the fluidic oscillator according to the invention with liquid or liquid mixtures is possible, but not advantageous because of the small compressibility of usual liquids which leads to high propagation of pressure waves so that achieving the usual range of frequencies means having an impractically long resonance channel. It is, however, possible to use as the working fluid a liquid containing in sufficient concentration small gas bubbles, the compressibility of which together with high density of
the liquid component of the mixture ensures low velocity of pressure changes propagation in the resonance channel.

[0021] The material of the plate in which the fluidic oscillator is made is inessential and the decisive role in its selection have practical manufacturing and operational aspects. Similarly inessential is the material of the cover plates that close off the oscillator cavities in the plate, because the reason why the cover plate is used is only preventing the fluid - in particular gas - from leaving the cavities. The material of the plates will be chosen in particular by consideration of the manufacturing technology applied in making the cavities, especially in the used technology is not a common one - such as the photochemical technology requesting sensitivity to light (or other forms of electromagnetic radiation) used to for the photographic transfer of the cavity shapes. The material in this case may also require special properties needed for efficient removal of the plate material by etching or similar processes. Nevertheless, these aspects are nowadays known in the field of fluidics and do not represent any new material properties.

[0022] According to the disclosure of this invention it may be advantageous to have the fluidic oscillator, with the cavities of the jet-type bistable amplifier made, e.g., by a photochemical procedure or by laser cutting on a numerically controlled machine tool, made as a recession in a plate of the depth everywhere the same so that the resonance channel is formed simultaneously using the same procedure in the same plate as the recession of the same depth as are the cavities of the jet-type bistable amplifier.

[0023] From known fluidic oscillators differs the layout according to the present invention only by the absence of the feedback channel or channels, in place of which the oscillation generation is maintained by the resonance channel connected to the first control nozzle, its one free end open into the atmosphere or another large space, while the second control nozzle is also open into such space.

[0024] The main advantage of the fluidic oscillator according to the invention is the fact that the frequency of generated oscillation is essentially dependent only on the length of the resonance channel - and on the speed of propagation of pressure wave in the resonance channel. It does not therefore depend on the magnitude of the fluid flow rate passing though the oscillator. It is thus possible to achieve rather high frequency of the generated oscillation without the necessity to work with high velocities of the flow through the oscillator. This means it is possible to avoid high energetic losses associated with high flow velocities. The new principle also avoids the unwanted frequency variations caused in the so far known oscillators by accidental causes as is the variations of the pressure of the supplied gas.

[0025] As was already mentioned above, the oscillator according to this invention makes possible its being used to measurement of fluid properties of fluids - especially gases - brought into the resonance channel. The advantage brought by this possibility is the fact that the change of the properties - such as change in temperature or chemical composition - causes the change of the frequency of generated oscillation. Frequency is easily and exactly measured by a relatively simple and inexpensive sensor. The output values coded in the oscillation frequency may be easily and with advantage converted into a digital signal, suitable particularly for subsequent computer processing of the acquired information.

Overview of the figures in drawings

[0026] The accompanying five pictures show five different examples of the fluidic oscillators according to this invention.

[0027] In Figs. 1, 2, and 3 is presented a fluidic oscillator designed for delivering air flow into actuator nozzles that suppress boundary layer separation on the wind turbine blades. There is, in Fig. 1, a perspective view of the cavities of the oscillator before their being covered by a cover plate. The next Fig. 2 is a scale drawing of the cavities of an oscillator that was used in feasibility studies in aerodynamic laboratory. The geometry of the amplifier has been known before and was already used in several other oscillators described in available literature. Because of the drawing to scale and of given most important basic dimensions, the shape of the cavities presented in Fig. 2 is fully determined. With an oscillator of this geometry was experimentally investigated the dependence of the frequency of generated oscillation on the length of a straight resonance channel which is shown in Fig. 3. It is, of course, possible to expect that with a different geometry the dependence would be somewhat different or the oscillator would function in a different frequency range than shown in Fig. 3. Nevertheless, the general character of the dependence is likely to be more or less similar.

[0028] In Fig. 4 is shown a layout for an application requiring very low frequency of generated oscillation while retaining the requirement of compactness.

[0029] Fig. 5 present the oscillator according to this invention used for digital measurement of high temperature gas.

[0030] Fig. 6 describes a version of the oscillator making possible adjustment of the oscillation frequency and also perform a frequency modulation of the generated fluidic signal.

[0031] The last Fig. 7 then presents an alternative layout of the input part of the digital gas temperature meter.

Examples

Example 1

[0032] In the example of the oscillator presented in Figs. 1 to 3, it is made of plastic. It is one of a large number of relatively small oscillators positioned side by side in-
side a wind turbine blade. Each of these small oscillators is connected by its output terminals to two actuator nozzles from a row of such nozzles with its exits opened at the blade surface. The oscillatory fluid flow from these nozzles achieves a control of the character of the airflow past the blade adapting the functioning of the wind turbine to the instantaneous wind velocity without the need of complicated and expensive mechanical turning of the blade. Immediately responding and fast change of the character of the airflow past the blade may be also used for suppressing the changes of the aerodynamic conditions arising when the rotating blade moves past the mast of the turbine. It is a relatively small change in the conditions, nevertheless it is associated with a change of the executing forces and because it arises periodically at each full circle of the turbine shaft rotation. This may lead, as all periodic loading do, to fatigue type collapse of the blade. Suppressing this effect by the action of the flow from the actuator nozzles may thus bring substantial advantages concerning the dimensioning and hence also price of the wind power station.

The oscillator in this example contains on one hand the bistable fluidic jet-type amplifier 10 and, on the other hand, the resonance channel 1. The cavities of the oscillator are made by photoetching as a recession of the same depth everywhere, formed in the plastic material plate. The cavities made this way are then closed so that the outflow cannot escape - by a flat plane cover plate 100. Only a part of the cover plate 100 is seen in Fig. 1. It is a part covering the end of the resonance channel 1. Nevertheless, the same uniform covering of the plastic plate with the cavities is made everywhere over the whole plate surface.

The working fluid is here air supplied under pressure into the supply nozzle 16. On one side of the exit from this supply nozzle 16 there is the first control nozzle 11, while on the opposite side is the second control nozzle 12. Next to the exit from the first control nozzle 11 there is the second attachment wall 14 - and symmetrically on the opposite side there is, next to the exit from the second control nozzle 12, is positioned the first attachment wall 13. Further downstream in the direction of the flow from the supply nozzle 16 exit there is the first output terminal 17 and similarly downstream from the second attachment wall 14 there is the second output terminal 18. Between the two inlets into the output terminals 17, 18 is positioned a wedge-shaped splitter 6, in upstream part of which, opposite to the supply nozzle 16, the experience has shown it is advisable to make at the wedge tip a small trough-shaped recession between two cusps, as it is particularly well apparent in the following Fig. 2.

Fig. 2 provides a general information about a specific layout of the cavities, as tested on a model. It is the layout in which all cavities were etched to the depth 2 mm (millimetres). The width of the supply nozzle 16 is also 2 mm. Both control nozzles with the mutually opposed exits, the first control nozzle 11 and the second control nozzle 12 are of 1.4 mm exit widths. The small trough-shaped recession between two cusps in the splitter 6 has radius 2.85 mm and the apex of this round recession is at the distance 13.78 mm from both control nozzles. Both attachment walls 13, 14 are planar and positioned symmetrically relative to the axis of the supply nozzle 16, from which each attachment wall is declined by the angular distance 20° so that the angle between both attachment walls is 40°.

As seen in Fig. 2, the first output terminal 17 is connected to the first actuator nozzle 40 with its exit on the blade surface 20 in a blade of a wind turbine, while the second output terminal 18 is in a similar manner connected to the second actuator nozzle 50. The second control nozzle 12 is open into the free space, which in this case is the atmosphere. To the oppositely located first control nozzle 11 is connected the resonance channel 1. Together with the cavities of the bistable fluidic amplifier 10 the straight resonance channel 1 is made in the same plastic plate. It is made by photoetching to the same depth and as a result it is of rectangular cross section. Its length is L. The free end 101 of the resonance channel 1, which is meant to be the end opposite to the one connected to the first control nozzle 11, is open into the free space of atmosphere.

The oscillator made according to Figs. 1 and 2, after connection of its supply nozzle 16 to a compressed air source, starts self-excited oscillation in which the air jet leaving the exit of the supply nozzle 16 is in an alternating manner switched from the first attachment wall 13 to the second attachment wall 14, back and forth. This switching is a consequence of pressure waves which travel through the resonance channel 1, are reflected form its free end 101 and enter into the first control nozzle 11.

At designing of this oscillator it was requested that the outflow pulsation from the actuator nozzles 40, 50 should be at frequency 300 Hz. At the same time, available for supplying the oscillators were sources with relatively low air pressure. They did not suffice for achieving the oscillation at that frequency level in the traditional oscillator layouts with the feedback flow channels. On the contrary, in the layout of the oscillator according to this invention, with the resonance channel 1, it was possible to obtain the requested frequency values even at rather low supply pressure levels, because the frequency is determined by the length L of the resonance channel 1, the supply pressure levels being almost irrelevant (considering the sources available in a wind turbine). The requested frequency value 300 Hz was in this case obtained with the resonance channel 1 length L equal to 140 mm, which is a size that made possible stowing the oscillators inside the turbine blade without any problems.

In principle, the same design of the fluidic oscillator, with the actuator nozzles 40, 50 connected to it, may be also used for different applications than just the boundary layer control. For example, the oscillation may be used for agitation of air in vessels or spaces in which...
the solid particles carried by air would separate and sediment. The agitation prevents such sedimentation. The actuator nozzles 40, 50 may be also positioned against a hot surface (e.g. a surface of highly loaded electronic components) that should be cooled. The oscillating output flow from actuator nozzles 40, 50 cools more effectively than it is possible to obtain with steady, non-pulsating air flow. Also the experience with drying wet surfaces has shown that with the pulsation the removal of water vapour is more intensive. The oscillation may also speed up or intensify the process of mixing various fluids, such as, e.g., the reagents entering into chemical reactions. Because some chemical reactions can be more rapid if the reagents pulse in small chemical reactors, it is possible to replace the actuator nozzles 40, 50 at the output terminals 17, 18 of the oscillator directly by connected small chemical reactors. For the case in which it is useful to know the oscillation frequency may be to the oscillator connected - or positioned anywhere in side the oscillator - a sensor 3. A practical location for placing the sensor 3 is the first output terminal 17 or the second output terminal 18.

Example 2

[0040] In originally tested models of the oscillator according to this invention had always a straight resonance channel 1. If there is a requirement of low frequency of generated oscillation, the corresponding length L of the straight resonance channel 1 is really large and this leads to problems. One of them is the difficulty with stowing the long straight resonance channel 1 in the available stowage space. Other problem is the manufacturing difficulty; the overall dimensions of the oscillator may exceed the working length of manufacturing facilities. Fig. 4 presents an example of the fluidic oscillator according to this invention that was required to oscillate at a rather low frequency - and at the same time was to be manufactured by laser cutting on a numerically controlled machine tool with relatively small dimensions of working table.

[0041] Even in this example the working fluid was air supplied under pressure into the supply nozzle 16. As is the case also in the other examples, on one side of the supply nozzle 16 exit is the first control nozzle 11 while on the opposite side is the second control nozzle 12. Further downstream in the direction of the flow from the supply nozzle 16 there is on one side the first attachment wall 13 leading to the first exit terminal 17 while on the opposite side there is the second attachment wall 14 and the second output terminal 18. These components are all made in a constant-thickness metal plate as cavities closed form the top as well from the bottom by flap metal cover plates 100, not shown in this illustration. They are similar to the cover plate 100 shown in Fig. 1, which closed the oscillator cavities only from the top side since in that case the cavities were of only a certain depth while here in Fig. 4 the metal is removed through the full thickness of the plate. As in the precious example, the resonance channel 1 is also in this second example connected to the first control nozzle 11 while its free end 101 is open to atmosphere - as is also the second control nozzle 12.

[0042] A special feature of this embodiment example is achievement of the desirable compactness in spite of the relatively large length L of the resonance channel 1, which is here not straight but curved. There were fears, when this version was designed, that the curvature would deform the fronts of the propagating pressure waves during their passage through the resonance channel 1. The deformation could lead, in some extreme operational regimes, to irregular character of the generated oscillation. Fortunately, experimental verifications proved that if the curvature radii of the resonance channel 1 axis are not smaller than the characteristic dimensions of the bistable fluidic amplifier 10 the curvature does not have an adverse influence of the oscillator functioning. In this particular embodiment, the resonance channel 1 of the overall length 317 mm could be placed together with the fluidic amplifier 10 in a metal plate of dimensions 97 mm x 160 mm, while the curvature radius of the resonance channel 1 was mere 35 mm, which is only 3.5-times the width of the resonance channel 1 and 0.58-times the overall length of the fluidic amplifier.

[0043] The operation of this example of the fluidic oscillator was the same as in the previous example and does therefore need a detailed explanation. The oscillator was also operated with actuator nozzles 40, 50. These were placed at a larger distance from the plate with the bistable amplifier 10 and the generated oscillations were led to them by metal tubes not shown in the illustration.

Example 3

[0044] Because the frequency of oscillation generated by the oscillator according to this invention depends on the propagation velocity of pressure waves in the resonance channel 1 and this velocity depends on the temperature of the fluid - the effect particularly strong if the fluid is a gas, it is possible to use the oscillator with advantage in the role of temperature sensor. An example is the sensor for measurement of temperature of combustion products - with the frequency-modulated output signal being a particularly attractive feature. If it is made from a temperature-resistant material (in the case discussed here the material is molybdenum alloy - but also suitable may be ceramic materials) which has no other role than to keep its structural integrity, the sensor may operate without limitations at temperatures so high that usual temperature sensors would withstand them only for seconds of not less.

[0045] Such temperature sensor is presented in Fig. 5. Its bistable fluidic amplifier 10 is with respect to its shape and size identical to the example discussed above in association with Fig. 1. The difference is on one hand in the cavities being in this latter case the cavities are
made in a small plate of molybdenum alloy, and on the other hand is the presence of the additional second gas inlet 2. This has here the form of three inclined nozzles 22 issuing into the resonance channel 1. In addition, to obtain proper pressure distributions, there is the first fluidic resistor 4 connected to the first output terminal 14. Similarly, there the second fluidic resistor 5 connected to the second output terminal 18. Also, a sensor 3 sensing air flow velocity is positioned in the first output terminal 17. In principle, the sensor may be placed anywhere in the oscillator cavities where there are periodic changes in the flow. The positioning in one of the output terminals 17, 18 is particularly advantageous because the changes there are very large.

Example 4

The fluidic oscillator according to this invention may be also used for measurement of other gas properties as long as these properties influence the pressure wave propagation velocity. As another example is here mentioned measurement of composition of binary gas mixtures-the components of this mixture having a different propagation velocity. The layout of this example is fully identical to the above discussed Example 1. The difference is the presence of the fluidic resistors 4, 5 replacing the actuator nozzles 40, 50 in the same manner as was mentioned in the Example 3 shown in Fig. 3. Of course, the difference is so to say a terminological one, because nozzles - such as the actuator nozzle 40, 50 - are actually a common form of fluidic resistors. Also identically as in the previous Example 3 shown in Fig. 3, the oscillator now contains a simple sensor reacting by a change in its electric output signal to a change of the instantaneous flow rate in the first output terminal 17. The investigated binary mixture - in this particular example it was a mixture of hydrogen and carbon monoxide, cannot have (in contrast to the danger associated with high temperature) an adverse effect on the sensor 3 so that the mixture is supplied directly into the supply nozzle 16. The fluidic resistors 4, 5 are adjusted so that the pressure drop on them will secure in the cavities of the bistable jet-type amplifier 10 a pressure higher than atmospheric. This pressure difference will preclude any possible mixing of the investigated gas mixture with atmospheric air, which may be in some regimes sucked into the oscillator cavities and thus change the properties if the investigated mixture. It is possible to adjust the fluidic resistors 4, 5 for keeping the pressure of the gas mixture in the cavities so high that some of the investigated gas mixture will leave through the resonance channel 1 into the atmosphere through the free end 101. In the case of the investigated gas mixture being poisonous, explosive or otherwise dangerous, the resonance channel 1 will lead it not into atmosphere but into a closed tank or vessel, from where it will be led further into a neutralisation facility.

Example 5

The oscillator in its basic embodiment as shown in Fig. 1 generates oscillation of practically constant frequency. The control of the action of the actuator nozzles 40, 50 connected to the oscillator output terminals 17, 18 is then only two-positional: the driving gas (air in the case of Fig. 1) is either brought into the oscillator or not. Thus the control of the actuator nozzles 40, 50 is either acting - at a given frequency - or not. There are, however, applications of the fluidic oscillators where it is advisable or even requested to adjust the control action or perhaps even vary it continuously. In particular, it may be requested to adjust the frequency of generated oscillation, e.g. according to the local conditions - or the task may be to vary continuously the frequency during the oscillator operation. The frequency change may be dependent on some input signal fed into the oscillator so that the generated oscillation is frequency-modulated. The Example 5 as shown in Fig. 6 represents a possible arrangement of the variable-frequency oscillator. It uses the fact of the frequency being dependent on the length L of the resonance channel 1. The frequency variation is in this case achieved by varying this length.

The jet-type bistable fluidic amplifier 10 itself as shown in Fig. 6 is essentially identical with the layout presented in Fig. 2. The working fluid is air supplied under pressure into the supply nozzle 16. On one side of the exit from this nozzle is the first control nozzle 11 and on the other, opposite side is also here the second control nozzle 12. Next to the exit of the first control nozzle 11 there is the second attachment wall 14 - and symmetrically on the other side is next to the exit of the second
control nozzle 12 is located the first attachment wall 13. Further downstream along the flow from the supply nozzle 16 there are the first output terminal 17 and the second output terminal 18. Between them there is - as was already in Fig. 2 - a wedge-shaped splitter 6, again with the groove between the two cusps. The first output terminal leads to the first actuator nozzle 40 while the second actuator nozzle 50 is connected with the second output terminal 18. Both output terminals 17, 18 are here longer than was the case in Fig. 2 above, but this is not of any significant consequence for the oscillator operation. The second control nozzle 12 is on its inlet side open into the reference space which in this case is the atmosphere. To the first control nozzle 11 on the opposite side is connected the resonance channel 1, which in this example is not straight but, in a certain kinship to the example presented in Fig. 4, its axis is curved. Also here the free end 101 of the resonance channel 1 is open to the reference space - the atmosphere.

[0050] To make possible the changes of the resonance channel 1 length, this channel is led in an arc formed in the slider 120. This is so shaped that it may be, by an action on the eyes 125, moved in the direction of the arrows S without the resonance channel 1 being discontinued. This is achieved by the fixed part of the resonance channel 1 being made in a body with two excrescences 122. This fit into the corresponding recessions in the slider 120. The wall of the excrescences 122 are very thin so that the cross sections in the resonance channel 1 in these locations do not vary substantially along the channel length if the slider is shifted at larger distances from the body with the fixed channel part. In adjustable version of this tuneable oscillator the changes in the position of the slider 120 are made, e.g., by turning a screw and then fixing the slider 120 in its new position. In the version with modulation of the carrier oscillation frequency the slider 120 is moved by an electromechanical transducer, for example based on the piezoelectric or electrodynamic (vice-coil) principle.

Example 6

[0051] In a similar manner as in the previous illustration, also the last Fig. 7 shows the oscillator according to this invention used as a sensor for digital measurement of high temperature of a gas (or gas mixtures). The difference is in the second gas inlet 2 being not led by the inclined nozzle(s) into the resonance channel 1, but is led into the supply nozzle 16. The inclined nozzle are here not needed. The geometry of the cavities immediately downstream from the supply nozzle 16 exit is identical to the already above described geometry examples. There is again one side of the exit from the supply nozzle 16 the first control nozzle 11 and on the other, opposite side is the second control nozzle 12. Next to the exit of the first control nozzle 11 there is the second attachment wall 14 and symmetrically on the other side is next to the exit of the second control nozzle 12 is located the first attachment wall 13. Further downstream along the flow from the supply nozzle 16 there are the first output terminal 17 and the second output terminal 18. Between them there is the wedge-shaped splitter 6, again with the groove between the two cusps. The first output terminal leads to the first actuator nozzle 40 while the second actuator nozzle 50 is connected with the second output terminal 18. The resonance channel 1 is also here connected to the first control nozzle 11 while its free end 101 is open into atmosphere.

[0052] The difference is in this last example in there being not only one fluidic amplifier: the first output exit terminal 17 is here led onto the second control nozzle of the second amplifier 212 and symmetrically the second output terminal 18 is connected to the first control nozzle of second amplifier 211. The supply nozzle of the second amplifier 216 is connected to a cold air source 202. Opposite to the supply nozzle of the second amplifier 216 there are also two outlets, the first output terminal of the second amplifier 217 and second output terminal of the second amplifier 218. Into the first output terminal of the second amplifier 217 is placed a sensor 3 reacting to the local pressure variations. Both output terminals of the second amplifier 217, 218 lead further downstream into the common outlet 220.

[0053] There were two problems solved in designing this input part of a digital gas temperature meter. Firstly, the temperature in the second gas inlet 2 is here so high that if the sensor 3 were to be chosen so as to withstand it permanently, its price would be inconveniently high. It would be probably necessary to complicate the sensor by an integral cooler. The second problem was in this particular case a too low available pressure in the second gas inlet 2. With this low supply pressure the amplitude of the generated oscillation would be small so that the sensor 3 would have to be very sensitive and, again of significantly higher price. Both problems are solves simultaneously by the addition of the second fluidic amplifier. Through the second amplifier flows - and thus is led to the sensor 3 - the cold air through the cold air inlet 202. An the same time the amplification property of the second fluidic amplifier is used to amplify the generated oscillation. The sensor 3 thus does not need to be very sensitive and may be significantly cheaper. Problems such as the imperfect linearity that may be encountered with fluidic amplifiers are of no consequences here since all what has to be asked for is just transfer of the frequency, which is not influenced by possibly imperfect properties of the second amplifier. There are no fluidic resistors in this example connected to the output terminals 17, 18, because their respective roles are taken over by the control nozzles of the second amplifier 211, 212. The pressure from on them secures the flow of the hot gas through the resonance channel 1.

Industrial applicability

[0054] Fluidic oscillators in general replace currently
the so far usually used mechanical pulsators serving to
generate periodic oscillation in fluids, for example for the
purposes of increasing the intensity of transport process-
es such as heat transfer (cooling or heating) or mass
transfer. Firs of all, however, the subject of the present
invention is expected to be used for control of boundary
layer separation from the surface of bodies exposed to
fluid flows and transition in turbulence. This way it is pos-
sible to achieve increased effectiveness of aircraft lifting
surfaces but also, when used in gas, steam, and wind
turbines, increased efficiency of such turbomachines.

[0055] The above embodiments of the invention as well
as the appended claims and figures show multiple char-
acterizing features of the invention in specific combina-
tions. The skilled person will easily be able to consider
further combinations or sub-combinations of these fea-
tures in order to adapt the invention as defined in the
claims to his specific needs.

Claims

1. A fluidic oscillator with a bistable jet-type amplifier
(10) having cavities including the supply nozzle (16),
first control nozzle (11), second control nozzle (12),
a cavity with the first attachment wall (13) and the
second attachment wall (14), the first output exit (17)
and second output exit (18), where on one side of
the supply nozzle (16) is located the first control noz-
kle (11) while on the opposite side of the supply noz-
kle (16) there is a second control nozzle (12) and the
first control nozzle (11) as well as the second control
nozzle (12) are located with their mouths against
each other, and downstream from the first control
nozzle (11) is positioned the second attachment wall
(14) and downstream from this there is the second
output exit (18), while downstream from the second
control nozzle (12) is positioned the first attachment wall
(13) downstream from which there is the first
output exit (17) and the first attachment wall (13) is
facing the second attachment wall (14) characterized by
presence of the resonance channel (1) which is connected to the first control nozzle (11) while its
free end (101) is open into space and the second
control nozzle (12) is open into the same or a different
space.

2. Fluidic oscillator with a bistable jet-type amplifier ac-
cording to claim 1 characterized by the space being
the atmosphere or a closed cavity, with an advantage
the inner space of a pressure tank.

3. Fluidic oscillator with a bistable jet-type amplifier ac-
cording to claim 1 or claim 2 characterized by the
resonance channel (1) positioned in the same plate
as the cavities of the jet-type bistable amplifier (10)
and made by removal of plate material into the same
depth as the cavities of the jet-type bistable amplifier
(10).

4. Fluidic oscillator with a bistable jet-type amplifier ac-
cording to any of the above claims 1 to 3 characterized by containing a sensor (3) for evaluating the
frequency of the oscillation generated in the oscilla-
tor, and this sensor (3) is positioned anywhere inside
the oscillator cavities where a periodic fluid flow
takes place, with advantage in the first output exit
(17) or in the second output exit (18).

5. Fluidic oscillator with jet-type bistable amplifier ac-
cording to any of the above claims 1 to 4 characterized by containing a second gas inlet (2) which is connected to the sup-
ply nozzle (16) and also a cold air inlet (202), which
is introduced into the cavities of the oscillator be-
tween the supply nozzle (16) and the sensor (3).

6. Fluidic oscillator with jet-type bistable amplifier ac-
cording to the claim 4 characterized by containing
a second-gas inlet (2) which is connected to the sup-
ply nozzle (16) and also a cold air inlet (202), which
is introduced into the cavities of the oscillator be-
tween the supply nozzle (16) and the sensor (3).

7. Fluidic oscillator with jet-type bistable amplifier ac-
cording to any of the above claims 1 to 6 characterized by the resonance channel (1) being either
straight or curved where in the latter case the curva-
ture radius is larger than one half of the total length
of the jet-type bistable amplifier (10).
REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description