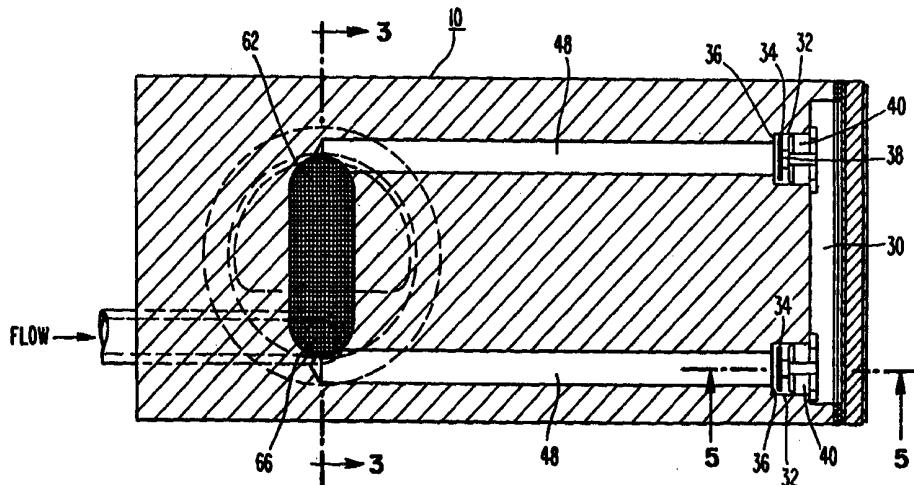




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ :	A1	(11) International Publication Number: WO 99/20467
B41J 2/03		(43) International Publication Date: 29 April 1999 (29.04.99)
(21) International Application Number: PCT/US98/13962		
(22) International Filing Date: 6 July 1998 (06.07.98)		
(30) Priority Data: 08/954,523 20 October 1997 (20.10.97) US		
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(54) Title: IMPULSE FLUID JET APPARATUS WITH DEPRIMING PROTECTION



(57) Abstract

An impulse fluid or ink jet print head (10) comprises a manifold (30) which is supplied with fluid in the form of ink through two check valves (32) located at an end of a plurality of supply channels (48). The check valves (32) comprise a diaphragm (34) which seats against a valve seat (36) in the print head (10) when the valve is closed. A diaphragm (34) when open permits the flow of ink when seated against an end (38) of a check valve insert or support (40).

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IMPULSE FLUID JET APPARATUS WITH DEPRIMING PROTECTION

Cross Reference to Related Application

This application is a continuation-in-part and claims the benefit of the filing date of U.S. Patent Application Serial No. 08/828,758, filed March 25, 1997.

5 Field of the Invention

This invention relates to a drop-on-demand or impulse fluid jets which eject a droplet of fluid such as ink in response to the energization of a transducer.

Background of the Invention

Impulse fluid or ink jets are designed and driven so as to eject a droplet of fluid such as ink on demand from a chamber through an orifice in the chamber. Where impulse jets are utilized in many applications including industrial applications, it is important that the impulse ink jets operate reliably. Such reliability can be jeopardized where the impulse jets can be deprimed due to fluid disturbances in the supply of ink to and through the impulse jet. Such depriming can occur as a result of brief disturbances to the fluid supply as well large, longer disturbances caused by, for example, bumping the apparatus.

Summary of the Invention

In accordance with this invention, an apparatus is provided for preventing depriming of an impulse jet.

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In still further accordance with the invention, an apparatus is provided for preventing depriming of an impulse jet in response to small and/or brief disturbances in the ink or fluid supply line to the impulse ink jet or elsewhere.

In still further accordance with the invention, an apparatus is provided for 5 preventing depriming of an impulse jet in response to large and/or longer disturbances in fluid supply line or elsewhere.

In accordance with a preferred embodiment of the invention, an impulse ink fluid apparatus comprises a transducer, and a fluid jet chamber coupled to the transducer, the chamber having an orifice through which droplets of fluid are ejected 10 in response to the energization of the transducer. A fluid supply is coupled to the fluid jet chamber through a compliant chamber which forms at least part of a low pass filter substantially attenuating fluid disturbances having a duration substantially less than time constant of the low pass filter formed by the compliant chamber.

In the preferred embodiment, the time constant represented by the product 15 of the fluidic capacitance of the compliant chamber and at least a portion of the fluidic resistance of the fluid supply substantially attenuates pressure disturbances having a duration less than 0.01 the value of the time constant. In the preferred embodiment, disturbances of less than 0.01 and preferably less than 0.05 seconds will be attenuated.

In the preferred embodiment, the compliant chamber comprises a 20 compliant member for absorbing pressure waves. The compliant chamber comprises a flexible diaphragm which is nonplanar in the undisturbed state such that deformation is nonlinear with respect to changes in pressure. Preferably, pressure waves are absorbed without pressure increases in the compliant chamber. In the preferred embodiment, the compliant chamber comprises an air passage allowing ambient air pressure to flow 25 through and reach the compliant member.

The compliant chamber may also include a filter permitting the flow of ink through the filter from the ink supply to the fluid jet chamber.

In one preferred embodiment, the apparatus further comprises at least one 30 check valve located between the fluid jet or a manifold serving a plurality of fluid jets and the compliant chamber for preventing the reverse flow of ink flow of ink from the ink jet chambers to the compliant chamber while permitting ink to flow from the compliant chamber to the ink jets. Each check valve includes passageways permitting

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the passage of air through the check valves. In this regard, the check valve comprises a valve seat, a valve member, a valve support comprising at least one passage permitting fluid flow between the valve seat and the valve member and through the fluid passage toward the fluid chamber. The check valve includes a valve body

5 forming the valve seat and containing the valve member and the valve support such that the fluid passage in the valve support is located adjacent to the valve body. Preferably, the valve support comprises a plurality of passages located adjacent to the valve body.

In another preferred embodiment, the check valve, which acts as a
10 rectifier to maintain positive pressure at the orifice(s), is coupled between the fluid supply and the compliant chamber. Moreover, in this embodiment the compliant chamber holds negative pressure between -0.1 and -10 in-H₂O created by orifice jetting and the static height of the ink supply. Further, the check valve is characterized by a cracking pressure of between 0.1 and 3 in-H₂O, whereby excessive buildup of negative
15 pressure at the orifice during jetting is prevented.

Brief Description of the Drawings

Figure 1 depicts an impulse ink jet head incorporating the invention shown in cross-sectional form with the ink supply with the compliant chamber rotated 90° for purposes of clarity.

20 Figure 2 is a view of the impulse ink jet head taken along section line 2-2 of Figure 1.

Figure 3 is a sectional view of the compliant chamber taken along line 3-3 of Figure 2.

25 Figure 4 is a sectional view of the compliant chamber taken along line 4-4 of Figure 3.

Figure 5 is an enlarged sectional view of the check valve and the ink jet chamber shown in Figure 1.

Figure 6 is a sectional view taken along line 6-6 of Figure 2 depicting the restrictor plate forming a portion of a plurality of ink jets in the head.

30 Figure 7 is a perspective view of a check valve support member shown in Figure 5.

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Figure 8 is an equivalent electrical circuit for the fluidic system shown in Figures 1-7.

Figure 9 corresponds to Figure 8 with the equivalent electrical circuit broken into sections A through C.

5 Figure 10 is a classical first order low pass filter schematic.

Figure 11 depicts an alternative embodiment of an impulse ink jet head in accordance with the present invention. The primary difference between the embodiments depicted in Figures 11 and 1, respectively, is in the location of the check valve 32.

10 Detailed Description of Preferred Embodiments

Referring to Figure 1, an impulse fluid or ink jet print head 10 comprises a chamber plate 12 and an orifice plate 14 forming a plurality of ink jet chambers 16 coupled to a transducer 18 through a foot 20 and a diaphragm 22 shown in enlarged form in Figure 5. The transducer 18 is energized and de-energized by applying a 15 voltage transverse to the longitudinal axis of the transducer 18 so as to operate the transducer in an expander mode, i.e., the transducer expands and contracts along the longitudinal axis parallel to arrows 19 to cause volumetric changes in the chamber 16 to jet droplets from orifices 15 in the plate 14.

Referring to Figures 1 and 5, fluid in the form of ink is supplied to each 20 chamber 16 through restricted inlets 24 formed in a restrictor plate 26 between the chamber plate 12 and a spacer plate 27 which is sandwiched up against the diaphragm 22 best shown in Figure 5. Such restricted inlets 24 are shown in Figure 6 which depicts the restrictor plate 26 having enlarged openings 28 as explained in co-pending application Serial No. 08/823,718, filed March, 25, 1997, titled "High Performance 25 Impulse Ink Jet Method and Apparatus" (Attorney's Docket No. TRID-0104), which is incorporated herein by reference. The foregoing structure including the size of the chambers 16 in conjunction with the resonant frequency of the transducers 18 produce a high performance ink jet.

Each of the restricted inlets 24 is supplied by a manifold 30 shown in 30 Figures 1 and 5 as well as Figure 2. In accordance with one important aspect of the invention, the manifold 30 is supplied with fluid in the form of ink through two check

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valves 32 as shown in Figures 1, 2 and 5. The check valves 32 are designed in a manner so as to prevent the reverse flow of ink from the 24 back through the fluid supply lines in the print head 10. In particular, the check valves 32 comprise a diaphragm 34 which seats against a valve seat 36 in the print head 10 when the valve is 5 closed as shown in dotted lines in Figure 5. The diaphragm 34 when open permits the flow of ink into the chamber 16 as shown in Figure 5 when seated against the end 38 of a check valve insert or support 40 as shown in full in Figure 5. Details of the support 40 can be best appreciated by reference to Figure 7 wherein flow channels 42 leading away from the end 38 and toward the manifold 30 are provided and a flange 44 10 through which the channels 42 pass is also provided for engaging a seat 46 in the print head in the valve body for the diaphragm 34 as best shown in Figure 5.

Referring again to Figures 1 and 2, the check valves 32 are located in the print head at the end of supply channels 48. In accordance with another important aspect of this invention, the supply channels 48 are terminated in a compliant chamber 15 49 shown in Figures 1 and 2 and best shown in Figures 3 and 4. The compliant chamber is provided to attenuate brief disturbances which might otherwise deprime the print head. To this end, the compliant chamber comprises a flexible membrane 50 which is capable of movement in the direction shown by the arrows 52 in an amount sufficient to absorb ink pressure disturbances in the supply line through the print head 20 so as to prevent depriming of the head. The membrane 50 is held in place between a stainless steel member 54 and a filter assembly 56. The stainless steel member 54 is in turn held in place between the membrane 50 and another gasket 58. In order to provide total freedom of movement of the flexible membrane 50, a vent hole 60 is provided in the print head juxtaposed to the membrane 50 so as to allow air to escape 25 which is displaced by the membrane 50.

The filter assembly 66 includes a filter 62. As will be appreciated with reference to Figures 1-4, ink is free to flow into the compliant chamber 49 from an inlet 66 on the membrane side of the filter 62.

In order for the compliant chamber to best serve its purpose of preventing 30 depriming of the ink jet, it is preferable that the membrane displacement be non-linear with respect to changes in pressure. For this purpose, the membrane 50 is shown as concave with respect to the interior of the chamber 49 such that resistance to

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deformation increases concavity of the diaphragm. In other words, deformation of the diaphragm is non-linear with respect to changes in pressure within the compliant chamber.

As also shown in Figure 1, the inlet 66 of the print head is supplied with
5 ink through a flexible tube 70 leading to a reservoir 72. The reservoir 72 as shown is including another filter 74 to assure that no agglomerations in the ink greater than the filler rating pass into the print head 10. Also note that the level of ink 76 in the reservoir 72 is maintained below the height of the ink jet chamber 14 so as to assure that no ink pressure at the chamber 16 thus avoiding weeping of ink from the orifices
10 15 in the orifice plate 14.

In order to better appreciate the manner in which the compliant chamber can prevent pressure disturbances from depriming ink jets, reference will now be made to Figure 8 wherein an electrical circuit is shown which is equivalent to the fluidic circuit of the ink jet apparatus shown in Figure 1. In particular, the apparatus shown
15 in Figure 1 is depicted in equivalent electrical circuit form using capacitance, resistance and inductance and a pressure disturbance equivalent to a voltage pulse being simulated by a pulse generator. More specifically, the equivalent circuit shown in Figure 1 comprises a capacitance 80 and a resistance 82 corresponding to the capacitance and resistance of the orifice 15 in the orifice plate 14 respectively. A resistance 84
20 corresponds to the resistance of the restrictor 24. A capacitance 86 and a resistance 88 correspond to the fluidic capacitance and resistance of the manifold 30 including the feed lines 46. A capacitance 90 corresponds to the fluidic capacitance of the compliant chamber. A resistance 92 and a resistance 94 correspond to the fluidic resistance of the feed line 72 while an inductance 96 and an inductance 98 correspond to the fluidic
25 inductance of that feed line 72. A capacitance 102 corresponds to the fluidic capacitance of the reservoir 72 and a voltage source 104 corresponds to the fluidic voltage or pressure generated by the reservoir 72. Any pressure disturbance in the feed line which is of a nature which could otherwise deprime the ink jet is depicted by a signal generator 106 located between the resistances 92 and 94 and the inductances
30 96 and 98 of the feed line.

The equivalent circuit of Figure 8 may be broken down for purposes of analysis into a series of low pass filters depicted in Figure 9. More specifically, a first

low pass filter is provided by sub-circuit 108 comprising the fluidic capacitance 80 and the fluidic resistances 82 and 84. A second sub-circuit 110 comprises fluidic capacitance 86 and fluidic resistance 88. A third sub-circuit 112 comprises fluidic capacitance 90 of the compliant chamber and fluidic resistance 92 which is part of the 5 feed line 70 resistance.

As may be seen be reference to Figure 10, each of the sub-circuits 108, 110 and 112 effectively form a classic first order low pass filter where $v_i(t)$ is an input voltage corresponding to the disturbance in the feed line and the $v_o(t)$ is the output voltage. By proper selection of the resistance R and the capacitance C of the low pass 10 filter, the output voltage $v_o(t)$ corresponding to the output effect of the pressure disturbance represented by the $v_i(t)$ may be severely attenuated if the duration of the disturbance is less than the time constant T corresponding to the product RC. In other words, disturbances which are sufficiently brief in time will be severely attenuated by the low pass filter represented by the sub-circuit 112 corresponding to the low pass 15 filter represented by the RC combination of the compliant chamber capacitance 90 and the line resistance 92. More specifically, disturbances having a duration shorter than 10% of T equal to the product of RC will be sufficiently attenuated so as not to have any material affect on the operation of the print head: *i.e.*, will not deprime the print head or cause weeping through the orifices. In this regard, the flexible membrane is 20 chosen so as to produce a time constant T of at least .1 second and preferably more than .5 seconds such that disturbances less than 1/10 or 10% of the time constant T will be substantially attenuated by the low pass filter formed by the compliant chamber in conjunction with the feed line resistance. More specifically, for a time constant of .1 seconds, the disturbance of less than .01 seconds or less than 1/10 or 10% of .1 25 seconds will have no effect on depriming or weeping. Similarly, for a time constant of at least .5 seconds, a disturbance of .05 seconds in duration will have little or no effect on depriming or weeping. It should be understood that in order for the compliant chamber to function as part of a low pass filter to serve the foregoing purpose, it is important that the compliant chamber be large enough to handle the volumetric 30 disturbance without an undue increase in pressure.

As indicated previously, the check valves 32 will only prevent depriming in gross overpressure situations where they are useful in preventing back flow of ink.

On the other hand, very small pressure changes which would otherwise produce depriming will not have that effect where the compliant chamber is utilized to provide the low pass filter characteristic. However, where there are very large pressure changes, the check valves do tend to pressurize the manifold section and prevent an

5 unobjectionable massive deprime at the expense of some slightly objectionable orifice weeping.

It will be appreciated that the compliant chamber may take on different shapes and sizes. In particular, the flexible membrane may take on a different shape although it is preferred that the membrane provide a non-linear change in deformation

10 with respect to changes in pressure.

Referring now to Figure 11, in an alternative preferred embodiment, the check valve 32 is allowed to float between the ink tube (feed line) 70 and the compliant chamber 49, in the "elbow" region of the filter assembly 66. It is important for proper operation of the invention that the wall surrounding the check valve have a

15 rough surface to create a sufficient amount of friction with the ink, to cause the ink to flow against the movable disk of the check valve rather than around the disk. This embodiment was made in the process of developing a bar code print head. It has been found that this embodiment improves upon the print head's ability to stay primed. A pressure wave, e.g., one caused by sudden movement of the reservoir 72 or tube 70

20 (including shock, vibration, pumping, elevation, squeezing or heating of the feed tube or ink supply), will travel past the check valve 32 and slightly pressurize the compliant chamber 49. Subsequently, a negative part of the pressure wave will travel backward, from the face of the print head toward the compliant chamber, and seat the disk 34 of the check valve 32. In this manner, the pressure in the compliant chamber will remain

25 large enough to prevent negative pressure from being developed at the orifices. This sequence can result in a small amount of ink being wept out of the face of the print head (during the positive cycle of the pressure wave), but it prevents air from being pulled into the print head. An important characteristic of this alternative embodiment of the invention relates to the way in which the check valve in combination with the

30 compliant chamber prevent air from being sucked into, and thus depriming, the print head.

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The compliant chamber is preferably designed to hold a negative pressure of between -0.1 and -10 in-H₂O, which is the range of pressures that are likely to be created by orifice jetting and the static height of said ink supply (i.e., the ink supply will typically be stationed slightly below the print head). In addition, to avoid jetting 5 anomalies, the check valve is preferably designed to have a cracking pressure of between 0.1 and 3 in-H₂O. This prevents excessive buildup of negative pressure at the orifice during jetting.

Although preferred embodiments of the invention have been described in detail and various modifications suggested, other such modifications will occur to those 10 of ordinary skill in the art which will fall within the true spirit and scope of the invention as set forth in the appended claims. For example, fluids other than ink may be utilized where the fluidic jets are used, for example, as meters. In addition, alternative ink jet configurations may be utilized where different types of transducers are used including the ink itself as in a bubble jet.

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We claim:

1. An impulse fluid jet apparatus comprising:
 - a transducer;
 - a fluidic jet chamber coupled to said transducer and having an orifice for ejection of droplets in response to energization of the transducer;
 - a fluid supply; and
 - a compliant chamber coupled between said jet chamber and said fluid supply for attenuating pressure disturbances in said fluid supply.
2. The impulse fluid jet apparatus of claim 1 wherein a time constant represented by the product of the fluidic capacitance of the compliant chamber and at least a portion of the resistance of the fluid supply substantially attenuates pressure disturbances having a duration less than 10% of the time constant represented by said product.
3. The impulse fluid jet apparatus of claim 1 wherein pressure disturbances having a duration substantially less than 0.01 seconds are substantially attenuated.
4. The impulse fluid jet apparatus of claim 1 wherein pressure disturbances of duration less than 0.05 seconds are substantially attenuated.
5. The impulse fluid jet apparatus of claim 1 wherein said compliant chamber includes a compliant member which is characterized by deformation which is non-linear with respect to changes in pressure.
6. The impulse fluid jet apparatus of claim 1 wherein said compliant chamber comprises a flexible diaphragm which is non-planar in the undeformed position.
- 25 7. The impulse fluid jet apparatus of claim 6 wherein said compliant chamber further comprises a fluid flow path in combination with said flexible

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diaphragm which attenuates pressure disturbances while permitting ink to flow through the path without substantial increases in pressure.

8. The impulse fluid jet apparatus of claim 7 wherein said compliant chamber further comprises an air passage for allowing air to flow through and reach 5 the flexible diaphragm.

9. The ink jet apparatus of claim 1 further comprising a check valve between said jet chamber and said compliant chamber to prevent the reverse flow of fluid from said orifice to said compliant chamber.

10. The ink jet apparatus of claim 9 wherein said check valve permits 10 the passage of fluid from said check valve to said jet chamber.

11. The apparatus of claim 10 wherein said check valve comprises a valve seat, a valve member, and a valve support comprising at least fluid passage permitting fluid to flow between said valve seat and said valve member and through said fluid passage toward said fluid jet chamber.

15 12. The apparatus of claim 11 wherein said check valve comprises a valve body including said valve seat, and containing the valve member and the valve support such that said fluid passage in the valve support is located adjacent to said valve body.

20 13. The apparatus of claim 12 wherein the valve support comprises a plurality of air passages located adjacent to valve body.

14. The apparatus of claim 1 wherein said compliant chamber comprises a fluid passage and a compliant member for absorbing pressure waves while permitting ink to flow through the ink passage.

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15. The apparatus of claim 14 wherein said compliant chamber comprises an air passage for allowing air to flow through and reach said compliant member.

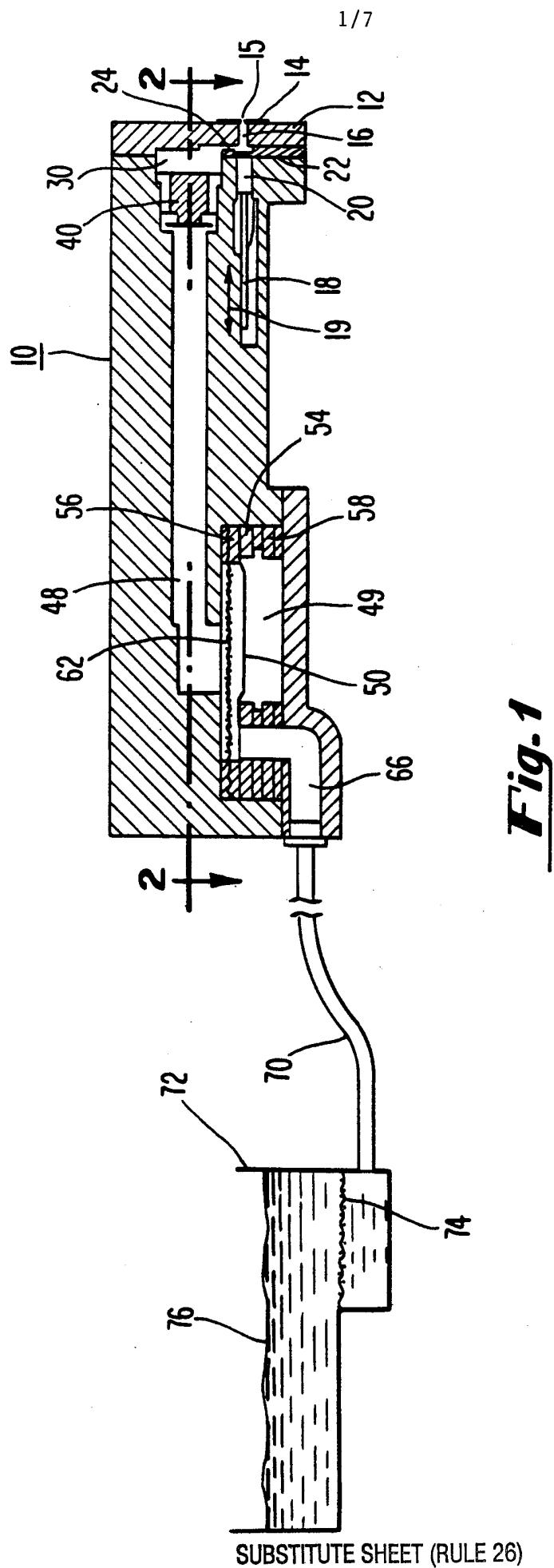
16. An apparatus as recited in claim 1 and further comprising a check
5 valve operatively coupled to said compliant chamber.

17. An apparatus as recited in claim 16, wherein said check valve acts as a rectifier to maintain positive pressure at said orifice.

18. An apparatus as recited in claim 17, wherein said check valve is coupled between said fluid supply and said compliant chamber.

10 19. An apparatus as recited in claim 18, wherein said compliant chamber holds negative pressure between -0.1 and -10 in-H₂O created by orifice jetting and a static height of said ink supply.

20. An apparatus as recited in claim 18, wherein said check valve is characterized by a cracking pressure of between 0.1 and 3 in-H₂O, whereby excessive
15 buildup of negative pressure at the orifice during jetting is prevented.



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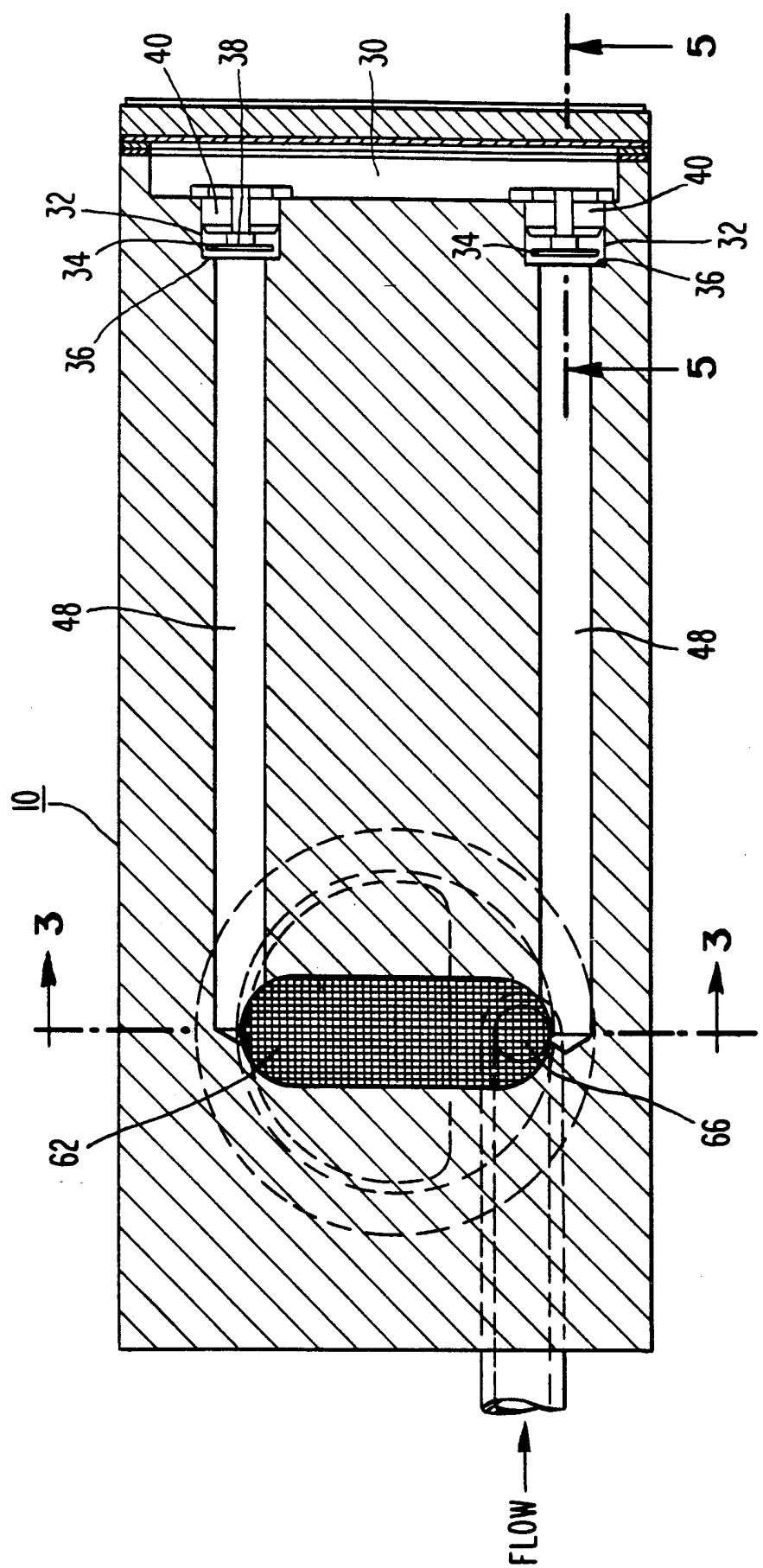


Fig. 2

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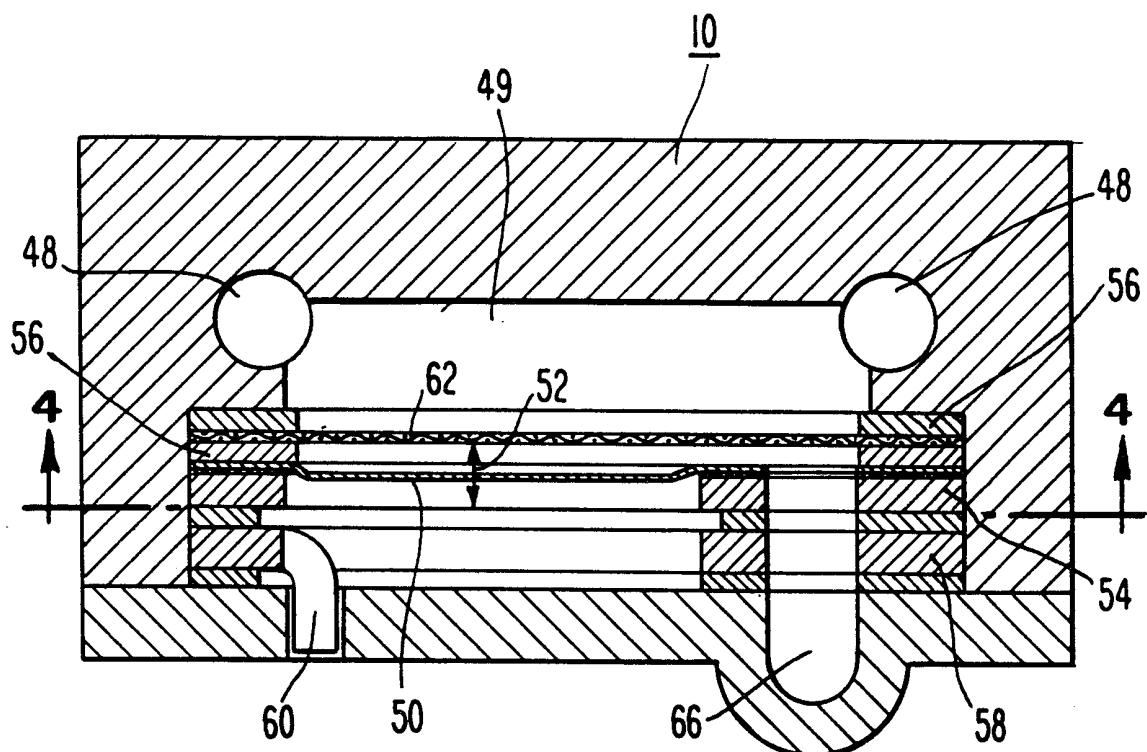


Fig. 3

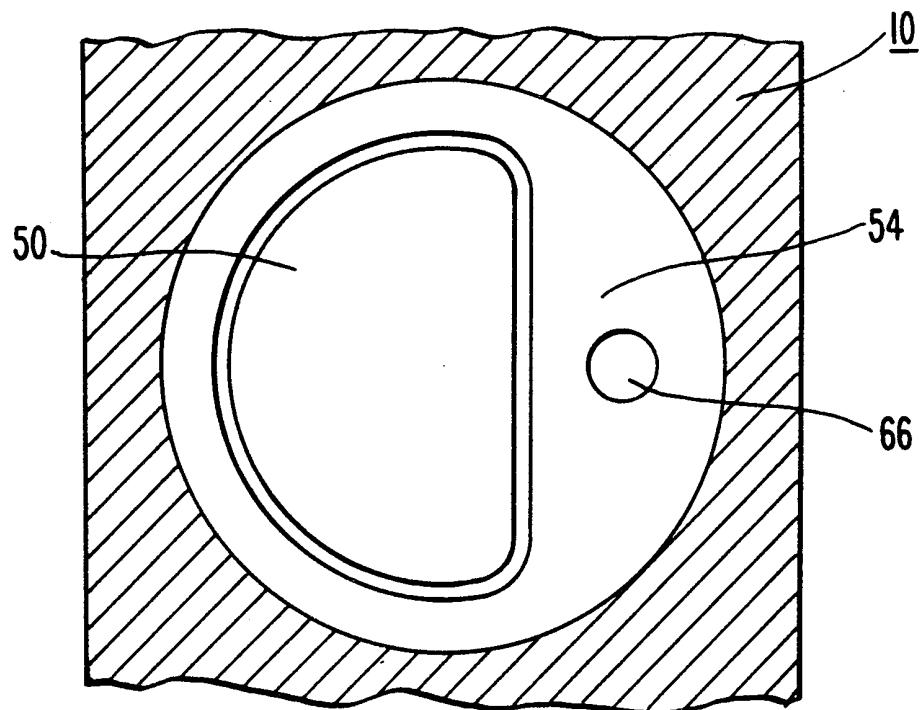


Fig. 4

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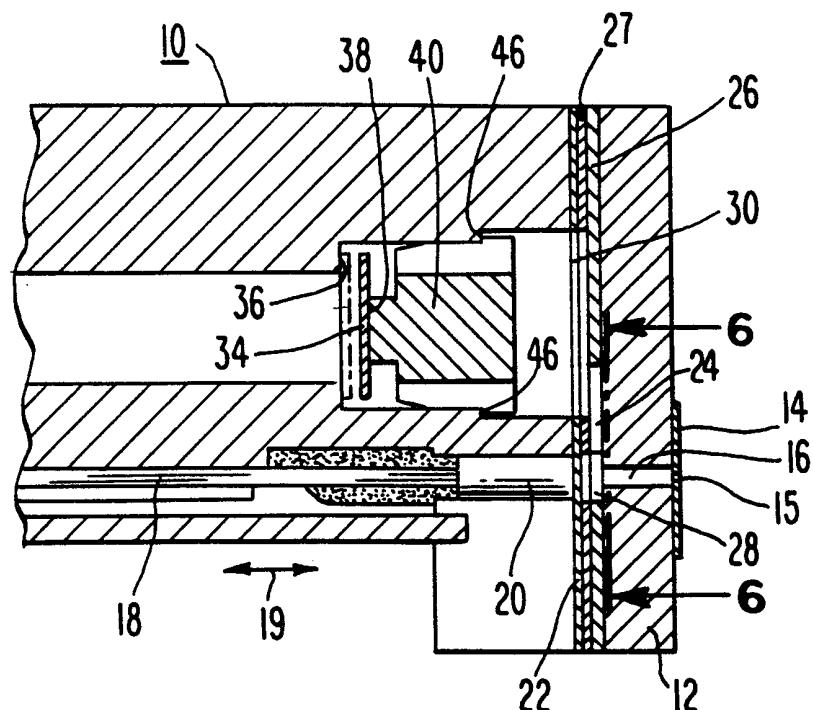


Fig. 5

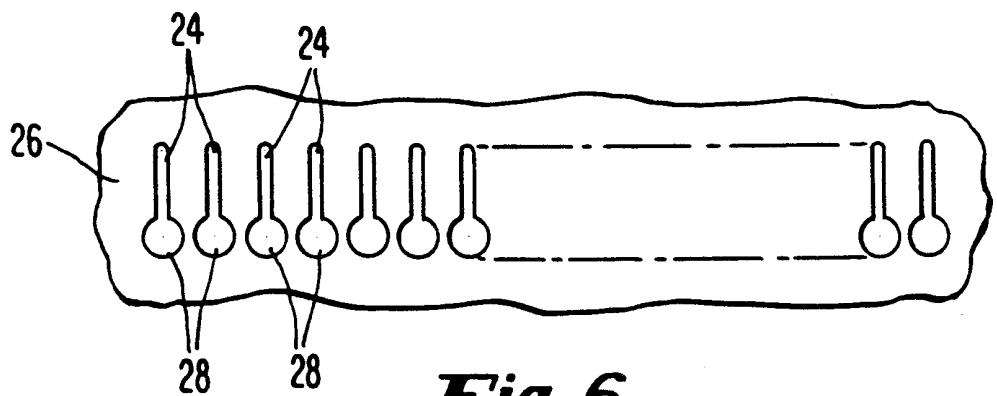


Fig. 6

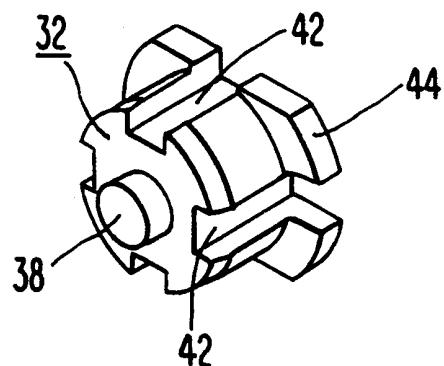


Fig. 7

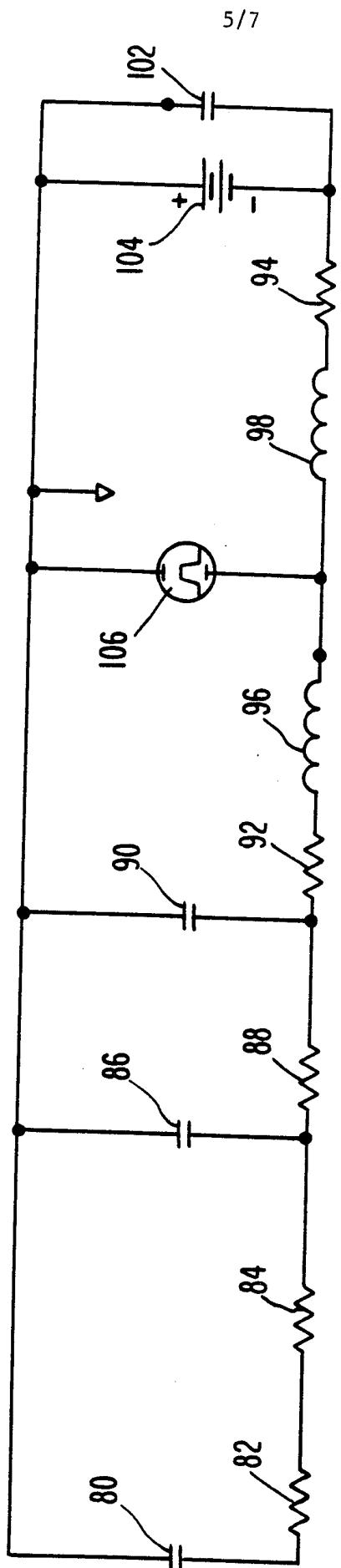
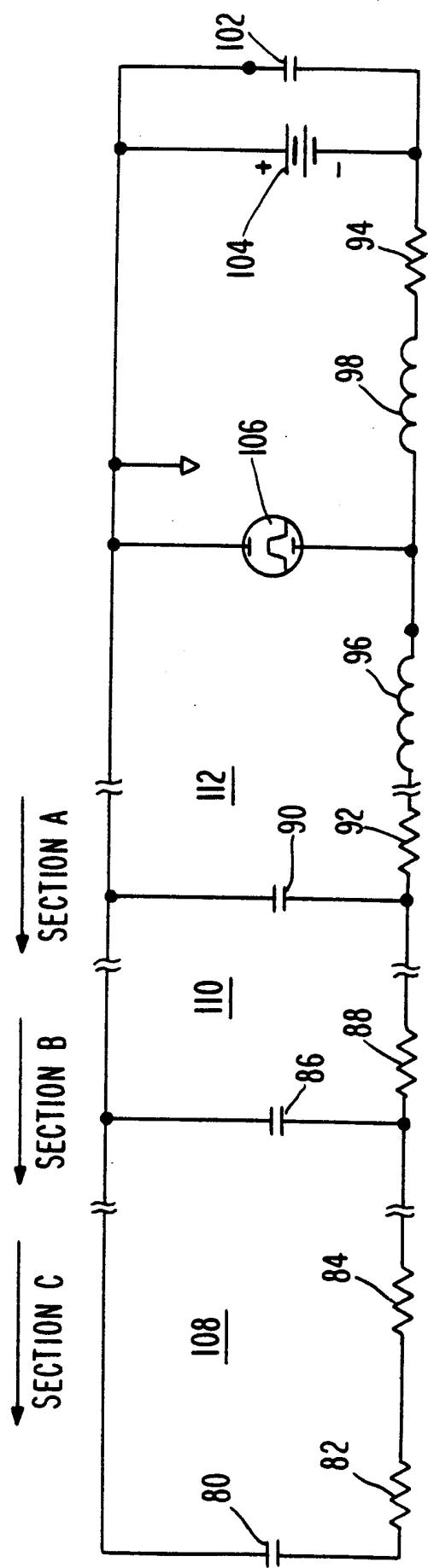
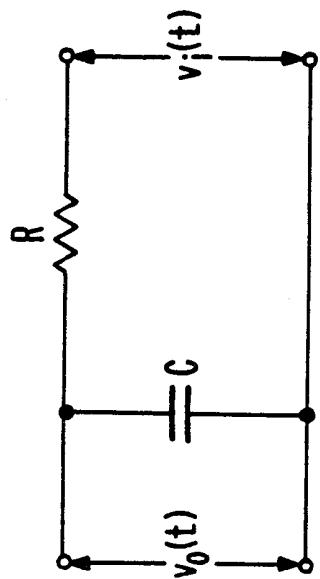
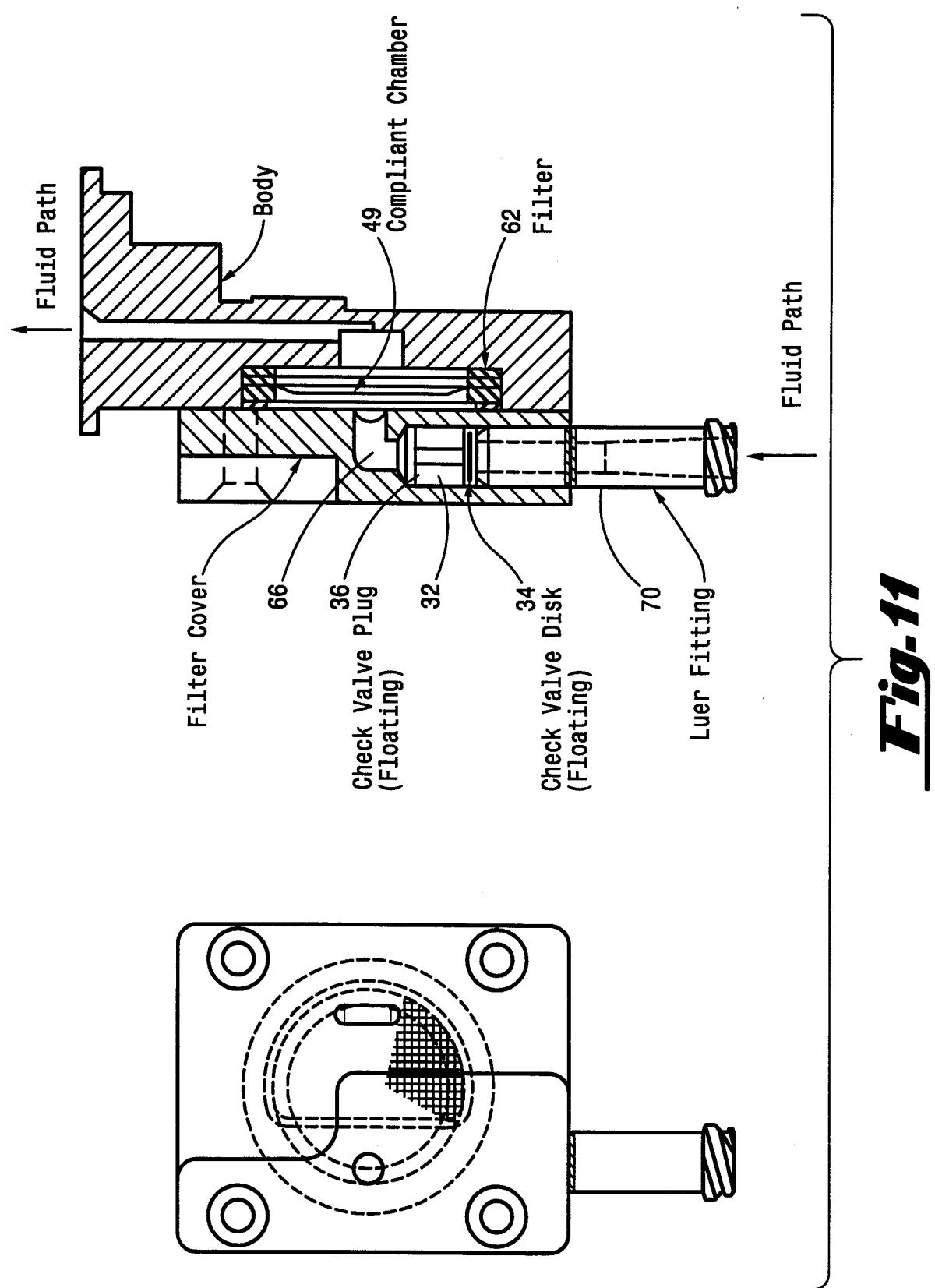


Fig. 8

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**Fig. 9****Fig. 10**



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/13962

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : B41J 2/03

US CL : 347/85, 94

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 347/85, 94

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

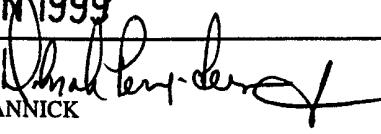
U.S. PTO APS Keywords: piezo?, transduc?, valv?, and seat? (p) valv?

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,263,602 A (MATSUMOTO ET AL.) 21 April 1981 (21/04/81), see entire document, especially Figures 1 and 2, column 3, lines 60-64.	1, 7, 9, 10, 14, and 16-20
Y	US 4,347,524 A (ENGEL ET AL.) 31 August 1982 (31/08/82), see entire document, especially column 3, lines 1-15.	2-6, 8, 11-13, 15
Y	US 4,777,497 A (NOZU ET AL.) 11 October 1988 (11/10/88), see entire document, especially Figures 4 and 5.	2-4
Y	US 5,650,811 A (SECCOMBE ET AL.) 23 March 1995 (23/03/95), see entire document, especially Figure 3A, #52.	5 and 6
		8, 15

Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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Date of the actual completion of the international search 14 SEPTEMBER 1998	Date of mailing of the international search report 26 JAN 1999
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INTERNATIONAL SEARCH REPORT

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,514,742 A (SUGA ET AL.) 30 APRIL 1985 (30/04/85), see entire document.	11-13