June 25, 1968 M. KADOSCH ET AL 3,389,698

FLUIDIC DEVICE FOR ALTERNATELY FILLING EMPTYING AN ENCLOSURE

Filed July 29, 1965 4 Sheets-Sheet 1

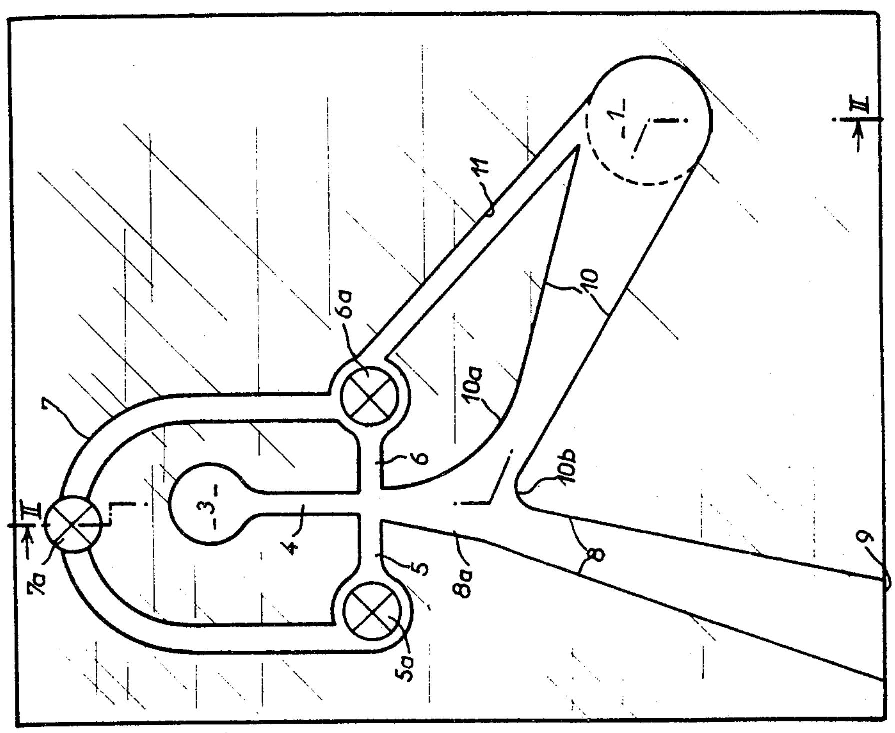

Fig:1

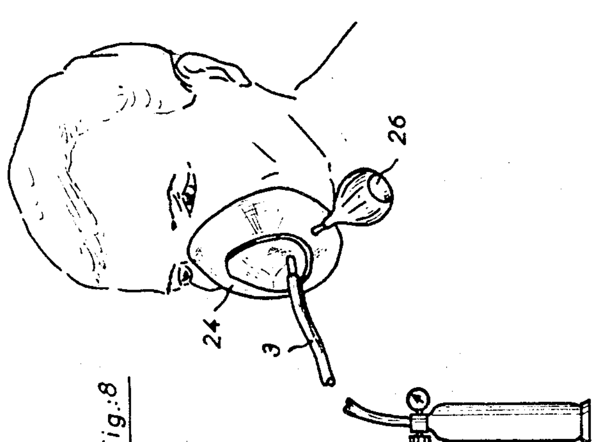

Fig:8

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FLUIDIC DEVICE FOR ALTERNATELY FILLING EMPTYING AN ENCLOSURE

Filed July 29, 1965 4 Sheets-Sheet 2

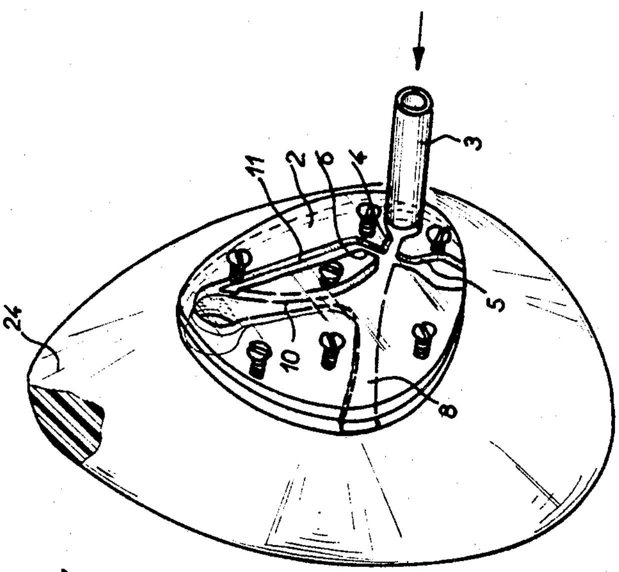

Fig.:7

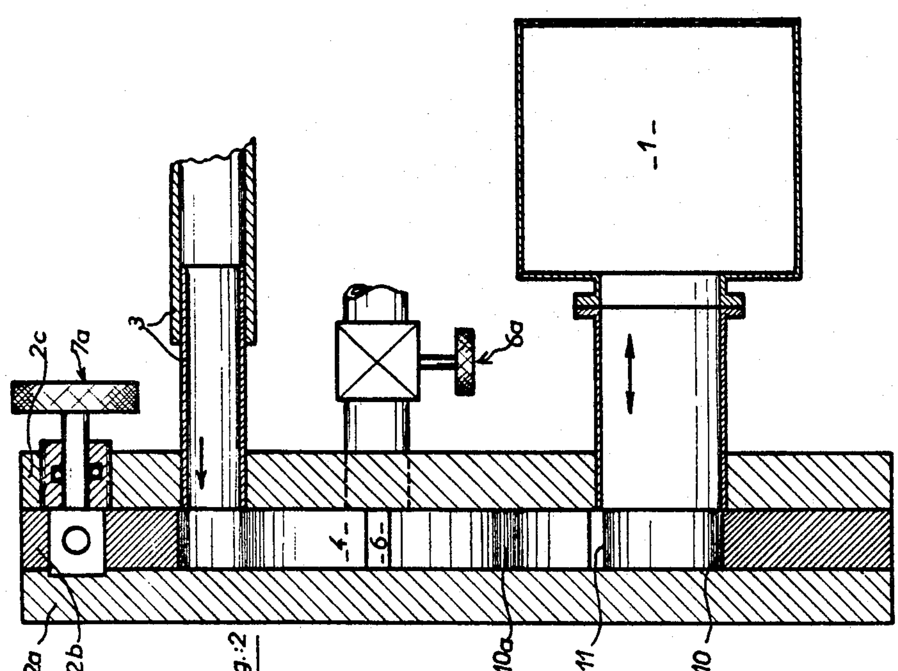

Fig.:2

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FLUIDIC DEVICE FOR ALTERNATELY FILLING EMPTYING AN ENCLOSURE

Filed July 29, 1965 4 Sheets-Sheet 3

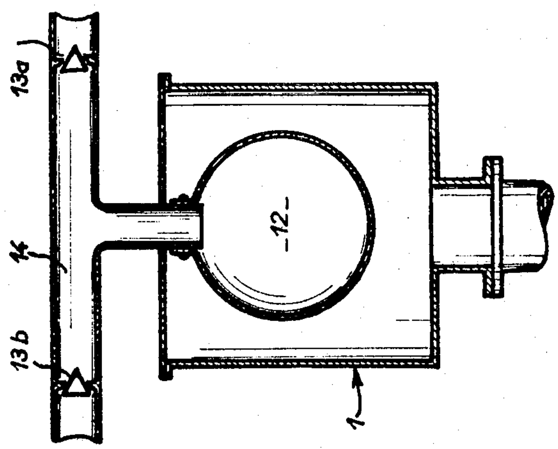

Fig: 3

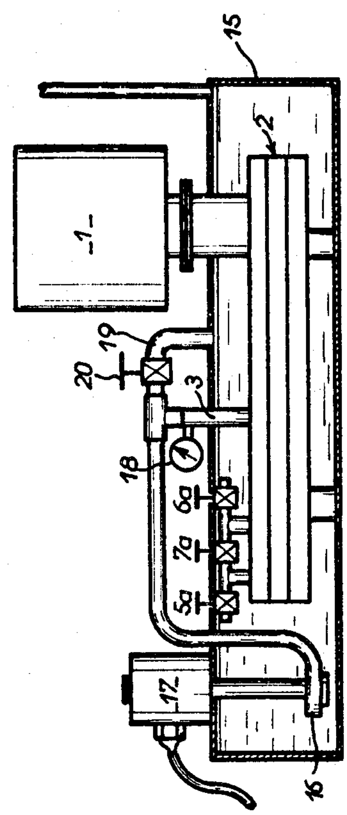

Fig: 4

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FLUIDIC DEVICE FOR ALTERNATELY FILLING EMPTYING AN ENCLOSURE

Filed July 29, 1965 4 Sheets-Sheet 4

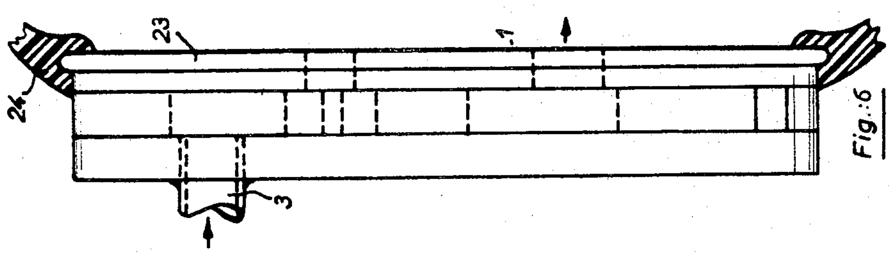

Fig. 6

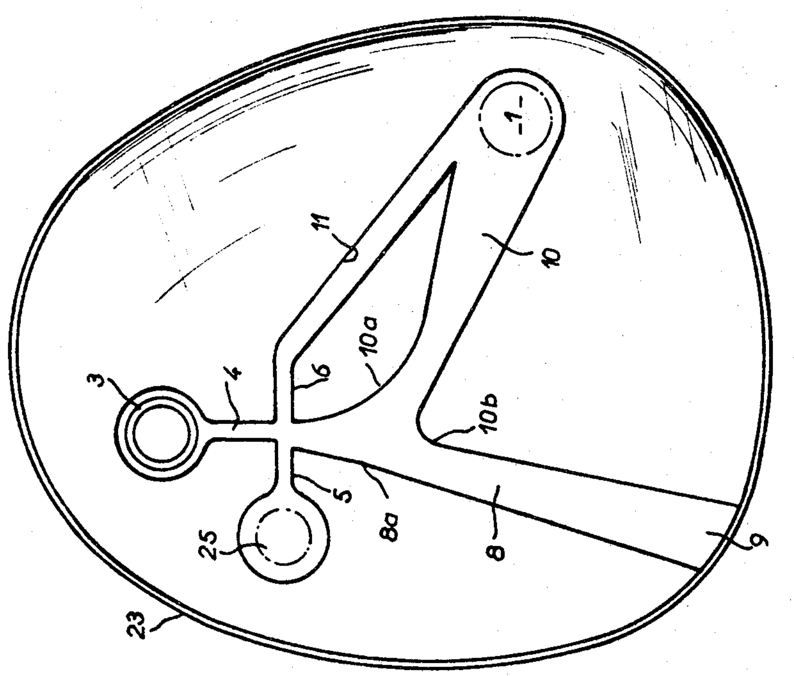

Fig. 5

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FLUIDIC DEVICE FOR ALTERNATELY FILLING AND EMPTYING AN ENCLOSURE

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16 Claims. (Cl. 128—1)

ABSTRACT OF THE DISCLOSURE

A fluidic device for alternately filling and emptying an enclosure comprising a motive fluid supply duct leading from an intake to a zone at opposite sides of which open two control nozzles adapted to deflect the motive fluid from the axis of the duct in either one of two opposite directions, the motive fluid supply duct being extended beyond the zone by two branched ducts, at different angular inclinations with respect to the axis of the duct, namely, an exhaust duct inclined at a relatively small angle and adapted to collect motive fluid deflected in one direction and a load duct inclined at a relatively large angle and adapted to collect motive fluid deflected in the other direction, the load duct leading into the enclosure and being connected to the supply duct along a curved convex wall and being further permanently connected with one of the control nozzles through a feedback passage.

This invention relates to a device devoid of moving parts other than valves or cocks for adjusting it, by means of which an enclosure may be alternately filled with and emptied of a pressurized fluid (i.e. set under negative pressure with respect to a reference pressure which is preferably the atmospheric pressure).

The invention has more particularly for its object to provide a device devoid of moving parts and enabling the above result to be achieved with great reliability.

A further object resides in the efficient use of the energy of a pressurized drive jet.

The invention lastly encompasses the application of such a device to the pumping of all fluids, and more particularly of biological fluids such as breathing air and blood, by reason of the ability of the device to reproduce the natural functional frequencies of the lungs and the heart.

The inventive device may be practiced with advantage as a so-called "artificial heart," a blood pump or as an artificial respirator with the use of a breathing mask. The device essentially comprises:

Motive fluid supply duct;

Opposed control passages substantially perpendicular to the axis of said duct, these passages being adapted to be interconnected and also to be connected individually to any convenient chamber maintained at a reference pressure, such as the atmospheric pressure;

An exhaust duct which extends at least to the proximity of the motive fluid supply duct;

A load duct which is connected through rounded sections to said supply duct and the axis of which forms with the axis of said supply duct an angle greater than the angle formed by said exhaust duct and the supply duct, said load duct terminating at the enclosure in which the pressure and mass of the fluid is to be varied; and lastly

A so-called tumbler or switching duct which connects the enclosure or the load duct to one of said control passages.

Preferably, the entire system may be executed by embodying, by any convenient method—a non-limitative example being by machining or casting—the nozzles, passages and ducts referred to in at least one flat part made of a material which will withstand abrasion by the fluid employed.

Exhaustive tests carried out with the device have revealed all its functional features and have led to providing for certain alternative constructional forms adapted to specific applications. The present invention consequently includes in its scope all such alternative embodiments taking the form of artificial breathing devices, hereinafter referred to as breathers.

The latter must be as light and robust as possible if they are to be used with ease in first-aid stations or ambulances and the like. In accordance with the present invention, such breathers are strictly devoid of moving parts—including valves—and are incorporated in a mask which can be supplied from an air or oxygen bottle, as well known per se, whereby the gas issuing from such a bottle subjects the patient's lungs to an assisted periodic ventilation.

In the accompanying drawings,

FIGURES 1 and 2 are respectively a plan view and a schematic fragmental section on the line II—II of FIGURE 1, of one specific form of embodiment of the invention;

FIGURE 3 illustrates schematically in section how the device can be supplemented to provide a diaphragm-type pump;

FIGURE 4 is a schematic side elevation view in partial section, on a smaller scale, of an alternative constructional form utilizing a liquid as the drive fluid;

FIGURES 5 and 6 are respectively front and side views of the essential part of a breathing mask according to the invention;

FIGURE 7 is a perspective view of the simplest form of embodiment of a breathing mask; and

FIGURE 8 shows correspondingly on a smaller scale an alternative form of construction thereof.

Reference to FIGURES 1 and 2 shows a device according to the invention for alternately setting a cavity or enclosure 1 under an overpressure and an underpressure condition with respect to atmospheric pressure. Said cavity may, for example, be a patient's or an accident victim's lungs.

The invention comprises, in the manner well known per se, at least two and in this particular example three juxtaposed plates 2*a*, 2*b*, 2*c* through the bodies of which are formed passages for conveying the drive fluid. The latter is delivered through an intake 3 and is discharged parallel to the plates 2 by a supply duct 4.

Two opposed control nozzles 5 and 6 open out at the outlet zone of the supply duct 4 and each is directed substantially perpendicularly to said duct. They are interconnected by a connecting duct 7 in which a valve 7*a*, or the like, is effective in progressively varying the cross-section through said duct, and are equipped with valves 5*a* and 6*a* respectively whereby the nozzles 5 and 6 may be progressively and independently vented to the atmosphere or connected to any other region in which prevails a reference pressure which is preferably the exhaust pressure, as will be explained hereinbelow.

The drive fluid supply duct 4 is extended by an exhaust duct 8 which is slightly inclined with respect to the axis of the supply duct and the flow cross-section of which increases preferably progressively in the downstream direction thereby forming a diffuser in which the drive fluid is susceptible to being recompressed before exhausting at 9 into the atmosphere.

A load duct 10 connected to the cavity 1 joins onto the supply duct 4 and the exhaust duct 8 through smoothly curved convex walls **10***a*, **10***b*. Said load duct also has a flow cross-section which increases progressively in the downstream direction in order to assist recompression of the drive fluid when the same flows towards the cavity **1**, and said duct is markedly more inclined than exhaust duct **8** (again with respect to the axis of the supply duct **4**).

Lastly, a feedback passage **11** connects load duct **10**, preferably at the downstream end thereof, to one of the control nozzles (the nozzle **6** in the example shown).

The apparatus hereinbefore disclosed functions in the following manner:

Assuming first of all that the valve **6***a* is open and the valves **5***a* and **7***a* closed, then delivery of a pressurized drive fluid through the intake **3** and discharge of this fluid through the supply duct **4** will result in a relative negative pressure prevailing in control nozzle **5** and the portion of duct **7** connected thereto, due to an ejector effect. A comparable negative pressure can prevail neither in **6** (which is vented to the atmosphere through valve **6***a* being open), nor in **10** (by reason of the existence of passage **11**). As a result, the jet of drive fluid hugs the wall **8***a* and flows in stable fashion through the exhaust duct **8** wherein it is at least partly recompressed before issuing at **9**.

If now the valve **5***a* is opened and the valve **6***a* closed, leaving the valve **7***a* closed, an ejector effect will occur in **6**, **10** and **11**. If the radius of curvature of the wall **10***a* is greater than four times the width of the duct **4**, then the jet issuing from duct **4** will hug the curved wall **10***a* and will consequently flow at least momentarily through the load duct **10** wherein it will be recompressed. Thus the drive fluid will distend the cavity **1** and the pressure therein will rise.

This pressure rise will be communicated via the feedback passage **11** to the control nozzle **6** and, whilst it may not be correct to speak of a control jet as such, the transverse pressure gradient at the exit of duct **4** will be reversed and will tend to divert the jet of drive fluid towards the wall **8***a* and the exhaust duct **8**. The pressure in the cavity **1** will thus drop, ultimately even to below atmospheric pressure, due to the ejector effect assisted by the rounded wall **10***b* and the divergent section of exhaust duct **8**. The cycle then recommences.

In other words, operating conditions are established in all cases once the drive jet flows into the exhaust duct **8**; for when the duct **4** is supplied with pressure fluid, since the nozzles **5** and **6** are at ambient pressure (atmospheric pressure, say) the jet issuing from the duct will maintain its initial shape and hug either wall **10***a* or wall **8***a*.

If it hugs wall **10***a* and therefore flows through duct **10**, it will in any event be impelled after a certain time into duct **8** due to the overpressure in the cavity **1** which it fills, this overpressure prevailing notably in the feedback passage **11** and the control nozzle **6**.

If it hugs wall **8***a*, it will either remain in duct **8** indefinitely or flow alternately through the latter and through duct **10**, depending upon the configuration of the connections between the various passages in the apparatus and of the connection between these passages and the surrounding atmosphere, i.e. upon the adjustment of valves **5***a*, **6***a*, **7***a*, as discussed herebelow.

(1) If valves **5***a* and **6***a* are both vented to the atmosphere, then valve **7***a* will remain without effect.

As the drive jet passes initially through exhaust duct **8** it produces a certain negative pressure in the cavity **1** due to an ejector effect. This negative pressure will cause the jet to be switched into the duct **10** and into said cavity, with the overpressure which results from the distension of said cavity diverting the jet after a certain time lapse into exhaust duct **8**. The pressure in cavity **1** is on an average greater than atmospheric pressure.

The jet flows alternately through duct **8** and duct **10**.

(2) If the **5***a* is closed and valve **6***a* vented to the atmosphere, then when valve **7***a* is closed the drive jet will remain in duct **8** and, by an ejector effect, will produce a

negative pressure in control nozzle **5** that will be greater than that which can prevail in cavity **1**.

When valve **7***a* is opened, the drive jet flows alternately through duct **8** and duct **10** due to the inertia of the mass of gas contained in cavity **1**. As the passageway through valve **7***a* increases, the frequency increases, as does also the mean value of the pressure in duct **10** and cavity **1**.

(3) If valves **5***a* and **6***a* are closed, then when valve **7***a* is likewise closed the drive jet will remain in duct **8** since the negative pressure induced in control nozzle **5** will be preponderant. Through an ejector effect the jet will produce a negative pressure in cavity **1**, the value of which can be exceeded with no other configuration for a given drive jet since it is not attenuated by any entry of gas.

When valve **7***a* is opened at least beyond a certain threshold, then the drive jet will pass periodically into duct **8** and into duct **10**, the preponderance of the negative pressure at **5** no longer being permanent. As the passageway through valve **7***a* increases, the oscillation frequency will increase and the maximum negative pressure in cavity **1** will drop in absolute value.

(4) If valve **5***a* is vented to the atmosphere and valve **6***a* is closed, then the drive jet will flow alternatively into duct **8** and duct **10**. (Due to an ejector effect, control nozzle **6** and the system **10**, **11**, **1** tend to be set under negative pressure, thus tending to cause the drive jet to hug wall **10***a* and fill cavity **1**. The resulting overpressure diverts the jet into exhaust duct **8**.)

As valve **7***a* is gradually opened, the value of the negative pressure increases in cavity **1**, while the overpressure decreases and the frequency increases.

Operation of the subject device of the invention in its various configurations is tabulated below (where O stands for "open," Cl for "closed":

		5*a*	6*a*	7*a*	Type of operation: A (alternating); C (continuous)
1		O	O		A.
2	1	Cl	O	Cl	C (negative pressure in 1).
	2			O	A.
3	1	Cl	Cl	Cl	C (big negative pressure in 1).
	2			O	A.
4	1	O	Cl	Cl	A.
	2			O	A.

Thus it will readily be appreciated that valve **7***a* permits adjusting the ratio of the maximum and minimum pressures in cavity **1**. When said valve is open the mean pressure prevailing in **6** is reduced.

By adjusting the pressure of the drive fluid it is possible to vary the mass of fluid entering and issuing from the cavity **1** at each cycle.

The frequency is determined by the calibration of the system as a function of the volume of cavity **1**, and especially by the cross sections of the supply duct **4** and the feedback passage **11**.

The great simplicity of the device and the absence of sharp edges which could be used to divert the drive jet but which could introduce unwanted vibration, ensure uniform operation and a wide adjustment range.

The absence of all valves between the supply and exhaust ducts is an additional advantage when the device is used as an artificial breather, since the patient's lungs are in constant communication with the surrounding atmosphere.

With a view to providing a diaphragm pump as schematically illustrated in FIGURE 3, the system hereinbefore described can readily be supplemented by a bladder **12** made of fluidtight, deformable and preferably elastic material, mounted in the cavity **1** and connected to any convenient pipe **14** fitted with two non-return valves **13***a*, **13***b*. Variations in the mass of drive fluid contained in cavity **1** cause the volume of bladder **12** to vary and the fluid to be pumped to flow through the line **14** and to be checked alternately by valves **13***a* and **13***b*. A device of this type could constitute a blood pump, or "artificial heart."

FIGURE 4 shows an alternative form of embodiment of the device of FIGURES 1 and 2, in which the drive fluid is a liquid.

As FIGURE 4 clearly shows, the device **2** proper is submerged in a tank **15** which is almost filled with liquid and into which the valves **5***a* and **6***a* open. The supply is effected by a submerged pump **16**, of the centrifugal type for instance, which is driven by an electric motor **17** and feeds the intake **3**. The latter is fitted with a pressure gauge **18** and a valve-type by-pass **19**, **20** for varying the pressure of the drive fluid.

The constructional details of the various figures referred to may be combined, or else the tank **15** may be filled with pressurized air or conversely be maintained at a negative pressure relatively to the atmosphere by means of the pump **16**. Further, a number at least of the valves **5***a*, **6***a* and **7***a* may be interconnected whereby to enable them to be controlled by a single lever.

In the breathing mask shown in FIGURES 5 and 6, like parts (to FIGURES 1 and 2) are used for the most part and are designated by like reference numerals.

On the other hand, the interconnecting duct **7** and the valves **6***a* and **7***a* are dispensed with, while the valve **5***a* is replaced by a filter **25** which places the passage in communication with the cavity (including the patient's lungs), which cavity is positioned behind the mask **24**. The subject device of the invention is mounted for instance on this mask, by simply engaging a peripheral flange formed thereon into a suitable groove in the mask. The latter is preferably made of plastic.

It will immediately be seen that the configuration of the device of FIGURES 5 and 6 may be likened to that corresponding to line 3/2 of the table above, in which the control nozzles **5** and **6** both communicate with the cavity **1** due to opening of the valve **7***a* alone. The chief advantage of dispensing with the duct **7** interconnecting these two control nozzles is that, in the event of its becoming obstructed by food particles or the like, there is no further danger of the patient's lungs being set under a permanent negative pressure (see lines 2/1 and 3/1 of the table above, which corresponds to closure of valve **7***a*). The filter **25** prevents such obstruction of nozzle **5**.

The device shown in FIGURE 7 corresponds similarly to line 4/1 of the table. It will be seen that its oscillation frequency is for all practical purposes lower than that of the device of FIGURES 5 and 6, in which the exhalation period is shorter. Said oscillation frequency can be lowered to some extent by replacing the filter **25** by one having a lower pressure loss, thereby adapting the frequency to the patient's natural breathing rate.

By adding a balloon **26** to the mask in both cases (FIGURE 8), so that it communicates with the interior of the mask and with the patient's lungs, is tantamount to artifically increasing the capacity of the latter. The frequency of the device can thus be lowered as desired, since a balloon can instantly be replaced by another, or even have its degree of distention controlled manually by an anesthetist, if not by the patient himself.

It goes without saying that a filter could be fitted to the end through which the load duct **10** opens out into the mask.

We claim:

1. A fluid amplifier device operable with a source of motive fluid for alternately filling and emptying an enclosure comprising a motive fluid intake to be connected to said source, a motive fluid supply duct leading from said intake and having two opposite sides, two control nozzles opening into said supply duct at said opposite sides thereof and adapted to deflect the motive fluid supplied by said duct away from the axis thereof in either one of two opposite directions, two branched ducts extending said motive fluid supply duct beyond said control nozzles respectively in said opposite directions and at different angular inclinations with respect to said axis, one of said branched ducts being an exhaust duct forming a branch of said supply duct extending the same beyond said control nozzles at a relatively small angle of inclination with respect to the axis of said supply duct, said exhaust duct being adapted to collect said motive fluid when the same is deflected in one of said two opposite directions and to lead said fluid to exhaust, the other of said branched ducts being a load duct leading into said enclosure and forming a further branch of said supply duct extending the same beyond said control nozzles at a relatively large angle of inclination with respect to the axis of said supply duct, said load duct having a boundary surface being connected to the adjacent one of said sides of said supply duct along a curved convex wall smoothly merging with said surface and adjacent side and being adapted to collect said motive fluid when deflected in the other one of said two opposite directions and to lead said fluid into said enclosure, and a feedback passage permanently interconnecting said load duct with one of said control nozzles.

2. A device as claimed in claim **1** wherein said exhaust duct and said load duct have respective boundary surfaces which are connected to each other along a curved convex wall.

3. A device as claimed in claim **1** wherein both said control nozzles are in communication with said enclosure in at least one operative condition of said device.

4. A device as claimed in claim **3** wherein both said control nozzles are permanently in communication with said enclosure.

5. A device as claimed in claim **4**, further comprising filtering means interposed into the communication of said enclosure with that one of said two control nozzles which is opposite to the one permanently connected with said feedback passage.

6. A device as claimed in claim **3**, further comprising valve means interposed into the communication of said enclosure with that one of said two control nozzles which is opposite to the one permanently connected with said feedback passage, for selectively and adjustably controlling said communication.

7. A device as claimed in claim **3** wherein both said control nozzles are isolated from an ambient medium in at least one operative condition of said device.

8. A device as claimed in claim **7** wherein both said control nozzles are permanently isolated from said ambient medium.

9. A device as claimed in claim **7** further comprising valve means for selectively and controllably connecting each of said control nozzles to said ambient medium.

10. A device as claimed in claim **1**, wherein said feedback passage leads to that one of said two control nozzles which is adapted to deflect said motive fluid into said exhaust duct.

11. A device as claimed in claim **1** wherein said exhaust duct opens into an ambient medium.

12. A device as claimed in claim **1** wherein said enclosure comprises a deformable fluid-tight membrane bounding at least partly a variable-volume, liquid pumping chamber.

13. A device as claimed in claim **12** wherein said liquid pumping chamber is an artificial heart for pumping blood.

14. A device as claimed in claim **1** wherein said enclosure comprises a breathing mask adapted to be fitted on a patient's face and to communicate with his respiratory system, whereby said device operates as an artificial respirator.

15. A device as claimed in claim **14** further comprising a balloon fitted on said mask and communicating with the interior thereof.

16. A device as claimed in claim **1** in which the motive fluid is a biological fluid selected from the group comprising breathing air and blood and in which said fluid is circulated in a patient in a periodic manner.

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