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[54] **METHOD FOR MAKING FLUID CHANNELS**

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[58] **Field of Search**....................29/157, 424, 604, 625, 627, 29/432

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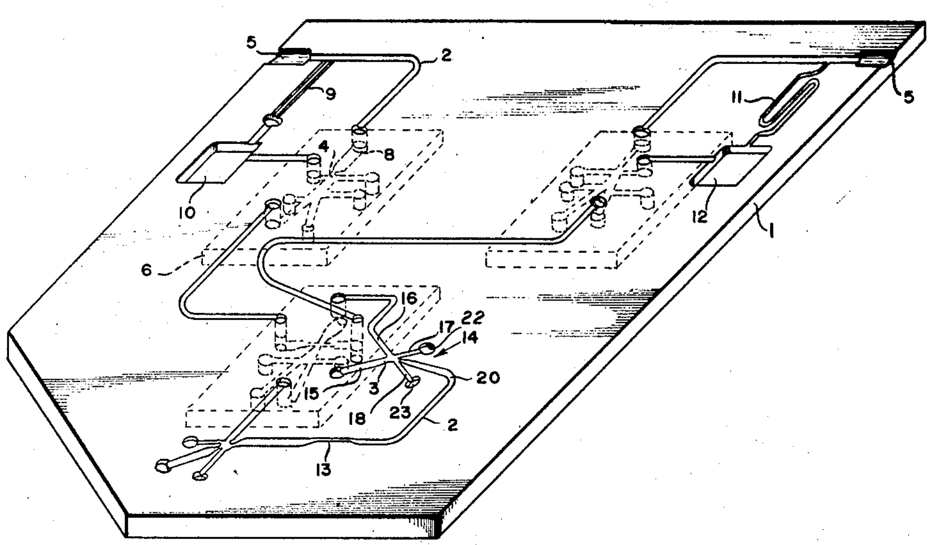
[57] **ABSTRACT**

A method of making flow channels in fluid control devices comprising coining into the surface of the device a length of hard drawn wire having an appropriate form, and removing the length of wire from the channel thus formed.

7 Claims, 3 Drawing Figures



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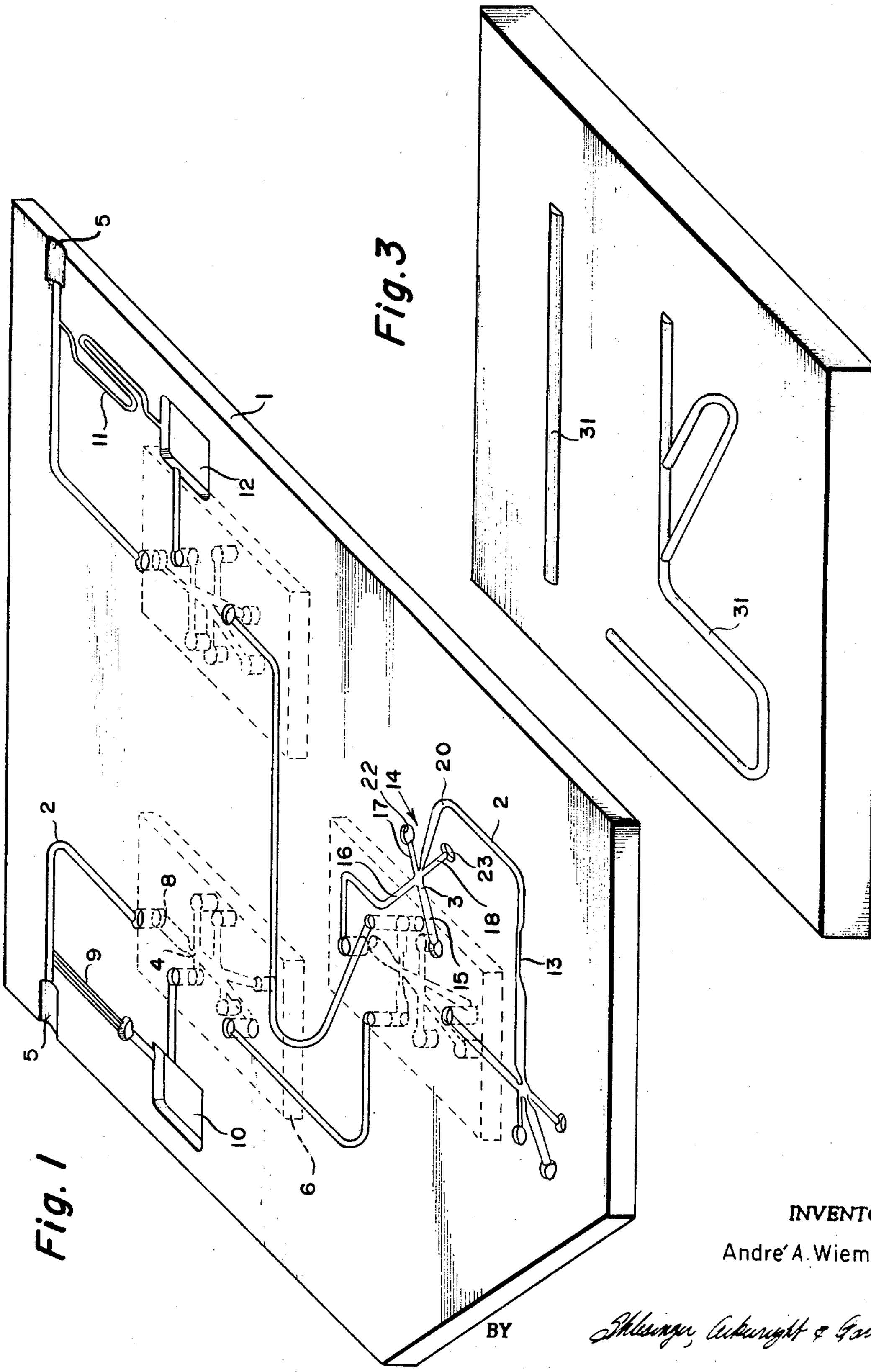

Fig. 1

Fig. 3

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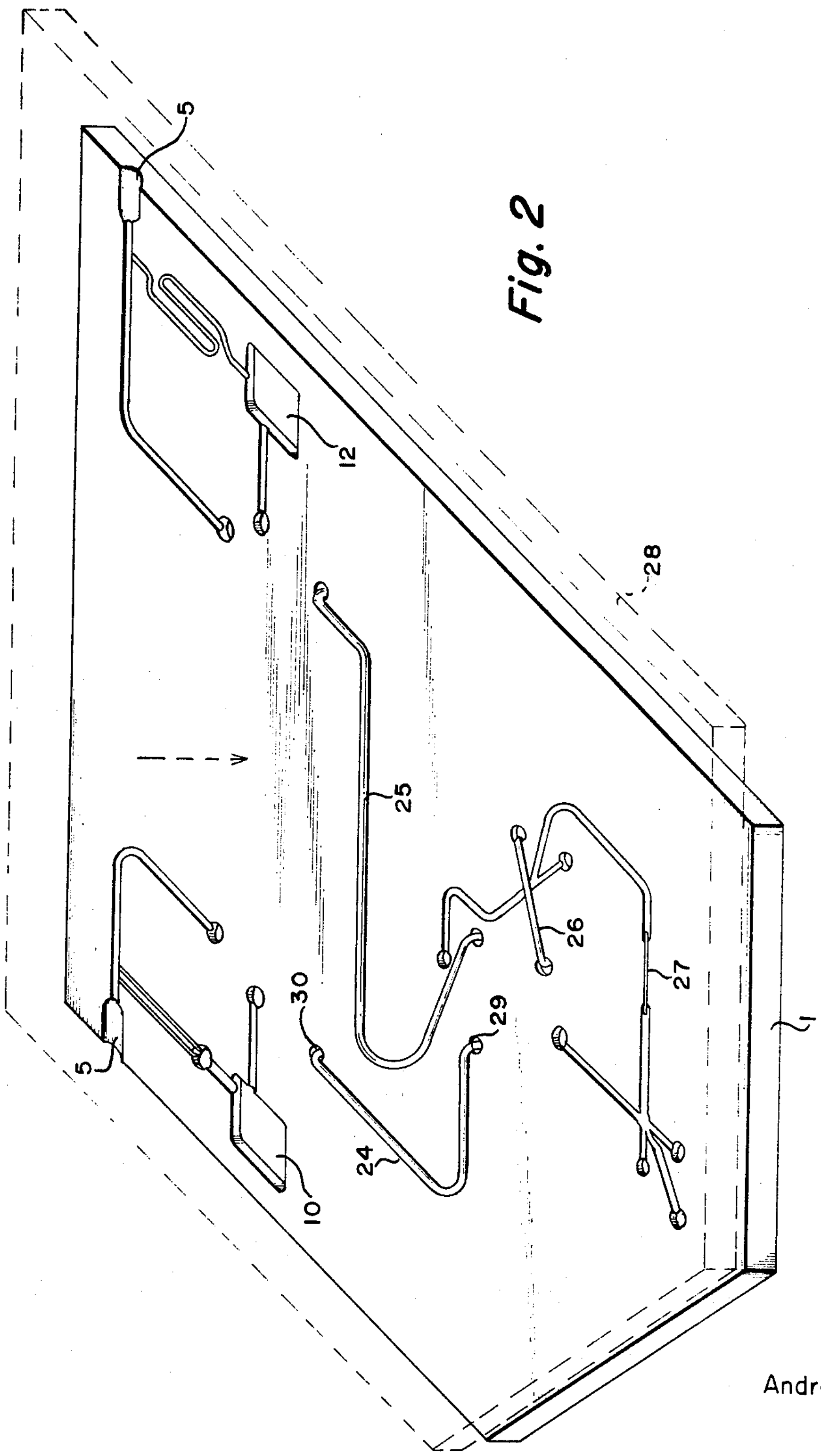

Fig. 2

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METHOD FOR MAKING FLUID CHANNELS

DESCRIPTION OF THE INVENTION

The present invention relates to fluid control and logic devices, and has particular relation to a method for making a unit of the sandwich-type structure comprising a channel configuration at the contact surface between two bodies. More particularly, the present invention resides in the fact that the flow channels are obtained by coining in the contact surface of at least one of the bodies a wire which has been prepared by the wire-drawing process and which has been bent in appropriate form.

Fluid control and logic systems are more and more used, instead of electronic systems, for the control and command of fluid operated machines, in order to avoid the need of signal transformers, such as electric or electromagnetic relay control valves, which must translate the electronic output command signal to a fluid pressure signal for the operation of the machine. The complete machine, control and logic system included, can then be supplied with fluid pressure power only and does not need any additional electrical power supply. Moreover, fluid elements have an almost infinite lifetime and do not break down when wrongly interconnected.

Logic elements perform the elementary logic functions (AND-function, OR-function, bistable memory function) in an interaction chamber according to, for example, either the principle of the exchange of kinetic energy between two or more fluid jets or the principle of the boundary layer effect. Amplification can be achieved for example, by a laminar high energy flow which can be made turbulent by a low energy impinging jet in an interaction chamber. Owing to the fact that the fluid interaction chambers perform the same elementary logic functions as the electronic logic components, the circuit diagrams of fluid logic and control systems are analogous to the electrical circuit diagrams, and not only fluid interaction chambers were to be developed, but it was also necessary to provide for the interconnection between the different interaction chambers by means of a number of channels through which the fluid can pass from one chamber to the other.

It is known, as disclosed, for example, in U.S. Pat. Nos. 3,207,168 3,016,066 and 3,024,805, that fluid channel configuration, including interaction chambers and interconnection channels can be formed by a plurality of flat plates, either two or three plates, the plates being sandwiched together and sealed fluid-tight one to the other by adhesives, machine screws, clamps or other suitable means. In the case of the two-plate sandwich structure, one plate is molded, etched or cut in order to contain the channel configuration on its surface, and this plate is covered by another flat plate, so that the flow in the unit is confined by the plates, and that the channel configuration is realized at the contact surface between the two plates. In this way, it is possible to realize at least a part of a circuit in a bidimentional arrangement.

In electrical systems, the interconnections between the electronic logic components are made by metallic conductors, either wired or printed, of practical zero resistance, and eventually in series with resistances of which the resistance value can be held between very narrow limits if necessary. In fluid logic systems however of the sandwich-type structure, the interconnection channels present more than one problem. Firstly, an interconnection channel always acts partly like a fluid integrator, as a result of the volume of the channel itself. Consequently, high frequency signals are strongly attenuated, sharp impulses are not transmitted, and the possible operating speed of the system is reduced. Secondly, an interconnection channel has always a flow resistance which cannot be neglected by the designer of the circuit. It is mostly desired to reduce that resistance to a minimum. Thirdly, even when the presence of a resistance is accepted or needed in the design, it is absolutely necessary that the predicted channel resistance could be realized without difficulties and within narrow value limits, and in a repetitive manner adaptable for mass production. And forthly, the "wiring" of flow channels can be realized as grooves in the surface of a flat plate, but the present methods for cutting, molding or etching the grooves are not very flexible. Those methods are only more economical with respect to the wiring with rubber tubes between separate interaction elements, when great quantities of the same circuit must be made.

It is an object of the present invention to provide a method for making an interconnection fluid channel configuration at the contact surface between two plates of a sandwich-type structure, which method can give a solution to one or more of the above mentioned problems.

Other objects, features and advantages will become apparent upon consideration of the following description and the accompanying drawings in which:

FIG. 1 is a perspective view of the contact surface of a plate of a fluid device having a plurality of fluid channels,

FIG. 2 is a view of the same surface comprising a number of hard drawn wires ready to be coined in the surface,

FIG. 3 is a press matrix obtained by coining hard drawn wires for a part of their thickness in the surface of the matrix.

Referring to the drawings, there is illustrated in FIG. 1 an embodiment of the invention, given by way of example. The device comprises a first plate 1 with a configuration of channels, such as channel 2, formed in its surface. A second flat plate (not shown) is laid upon the first plate and clamped, sealed or otherwise fastened by screws, clamps or adhesives to this plate. The connection between the plates should be made fluid-tight, so that the fluid flow in the resulting unit is confined by the plates, and that the fluid is only enabled to flow through the defined openings, passages and cavities between the two plates. The channels 2 serve to interconnect the different fluid interaction chambers of a pure fluid logic system, such as chamber 3 or 4. It is clear however that the channels can serve for interconnection of fluid logic devices with moving parts, analog elements instead of digital devices, and other fluid control systems in which interconnection is needed between different function devices. The channels serve partly also to connect the functional devices, such as the pure fluid logic interaction chambers of this example, to the input and output orifices 5.

The interaction chambers may have been formed in the plate 1 itself, such like chamber 3, but may also be a part of a separate fluid flow device, such like chamber 4, which is connected to the channel configuration in any suitable manner by which the fluid flow is enabled to pass from the separate device to the channel configuration of the plate. In this example, the separate device is formed by a plate 6, which comprises an interaction chamber 4 and the necessary input, output and exhaust channels. This plate 6 is fixed on the back sides of plate 1 in the same way as the cover plate (not shown) of plate 1, in order to define a fluid-tight configuration of passages and cavities which is connected to the configuration on the top side of plate 1 by means of holes 8 in this plate.

The configuration between plate 1 and its cover plate may only be a part of a complete system, where several analogous plates are, for example, stacked on top of each other. The plate 1 may only serve to interconnect several functional standard plates to each other, and consequently contain the interconnection "wiring," but, as will be explained later, can also contain the necessary resistances, capacitances and even passive or active elements. The orifices to the other devices of the system can be made in the plane of the configuration, such as orifice 5, or perpendicular to that plane, such as orifice 8.

The fluid interaction chambers 3 may have been made in the plate 1 by any suitable method, such like cutting, etching or molding, before, after or during the operation by which the channels are formed, the invention being confined as to the method by which the channels are obtained. Those channels are obtained by coining pieces of hard drawn wire into the surface of the plate.

When pressing a body of sufficient hardness into a plate of soft material, the body penetrates into the plate, pushing away the soft material by plastic deformation. Heating is not necessary, but the material of the plate must be much softer than the material of the wire. Otherwise the wire is deformed during the coining operation, the channel cannot be made in the desired shape, and the wire can no longer be used for a subsequent operation. The hardness of the wire in relation to the hardness of the plate depends on the desired degree of accuracy. By a hard steel wire is consequently meant a wire the hardness of which is sufficiently high in relation to the hardness of the plate in order to reach the desired degree of accuracy. Aluminum can be used successfully in connection with hard drawn steel wire ends. Aluminum has a Brinell BHN hardness of 50 to 100 which corresponds to a tensile force of maximum 45 kilograms per square millimeter, and a steel wire of carbon content of, for example, 0.85 percent, drawn to 20 percent of its original section gives excellent results. But it is clear that other combinations of plate material and drawn wire material can easily be found. As plate material may also be used soft iron, tin, copper, stainless steel or plastic material, such like polyethylene - polyvinyl chloride - polypropylene - ABS. Aluminum however has the advantage to be a light-weight, not easily deformable material and soft enough to be used with steel wires. Drawn wires of any material, hardness and diameter are available on the market in great quantities. Especially steel wires can be found in any combination of diameter and hardness from 0.05 mm on with tolerances of 0.005 mm, and with a tensile force of 300 kilograms per square millimeter being also a value of evaluation of the hardness, which can be obtained by a judicious choice of carbon content, percentage of reduction of the cross-sectional area during the drawing operation and eventually by a subsequent process of oil hardening. These processes of wire drawing are sufficiently known in the literature on wire drawing, such as the book *Stahdraht* of A. Pomp, and the products are widely on the market in any combination of diameter and hardness.

The resulting coined channels will be very smooth owing to the fact that the body impressed in the plate surface is a drawn wire, which is itself very smooth owing to the drawing process in a wire die. The smoothness can be increased when the reduction of the wire cross-sectional area per drawing die is diminished, and also when at least the last reduction steps are obtained by a wet drawing process as explained for example in *Trefilage de l'Acier* of M. Bonzel. Such smooth shining steel wires are also obtainable in the market in any combination of diameter and hardness. When aluminum plates are used with hard steel wire, it has also been observed that the grain structure is refined in the regions undergoing the plastic deformation during the coining process. Consequently, very smooth channel surfaces are obtained.

Smooth channel surfaces are advantageous because of the resulting small flow resistance. For the same desired or maximum allowed resistance value it is possible to design channels of smaller sections, so that the channel volume is diminished and consequently the working speed of the system can be increased. Channels with a high l/d ratio (l= length and d = diameter) have also a higher pressure limit under which limit a laminar flow can be secured. Laminar flow in the channels is desirable because it preserves the signal strength and decreases internal heating. As a result, the devices with narrow-smooth channels can work at higher signal pressures without entering in turbulence.

In order to make very narrow channels by coining, it is not only necessary to have smooth hard cylindrical bodies to be coined into a soft plate, but those bodies must be made within very narrow tolerances in order to be able to make the devices in a repetitive manner and to meet the specifications of the devices. For a relative tolerance value of for example 10 percent, the region of acceptable diameter values decreases in proportion to the diameter, and for very narrow channels, the possibility of shaping cylindrical bodies within narrow tolerances becomes critical. As has been pointed out hereinabove, smooth hard drawn wires are available in the market in any combination of diameter and hardness and with tolerances up to 0.005 mm.

There are two kinds of flow resistances. Firstly, there are channels in which the flow resistance is realized by narrowings and sharp turnings. These resistance-devices are not very linear, that is to say the pressure difference output and input is not a linear function of the fluid flow, but rather a quadratic function. There are also channels in which the flow resistance is realized by porous plugs. With very narrow smooth channels, it is, however, possible to realize in any easy way, calibrated flow resistances within narrow tolerance limits and which are acceptably linear. The flow can be held laminar for high pressure values and the resistance is realized by the flow resistance of the walls. An example of the obtained results will be given hereunder. Resistance-elements are sometimes needed in a flow circuit for purposes of feedback, time delaying with a resistance-capacitance element, such as resistance **9** and capacitance **10** or resistance **11** and capacitance **12** in the example of FIG. **1**. In this example three forms of execution of narrow channel resistances are shown. Resistance **13** is a simple straight channel resistance. Resistance **9** is made by two parallel straight channels. The l/d-ratio of each channel is greater than the ratio of a single channel with the same total resistance value. In that way higher pressures can be used with less possibility of turbulence. Consequently, for low resistance values it can be preferable to use several parallel channels, which may not necessarily have the same cross-section. One or more narrow channels can be used for adjustment. Large resistance values can be obtained with a channel such like **11**. Owing to the large l/d-ratio, the laminar flow is not disturbed in the bendings of the channel and cannot turn into turbulent flow. As a result, a large laminar channel of high resistance value can be formed in a small area of the surface of the plate.

Plate **1** also comprises, as a way of example, two passive AND-circuits, of which one has been indicated by the numeral **14**. This circuits comprise two inlet channels **15** and **16** for the input signal flow jets and two output channels **17** and **18**, which are in the prolongation of channels **15** and **16** respectively and which lead to the exhaust orifices **22** and **23**. At the intersection of input and output channels, there is a flow jet interaction chamber **3**. An output-signal channel **20** starts from this chamber to another functional element. In operation, when only one of the input channels **15** or **16** deliver a flow jet, this jet flows directly from the input channel in the opposed output channel to the corresponding exhaust-orifice and no output signal appears in channel **20**. When however both input channels deliver a flow jet, those flow jets inpinge on each other and deviate the other jet in this way so that only one resulting jet is formed which is directed to output channel **20**. It is clear that it is necessary that input and opposed output channel be accurately in the prolongation of each other. This is possible when one single straight wire is used for coining the input and output channel together.

FIG. **2** illustrates a way for coining the wire into the surface of plate **1**. The same plate has been shown, without cover plate and without the active elements fixed on the back, ready to undergo the last operation of coining wires **24**, **25**, **26** and **27** into the surface. The other orifices, cavities and channels are supposed to be made in a preceding operation. Four pieces of hard wire are cut at length, properly bent and laid on the surface in coincidence with the place where the channel is to be coined. Subsequently, a plate of hard steel **28**, shown in dotted lines in FIG. **2**, is pressed against plate **1**, in the direction of the arrow, and the wires enter into the material of plate **1**. In order to prevent any movement of the wire before it penetrates in the plate, it will be sometimes necessary to fix the wires to the surface, for example, by gluing, or as shown with wire **24**, by bending both ends of the wire into the orifices **29** and **30** in which the corresponding channel will debouch. This gives a smooth transition between channel and orifice. It has been shown especially that the input and output channels **15** and **17** of the passive AND-element **14** of FIG. **1** are obtained by coining of one single straight wire **26**. As for the hardness of plate **28**, there is no problem when it is at least as hard as the wire, although this is not necessary. It must be hard enough in proportion to the hardness of the plate **1**, in order that the wires be coined completely in plate **1**, and only for a negligible part in plate **28**.

The illustrated method of laying the wires separately on the surface and coining the unit, is not the only one which can give satisfying results. The wires may be firstly bent in proper form and laid upon a hard flat steel surface in the same configuration of the channels. Subsequently a plate of soft iron is pressed upon the wires, which penetrate into this soft iron plate. But the plate is not pressed until it comes in contact with the hard steel surface. The wires are only partly impressed in the soft iron. After that, the wires are glued in the channels which have been formed in the soft iron plate, and a press matrix is obtained in that way, as shown on FIG. **3**. The plate has then on its surface a number of projecting ribs **31**. Such a press matrix plate can then be turned upside down and pressed upon for example an aluminum plate or a plate of plastic material. Wires of different thickness will have to be impressed in the soft iron plate at different moments.

Returning to FIG. **2**, when the plate **28** is not of hard material, but of the same material as plate **1**, then the wire is partly impressed in plate **1** and partly in plate **28**, when both plates are pressed together. The wire is removed afterwards and the plates brought together in the same relative position as they are when pressed together. Then a canalisation is formed of exactly the shape of the wires. Reference holes can be drilled when both plates are pressed with the wires between them. At that moment, the contact surfaces of both plates adapt to each other by the influence of the pressure, and flow leakage through the area between the plates can be reduced to a minimum. In this way, two plates of aluminum can be pressed together with hard steel wires between them, and channels of very accurate dimensions can be formed. This method is particularly interesting for making resistance devices. A resistance has been made in this way, by pressing two flat aluminum plates together, with an oil-tempered steel wire (0.65 percent carbon, diameter 0.5 mm, length 42 mm) between them. The resistance value varied from 22.7 gr-sec/cm$^5 \pm 5\%$ to 27.80 gr-sec/cm$^5 \pm 5\%$ for a pressure difference between input and output varying from **600** gr/cm^2 to 1,000 gr/cm^2.

When using the first method (pressing with a hard plate which is not the cover plate) the coining may give irregularities on the surface of the soft plate, in the vicinity of the coined channels and the material tends to be pushed upwards. These irregularities can be lapped away in order to secure fluid tightness. As the lapping operation can be controlled very accurately, and the lapping does not affect the internal surface of the channel, this operation does not present any problem.

Using drawn wires as press matrices is an extremely simple, cheap and flexible method for making wiring boards, analogous to printed circuit boards in electronics. Standard functional elements can be made in great number, but generally wiring boards are more adapted to specific applications and rarely must be made in great quantities which could justify to develop etching masks, moulds etc. No special tools are needed for using this coining method. The wires may be bent by hand. For this reason, this method is very well adapted for small quantity wiring boards.

It will be clear that the drawn wire must not have necessarily a circular section. Hard steel wires with square sections for example can also be found in the market. The method is not only adapted for coining into flat surfaces or plates. Press matrices can be made in cylindrical form, with coined wires therein, to be used as rotating press matrices.

While the invention has been described in its preferred embodiments, it is understood that those embodiments and the words used have only been given as an example, rather than as a limitation, and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention.

What I claim is:

1. A method for making a fluid control device having a tubular fluid passageway therein comprising:
a. providing a plate member,
b. coining into the surface of the plate member a length of hard drawn wire having an appropriate form,
c. removing the length of wire so as to leave a channel therein generally conforming to the form of the wire,
d. applying to the plate member a cover member of sufficient dimension to cover the channel,
e. thereby forming a tubular fluid passageway in the fluid control device, and including the step of
f. providing means in said device for providing fluid access to said passageway from an external source.

2. A method for making a fluid control device having a tubular fluid passageway therein comprising:
a. providing a plate member,
b. bending a length of hard drawn wire in the form of the passageway,
c. positioning said length of hard drawn wire on the surface of the plate member in coincidence with the place where the passageway is to be formed,
d. coining said length of hard drawn wire into said surface,
e. removing said length of hard drawn wire,
f. applying to the plate member a cover member of sufficient dimension to cover the passageway,
g. thereby forming a tubular fluid passageway in the fluid control device, and including the step of
h. providing means in the device for providing fluid access to said passageway from an external source.

3. A method for making a fluid control device having a tubular fluid passageway therein comprising:
a. providing a plate member,
b. providing a press matrix,
c. coining a length of hard drawn wire having an appropriate form partially into the surface of the press matrix so as to provide a projection on the surface of the press matrix in the form of the passageway,
d. pressing together the surface of the press matrix and the surface of the plate member,
e. removing the press matrix and the wire so as to leave a channel in the surface of the plate member generally conforming to the form of the wire,
f. applying to the plate member a cover member of sufficient dimension to cover the channel,
g. thereby forming a tubular fluid passageway in the fluid control device, and
h. providing means in the device for providing fluid access to the passageway from an external source.

4. A method for making a fluid control device having a tubular fluid passageway therein comprising:
a. providing a pair of plate members,
b. positioning a length of hard drawn wire of an appropriate form between the two plate members,
c. pressing the pair of plate members together in a registering position so as to coin the wire into the surface of at least one of the members,
d. separating the plate members,
e. removing the wire so as to leave a channel in the surface of at least one of the plate members,
f. replacing the plate members together in the registering position,
g. thereby forming a tubular fluid passageway in the fluid control device, and
h. providing means in the device for providing fluid access to the passageway from an external source.

5. A method as in claim **1** and wherein:
a. the plate member is aluminum, and
b. the hard drawn wire is a steel wire.

6. A method as in claim **2** and wherein:
a. the plate member is aluminum, and
b. the hard drawn wire is a steel wire.

7. A method as in claim **3** and wherein:
a. the plate member is aluminum, and
b. the hard drawn wire is a steel wire.

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