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(54) HEAT EXCHANGER ASSEMBLY

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(57) ABSTRACT

A heat exchanger, includes a plurality of MCC microchannel tubes, each microchannel tube of the plurality of microchannel tubes having at least one microchannel fluid passage defined therein and having a chord, the chord being the orthogonal distance from a leading edge to a trailing edge, each microchannel tube of the plurality of microchannel tubes being disposed such that the chord is less than orthogonally disposed relative to a heat exchanger plane. A method of forming such a heat exchanger is further included.

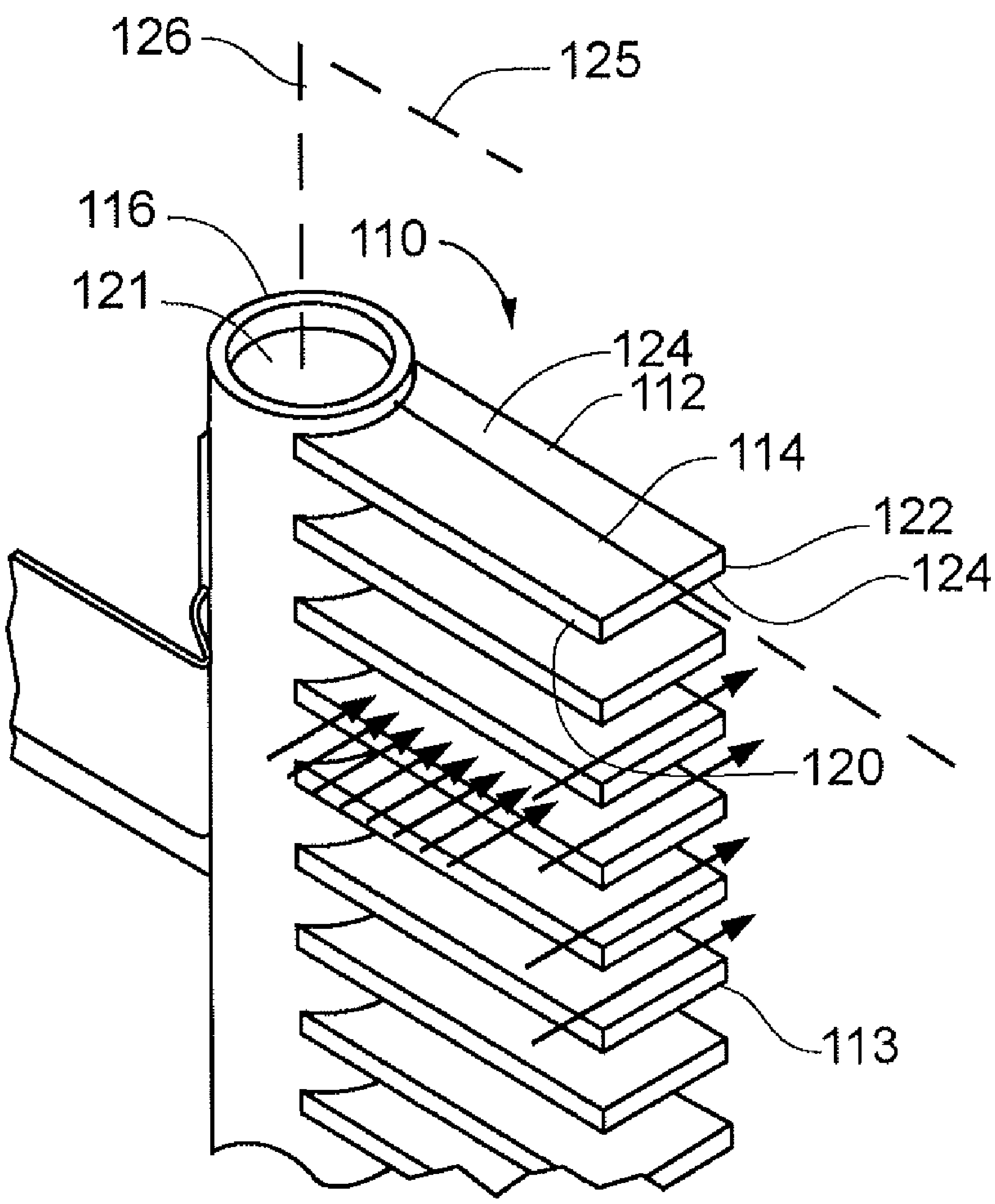


Fig. 1

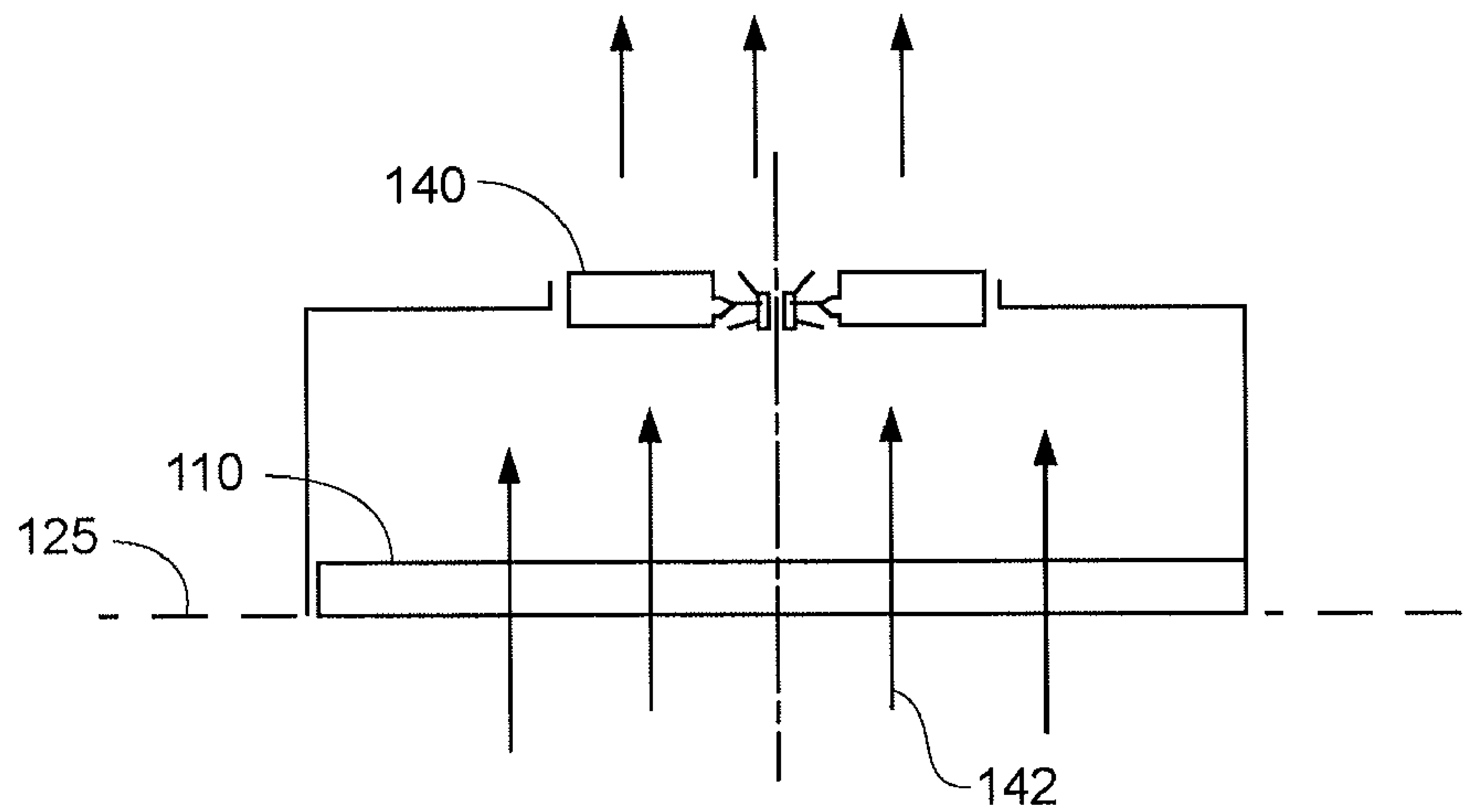


Fig. 2

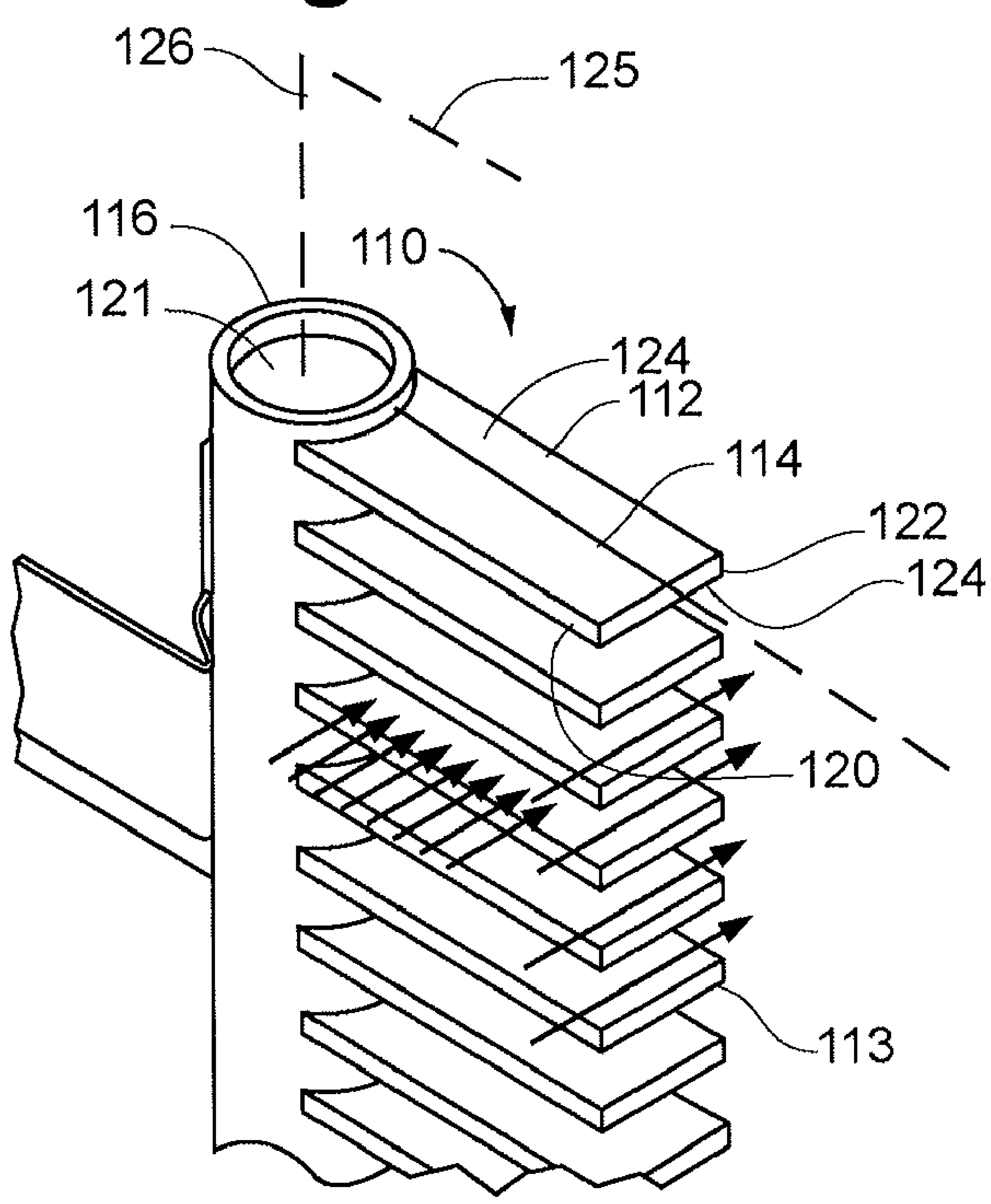


Fig. 3

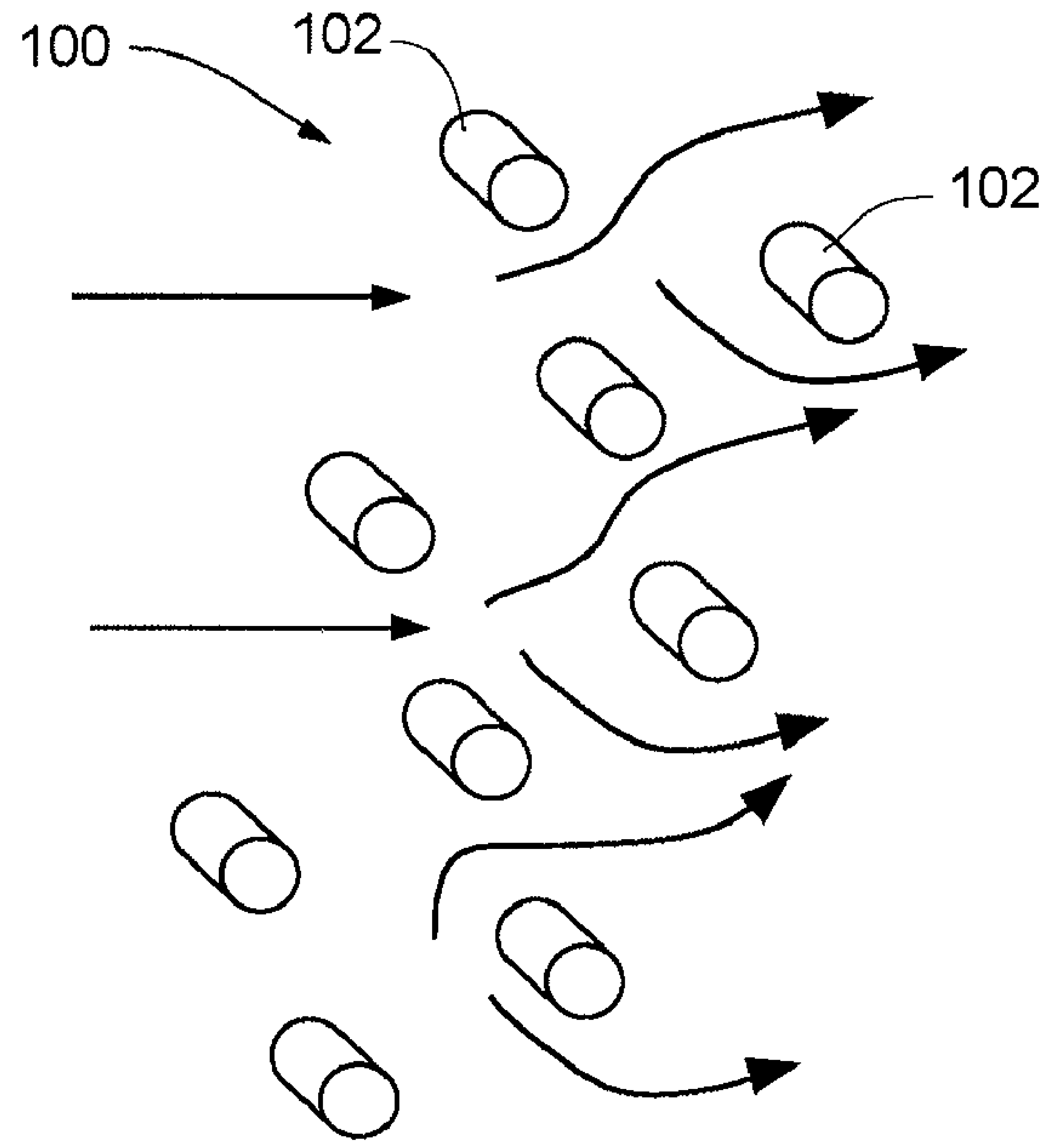


Fig. 4

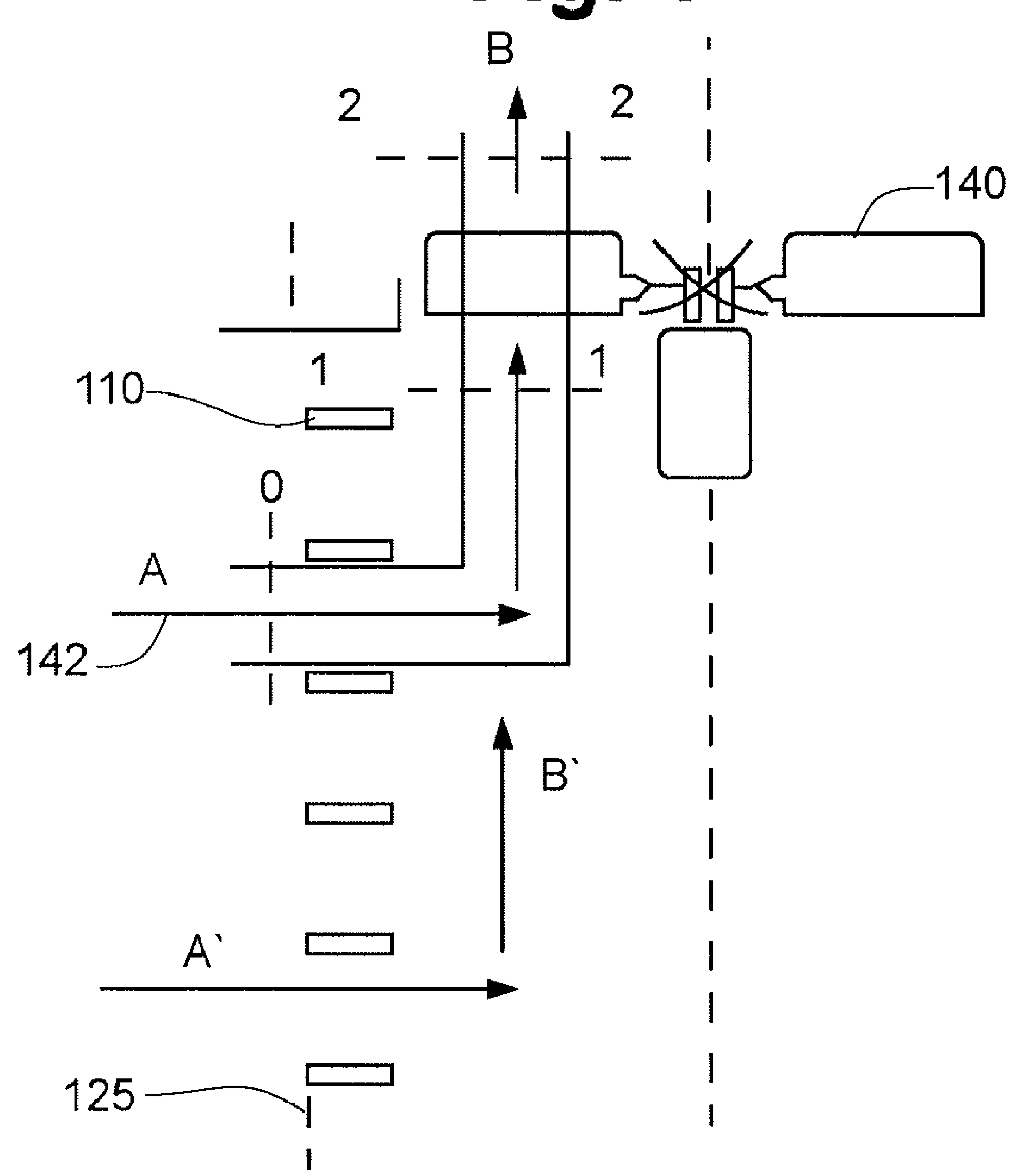


Fig. 5

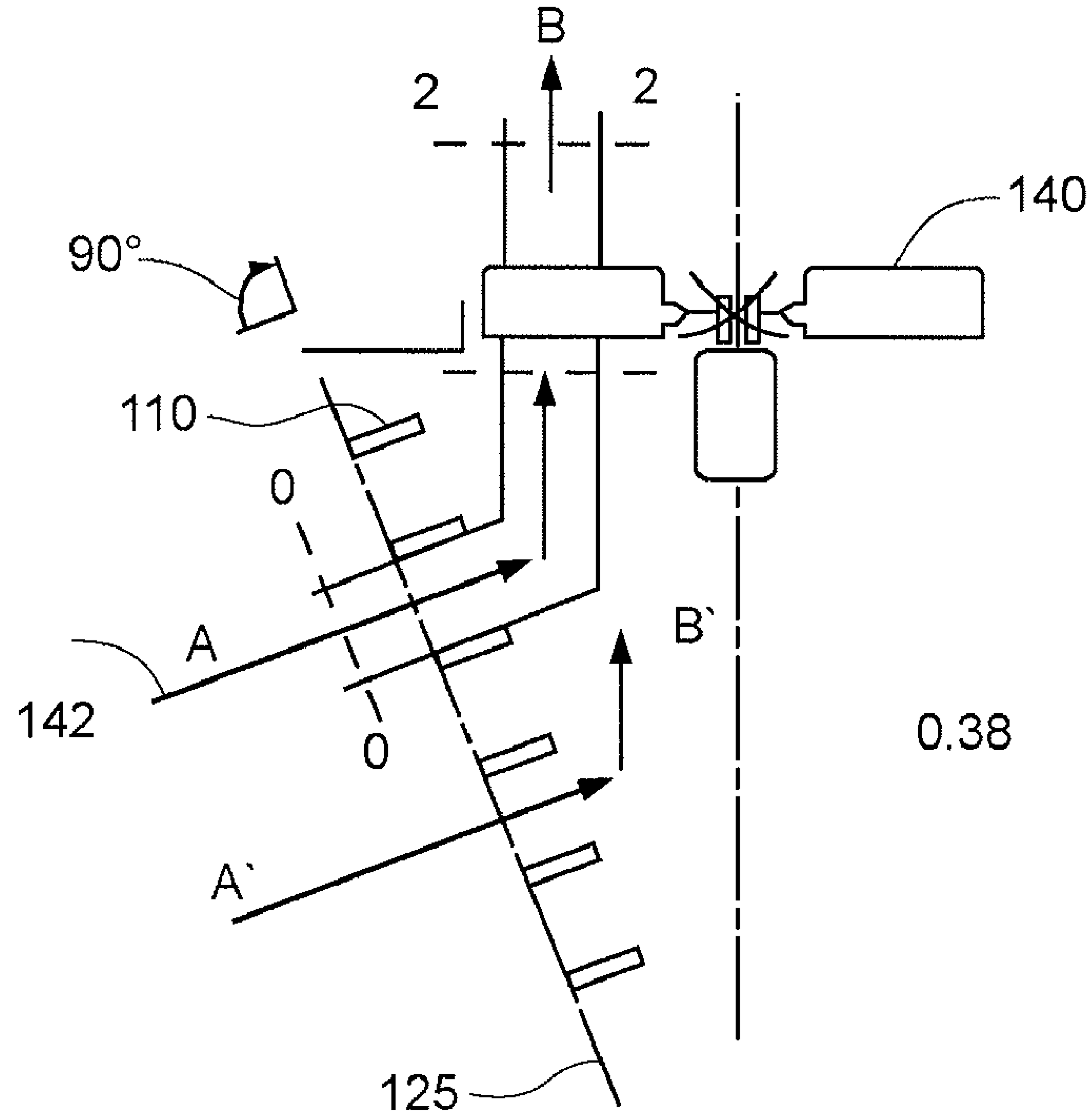


Fig. 6

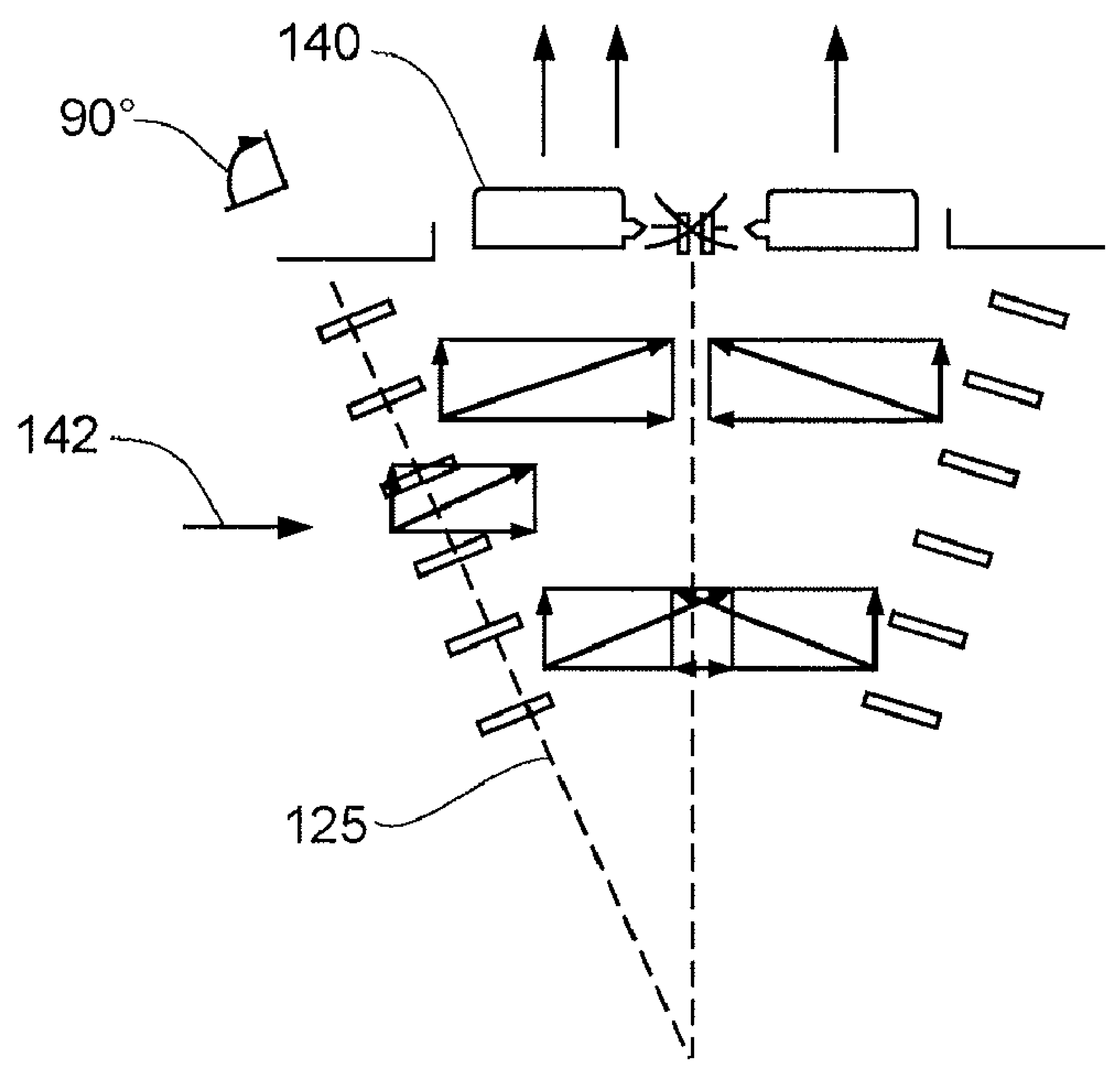


Fig. 7

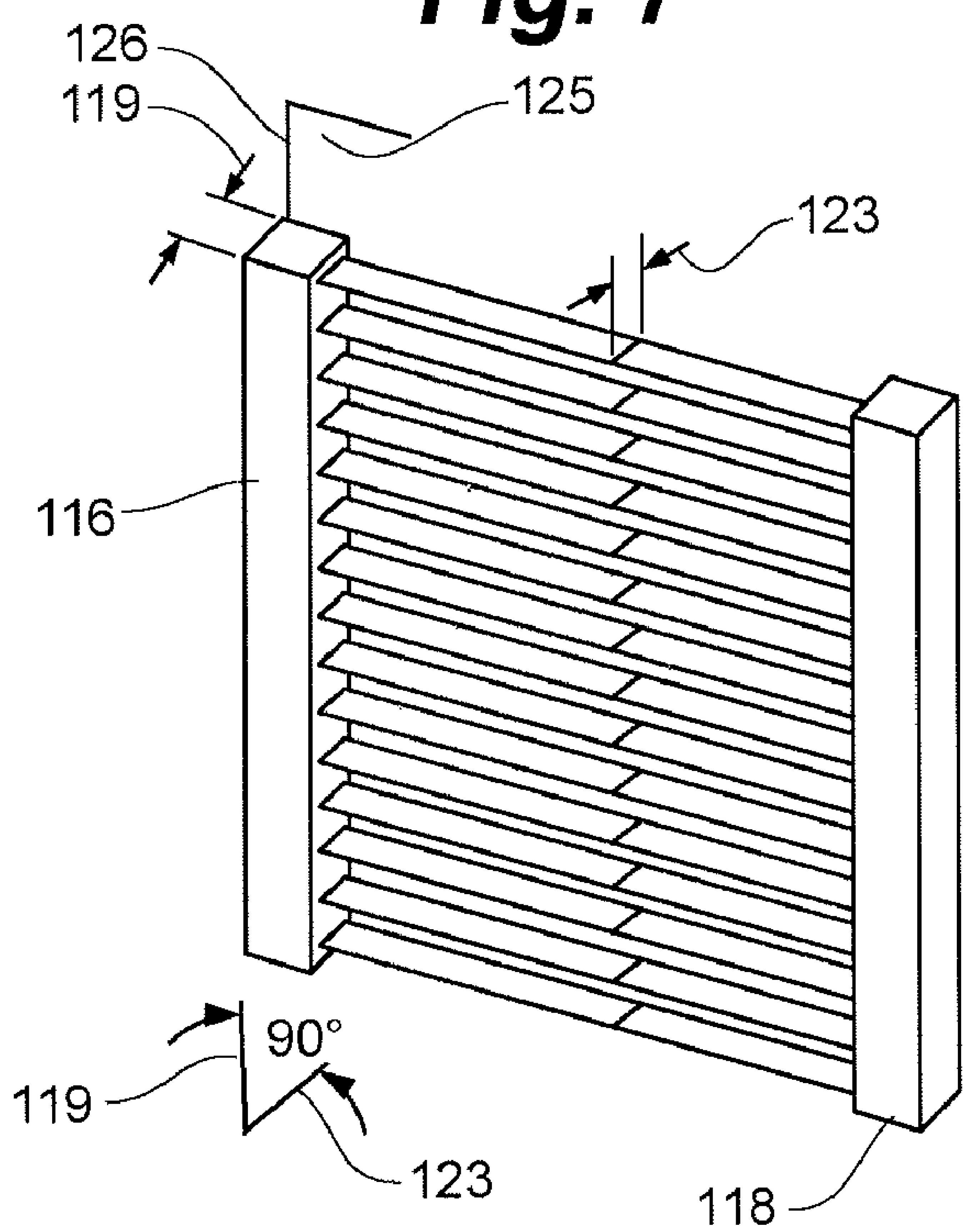

126
119
125
123
116
90°
119
123
118

Fig. 8

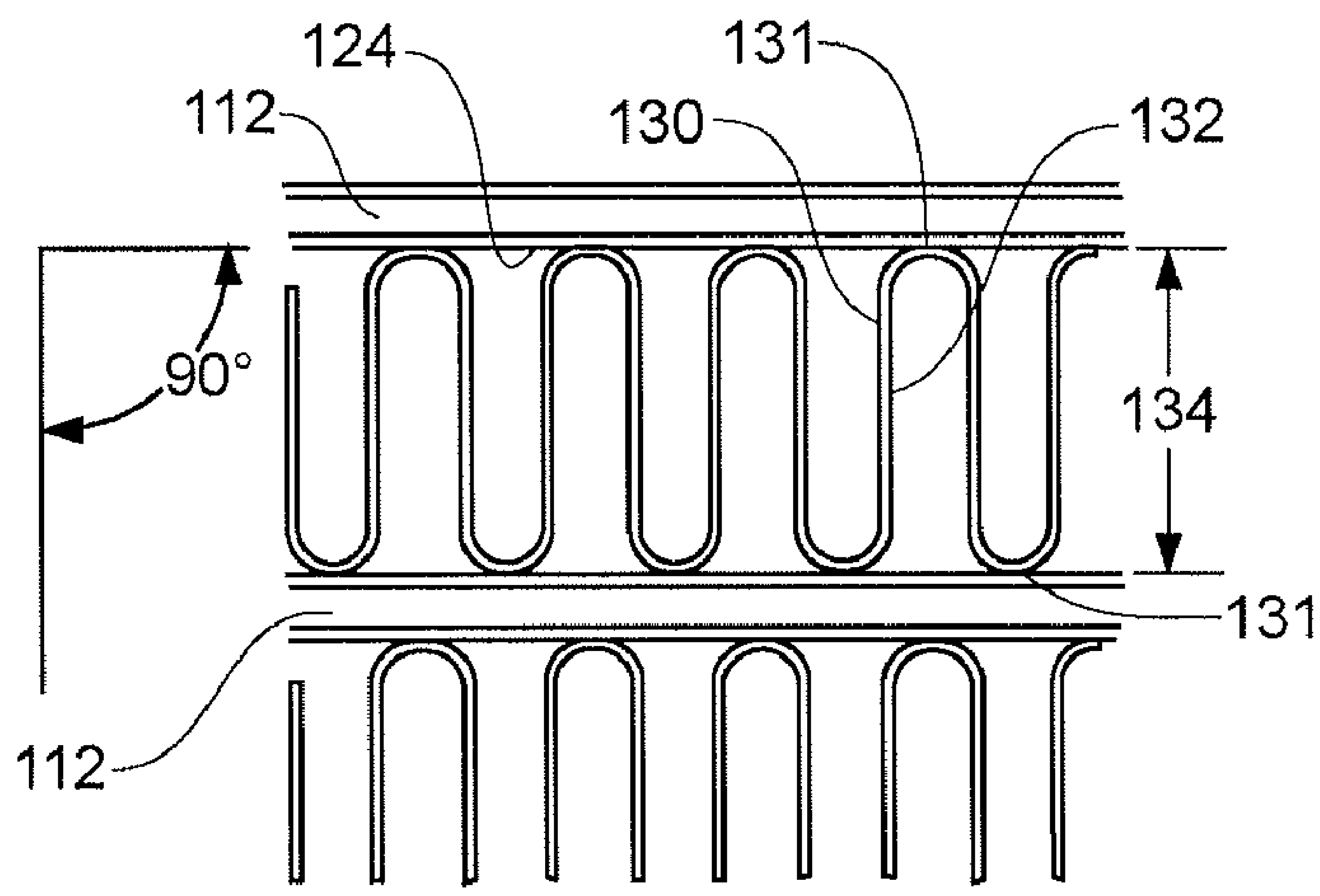

124
131
112
130
132
90°
134
131
112

Fig. 9

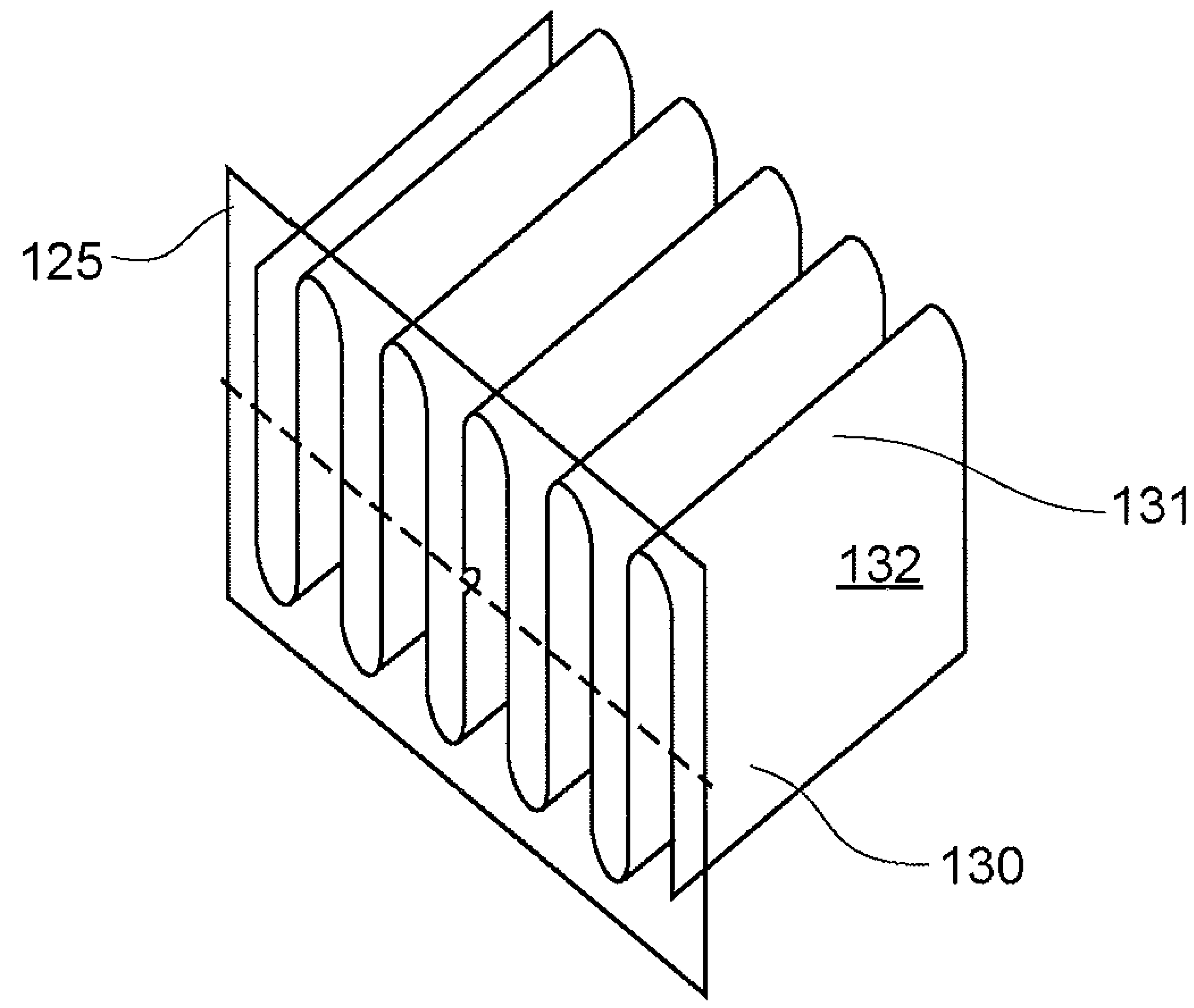


Fig. 10A

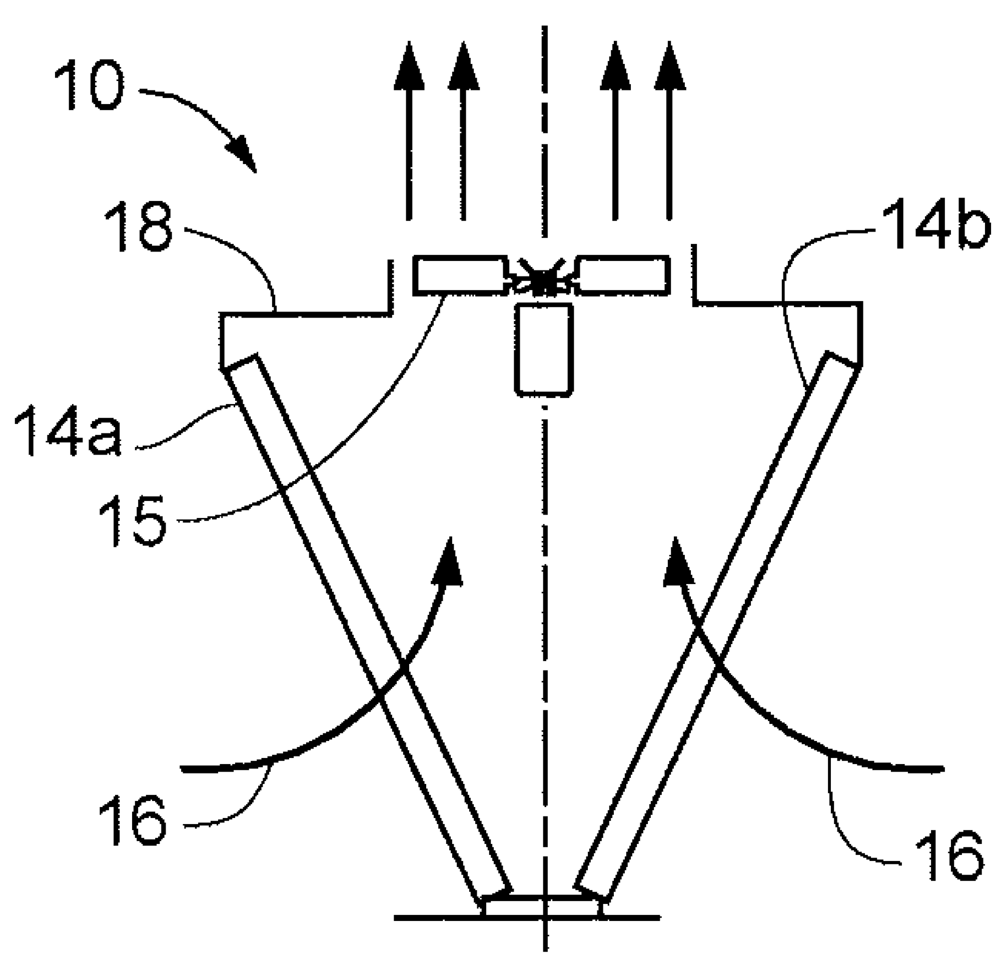


Fig. 10B

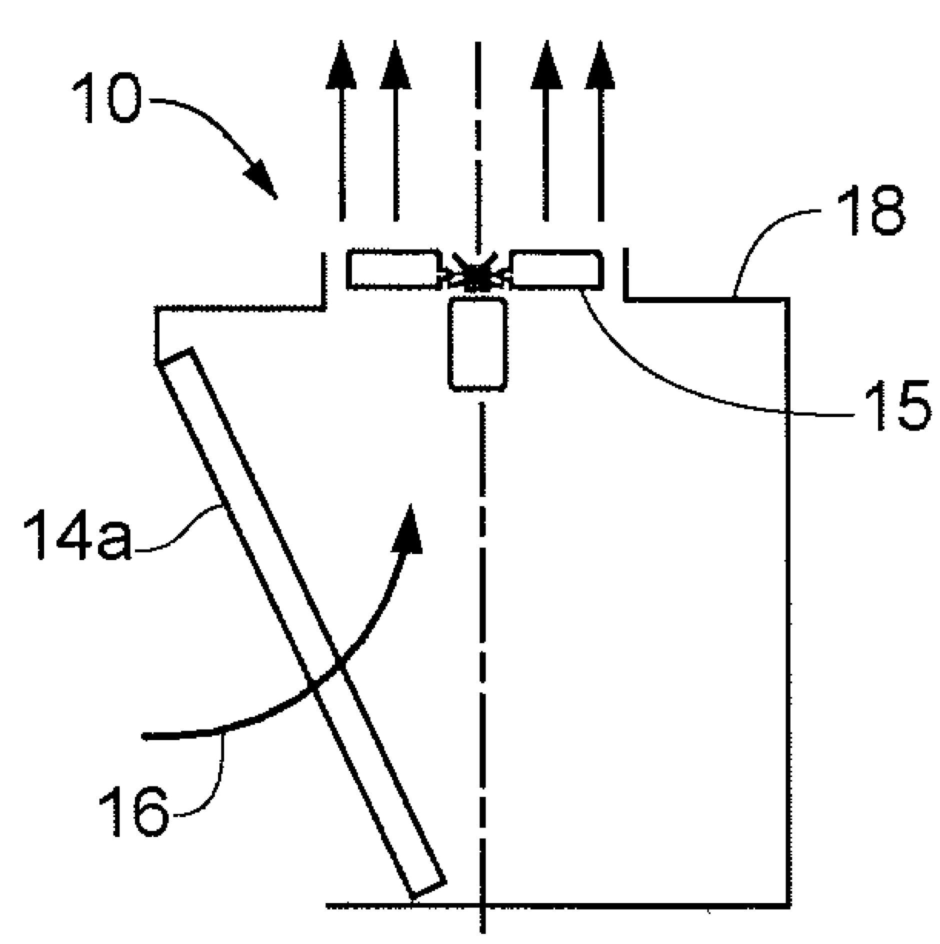


Fig. 10C

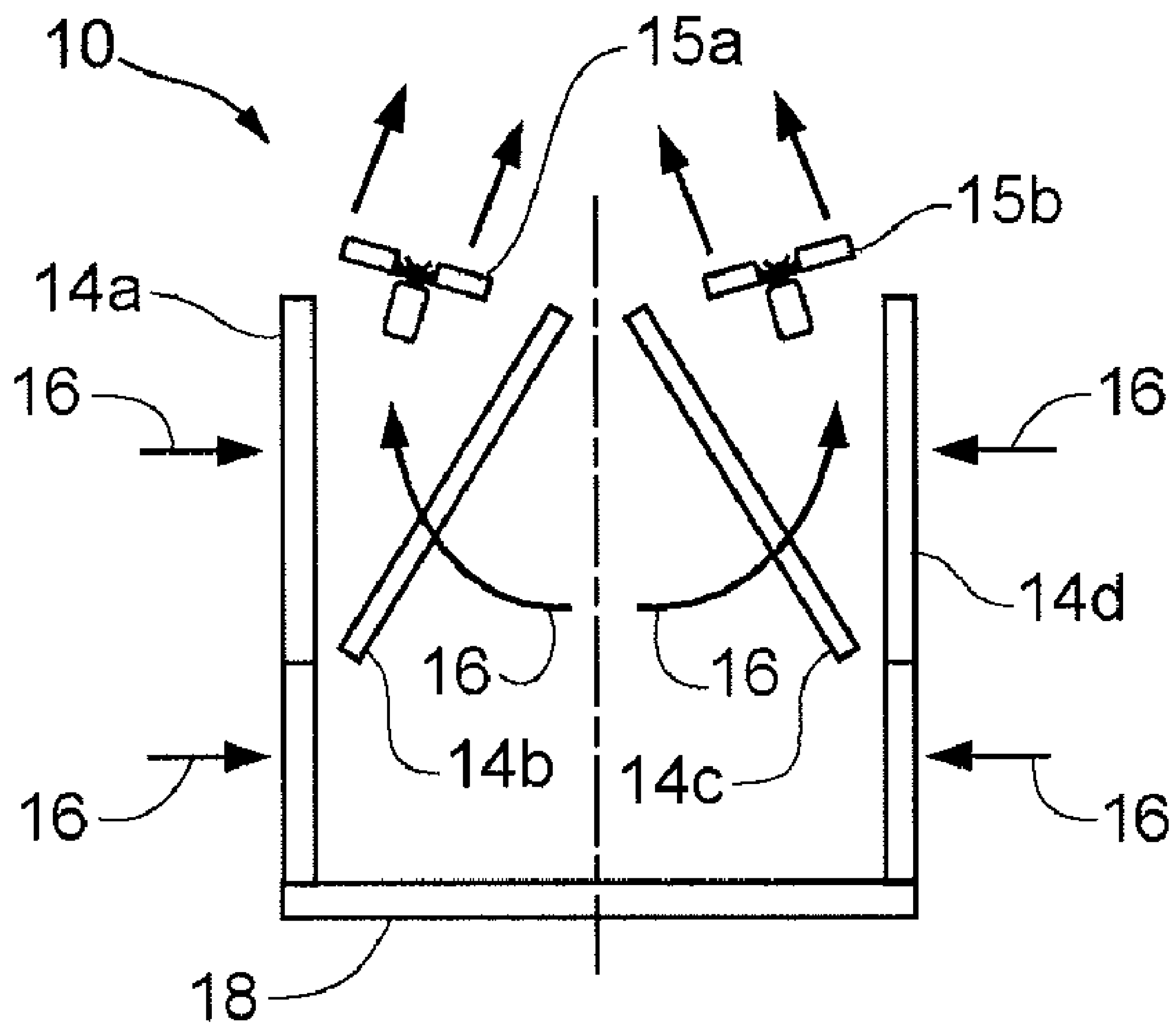


Fig. 11

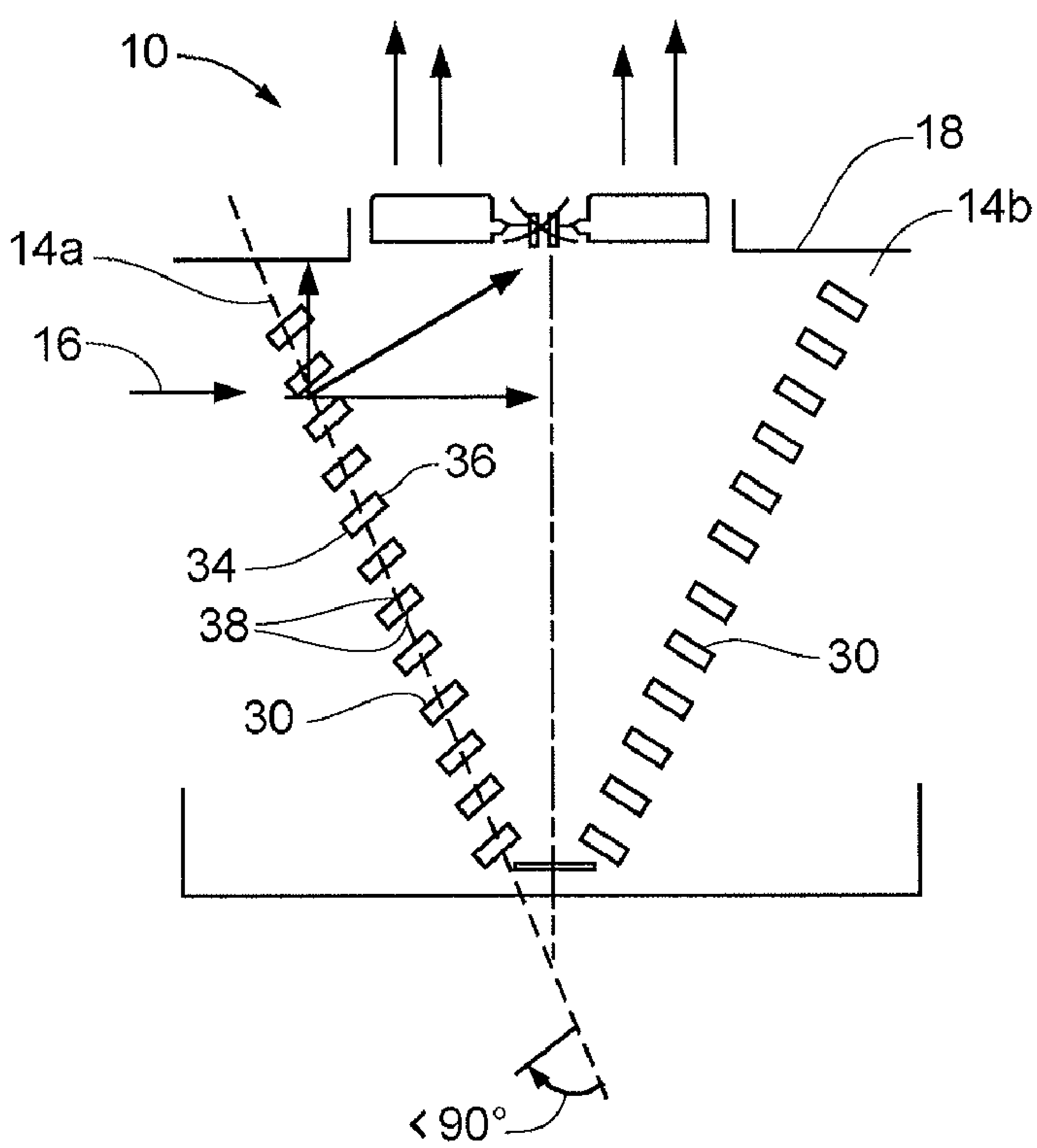


Fig. 12

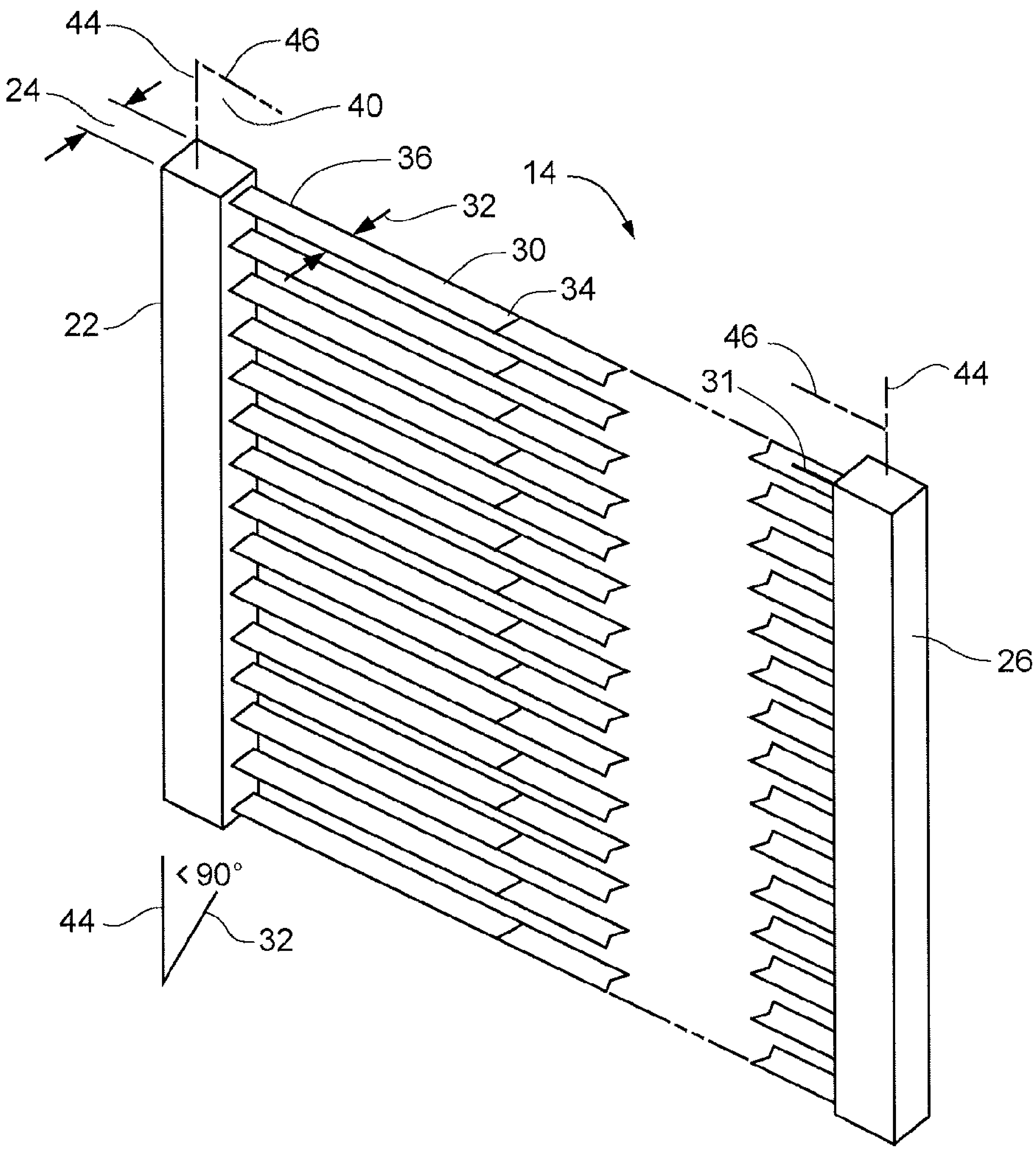


Fig. 13

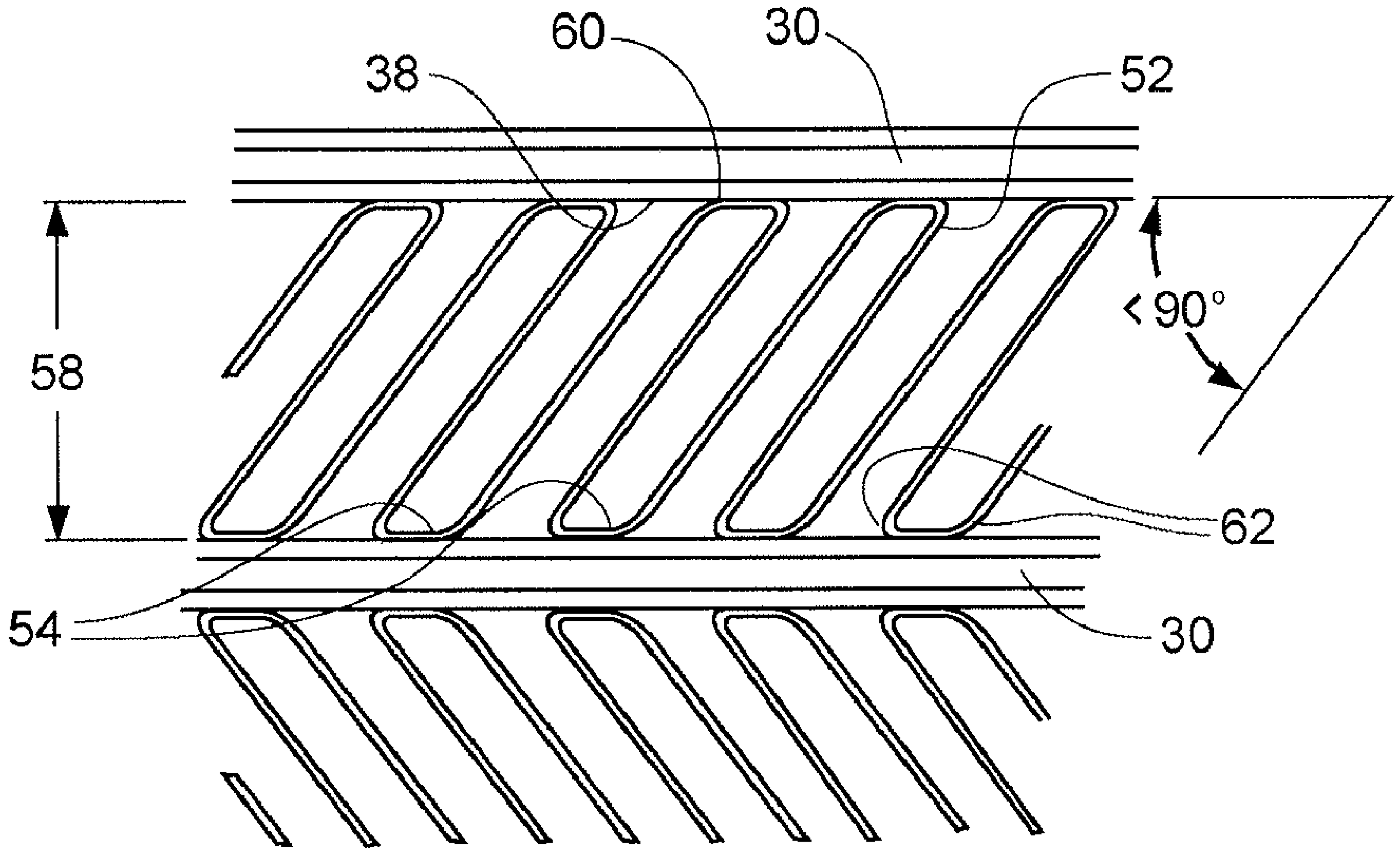


Fig. 14

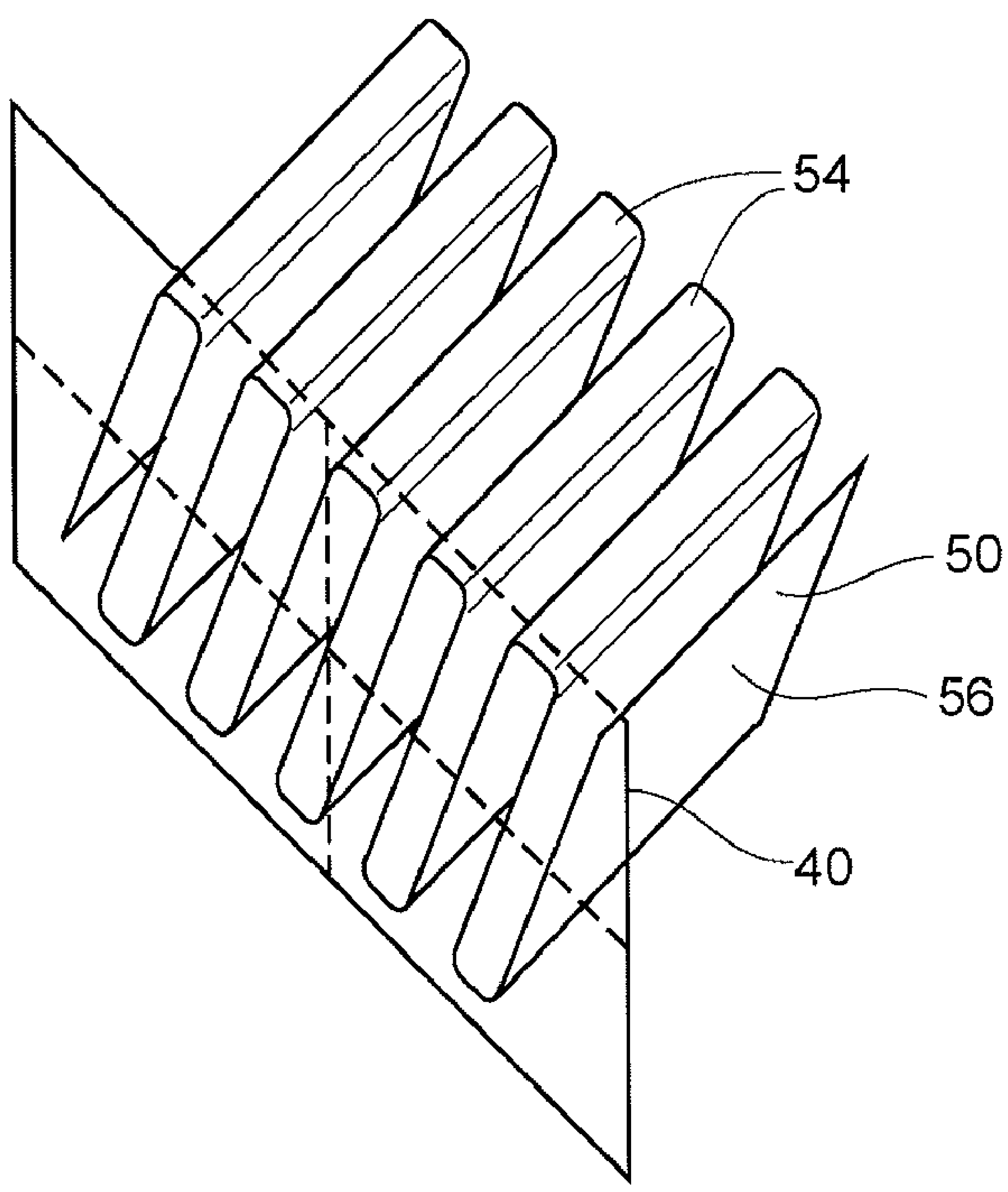


Fig. 15

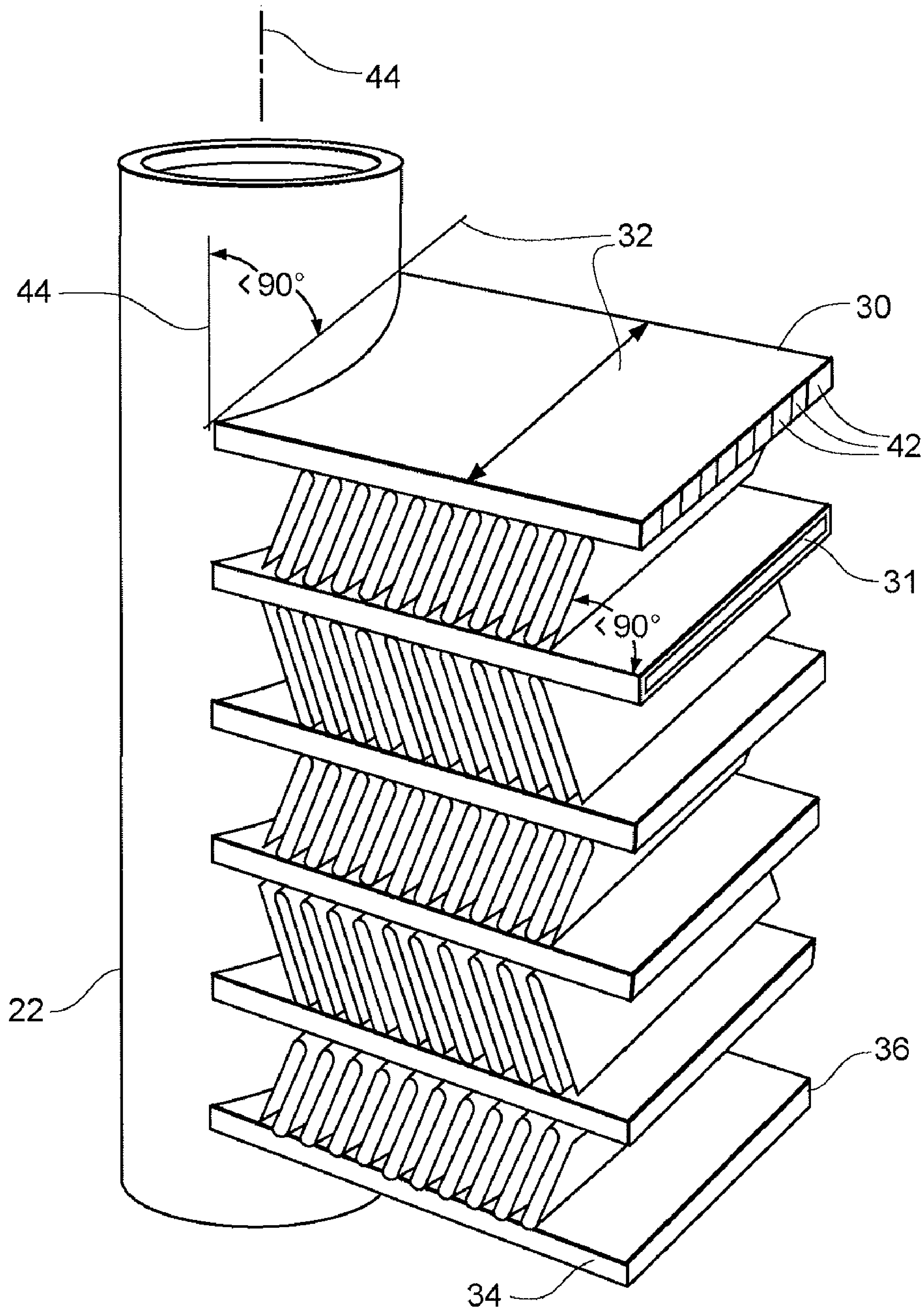


Fig. 15a

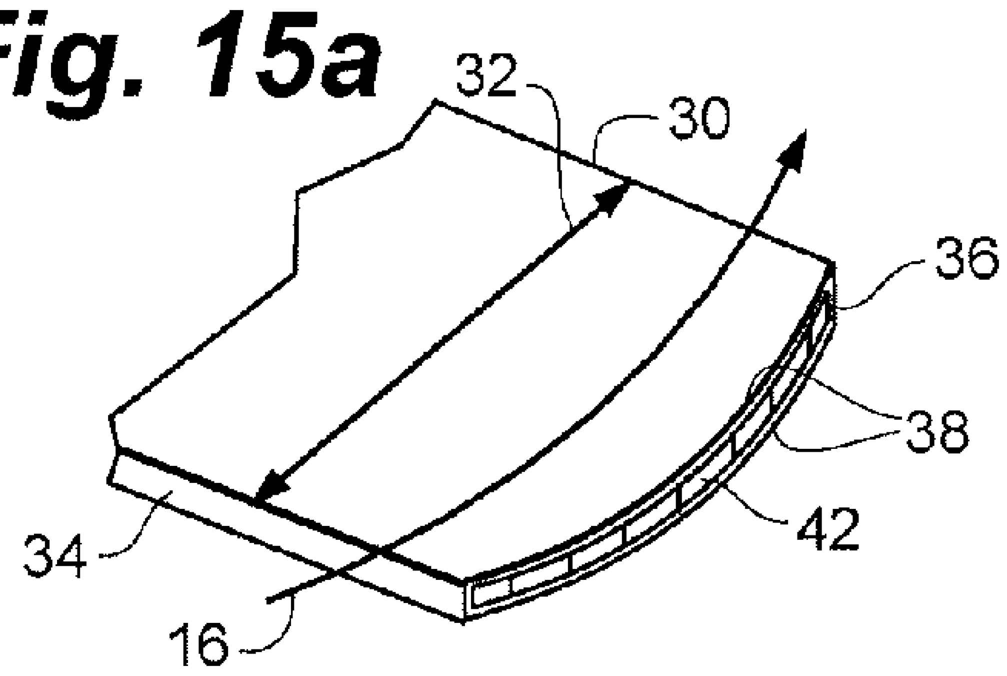


Fig. 15b

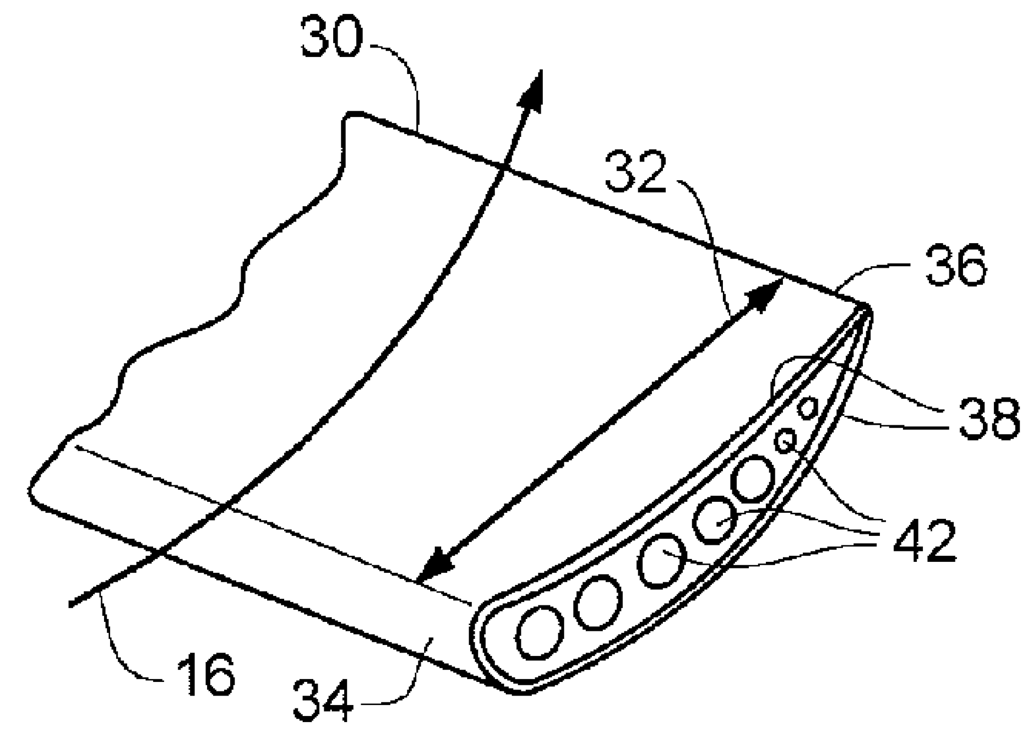
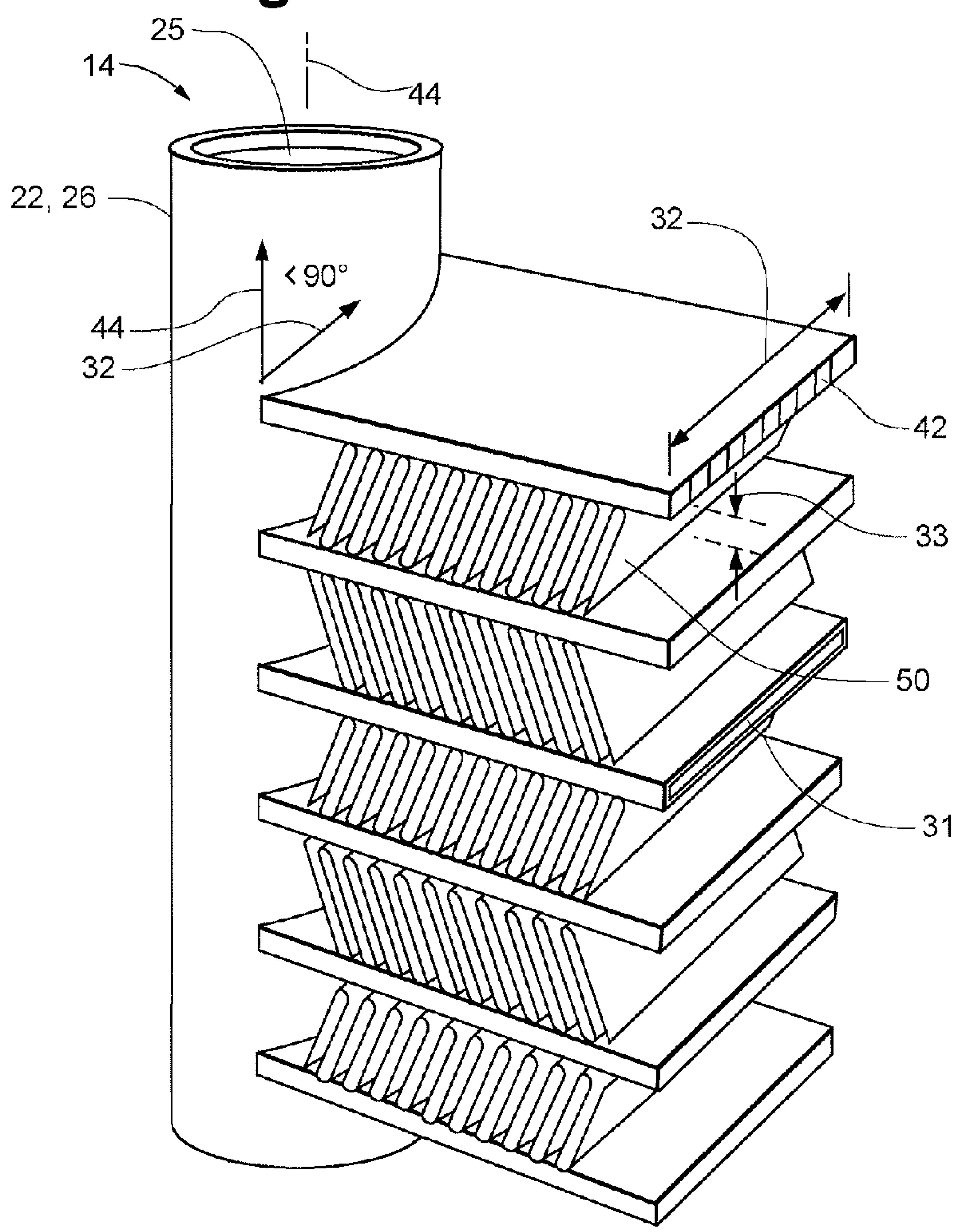


Fig. 16



HEAT EXCHANGER ASSEMBLY

FIELD OF THE INVENTION

[0001] This invention relates generally to cooling systems, and more particularly to heat exchangers usable in such cooling systems.

BACKGROUND OF THE INVENTION

[0002] Typical refrigeration systems often utilize conventional fin-and-tube heat exchanger coils to dissipate heat from refrigerant passing through the heat exchanger coils. Usually, in large-scale cooling systems, a single, oftentimes large, conventional fin-and-tube heat exchanger coil **100**, as depicted in prior art FIG. **3**, is sized to dissipate or reject an amount of heat equal to the heat load of the refrigeration system. Multiple conventional fin-and-tube heat exchanger coils **100** might also be used. The fin-and-tube heat exchanger coil(s) is/are sized to dissipate the amount of heat in the refrigerant that was absorbed in other portions of the refrigeration system.

[0003] Usually, in large-scale cooling systems, the fin-and-tube heat exchanger coil(s) is/are positioned outside a commercial building, such as on a rooftop, to allow heat transfer between the fin-and-tube heat exchanger coil and the outside environment (i.e., to allow the heat in the refrigerant to dissipate into the outside environment). Further, natural or ram airflow may be augmented by a mechanical airflow that may be provided by a fan, for example, to assist in air-cooling the fin-and-tube heat exchanger coil.

[0004] Fin-and-tube heat exchanger coils, depicted generally at **100**, in prior art FIG. **3**, often display less than ideal efficiencies and relatively high cost in dissipating heat from the refrigerant passing through the coils as compared to newer technologies. Typically, fin-and-tube heat exchanger coils can be rather large for the amount of heat they can dissipate from the refrigerant as compared to newer technologies. Additionally, fin-and-tube heat exchanger coils use a great deal of copper in their construction. Presently, copper is a very expensive commodity. Further, the larger the heat exchanger coil becomes, the more refrigerant used in the refrigeration system, thus effectively increasing the risk of potential damage to the environment by an accidental atmospheric release. The efficiency of fin-and-tube heat exchanger coils is however not very dependent on the direction of the air flow relative to the coils the coils. This can be seen in prior art FIG. **3**, the arrows indicating air flow over the various tubes **102**.

[0005] A more recent form of heat exchanger is the microchannel coil (MCC) heat exchanger. Microchannel coil (MCC) heat exchangers are typically made of aluminum, replacing the costlier copper of the fin-and-tube heat exchanger coils. Further, in similar heat exchange applications, MCC heat exchangers can be made significantly smaller than fin-and-tube heat exchanger coils that effect similar heat exchanges. To date, however, microchannel coil (MCC) heat exchangers are known to be quite sensitive to the direction of airflow relative to the plane of the MCC heat exchanger. Efficiency drops off dramatically as the direction of airflow varies from the normal relative to the plane of the MCC heat exchanger.

[0006] Currently, the major application of microchannel coils is in the automotive industry. Microchannel coils **110** may be used as a condenser and/or an evaporator in the air conditioning system of an automobile. See prior art FIGS. **1** and **2**. A microchannel heat exchanger coil, for example, in an automotive air conditioning system, is typically located toward the front of the engine compartment, where space to mount the heat exchanger coil is limited and where the direction of airflow is normal. Therefore, the microchannel heat exchanger coil, which is much smaller, lighter, and less costly than a conventional fin-and-tube heat exchanger coil that would otherwise be used in the automotive air conditioning system, is a suitable fit for use in an automobile.

[0007] Referring to FIGS. **2** and **7**, the prior art MCC tube heat exchanger **110** includes an inlet header **116** and a spaced apart outlet header **118**. Each of the headers **116**, **118** has a fluid passageway **121** defied therein. The respective fluid passageways **121** are in fluid communication by means of the microchannel tubes **112** that extend between the headers **116**, **118**. The headers **116**,**118** each have a known depth dimension **119**. A heat exchanger plane **125** includes the longitudinal axes **126** of the headers **116**, **118** and can be thought of as the windward face of the MCC tube heat exchanger **110**. The plane **125** is usually presented normal to the incoming air flow.

[0008] The MCC tube heat exchanger **110** includes a plurality of microchannel tubes **112**. Each microchannel tube **112** has a length dimension **114** extending from header **116** to header **118**, as depicted in prior art FIG. **7**. The two edges **120**, **122** are joined by two spaced apart, parallel relatively long sides **124** defining a chord **123** of the microchannel tube **112**. In cross section, the edges **120**, **122** and sides **124** of the microchannel tube **112** define a very thin rectangle with an interior fluid passage **113**. The fluid coupling of the headers **116**, **118** is by means of the plurality of microchannel tubes **112**. In the prior art MCC tube heat exchanger **110**, the chord **123** of each of the microchannel tubes **112** is disposed orthogonally with respect to the plane **125** of the MCC tube heat exchanger and the length of the chord **123** is therefore limited to a maximum equal to the depth **119** of the respective headers **116**, **118**.

[0009] The prior art MCC tube heat exchanger **110** further includes fins **130**, as depicted in prior art FIGS. **8** and **9**. The fins **130** are typically formed of a single metallic ribbon that is compressed at series of bends **131**, the bends **131** being formed in alternating directions. The ribbon of the fins **130** is affixed at the alternating bends **131** to respective adjacent microchannel tubes **112** in a heat conducting joint. The fins **130** include heat exchange surfaces **132**. The plane of each of the heat exchange surfaces **132** is, in the prior art, usually disposed generally orthogonal with respect to a respective side **124** of an adjacent microchannel tube **112**, adjacent heat exchange surfaces **132** being disposed in a parallel array. The height dimension **134** of the heat exchange surfaces **132** is absolutely limited by the distance **134** between adjacent microchannel tubes **112**.

[0010] The plane of adjacent fins **130** of some prior art MCC heat exchangers **110** is angled with respect to one another. The ribbon forming the fins **130** has very sharp bends. See U.S. Pat. No. 6,988,538. Such alternate angling reduces the number of heat transferring heat exchange surfaces **132** that can be included in a given length **114** of the microchannel tube **112** and the sharp bends **131** provide for only a minimal heat conducting joint with the respective microchannel tube **112**. For these reasons the alternating angling disposition is not favored as being less efficient than the parallel array disposition of prior art FIGS. **8** and **9**.

[0011] For most efficient heat exchange in the prior art, the flow of air through the MCC tube heat exchanger **110** is normal to the plane **125** of the heat exchanger **110**, as depicted in prior art FIGS. **1** and **2**. Efficiency of the known MCC tube heat exchanger **110** depends on the flow of air being substantially parallel with the chord **123** and across the two sides **124**, as depicted in prior art FIG. **2**, and past the orthogonally disposed fins **130**. For this reason, the most efficient of all known uses of the MCC technology has been with normal air flow relative to the plane of the MCC heat exchanger, where the leading edge **120** of each microchannel tube **112** is presented to the air flow and the air flow proceeds down both sides **124** to the trailing edge **122**.

[0012] Angling the known MCC tube heat exchanger **110** to the direction of airflow results in known and calculable reductions of efficiency, as compared to normal airflow with the same MCC tube heat exchanger **110**. Such angling is noted in Prior art FIGS. **4**-**6**. Angling of the MCC tube heat exchanger **110** reduces the footprint of the heat exchanger unit, which in turn reduces cost. However, such angling disadvantageously sacrifices efficiency of the heat exchanger unit because the MCC tube heat exchanger **110** is angled with respect to the fan **140** and airflow through the MCC tube heat exchanger **110** is then not normal, but is turned. A resulting issue with heat exchanger units that are mounted on a rooftop is that the airflow is typically turned 90 degrees as it flows through the heat exchanger. This results from a horizontally mounted fan **140** drawing in a generally horizontal flow of air **142** and expelling the airflow **142** in a generally vertical direction. Such flow path change results in reduced efficiency of the MCC tube heat exchanger **110**. For example a representative reference local loss coefficient of the orientation depicted in prior art FIG. **4** is 0.83. The coefficient is directly applied to a local mass flow, resulting in a significantly diminished mass flow.

[0013] The above reduction of mass flow has led engineers to angle known MCC heat exchangers **110** to the relative airflow, such as the 60 degree angle of prior art FIGS. **5** and **6** in which the direction of air flow **130** is not normal to the plane **125** of the MCC tube heat exchanger **110**. Such angling advantageously results in a greater height dimension of the MCC heat exchangers **110** relative to the overall height of the heat exchanger unit. Further, angling the MCC heat exchangers **110** results in a reduced footprint of the heat exchanger unit, thereby reducing cost. While cost is reduced, efficiency is reduced as a result of the MCC heat exchangers **110** being angled with respect to the fan **140**. In this case, the exemplary reference local loss coefficient of the angled orientation is 0.38, a considerable reduction as compared to the orientation of FIG. **4**, but still a significant source of energy loss. Even this reduced loss generates a significant loss in airflow velocity and loss in efficiency of the MCC tube heat exchanger **110**.

[0014] There is a need in the industry for more efficient MCC tube heat exchangers in applications in which the flow of air is not normal to the plane of the heat exchanger. In this situation, the direction of airflow is altered from the intake side of the MCC tube heat exchanger to the exhaust side by as much as ninety degrees. As noted above, with known MCC tube heat exchangers, such non-normal air flow significantly diminishes the efficiency of the MCC tube heat exchanger as compared to normal air flow on both the intake and exhaust sides of the MCC tube heat exchanger.

SUMMARY OF THE INVENTION

[0015] The present invention substantially meets the aforementioned needs of the industry by providing a high efficiency MCC tube heat exchanger for use with air flows that are not normal to the MCC heat exchanger. The present invention provides, in one aspect, a heat exchanger assembly adapted to efficiently condense a refrigerant in a refrigeration system where the flow of air to the MCC tube heat exchanger is not normal. The MCC tube heat exchanger assembly includes at least one microchannel heat exchanger coil including an inlet header and an outlet header, each microchannel of the coil being angled with respect to the plane of the MCC heat exchanger.

[0016] The present invention provides, in a further aspect, a method of assembling a MCC tube heat exchanger assembly. The MCC tube heat exchanger assembly may be adapted to condense a refrigerant for use in a refrigeration system. The method includes forming a MCC tube heat exchanger assembly with angled microchannel tubes and/or fins that provide for increased efficiency of the MCC tube heat exchanger assembly when the MCC tube heat exchanger assembly is angled with respect to the direction of airflow, i.e. the air flow is not normal to the plane of the MCC tube heat exchanger assembly.

[0017] The present invention provides, in addition to microchannel tubes and fins oriented to non-normal air flow, a greater heat transfer area of the respective microchannels and fins for a given depth of the headers of the MCC heat exchanger. Efficiency of the device of the present invention is therefore improved by two means. The first is angling the microchannel tubes and fins into the airflow and the second is the greater heat changer area of the microchannel tubes and fins presented to the air flow that is made possible by the angling of the microchannels and/or fins.

[0018] The present invention is a heat exchanger that includes a plurality of MCC microchannel tubes, each microchannel tube of the plurality of microchannel tubes having at least one microchannel fluid passage defined therein and having a chord, the chord being the orthogonal distance from a leading edge to a trailing edge, each microchannel tube of the plurality of microchannel tubes being disposed such that the chord is less than orthogonally disposed relative to a heat exchanger plane. The present invention is further a method of forming such a heat.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. **1** is a top plan view of a prior art MCC heat exchanger;

[0020] FIG. **2** is a sectioned perspective view of a prior art MCC heat exchanger;

[0021] FIG. **3** is a perspective view of a sectioned prior art fin and tube heat exchanger;

[0022] FIG. **4** is a partially sectioned perspective view of a prior art MCC tube heat exchanger;

[0023] FIG. **5** is a perspective view of a of a prior art MCC tube heat exchanger;

[0024] FIG. **6** is a side elevational schematic of a prior art heat exchanger assembly employing prior art MCC tube heat exchangers;

[0025] FIG. **7** is a perspective view of a prior art heat exchanger as employed in the heat exchanger assembly of FIG. **6**;

[0026] FIG. **8** is an elevational view of the microchannel tubes and fins of the prior art MCC tube heat exchanger of FIG. **7**;

[0027] FIG. **9** is a perspective view prior art fins of FIG. **8**;

[0028] FIG. **10** includes three-side elevational schematic depictions of heat exchanger assemblies in v-shape, single heat exchanger, and w-shape configurations;

[0029] FIG. **11** is a side elevational schematic of a v-shaped heat exchanger assembly employing two MCC tube heat exchangers of the present invention;

[0030] FIG. **12** is a perspective view of a MCC tube heat exchanger of the present invention as employed in the heat exchanger assembly of FIG. **11**;

[0031] FIG. **13** is a front elevational depiction of the microchannel tubes and fins of the present invention;

[0032] FIG. **14** is a perspective view of the fins of the present invention;

[0033] FIG. **15** is a perspective view of a portion of a MCC tube heat exchanger of the present invention employing both angled microchannel tubes and angled fins;

[0034] FIG. **15***a* is a perspective view of a microchannel tube of the present invention having curved sides;

[0035] FIG. **15***b* is a perspective view of a microchannel tube of the present invention having an airfoil shape; and

[0036] FIG. **16** is a perspective view of a portion of a MCC tube heat exchanger of the present invention employing both angled microchannels and angled fins.

DETAILED DESCRIPTION OF THE DRAWINGS

[0037] The heat exchanger assembly of the present invention is depicted generally at **10** in the figures. The heat exchanger assembly **10** may be used as a heat exchanger in a large-scale refrigeration system, such as that found in many commercial applications and multi-unit residences. In such a refrigeration system, the heat exchanger assembly **10** is frequently positioned outside the building, such as on the rooftop of the building, to allow heat transfer from the heat exchanger assembly **10** to the outside environment. The coils **14** of the heat exchanger assembly **10** may be advantageously disposed in a non-normal relationship relative to the incoming airflow. The usual role of the heat exchanger assembly **10** in the refrigeration system is to receive compressed, gaseous refrigerant from one or more compressors (not shown), condense the gaseous refrigerant back into its liquid form, and discharge the compressed, liquid refrigerant to one or more evaporators (not shown) located inside the store. The liquid refrigerant is evaporated when it is passed through the evaporators, and the gaseous refrigerant is drawn into the one or more compressors for reprocessing into the refrigeration system.

[0038] Refrigerants are typically given an R-XXX designation, such as "R-134a" or "R-22." Additionally, other compounds, such as anhydrous ammonia, for example, may be used in such a refrigeration system to provide sufficient cooling to the refrigeration system. If any of the R-XXX designated refrigerants is used as the refrigerant of choice, the components of the refrigeration system in contact with the R-XXX may be made from copper, aluminum, or steel, among other materials. However, as understood by those skilled in the art, other refrigerants may not be compatible with some materials. If anyhydrous ammonia, for example, is used as the refrigerant of choice, copper components of the refrigeration system in contact with the anyhydrous ammonia may corrode. Alternatively, other refrigerants (including both two-phase and single-phase refrigerants or coolants) may be used with the heat exchanger assembly **10**.

[0039] In addition to large refrigeration systems as noted above, the heat exchanger assembly **10** may also be used in various process industries, where the heat exchanger assembly **10** may be a portion of a fluid cooling system using a single-phase coolant (e.g., glycol). In such an application, the role of the heat exchanger assembly **10** in the fluid cooling system is to receive heated liquid coolant from one or more heat sources (e.g., a pump or an engine, for example), cool the heated liquid, and discharge the cooled liquid coolant to one or more heat sources. The cooled liquid coolant is again heated when it is put in thermal contact with the one or more heat sources, and the heated coolant is routed by the pump for re-processing into the fluid cooling system.

[0040] Further, the heat exchanger assembly **10** may be used with vehicles, including in applications using either two-phase or single-phase refrigerants or coolants. Such applications include, for example, air conditioning systems and the engine cooling system. The application of the heat exchanger assembly **10** is particularly desirable in low frontal profile vehicles where it may be desirable to angle the heat exchanger assembly **10** with respect to the incoming airstream, such angling being necessary to achieve sufficient cooling while maintaining a desired low frontal profile of the vehicle.

[0041] As depicted in FIGS. **10***a* and **11**, the heat exchanger assembly **10** may include two microchannel heat exchanger coils **14***a*, **14***b* being supported by a frame **18**. The frame **18** may be a freestanding structure. However, the frame **18** may comprise any number of different designs other than that shown. As such, the illustrated frame **18** is intended for illustrative purposes only.

[0042] FIGS. **10***a*, **10***b*, and **10***c* depict exemplary embodiments of the heat exchanger assembly **10** of the present invention. Such embodiments are typical of rooftop installations where the heat exchanger assembly **10** is employed as a condenser. FIG. **10***a* is a V configuration employing two heat exchanger assemblies **10**. FIG. **10***b* is configuration employing only a single heat exchanger assembly **10**. FIG. **10***c* is W configuration employing four heat exchanger assemblies **10** and having the fans **15***a*, **15***b* set at an angled disposition as compared to the horizontal disposition of the fans **15** of FIGS. **10***a*, **10***b*.

[0043] As shown in FIGS. **11** and **12**, each microchannel heat exchanger coil **14***a*, **14***b* includes an inlet manifold or header **22** and an outlet manifold or header **26**. The headers **22** and **26** are fluidly connected by a plurality of microchannel tubes **30**. One or more baffles (not shown) may be placed in the manifolds **22**, **26** to cause the refrigerant to make multiple passes through the microchannel tubes **30** for enhanced cooling of the refrigerant. Each of the headers **22**, **26** has a known depth dimension **24**. A heat exchanger plane **40** is defined including the longitudinal axes **44** of the respective headers **22**, **26** and an orthogonal line **46** extending between the respective axes **44**.

[0044] Each of the microchannel tubes **30** extends between a respective header **22** and respective header **26**. As depicted in FIG. **12**, each microchannel tube **30** has a length dimension **32** defining the distance between the two headers **22**, **26** to which the respective microchannel tube **30** are coupled. Each microchannel tube **30** has a leading edge **34** and a trailing edge **36**. A pair of opposed sides **38** extend between leading edge **34** and the trailing edge **36**. The area sides **38** of the microchannel tube **30** comprise the bulk of the heat transfer of the microchannel tube **30**. An interior fluid passage **31**, as depicted in FIG. **16**, is defined in each of the microchannel tubes **30**. The fluid passage **31** is in fluid communication with the fluid passage **25** of the respective headers **22**, **26**. Each of the microchannel tubes **30** further has a height dimension **33** and a chord dimension **32**. The height dimension **33** extends between the respective outer margins of the two sides **38**. The chord **35** extends orthogonally between the leading edge **34** and the trailing edge **36** and is one dimension in the determination of the area sides **38**. The longer the chord **35**, the greater the heat exchange area of the sides **38**. Advantageously, the microchannel tubes **30** of the present invention are angled at an angle of less than 90 degrees with respect to the plane **40** of the MCC tube heat exchanger **14** as depicted in FIGS. **11**, **12**, **15** and **16** and preferably between 10 and 60 degrees. Such angling increases the length dimension of the chord **35** as compared to the chord **123** of the prior art. The advantage of this angling where the angle of the incoming airflow is less than normal with respect to the MCC tube heat exchanger **14** is twofold and is noted below.

[0045] Referring to FIGS. **15**, **15***a*, **15***b*, and **16**, the microchannel tubes **30** may be formed to include a single internal passageway **31** or may be formed to include multiple internal passageways, or microchannels **42**, that are much smaller in size than the internal passageway of the coil in a conventional fin-and-tube heat exchanger coil. The microchannels **42** may be round in cross section, as depicted in FIG. **15***b*, or rectangular, as depicted in FIG. **16**. Other shapes may as well be used, as depicted in FIG. **15***a* where the sides **38** are curved. The microchannels **42** allow for more efficient heat transfer between the airflow passing over the microchannel tubes **30** and the refrigerant carried within the microchannels **42**, as compared to the airflow passing over the coil of the conventional fin-and-tube heat exchanger coil.

[0046] The microchannel tubes **30** may be separated into about twenty or less microchannels **42**, with each microchannel **42** being about 0.5-2.0 mm in height and about 0.5-2.0 mm in width, compared to a diameter of about 9.5 mm (⅜") to 12.7 mm (½") for the internal passageway of a coil in a conventional fin-and-tube heat exchanger coil. However, in other constructions of the flat microchannel tubes **30**, the microchannels **42** may be as small as 0.4 mm by 0.4 mm, or as large as 4 mm by 4 mm.

[0047] Referring to FIG. **15***a*, in cross section, the microchannel tubes **30** may be curved to further enhance the passage of airflow **16** through the microchannel heat exchanger coil **14** where the direction of the airflow is changing in the passage. In cross section, the microchannel **30** has curved sides **38** preferably having the same radius so that the distance between the sides **38** is constant across the chord **32**. Preferably, the edges **34**, **36** are parallel.

[0048] Referring to FIG. **15***b*, in cross section, the microchannel tubes **30** may be airfoil shaped to even further enhance the passage of airflow **16** through the microchannel heat exchanger coil **14** where the direction of the airflow is changing in the passage. In cross section, the microchannel **30** has curved sides **38** preferably having the different radii to achieve the traditional air foil shape with a radiused leading edge **34** and tapering to a juncture of the sides **38** at the trailing edge **36**. Preferably, the edges **34**, **36** are parallel. The chord extends from the forwardmost point on the radiused leading edge **34** to the trailing edge **36**.

[0049] The microchannel tubes **30** may be made from extruded aluminum to enhance the heat transfer capabilities of the flat tubes **30**. In the illustrated construction, the flat microchannel tubes **30** are about 22 mm wide. However, in other constructions, the flat microchannel tubes **30** may be as wide as 50 mm, or as narrow as 10 mm. Further, the spacing between adjacent flat microchannel tubes **30** may be about 9.5 mm. In other constructions, the spacing between adjacent flat microchannel tubes **30** may be as much as 20 mm, or as little as 3 mm.

[0050] In distinction with respect to the prior art, the microchannel tubes **30** of the present invention are disposed at an angle of less than ninety degrees with respect to the plane **40** of the MCC tube heat exchanger **14**, the plane **40** including the longitudinal axes **44** of the headers **22**, **26** and an orthogonally disposed line **46** extending between axles **44**. The microchannel tubes **30** are therefore disposed such that chords **32** are also disposed less than orthogonally with respect to the plane **40**.

[0051] In distinction to the above prior art microchannel heat exchanger **110**, the heat exchanger **10** of the present invention mounted as depicted in FIG. **11** at 60 degrees to the incoming airflow has an estimated loss coefficient that is less than 0.38, but greater than 0.05. This reduced loss coefficient provides for a more efficient heat exchanger assembly **10** where the airflow is changing direction as the airflow passes through the heat exchanger assembly **10**. Further, the heat exchanger **10**, by simply tilting the microchannel tubes **30** at 20 degrees from normal (as in the prior art) increases the area of the sides **38** by 6.4% as a result of the increased length of the chord **32**. Such increased area increases the heat transfer ability of the microchannel tubes **30**, thereby further contributing to increased efficiency of the present invention.

[0052] For further efficiency improvement of the present invention, the fin stock comprising the fins **50**, as depicted in FIGS. **13** and **14** is tilted between 10 degrees and 45 degrees with respect to the respective adjacent microchannel tubes **30** between which the fins **50** are disposed. As noted in the background section above and depicted in prior art FIGS. **8** & **9**, in many known applications of microchannel tube heat exchangers **110**, including its birthplace, the automotive industry, the fin stock designs are generally straight, upright and parallel fin-to-fin. In such orientation, the plane of the radiator elements **132** is disposed orthogonal with respect to the plane of the sides **124** of the adjacent microchannel tubes **112** between which the fin **130** is disposed. In such disposition, the area of the radiator elements **132** is limited by the spacing dimension **134** between the adjacent microchannels **112**.

[0053] The tilted fin stock arrangement of the present invention provides for a larger heat exchange surface **56** within the limited installation space defined between adjacent microchannel tubes **30**. As depicted in FIGS. **13** & **14**, for a microchannel spacing **58** that is equal to the microchannel spacing **134** in the prior art, the fins **50** angled at a preferred angle are of 20 degrees with respect to the plane of the side **38** of the microchannel **30** results in about a 15.6% increase in the surface area of the heat exchange surface **56** of the fin **50**. Such increase in surface area significantly increases the efficiency of the tilted fins **50** with respect to the fins **130** of the prior art.

[0054] A further benefit of the tilted fins **50** of the present invention is that the bends **54** and the ribbon **52** comprising the fins **50** are formed of a flat section **60** formed between two smaller radius bends **62**. The full area of the flat section **60** may be joined in a heat conductive joint to the sides **38** of the adjacent microchannel tubes **30**. Such joint has a significantly greater area as compared to the joint defined between the bin **131** and the side **124** of the microchannel **112** in the prior art. A larger heat conducting joint results in greater transfer of heat from the microchannel **30** to the fin **50**.

[0055] A depiction of FIGS. **15** & **16** shows both tilted microchannel tubes **30** and tilted fins **50**. A user of a heat exchanger **10** as depicted in FIGS. **15** & **16** could expect a thermal performance improvement as follows:

[0056] Aerodynamic performance improved by 10-20%

[0057] Fin stock surface increased by 15.6%

[0058] Tube surface increased by 6.4%.

[0059] The total estimation of thermal improvement from both the tilted tube installation and the tilted fin stock installation is estimated to be greater than 12%.

[0060] The heat exchanger assemblies are described and shown for exemplary reasons only, and are not meant to limit the spirit and/or scope of the present invention.

1. A heat exchanger, comprising:

a plurality of MCC microchannel tubes, each microchannel tube of the plurality of microchannel tubes having at least one microchannel fluid passage defined therein and having a chord, the chord being the orthogonal distance from a leading edge to a trailing edge, each microchannel tube of the plurality of microchannel tubes being disposed such that the chord is less than orthogonally disposed relative to a heat exchanger plane.

2. The heat exchanger of claim **1**, the chord of each microchannel tube of the plurality of microchannel tubes being disposed at an angle relative to the heat exchanger plane that is between ten and sixty degrees.

3. The heat exchanger of claim **1**, the angled disposition of the chord resulting in an increased length of the chord, the increased length dimension of the chord providing for improved thermal performance by means of the resulting greater heat exchange surface area of a respective microchannel tube.

4. The heat exchanger of claim **1**, providing for improved thermal performance by means of an increased surface area of each microchannel tube resulting from the angled disposition that results from the chord being less than orthogonally disposed relative to the heat exchanger plane.

5. The heat exchanger of claim **1**, including a plurality of fins extending between adjacent microchannel tubes, the fins having heat exchange surfaces, the heat exchange surfaces being less than orthogonally disposed with respect to the sides of the respective adjacent microchannel tubes.

6. The heat exchanger of claim **5**, the heat exchange surfaces of the fins being disposed at an angle relative to the heat exchanger plane that is less than a right angle and greater than forty-five degrees.

7. The heat exchanger of claim **5**, providing for improved thermal performance by means of the angled disposition resulting of the heat exchange surfaces of the fins being less than orthogonally disposed relative to the heat exchanger plane, thereby resulting in a greater heat exchange surface of the fins.

8. The heat exchanger of claim **5**, providing for improved thermal performance by means of an increased surface area of the fin heat exchange surface resulting from the angled disposition that results from the heat exchange surface of the fins being less than orthogonally disposed relative to the heat exchanger plane resulting in a greater microchannel surface area as compared to an orthogonally disposed radiator elements of the fins.

9. The heat exchanger of claim **1**, each of the plurality of microchannel tubes being formed with curved sides.

10. The heat exchanger of claim **1**, each of the plurality of microchannel tubes being formed in an airfoil shape.

11. A heat exchanger, comprising:

a plurality of microchannel tubes; and

a plurality of fins disposed between adjacent microchannel tubes, the fins having heat exchange surfaces, the heat exchange surfaces being less than orthogonally disposed with respect to a side of an adjacent microchannel tube.

12. The heat exchanger of claim **11**, the heat exchange surfaces of the fins being disposed at an angle relative to the heat exchanger plane that is less than a right angle and greater than forty-five degrees.

13. The heat exchanger of claim **11**, providing for improved thermal performance by means of the angled disposition resulting of the heat exchange surfaces of the fins being less than orthogonally disposed relative to the heat exchanger plane, thereby resulting in a greater heat exchange surface of the fins.

14. The heat exchanger of claim **11**, providing for improved thermal performance by means of an increased surface area of the fin heat exchange surface resulting from the angled disposition that results from the heat exchange surface of the fins being less than orthogonally disposed relative to the heat exchanger plane resulting in a greater microchannel surface area as compared to an orthogonally disposed radiator elements of the fins.

15. A method of forming a heat exchanger, comprising:

forming a plurality of microchannel tubes, defining at least one microchannel fluid passage in each microchannel tube of the plurality of microchannel tubes;

providing a microchannel dimension being a chord, the chord being the orthogonal distance from a leading edge to a trailing edge; and

disposing each microchannel tube of the plurality of microchannel tubes such that the chord is less than orthogonally disposed relative to a heat exchanger plane.

16. The method of claim **15**, including forming each of the plurality of microchannel tubes with curved sides.

17. The heat exchanger of claim **15**, including forming each of the plurality of microchannel tubes in an airfoil shape.

18. The method of claim **15**, including providing for improved thermal performance by means of the angled disposition resulting from the chord being less than orthogonally disposed relative to the heat exchanger plane resulting in a greater microchannel surface area as compared to an orthogonally disposed microchannel.

19. The method of claim **15**, including extending a plurality of fins between adjacent microchannel tubes, the fins having heat transfer surfaces, and disposing the heat transfer surfaces less than orthogonally with respect to a side of a respective adjacent microchannel tube.

20. The method of claim **17**, including disposing the heat transfer surfaces of the fins at an angle relative to the heat exchanger plane that is less than a right angle and greater than forty-five degrees.

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