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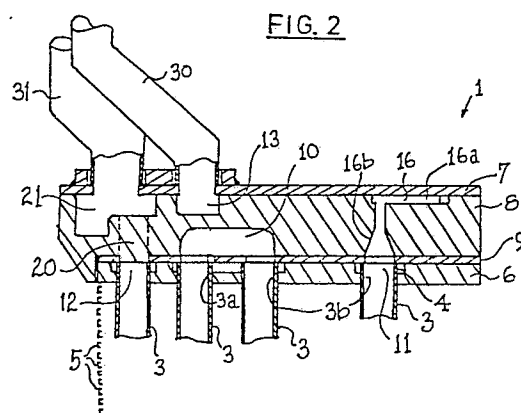
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54 **Heat exchanger.**

57 A heat exchanger (1), e.g. an evaporator for a vehicle air conditioning system, comprises a plurality of finned U-shaped tubes (3) having free ends (3a, 3b) permanently fixed, e.g. adhesively bonded, to an end plate assembly formed of a number of end plate means (6-9) defining connecting channels (10) connecting together pairs of free ends of the tubes (3) to provide at least one flow channel for heat exchange fluid. The end plate means (6-9) are permanently united, e.g. adhesively bonded, together to form with the end portions of the U-shaped tubes (3) a permanently united integral end plate assembly.



Description

Heat exchanger

This invention relates to a heat exchanger of the kind comprising a plurality of U-shaped tubes each having a pair of free ends, heat conductive fin means thermally connected to the U-shaped tubes and an end plate assembly in which are permanently fixed portions of said tubes adjacent the free ends of the latter, the end plate assembly comprising a number of end plate means defining connecting channels isolated from each other for connecting together pairs of said free ends to provide at least one flow channel for heat exchange fluid formed of a number of interconnected ones of said U-shaped tubes and having a flow inlet and a flow outlet. In particular, but not exclusively, the invention relates to a heat exchanger, e.g. an evaporator, for an air conditioning system, e.g. for an automobile. This invention also relates to a method of making a heat exchanger of the kind referred to.

A known heat exchanger of the kind referred to of an air conditioning system for an automobile is described in GB-A-1444609. In this prior art specification the heat exchanger is in the form of an evaporator and the free end portions of the U-shaped tubes are individually welded to the end plate assembly. However the plate means of the end plate assembly are bolted together. These fixing techniques are time consuming and labour intensive and are not conducive to automation of the manufacture of the evaporator.

Another known heat exchanger is described in GB-A-1478015. In this prior art specification there is disclosed a heat exchanger having spaced apart header tanks connected by a plurality of elongate connecting tubes. These elongate connecting tubes communicate with each header tank by passing through, and being bonded into, holes in a tube plate which is formed of a resin compound and which forms a wall of each header tank. However this known heat exchanger is not of the kind referred to since all the connecting tubes are connected to common header tanks. The problem of connecting many pairs of connecting tubes is thus not addressed in this known design.

The present invention seeks to provide an improved heat exchanger of the kind referred to which can be manufactured relatively economically.

According to one aspect of the present invention there is provided a heat exchanger of the kind referred to characterised in that the said end plate means are permanently united together to form with the said end portions of the tubes a permanently united integral end plate assembly.

Conveniently the permanent fixing of the end portions of the tubes to the end plate assembly and/or the permanently uniting of the end plate means is by adhesive bonding. However alternatively, for example, the permanent fixing and/or uniting may be achieved by ultrasonic welding.

Preferably the end plate assembly also defines a distribution chamber having a number of outlets for supplying heat exchange fluid, e.g. refrigerant, to a

corresponding number of the said flow inlets and/or a collection chamber having a number of inlets for receiving heat exchange fluid from a corresponding number of the said flow outlets. Preferably separate inlet flow control channels connect the outlets of the distribution chamber to the said flow inlets, the distribution chamber and the inlet flow control channels being designed to provide equal and/or consistent distribution of the heat exchange fluid to the flow inlets. Typically, at least when the heat exchanger comprises an evaporator, the cross-sectional size of each outlet of the distribution chamber is smaller than that of the said flow inlet to which it is connected. To prevent adverse noise from being generated during expansion of the heat exchange fluid as it flows from the outlets of the distribution chamber to the said flow inlets, each inlet flow control channel is suitably shaped to provide a gradual decrease in fluid pressure between the distribution chamber outlet and the flow inlet. This is achieved by designing each inlet flow control channel to have a gradually increasing cross-sectional size over at least part of its length. Typically each inlet flow control channel comprises an upstream first channel portion of substantially constant cross-sectional size and a down-stream second channel portion in which the cross-sectional size gradually increases. The lengths of the first channel portions of the inlet flow control channels are designed, as previously mentioned, to provide equal and/or consistent distribution of the heat exchange fluid to the flow inlets. In practice the lengths of the various first channel portions are different.

Conveniently the end plate assembly comprises an inner end plate means to which the said end portions of the tubes are permanently fixed, e.g. by adhesive bonding, an outer end plate means and, intermediate the inner and outer plate means, a first intermediate end plate means defining, at least in part, the said connecting channels. If the distribution chamber and/or the collection chamber is/are also formed in the end plate assembly, the or each chamber is also defined, at least partly, by the said first intermediate end plate means. Suitably the end plate assembly also includes a second intermediate end plate means positioned between the first intermediate end plate means and the inner end plate means and defining in part the said connecting channels. Conveniently the second intermediate end plate means has a plurality of apertures formed therein which are in registry with the said free ends of the U-shaped tubes, the said flow inlet(s) and the said flow outlet(s).

Preferably the said connecting channels are designed to provide a smooth flow of heat exchange fluid between the free ends of the U-shaped tubes so that there is a minimum pressure loss in the connecting channels and a minimum generation of noise in the connecting channels. Typically the connecting channels are in the form of smoothly

curved U-bends, although, of course, other shaped channels may be employed.

The end plate means of the end plate assembly are conveniently flat but may, alternatively, be of suitably contoured design, e.g. of corrugated form. Suitably the end plate means are made of aluminium, although other metallic materials, e.g. copper, or plastics materials may be employed. The U-shaped tubes are preferably made of aluminium or copper although other materials having good heat conducting properties may be employed.

If adhesive bonding is employed to provide the permanent fixing and/or uniting, any suitably type of adhesive may be used to bond the end plate means together, although it is presently preferred to use a toughened adhesive such as, for example, a heat curable single-part epoxy resin (obtainable, for example, from Permabond Adhesives Ltd.).

According to another aspect of the present invention a method of manufacturing a heat exchanger comprising forming a partial heat exchanger assembly having an apertured inner end plate means, a plurality of U-shaped tubes each having a pair of free ends projecting through apertures of said inner end plate means and heat conductive fin means thermally connected to the U-shaped tubes, arranging on the said inner end plate means at least one intermediate end plate means and an outer end plate means, permanently fixing portions of the U-shaped tubes adjacent said free ends to the said inner plate means and joining the said end plate means together to define connecting channels isolated from each other for connecting together pairs of said free ends to provide at least one flow channel for heat exchange fluid formed of a number of interconnected ones of said U-shaped tubes and having a flow inlet and a flow outlet, is characterised in that the said end plate means are permanently united together to form a permanently united integral end plate assembly.

Preferably the said end plate means are provided with interengaging locating means for assisting assembling them together during formation of said end plate assembly.

Preferably the assembling together of the said end plate means and the permanent uniting together of the end plate means and of the end portions of the U-shaped tubes to the inner plate means are performed automatically, e.g. with robots. Preferably the permanent uniting/fixing is performed by adhesive bonding. In this case the inner end plate means conveniently has recesses formed about each of said apertures, into which recesses adhesive is applied for bonding the said portions of the U-shaped tubes adjacent said free ends to the said inner plate means.

If adhesive bonding is employed, the adhesive typically comprises heat curable adhesive, e.g. an epoxy resin, the heat exchanger being heated in an oven device to effect said heat curing.

As a final step of the manufacturing process, the heat exchanger is tested for leaks in the said flow channels. Conveniently mass spectrometry is used to test for leaks.

Embodiments of the invention will now be de-

scribed by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a top view of part of an end plate assembly of one embodiment of a heat exchanger according to the invention in the form of an evaporator of a vehicle air conditioning system,

Figure 2 is a sectional view taken on the line II - II of Figure 1,

Figure 3 is a top view of an inner end plate of the end plate assembly shown in Figures 1 and 2,

Figure 4 is a sectional view of the inner end plate taken on the line IV - IV of Figure 3,

Figure 5 is a top view of a first intermediate end plate of the end plate assembly shown in Figures 1 and 2,

Figure 6 is a sectional view of the first intermediate end plate taken on the line VI - VI of Figure 5,

Figure 7 is a top view of a second intermediate end plate of the end plate assembly shown in Figures 1 and 2,

Figure 8 is a sectional view of the second intermediate end plate taken on the line VIII - VIII of Figure 7,

Figure 9 is a top view of an outer end plate of the end plate assembly shown in Figures 1 and 2,

Figure 10 is a sectional view taken on the line X - X of Figure 9,

Figure 11 is a schematic view of part of an assembly line for manufacturing heat exchangers according to the present invention,

Figure 12 is a schematic sectional view through an end plate assembly of a second embodiment of a heat exchanger according to the invention,

Figure 13 is a schematic sectional view through an end plate assembly of a third embodiment of a heat exchanger according to the invention.

Figure 14 is a top view of part of an end plate assembly of a fourth embodiment of a heat exchanger according to the invention in the form of an evaporator of a vehicle air conditioning system,

Figure 15 is a sectional view taken on the line XV-XV of Figure 14,

Figure 16 is a top view of a first intermediate end plate of the end plate assembly shown in Figures 14 and 15,

Figure 17 is a sectional view of the first intermediate end plate taken on the line XVII-XVII of Figure 16,

Figure 18 is a top view of a first intermediate end plate of a modified end plate assembly, and

Figure 19 is a sectional view taken on the line XIX-XIX of Figure 18.

Figures 1 to 10 show various parts of an evaporator 1 for a motor vehicle air conditioning system. The evaporator 1 includes a plurality of metallic U-shaped tubes 3, typically made of aluminium or copper, each having free ends 3a, 3b which project through apertures 4 of an inner end plate 6,

and a plurality of heat conductive fins 5, e.g. of aluminium, thermally connected to the U-shaped tubes. The inner end plate 6 forms part of an end plate assembly comprising the inner end plate 6, an outer end plate 7 and, intermediate the inner and outer end plates 6 and 7, a first intermediate end plate 8 and a second intermediate end plate 9. The end plates 6-9 are typically made of aluminium, e.g. die case aluminium. Furthermore the end plates are adhesively bonded together, and portions of the U-shaped tubes adjacent their ends 3a, 3b are adhesively bonded to the inner end plate 6, with, for example, a heat cured adhesive such as a heat cured epoxy resin (e.g. a heat cured epoxy resin obtainable from Permabond Adhesives Ltd).

The end plates 6-9 of the end plate assembly are each provided with recesses, slots and/or passages as shown in Figures 1 to 10. These various recesses, slots and passages communicate with each other in the completed end plate assembly to define:

(a) Isolated connecting channels 10 for connecting the free ends 3a and 3b of different U-shaped tubes 3 together to provide a plurality of fluid flow channels for heat exchange fluid, e.g. refrigerant, each fluid flow channel being formed of a number of the U-shaped tubes 3 which are connected together by the connecting channels 10 and which have a flow inlet 11 and a flow outlet 12.

(b) An elongate distribution chamber 13 which decreases in cross-section from one end to the other and which has a number of outlets 14a - 14e.

(c) A plurality of inlet flow control channels 15-19 connecting the outlets 14a - 14e to the flow inlets 11 and each comprising an upstream first channel portion 15a - 19a of narrow, generally sinuous form and a downstream second channel portion 15b - 19b which gradually increases in cross-section between the downstream end of the first channel portion and the flow inlet.

(d) An elongate collection chamber 21 having a plurality of inlets 22a - 22e.

(e) Connecting channels 20 connecting each flow outlet 12 to respective inlets 22a - 22e.

Inlet and outlet tubes 30 and 31, respectively, are adhesively bonded to the outer end plate 7 to place the inlet tube 30 in communication with the distribution chamber 13 and the outlet tube 31 in communication with the collection chamber 21.

In use of the evaporator, refrigerant is supplied via the inlet tube 30 to the distribution chamber 13 from where it passes to the flow inlets 11 via the inlet flow control channels 15 - 19. The refrigerant then passes through the different fluid flow channels provided by the various interconnected U-shaped tubes 3 and is eventually collected in the collection chamber 21 before exiting via the outlet tube 31. To function efficiently, the temperatures of the refrigerant exiting the flow outlets 12 of the fluid flow channels should be substantially the same. The amount of refrigerant supplied to the flow inlets 11 is dependent on the relative lengths and dimensions of the various inlet flow control channels 15 - 19 and in particular the

first channel portions 15a - 19a thereof. This explains the different lengths of the channel portions 15a - 19a, the precise lengths and designs of these channel portions being determined experimentally for each application. The aim, however, in the design of the distribution chamber 13 and the channel portions 15a - 19a is to provide, in use of the evaporator, equal and/or consistent distribution or refrigerant to the flow inlets 11. The purpose of the second channel portions 15b - 19b is to ensure that the refrigerant expands gradually when passing from the narrow first channel portions 15a - 19a to the wider flow inlets 11. This serves to ensure that the expansion occurs as silently as possible - i.e. without an accompanying generation of sound as the refrigerant passes into the fluid flow channels provided by the U-shaped tubes 3.

A process for automatically assembling the end plate assembly of the evaporator is shown schematically in Figure 11. Partly formed evaporators 50, with the free ends of the tubes 3 projecting through the inner end plate 6, are passed through a warming oven 51 to warm the partly formed evaporators to a predetermined temperature, e.g. approximately 30°C for the presently preferred adhesive. After passing through the oven 51, the evaporator 50 is accurately located and clamped at a first adhesive applying station 52. At station 52, heat curable adhesive, e.g. epoxy resin, from a reservoir 53 is applied via an automatic programmable XY adhesive dispenser 54, movable in two dimensions, to the inner end plate 6 to flood the inner plate with adhesive around each tube end 3a, 3b. As can be seen in Figures 3 and 4, the plate 6 is provided with elongate recesses 55 around pairs of holes 56 through which the ends 3a, 3b of different tubes project, with annular recesses 40 about holes 41 through which project the tube end 3a defining the fluid inlets 11 and with annular recesses 42 about holes 43 through which project the tube ends 3b defining the fluid outlets 12. It is there recesses 55, 40 and 42 into which the dispenser 54 floods the adhesives. The adhesive reservoir 53 is heated to ensure that the adhesive is dispensed at a predetermined temperature, e.g. 30°C.

The evaporator 50 is then moved to a second adhesive applying station 57 where it is accurately located and clamped. An automatic programmable XYZ adhesive dispenser 58 movable in three dimensions dispenses beads of adhesive from the reservoir 53 over the inner end plate in a predetermined pattern. A 4-axis robot 59 then picks up the second intermediate end plate 9 from a support surface 60 heated to a predetermined temperature, e.g. 30°C, and places the plate 9 on top of the inner end plate 6.

Adhesive from the reservoir 53 is again applied in bead form via the dispenser 58 to the partially formed end plate assembly but this time to the second intermediate end plate 9. The robot 59 then picks up the first intermediate end plate 8 from the support 60 and places in on top of the second intermediate end plate 9.

The dispenser 58 then applies beads of adhesives to the first intermediate end plate 8 and the robot 59

picks up the outer end plate 7 from the support 60 and places it on top of the first intermediate end plate 8.

The robot 59 then picks up each of the inlet and outlet tubes 30 and 31 in turn and places them, correctly orientated, in inlet and outlet holes 61 and 62, respectively, formed in the outer end plate 7. The dispenser 58 then applied adhesive into a raised elongate trough 63 formed in the plate 7 and which surrounds the inlet and outlet holes 61 and 62. The location of the inlet and outlet tubes in the holes 61 and 62 requires the robot 59 to have a special gripper (not shown). To enable use of a cheaper robot 59, the location of, and application of adhesive to, the inlet and outlet tubes 30 and 31 may alternatively be performed manually at a separate station (not shown).

The evaporator assembly is then loaded into a curing oven (not shown) for a predetermined period of time, e.g. 15 minutes, to allow the applied adhesive to heat cure. Generally a number, e.g. about 20, of evaporator assemblies will be placed together in a batch in the curing oven for curing in any one curing operation.

After curing the evaporator assemblies are removed from the oven and taken to a leak testing station (not shown). At the leak testing station, each evaporator is tested for leaks using a helium mass spectrometer. Any rejected evaporators are returned for re-sealing - e.g. by the application of further adhesive around the periphery of a plate interface.

The end plates may be provided with interengaging locating means (not shown), e.g. studs and recesses, to assist in their accurate placement on top of each other by the robot 59.

The evaporator assemblies are suitably automatically transported from station to station on simple support platens operating on a "power and free" principle allowing platens to accumulate before a work station and be rapidly indexed in and out of the work station to maximise process time. After each evaporator assembly is manually off-loaded from the support platen on to an oven jig trolley, the empty support platen is returned to the load station on an automatic transfer device.

The evaporator assembly, end plates 6-9, adhesive and inlet and outlet tubes 30, 31 are preferably all pre-heated and predetermined temperatures so that the process can be accurately reproduced whatever the temperature of the premises in which the manufacturing process occurs.

Other embodiments of the invention are schematically shown in Figures 12 and 13.

Figure 12 shows an end plate assembly comprising an inner end plate 70, an outer end plate 71 and an intermediate end plate 72. The inner end plate 70 is provided with a plurality of apertures 73 through which project the free ends 3a, 3b of the U-shaped tubes 3. The intermediate plate 72 is of contoured form and defines connection channels 74 for connecting together pairs of tube ends 3a, 3b of different U-shaped tubes. The inner end plate 70 is designed to be flooded with adhesive 75 to adhe-

sively bond both the free ends 3a, 3b and the intermediate end plate 72 to the inner end plate 70. The intermediate end plate 72 is of corrugated form and has crests 76 which define the connection channels 74 and trough 77 between the crests 76. The other end plate 71 is adhesively bonded to the intermediate end plate in such a manner as to provide channels 78 between the base of the troughs 77 and the overlying end plate 71. These channels 78 are designed to provide flow channels for distributing refrigerant to, and collecting refrigerant from, the flow channels formed by the interconnected U-shaped tubes 3.

Figure 13 is similar to the end plate assembly shown in Figure 12 with the exception that a further intermediate end plate 80 is provided to improve the curved shape of the connection channels 74. The plate 80 need not be bonded in position since in use it will automatically adopt its correct position.

A further embodiment of the invention is shown in Figures 14-17. In this embodiment the end plate assembly is the same as that shown in Figures 1-10 with the exception of the new design of the first intermediate end plate 108 (the same reference numbers + 100 have been used to designate similar parts). In particular the distribution chamber 113 is slightly longer than chamber 13, and the first channel portions 115a - 119a of the inlet flow control channels 115-119 are straight and of the same length. The downstream section channel portions 115b - 119b incorporate expansion orifices 300, each in the form of a venturi-like passage. The provision of these expansion orifices 300 improves the efficiency of the evaporator since the refrigerant is not expanded until just before entering the U-shaped tubes 113 and dispenses with the need to connect a separate expansion valve to the inlet tube 130.

A modified end plate 208 is shown in Figures 18 and 19 in which the distribution chamber 213 and collection chamber 221 have varying cross-sectional throughout their lengths and are separated from each other by a thin "wavy" boundary wall. The "wavy" nature of this boundary wall increases its length over a straight boundary wall and thus improves the heat transfer between the collection and distribution chambers. Thus the "hot" liquid (typically about 50°C) in the "inlet" distribution chamber 213 is cooled by the "cold" vapour in the "outlet" collection chamber 221, the thin, wavy boundary wall ensuring good heat transfer between the two chambers. The good heat exchange between the chambers and the "sub-cooling" of the liquid in the distribution chamber thus provides an improved thermal efficiency.

In the end plate assemblies shown in Figures 14-19, the metallic end plates may be ultrasonically welded together. In addition the ends of the U-shaped tubes may also be ultrasonically welded to the end plate assemblies. In this manner each tube/end plate assembly is permanently united as an integral structure. Alternatively the tubes-/end plates may be adhesively bonded together as previously described in the earlier embodiments.

The invention has been specifically described herein with reference to an evaporator of a vehicle air conditioning system. However the invention can be

applied to other types of heat exchanger of the kind referred to. For example the invention could find application in a condensor of a vehicle air conditioning system. However higher temperatures and pressures are employed in condensers and the adhesive used must, of course, be capable of withstanding these higher temperatures and pressures.

Claims

1. A heat exchanger (1) comprising a plurality of U-shaped tubes (3) each having a pair of free ends (3a, 3b), heat conductive fin means (5) thermally connected to the U-shaped tubes and an end plate assembly (6-9) in which are permanently fixed portions of said tubes adjacent the free ends (3a, 3b) of the latter, the end plate assembly (6-9) comprising a number of end plate means (6-9) defining connecting channels (10) isolated from each other for connecting together pairs of said free ends to provide at least one flow channel for heat exchange fluid formed of a number of interconnected ones of said U-shaped tubes (3) and having a flow inlet (11) and a flow outlet (12), characterised in that the said end plate means are permanently united together to form with the said end portions of the tubes a permanently united integral end plate assembly.

2. A heat exchanger according to claim 1, characterised in that the permanent fixing of the end portions of the tubes to the end plate assembly and/or the permanently uniting of the end plate means is by adhesive bonding.

3. A heat exchanger according to claim 1, characterised in that the permanent fixing of the end portions of the tubes to the end plate assembly and/or the permanently uniting of the end plate means is by ultrasonic welding.

4. A heat exchanger according to any one of claims 1 to 3, characterised in that the end plate assembly also defines a distribution chamber (13) having a number of outlets (14a-14e) for supplying heat exchange fluid, e.g. refrigerant, to a corresponding number of the said flow inlets (11) and a collection chamber (21) having a number of inlets (22a-22e) for receiving heat exchange fluid from a corresponding number of the said flow outlets (12).

5. A heat exchanger according to claim 4, characterised in that separate inlet flow control channels (15-19) connect the outlets (14a-14e) of the distribution chamber (13) to the said flow inlets (11), the distribution chamber (13) and the inlet flow control channels (15-19) being designed to provide equal and/or consistent distribution of the heat exchange fluid to the flow inlets (11).

6. A heat exchanger according to claim 4 or 5, characterised in that the cross-sectional size of each outlet (14a-14e) of the distribution chamber (13) is smaller than that of the said flow inlet (11) to which it is connected.

7. A heat exchanger according to claim 4, 5 or 6, characterised in that each inlet flow control channel (15-19) has gradually increasing cross-sectional size over at least part of its length in the direction from the distribution chamber (13) to the flow inlet (11).

8. A heat exchanger according to any one of claims 4 to 7, characterised in that each inlet flow control channel (15-19) comprises an upstream first channel portion of substantially constant cross-sectional size and a downstream second channel portion in which the cross-sectional size gradually increases towards the flow inlet (11).

9. A heat exchanger according to claim 7 or 8, characterised in that each inlet flow control channel includes a restricted section (300) e.g. a venturi-like passage, immediately upstream of the gradually increasing section.

10. A heat exchanger according to any one of claims 4 to 9, characterised in that the lengths and/or sizes of the inlet flow control channels are designed to provide equal and or consistent distribution of the heat exchange fluid to the flow inlets (11).

11. A heat exchanger according to any one of claim 4 to 10, characterised in that the distribution chamber (13) and the collection chamber (21) are positioned adjacent each other being separated by a boundary wall.

12. A heat exchanger according to claim 11, characterised in that the said boundary wall is relatively thin and is of tortuous form.

13. A heat exchanger according to any one of the preceding claims, characterised in that the end plate assembly comprises an inner end plate means (6; 70) to which the said end portions of the tubes (3) are permanently fixed, an outer end plate means (7; 71) and, intermediate the inner and outer plate means, a first intermediate end plate means (8; 72) defining, at least in part, the said connecting channels (10; 74).

14. A heat exchanger according to claim 13, characterised in that the end plate assembly also includes a second intermediate end plate means (9; 80) positioned between the first intermediate end plate means and the inner end plate means and defining in part the said connecting channels.

15. A heat exchanger according to any one of the preceding claims, characterised in that the end plate means of the end plate assembly are made of aluminium.

16. A method of manufacturing a heat exchanger (1) comprising forming a partial heat exchanger assembly having an apertured inner end plate means (6), a plurality of U-shaped tubes (3) each having a pair of free ends (3a, 3b) projecting through apertures (40, 41) of said inner end plate means (6) and heat conductive fin means (5) thermally connected to the U-shaped tubes, arranging on the said inner end plate means (6) at least one intermediate end plate means (8, 9) and an outer end plate

means (7), permanently fixing portions of the U-shaped tubes adjacent said free ends to the said inner plate means (6) and joining the said end plate means (6-9) together to define connecting channels (10) isolated from each other for connecting together pairs of said free ends to provide at least one flow channel for heat exchange fluid formed of a number of interconnected ones of said U-shaped tubes (3) and having a flow inlet (11) and a flow outlet (12), is characterised in that the said end plate

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means are permanently united together to form a permanently united integral end plate assembly.

17. A method according to claim 16, characterised in that the assembling together of the said end plate means and the permanent uniting together of the end plate means and of the end portions of the U-shaped tubes to the inner plate means are performed automatically, e.g. with robots.

FIG. 1

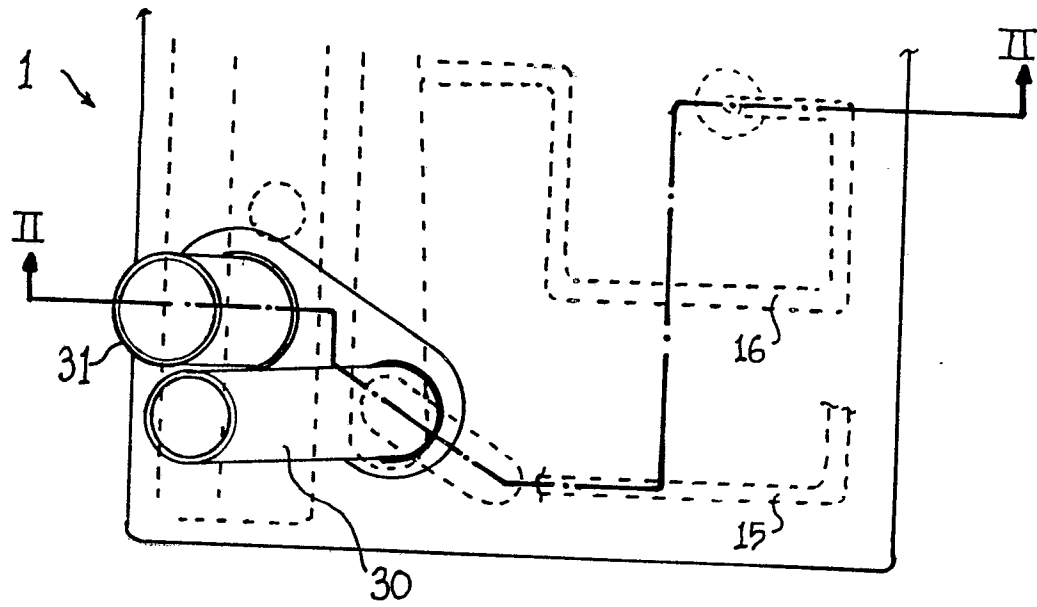


FIG. 2

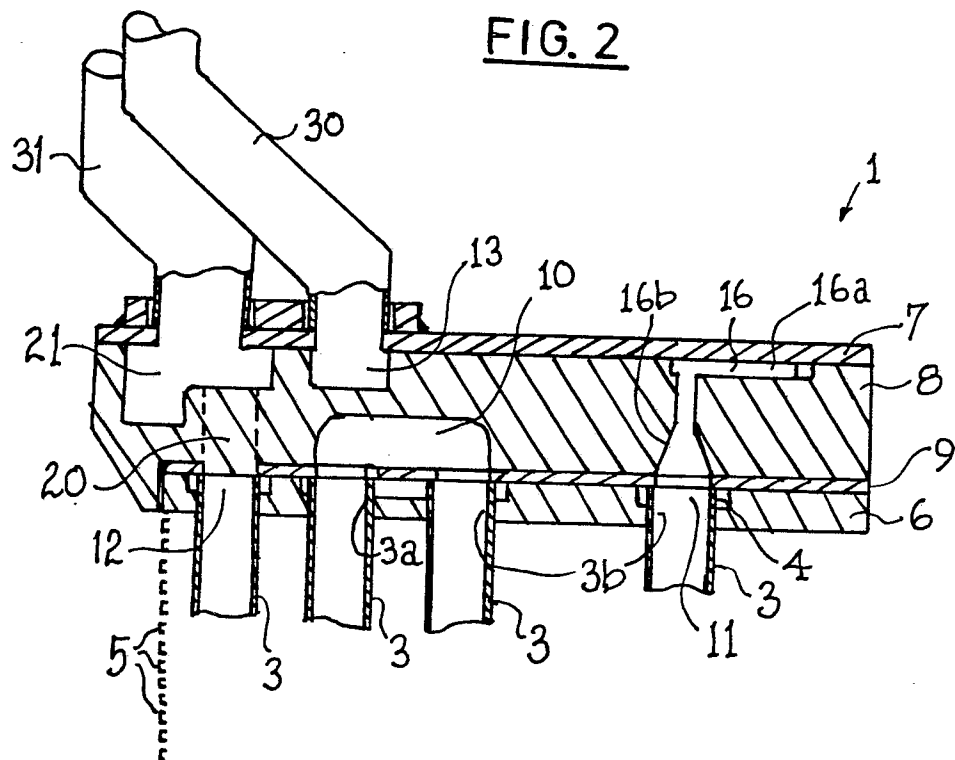


FIG 4

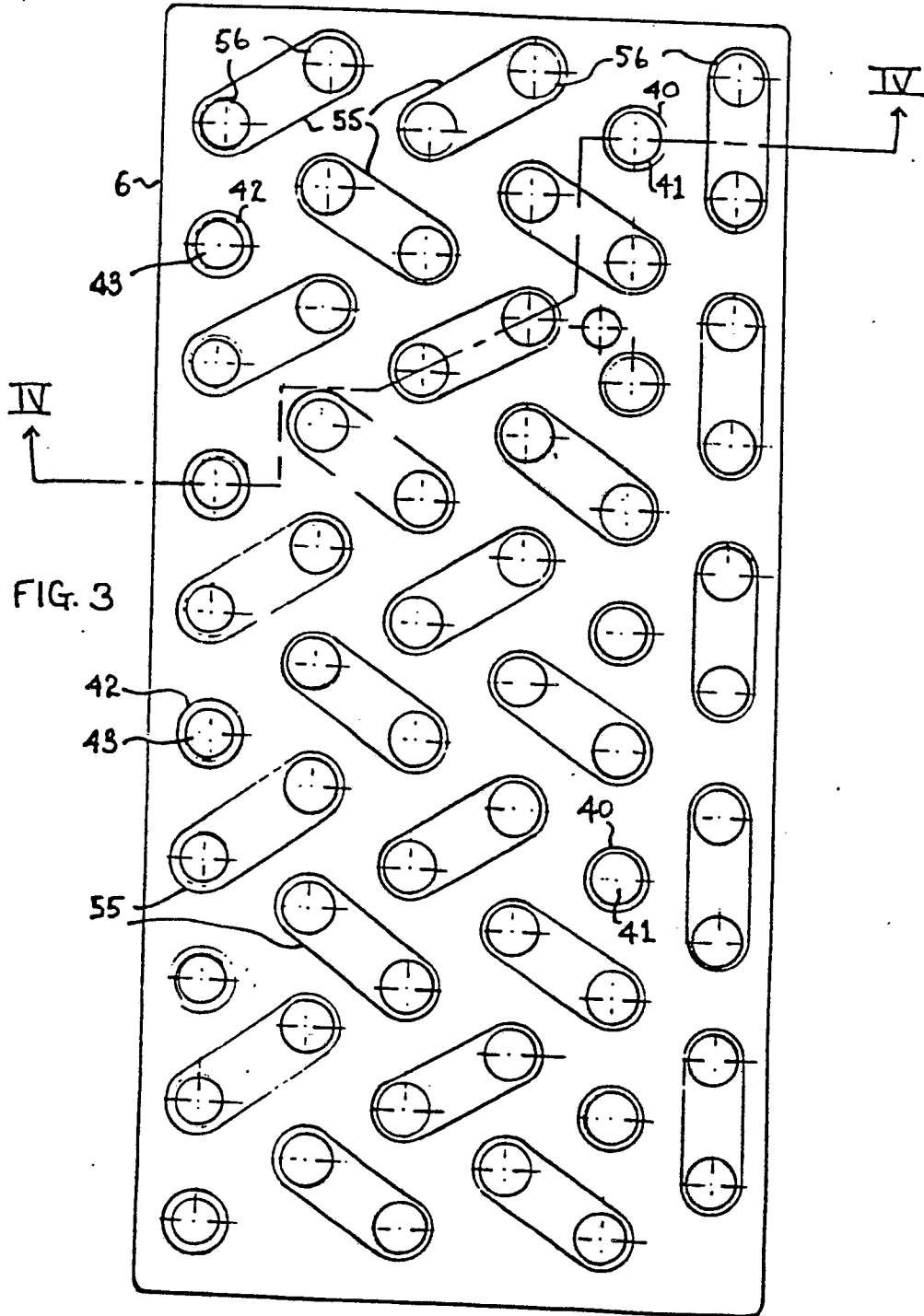
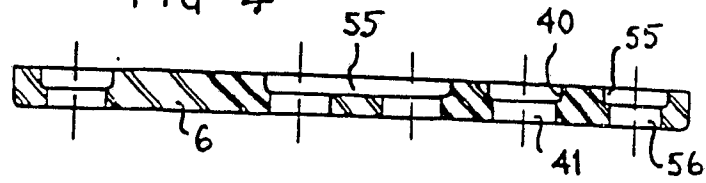


FIG. 3

FIG. 6

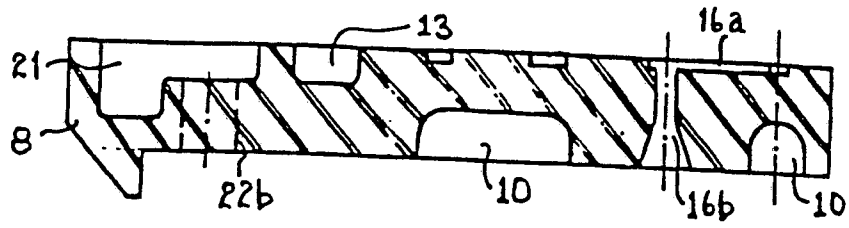


FIG. 5

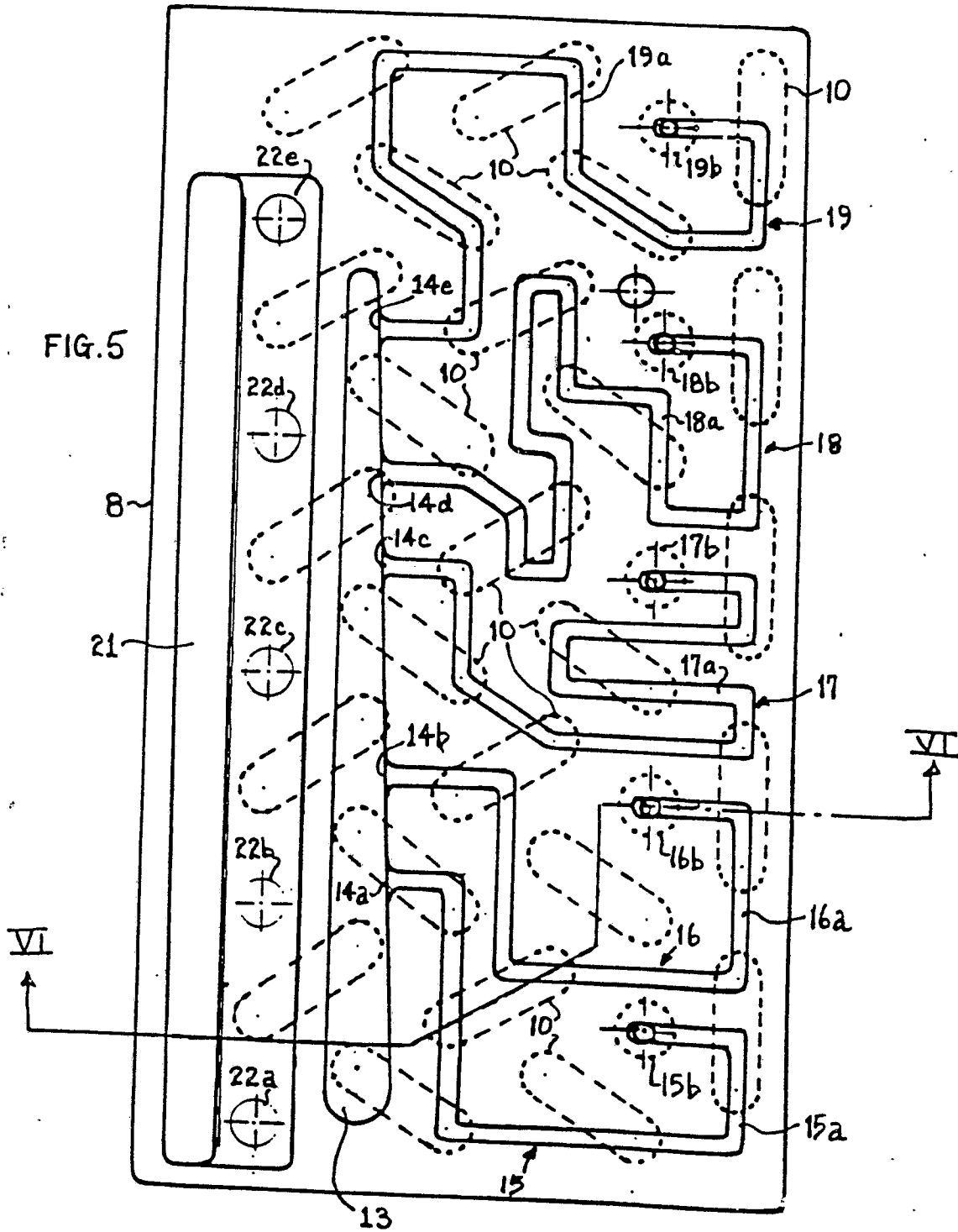


FIG. 8

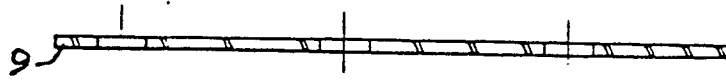


FIG. 7

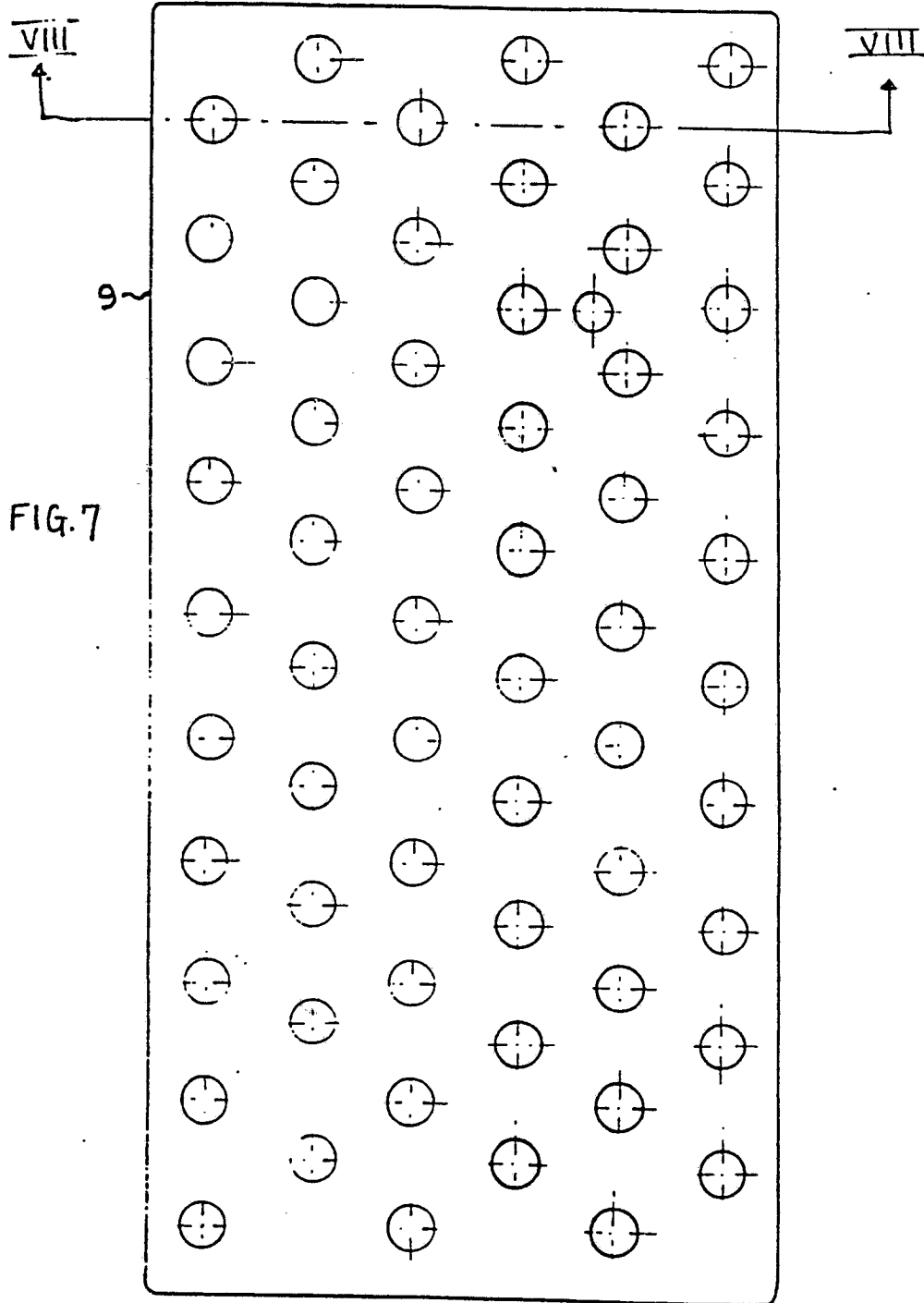


FIG. 10

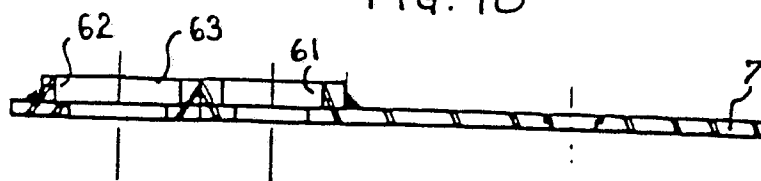


FIG. 9

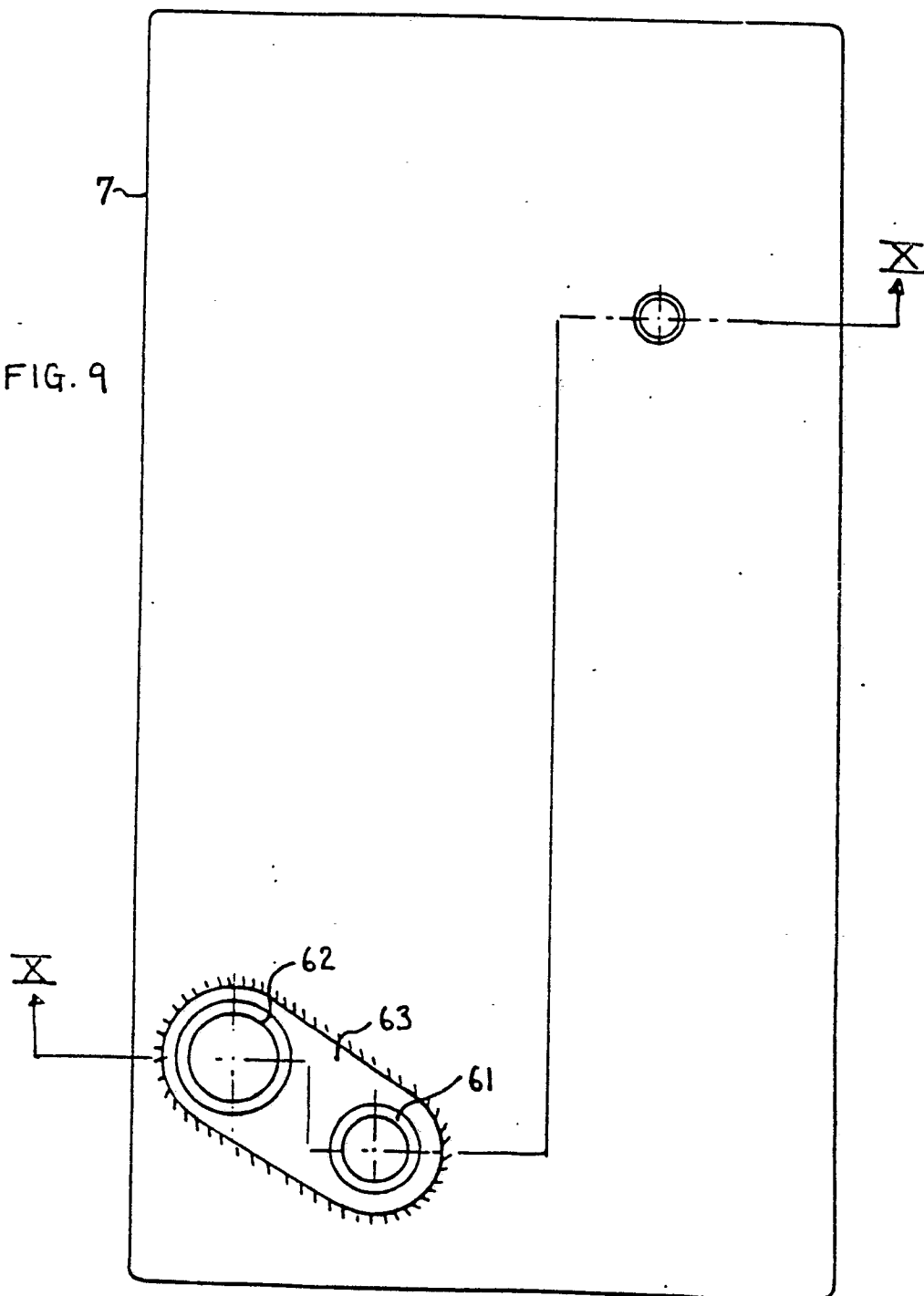


FIG. 11

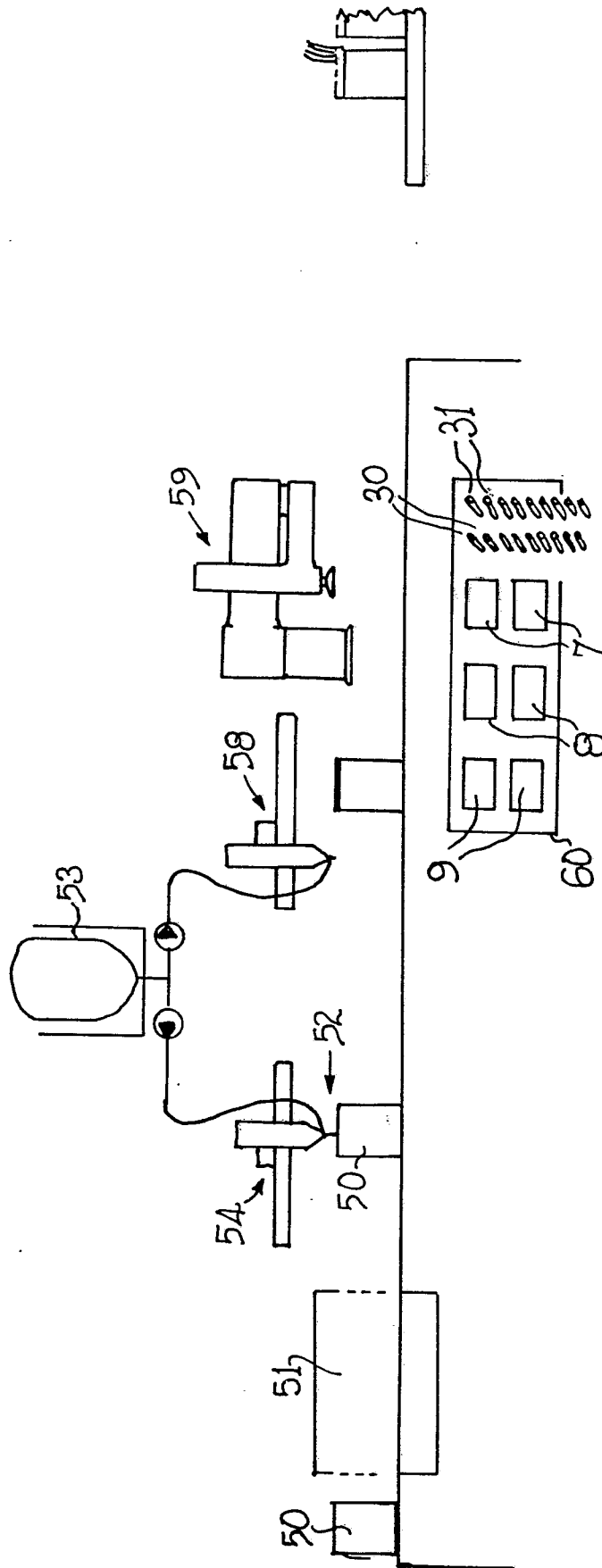


FIG. 12

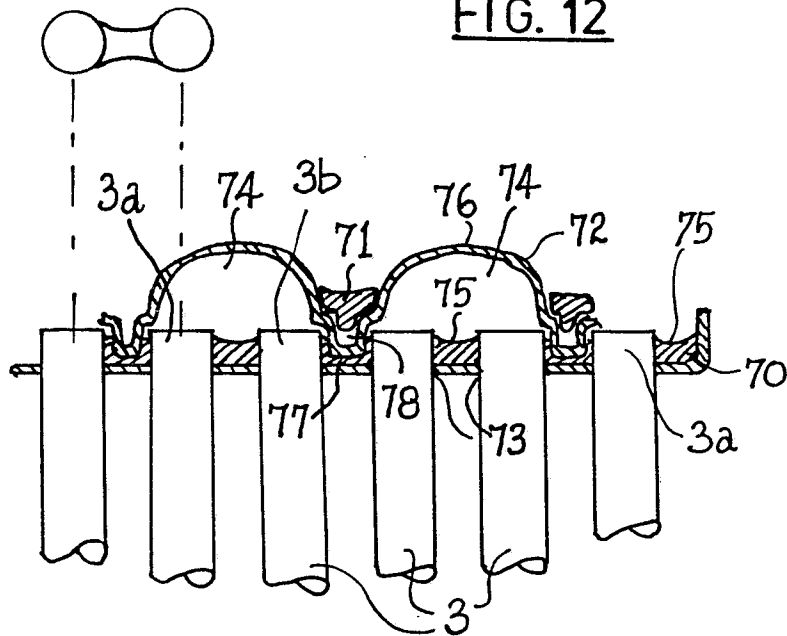


FIG. 13

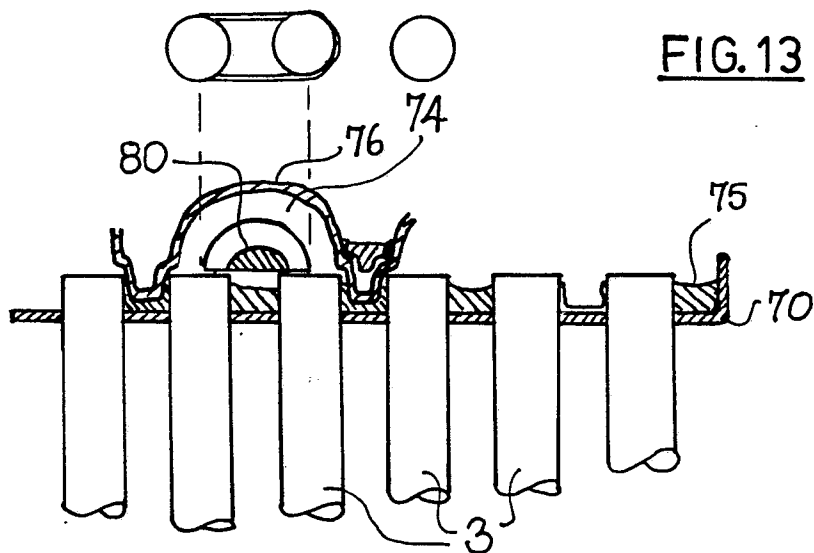


FIG. 14

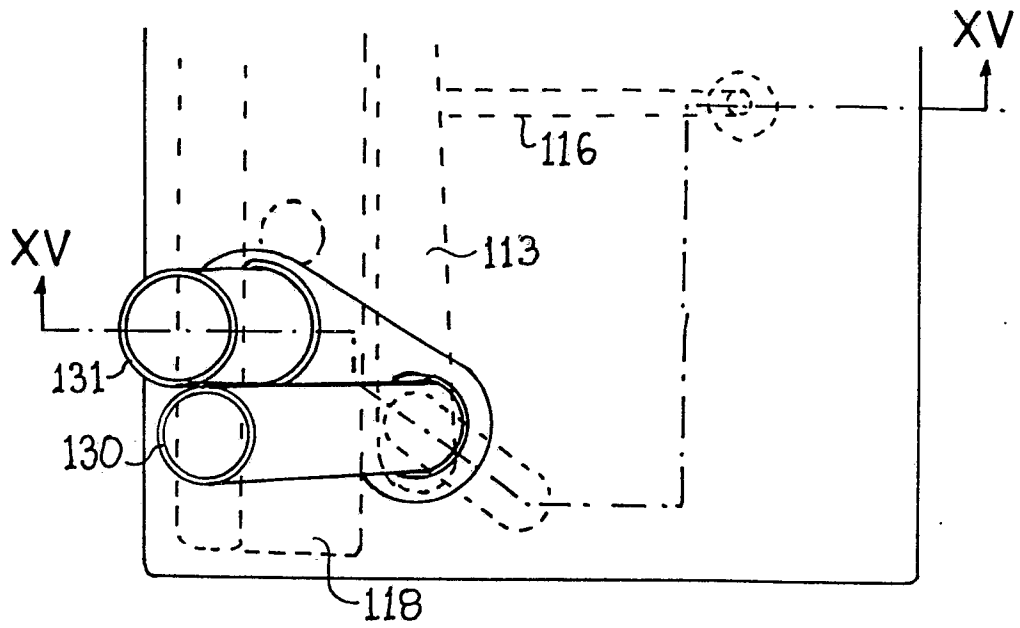


FIG. 15

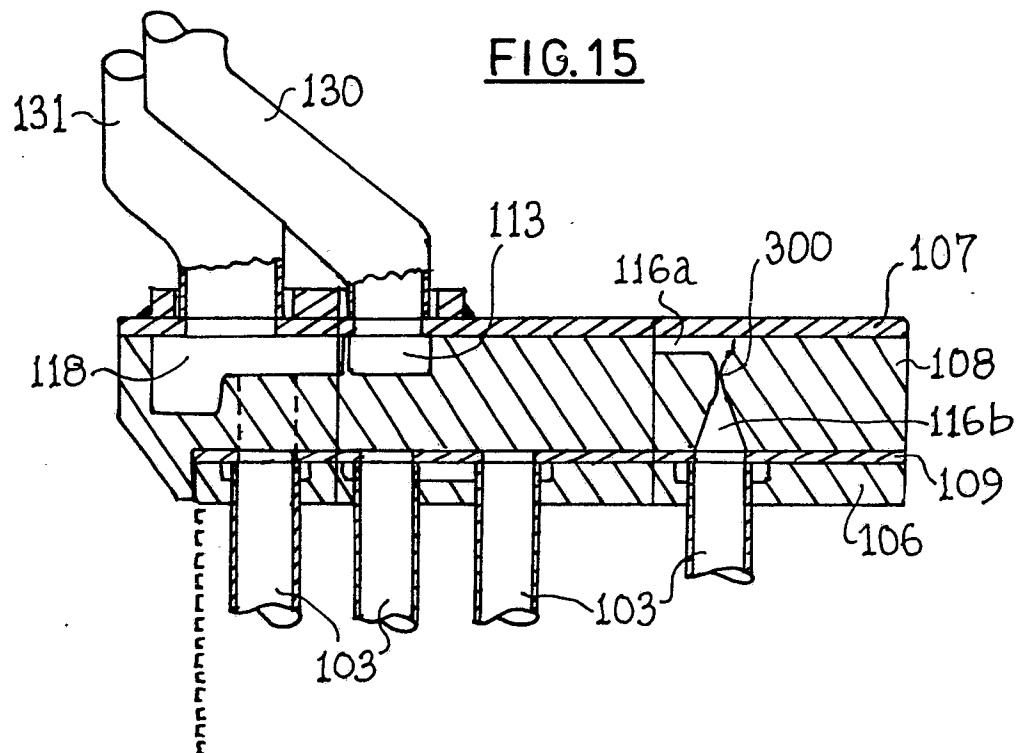


FIG. 17

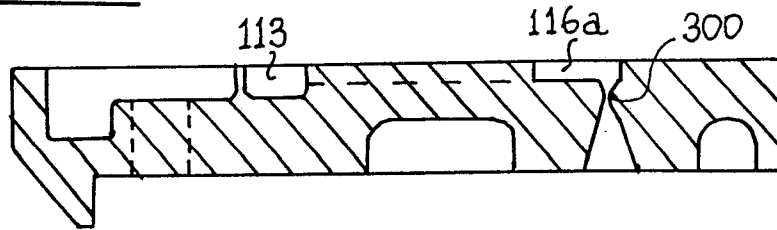


FIG. 16

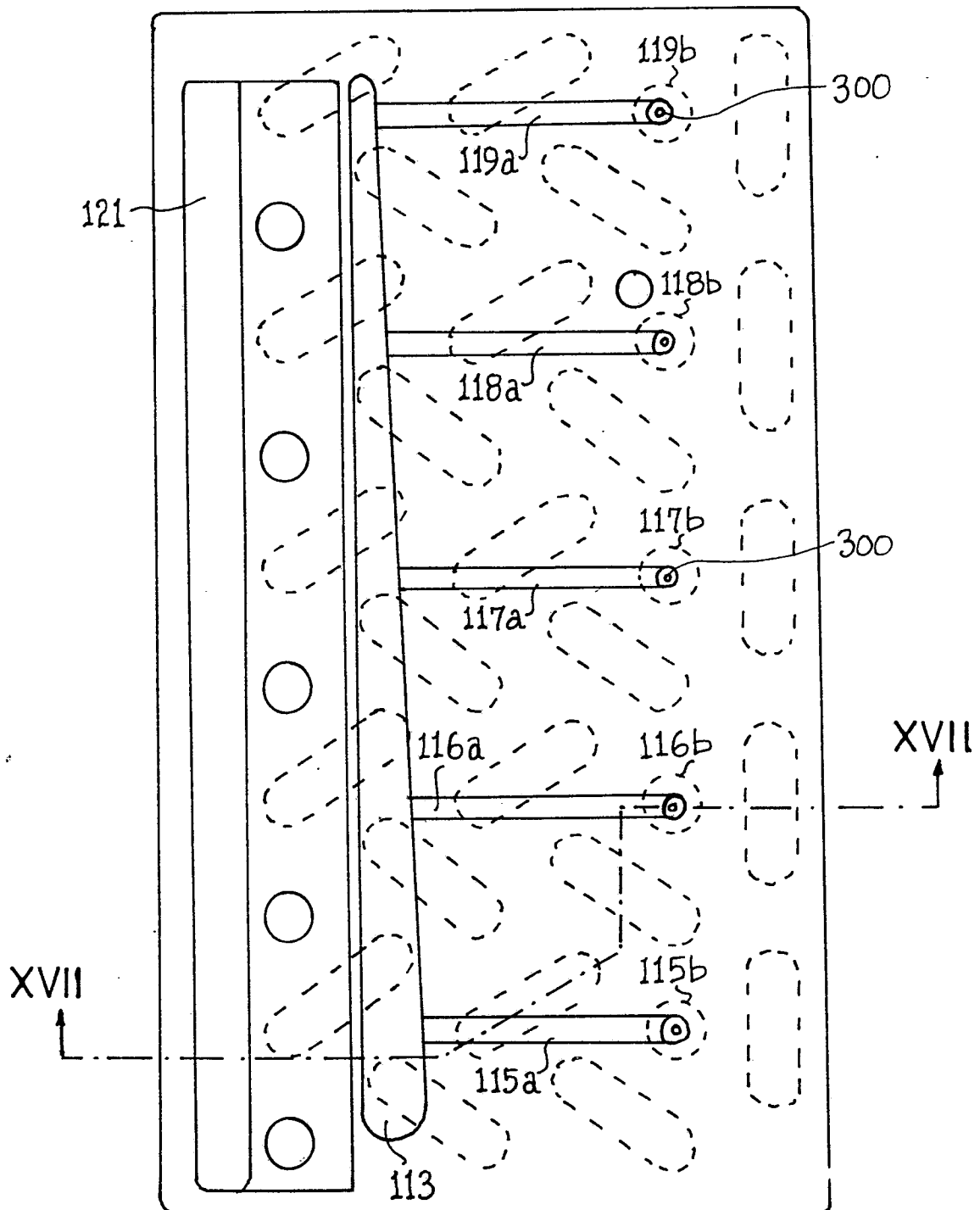


FIG. 19

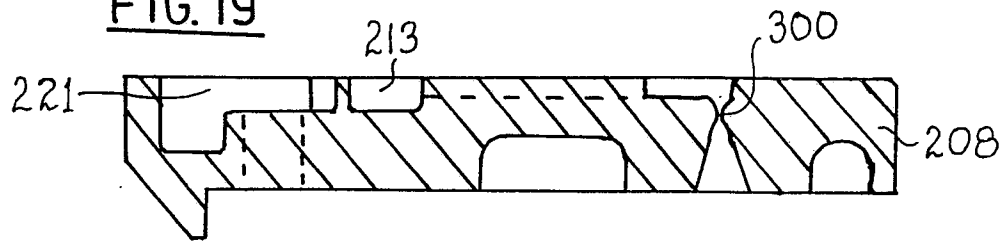


FIG. 20

