

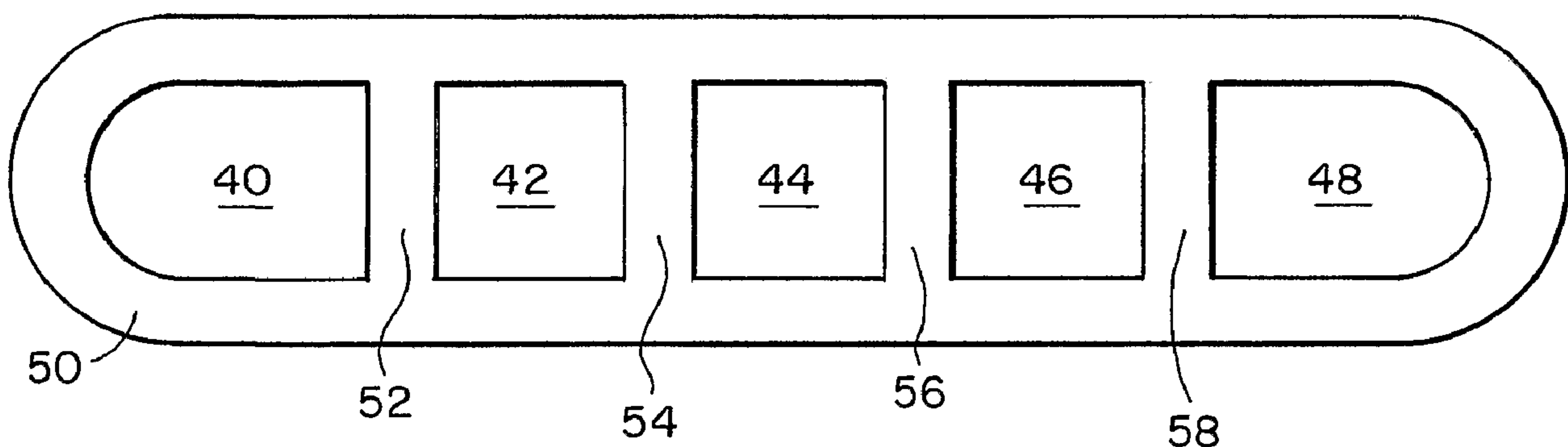


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(54) Title: CONDENSER FOR AIR COOLED CHILLERS

32



(57) Abrégé/Abstract:

A heat exchanger comprising a first coil assembly (14) including an inlet manifold (30); an outlet manifold (34) parallel to and spaced from the inlet manifold (30); and a plurality of tubes (32) each operably connected to and linking the inlet (30) and the outlet (34) manifolds, each tube (32) having a multiplicity of flow paths (40, 42, 44, 46, 48, 60) and a hydraulic diameter HD in the range of $0.07 \leq \text{HD} \leq 0.30$ inches.

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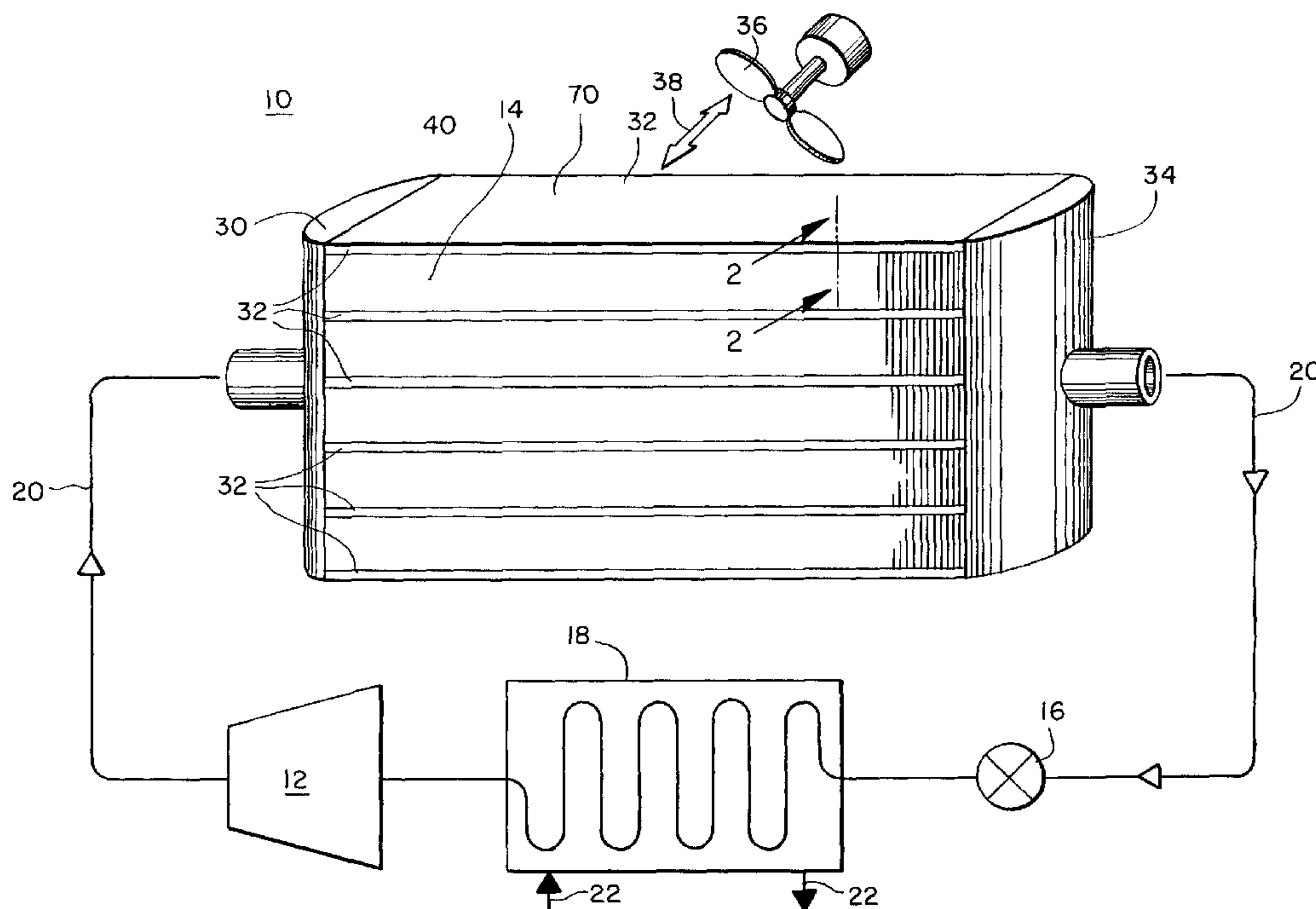
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(54) Title: CONDENSER FOR AIR COOLED CHILLERS



(57) Abstract: A heat exchanger comprising a first coil assembly (14) including an inlet manifold (30); an outlet manifold (34) parallel to and spaced from the inlet manifold (30); and a plurality of tubes (32) each operably connected to and linking the inlet (30) and the outlet (34) manifolds, each tube (32) having a multiplicity of flow paths (40, 42, 44, 46, 48, 60) and a hydraulic diameter HD in the range of $0.07 \leq \text{HD} \leq 0.30$ inches.

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D E S C R I P T I O N

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Title

CONDENSER FOR AIR COOLED CHILLERS

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Background of the Invention

The present invention is directed to air cooled condensers for heating, ventilating and air conditioning (HVAC) systems. More specifically, the present invention is directed to aluminum heat exchangers for use in large air cooled air conditioning chillers, such chillers cooling a transport fluid for use in air conditioning elsewhere. In particular the present invention applies to a condenser using microchannel tubing, also known as parallel flow tubing or multi-path tubing.

HVAC condensers presently use fin and tube coils, primarily with copper tubes and aluminum fins. A significant weight reduction of the overall unit could be accomplished if the tubes were also formed of aluminum and then brazed or glued to the fins. Small sized brazed aluminum heat exchangers as

microchannel tubing are used in the automotive industry. However, the application and the sizes are distinct. Automobile radiators are not as concerned about efficiency as the HVAC industry is. Also, simply resizing an automotive heat exchanger does not
5 provide an optimum solution.

In order to accomplish this, the design of an aluminum heat exchanger with microchannel tubing must be analyzed and optimized.

U.S. Patent 4,998,580 to Guntly et al. and U.S.
10 patent 5,372,188 to Dudley et al. are directed to a condenser with a small diameter hydraulic flow path where hydraulic diameter is conventionally defined as four times the cross sectional area of the flow path divided by the wetted perimeter of the flow path. The Guntly et al. patent requires hydraulic
15 diameters of about 0.07 inches and less while the Dudley et al. patent requires a hydraulic diameter in the range of 0.015 to 0.040 inches. This technology is used in the automotive industry and is not optimum for an air cooled chiller application.

20 Summary of the Invention

It is desirable to provide an aluminum heat exchanger with multiple parallel flow paths for use in a large chiller for air conditioning purposes. It also desirable to significantly
25 reduce the weight of a large chiller.

It is also desirable to provide a heat exchanger with multiple parallel flow paths having a hydraulic diameter greater than about 0.07 inches and less than about 0.30 inches. It is also desirable to provide a hydraulic diameter in the range
30 greater than about 0.07 inches and less than or equal to about 0.26 inches. It is also desirable to provide a hydraulic diameter in the range greater than about 0.07 inches and less than or equal to about 0.14 inches. It is also desirable to provide a hydraulic diameter in the range of about 0.14 inches less than or
35 equal to about 0.26 inches. Finally, in the preferred embodiments

of the present invention the hydraulic diameter is either about 0.07 inches or about 0.14.

The present invention provides a heat exchanger. The heat exchanger comprises a first coil assembly including an inlet manifold, an outlet manifold parallel to and spaced from the inlet manifold; and a plurality of tubes each operably connected to and linking the inlet and the outlet manifolds. Each tube has a multiplicity of flow paths and a hydraulic diameter in the range of $0.05 \leq HD \leq 0.30$; and fins arranged in heat transfer relation between adjacent tubes of the plurality of tubes; wherein the multiplicity of flow paths are in a parallel arrangement; and wherein the multiplicity of flow paths has at least first and second cross sectional shapes.

The present invention also provides an air conditioning system including a compressor, a first heat exchanger, a fan motivating air across the first heat exchanger, an expansion device and a second heat exchanger serially linked into an air conditioning cycle by tubing. The first heat exchanger includes an inlet manifold, an outlet manifold, and a multiplicity of adjacent flow paths surrounded by a common tube wall and interconnecting the inlet manifold with the outlet manifold. The flow paths are sized wherein the flow paths are sized and shaped to form a preferred hydraulic diameter HD within the range of about $0.08 \leq HD < 0.30$ inches where hydraulic diameter HD is defined as four times the cross sectional area of the flow paths divided by the total wetted perimeter of the flow paths; wherein the multiplicity of flow paths are in first and second differing shapes.

The present invention further provides a method of manufacturing an air cooled chiller. The method comprises the steps of: forming a first heat exchanger to include a multiplicity of adjacent flow paths wherein the flow paths are sized and shaped to first and second differing shapes and each having a hydraulic diameter within the range of about $0.8 \leq HD \leq 0.30$ inches where hydraulic diameter = 4 times the cross

sectional area divided by the total wetted perimeter; providing a fan to move air across the multiplicity of adjacent flow paths; providing a compressor, a second heat exchanger, and an expansion device; and linking the compressor, the first heat exchanger, the expansion device, and the second heat exchanger serially into an air conditioning cycle by tubing.

The present invention still further provides a method of transferring heat in a heat exchanger. The method comprises the steps of: forming a first heat exchanger to include a multiplicity of adjacent flow paths wherein the flow paths are sized and shaped to a preferred hydraulic diameter HD within the range of $0.7 < HD < 0.30$ inches where hydraulic diameter HD as defined as four times a cross sectional area divided by a total wetted perimeter; forming the flow paths into first and second distinct cross-sectional shapes; and transferring heat thru a wall enclosing said flow paths and to a fluid contained therein.

According to another aspect of the invention, there is provided a heat exchanger comprising: a first coil assembly including an inlet manifold; an outlet manifold parallel to and spaced from the inlet manifold; and a plurality of tubes each operably connected to and linking the inlet and the outlet manifolds, each tube having a multiplicity of flow paths in a parallel arrangement characterized by each of the multiplicity of flow paths having at least first and second cross-sectional shapes and a hydraulic diameter HD in the range of $0.07 < HD < 0.30$ inches ($1.8\text{mm} < HD < 7.6\text{mm}$).

According to another aspect of the invention, there is provided a method of manufacturing an air cooled chiller comprising the steps of: forming a first heat exchanger to include a multiplicity of adjacent flow paths having at least first and second cross-sectional shapes, wherein the flow paths are sized and shaped to a preferred hydraulic diameter HD within the range of $0.07 < HD < 0.30$ inches ($1.8 < HD < 7.6$ mm); providing a fan to move air across the multiplicity of adjacent flow paths; providing a compressor, a second heat exchanger, and

4a

an expansion device; and linking the compressor, the first heat exchanger, the expansion device, and the second heat exchanger serially into an air conditioning cycle by tubing.

5

Brief Description of the Drawings

Figure 1 is a block diagram of an air cooled chiller system in accordance with the present invention.

10 Figure 2 shows a first preferred embodiment of the present invention taken along lines 2-2 of Figure 1.

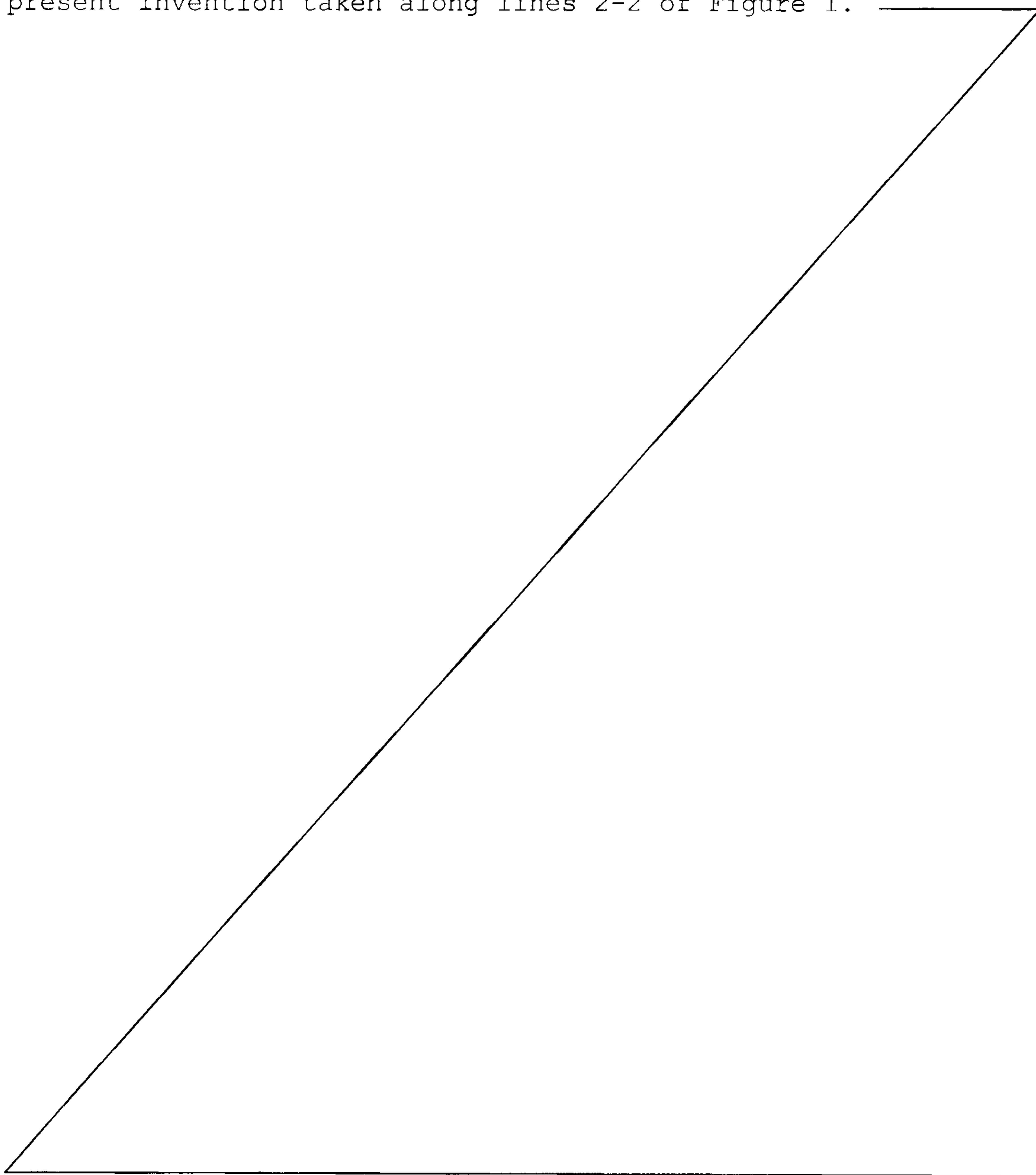


Figure 3 is an alternative embodiment of the multi-path tubes shown in Figure 2.

Figures 4a and 4b are diagrams of fins used in the heat exchanger shown in Figure 1.

5 Figure 5 is a block diagram of a multiple coil assembly configuration as a preferred embodiment of Figure 1.

Detailed Description of the Drawing

10 Figure 1 shows an air conditioning system 10 including a compressor 12, a first heat exchanger 14 functioning as a condenser, an expansion device 16 such as an expansion valve, and a second heat exchanger 18 functioning as an evaporator. The compressor 12, the first heat exchanger 14,
15 the expansion device 16, and the second heat exchanger 18 are serially linked in an air conditioning cycle by tubing 20. The first heat exchanger 14 functions as a condenser in releasing heat from the system, while the second heat exchanger 18 functions as an evaporator in cooling a fluid transported to
20 and from the heat exchanger 18 by means of conduit 22. Such systems are generally well known and are sold by The Trane Company, a Division of American Standard Inc., under the registered trademarks CenTraVac and Series R.

The present invention is directed to an improved
25 condenser 14. This improved condenser 14 is preferably formed of aluminum and has an inlet manifold 30 receiving hot gaseous refrigerant from the conduit 20 and the compressor 12. This hot gaseous refrigerant is distributed by the inlet manifold 30 to a plurality of tubes 32. These tubes 32 conduct the hot
30 gaseous refrigerant from the inlet manifold 30 through the

tubes 32 to an outlet manifold 34. In the process, the hot gaseous refrigerant is condensed and returns to the conduit 20 as a liquid where it is modulated through the expansion device 16 to the second heat exchanger 18. The tubes 32 are preferably microchannel or parallel flow tubing. Microchannel tubing is shown by applicant's U.S. Patent 5,967,228 to Bergman et al. which is assigned to the assignee of the present invention.

Air is moved over the tubes 32 by an air moving device 36 such as a fan either to or away from the fan 36 as indicated by arrow 38. To enhance heat transfer from the tubes 32, fins 40 are provided to enhance the heat transfer. These fins 40 will be subsequently described with reference to Figure 4.

The preferred embodiment of the tubes 32 is shown in Figure 2 and an alternative embodiment is shown in Figure 3. The heat transfer tube 32 shown in Figure 2 includes a multiplicity of adjacent flow paths 40, 42, 44, 46 and 48 throughout the length of the tube 32 and surrounded by a common tube wall 50. The adjacent flow paths 40 through 48 are separated by barrier walls 52, 54, 56 and 58 respectively.

In Figure 2, the flow paths 40 and 48 are of similar shape and cross sectional area and the flow paths 42, 44 and 46 are of similar shape and cross sectional area. The flow paths 40, 42, 44, 46 and 48 are sized and shaped to form a preferred hydraulic diameter HD within the range of:

$$0.7 < HD \leq 0.30 \text{ inches.}$$

Hydraulic diameter is conventionally calculated according to the following formula:

$$\text{Hydraulic Diameter (HD)} = \frac{\text{cross sectional area} \times 4}{\text{total wetted perimeter}}$$

Empirical study shows that a 100 ton air cooled chiller should have a hydraulic diameter of at least 0.07 whereas a 240 ton air cooled chiller should have a hydraulic diameter of about 0.14 inches. Linear extrapolation shows that a 480 ton air cooled chiller should have a hydraulic diameter of about 0.26 inches. Thus, the preferred range of hydraulic diameters is $0.07 < \text{HD} < 0.30$ with an intermediate range of $0.07 < \text{HD} \leq 0.26$. An optimum range appears to be $0.07 < \text{HD} < 0.14$, with preferred hydraulic diameter of 0.14.

In determining the hydraulic diameter, the total cross sectional area of the flow paths 40, 42, 44, 46 and 48 is either measured or calculated, and the total wetted perimeter for those same flow paths is determined in a similar manner.

For the sake of expediency, exemplary calculations are performed for the alternative embodiment shown in Figure 3. In this Figure 3, like reference numerals are used to denote like elements.

In the tube 32 shown in Figure 3, each of the multiplicity of flow paths has an identical size and shape 60. The cross sectional area for these multiplicity of flow paths 60 can be determined by taking an individual flow path 60a, determining a height 62 and a width 64, and multiplying the height 62 and width 64 together to determine an area for a

single flow path 60a. The total cross sectional area for the tube 32 is determined by multiplying by the number of flow paths, in this case 5, by the cross-sectional area per flow path leading to the calculation that the total cross sectional area equals 5 times the height 62 time the width 64.

The wetted perimeter for any individual flow path 60 can be calculated as two heights (62) plus two widths (64). Total wetted perimeter can be determined by multiplying the wetted perimeter for any particular flow path by the number of individual flow paths 60, in this case 5, to result in a total wetted perimeter of 5 times (2H plus 2W). This results in a hydraulic diameter according to the following formula:

$$HD = 10(H \times W) \times 4 / 20 (H + W)$$

which reduces to:

$$HD = 2H \times W / (H + W)$$

Figure 4a shows a first fin embodiment where a corrugated fin 40a is used. Similarly, Figure 4b shows the use of a sinusoidal fin 40b.

Figure 5 is directed to a multiple coil assembly embodiment of the invention in contrast to Figure 1 which shows a single coil assembly 70. In practice, multiple coil assemblies 70, 72, 74 and 76 might be used. The arrangement shown in Figure 5 is described in applicant's previous U.S. Patent 5,067,560 to Carey et al. which is assigned to the assignee of the present invention. The control of such a

condenser is described in applicant's U.S. Patent 5,138,844 to Clanin et al. which is assigned to the assignee of the present invention.

5 In Figure 5, the first coil assembly 70 is
basically perpendicular to ground and a second coil assembly 76
is spaced from the first coil assembly 70 and is generally
arranged in a parallel plane. A third coil assembly 72 is
10 positioned between the first and second coil assembly 70, 76
and lying in a plane which is not parallel to the planes of
first and second coil assemblies 70, 76. A fourth coil
assembly 74 also lies between the first and second coil
assembly 70, 76 at a line in a plane which is not parallel to
the planes of the first and second coil assembly 70, 76. The
15 fourth coil assembly 74 preferably is at a complimentary angle
to the third coil assembly 72. The potential airflow paths are
shown by arrows 80.

 What has been described is a condenser for use in
the large air cooled chiller. It will be apparent to a person
20 of ordinary skill in the art that many alterations and
modifications are readily apparent. Such modifications include
varying the material from aluminum to other light weight
materials having a good heat transfer coefficient as well as
modifying the number and shape of the multiple flow paths
25 within each tube. All such modifications and alterations are
contemplated to fall within the spirit and scope of the
following claims.

C L A I M S

1. A heat exchanger comprising:
 - 5 a first coil assembly including an inlet manifold;
an outlet manifold parallel to and spaced from the inlet manifold;
a plurality of tubes each operably connected to and linking
 - 10 the inlet and the outlet manifolds, each tube having a multiplicity of flow paths and a hydraulic diameter HD in the range of about $0.08 \leq HD < 0.30$ inches; and
fins arranged in heat transfer relation between adjacent tubes of the plurality of tubes;
 - 15 wherein the multiplicity of flow paths are in a parallel arrangement; and
wherein the multiplicity of flow paths has at least first and second cross sectional shapes.
- 20 2. The heat exchanger of claim 1 wherein the fins have a sinusoidal shape.
3. The heat exchanger of claim 1 wherein the fins have a corrugated shape.
- 25 4. The heat exchanger of claim 1 wherein the multiplicity of flow paths extend in a direction connecting the inlet and outlet manifolds.
- 30 5. The heat exchanger of claim 1 further including a device moving air across the first coil assembly and the heat exchanger is primarily formed of aluminum.
6. The heat exchanger of claim 1 further including a second
- 35 coil assembly parallel to and spaced from the first coil assembly, each coil assembly lying in first and second respective planes which are substantially parallel to each other.

7. The heat exchanger of claim 6 including a third coil assembly located between the first and second coil assemblies and lying in a third plane not parallel to the first and second planes.

5

8. The heat exchanger of claim 7 further including a fourth coil assembly between the first and second coil assemblies and lying in a fourth plane not parallel to the first and second planes wherein the angle of the fourth plane is complementary to the angle of the third plane.

9. An air conditioning system comprising:
a compressor,
a first heat exchanger,
15 a fan motivating air across the first heat exchanger,
an expansion device and
a second heat exchanger serially linked into an air conditioning cycle by tubing;
the first heat exchanger including an inlet manifold, an
20 outlet manifold, and a multiplicity of adjacent flow paths of similar cross sectional area surrounded by a common tube wall and interconnecting the inlet manifold with the outlet manifold wherein the flow paths are sized and shaped to form a preferred hydraulic diameter HD within the range of about $0.08 \leq HD < 0.30$
25 inches where hydraulic diameter HD is defined as four times the cross sectional area of the flow paths divided by the total wetted perimeter of the flow paths;
wherein the multiplicity of flow paths are in first and second differing shapes.

30

10. The system of claim 9 wherein the multiplicity of adjacent flow paths extend in a direction connecting the inlet and outlet manifolds.

35 11. The system of claim 9 wherein the first heat exchanger includes first, second, third and fourth coil assemblies, each

coil assembly including the multiplicity of flow paths, and said first, second, third and fourth coil assemblies each having a planar dimension such that the coil assemblies form a W shape when viewed in a direction perpendicular to a common plane to first, second, third and fourth coil assemblies.

12. The system of claim 9 wherein the first shape is rectangular and the second shape includes an arced surface.

10 13. A method of manufacturing an air cooled chiller comprising the steps of:

forming a first heat exchanger to include a multiplicity of adjacent flow paths wherein the flow paths are sized and shaped to first and second differing shapes, each having a hydraulic diameter HD within the range of about $0.08 \leq HD < 0.30$ inches;

providing a fan to move air across the multiplicity of adjacent flow paths;

providing a compressor, a second heat exchanger, and an expansion device; and

20 linking the compressor, the first heat exchanger, the expansion device, and the second heat exchanger serially into an air conditioning cycle by tubing.

14. The method of claim 13 including the further step of:

25 adaptively configuring the second heat exchanger to chill the temperature of a liquid.

15. The method of claim 13 including the further step of:

30 forming the first heat exchanger to include a long dimension; and

arranging the multiplicity of adjacent flow paths to extend in a direction parallel to said long dimension.

16. The method of claim 15 including the further step of

35 interconnecting adjacent ones of the multiplicity of flow paths with a corrugated or sinusoidal fin.

17. The method of claim 16 including the step of arranging the multiplicity of flow paths in a common plane.

18. A method of transferring heat in a heat exchanger
5 comprising the steps of:

forming a first heat exchanger to include a multiplicity of adjacent flow paths wherein the flow paths are sized and shaped to a preferred hydraulic diameter HD within the range of about $0.08 \leq HD < 0.30$ inches;

10 forming the flow paths into first and second distinct cross-sectional shapes; and

transferring heat thru a wall enclosing said flow paths and away from fluid contained therein.

15 19. The method of claim 18 including forming the first heat exchanger to have a long dimension; and

arranging the multiplicity of adjacent flow paths to extend in a direction parallel to the long dimension.

20 20. The heat exchanger of claim 1 wherein the hydraulic diameter ranges between about $0.08 \leq HD \leq$ about 0.15 inches.

21. The heat exchanger of claim 20 wherein a 90 inch flow path has a hydraulic diameter of about 0.08 inches.

25

22. The heat exchanger of claim 20 wherein a 110 inch flow path has a hydraulic diameter of about 0.1 inches.

23. The heat exchanger of claim 20 wherein a 130 inch flow path
30 has a hydraulic diameter of about 0.12 inches.

24. The heat exchanger of claim 20 wherein a 150 inch flow path has a hydraulic diameter of about 0.13 inches.

35 25. The heat exchanger of claim 20 wherein a 200 inch flow path has a hydraulic diameter of about 0.14 inches.

26. The heat exchanger of claim 20 wherein a 250 inch flow path has a hydraulic diameter of about 0.15 inches.

27. The air conditioning system of claim 9 wherein the preferred hydraulic diameter is within the range of about $0.08 \leq HD \leq$ about 0.15 inches.

28. The air conditioning system of claim 27 wherein a 90 inch flow path has a hydraulic diameter of about 0.08 inches.

10

29. The air conditioning system of claim 27 wherein a 110 inch flow path has a hydraulic diameter of about 0.1 inches.

30. The air conditioning system of claim 27 wherein a 130 inch flow path has a hydraulic diameter of about 0.12 inches.

15

31. The air conditioning system of claim 27 wherein a 150 inch flow path has a hydraulic diameter of about 0.13 inches.

32. The air conditioning system of claim 27 wherein a 200 inch flow path has a hydraulic diameter of about 0.14 inches.

20

33. The air conditioning system of claim 27 wherein a 250 inch flow path has a hydraulic diameter of about 0.15 inches.

25

34. The method of claim 13 wherein the forming step includes sizing and shaping the flow paths to a hydraulic diameter within the range of about $0.08 \leq HD \leq$ about 0.15 inches.

35. The method of claim 34 including sizing the flow paths to a length of about 90 inches and shaping them to a preferred hydraulic diameter of about 0.08 inches.

30

36. The method of claim 34 including sizing the flow paths to a length of about 110 inches and shaping them to a preferred hydraulic diameter of about 0.1 inches.

35

37. The method of claim 34 including sizing the flow paths to a length of about 130 inches and shaping them to a preferred hydraulic diameter of about 0.12 inches.

5 38. The method of claim 34 including sizing the flow paths to a length of about 150 inches and shaping them to a preferred hydraulic diameter of about 0.13 inches.

39. The method of claim 34 including sizing the flow paths to a
10 length of about 200 inches and shaping them to a preferred hydraulic diameter of about 0.14 inches.

40. The method of claim 34 including sizing the flow paths to a
length of about 250 inches and shaping them to a preferred
15 hydraulic diameter of about 0.15 inches.

41. The method of claim 18 wherein the forming step includes
sizing and shaping the flow paths to a hydraulic diameter within
the range of about $0.08 \leq HD \leq$ about 0.15 inches.

20

42. The method of claim 41 including sizing the flow path to a
length of about 90 inches and shaping them to a preferred
hydraulic diameter of about 0.08 inches.

25 43. The method of claim 41 including sizing the flow path to a
length of about 110 inches and shaping them to a preferred
hydraulic diameter of about 0.1 inches.

44. The method of claim 41 including sizing the flow path to a
30 length of about 130 inches and shaping them to a preferred
hydraulic diameter of about 0.12 inches.

45. The method of claim 41 including sizing the flow path to a
length of about 150 inches and shaping them to a preferred
35 hydraulic diameter of about 0.13 inches.

46. The method of claim 41 including sizing the flow path to a length of about 200 inches and shaping them to a preferred hydraulic diameter of about 0.14 inches.

5 47. The method of claim 41 including sizing the flow path to a length of about 250 inches and shaping them to a preferred hydraulic diameter of about 0.15 inches.

48. A heat exchanger comprising:
10 a first coil assembly including
an inlet manifold;
an outlet manifold parallel to and spaced from the inlet manifold; and
a plurality of tubes each operably connected to and linking
15 the inlet and the outlet manifolds, each tube having a multiplicity of flow paths in a parallel arrangement characterized by each of the multiplicity of flow paths having at least first and second cross-sectional shapes and a hydraulic diameter HD in the range of $0.07 < HD < 0.30$ inches.

20

49. The heat exchanger of claim 48 wherein the multiplicity of flow paths are in a parallel arrangement.

50. The heat exchanger of claim 49 further including fins
25 arranged in heat transfer relation between adjacent tubes of the plurality of tubes.

51. The heat exchanger of claim 50 wherein the fins have a sinusoidal shape.

30

52. The heat exchanger of claim 50 wherein the fins have a corrugated shape.

53. The heat exchanger of claim 50 further including a device
35 moving air across the first coil assembly and the heat exchanger is primarily formed of aluminum.

54. The heat exchanger of claim 50 further including a second coil assembly parallel to and spaced from the first coil assembly, each coil assembly lying in first and second respective planes which are substantially parallel to each other.

5

55. The heat exchanger of claim 54 including a third coil assembly located between the first and second coil assemblies and lying in a third plane not parallel to the first and second planes.

10

56. The heat exchanger of claim 55 further including a fourth coil assembly between the first and second coil assemblies and lying in a fourth plane not parallel to the first and second planes wherein the angle of the fourth plane is complementary to the angle of the third plane.

15

57. A method of manufacturing an air cooled chiller comprising the steps of:

forming a first heat exchanger to include a multiplicity of adjacent flow paths having at least first and second cross-sectional shapes, wherein the flow paths are sized and shaped to a preferred hydraulic diameter HD within the range of $0.07 < HD < 0.30$ inches;

20

providing a fan to move air across the multiplicity of adjacent flow paths;

25

providing a compressor, a second heat exchanger, and an expansion device; and

linking the compressor, the first heat exchanger, the expansion device, and the second heat exchanger serially into an air conditioning cycle by tubing.

30

58. The method of claim 57 including the further step of:

adaptively configuring the second heat exchanger to chill the temperature of a liquid.

35

59. The method of claim 57 including the further step of:
forming the first heat exchanger from aluminum.

60. The method of claim 59 including the further step of
5 interconnecting adjacent ones of the multiplicity of flow paths
with a corrugated or sinusoidal fin.

61. The method of claim 60 including the step of arranging the
multiplicity of flow paths in a common plane.

10

62. A method according to any one of claims 57 to 61 further
comprising the step of transferring heat through a wall enclosing
said flow paths and to a fluid contained therein.

15 63. The method of claim 62 including forming the wall from
aluminum.

64. A method according to any one of claims 57 to 63 including
forming the flow paths into first and second distinct cross-
20 sectional shapes.

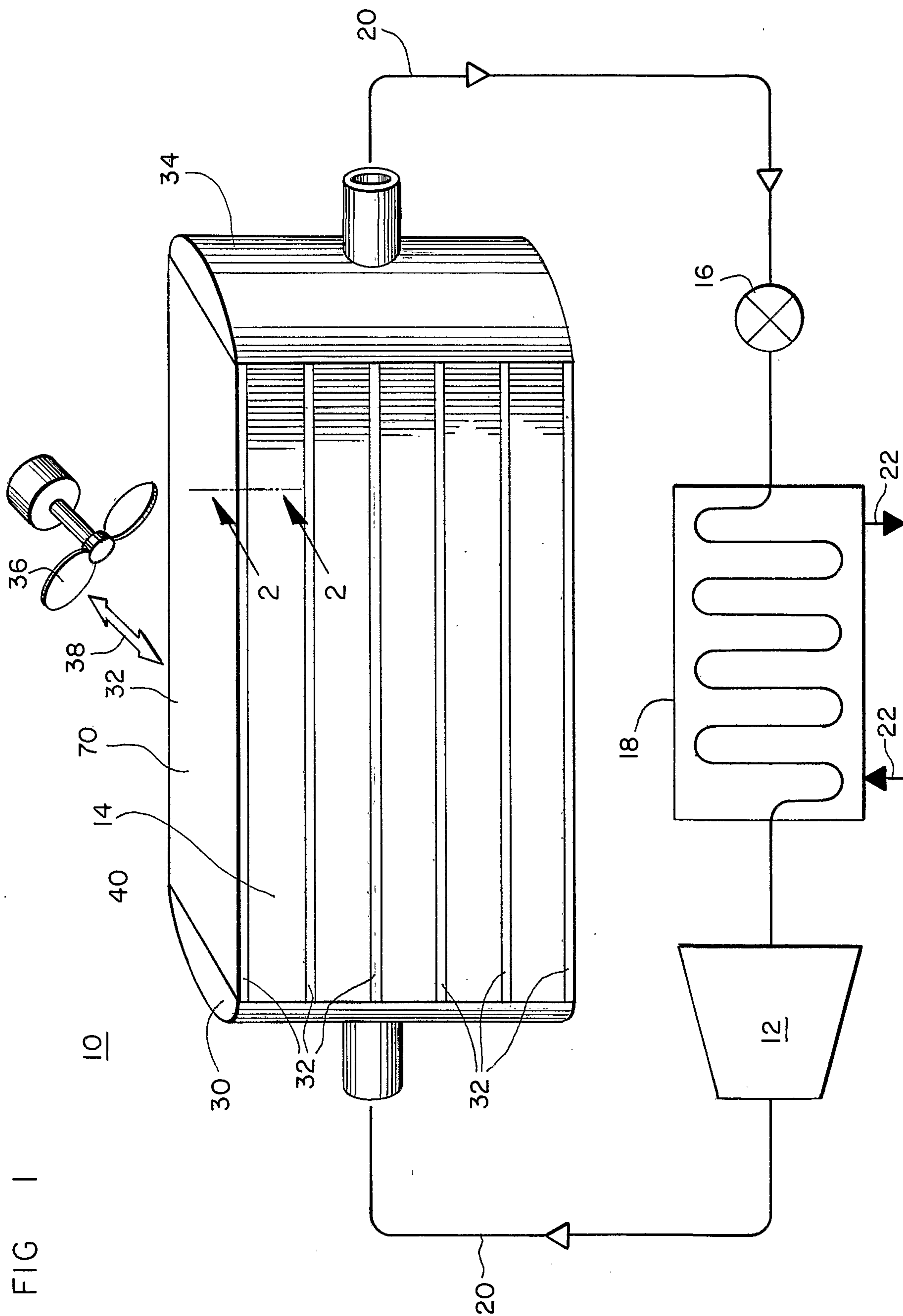


FIG. 2

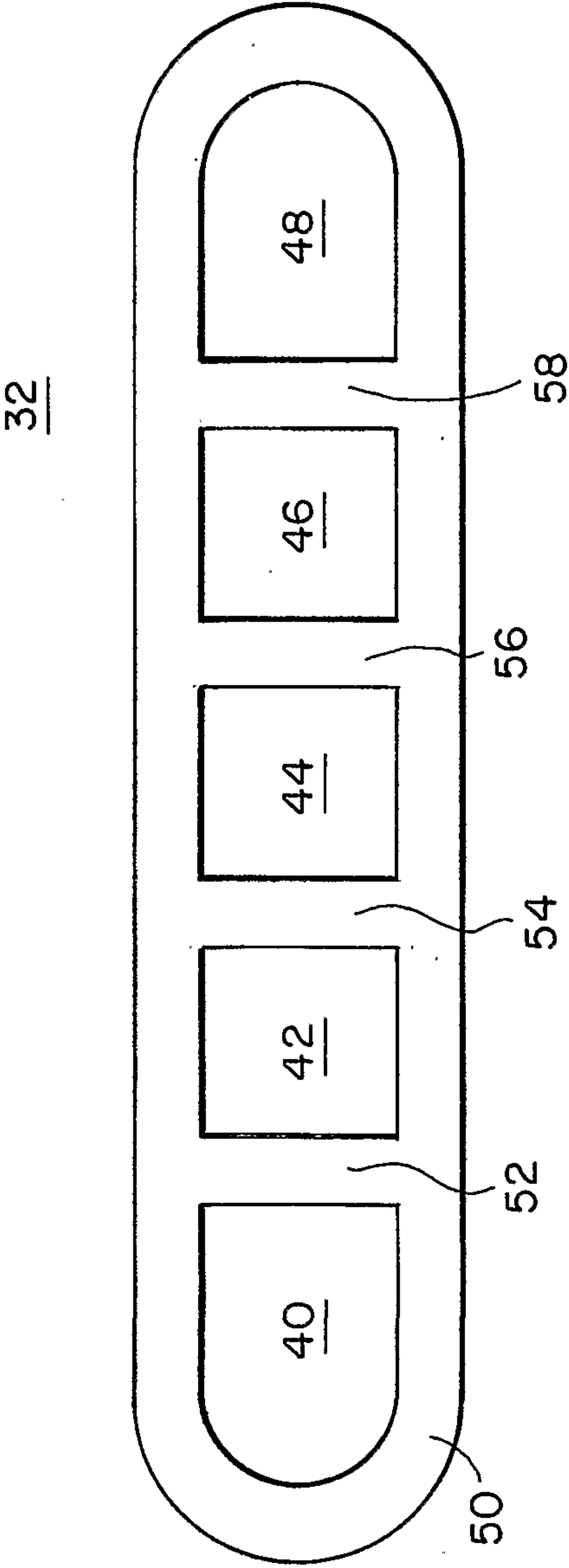
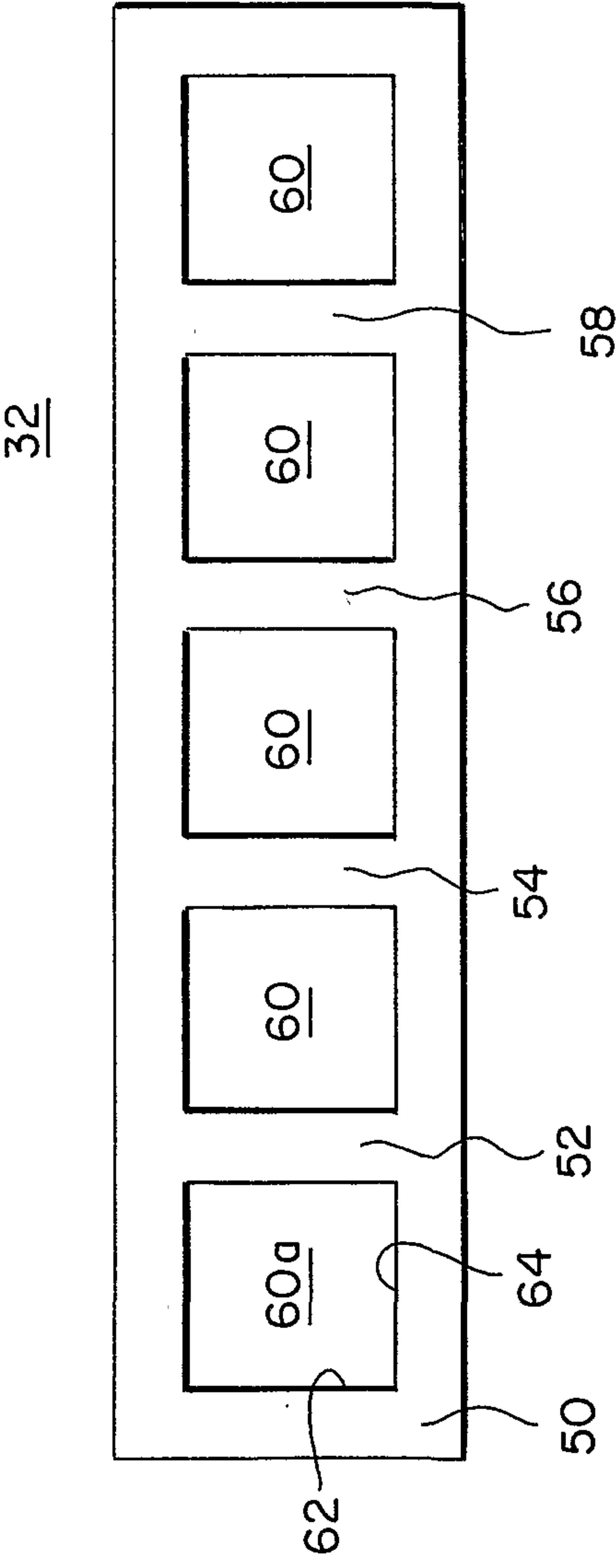


FIG. 3



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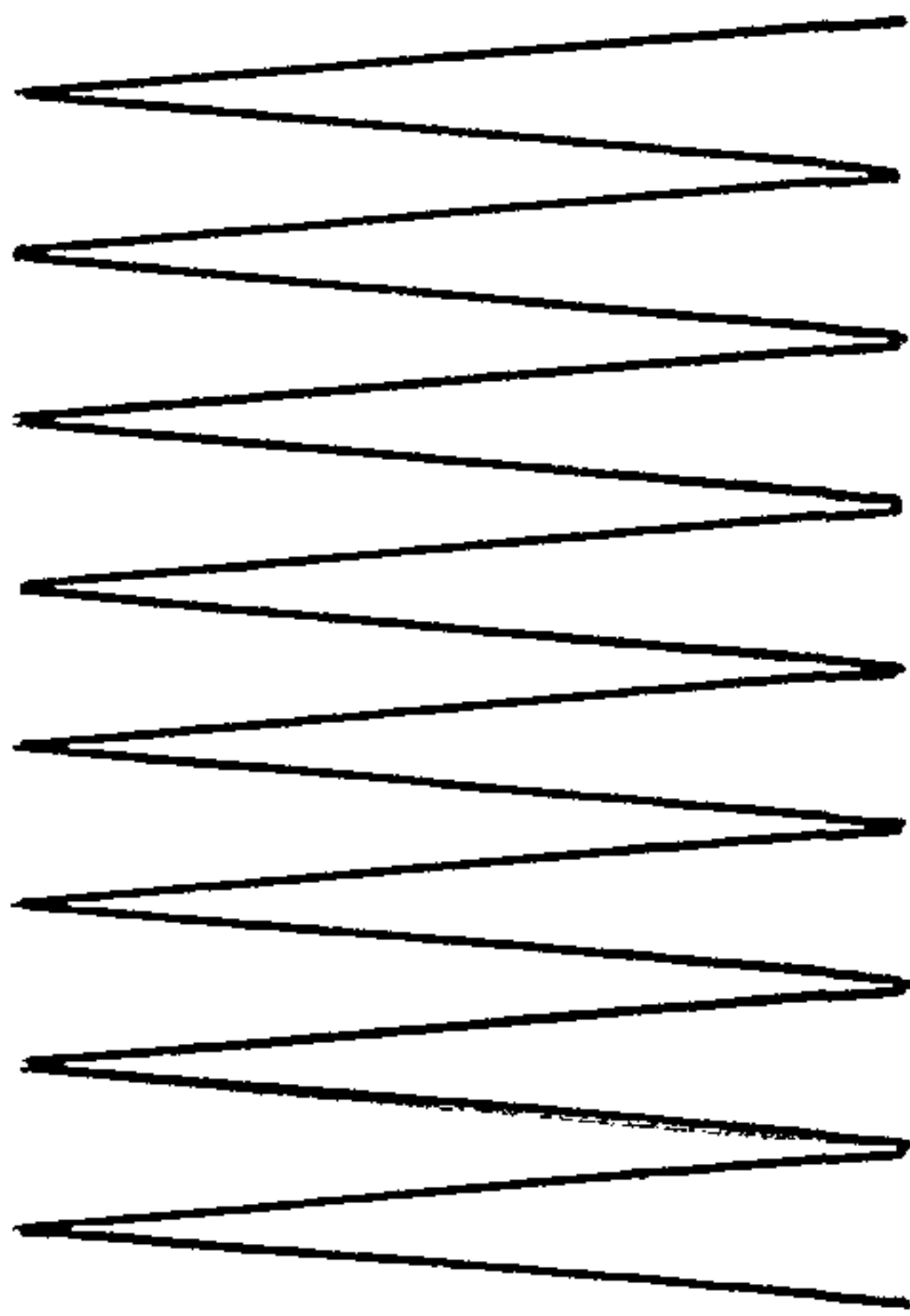


FIG. 4A

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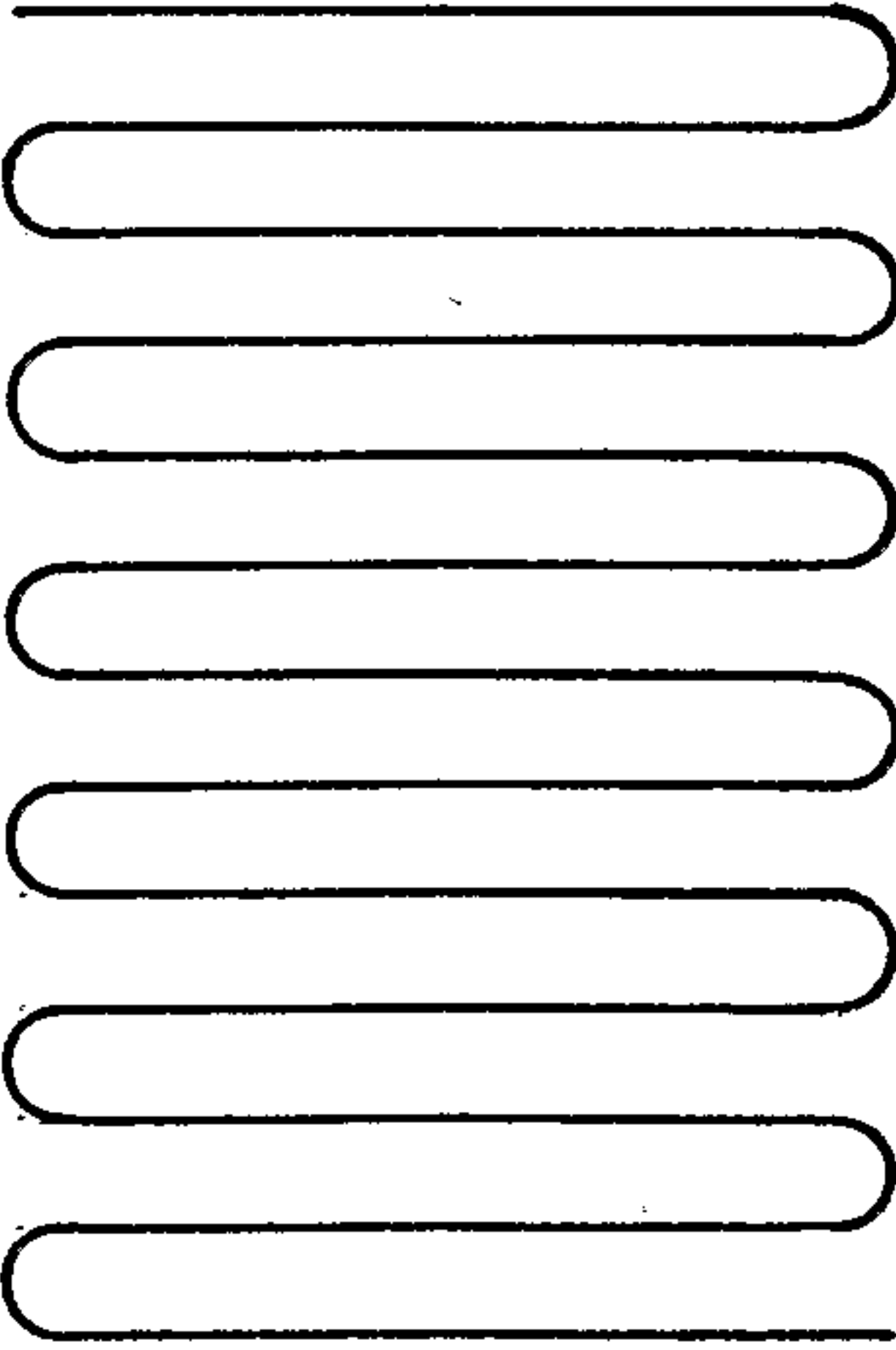


FIG. 4B

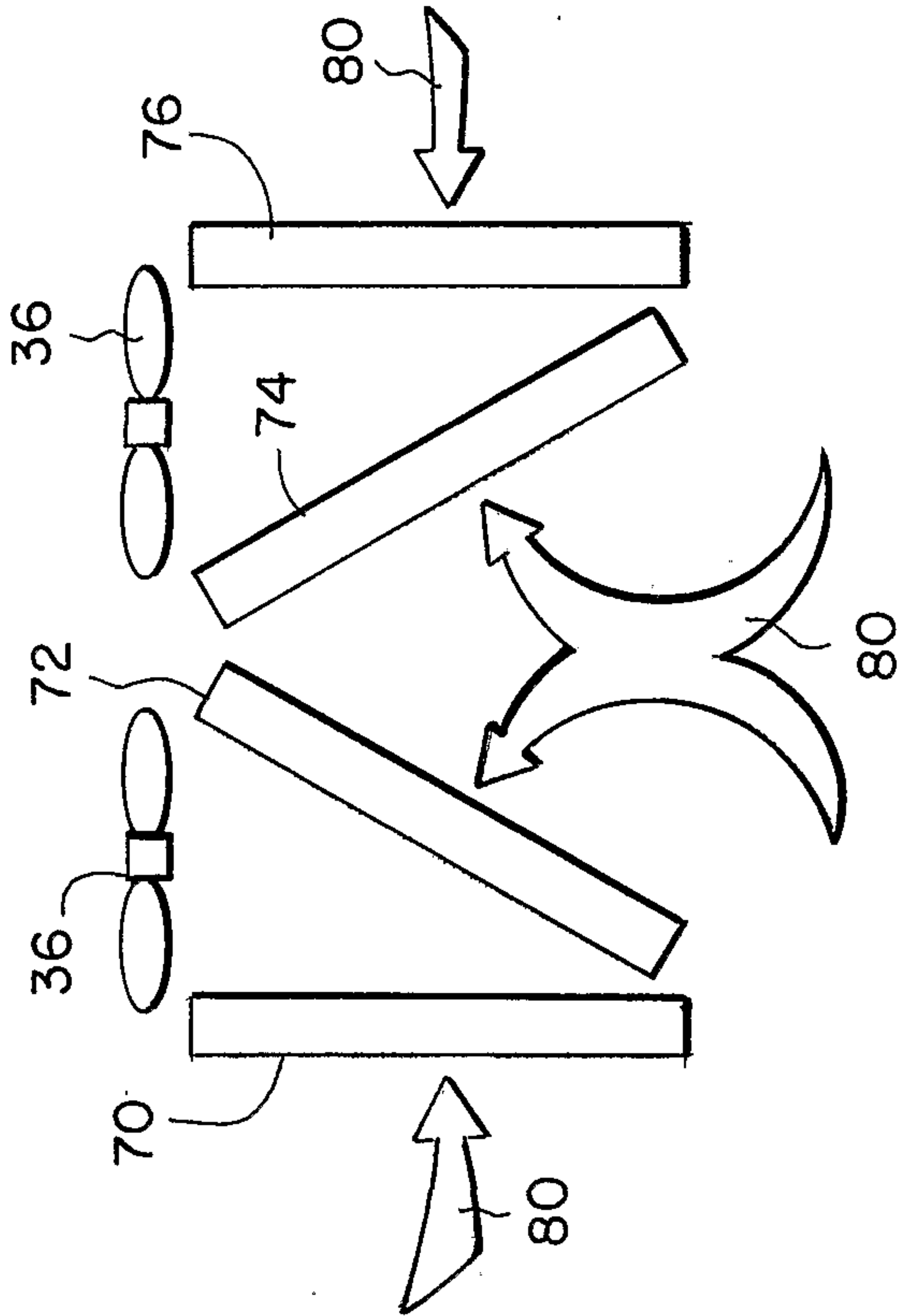


FIG. 5

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