HEAT EXCHANGER

Filed Feb. 3, 1966 11 Sheets-Sheet 1

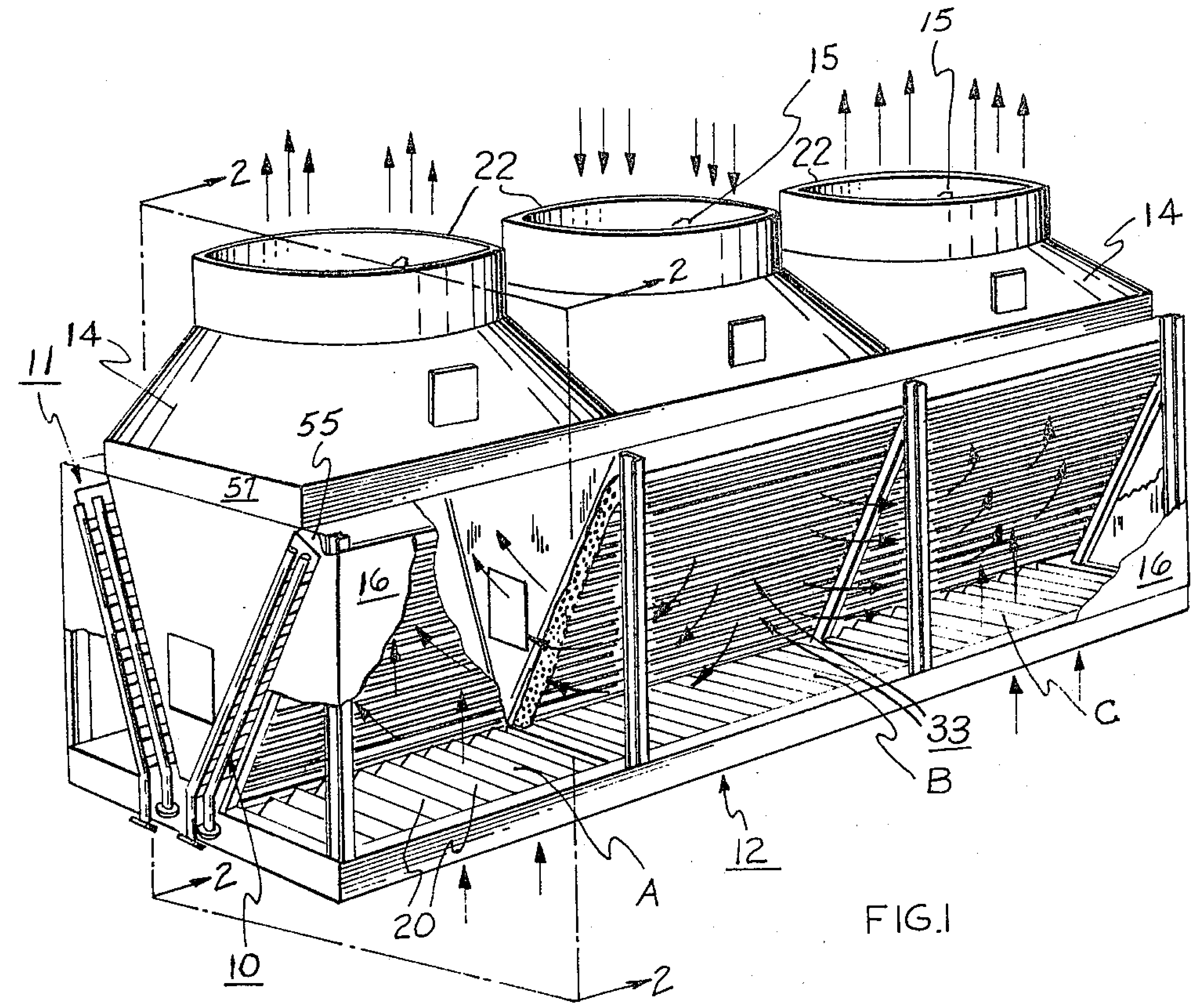

FIG.1

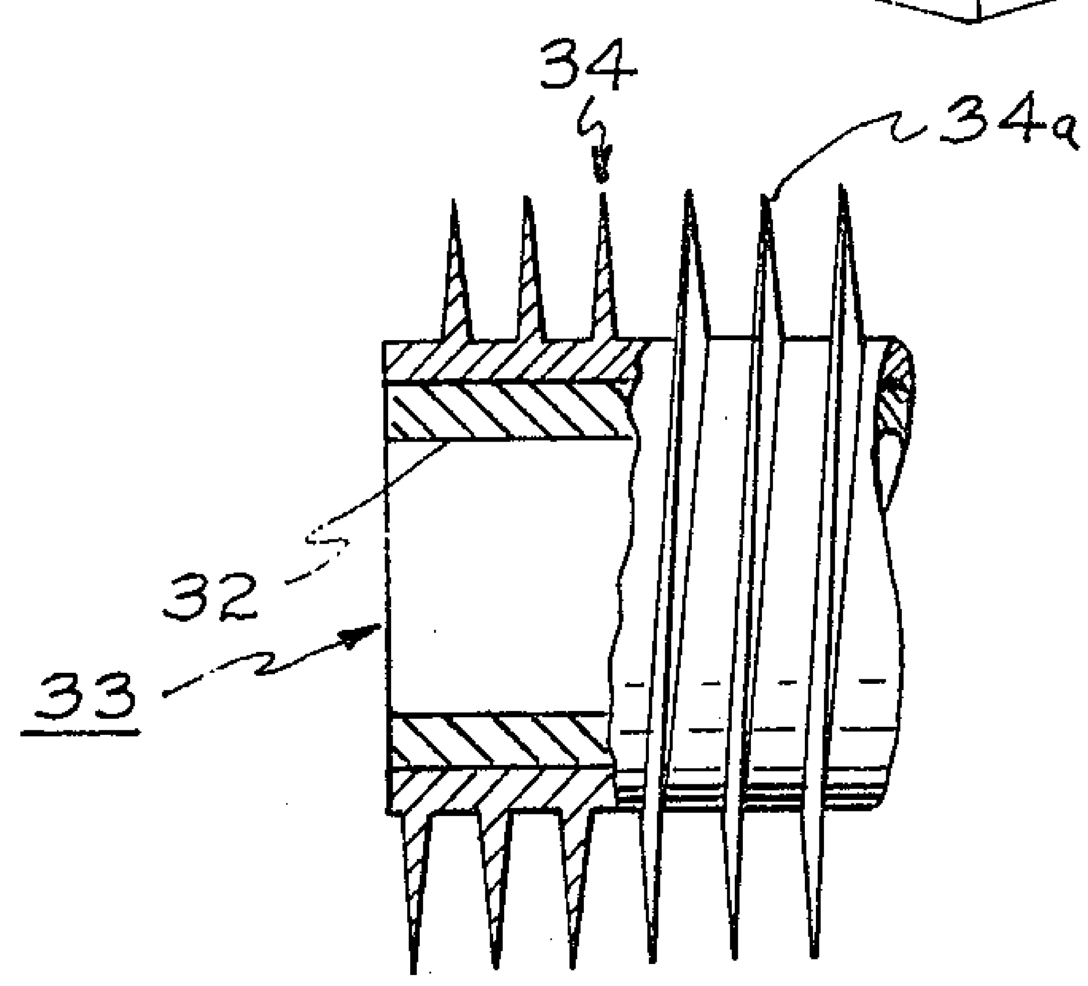

FIG.3

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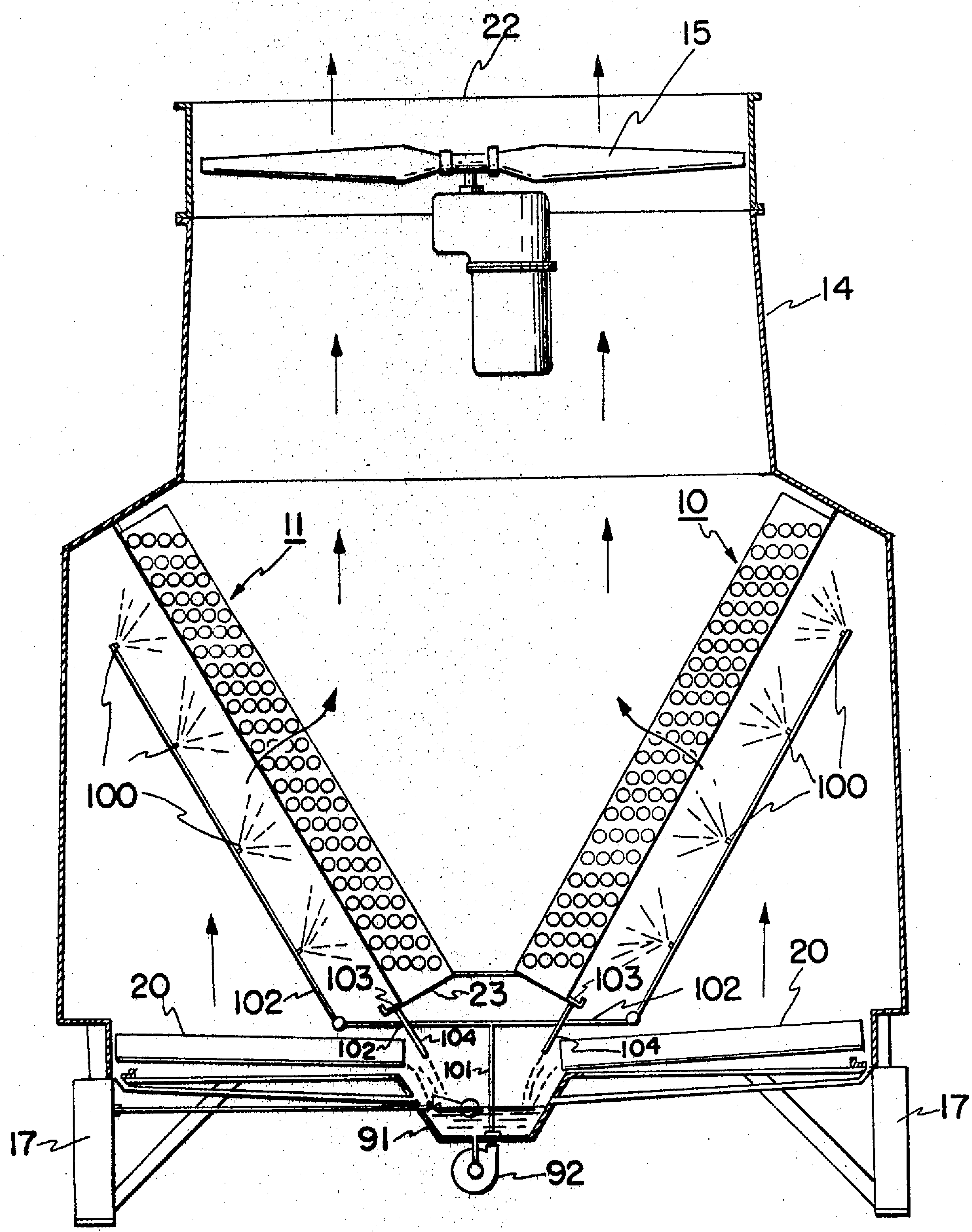

FIG.2

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May 21, 1968 R. T. MATHEWS 3,384,165

HEAT EXCHANGER

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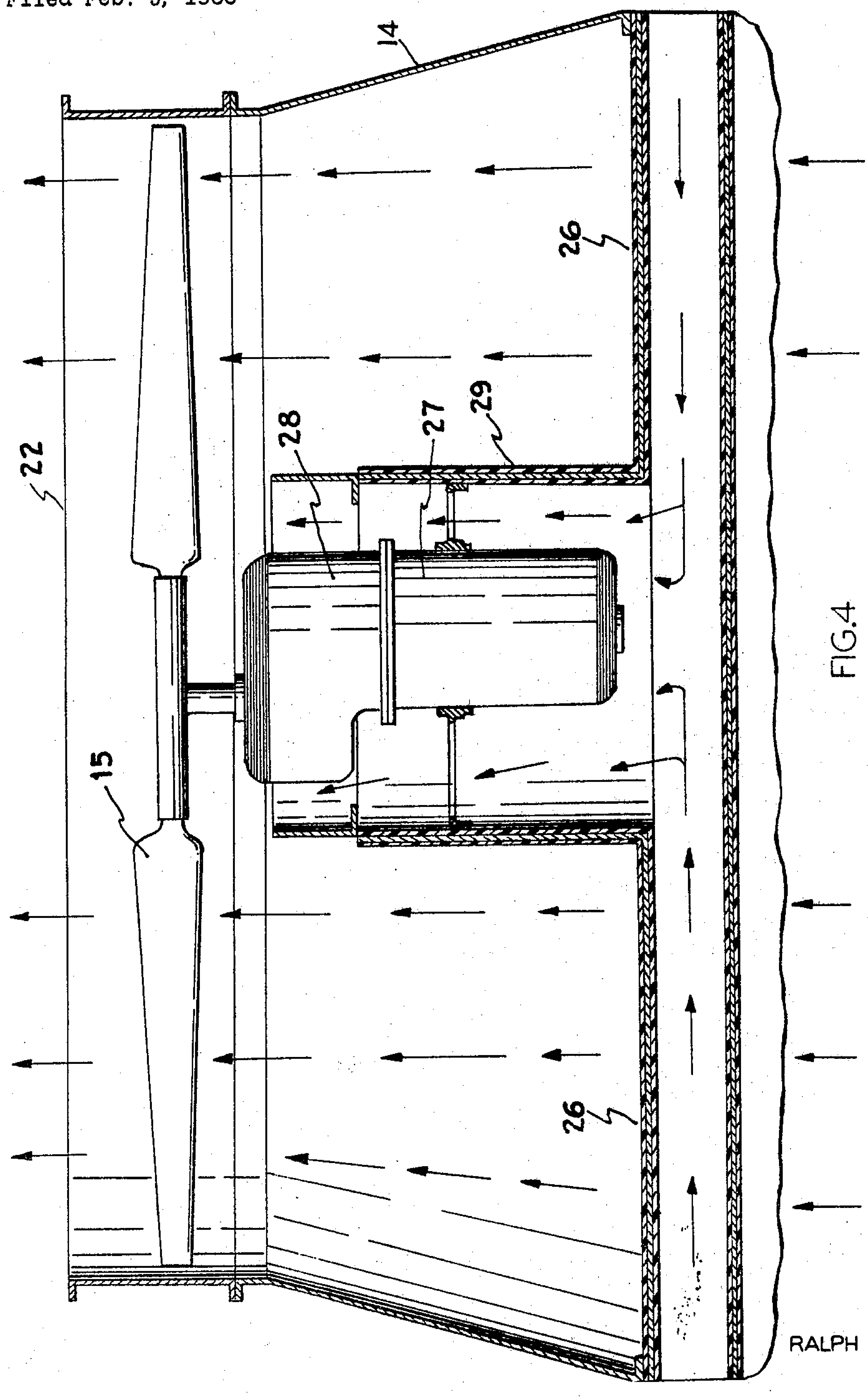

FIG.4

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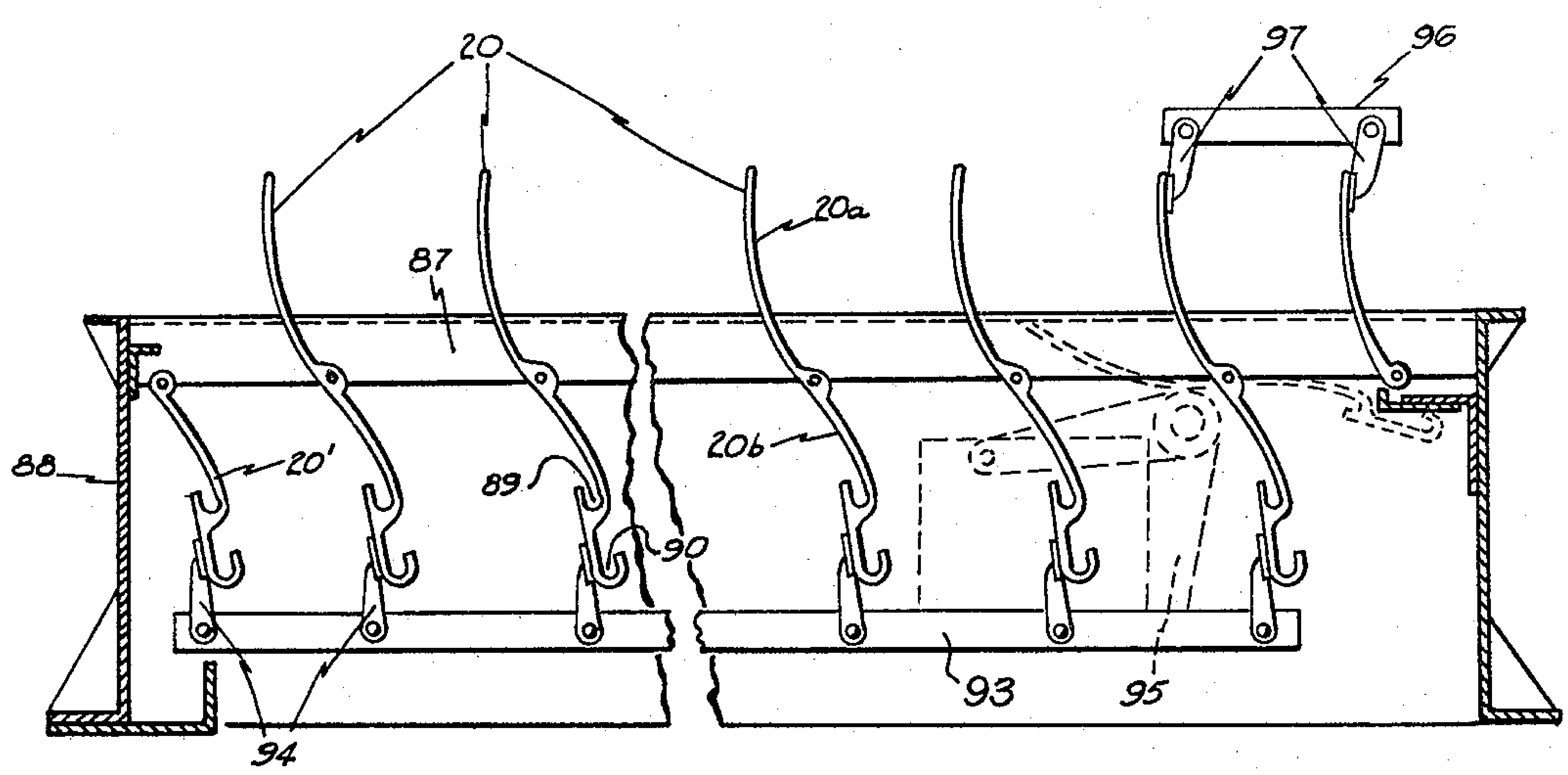

FIG.5

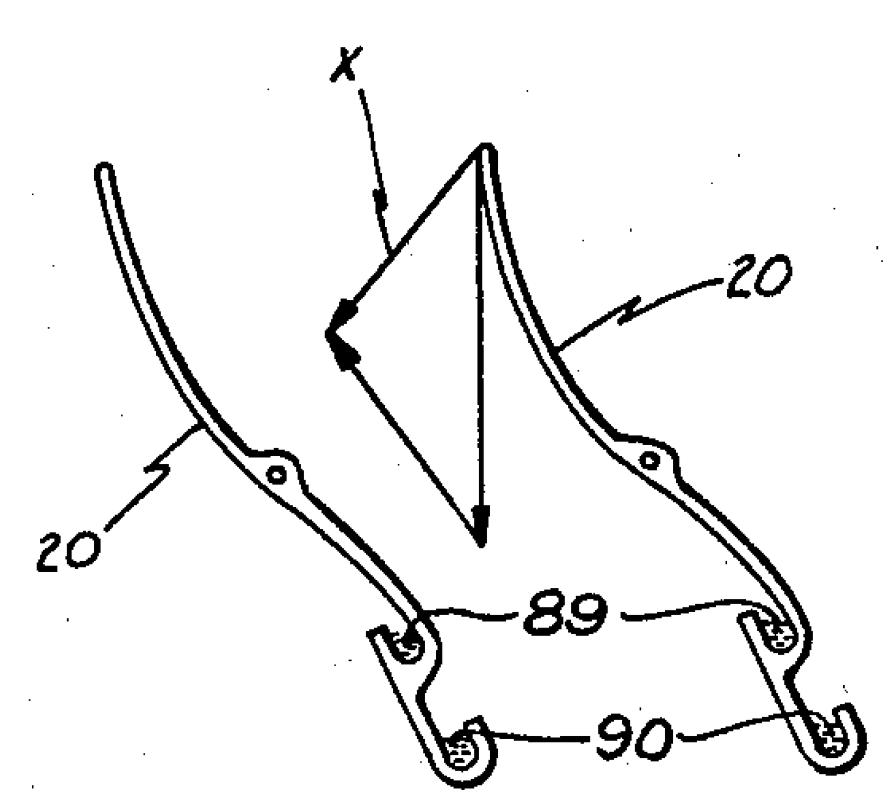

FIG. 6

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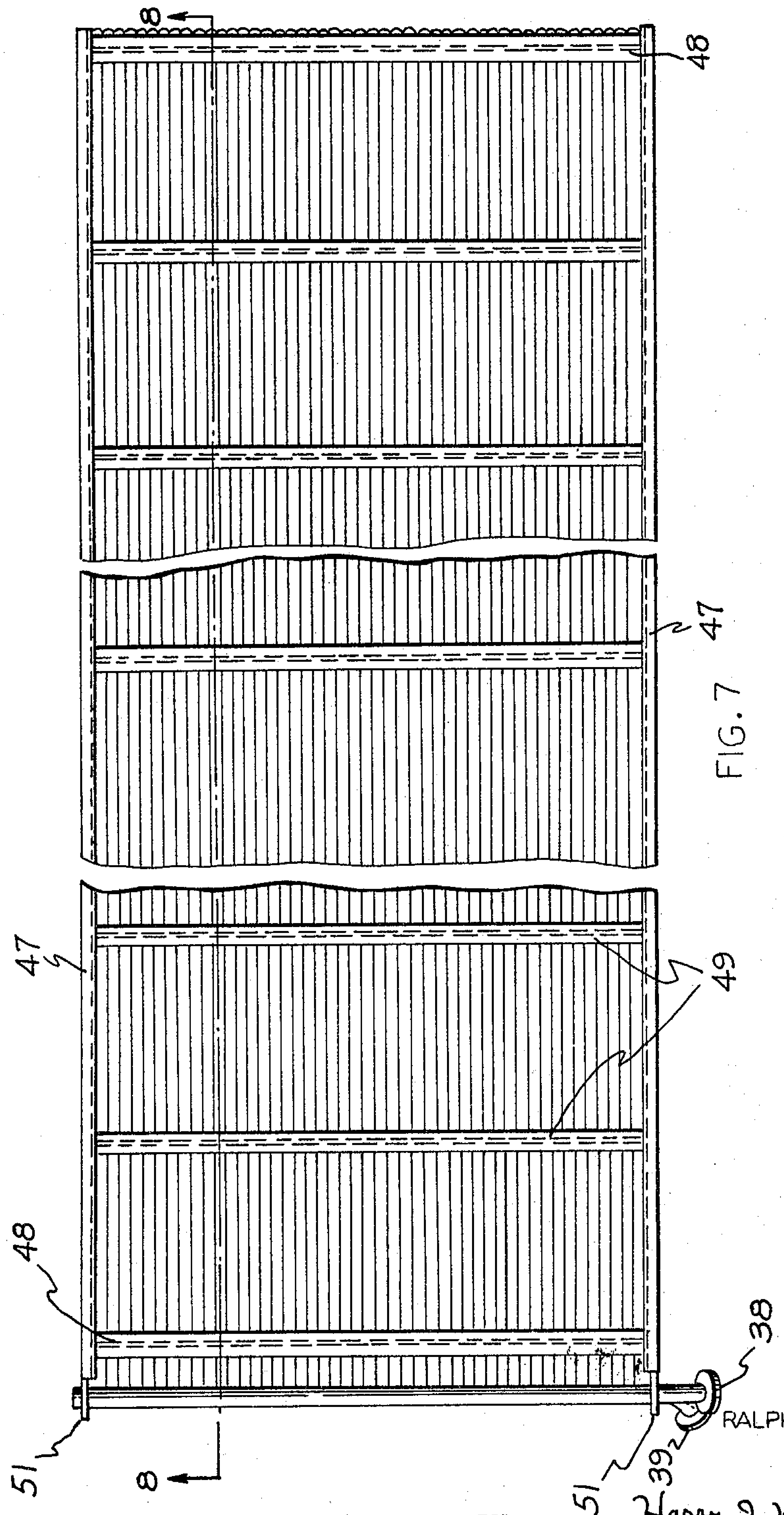

FIG. 7

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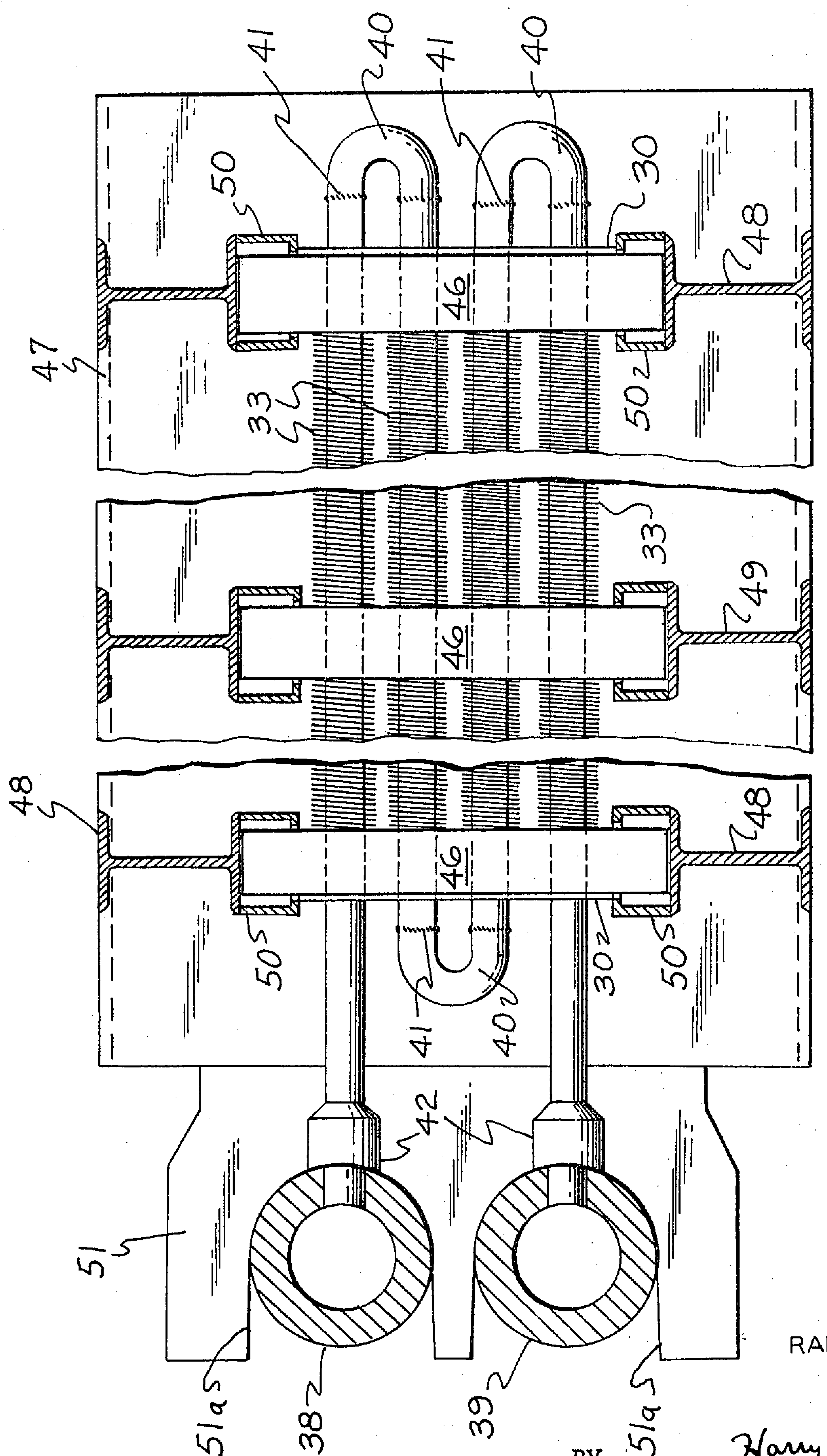

FIG. 8

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HEAT EXCHANGER

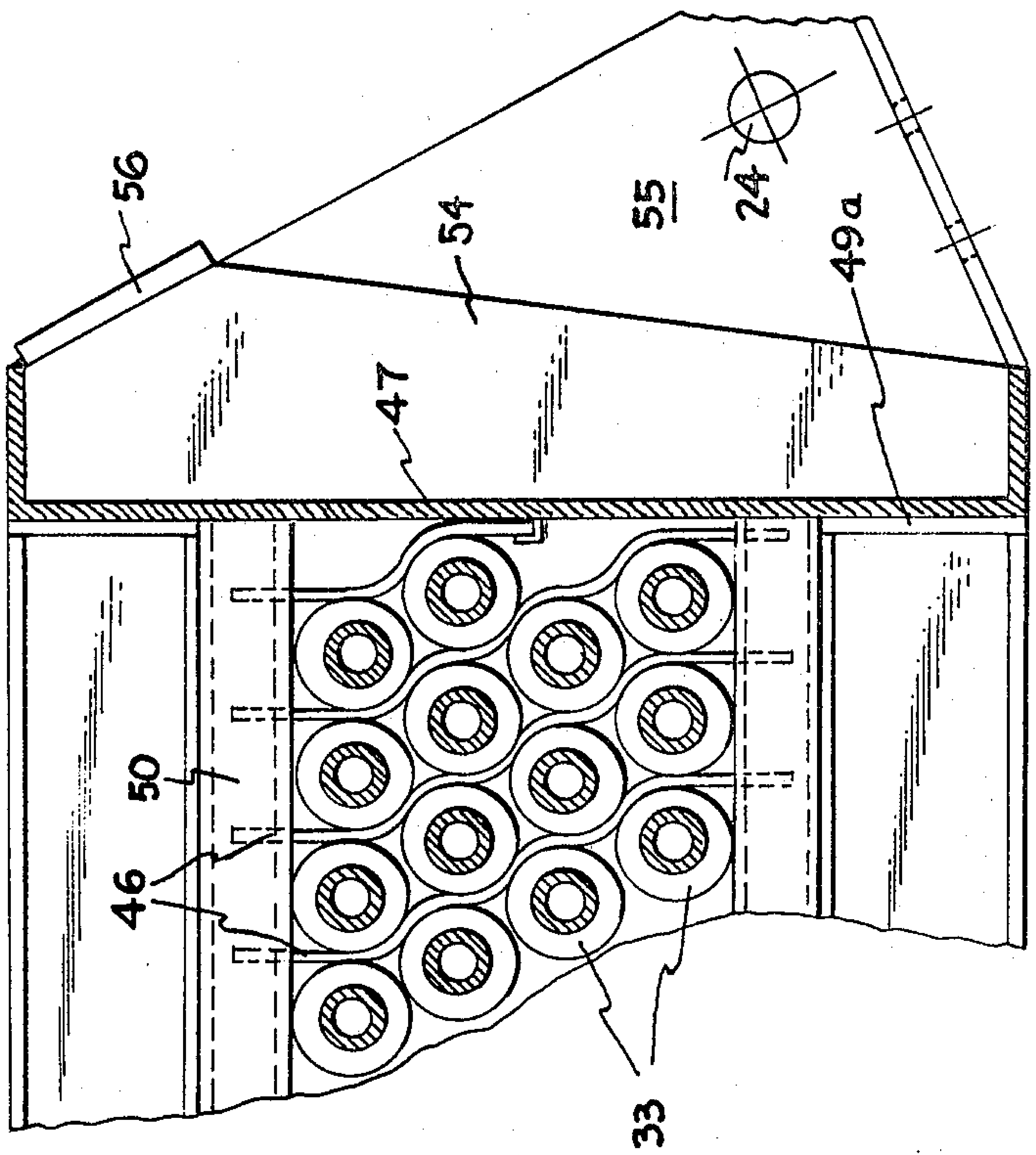

FIG. 9B

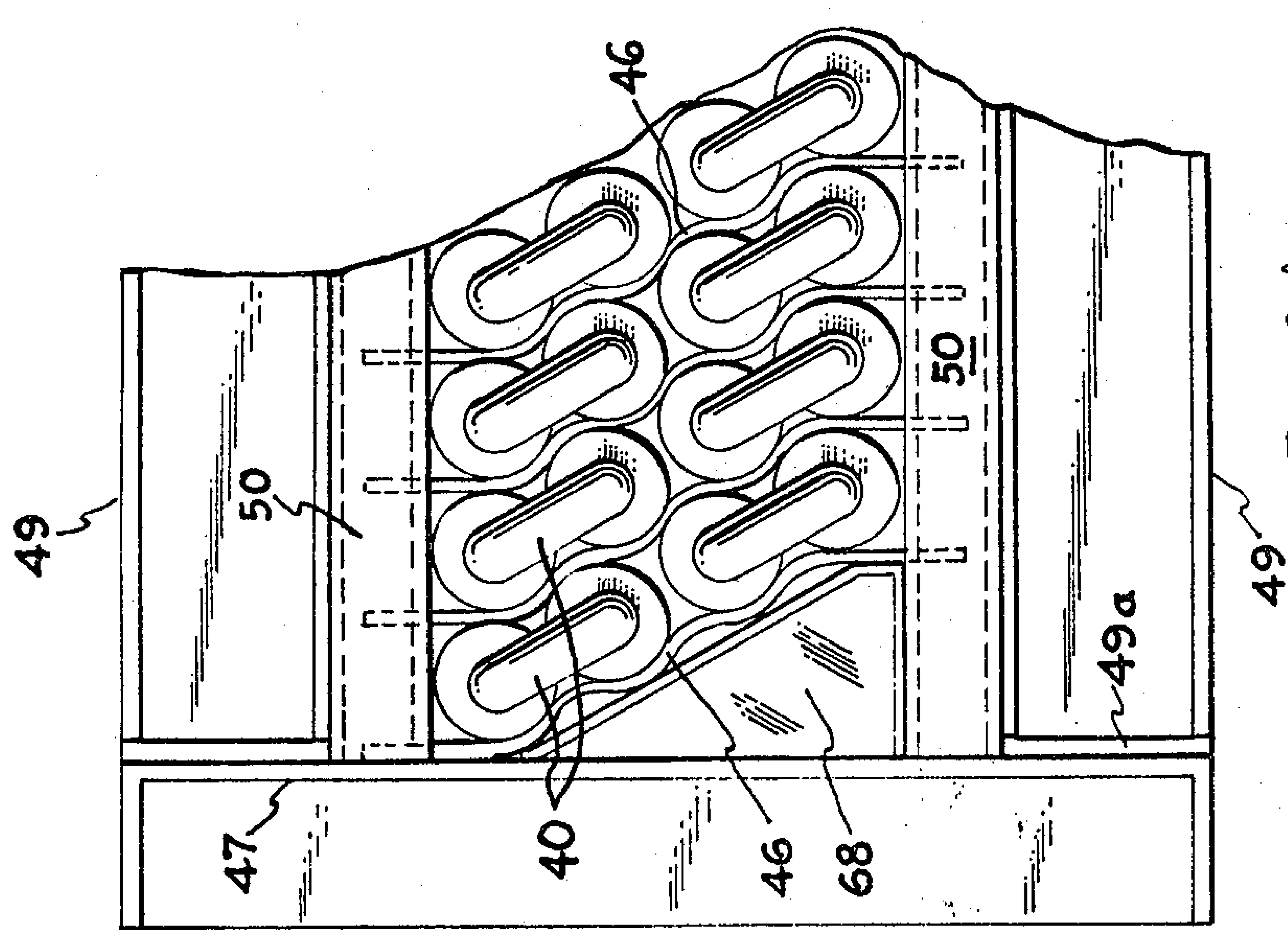

FIG. 9A

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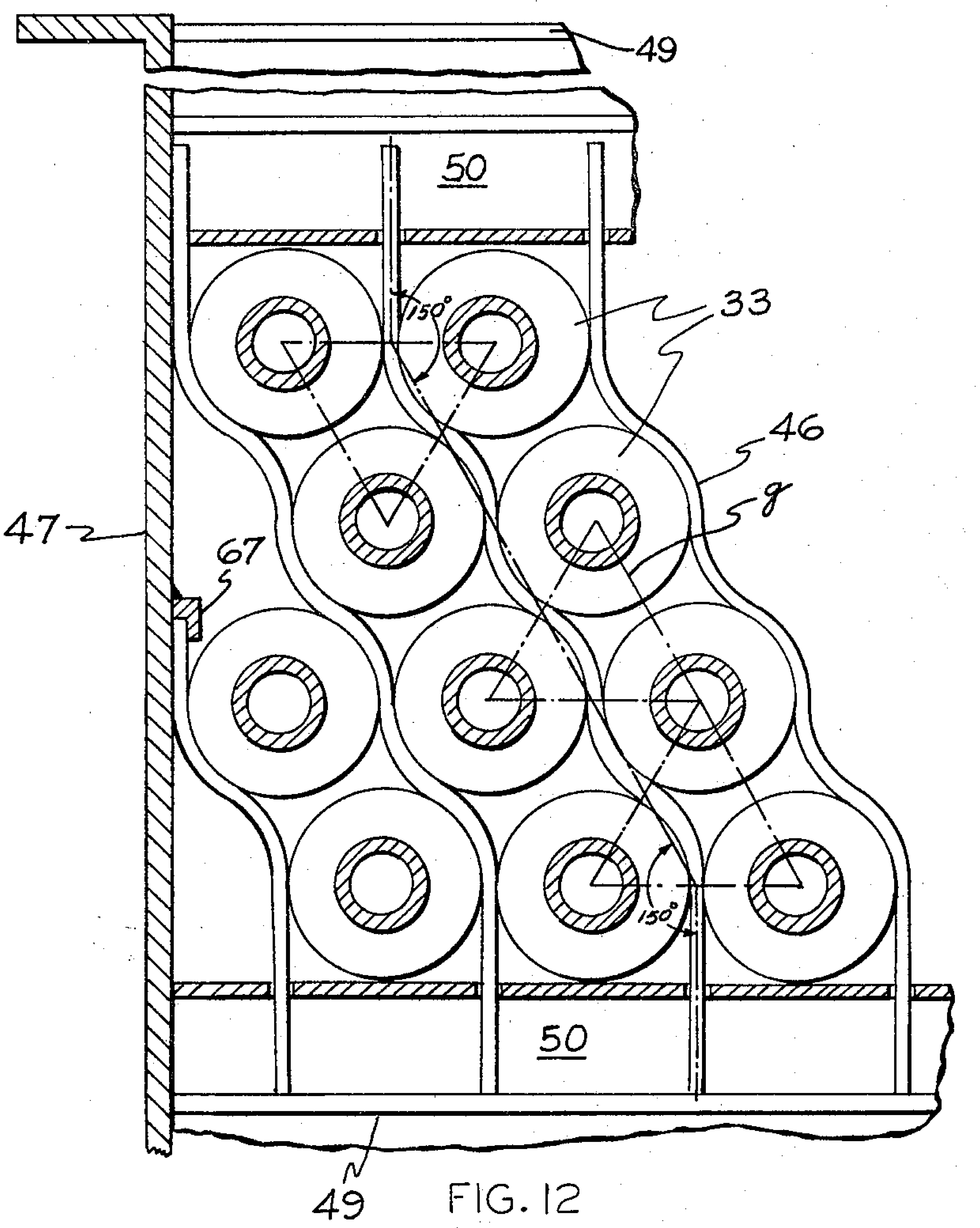

FIG. 12

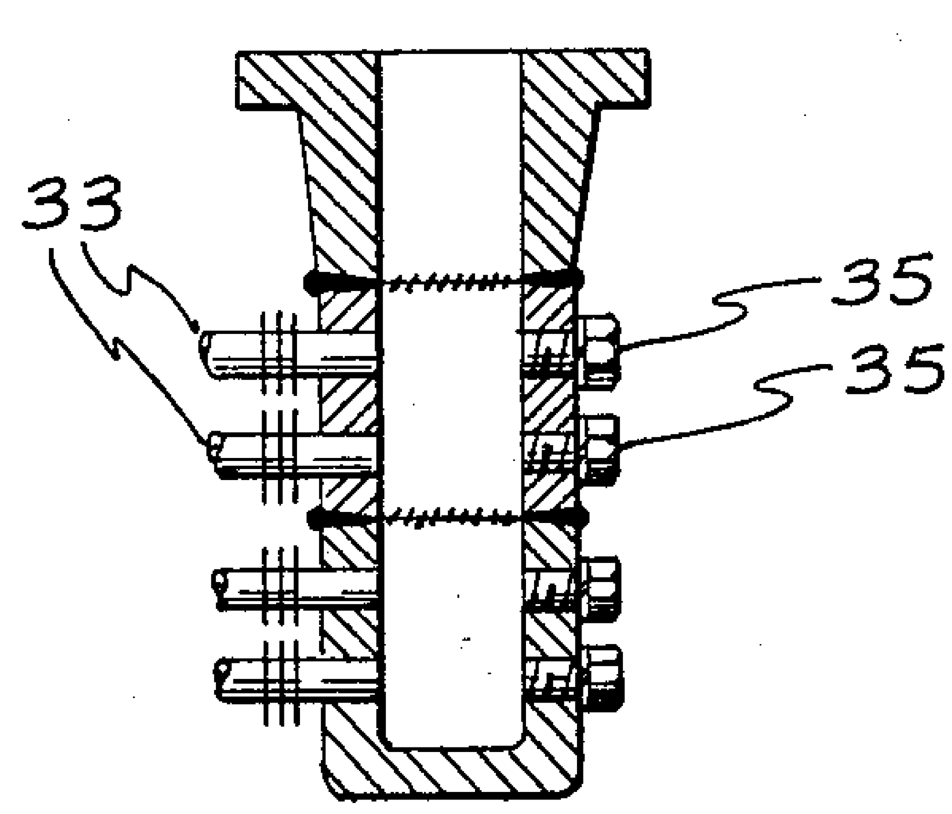

FIG 10

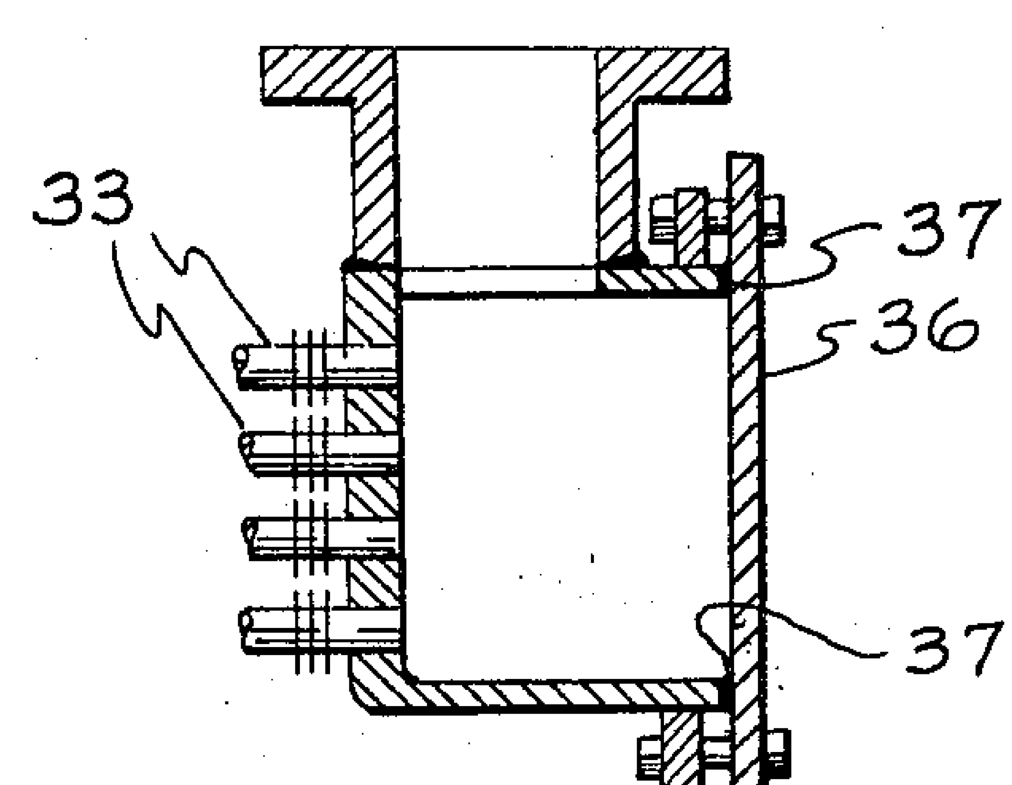

FIG. 11

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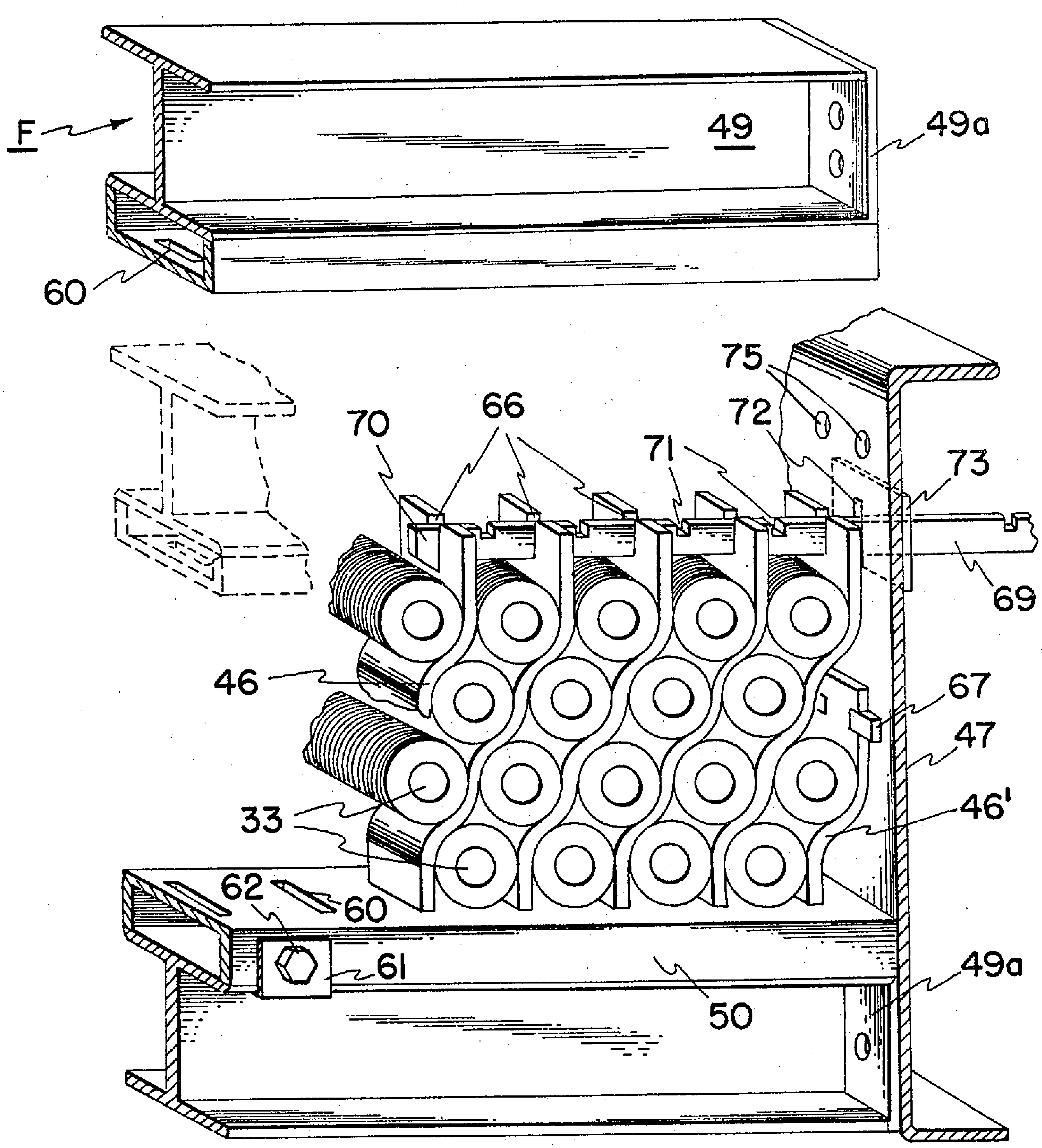

FIG. 13

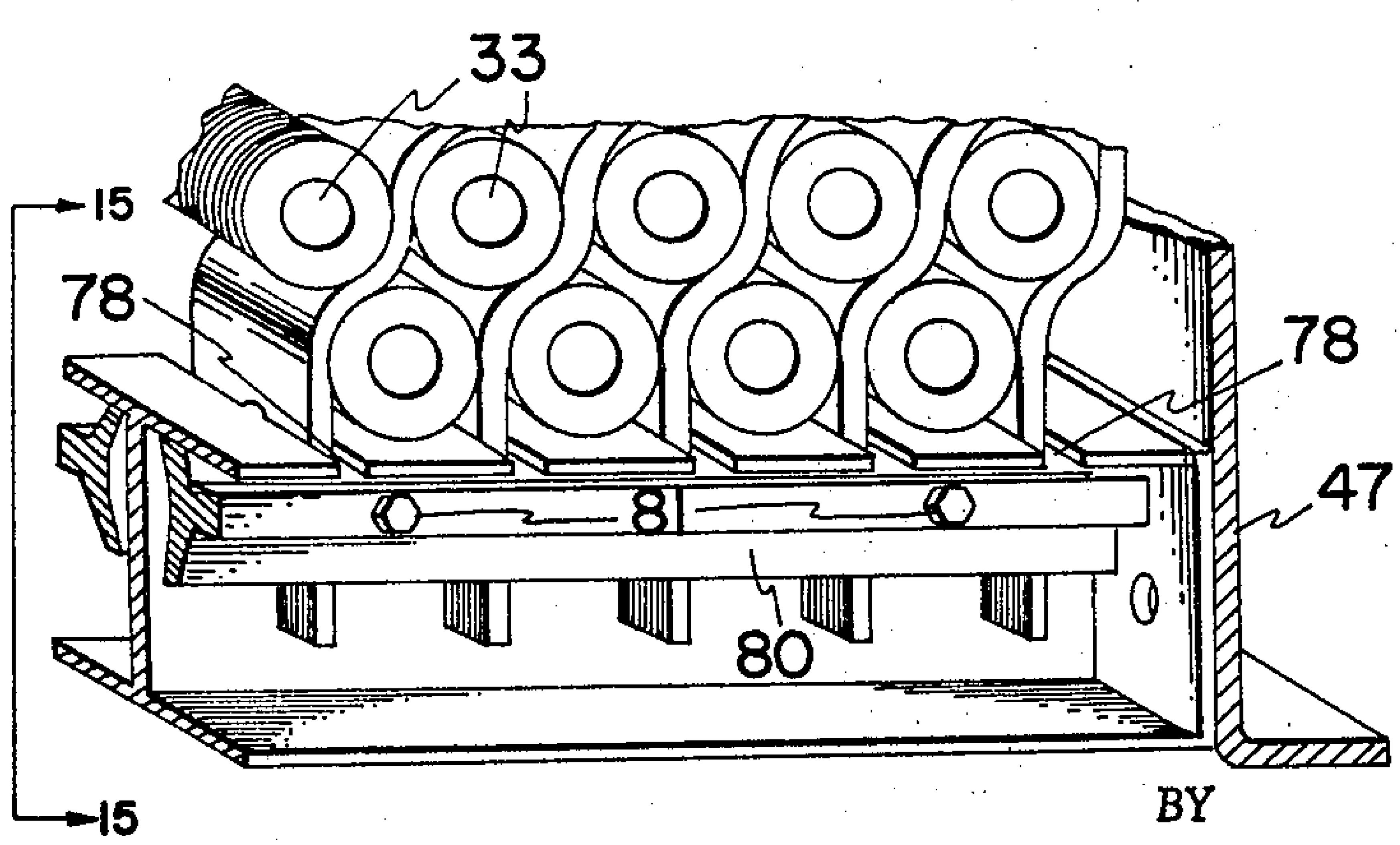

FIG. 14

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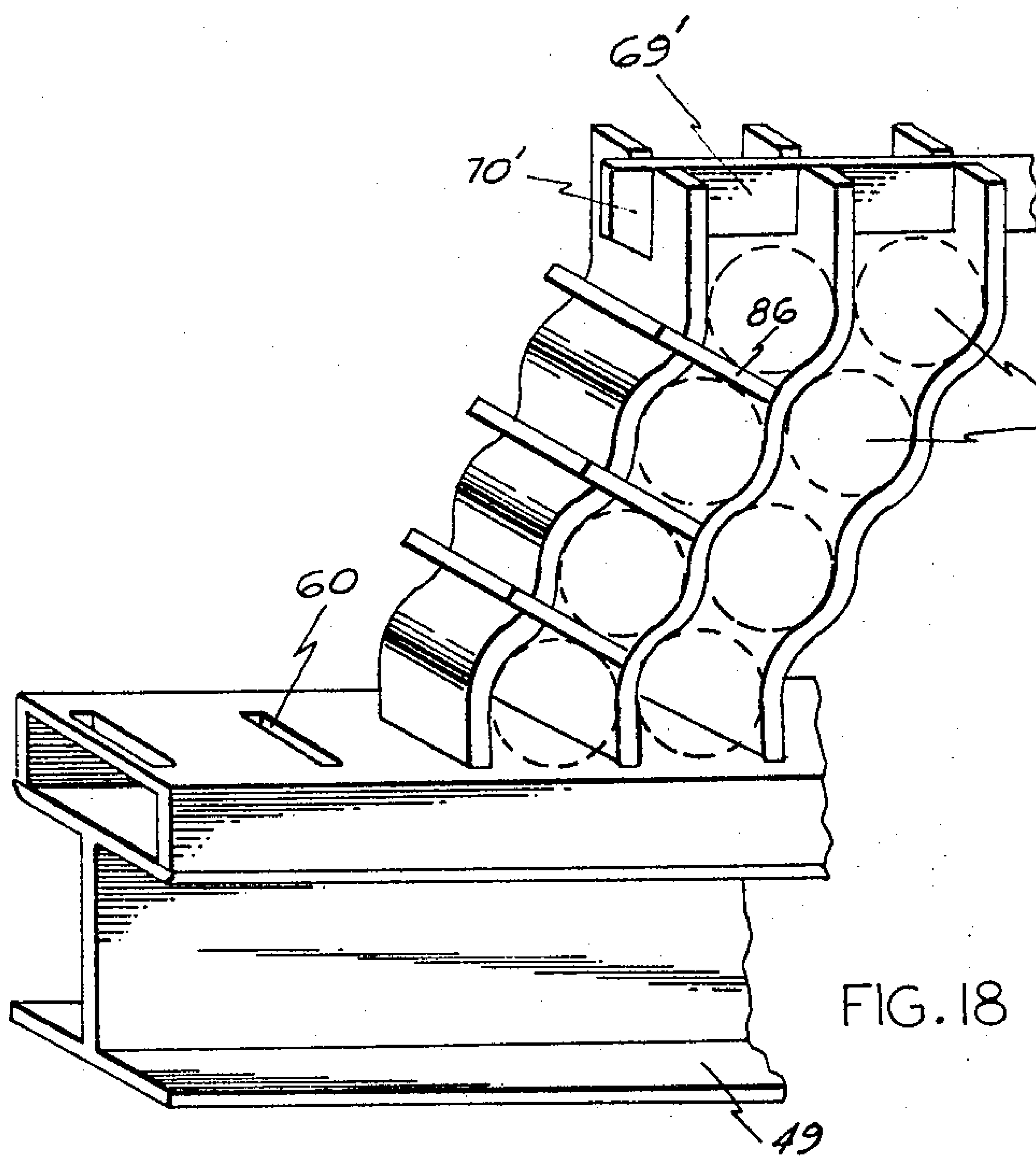

FIG. 18

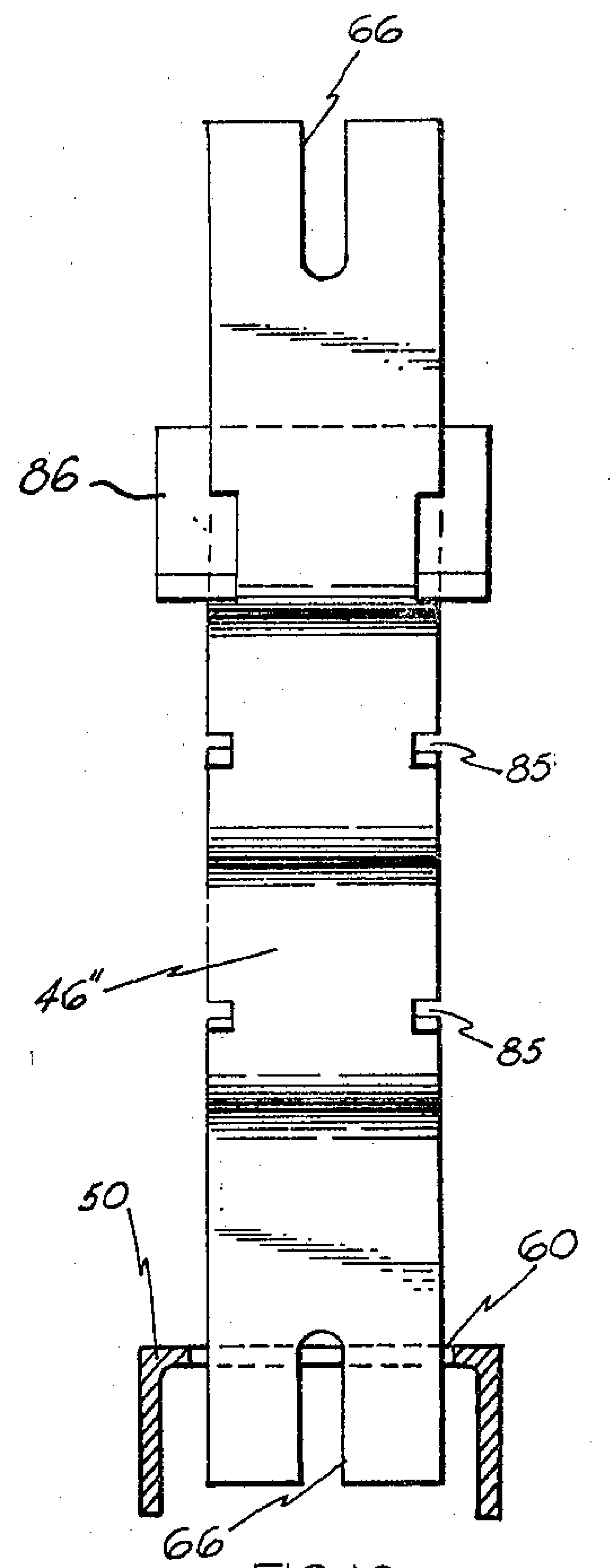

FIG. 16

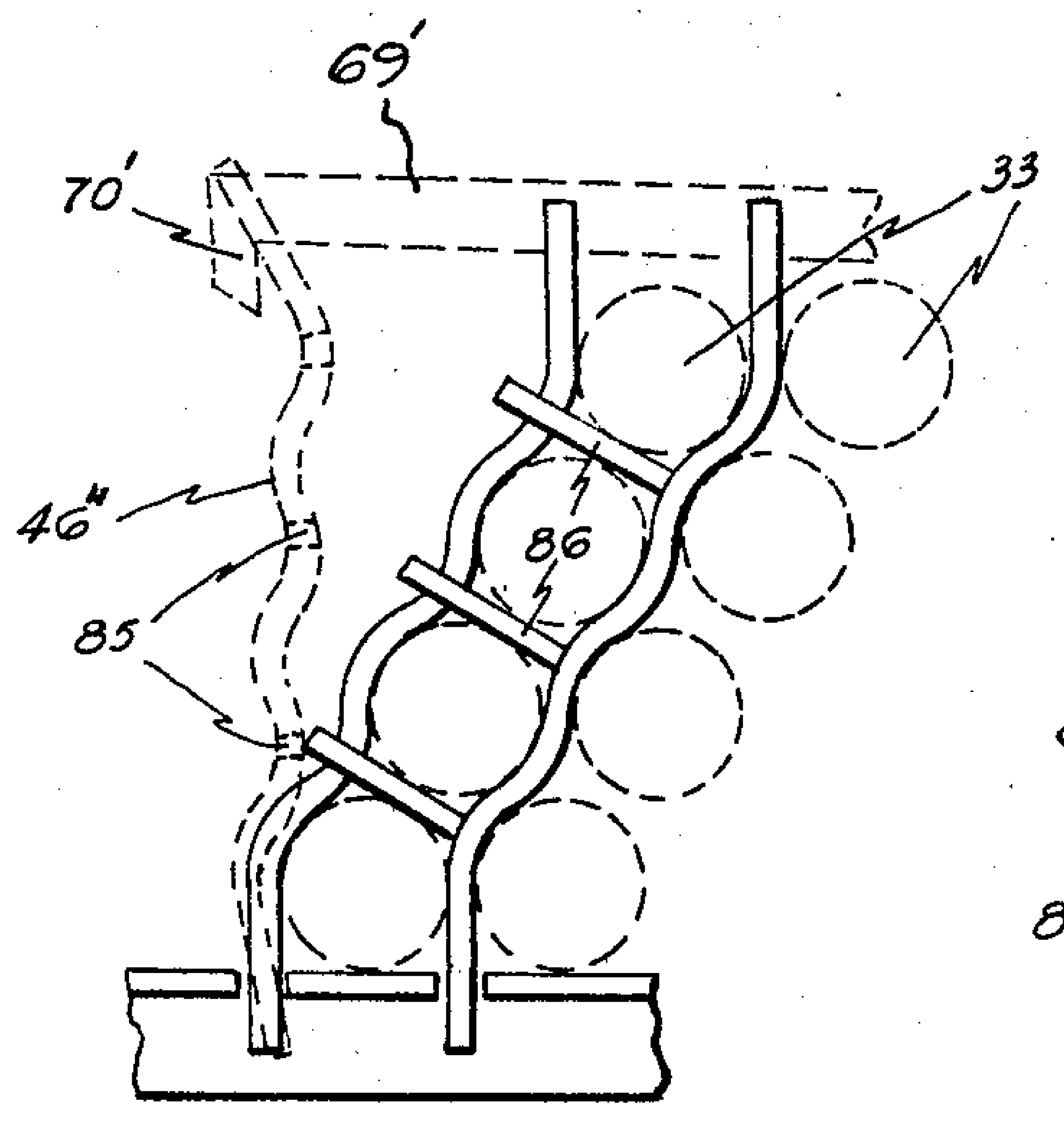

FIG. 19

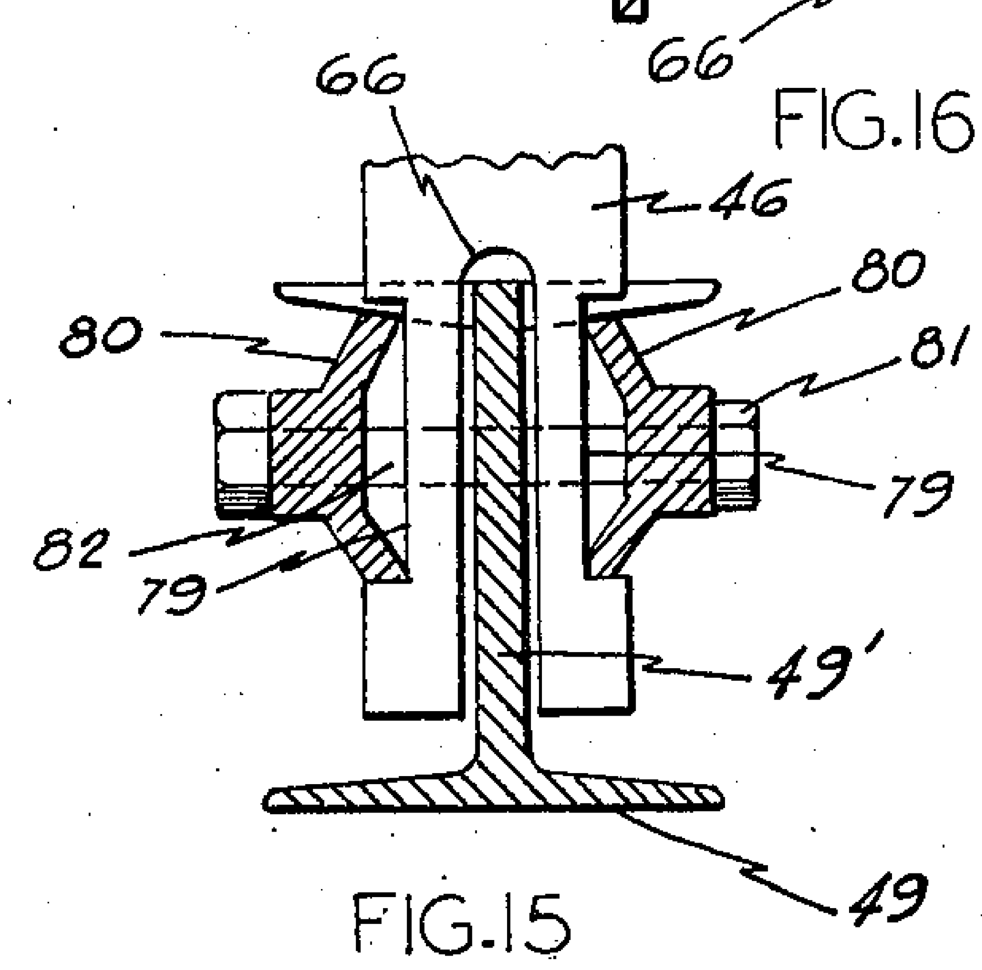

FIG. 15

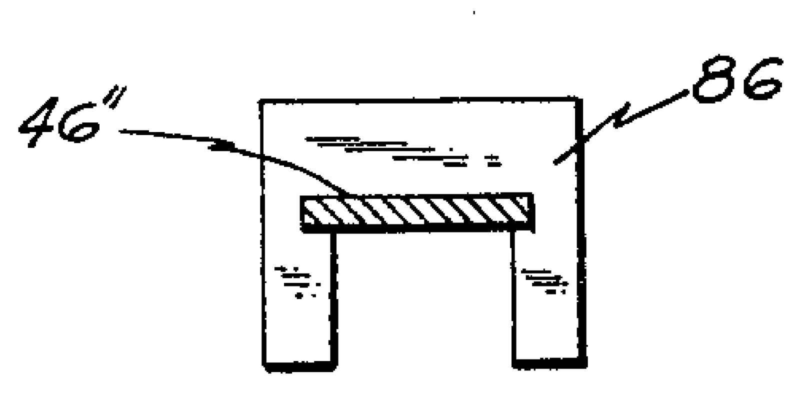

FIG. 17

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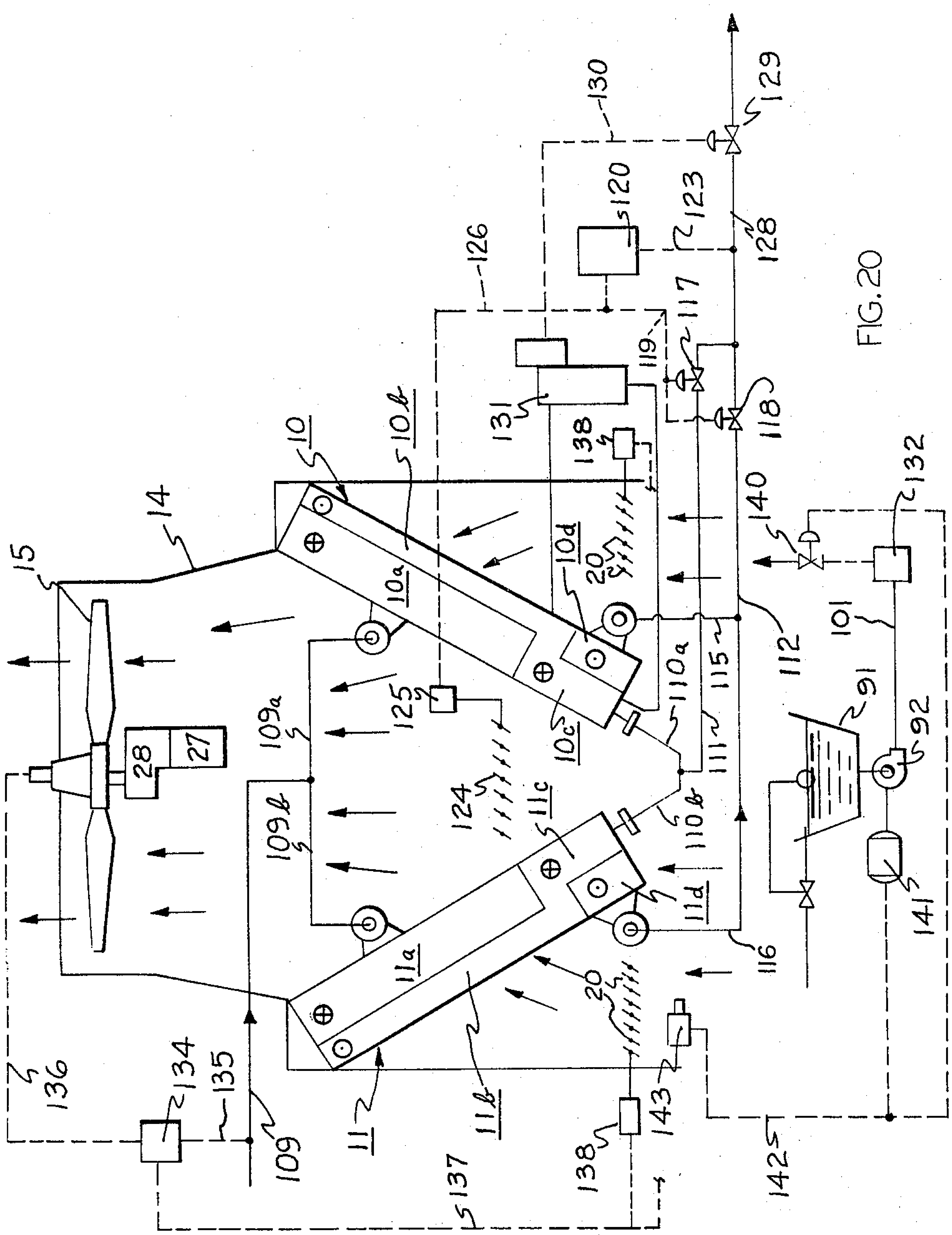

FIG. 20

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United States Patent Office

3,384,165

Patented May 21, 1968

3,384,165

HEAT EXCHANGER

Ralph T. Mathews, Wallingford, Pa., assignor to E. I. du Pont de Nemours and Company, Wilmington, Del., a corporation of Delaware

Filed Feb. 3, 1966, Ser. No. 524,712
5 Claims. (Cl. 165—122)

ABSTRACT OF THE DISCLOSURE

An air type, finned tube heat exchanger having pairs of tube bundles disposed in upright V arrangement, in which the tubes have a length-to-diameter ratio above about 200 and are supported in generally horizontal planes, provided with means producing air flow generally transverse the tube bundles.

This invention relates to heat exchangers, and particularly to a V-type heat exchanger utilizing air flow past finned tubes through which process fluid is circulated in order to effect heat exchange.

Heat exchange on a large scale is an exceedingly serious problem for a wide range of industries, including, for example, power utilities, chemical manufacture, oil refining, and heating and ventilating generally, the problem being particularly severe in hot regions and those having water scarcities or water supplies so loaded with salts or the like as to require expensive pretreatment. However, air type heat exchangers have proved equally useful in cool climates and, in fact, even where there exist plentiful water supplies, because excessive heating or cooling of natural waters is objectionable from the water pollution standpoint, and this has led to a growing utilization of air as one component of the heat exchange pair.

A serious disadvantage of conventional air type heat exchangers has been the excessive space requirements necessary for their accommodation, plus the fact that large size air-moving equipment of heavy power consumption is necessary to maintain the high-magnitude air flows through the apparatus. Moreover, conventional units are not well-suited to the utilization of auxiliary water sprays, which are necessary, as hereinafter detailed, in order to take care of heat loads where the ambient temperature of the atmosphere might be temporarily well above usual levels, or where process overloads are encountered exceeding substantially the dry air design limit of the equipment.

The V-type heat exchanger of this invention cures the foregoing problems, while affording enhanced efficiency in heat exchange, the manner in which this is accomplished being set forth in the following detailed description and the drawings, in which:

FIG. 1 is a somewhat schematic, broken-away perspective view of a preferred embodiment of heat exchanger according to this invention utilizing three air propulsion units in parallel arrangement to move air past tube bundles spanning the air paths of all three units,

FIG. 2 is an end elevation view of FIG. 1 taken on line 2—2 thereof, details of fan assembly support and inlet and outlet connections with the tube bundles being omitted in order to simplify the showing, but one type of associated water spray auxiliary being added,

FIG. 3 is a partially broken-away view of a short length of finned tube employed in the apparatus of FIGS. 1 and 2,

FIG. 4 is a side elevation view in section showing the moderate temperature chamber housings for the fans of FIGS. 1 and 2,

FIG. 5 is a sectional side-elevation view detailing the construction and operative mounting of a preferred design of louvers optionally employed with the apparatus of FIGS. 1 and 2,

FIG. 6 is a schematic portrayal of a pair of louvers of the type shown in FIG. 5, provided with a balanced force diagram representative of the forces acting on water droplets entrained in the air intake to the exchangers,

FIG. 7 is a plan view of an assembled manifold type tube bundle prior to V mounting in the apparatus of FIGS. 1 and 2,

FIG. 8 is a section taken on line 8—8, FIG. 7,

FIG. 9A is a fragmentary end view of the tube bundle of FIGS. 7 and 8,

FIG. 9B is a fragmentary cross-sectional end view of a tube bundle such as that shown in FIG. 9A, except that this bundle is provided with box headers,

FIG. 10 is a cross-sectional side elevation of a box header provided with individual end plug access to individual tubes,

FIG. 11 is a cross-sectional side elevation of an alternate design of box header provided with a removable cover plate for access to all tubes simultaneously,

FIG. 12 is a fragmentary transverse cross-section of a tube bundle showing details of a preferred support strap construction and the assembly with respect to the finned tubes supported thereby,

FIG. 13 is a fragmentary perspective view showing a convenient way of assembling the tube bundles of this invention,

FIG. 14 is a fragmentary perspective view of an alternate design of tube support strap adapted to longitudinal tension assembly within the tube framework,

FIG. 15 is an end view taken on line 15—15, FIG. 14,

FIG. 16 is a side elevation view of a special design of strap employed as a temporary aid in the assembly of finned tubes within bundles,

FIG. 17 is a plan view of a horseshoe type individual tube support member shown in assembled relationship with the tube support strap of FIG. 16,

FIGS. 18 and 19 illustrate a finned tube assembly technique readily performed with the aid of the tube support strap of FIG. 16, and

FIG. 20 is a schematic representation of a control system adapted to the automatic control of heat exchangers according to this invention.

Generally, the heat exchanger of this invention comprises a pair of tube bundles disposed in upright V arrangement, each tube bundle being made up of a multiplicity of finned tubes having a length-to-diameter ratio above about 200, the tubes being disposed in generally horizontal superposed planes, an inlet header provided with a process fluid supply line connected in open communication with a first preselected group of terminal ends of the tubes, an outlet header provided with a process fluid removal line connected in open communication with a second preselected group of terminal ends of the tubes, support means carrying substantially the full weight of the tubes individually disposed longitudinally between the inlet header and the outlet header substantially transverse rows of the tubes lying in a common horizontal plane within the tube bundles, and powered means impelling air flow generally transverse the tube bundles.

By way of example solely, there is hereinafter described a heat exchanger according to this invention utilized for the cooling of a chemical process fluid, because this application presents special problems which have not been hitherto solved by apparatus and methods of the prior art.

As is well known, the chemical industry usually requires special materials of construction for the fabrication of its vessels, piping and other equipment to minimize corrosion difficulties and, frequently, operations have to be conducted at relatively high pressures and temperatures, so that heavy stainless steel and, often, even more expensive materials are employed, which represents a heavy capital investment. It is thus of the utmost importance that there be extreme compactness in design, with a minimum weight utilization of expensive materials of construction, not only as regards lengths of connecting pipe lines but also for the tube bundles of heat exchangers and other apparatus.

Compactness is achieved with the heat exchangers of this invention by utilization of an upright V design for the tube bundles, which results in a lateral space saving of approximately 40% over conventional horizontal flat bundle exchangers, and by utilizing multiple unit installations mounted closely adjacent one another, conveniently at overhead locations which represent the only aboveground space available in already congested chemical plant manufacturing areas.

Referring to FIGS. 1 and 2, there is shown a typical triple air propulsion unit design which, collectively, services two tube bundles, indicated generally at **10** and **11**, running the full length of the assembly. The apparatus can be conveniently erected on a structural steel framework, indicated generally at **12**, on a cubical modular basis, each of the identical bays A, B and C housing one-third of the apparatus, and each being provided at the top with a transition fitting **14** within which is mounted an induction fan **15** drawing the cooling air through the unit. Adjacent units are normally closed off from their neighbors by air-impermeable side walls **16**; however, the design of FIG. 1 is special as hereinafter described, in that the two interior side walls are eliminated on the exteriors of the V arrangement to permit side-directed air flow as shown by the directional arrows.

The heat exchangers are mounted on elevating legs, not shown in FIG. 1 but denoted at **17**, FIG. 2, presenting the base ends to free air flow from the bottom of the construction. Optionally, the base ends are closed off by adjustable louvers **20**, which are advantageous as control mechanims but which can have a dual function as spray drop collectors, as hereinafter set forth.

FIG. 2 depicts the upright V construction for the tube bundles **10** and **11**, the included angle of which can vary from about 40° to about 65°, with the 60° angle shown being especially preferred. The cooling air flow in this instance is, as denoted by the arrows, up from the base of the apparatus, past louvers **20**, through the tube bundles in substantially transverse flow with respect to the tubes, as shown for the cut-away portion at the upper end of tube bundle **10**, thence out through transition fitting **14** under the induced draft of fan **15**, with discharge through stack opening **22**.

Since the cooling air is elevated rapidly in temperature when used dry, as in the usual case, it is essential that the direct drive for fan **15** be protected from heat exposure. This is conveniently accomplished (see FIG. 4) by employing structural steel members (not shown) from which depend thermally-insulated ducts **26** which carry air to the fan drive motor **27** and its direct-connected gear box **28** disposed in vertical orientation within an axially disposed draft tube **29** open at the top end. Thus, fan **15**, during rotation, simultaneously draws clean, cool air from the outside surroundings radially inward through struts **26** and annularly around motor **27** and gear box **28**, thereby affording ventilation at all times during operation. If desired, an externally mounted auxiliary blower (not shown) can be provided outside transition fitting **14** to force cooling air through the duct structure to continue cooling even when motor **27** is shut down for repairs or servicing. However, frequently, natural draft produces enough cooling air circulation through struts **26** to keep the motor and gear box cool even when fan operating power is switched off.

A preferred design of finned tube **33** useful in this invention is that shown in FIG. 3, this comprising an inner conventional round cross-section process tube **32**, which is fabricated from an appropriate material of construction (e.g., stainless steel) resistant to corrosion by the process fluid passed through it and of the necessary strength, heat resistance and other characteristics to accommodate the process fluid from the chemical manufacturing standpoint. The fin assembly indicated generally at **34** is of unitary construction tightly forced on or otherwise intimately bonded over the full inside periphery coaxially with process tube **32**, making the construction as nearly integral as practicable. Aluminum has proved to be a good material of construction for fin assembly **34**, due to its light weight, ease of working, good resistance to plant atmosphere corrosion and its high heat conductivity.

As shown, the external fin **34*a*** is a continuous extruded helical screw having an outside diameter of, typically, 2.25″ with a pitch providing seven to nine fins per inch of tube length for a process tube **32** of 1″ outside diameter. The fin tube can typically be approximately 0.040″ wall thickness, while individual fins can have a crest thickness of 0.018″ and a root thickness of 0.065″ where water sprays are used.

FIG. 7 is a plan view of a high pressure service manifold type tube bundle, shown in section along line **8—8** in FIG. 8. The manifold design utilizes, in this instance, four-pass serpentine flow from process fluid inlet header **38**, through the finned tubes **33**, to process fluid outlet header **39**.

As will become clearer from description to follow, tube bundles **10** and **11** are built up from parallelly disposed individual finned tube **33** sub-assemblies, the straight length ends of which are connected in process fluid flow continuation by U-bends **40**, welded or otherwise fixedly attached thereto at joints **41**. Connection is made to headers **38** and **39** via enlargements **42** at the tube ends, which are weld-attached in open communication with the headers, disposed parallel one to another but transverse the tube bundle. Since the finned tube assemblies **33** can be relatively long (e.g., 36′ for the three-unit assembly shown in FIG. 1), it is imperative that the weight of the tubes be supported at frequent intervals along their lengths with retention of full freedom to expand or contract with variation in temperature of the process fluid, particularly when the tubes are full of a liquid phase process fluid, as this adds appreciably to the gross weight. Otherwise the tube bundles will sag in random fashion, thereby preventing all uniformity in air flow passage through the bundle as well as any uniform ingress of cooling liquid sprayed on the outside of the fin assembly **34**. Moreover, since individual finned tubes **33** sometimes require that maintenance work be done on them, tube weight supporting means should preferably be readily demountable to permit access to any point in the interior of the tube bundle by temporarily displacing adjacent tubes laterally, so as to expose any particular one for repair without the necessity to first remove any more tubes from the bundle than is absolutely essential.

Tube support in this invention is provided by demountable support straps **46**, shown in plan in FIG. 8 and in side elevation in FIG. 9A, the details of which are hereinafter described. First, however, it is believed essential to orderly description to treat of the external framework for the individual tube bundles. This framework is fabricated from conventional structural steel shapes consisting of longitudinal channels **47** bolt-attached to heavy end transverse I-beams **48**. To provide lateral stiffening at intervals along the length of the bundle, additional, somewhat lighter transverse I-beams **49** have been incorporated, these being provided with fixedly-attached end plates **49*a*** for bolt attachment to the webs of channels **47**. Channels **50**, which constitute the support members receiving the ends of support straps **46**, are fixedly attached to the inwardly disposed lengths of I-beams **49**.

The weight of headers **38** and **39** is carried in yoke plates **51** mounted with yoke openings **51***a* disposed parallel to but outboard of longitudinal channels **47**, plates **51** being welded or otherwise joined to the webs of channels **47**.

Referring to FIGS. 1 and 9B, the right-hand end of the tube bundle is the top end of the bundle in the upright V final assembled position. Stiffening plates **54** are weld-attached across the channel **47** flanges at appropriate intervals to stiffen and strengthen the construction, whereas triangular-shaped pieces **55** securely welded or otherwise attached to the web at the ends of channels **47** constitute the corner attachment points to the upper ends of the upright frame pieces defining bays A, B and C of FIG. 1, whereas pad pieces **56** constitute base supports for the framework denoted generally at **57** to which transition fittings **14** are attached.

Tube bundles **10** and **11** are supported in upright V arrangement upon longitudinal pedestal strip **23** (FIG. 2), the central portion of which is closed off for its full length to bar by-pass air flow. It is most convenient, as hereinafter described, to assemble all of the tubes within framework **12** while the latter is laid flat and thereafter lift the fully assembled tube bundle pairs into place on opposite sides of pedestal strip **23**. Since the tube bundles are relatively heavy, this final assembling is most readily accomplished with the aid of a power crane and it is preferred to provide drilled holes, such as hole **24** in triangular pieces **55** (FIG. 9*b*) for ready insertion of the crane lift hook.

In the interests of weight saving, channels **50** are preferably aluminum, although they can equally well be aluminized steel to reduce possible electrolytic interaction with aluminum support straps **46**. Where aluminum channels **50** are employed, they are preferably isolated from direct contact with I-beams **49** by interposition therebetween of a micarta strip, not shown.

Channels **50** are assembled with their webs inwardly disposed from the inner flanges of transverse I-beams **49**, thereby forming opposed enclosed box constructions **59** adapted to receive the opposite ends of support straps **46** through slots **60** spaced at regular intervals along the channel length.

There exist a number of ways in which channels **50** can be attached to I-beams **49**, so as to form a unit construction therewith, one of which (FIG. 13) constitutes the use of angle clips **61** adapted to be attached in opposition to the two sides of the I-beams by a common through-bolt **62** with lower legs wedged tightly beneath the adjacent flanges of the I-beams, micarta isolation strips (not shown) being again used to isolate aluminum components from steel.

As seen particularly in FIGS. 9A, 9B, 12 and 13, support straps **46** are stiff but springy pieces (typically 2″ x 12¼″ x 3⁄16″ thick aluminum) having their central lengths bent in a regular repetitive undulatory pattern to form individual concave recesses formed on a circular arc conforming quite closely to approximately 60° of the lowermost peripheral expanse of finned tubes **33**. The rigorous development of a preferred design of strap **46** is shown schematically in FIG. 12. Here the longitudinal center lines of the strap ends are drawn in in broken line representation and a construction line drawn from the center line at the left-hand side, where the strap is first bent arcuately, to the center line at the right-hand side, where the straight strap end recurs again. This construction line makes angles of 150° measured counterclockwise as seen in FIG. 12 with respect to both left-hand and right-hand strap end center lines. The pitch of the undulations is such that neighboring finned tubes **33** in any given row are spaced one from another on equal pitches of, typically, 2½″ for the specific tubes of 2¼″ outside diameter hereinbefore mentioned, thus leaving a longitudinal ¼″ air passage clearance between adjacent tubes of any given horizontal row. A small clearance of typically 1⁄16″ is provided between the tops of the finned tubes **33** and the undersides of the support straps for the next succeeding row thereabove, which accommodates some lack of straightness in adjacent tubes, however, tubes **33** are brought up snugly into fixed spotted relationship one with another by the springiness of individual tubes, locking the tubes in a tight uniform tube center-to-tube center equilateral triangular pattern *g*, FIG. 12, throughout. At the same time, essentially the full weight of each row of the tubes is carried exclusively by the support straps **46** and transmitted in turn to channels **50**, I-beams **49** and the bundle framework generally. Thus, there is no sagging of the finned tubes, provided that support straps **46** are employed at relatively short spacings (e.g., every four feet) of unsupported tube length extending between the extreme ends of the tube bundle.

The support strap hereinabove described is the subject of my patent application Ser. No. 524,811 of common assignment filed of even date herewith.

The convenience in assembly of the foregoing construction is portrayed in FIG. 13, which illustrates how successive tube layers can be readily built up in sequence between pairs of adjacent support straps **46**.

It is usually preferred to assemble the tubes in a bundle by bringing them into place from the top, and this is most easily done by laying the bundle framework flat before attachment thereto of the uppermost I-beam **49**, channel **50** sub-assembly, denoted generally at F in FIG. 13. The lower ends of straps **46** are then inserted in order from right to left in slots **60** of the bottom channel **50**, successive finned tubes **33** being next placed one above the other in each row, cradled within the opposed undulations of adjacent straps, after which the next rows in horizontal progression to the left are built up in turn. As shown in FIG. 13, the extreme right-hand strap denoted **46′** is actually only a half-strap, retained at its end abutting channel **47** by a welded clip **67**, the purpose being to utilize to the utmost all available cross-sectional area within the bundle framework for the accommodation of heat exchange tubes. Any unused open area remaining is closed off by spring-clipped panels **68** (FIG. 9A), which thus prevents by-pass of air through the unit.

Usually, the weights of tubes **33** bias straps **46** rightwardly as seen in FIG. 13, so that there is automatic alignment of the straps in their proper final positions; however, if desired, a rake tooth retainer (not shown) can be used to temporarily secure the straps against lateral displacement one from another.

An exceptionally convenient temporary retainer is that detailed in FIG. 13, straps **46** being in this instance provided with slots **66** at their upper ends deep enough for full reception of tension bar **69**, which is advanced in notch-by-notch progression from right to left. The left-hand end of bar **69** is formed into a hook **70** adapted to overlie the bottom of slot **66** in the left-most strap **46** and thereby lock all tube rows to the right against any shifting during the time that the tube bundle is being assembled.

The top edge of tension bar **69** is provided with a succession of equally spaced notches **71** located distances apart equal to the final desired spacing of individual straps **46** one from another. A slot **72** large enough to slidably receive tension bar **69** is cut in longitudinal channel **47** at the points where support straps **46** are employed, and there is slipped over the right-hand free end of the bar a freely slidable slotted keeper piece **73** which drops by force of gravity into successive notches **71** on bar **69** during its advance to the left, securely locking all straps in place until another notch advance is desired. When all finned tubes **33** have been assembled within the bundle, sub-assembly F can be lowered into place to an extent where the upper ends of straps **46** just enter top slots **60**, which position can be preserved by using temporary locking dowels inserted through holes **75** drilled in the web of channel **47**. Then tension bar **69** can be rocked slightly to disengage hook **70** and the bar withdrawn completely through slot 72, after which the sub-assembly F is lowered to final position with upper ends of straps 46 fully inserted within slots 60. Finally, sub-assembly F is bolted securely at both ends to the longitudinal channels 47 and the tube bundle assembly is complete.

An alternate, somewhat simplified design for retention of support straps 46 is detailed in FIGS. 14 and 15, this having the advantage that straps 46 can be assembled under predetermined longitudinal tensions, which can be particularly desirable in installations where there exists considerable transmitted vibrational stress from adjacent plant equipment, such as reciprocatory compressors or the like. In this case, an exceptionally tight tube assembly is desirable to insure that invariant air passages are maintained throughout the tube bundles.

The alternate design dispenses with channels 50 and substitutes I-beams 49 which are slotted on the inboard flanges at 78 to receive the ends of the straps, again provided with longtiudinal slots 66, which then overlie the web portions 49′ of the I-beams. The outer edges of the slotted ends of the straps are cut away to form notches 79 which receive oppositely disposed C-profile spring clamps 80, brought into tight abutment at the top edges against the underside of the inboard flanges of I-beams 49 and at the bottom edges against the lower ends of notches 79 by tightening the nuts 81 on bolts 82 threaded at both ends and passed through drilled holes in web 49′. It will be understood that an identical construction is employed on the other ends of straps 46, making it possible to effect tension adjustment at will from either side of the tube bundles.

Regardless of which design is employed, straps 46 apparently cross brace finned tubes 33 in tight rigidity, which enables tilting of the assembled tube bundles into any plane without change of tube position.

It is sometimes desirable, as an aid in the assembly, to support individual tubes in temporary position at preselected points farther apart than the 4′ span intervals hereinbefore described, and the apparatus shown in FIGS. 17–19 has been devised for this purpose. Here a strap 46″ identical in all respects with straps 46 hereinbefore described, except with the modifications now to be detailed, is employed solely for assembly purposes.

Strap 46″ is notched along both edges as indicated at 85 in the root portions of the undulations so as to receive U-pieces 86, which are proportioned to just abut the crests of the opposed undulations on the strap 46 disposed to the right, thereby affording a temporary base for support of the finned tube 33 thereabove. It is contemplated that straps 46″ and their U-pieces 86 will be employed at alternate intervals of, for example, every 8′ apart over the tube bundle length, thereby affording support and location to individual tubes while they are being rolled in or otherwise attached to their headers. Thereafter, when the final straps 46 are put into place, these are first assembled in the alternate vacant positions existing between straps 46″. Then the latter are pulled and replaced by regular straps 46, bringing the assembly to completion.

For purposes of the description, a tension bar 69′ is shown in FIG. 18 in conjunction with notched end straps 46 and 46″.

While, as hereinbefore mentioned, louvers 20 are optional, their use is especially advantageous where critical heat exchange control is to be maintained, or where water sprays are employed as cooling aids; however, louvers possess advantages even in dry air operation, and where manual control is relied upon, so that their general use is preferred.

Referring to FIGS. 2, 5 and 6, the louvers are mounted within a squat, square cross-section breeching 88 located beneath the upright V tube bundle assembly and athwart the lowermost air passage of the unit, which is provided with a multiplicity of longitudinal members 87, upon which are pivotally mounted the co-parallel individual

louvers 20. These louvers are typically approximately 8$\frac{7}{16}$″ long, measured tip-to-tip, and are spaced at uniform distances apart of about 4″, so that they overlap when closed, as will be apparent from the right-hand broken-line representation of one louver shown in closed position.

It will be noted that the left-hand louver 20′ is of shortened construction, so that it presents no interference troubles in the course of closure.

Louvers 20 are formed with reverse curvatures as regards the blade portions 20*a* and blade portions 20*b*, both being formed, typically, on 5″ radii. Blade portions 20*b* are provided with oppositely disposed U cross-section water collection gutters 89 and 90, respectively, each serving an individual side of a louver 20 on which it is mounted. It is contemplated that louvers 20 will be mounted at a slight slope inwardly toward the center of the unit, so as to obtain ready gravitational drainage of water collected thereon into a central sump 91 (FIG. 2) from which it can be recycled as spray water by centrifugal pump 92, where sprays are used as hereinafter described, or run to waste if the water is wash water or otherwise contaminated.

Louvers 20 are operated in unison through bar connector 93, which is provided with upstanding finger portions 94 fixedly attached to the ends of all blade portions 20*b*, and actuating crank 95 pinned to bar connector 93 at the right-hand end of the sub-assembly. In order to coordinate the actuation of the abbreviated right-hand louver with its neighbors, there is provided a short connector bar 96 securely attached through finger portions 97 to the tip ends of the two rightmost louvers shown in FIG. 5.

The foregoing design of louver was evolved in order to entrap and conserve virtually all droplet water draining from the tube bundles in their upright V mounting, since the resultant of forces (gravitational and air supply velocity) acting on water drops, as shown schematically in FIG. 6, is a component of force x directed against louvers 20 for the full range of settings of the louvers. Accordingly, the water droplets impinge on the louvers and drain via gutters 89 and 90 into sump 91. This is an important function of the louvers which, besides their streamlined direction of cooling air over the entire cross-section of the apparatus, are simultaneously adapted to collect and retrieve any cooling water, or cleansing water used to wash down finned tubes 33 from time to time.

A preferred auxiliary water spray arrangement is depicted in FIG. 2 and comprises manifolded spray nozzles 100 mounted, typically, in multiples of four across the width of a tube bundle 72″ wide, the nozzles oriented with openings generally parallel to the outboard faces of the tube bundles at spacings therefrom of about 12″. Typically, the nozzles can discharge 1–10 gals/hr., depending upon the heat removal requirements of the particular installation. As will be clear from description to follow, both the location and the spacing of the sprays longitudinally of the bundles can be varied widely to obtain predetermined cooling patterns. Spray water is supplied to nozzles 100 by one or more pumps 92 via supply lines 101 and 102, with gravitational drainage return effected via collection gutters 103 and drain pipes 104 discharging into sump 91.

Nozzles 100 can be of either the atomizing type or can be relatively coarse sprays, the latter being ordinarily preferred for exteriorly mounted nozzles because the fins of tubes 33 are then well-wetted, which produces the maximum cooling action. Water atomized into the air stream lowers the air temperature, thus reducing the mean temperature difference (abbreviated MTD in the literature) between the cooling air and the process fluid in transit through finned tubes 33 without, however, extensively wetting the tubes. Atomized water spraying is sometimes advantageous to reduce the temperature of the ejected air at the hot side (inboard faces) of the tube bundles and thus is preferably applied by sprays which are disposed interiorly of the tube bundles, as by omitting one row of finned tubes **33** of a given bundle and directing the spray atomizers in opposition, or at right angles, to the air flow through the bundles.

I have found that intermittent spraying of finned tubes **33** is particularly efficient in the utilization of cooling water, this type spraying being effected by reciprocally-mounted nozzle assemblies (not shown) adapted to traverse the tube bundles longitudinally, with return timed to occur prior to drying of water on the tube fins, thereby minimizing the build up of heat-insulating deposits on the fins.

It is essential that clean water be employed as the spray liquid, and the use of filters, sedimentation removal of solids within sump **91** and even treatment of the water with wetting agents and/or soluble corrosion inhibitors are all worthwhile procedures. Moreover, the water should be of low sedimentation characteristics on drying.

The upright V tube bundle arrangement according to this invention has proved exceptionally advantageous when auxiliary spray water is utilized, it being found that the penetration of water droplets from nozzles **100** occurs to an appreciable extent throughout practically the entire transverse extent of the air path of a 4–6 tube bank size heat exchanger.

A problem with horizontally disposed prior art heat exchangers has been that spray water collected between tubes unpredictably until such severe flooding occurred that random extensive areas would actually dump large amounts of water at different times impossible to anticipate. The cooling water was thus wastefully employed and oftentimes did as much harm as good, since it blocked air flow past the heat exchange tubes over relatively large areas and, in addition, unbalanced the air passage so that some areas of the exchanger preferentially funneled air through at exceedingly high velocities whereas, in others, there existed substantially zero flow.

In comparison, the V tube bundle arrangement preserves an exceedingly even stratified air flow throughout the entire construction, as has been verified by smoke tests, especially when side walls **16** are employed, with or without louvers **20**. Moreover, there is no localized water flooding of the tubes, any excess fin-wetting water draining downwardly from one tube layer to its next-lower neighbors and thence into gutters **103** with speedy return to sump **91** via drains **104**. This latter is an important advantage, not only from the standpoint of conserving high cost spraying water but also because it eliminates spray drift, which is a nuisance to plant personnel and a potential hazard to electrical and other process equipment located anywhere in the vicinity.

Referring to FIG. 1, the usual operation of heat exchange units according to this invention is that represented by the discharge air flow directional arrows drawn for the two outside units. That is, with louvers **20** opened at the bottom, air is impelled through the units, generally transversely inwardly past the tubes of the bundle pairs in V arrangement, and thence past the blades of induction fans **15**, with discharge of the heated air through stacks **22**.

The typical V heat exchanger design hereinbefore detailed dimensionally by way of example, which allows for ¼" clearance between adjacent fin peripheries, has proved to be especially effective in maintaining constant air velocities through the units. Thus, with air supplied, through louvers **20** at a velocity of approximately 1200'/min. there is, of course, throttling in passage past the tubes of bundles **10** and **11**, which accelerates the air flow. However, since the discharge from both bundles is thereafter combined inside the V, the final discharge velocity maintained is again at about the original 1200'/min. supply level.

I have found that, throughout practically the entire extent of the United States, one can rely on dry air cool-

ing without any auxiliary water spray utilization for at least 95% of the time for most chemical plant cooling processes. However, it is highly desirable to make provision for at least limited water spray cooling supplementation in locations where exceedingly high dry bulb temperatures are encountered over protracted periods of time. In addition, spray supplementation should, of course, be provided where an adjustable range of process fluid cooling is necessary incident to the manufacturing operation for which the heat exchange is being conducted. Finally, spray supplementation has a distinct economic advantage in many instances, because the air volumes to be handled are sharply reduced when water sprays are available as cooling aids, reducing fan power costs and permitting certain fans to be shut off entirely in order to effect repairs or general maintenance.

The heat removal advantage of spray supplementation is so marked in most instances that a 300–400% increase in heat removal capability on the air side is often very quickly obtained after water spraying of the finned tubes **33** is commenced. The reason for this is evidently that maintenance of a water film on fins **34***a* and their support tubing increases greatly evaporation of water from the fins and the temperature differential between the hot fluid passing through tubes **32** and the fins. So effective is this action, that I have found that I can easily obtain condensation of process fluids with my exchangers, and even a measure of appreciable process liquid sub-cooling, all as taught with reference to FIG. 20.

Atomizing sprays as hereinbefore described are generally less effective; however, they do increase the mean temperature difference by lowering the air temperature appreciably by the heat take-up ascribable to cooling water evaporation and are definitely worthwhile, either alone or in conjunction with coarse sprays.

Extensive operating experience has shown that V-type heat exchangers according to this invention are usually superior to conventional river water-cooled shell-and-tube exchangers, and, in many cases, are also better than expensive cooling tower water-cooled installations.

FIGS. 10 and 11 show typical box header constructions which can be utilized for low pressure installations, FIG. 10 detailing a header having multiple plugs **35** in longitudinal alignment with finned tubes **33**, so as to permit ready rod or hose cleaning. FIG. 11 shows a header closed by a common plate **36**, provided with a gasket **37**, preventing leakage.

Obviously, as is well known in the art, a wide variety of process fluid flow patterns through preselected groups of tubes within the heat exchangers can be readily obtained by sub-dividing the box headers with transverse flow-routing partitions, and this is accordingly not further elaborated. Also, if desired, the process liquid can be cooled by dividing it into parallel flow through tube bundles **10** and **11** separately, or by routing it in series through first one bundle and then the other, or in various combination series-parallel flows best-suited to the requirements of the particular installation, the design affording a broad choice of alternatives in this regard.

Turning now to FIG. 20, there is shown in schematic cross-section a V-type heat exchanger according to this invention provided with automatic control facilities.

In this instance, the hot vaporous process fluid is introduced via line **109**, which is divided into separate branches **109***a* and **109***b* leading to the inboard tubes of tube bundles **10** and **11**, respectively. A box header construction, as shown in cross-section in FIG. 10, routes the flow into the plane of the figure for the first vaporous fluid pass, as indicated by the arrow representation within sections **10***a* and **11***a*, FIG. 20, whereas reverse flow as a second condensed liquid pass occurs in sections **10***b* and **11***b*. This produces a hot condensate product withdrawn from lines **110***a* and **110***b*, which latter are manifolded into line **111**.

A portion of the condensate, determined by the liquid level maintained at the bottom of sections **10**b and **11**b, which are cross-tied by connections **110**a and **110**b, is retained in the sub-cooler sections consisting of first passes **10**c, **11**c and second passes **10**d, **11**d, the cold condensate discharged therefrom leaving via lines **115** and **116**, respectively.

Hot condensate discharge line **111** is provided with a conventional air-operated flow control valve **117**, and cold condensate discharge line **112** is provided with a similar automatic valve **118**. These two flow control valves are connected in reverse-acting relationship, so that one opens when the other closes responsive to a signal transmitted to both valves via control line **119** running from conventional temperature controller **120**. Temperature controller **120** operates on the basis of the temperature of the commingled hot and cold condensate mixture, sensed via line **123** at a point far enough removed downstream from the junction of lines **111** and **112** to insure that intimate mixture has been obtained.

Control of sub-cooler operation is achieved by interposing a set of automatically operated louvers **124** athwart the exit air passage from the sub-coolers **10**c, **10**d and **11**c, **11**d, these louvers being operated collectively as hereinbefore described with respect to FIG. 5 by an air pressure actuation mechanism **125** responsive to a control signal transmitted from temperature controller **120** via line **126**. In operation, it is usually satisfactory to confine the condensate flow control effected by valves **117** and **118** to the 3–10 lbs. part of the conventional 3–15 lbs. instrument air pressure range, reserving pressures above 10 lbs. to effect progressive throttling closure of louvers **124**, which otherwise remain full open.

Condensate is withdrawn from the system via line **128**, into which lines **111** and **112** discharge, provided with air pressure-actuated flow control valve **129**. This valve is responsive to a signal transmitted via line **130** from level controller **131** connected in parallel across the high and low level points of the first pass of the sub-cooler, denoted **10**c.

It is usual, in chemical manufacturing practice, to maintain a quite constant pressure in the vapor input line **109**, and conventional pressure controller **134** is provided to effect this, the ambient vapor pressure being sensed via line **135** and control signals then generated which are passed via line **136** to control the pitch of variable pitch fan **15**, or, via line **137**, to conventional actuator **138** adjusting the position of louvers **20**.

The supplementation water sprays are not detailed in FIG. 20, in order to simplify the showing, however, it will be understood that an arrangement such as that shown in FIG. 2 is suitable. This comprises a sump **91** with float-controlled fresh water make-up replenishment and water delivery throttling valve **140** interposed in line **101** running via filter **132**, to the spray nozzles **100** (not shown in FIG. 20). Both the drive motor **141** for pump **92** and throttling valve **140** are controlled via signal line **142** provided with a thermal switch **143** disposed in the heat exchanger air intake passage. Thus, when the intake air attains a temperature too high for effective cooling, thermal switch **143** closes the power circuit to drive motor **141** and simultaneously opens valve **140** a suitable amount to commence supplementary water spraying. As the ambient air temperature increases, valve **140** opens wider, thus supplying additional spray water to meet the heat removal requirements.

I have found that the greatest economies in heat exchanger construction are obtained by employing relatively long finned tube assemblies 33 (e.g., of length-to-diameter ratios above about 200) and these are readily obtainable from the fabricators; however, there has hitherto been no method of assembling and supporting the long, naturally sagging lengths. Support straps **46** are effective for tubes of any conceivable length and, thus, tube length constitutes no limitation in the utilization of my invention.

Most often, air type heat exchangers are mounted at high, quite inaccessible locations, such as at rooftop levels, for example, so that they are subjected to gusting winds and full exposure to the weather. Side walls **16** are then especially important to the maintenance of uniform air flows. Additionally, arcuately recessed plates **30** slipped in place over finned tubes **33** in prolongation of sidewalls **16** restrict air by-passing at the tube bundle ends.

Very satisfactory protection from rain water intrusion is obtained by providing stacks **22** with internal peripherally arranged collection gutters disposed just below the fan level, fans **15** quite effectively throwing the rain water outwardly by centrifugal action, whereupon it is drained off through a conventional storm water drainage system not detailed.

Also, it is sometimes helpful to vary the air throughput of selected heat exchange units in order to safeguard against freezing the process liquid being cooled. One example is the specific apparatus detailed in FIG. 1. Here provision is made for optional reverse air flow during cold weather through the middle heat exchange unit, housed in bay B, with discharge laterally through the cut away side walls **16** into the adjacent heat exchange units housed in bays A and C. This is readily accomplished by closing the louvers **20** on the bottom of bay B, and reversing the direction of fan **15** operation for the center unit. Under these circumstances, air is drawn in from the top of the center unit, contacting the hottest process fluid first in its reverse transit through the tube bundles, after which this heated air is discharged laterally into the air intakes of the adjacent units in bays A and C as indicated by the air flow directional arrows. This tempers the air intakes to the latter, and reduces the overall heat removal for the three-unit combination assembly to a level accommodating severe cold weather conditions. It will be understood that, in warm weather, the center unit is operated with louvers **20** open and the fan drawing air inwardly, the same as its two neighboring units, the absence of the side partitions causing little or no difficulty.

A great variety of control facilities are available to the designer in the case of air type heat exchangers, especially convenient devices being variable pitch fans **15**. Also, while the foregoing description has been directed to induction fans, solely by way of example, the substitution of propulsion blowers located at the intake ends of the units is, of course, entirely practicable; however, the induction fan design has the advantage that its housed protection as shown in FIG. 4 shields motors and gear boxes from water spray damage to perhaps the fullest extent.

Also, while the most extensive present use of the construction is for process fluid cooling, the units are equally well-adapted to heating service, if this is desired. Employment of the term "fluid" as descriptive of the material flowing through finned tubes **33** is intended to be comprehensive of both vapors and liquids and, while substantially horizontally disposed tubes **33** have been hereinbefore specifically taught, support straps **46** can be fabricated in slightly twisted edge-to-edge slopes, so as to furnish a slight progressive downward inclination throughout successive rows of tubes insuring gravitational liquid flow therethrough, if this is desirable. Accordingly, the term "generally horizontal," as used in the claims, is intended to comprehend also tubes slanted enough to be self-draining.

It is convenient to provide walkways between neighboring batteries of heat exchangers constructed according to this invention, and this has proved completely practicable for the very light maintenance work which the units require. The only regular maintenance required is lubrication supply to the individual fan gear boxes **28**, and this is readily achieved by using externally located oil supply-dip stick assemblies cut-in in parallel circuit with the counterparts integral with the conventional apparatus components.

A very important advantage of the construction is that support straps **46** are sufficiently springy so that, when disengaged from slots **60** at one end, they can be deflected laterally a sufficient amount to permit removal of a defective tube from anywhere within the tube bundles with the prior disengagement of only a few overlying tubes being necessary to open the way. This is made possible by the relatively shallow cradle portions of the straps abutting the finned tube peripheries, which readily free the tubes from restraint when straps **46** are temporarily bent aside.

From the foregoing it will be apparent that this invention can be modified in numerous respects without departure from its essential spirit, and it is accordingly intended to be limited only within the scope of the following claims.

What is claimed is:

1. A heat exchanger comprising, in combination:

(a) a pair of tube bundles disposed in upright V arrangement within a structure provided with air throughput passages at upper and lower ends but closed off from the exterior by substantially air-impermeable side walls,

(b) each tube bundle being made up of a multiplicity of finned tubes having a length-to-diameter ratio above about 200, said tubes being disposed on substantially triangular centers in generally horizontal superposed planes,

(c) an inlet header provided with a process fluid supply line connected in open communication with a first preselected group of terminal ends of said tubes,

(d) an outlet header provided with a process fluid removal line connected in open communication with a second preselected group of terminal ends of said tubes,

(e) support means carrying substantially the full weight of said tubes individually disposed longitudinally between said inlet header and said outlet header generally transverse rows of said tubes lying in a common substantially horizontal plane within said tube bundles oriented in said V arrangement, and

(f) powered means impelling air flow generally transverse said tube bundles.

2. A heat exchanger according to claim **1** wherein said tube bundles are provided at preselected intervals with partitions extending across the full widths of said bundles interiorly of said V arrangement and said powered means impelling air flow generally transverse said tube bundles are disposed in parallel relationship one with another longitudinally of said tube bundles and on opposite sides of said partitions.

3. A heat exchanger according to claim **1** provided with adjustable louvers disposed in line with the air throughput course of said heat exchanger.

4. A heat exchanger according to claim **3** provided additionally with automatic control means adjusting the degree of opening of said louvers responsive to a sensed temperature which is a function of the current heat-exchanging capability of said heat exchanger.

5. A heat exchanger according to claim **1** provided with water sprays discharging water into said air flow generally transverse said tube bundles.

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