Jan. 2, 1968 D. T. MEYER 3,361,149

USE OF LIQUID HELIUM IN HYDRAULIC COMPUTERS

Filed Oct. 21, 1965 2 Sheets-Sheet 1

PRIOR ART

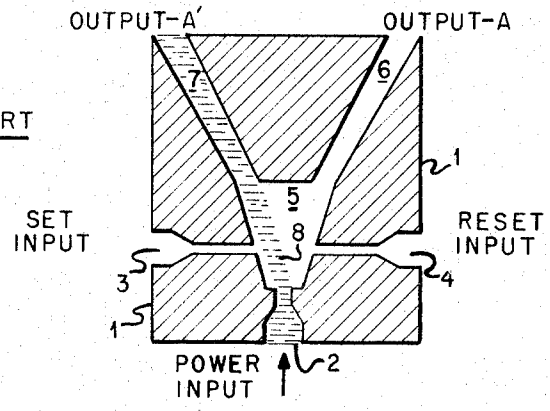



Fig. 1

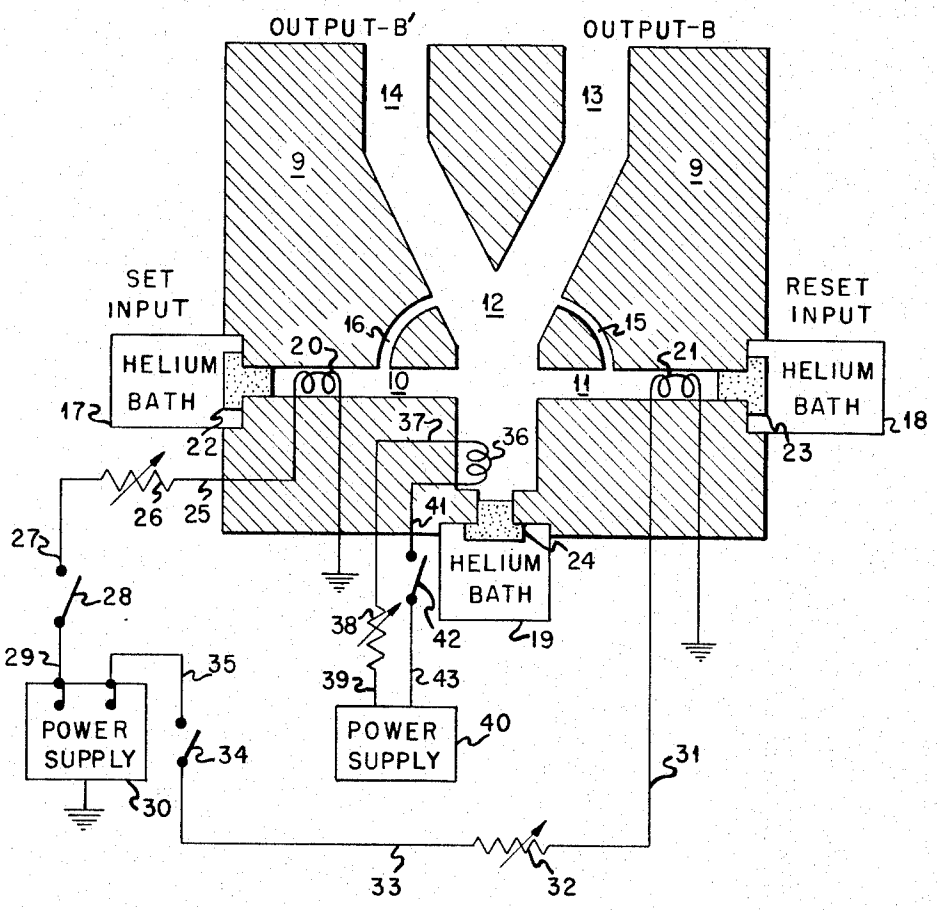



Fig. 2

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USE OF LIQUID HELIUM IN HYDRAULIC COMPUTERS

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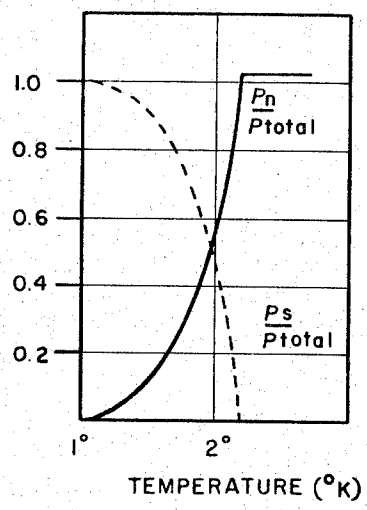



Fig. 3

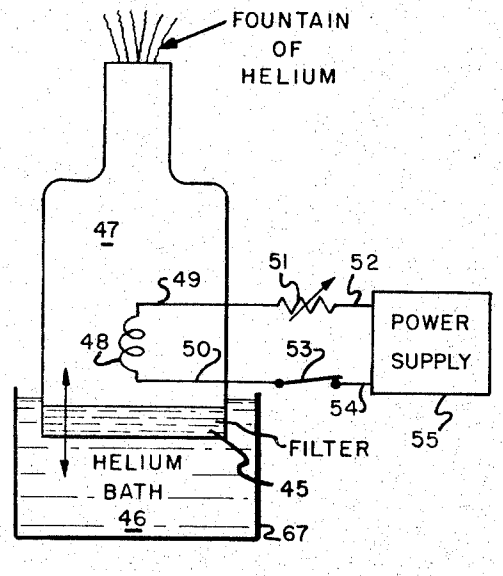



Fig. 4

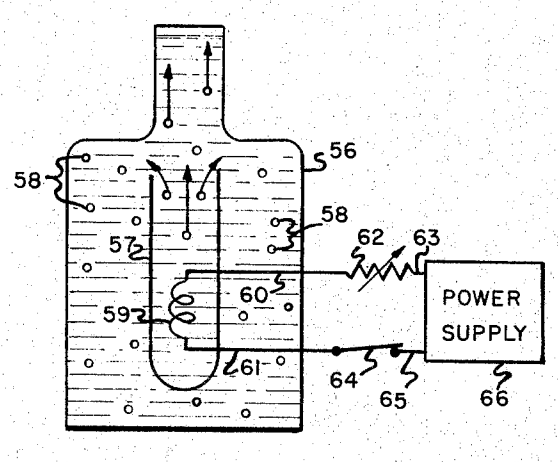



Fig. 5

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3,361,149

# USE OF LIQUID HELIUM IN HYDRAULIC COMPUTERS

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6 Claims. (Cl. 137—81.5)

The invention described herein was made in the course of, or under, a contract with the U.S. Atomic Energy Commission.

This invention relates to hydraulic computers and more particularly to means for effecting a faster response time in such computers.

In recent years, a great deal of interest has been aroused in the possibility of constructing hydraulic devices which could be used in the transmission and processing of information. These devices are based upon the properties of fluid flow. One of the most useful of these properties is the deflection of a larger jet of fluid by a smaller one, thereby producing an amplified flow-rate signal.

Fluid amplifiers of the type utilizing a side control jet to deflect a main fluid flow into one of several branch passages are well known in the art. In this type of device a main flow passageway is connected to a juncture from which branch passageways lead off. At the point where the main flow enters the juncture, side ports for passage of control fluid flow normal to the main flow are provided which, by selectively allowing such control fluid to flow, will control the main flow by deflecting it into the desired branch passage.

Fluid amplifiers, such as described above, can be and have been used as fluid logic elements for assembly into a hydraulic computer. An array of logical components such as AND gates, OR gates, AND-OR gates, inverters, NOR gates, and flip-flops are piped together to form a standard computer unit. The use of such logical components for a hydraulic computer has been described in the publication, "Science and Technology," pp. 44–52, November 1963.

In some instances, hydraulic computers built using logical elements, such as mentioned above, have certain advantages over electronic computers such as a good deal less sensitivity to environmental factors such as radiation, heat, and vibration. The interaction of fluid jets with each other and with the walls of the devices containing them provides a stable system for digital processing. However, the most notable limitation of prior hydraulic computers is their response time, which is much longer than that attainable in analogous electronic circuits. Fluid oscillators, for example, have been built with minimum response times of about 10 μsec., and the reciprocals of these response times are equal to the maximum operating frequencies which in this case provide for operating frequencies up to about 100 kc., which is a low frequency by electronic standards. Attempts to decrease the response time by reducing the size of the devices results in another problem; that is, the higher resistance to viscous flow of the smaller devices makes it necessary to operate them with higher pressures and larger pumps. This problem is especially difficult in the case of multi-stage fluid logic devices in that the power supplies become cumbersome and the high pressures require special materials and fabrication techniques, and even with such modifications the maximum operating frequency of a single fluid logic element is about 100 kc., which provides for a minimum switching or response time of about 10 μsec., as mentioned above.

Thus there exists a need for a fluid logic element, especially a fluid flip-flop or oscillator, that has a faster response time than is obtainable with devices that are currently available.



With a knowledge of the response time limitation of prior fluid logic elements, it is the object of the present invention to provide a fluid logic element with means to substantially decrease the response time thereof above that obtainable with prior art devices.

This and other objects and advantages of the present invention will become apparent upon a consideration of the following detailed specification and the accompanying drawings, wherein:

FIG. 1 is a cross-sectional view of a typical and known fluid amplifier;

FIG. 2 is a schematic view of a fluid amplifier in which the above object can be accomplished;

FIG. 3 is a graph illustrating the relative concentration of normal fluid and superfluid constituents of Helium II as a function of temperature;

FIG. 4 is a sectional view of a device illustrating the flow of Helium II by the "fountain effect"; and

FIG. 5 is a sectional view of a device illustrating the flow of Helium II by the "heat flush effect."

The above object has been accomplished in the present invention by the use of liquid helium in fluid amplifiers, thus permitting the use of smaller devices than heretofore possible and substantially decreasing the response time of such amplifiers below that possible with prior amplifiers using conventional fluids therein.

Referring now to the drawings, a typical fluid flip-flop of the prior art is shown in FIG. 1. The device of FIG. 1 is provided with a "power input" opening **2** in a block member **1**. Block **1** is also provided with a "set input" opening **3**, a "reset input" opening **4**, a fluid junction chamber **5**, a fluid output channel **6**, and a fluid output channel **7**.

In the device of FIG. 1, the flow of the fluid stream **8** coming from the input **2** is attached to the left wall of the interaction region by the Coanda effect, and the flow is thus issuing from the A′ output through channel **7**. As long as no control flow issues from the set input **3**, the device exhibits a stable A′ output flow and a vortex or bubble of low pressure is formed between the free jet and left wall of the interaction region. However, the set control input provides a means for introducing fluid into or near the bubble of low pressure. Flow from the set control input **3** can thus destroy the low pressure vortex, detach the flow from the left wall, and move the free jet closer to the right wall of the interaction region, where the Coanda effect takes over. In this condition, the flow issues from the A output through channel **6**. This condition is also stable—the jet remains attached to the right wall and the flow proceeds through the A output after the set control flow through **3** is terminated. When the reset input **4** is pulsed, however, the jet again issues from output A′.

Thus, the above fluid flip-flop provides for a memory element; that is, it has two stable states and can, hence, remember a "one" (presence of flow) or a "zero" (absence of flow) at one of the outputs which is useful for binary logic. The basic flip-flop of FIG. 1 can be adapted for use in a variety of other useful fluid logic devices such as NOR gates, AND gates, inverters, OR gates, etc., in a manner as described in the above-mentioned publication.

As mentioned above, fluid logic devices such as shown in FIG. 1, and in the above publication, and other prior devices are limited in their response time to a minimum of about 10 μsec. The present invention, as described below, provides for fluid amplifiers that have a response time substantially less than the above value, and this is accomplished by the use of liquid helium in such devices.

In order to provide a better understanding of the principles of operation of the fluid amplifier using liquid helium therein, some of the properties of liquid helium will now be described.

A sample of liquid helium at atmospheric pressure boils at 4.2° K. If the helium vapor above the liquid is pumped away, the liquid boils vigorously as its high-velocity helium atoms are lost into the vacuum pump. This normally observed phenomenon continues as the temperature is lowered, until a temperature of 2.2° K. is reached. At this temperature, all of the boiling suddenly stops, and the surface of the liquid helium becomes flat and placid. The heat conduction within the helium has become so rapid that bubbles can no longer form. Helium above 2.20 K. is known as Helium I, and below 2.2° K. as Helium II.

In comparison with ordinary fluids, Helium II has other unusual properties. They can be explained by a simple model which fits all observations made on the fluid above 1° K. According to the model, liquid Helium II consists of two mutually interpenetrating fluids, one of which is identical with Helium I. As the temperature is lowered below 2.2° K., the concentration of this "normal fluid" decreases as it becomes converted to "superfluid." FIG. 3 shows the relative concentration of normal fluid and superfluid as a function of temperature.

The superfluid component of the mixture is assumed to possess zero viscosity and carries no entropy. As long as the total density of the liquid remains constant (to a good approximation), the fluids freely intermingle with each other.

This model permits us to examine briefly some of the effects which have been experimentally observed. It is possible to construct a "semi-permeable" filter out of compressed powder. If the powder is sufficiently compressed, its intergranular voids become too small to permit the passage of the viscous normal fluid, but will not inhibit the passage of the superfluid. If this plug is sealed into one end of a glass tube, and if the plugged end is then placed into a sample of Helium II, some of the superfluid will flow into the end of the tube. If this fluid is continuously heated, a continuous flow of liquid helium up the tube will result. This phenomenon is called the "fountain effect," and is illustrated in FIG. 4.

In FIG. 4, a tubular member **44** is provided with a chamber **47** with a semi-permeable filter **45** mounted in the lower end thereof. The lower end of member **44** with the filter **45** is placed in a chamber **46** of a cup-shaped member **67** containing liquid Helium II. An electrical heater **48** is disposed in chamber **47** and this heater is connected to a power supply **55** by a lead **49**, a variable resistor **51**, a lead **52**, and by a lead **50**, a manual switch **53** and a lead **54**.

The fountain effect can be explained very simply according to the two-fluid model. The heating converts some of the superfluid into normal fluid, thus decreasing the concentration of superfluid in the chamber **47** to a level below its value in the chamber **46**. The superfluid flow from chamber **46** into the chamber **47** becomes greater than the superfluid flow from the chamber **47** into the chamber **46**, thereby producing a net flow of helium into the chamber **47**. The heat energy may be supplied by any appropriate method, such as by electrical heating as shown in FIG. 4, or by radiation.

Another characteristic property of Helium II is called the "heat flush effect," and is illustrated in FIG. 5. In FIG. 5, a chamber **56** enclosing Helium II is provided with an inner chamber **57**. The chamber **57** has an electrical heater **59** disposed therein and this heater is connected to a power supply **66** by a lead **60**, a variable resistor **62**, a lead **63**, and by a lead **61**, a manual switch **64** and a lead **65**. The liquid Helium II has impurity atoms **58** disposed therein. The current of "normal fluid" produced by the heat source interacts with the impurity



atoms, but not the opposing current of superfluid. As a consequence, impurity atoms are swept out of the enclosure **57** of FIG. 5 along with the normal fluid when the heater **59** is energized.

Thus, it can be seen that it is possible to generate two distinctly different types of fluid flow in Helium II. One type of flow is the ordinary mass flow which can be obtained with any fluid. With liquid Helium II, however, it is possible to generate this type of flow with electrical heating by means of the "fountain effect" as discussed above. The simplicity of design required for this effect makes it possible to design very small or very large fountains, the larger ones being limited by the power consumption limitations of the refrigeration system.

The other type of fluid flow is illustrated by the "heat flush effect" as discussed above. This flow is only possible in Helium II, and it involves the flow of energy rather than mass. This type of flow may be observed by means of the temperature changes which are created by the flow pattern and these changes can be very precisely measured by several well known techniques if such is desired. The conversion of electrical signals to hydraulic signals, and vice versa, is made relatively simple by using this type of fluid flow. Also, any impurities present within the system or created by radiation damage would be washed out by the heat flush effect.

The above-discussed types of flow that can be generated in Helium II can be utilized in a fluid amplifier logic device. One such device is shown in FIG. 2. The fluid amplifier of FIG. 2 is similar to the one shown in FIG. 1, and includes a member **9** in which is disposed a fluid junction chamber **12**, a fluid output channel **13**, a fluid output channel **14**, a fluid set input control channel **10**, and a fluid reset input control channel **11**. In the lower end of chamber **12** there is disposed a semi-permeable plug **24**, and similar plugs **22** and **23** are disposed in the ends of channels **10** and **11**, respectively, as shown. Below the plug **24** there is mounted a chamber containing a liquid Helium II bath **19** which serves as the input to the amplifier. An electrical heater **36** is disposed in the lower end of chamber **12** and this heater is connected to a power supply **40** by means of a lead **37**, a variable resistor **38**, a lead **39**, and by a lead **41**, a manual switch **42** and a lead **43**.

An electrical heater **20** is disposed in the control input channel **10**. One side of heater **20** is grounded and the other side is connected by means of a lead **25**, a variable resistor **26**, a lead **27**, a manual switch **28**, and a lead **29** to a grounded power supply **30**. An electrical heater **21** is disposed in the control input channel **11**. One side of heater **21** is grounded and the other side is connected by a lead **31**, a variable resistor **32**, a lead **33**, a manual switch **34**, and a lead **35** to the ground power supply **30**. The heaters **20** and **21** are shown within the respective channels **10** and **11** for the sake of clarity. It should be understood that these heaters may be disposed about and encompassing channels **10** and **11** and preferably so since these channels are to be made as small as practicable as a means for decreasing the response time of the fluid amplifier in a manner to be described below.

Exterior to the housing member **9** there is mounted a chamber containing a liquid Helium II bath **17** associated with the permeable plug **22**, and this serves as the "set input" to the fluid amplifier. A similar chamber containing a liquid Helium II bath **18** is associated with the permeable plug **23**, and this serves as the "reset input" to the fluid amplifier. It should be understood that the helium baths **17**, **18** and **19** are not closed volumes as shown in FIG. 2 when the fountain effect is used for flow control or main flow generation, but may be closed when the heat flush effect is used for flow control or main flow generation.

A feedback channel **16** is connected between the output B′ channel **14** and the set input control channel **10**. Another feedback channel **15** is connected between the

output B channel 13 and the reset input control channel 11. These feedback channels may or may not be used in FIG. 2 depending upon the use of the device. When it is used as a simple fluid flip-flop device, these channels 15 and 16 are not required and it should be understood that the device of FIG. 2 may be modified to eliminate such feedback channels. The operation of such a modified structure will be described below. When the device of FIG. 2 is used as an oscillator, then these channels 15 and 16 are required in one mode of operation thereof. However, other modes of operation of the oscillator are possible and will be discussed below.

In one operation of the device as shown in FIG. 2, the chambers containing the Helium II as well as the fluid amplifier structure are maintained at a temperature below 2.2° K. by conventional refrigeration means, not shown. It should be understood that the actual physical size of the device of FIG. 2, including the flow passageways, is not as large as shown in the drawing, but was so illustrated for the sake of clarity. The main flow of liquid helium through the chamber 12 and through channel 13 or channel 14 is provided by the "fountain effect," as discussed above, which is effected by the energization of the heater 36, with the superfluid portion of the liquid Helium II in the bath 19 flowing through the permeable plug 24 into the chamber 12 at a faster rate than the reverse flow from the chamber 12 into the helium bath 19, thus providing a net flow of helium through the amplifier.

When the heaters 20 and 21 are energized, there is also a "fountain effect" provided in each of the control channels 10 and 11, respectively. The amount of heating provided by the heaters 20 and 21 is adjusted by the respective variable resistors 26 and 32 such that the rates of flow of helium created by the respective fountain effects through the channels 10 and 11 is insufficient to divert the main flow from one of the channels 13, 14 to the other. However, when the main flow is flowing through channel 13, for example, a portion of this flow feedbacks through channel 15 to channel 11 and this flow coupled with the fountain effect flow in channel 11 is sufficient to divert the flow from channel 13 to channel 14. As soon as the main flow is proceeding through the channel 14, a portion thereof will be fed back through channel 16 to the channel 10 to supplement the fountain effect flow through channel 10 thus diverting the main flow back to channel 13. Thus the main flow is automatically diverted back and forth to the respective output channels 13 and 14, to thus provide for a fluid oscillator logic device.

The oscillator described above may be operated in a different manner, if desired. For example, the feedback channels 15 and 16 are eliminated or plugged up, and the amount of current to the respective heaters 20 and 21 is increased by varying the respective resistors 26 and 32 such that the fountain effect in each of the channels 10 and 11 is now sufficient to divert the flow from one of the channels 13, 14 to the other. The power supply 30 would then be modified to include a pulse generator to provide alternate energization of the heaters 20 and 21 such that the fountain effect would be provided in only one of the channels 10 and 11 at a time with the fountain effect alternating between these channels to thus provide alternate flow through the output channels 13 and 14.

In still another mode of operation of the oscillator of FIG. 2, the fountain effect is used for providing the main flow through the device and the "heat flush effect" is used to provide the control flow in channels 10 and 11 supplemented by the feedback channels 16 and 15 in the manner described above. In this mode of operation the plugs 22 and 23 are sealed and the helium baths 17 and 18 are not required, or alternatively the plugs 22 and 23 are removed such that the channels 10 and 11 are in communication with the respective helium baths 17 and 18. In either case, flow of "normal fluid" through the channels 10 and 11 into the chamber 12 is effected by energizing the heaters 20 and 21 to provide the "heat flush effect" in the channels 10 and 11. The flow through these channels supplemented by the alternate flow through the feedback channels 16 and 15 provides for the oscillator action of the device to cause the main flow to alternate between output channels 13 and 14. It should be understood that the "heat flush effect" can also be used to provide the main flow of helium through the device, if such is desired.

As mentioned above, when the device of FIG. 2 is used as a fluid flip-flop logic device, the feedback channels 15 and 16 are not required and in such case they are plugged up or the device constructed without such channels. In such a device the current to the heaters 20 and 21 is increased to a value such that the flow provided by the "fountain effect" is sufficient to divert the main flow from one of the channels 13, 14 to the other. In operation of such a device, the switches 28 and 34 are normally open. When the output flow of the main fluid is through channel 13, for example, and it is desired to divert the flow to output channel 14, then switch 34 is closed to energize heater 21 to provide the fountain effect in channel 11 to thus divert the main flow from channel 13 to channel 14, after which the switch 34 is opened. Subsequently, when it is desired to divert the main flow back to channel 13 of the flip-flop, then switch 28 is closed to provide the "fountain effect" in channel 10 to perform this operation, after which the switch 28 is opened. The switches 28 and 34 may be operated manually, or automatically by means, not shown, in response to some desired control function or functions in any desired programmed manner, such means being any well known control device. It should be understood that the "heat flush effect" can be used in such a flip-flop device in place of the "fountain effect" if such is desired.

The limitations placed upon device operation of prior fluid amplifier devices by the viscosity of the working fluid are markedly altered when liquid helium is used in such devices as described above. Even the viscosity of Helium I is an order of magnitude lower than the viscosity of more conventional fluids. Liquid Helium II has no ordinary viscosity, and zero resistance to liquid flow up to a certain critical velocity has been found in channels as small as 100 A. in diameter, such channels being substantially smaller than those usable with conventional fluids.

Two types of wave motion in Helium II can be derived from the solution of the hydrodynamical equations of this two-fluid system. The first type corresponds to the variation of the total density of the fluid, and it is identical to ordinary sound. The second type involves a reciprocal variation of the densities of superfluid and normal fluid in such a way that the total density remains constant. It implies that "waves" of energy-rich normal fluid may be generated at will by a heat source, and will propagate through the liquid with only slight attenuation. This mechanism, called "second sound," is the principal mode of energy transportation in Helium II, and accounts for its unusually large thermal conductivity (about three orders of magnitude greater than that of copper at these temperatures). The velocity of these waves is a function of temperature, being approximately equal to 20 meters/second from 1° to 2° K. The first type of wave motion is produced by the "fountain effect" and the second type of wave motion is produced by the "heat flush effect."

As mentioned above, chanels as small as 100 A. in diameter can be used in the devices described above using liquid Helium II. However, it should be noted that such devices are not limted to use of channels of this size and such devices could be constructed with chanels of any desired size; however, the smallest device will have the most rapid response.

In order to arrive at an upper limit for the operating frequency of a fluid amplifier device using liquid Helium II therein, let it be assumed that the walls must be at least as thick as the channels, and that the shortest possible geometrical path may be used as a complete feedback

loop. For a channel with diameter $d$, this path would be a toroid with the inner diameter $d$ and the outer diameter $3d$, having an average path length of $2\pi d$. The time necessary to move an excitation once around this loop will be the shortest possible time an oscillator cycle could be completed, and the reciprocal of this quantity would therefore represent an upper limit to the operating frequency of the device. This is given by the expression:

$$f_{max.}=\frac{v \text{ excitation}}{2\pi d}$$

Using Helium II, two modes of operation are available, corresponding to the use of the excitations of either first or second sound. The velocity of first sound is about 230 meters/second, and that of second sound about 20 meters/second. Accordingly, the use of 100 A. channels with minimum path lengths will give use upper limits of:

$$\frac{230\times10^2}{2\pi\times100\times10^{-8}}\simeq4\times10^9 \text{ cycles}=4000 \text{ kc.}$$

for first sound, and

$$\frac{20\times10^2}{2\pi\times100\times10^{-8}}\simeq3\times10^8 \text{ cycles}=300 \text{ kc.}$$

for second sound. Actual operating frequencies, of course, will be lower when longer feedback paths are used.

It should be noted that second sound excitations are pressure-invariant, and would produce essentially no mechanical strain upon the channel wall container. Thus, a fluid amplifier device using liquid Helium II would maintain its reliability over long periods of service.

The use of liquid Helium II in fluid amplifiers, as described above, to provide control of the flow therethrough by means of the "fountain effect" and/or the "heat flush effect" eliminates the need for any moving parts, and the response time of such amplifiers is substantially improved, that is, decreased, over prior devices since now, for the first time, substantially smaller channels can be used than heretofore possible because of the flow characteristics of Helium II as discussed above.

This invention has been described by way of illustration rather than by limitation and it should be apparent that the present invention is equally applicable in fields other than those described.

What is claimed is:

**1.** A fluid valve comprising the combination of a first passage for carrying a main fluid flow of liquid Helium II, a plurality of branch passages leading from said first passage at a common juncture and positioned to receive said main fluid flow individually, a plurality of control fluid channels positioned to carry a control fluid flow of liquid Helium II normal to said main flow which reacts on said main flow to cause it to flow into one of said branch passages, heater means disposed within said first passage for heating said Helium II for effecting flow thereof through said valve, means to control said control fluid flow, said last-named means including an electrical heater associated wtih each of said control channels for heating the Helium II associated with each of said channels for effecting said control fluid flow through each of said channels, and means for selectively energizing each of said electrical heaters whereby flow through each of said control fluid channels can be selectively controlled to selectively cause said main fluid flow to deflect into a desired branch passage.

**2.** The fluid valve set forth in claim **1**, wherein a fluid feedback channel is connected between each of said branch passages and an associated one of said control fluid channels, said electrical heaters being continuously energized by a selected current therethrough, whereby each of said feedback channels alternately feeds a portion of said main fluid flow back into the control fluid channel associated therewith thereby alternately deflecting said main fluid flow into each of said main branch passages.

**3.** The fluid valve set forth in claim **2**, wherein a Helium II bath is associated with said first passage and with each of said control fluid channels, a semi-permeable plug being disposed between said first passage and its associated helium bath, and a similar plug being disposed between each of said cotnrol fluid channels and their associated helium baths, said heater means effecting said main flow of said liquid helium through said valve by the "fountain effect," and said electrical heaters effecting said control fluid flow of said liquid helium in said control channels by the "fountain effect."

**4.** The fluid valve set forth in claim **2**, wherein each of said control fluid channels is directly connected to a source of liquid Helium II, whereby said electrical heaters associated with said channels effect the flow of liquid helium therethrough by the "heat flush effect."

**5.** The fluid valve set forth in claim **4**, wherein said first passage is directly connected to a source of Helium II, whereby said heater means associated with said first passage effects the main flow of liquid helium through said valve by the "heat flush effect."

**6.** The fluid valve set forth in claim **2**, wherein said channels are about 100 A. in diameter.

**References Cited**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 3,052,253 | 9/1962 | Priaroggia et al. | 137—341 XR |
| 3,122,062 | 2/1964 | Spivak et al. | 137—81.5 XR |
| 3,228,411 | 1/1966 | Straub | 137—81.5 |
| 3,258,685 | 6/1966 | Horton | 137—81.5 XR |
| 3,263,695 | 8/1966 | Scudder et al. | 137—81.5 |
| 3,266,514 | 8/1966 | Brooks | 137—81.5 |
| 3,273,594 | 9/1966 | Mayer | 137—81.5 XR |
| 3,327,726 | 6/1967 | Hatch | 137—81.5 |

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