United States Patent [19]

Beck

[11] **3,887,004**

[45] **June 3, 1975**

[54] **HEAT EXCHANGE APPARATUS**

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[73] Assignee: **Hayden Trans-Cooler, Inc.**, Corona, Calif.

[22] Filed: **June 19, 1972**

[21] Appl. No.: **263,931**

[52] **U.S. Cl.** .... **165/179**; 29/157.3 A; 165/184

[51] **Int. Cl.** **F28f 1/42**

[58] **Field of Search** 165/179, 183, 184; 138/38; 60/329, 337

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Assistant Examiner—Theophil W. Streule
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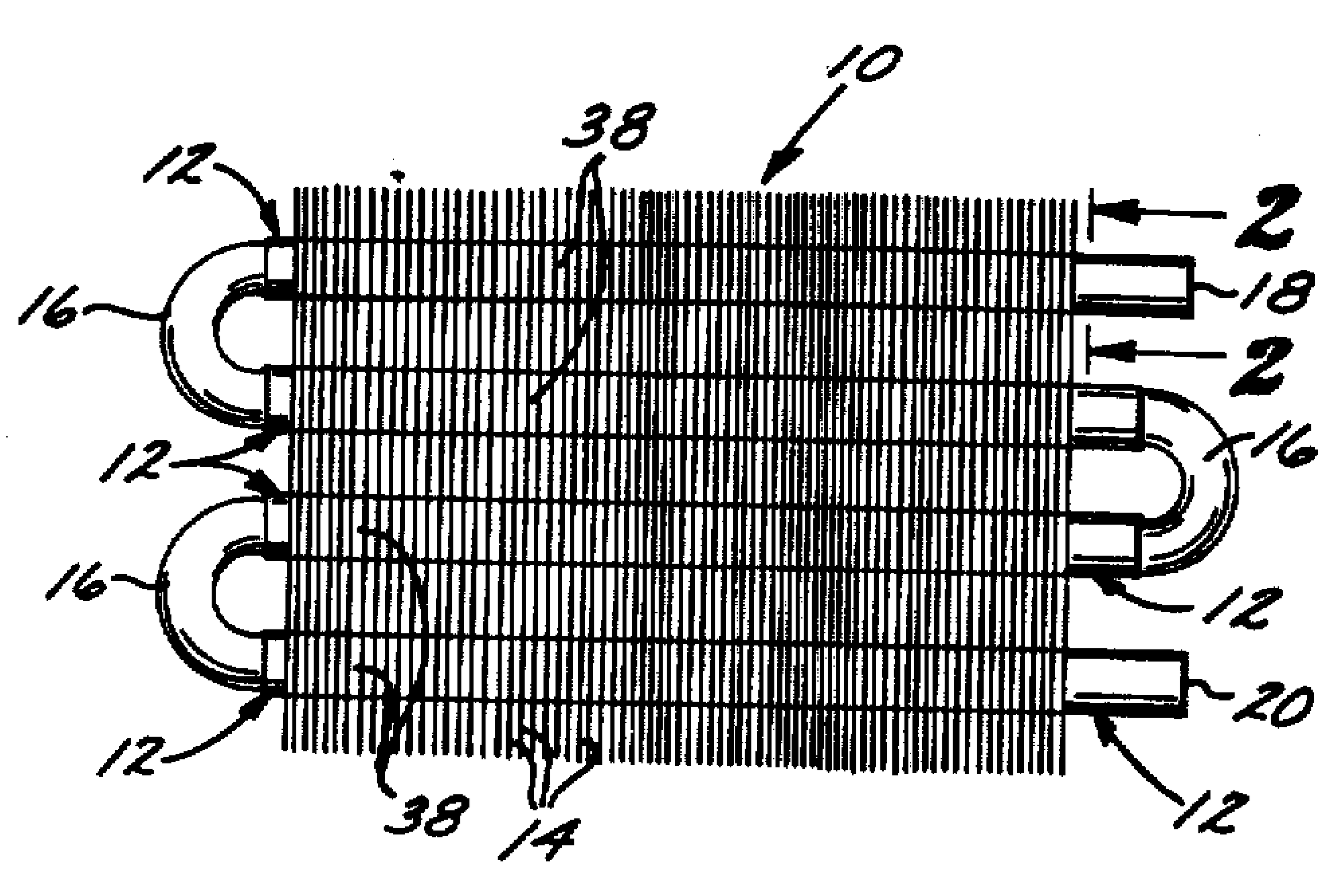
[57] **ABSTRACT**

The present invention relates in general to heat exchangers, and in particular to the type of heat exchanger which includes one or more tubular heat exchange units as a part thereof. More particularly, the present disclosure is directed to an improved tubular heat exchange unit usable in various types of heat exchange apparatus, and including a fluid flow control core which supports a plurality of regularly spaced, generally radially oriented heat exchange fins or splines that are preferably integrally extruded as a part of the core. In a preferred form the core fins have a novel cross-sectional configuration with symmetrical concave sides providing better heat exchange performance by combined improvements in fluid flow and heat gathering and conducing capacities, such cross-sectional fin configuration also providing improvements in assembly and structural integrity. Also disclosed herein are novel longitudinal configuration of the heat exchange fins including a step twisted or joggled configuration, a helically or spirally twisted configuration, and longitudinally segmented fin constructions provided by either annular grooving of the fins or helical grooving of the fins, these fin configurations providing improved heat transfer characteristics by turbulation of fluid conducted between the fins, and causing a circumferential component of fluid flow around the tubular heat exchange unit between cold and hot sides of the overall heat exchange apparatus.

15 Claims, 13 Drawing Figures



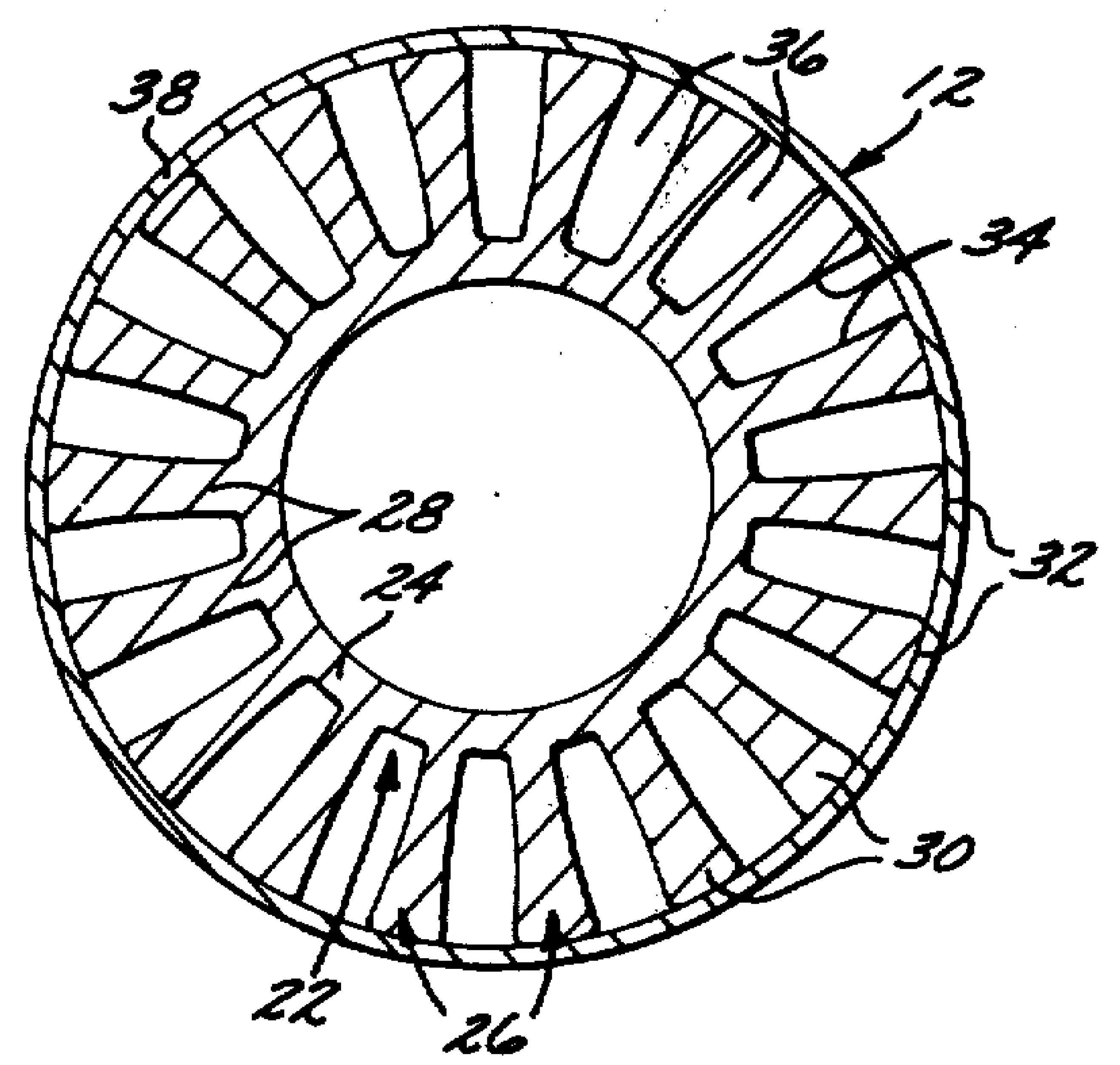
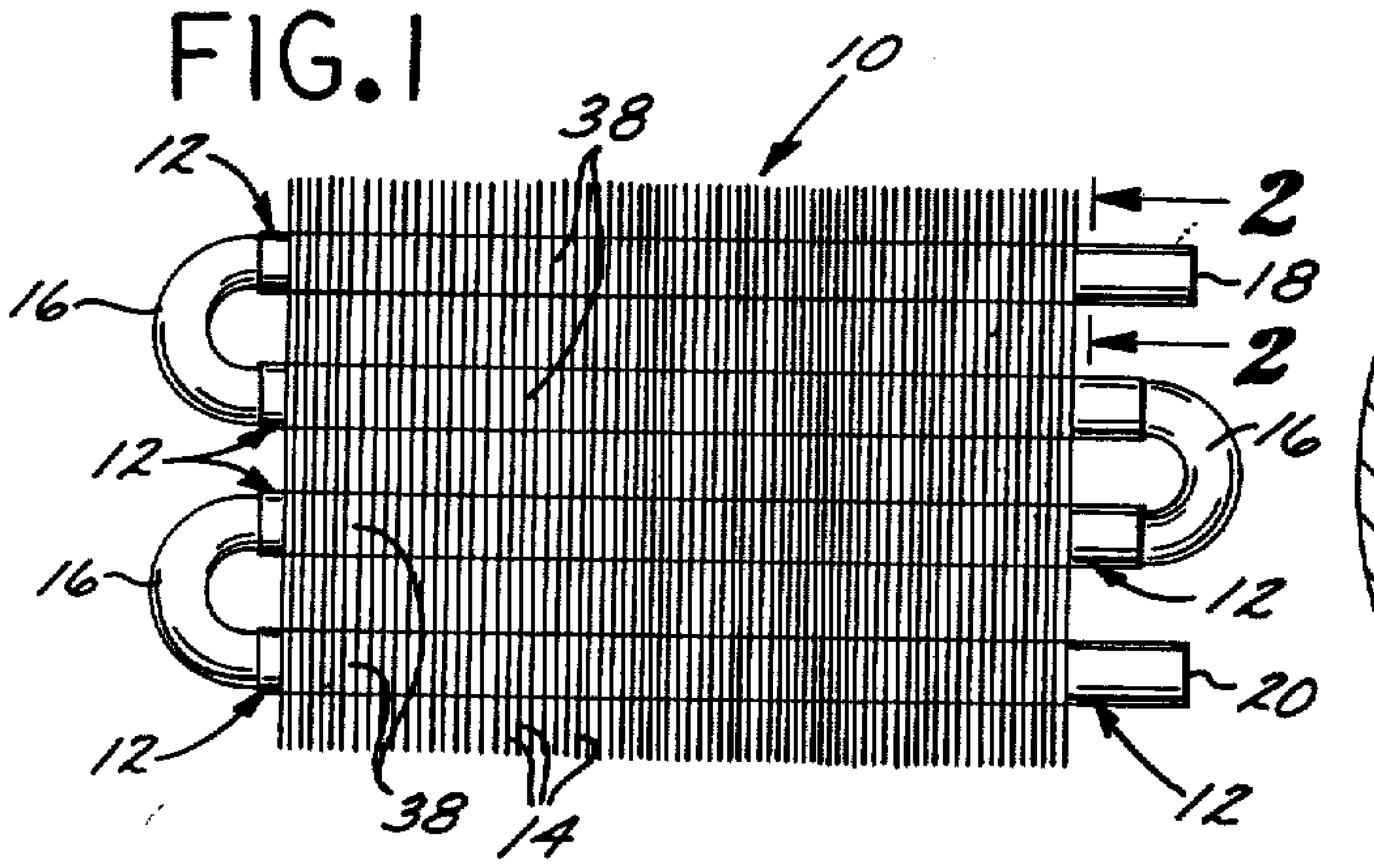


FIG.1



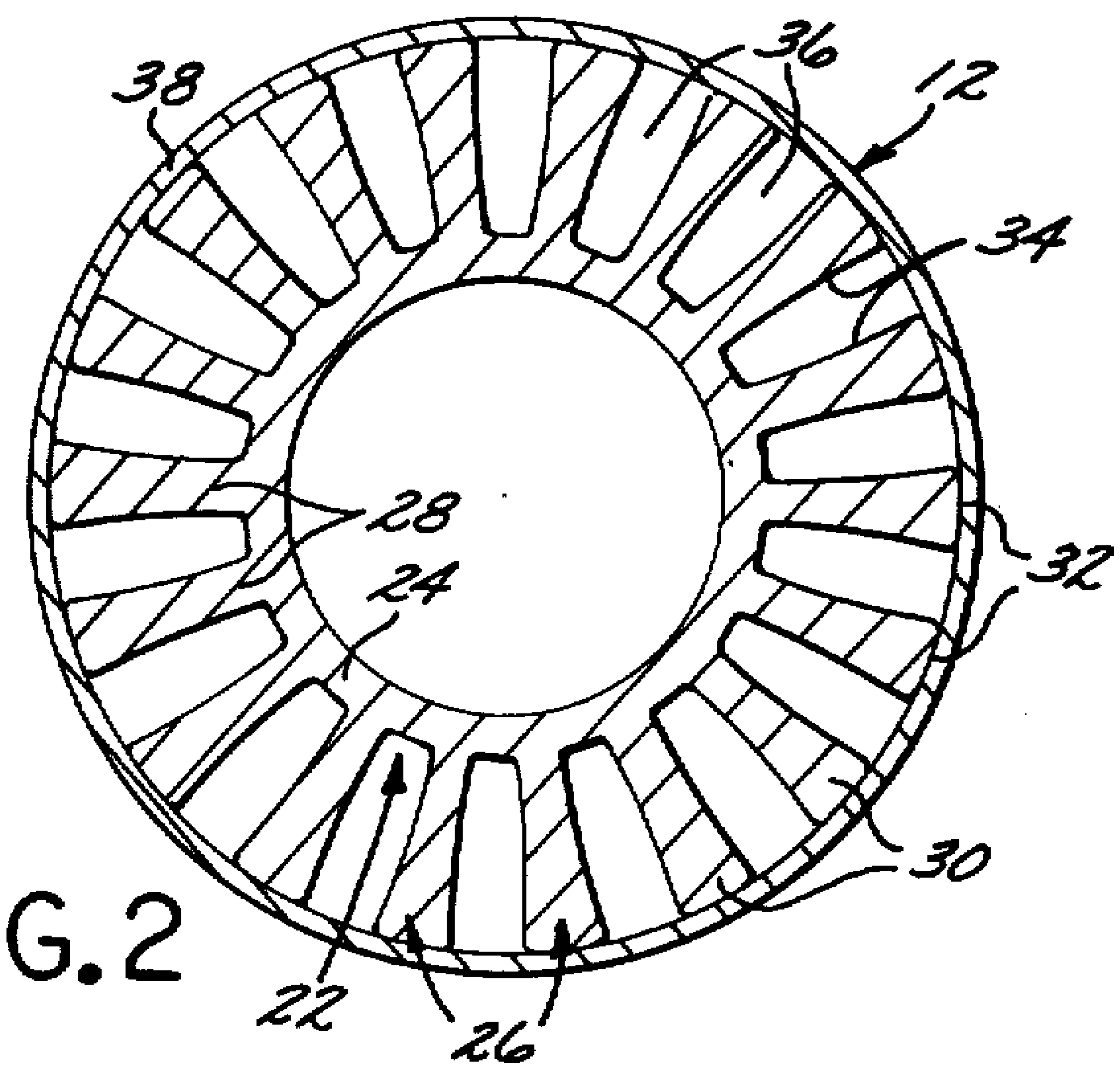


FIG.2

FIG.3

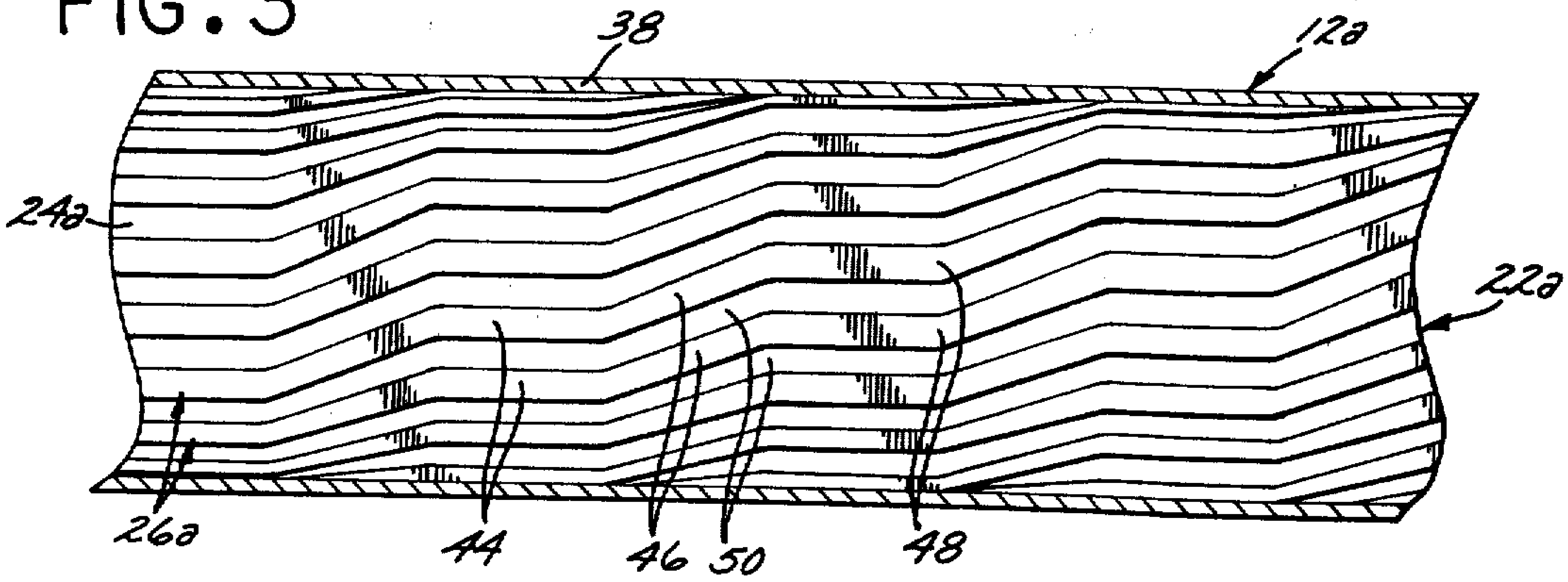


FIG.4

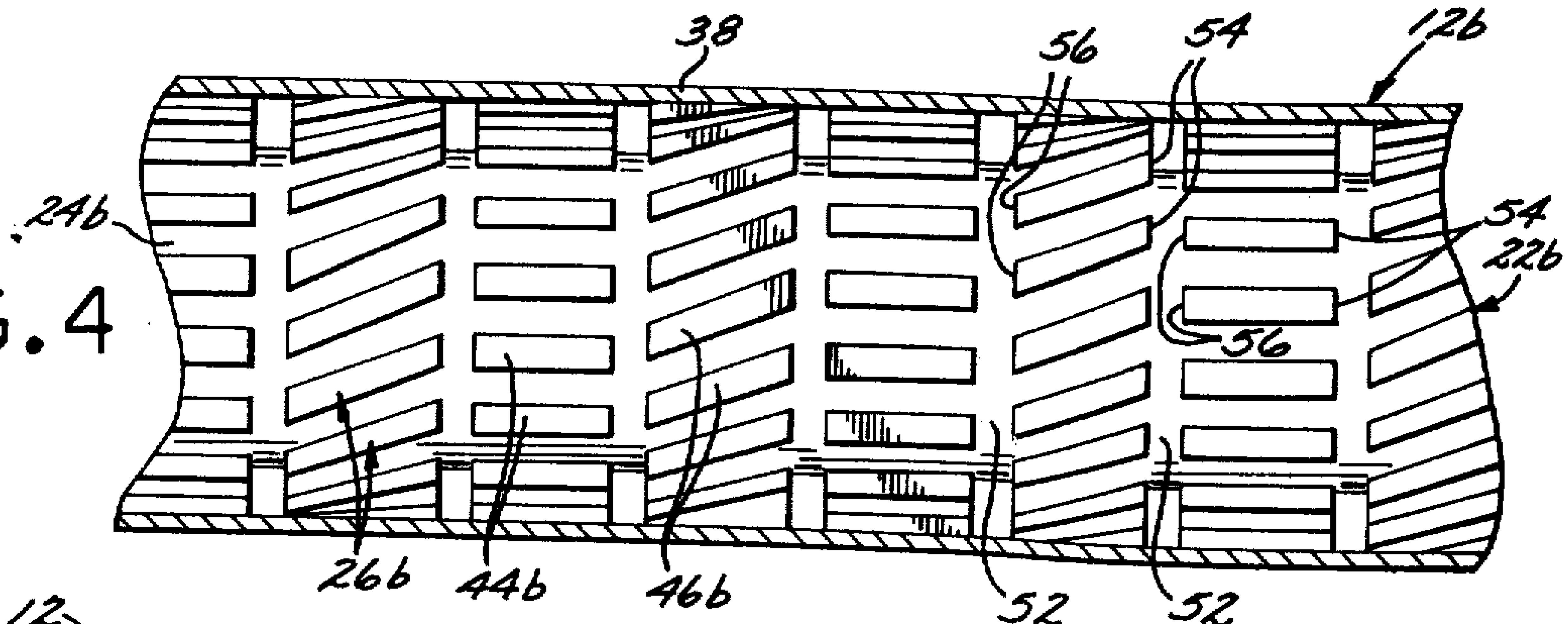


FIG.5

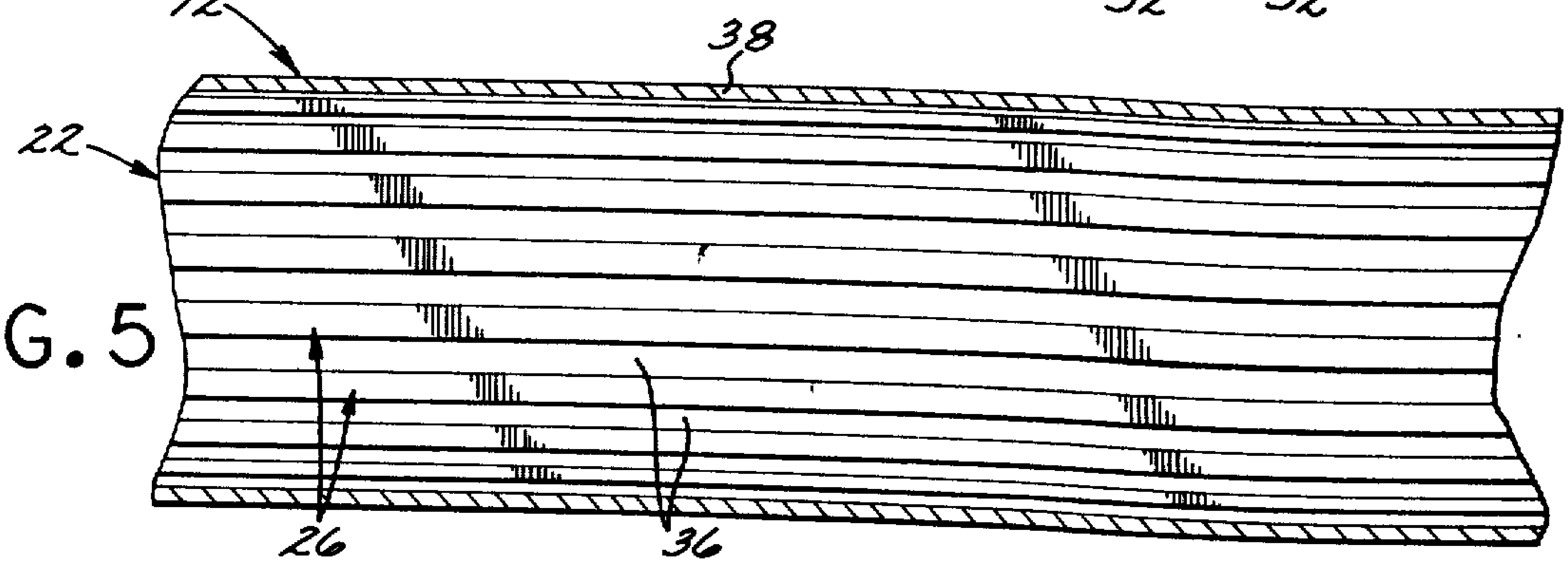


FIG. 6

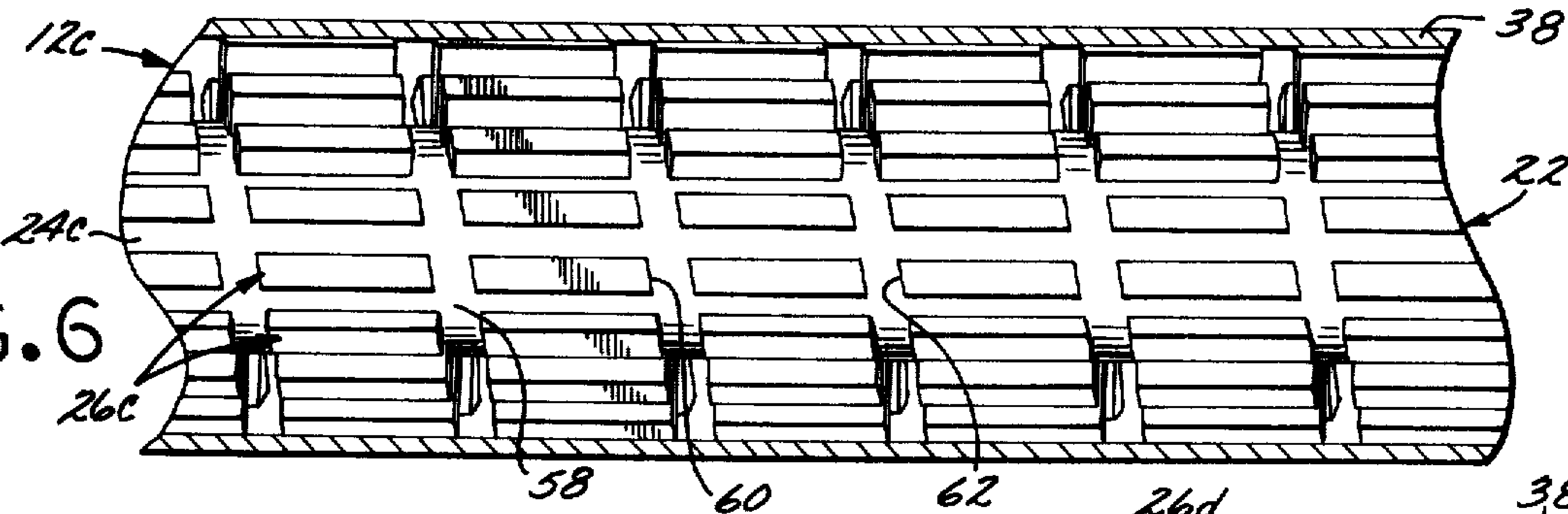


FIG. 7

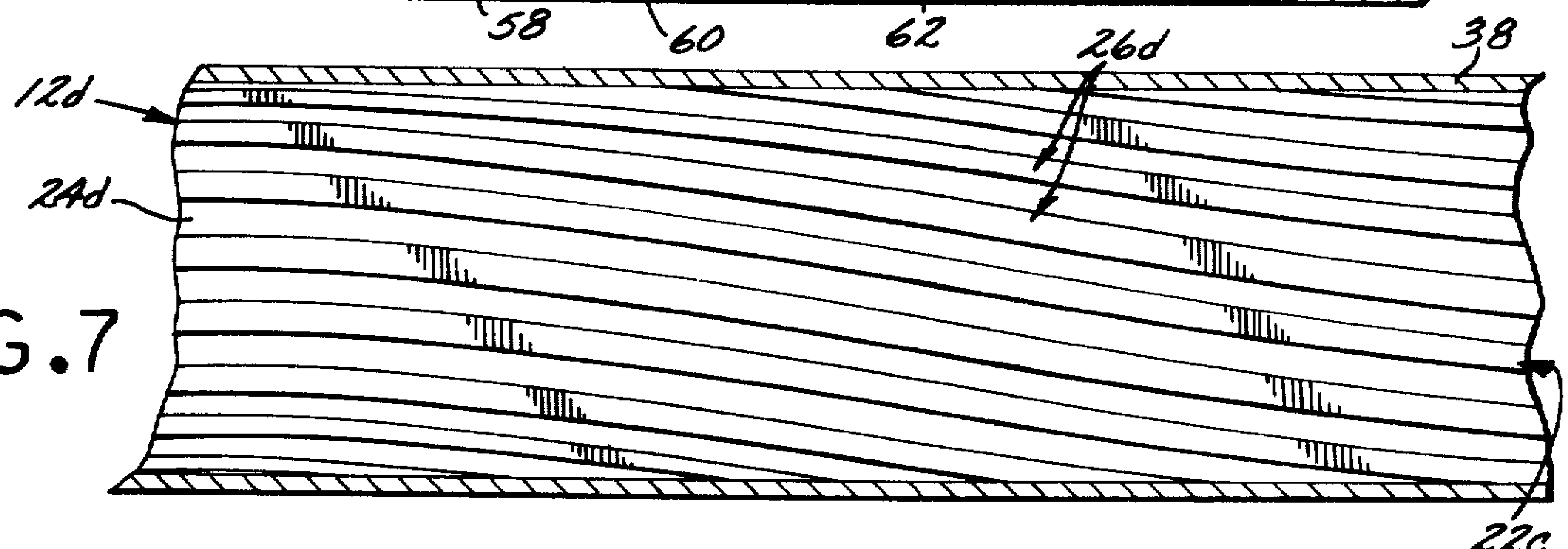


FIG. 8

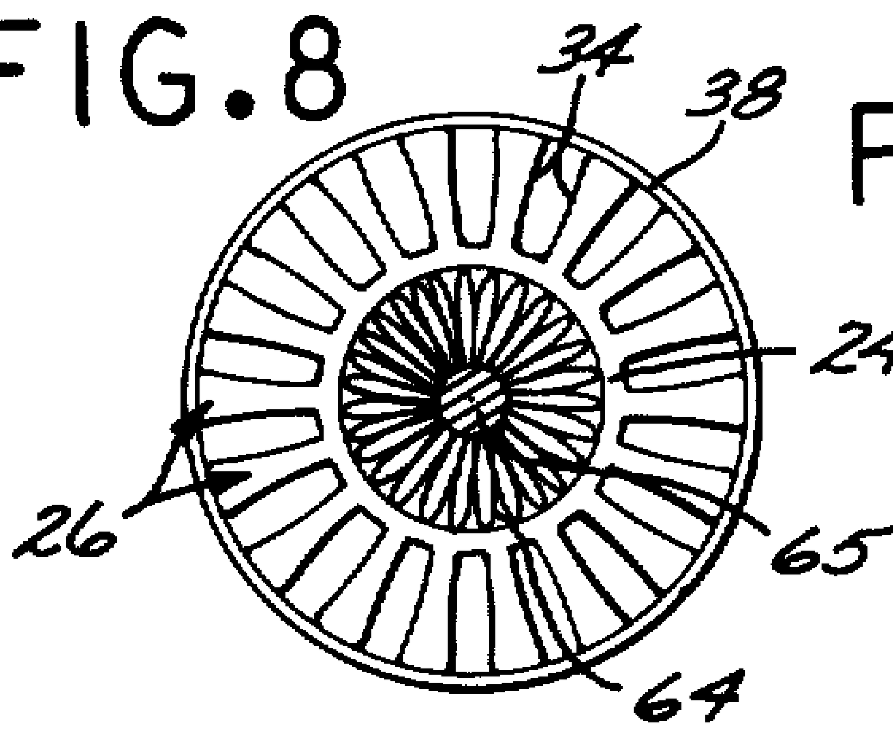


FIG. 9

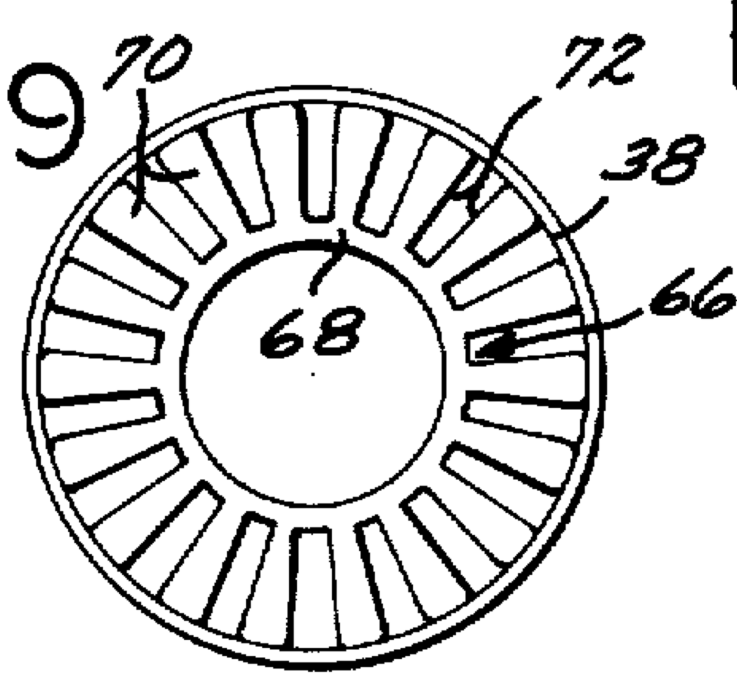


FIG. 10

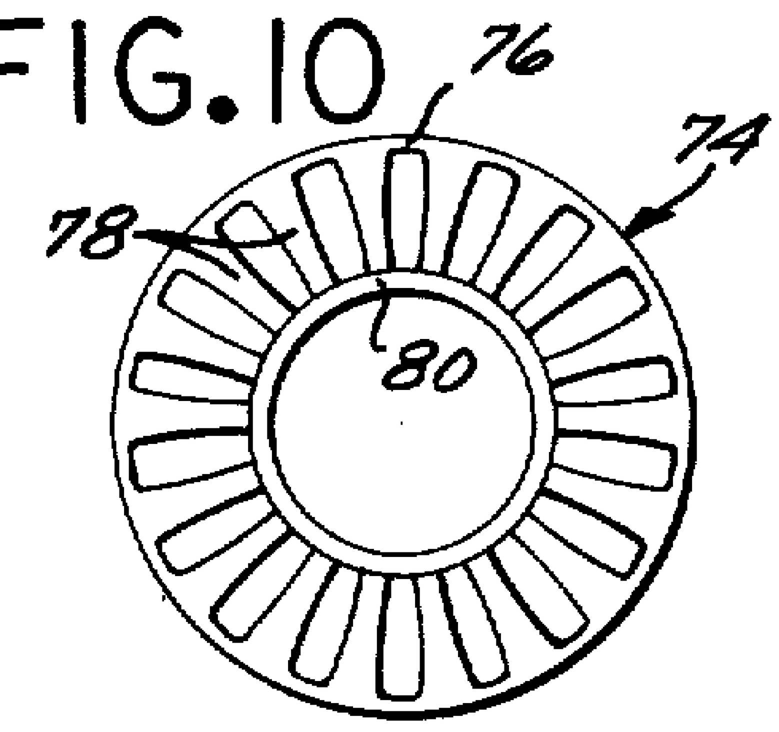


FIG. 11

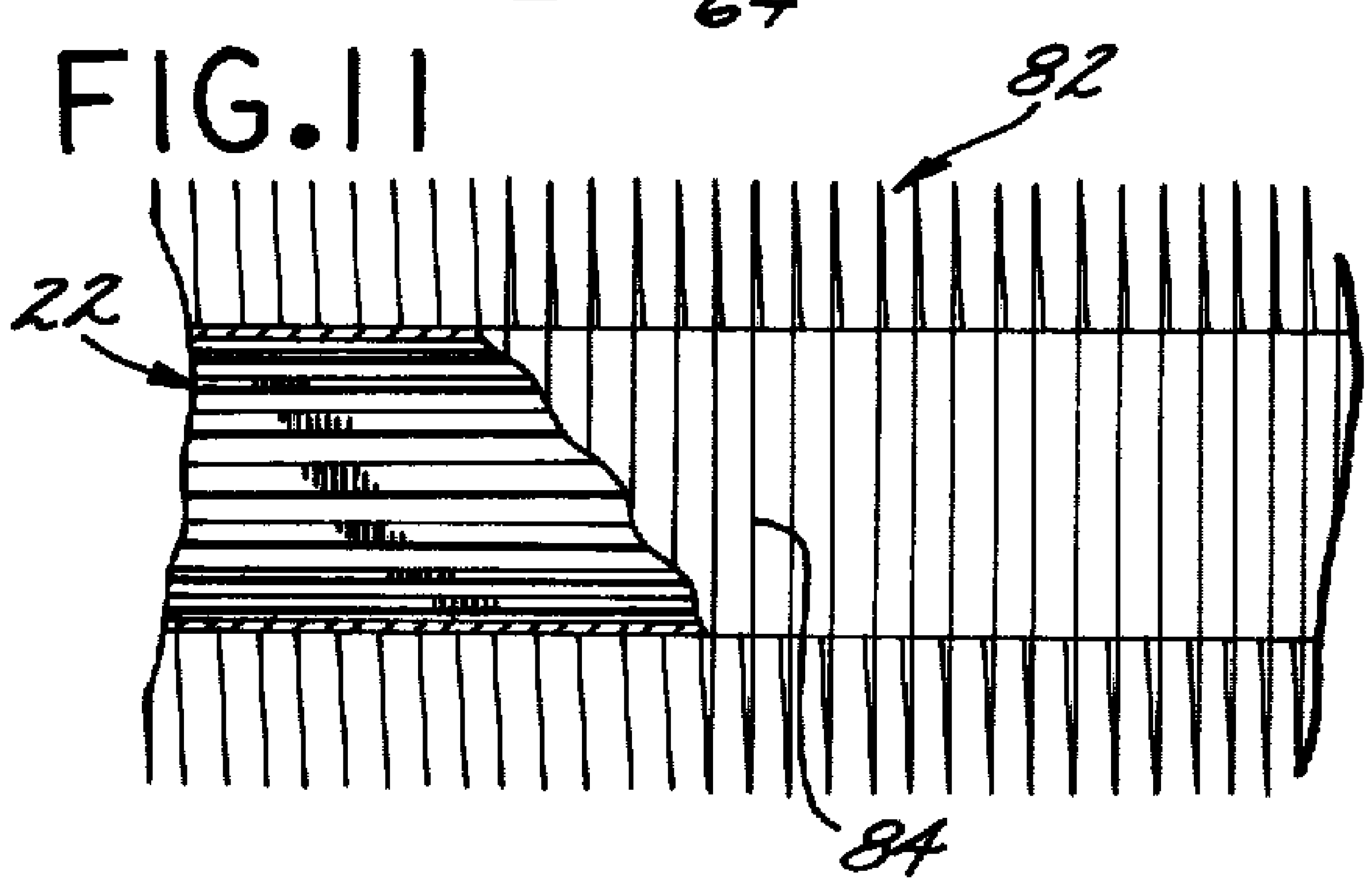


FIG. 12

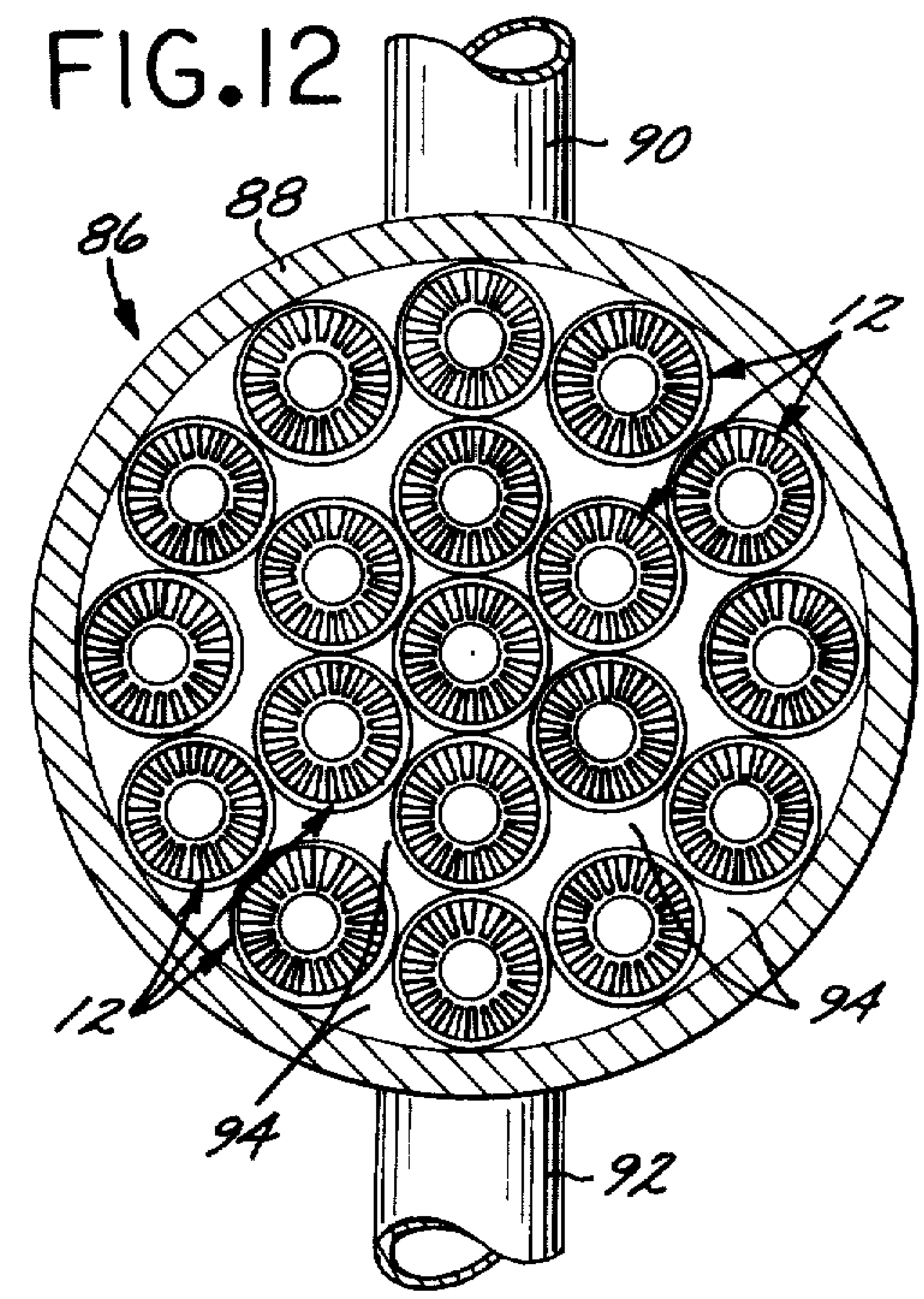
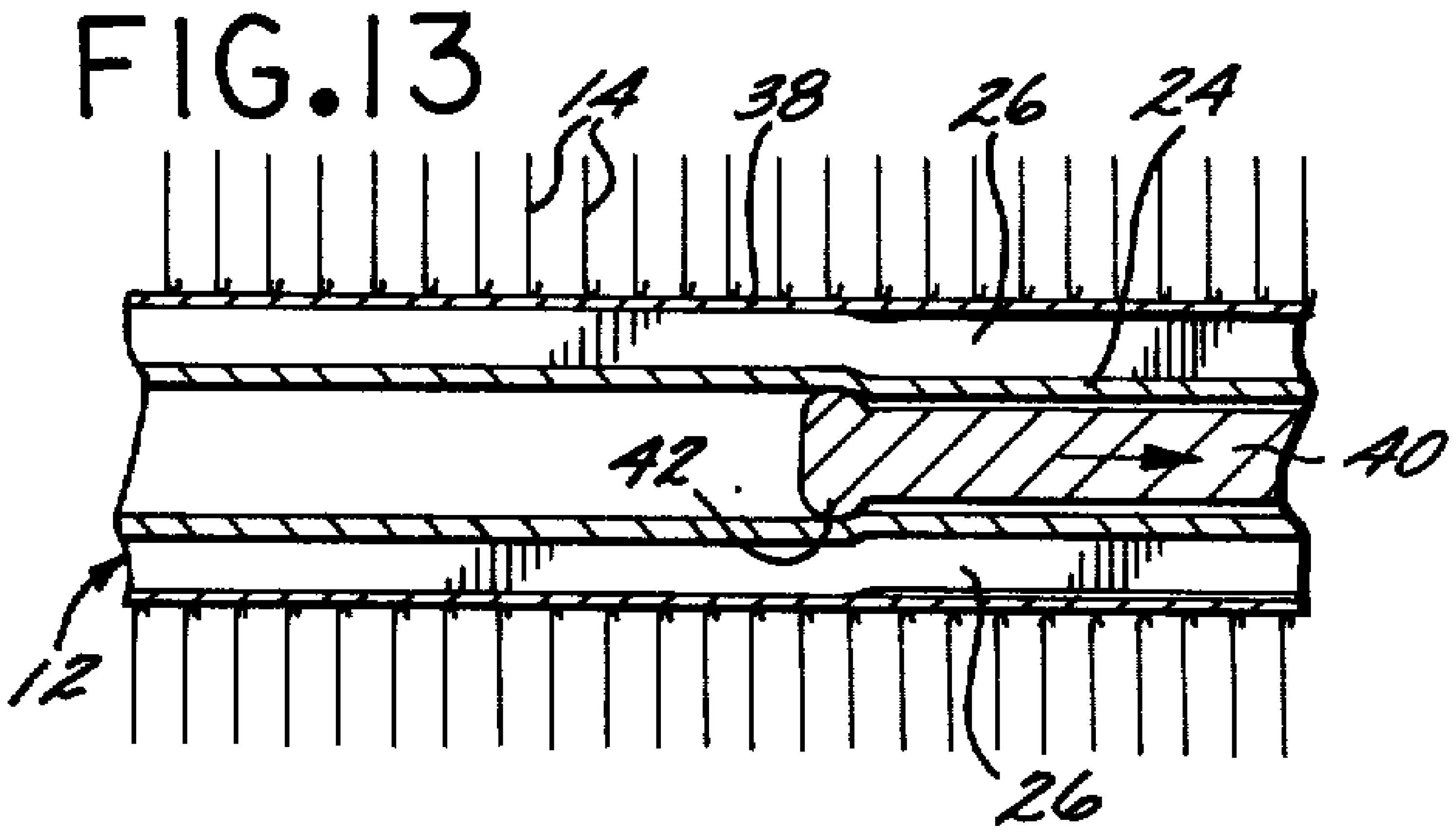


FIG. 13



HEAT EXCHANGE APPARATUS

BACKGROUND OF THE INVENTION

Heat exchangers are currently employed in a wide variety of fields, and they take a number of different forms. In many fields of heat exchanger usage, such as oil refining plants and industrial refrigeration apparatus, neither space nor weight is at a premium, so the heat exchangers can be large and bulky, and need not be particularly efficient. However, in certain heat exchanger environments it is of particular importance to provide a maximum of heat exchange capacity with a minimum size and weight. An example of such environment is the use of heat exchange apparatus for cooling the oils employed in connection with the operation of motor vehicles, such as transmission fluid used in automatic transmissions and torque converters, engine oil, power steering fluid, hydraulic fluids, and the like, such oils hereinafter being referred to simply as motor vehicle oils. In this motor vehicle environment, during excessive load conditions large amounts of heat must be exchanged from the fluid system into the atmosphere. Nevertheless, there is only minimal space or airflow available in most motor vehicles for placement of heat exchange apparatus for such purposes, and only part of the available space is disposed with good access to the air flow that is necessary for maximum heat exchanging. Accordingly, it is of vital importance in motor vehicle heat exchangers of this type to provide a maximum of heat exchange capacity in heat exchange apparatus of minimum overall dimension.

Similar considerations of high heat exchange capacity in a minimum space also prevail in other environments, as for example with other types of vehicles, in relatively small and compact refrigerations systems such as those found in the home, in restaurants, in computers, and the like.

Most heat exchange apparatus of high capacity with minimum size, such as heat exchange apparatus employed for cooling motor vehicle oils, is of a type having one or more tubular heat exchange units having external fins associated therewith, the oil passing through the tubular units giving up heat to internal fins thereof, the heat being conducted radially outwardly through the walls of the tubular units and thence to the external fins and being removed primarily by radiation and convection from the external fins. Conventional internal turbulating fin structures in such tubular heat exchange units are relatively inefficient, tending to permit laminar fluid flow, and not having particularly good heat gathering capability; and conventional fin constructions also tend to reduce heat transfer by obstructing the flow of fluid through the tubular heat exchange units.

SUMMARY OF THE INVENTION

In view of these and other problems in the art, it is an object of the present invention to provide a novel tubular heat exchange unit having a regular annular array of heat transfer fins therein of improved heat exchange characteristics.

Another object of the invention is to provide a tubular heat exchange unit of the character described wherein the heat transfer fins have a novel cross-sectional configuration with symmetrical concave sides that are preferably, but not necessarily, of generally parabolic curvature. This concave-sided fin configura-

tion improves heat transfer performance in a number of ways, including increasing the fluid flow channel cross section between the adjacent pairs of fins, reducing pressure drop, adding to the heat collecting surface areas of the fins, provided improved heat transfer characteristics between the inner root portions and outer toe portions of the fins, and adding surface contact area between the outer ends of the fins and the surrounding tubular shell.

In the presently preferred form of the invention the fins are integrally extruded with an inner tubular core body, the fins extending generally radially outwardly from this tubular core body and having their outer ends seated in metal-to-metal heat-exchange contact with the tubular outer shell of the tubular heat exchange unit. In assembling the flow control core consisting of the tubular core body and its fins to the outer tubular shell, the tubular core body is expanded radially outwardly to a much greater extent than the clearance to be taken up between the outer ends of the fins and the outer shell, and such outward expansion involves a unique cooperation of varying work hardening from the "as extruded" condition of the flow control core with the configuration of tubular core body and fins, wherein the tubular core body becomes a generally rigid internal supporting structure, the fins are hardest in their inner root portions where they are thinnest and need strengthening, and become softer radially outwardly to soft outer toe portions that are thereby made formable for intimate mating with the outer tubular shell, the hard internal supporting tube structure maintaining outward compression of the flow control core against the outer tubular shell for good structural integrity and heat conducting interfaces.

Another important feature of the present invention is the provision of novel longitudinal configurations of the heat exchange fins. One such longitudinal configuration is a step-twisted or joggled configuration wherein the fins are maintained in parallel relationship to each other, while they are stepped or joggled in a succession of alternate longitudinal portions which are preferably generally parallel to the axis of the tubular heat exchange unit and twisted portions which are inclined at a substantial angle to the axis and are generally helical; such step twisted or joggled fin configurations reducing the tendency for laminar flow and introducing turbulation into the fluid, as well as rotating the fluid circumferentially about the tubular heat exchange unit between cold and hot sides thereof.

Another novel longitudinal configuration of the fins is the segmentation thereof by either a series of annular longitudinally spaced grooves, or a single spiral or helical groove, such segmentations being applicable to either straight or joggled or spirally twisted fins, and adding additional turbulation and in the case of the spiral groove circumferential movement of the fluid. An important aspect of such longitudinally interrupted fins is that the grooves which provide the interruptions, while removing side surface areas from the fins, add the end surface areas of the fin segments so that overall surface area is not substantially reduced.

Other objects, aspects and advantages of the present invention will be apparent from the following description taken in connection with the accompanying drawings, wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevational view illustrating heat exchange apparatus of one type which is particularly suitable for use with the present invention.

FIG. 2 is an enlarged cross-sectional view taken on the line 2—2 in FIG. 1 illustrating one form of tubular heat exchange unit according to the invention.

FIG. 3 is a side elevational view, partly in axial section, showing a form of the invention wherein the core fins in the tubular heat exchange unit have a joggled or stepped twist configuration.

FIG. 4 is a view similar to FIG. 3 illustrating a form of the invention wherein the core fins are longitudinally interrupted by a series of longitudinally spaced annular grooves.

FIG. 5 is a view similar to FIGS. 3 and 4, but illustrating a flow control core of the tubular heat exchange unit which has longitudinaly arranged core fins that are generally parallel to the axis of the unit.

FIG. 6 is a view similar to FIGS. 3, 4, and 5, but illustrating longitudinal interruption of the core fins by a helical groove which provides a series of longitudinally spaced grooves in each of the fins.

FIG. 7 is a view similar to FIGS. 3 to 6, but illustrating a core body having helically twisted fins.

FIG. 8 is an end elevational view illustrating a heat exchange unit similar to that shown in FIG. 2, but with the addition of an inner fin structure disposed within the tubular core body.

FIG. 9 is an end elevational view illustrating a modified flow control core having generally flat-sided fins.

FIG. 10 is a view similar to FIG. 9, but illustrating a flow control core of generally inverted construction wherein the tubular core body is on the outside and the integral fins extend generally radially inwardly therefrom.

FIG. 11 illustrates heat exchange apparatus embodying the invention which has a spiral finned outer shell.

FIG. 12 is a transverse section, with portions shown in elevation, illustrating heat exchange apparatus wherein a "bundle" of tubular heat exchange units according to the invention is enclosed within an outer heat exchanger shell.

FIG. 13 illustrates an expansion method step used in making a tubular heat exchange unit according to the invention and securing the same within finned heat exchange apparatus.

DETAILED DESCRIPTION

FIG. 1 illustrates heat exchange apparatus 10 of a general type that is currently widely employed in heat exchange systems for cooling motor vehicle oils. Such heat exchange systems employing heat exchange apparatus of the general type shown in FIG. 1 are described in U.S. Pat. No. 3,315,464, issued Apr. 25, 1967 to Perez M. Hayden for "Heat-Exchange System." The heat exchange apparatus 10 represents typical heat exchange apparatus in which the present invention may be employed, although it is to be understood that the present invention is adaptable for any type of heat exchange apparatus which utilizes tubular heat exchange members therein. It is also to be understood that while the present invention is particularly useful in heat exchange apparatus that is employed for cooling motor vehicle oils under circumstances of excessive heat production, nevertheless the invention is suitable for any

heat exchange purpose involving the transfer of heat from one fluid to another.

The heat exchange apparatus of FIG. 1 includes a plurality of tubular heat exchange units 12 according to the present invention, these heat exchange units 12 being four in number in the apparatus 10, and being arranged in a generally parallel, regularly spaced planar array. The tubular heat exchange units 12 are maintained in this array by engagement thereof through spaced apertures in a series of parallel fins 14 that are disposed normal to the axes of the tubular heat exchange units 12. The fins 14 serve not only as supporting structures, but they are in heat exchange relationship with the outer surfaces of the tubular heat exchange units 12, and thereby add considerable additional heat exchange area to the outer surfaces of the tubular heat exchange units 12 so as to increase the overall heat exchange efficiency of the apparatus 10.

The tubular heat exchange units 12 are interconnected by means of a series of U-shaped end fittings 16 so that the tubular heat exchange units 12 are arranged for serial flow of fluid therethrough between open ends 18 and 20 which are adapted to be connected into the heat exchange system.

FIG. 2 illustrates a presently preferred cross-sectional arrangement for a tubular heat exchange unit 12 according to the present invention. The heat exchange unit 12 includes two principal structural components, a tubular flow control core 22 and a tubular outer shell 38. Both of these components 22 are preferably extrusions, and they may be extruded from any material having good heat transfer characteristics, as for example aluminum, copper or other heat conducting metal.

The flow control core 22 includes a tubular core body 24 which serves as an inner tube member for the heat exchange unit 12. Integrally extruded with the core body 24 are a plurality of regularly spaced, generally radially outwardly extending core fins or splines 26. For illustrative purposes 18 of these regularly spaced core fins 26 have been shown in FIG. 2. However, any desired number of these core fins 26 may be provided without departing from the present invention. Thus, for example, flow control cores 22 may be provided with 12 fins, 18 fins, 22 fins, or other desired number of fins. Since most of the useful heat transfer area of heat exchange unit 12 exposed to the fluid that flows therethrough is in the side surfaces of the core fins 26, what is desired is a maximum of such core fin side surface heat transfer area, while at the same time maintaining a maximum flow conduit cross section between adjacent fins 26. In other words, what is desired is the best possible combination of heat transfer area and minimum pressure drop in the tubular heat exchange unit 12. With present extrusion techniques, the presently preferred number of core fins 26 is about 22, which allows the fins to be relatively long in the radial direction, while at the same time being relatively narrow in the circumferential direction, so as to provide an excellent combination of large heat transfer area and low pressure drop. However, if extrusion die manufacturing techniques materially improve over those currently available, then the "tongue ratio" (area/width^2) of the fins could be increased to allow an increase in the number of fins without the fins being shortened to the point of losing performance.

Nevertheless, the optimum number of fins will depend upon the viscosity, specific heat and conductivity of the heat exchange fluid, as these factors will determine the frictional losses and the heat transfer characteristics in relation to any particular number of the fins **26.**

Still referring to FIG. **2** of the drawings, each of core fins **26** commences at a root portion **28** proximate the core body **24** and terminates in a toe portion **30** having a free end surface **32** that is preferably arcuately complementary to the curvature of the inside of the tubular shell **38** within which the flow control core **22** is engaged. Each core fin **26** is symmetrical about its radial axis, and in the preferred cross-sectional form of the invention as shown in FIG. **2**, each core fin **26** has symmetrical side surfaces **34** which are concave in the general radial direction, the core fin being relatively thin at its root portion **28**, and thickening at a non-uniform, progressively increasing rate from the root portion **28** to the free end surface **32.** The preferred form of this concave curvature of the side surfaces **34** is parabolic.

The symmetrical concave side surface configuration for the core fins **26** provides a number of advantages over core fins that have parallel straight sides or radially outwardly flaring straight sides. One advantage is that the concave side surfaces **34** provide a substantial increase in the cross sections of the fluid flow channels **36** between adjacent fins **26,** without losing any heat collecting or transferring capacity of the fins. In fact, a second advantage of the concave side surfaces **34** of the fins **26** is that the increased surface area provided thereby and the flaring at the toe portion **30** actually provide increased efficiency in heat collection and transfer to the free end surfaces **32** of the fins **26.** Another advantage of the concave side configuration for the core fins **26** is that when the flow control core **22** is expanded outwardly against the tubular outer shell **38** as hereinafter described in detail, the concavities in the sides of the core fins **26** accommodate some bulging in the fins. Another factor of improvement caused by the concave sides is that the resulting circumferential widths of the free end surfaces **32** of the fins **26** are greater, providing increased heat flow contact surface areas between the outer surfaces of the fins **26** and the inner surface of the tubular shell **38.** Not only does this added circumferential width at the fin ends **32** increase the heat transfer, but it also tends to stabilize the generally radial orientation of the fins against buckling or distortion as the flow control core **22** is expanded outwardly against the tubular shell **38.**

FIG. **13** illustrates a presently preferred method of making heat exchange apparatus embodying the present invention. FIG. **13** illustrates a fragmentary section of heat exchange apparatus like the apparatus **10** shown in FIG. **1,** taken axially of one of the tubular heat exchange units **12** of the invention. Prior to the method step that is in progress in FIG. **13,** the parallel fins **14** were assembled over the tubular shell **38** of heat exchange unit **12,** and the tubular shell **38** was expanded outwardly against the fins **14** to provide secure mechanical interconnection between the shell **38** and fins **14.** Such outward expansion of the tubular shell **38** against the fins **14** is by conventional means, as for example by passing an expander mandrel axially through the tubular shell **38.** Such outward expansion of the tubular shell **38** causes work hardening in the shell **38** so that shell **38** is illustrated in FIG. **13** is substantially harder than in the "as received" condition thereof.

In making heat exchange apparatus like the apparatus **10** shown in FIG. **1,** normally all of the tubular shells **38** will be assembled with the fins **14** by the aforesaid expansion of the shells **38,** and at least one end of each of the shells **38** (i.e., each of the four in the apparatus **10** of FIG. **1**) will be left open for insertion of a respective flow control core section **22** therein. Thus, for example, in the apparatus **10** of FIG. **1,** the U-shaped end fittings **16** may all be absent when the cores **22** are inserted in the respective tubular shells **38,** or if desired the two end fittings **16** at the left-hand side of the apparatus **10** as shown may be installed, and the single central fitting **16** may still be unconnected, so that all of the four flow control cores **22** can be inserted from the right-hand ends of the tubular shells **38.** For ease of assembly, it is preferred to provide some clearance between the free end surfaces **32** of the core fins **26** and the inner surface of the tubular shell **38.** For example, for a typical flow control core **22** having an O.D. of approximately 11/16 inch, it is desirable to have a clearance of approximately 0.005 inch between the thin ends **32** and the inner surface of shell **38.** With present extrusion techniques it is difficult to establish such clearance with the desired uniformity, so that it is preferred to either roll or draw the flow control cores **22** to the desired size. Such rolling or drawing provides a configuration of the free end surfaces **32** of the core fins **26** which is more nearly accurately complementary to the inner surface of tubular shell **38,** for better mating therebetween and hence better heat transfer characteristics.

Referring to FIG. **13,** after the flow control core **22** is slidably inserted into tubular shell **38,** the core **22** is then expanded radially outwardly into compressive engagement with the shell **38** by any conventional means, as for example by one or more passes of a mandrel **40** axially through the tubular core body **24** of the flow control core **22,** the mandrel **40** having a bead or "bug" **42** thereon which causes the expansion. It is preferred to expand the core body **24** outwardly much more than the amount of the clearance between the end surfaces **32** of the fins and the shells **38** in order to provide a preferred combination of work hardening in strategic portions of the core **22** and intimate mating between the free end surfaces **32** of the core fins and the shell **38.** For example, with an initial clearance of about 5/1000 inch between the fin end surfaces **32** and the shell **38,** it is desirable to apply approximately three times this amount or about 15/1000 inch of radial expansion to the tubular core body **24.** This expansion step is illustrated in FIG. **13,** the flow control core **22** being expanded from left to right by the mandrel bead **42.**

This relatively large amount of radial expansion of the core body **24** relative to the initial clearance causes a considerable amount of work hardening of the tubular core body **24** from its initially soft "as extruded" condition, so that the internal supporting tubular core body **24** becomes quite hard, and serves as a stable internal supporting structure for the core fins **26.** This expansion also causes a considerable amount of work hardening in the actual fins **26,** but such work hardening is greatest proximate the root portions **28** of the fins, and decreases outwardly through the fins to a minimum of work hardening proximate the toe portions **30** of the fins, and particularly at the free end surfaces **32** of the fins. Thus, the relatively thin root portions **28** of the fins are substantially strengthened by work hardening, while the thicker toe portions **30** which inherently have greater structural strength remain softer, and the soft free end surface portions **32** of the fins are formable against the tubular shell **38** for excellent mating contact therewith and consequent good thermal flow characteristics therebetween. Generally the tubular shell **38** will be harder from its aforesaid work hardening than the free end surfaces **32** of the fins **26**, and with the relatively hard inner core body **24** and the relatively hard outer tubular shell **38**, there will be good permanent radial loading on the fins **26** under all operative conditions of the heat exchange apparatus.

For the example given, with an initial clearance between the O.D. of the flow control core **22** and the I.D. of tubular shell **38** of about 0.005 inch, and with an expansion of the tubular core body **24** of about 0.015 inch, it is found in practice that the outer tubular shell **38** will be further expanded outwardly approximately another 0.001 inch, which serves to further secure the structural connection between the shell **38** and the fins **14** and thereby provide a stronger overall heat exchange apparatus.

After a flow control core **22** is thus inserted and expanded into each of the tubular shells **38** of the heat exchange apparatus **10**, then the end fitting connections of the apparatus **10** may be completed.

While the flow control cores **22** will normally only be used in straight sections of the outer tubular shells **38**, it is to be understood that an assembled tubular heat exchange unit **12**, including both the flow control core **22** and the tubular outer shell **38**, may be bent as desired for a particular heat exchange installation, provided the arc of the bend is sufficiently large to avoid crimping or collapsing of the assembly.

In addition to the forming of the free end surfaces **32** of the core fins **26** against the inner surface of tubular shell **38**, the outward pressurization of the fins against the shell **38** described in detail hereinabove results in the outer ends of the fins actually slightly sinking into the material of tubular shell **38**, which is a factor in the excellent heat flow characteristics of the interface between the fins **26** and the tubular shell **38**.

If desired the core **22** may be secured within the tubular shell **38** by furnace brazing as an alternative to the aforesaid preferred expansion technique.

The central passage within tubular core body **24** may either be blocked off against the flow of fluid therethrough so as to force all of the fluid to flow through the flow channels **36**, or left open so that fluid will flow both through the flow channels **36** and through the center of core body **24**. If there is an unlimited flow of fluid available, then the maximum heat exchange capacity of a tubular heat exchange unit **12** will be achieved by having the center of core body **24** open and passing fluid through both the flow channels **36** and the center of core body **24**. However, without a large fluid flow availability the tubular heat exchange unit **12** will be more efficient if the center of core body **24** is blocked off and the fluid is thereby required to flow through the channels **36**. An alternative arrangement is to provide valve means within core body **24** which permits the flow of fluid through core body **24** according to the temperature and/or viscosity of the fluid, such alternative being the subject matter of another patent application concurrently filed by the present applicant and entitled "Heat Exchange Valve System."

FIG. **3** illustrates a tubular heat exchange unit **12*a*** having a flow control core **22*a*** which includes a tubular body **24*a*** and core fins **26*a***. This flow control core **22*a*** preferably, but not necessarily, has a cross-sectional configuration like that illustrated in FIG. **2** and described in detail in connection therewith. In the heat exchange unit **12*a*** the core fins **26*a*** are provided with a stepped twist or joggle, while nevertheless being maintained parallel to each other. Thus, each of the core fins **26*a*** is formed to a series of alternating longitudinal portions **44** which are generally parallel to the axis of the core **22*a*** and twisted portions **46** which are inclined at a substantial angle relative to the axis of core **22*a*** so as to be generally helically disposed. The transitions from longitudinal portions **44** to twisted portions **46** and from twisted portions **46** back to longitudinal portions **44** are preferably sharply defined direct angle bends **48** in the core fins **26*a***. The step twisted or joggled core fins **26*a*** provide step twisted or joggled flow channels **50** therebetween, and each of these channels as it extends longitudinally along the flow control core **22*a*** progresses circumferentially around the flow control core **22*a***, preferably at least 180°.

The step twisted or joggled flow channels **50** have several important advantages. One advantage is that each direction change imposed upon the fluid flowing through the channels **50** causes a reduced film thickness of the fluid proximate the fin surfaces, thereby improving the heat transfer characteristics. Additionally, each direction change causes a turbulence in the fluid, which further increases the heat transfer characteristics. The sharper and more direct the change in direction of the fluid flow at the angle bends **48**, the more effective the film thickness reduction and turbulation, and accordingly the better the heat transfer characteristics. Also, the channels between the twisted fin portions **46** are narrower than those between the straight fin portions **44**, whereby the fluid flow in the twisted channels will have increased velocity and reduced pressure (according to Bernouli's principle), which causes a further turbulation, tending to create fluid vortices when the fluid is suddenly subjected to speed reduction, pressure increase and direction change as it enters the straight channels from the twisted channels.

Another important advantage of the step twisted or joggled fin construction as shown in FIG. **3** is that it conducts the fluid peripherally around the tubular heat exchange unit **12a** from one side to the other in a heat exchange apparatus such as the apparatus **10** that embodies a heat exchange unit **12*a***. Heat exchange apparatus such as apparatus **10** is typically disposed in an airstream which enters through one flat side of the apparatus **10** and leaves through the other, so that the side through which the airstream enters becomes colder than the side from which the air-stream leaves. The stepped twist or joggled arrangement of the core fins **26*a*** thus causes the fluid in the tubular heat exchange unit **12*a*** to rotate around the unit **12*a*** between the cold and hot sides of the overall heat exchange apparatus, producing maximum heat transfer efficiency.

FIG. **4** illustrates a tubular heat exchange unit **12*b*** that is similar to the heat exchange unit **12*a*** shown in FIG. **3**, but which has annular grooves cut in the core fins thereof by saw or knife cutting or the like for further turbulation of the fluid passing generally axially through the heat exchange unit **12**b. Thus, the unit **12**b includes flow control core **22**b having step twisted or joggled core fins **26**b which are parallel and which each include a series of alternate longitudinal portions **44**b and twisted portions **46**b. The core fins **26**b are longitudinally interrupted by a series of longitudinally spaced annular grooves **52** which may extend into the core fins **26**b to any desired depth. Preferably, the annular grooves **52** are cut approximately through the entire depth of the core fins **26**b to the tubular core body **24**b, but if desired the depth of the cut may be either less or more. Some or all of the grooves **52** may be unequally cut, if desired, to an extent providing some communicating passages between the flow control channels defined between adjacent core fins **26**b and the bore within the tubular body **24**b.

As the fluid passes through a channel defined between either a pair of longitudinal fin portions **44**b or a pair of twisted fin portions **46**b, the velocity and viscosity of the fluid tend to make its flow become laminar; but before substantial laminar characteristics of flow can be established, the fluid reaches a groove **52** and becomes turbulated to disturb such laminar flow. In this manner, the fluid flow is repeatedly disturbed as the fluid progresses both axially and circumferentially through the heat exchange unit **12**b, and optimized heat exchange characteristics are obtained by maintaining a balance of turbulent and laminar flow.

It will be noted that in FIG. **4** the grooves **52** are shown as being cut proximate the angle bends of the step twisted or joggled fins. This provides opposite end faces **54** and **56** on the discrete core fin segments which are proximate the change of direction of flow of the fluid for good turbulating effect of both upstream and downstream faces. The sharp, knife-like corners of the fin segments which face upstream scavenge some of the central fluid flow from each channel and divert it into the next channel and against the fin sides, thereby assuring repeated fin surface contact of all portions of the fluid.

However, if desired the grooves **52** may alternatively be cut through the longitudinal centers of the longitudinal portions **44**b and the twisted portions **46**b of the core fins **26**b; or the grooves **52** may be longitudinally spaced at other intervals.

Satisfactory turbulating results have been achieved with the grooves **52** cut from about 0.020 inch to about ¼ inch in axial width, with their centers axially spaced from about ¼ inch to about 1 inch. However, it is preferred to have the axial width of each groove **52** approximately equal to the average core fin thickness, which provides a substantial turbulating gap, without any substantial loss in heat transfer surface area of the fins since the surface area of the added faces **54** and **56** substantially completely compensates for the loss in side surface area of the fins. If the grooves **52** were made substantially wider in the axial direction of the unit **12**b, then heat transfer surface of the fins would be sacrificed; while on the other hand, if the grooves **52** were made substantially narrower in the axial direction of the unit **12**b, then turbulation would be decreased. Because of the importance of having a maximum amount of heat transfer surface area in the fins, and since the heat transfer area is actually increased by the grooves **52** if they are narrower than the average fin thickness, and heat transfer surface area is not reduced until the width of the grooves **52** becomes greater than the average thickness of the fins, it is preferred according to the invention to provide grooves **52** which are not substantially wider in the axial direction than the average fin thickness.

The stepped type of twist is shown in FIGS. **3** and **4** can be provided by taking an untwisted flow control core **22** such as that shown in FIG. **5** and, before insertion thereof in the outer shell **38**, gripping the core **22** at spaced axial locations corresponding to the longitudinal portions **44** of the fins as shown in FIG. **3** and applying the required twisting forces to twist the core **22** until the fins acquire the desired amount of twist, such as the twist of the fin portions **46** as shown in FIG. **3.** Gripping force for such twisting action, and definition of discrete angle bends **48,** may be achieved by engaging a series of gripping lugs between adjacent core fins proximate the longitudinal portions **44** thereof as shown in FIG. **3**, such lugs having substantially the same axial length of the longitudinal fin portions **44** as shown in FIG. **3.**

Nevertheless, a tubular heat exchange unit **12** as shown in FIG. **5**, including a flow control core **22** having generally straight core fins **26** and intermediate flow channels **36** which are generally parallel to the axis of the heat exchange unit **12,** will have good heat exchange characteristics with a cross-sectional configuration generally as shown in FIG. **2.**

Referring now to FIG. **6** of the drawings, a tubular heat exchange unit **12**c is illustrated which embodies a generally untwisted or straight flow control core **22**c having tubular core body **24**c and core fins **26**c. In this form of the invention a helical groove **58** is provided in the core fins **26**c, as by saw or knife cutting or the like, such helical groove **58** separating each of the core fins **26**c into a series of discrete core fins sections having end faces **60** and **62.** The angular inclines and sharp leading corners of the faces **62** resulting from the helical type groove **58** tend to deflect and swirl the fluid streams in vortexlike movements proximate the groove for good turbulation. The angular faces also tend to circulate the fluid circumferentially as it progresses axially through the heat exchange unit **12**c, shifting the centers of the fluid streams into contact with fin surfaces and moving the fluid between cold and hot sides of heat exchange apparatus embodying this type of heat exchange unit **12**c.

The spiral frequency or number of spirals per inch of the groove **58** is important to the heat transfer capability, and is preferably about the same as the spacing between adjacent grooves **52** in the form shown in FIG. **4.** Accordingly, a suitable "lead" for the groove **58** is about ⅜ inch between groove centers for a particular fin, with leads between ¼ inch and 1 inch operating satisfactorily, for a flow control core **22**c that is roughly ¾ inch in diameter. However, an increase in the spiral frequency will generally be desirable to accommodate an increase in the number of fins. As with the grooves **52** of FIG. **4**, groove widths for the helical or spiral grooves **58** may be a width from about 0.020 inch to about ¼ inch, but it is preferred that the width be approximately the same as the average thickness of the fins **26**c, and not be substantially greater than the average thickness of the fins **26**c. The helical groove **58** preferably extends radially inwardly through the entire radial depth of the core fins **26**c.

While the helical groove form a flow control core has been shown in FIG. **6** with generally straight fins **26**c, it is to be understood that the helical groove may be applied to a flow control core according to the invention which has step twisted or joggled core fins like those shown in FIG. **3,** or which has helically twisted fins like the fins **26***d* illustrated in FIG. **7** which figure illustrates a tubular heat exchange unit **12***d* having flow control core **24***d* comprising tubular core body **24***d* and the helically twisted fins **26***d* extending generally radially therefrom. Similarly, the annular type grooves like those shown in FIG. **4** in connection with the step twisted or joggled core fins may alternatively be applied to straight core fins like those shown in FIG. **5** or to helically twisted core fins like those shown in FIG. **7.**

If desired, further heat exchange capacity can be provided in tubular heat exchange units according to the present invention by incorporating within the tubular core body a small inner fin structure **64** as shown in FIG. **8,** and allowing the fluid to pass through the core body. Such fluid flow may, if desired, be controlled by valve means in the core body **24** which regulates the flow according to the temperature and/or viscosity of the fluid, as shown and described in said concurrently filed application for "Heat Exchange Valve System." The inner fin structure **64** shown in FIG. **8** may be formed of a multifolded strip of metal, and fin constructions similar to this are disclosed in the aforesaid Hayden U.S. Pat. No. 3,315,464, and also in U.S. Pat. No. 2,797,554, issued July 2, 1957 to W. J. Donovan for "Heat Exchanger in Refrigeration System" and U.S. Pat. No. 3,197,975, issued Aug. 3, 1965 to C. Boling for "Refrigeration System and Heat Exchangers." If desired, the inner fin structure **64** may be supported in its operative position by a central core **65** which is shown as a rod, but may be a small tube.

FIG. **9** illustrates a tubular heat exchange unit according to the present invention wherein the flow control core **66** has a tubular core body **68** with integral core fins **70** which expand radially outwardly from the core body **68** to the outer shell **38** with generally flat, radially oriented sides **72.**

FIG. **10** illustrates a tubular heat exchange unit which is generally inverted or "inside out" from the other forms of the invention disclosed herein, having a flow control core **74** that consists of an outer tubular core body **76** having integral inwardly extending fins **78** therein, the core body **76** and fins **78** preferably being formed together by extrusion. The inner tubular shell **80** may be a separately extruded tube that is inserted inside the inner ends of the fins **78** and then expanded outwardly against the fins **78.** If desired, such outward expansion of the inner shell **80** may be sufficient to cause an overall outward expansion of the outer tubular core body **76** for securing the latter in a series of fins such as the fins **14** shown in FIGS. **1** and **13.**

FIG. **11** illustrates heat exchange apparatus generally designated **82** comprising a spiral finned outer shell **84** commonly referred to as "wolverine tubing," with a flow control core **22** of the present invention fitted therein. The core **22** is preferably expanded outwardly into intimate heat transfer engagement with the inner tubular surface of the shell **84** generally in the manner illustrated in FIG. **13.** Heat exchange apparatus **82** of this type is particularly useful for small heat exchange requirements wherein a plurality of tubular heat exchange units such as the arrangement in FIG. **1** is not required.

FIG. **12** illustrates a further type of heat exchange apparatus **86** within which tubular heat exchange units **12** according to the present invention may be employed. The apparatus **86** includes a tubular outer shell **88** within which a bundle of the heat exchange units **12** is contained, the outer shell **88** having inlet and outlet conduits **90** and **92** for circulation of one fluid about the outsides of the tubular heat exchange units **12** through the interstitial flow channels **94**; while the ends of the heat exchange units **12** communicate with respective headers (not shown) for passage of another fluid through the heat exchange units **12.** Heat exchange apparatus of this general type is illustrated in the aforesaid Donovan U.S. Pat. No. 2,797,554.

In general, tubular heat exchange units **12** according to the present invention will provide improved heat exchange performance in any type of heat exchange apparatus which employs tubular heat exchange members therein, such as the apparatus **10** shown in FIG. **1,** apparatus similar to that of FIG. **1** but with a plurality of the tubular heat exchange units arranged for parallel flow between end headers, the apparatus **82** shown in FIG. **11,** the apparatus **86** shown in FIG. **12,** or other heat exchange apparatus.

While the instant invention has been shown and described herein in what are conceived to be the most practical and preferred embodiments, it is recognized that departures may be made therefrom within the scope of the invention. I claim:

1. A tubular heat exchange conduit which comprises an elongated central tubular core, a plurality of elongated, generally longitudinally arranged, circumferentially spaced heat transfer fins extending generally radially outwardlly from said core, both sides of each of said fins being concavely curved in the general radial direction throughout substantially their entire radial width, with their outer edges being thicker than inner portions thereof and an elongated, tubular shell peripherally engaged about and in heat conducting abutting relationship with the outer edges of said fins, said core, fins and shell defining a plurality of fluid flow channels between adjacent pairs of the fins.

2. A tubular heat exchange unit as defined in claim **1,** wherein said concave fin sides are of generally parabolic curvature.

3. A tubular heat exchange unit as defined in claim **1,** wherein the rate of curvature of said concave fin sides increases progressively from the root portions to the toe portions of the fins, so that the thickness of the fins increases at greater than a linear rate from said root portions.

4. A tubular heat exchange unit as defined in claim **1,** wherein said tubular core is compsed of a heat conducting metal that is hardest proximate said tubular core and is progressively softer from said core radially outwardly through said fins to the outer edges of the fins.

5. A tubular heat exchange unit as defined in claim **4,** wherein said shell is composed of heat conducting metal that is harder than the outer edge portions of said fins that are in contact therewith.

6. A tubular heat exchange unit as defined in claim **1,** which includes a series of external fins arranged over said shell with their planes generally normal to the axis of the tubular unit, said shell being generally radially outwardly stressed by said extrusion core and fins against said external fins.

7. A tubular heat exchange unit as defined in claim 1, wherein said shell has spiral external fin means externally formed thereon.

8. A tubular heat exchange unit as defined in claim 1, which includes an elongated inner fin structure disposed within said tubular core.

9. A tubular heat exchange unit as defined in claim 1, wherein said fins are provided with a twist along at least a portion of the length thereof, and wherein said twist is stepped.

10. A tubular heat exchange unit as defined in claim 9, wherein said stepped twist includes a series of alternating, generally longitudinally oriented fin portions and generally helically inclined fin portions.

11. A tubular heat exchange unit as defined in claim 10, wherein the transitions between successive fin portions are discrete angle bends on the fins.

12. A tubular heat exchange unit as defined in claim 1, having grooves segmenting said fins throughout substantially their entire height, said groove means comprising a series of longitudinally spaced, generally circumferentially arranged grooves in the fins.

13. A tubular heat exchange unit as defined in claim 12, wherein said groove means comprises a generally spirally arranged groove in the fins.

14. A tubular heat exchange unit as defined in claim 12, wherein said groove means comprises a series of longitudinally spaced, generally transverse grooves in the fins, the widths of said grooves being not substantially greater in the longitudinal direction of the fins than the average fin thickness.

15. A tubular heat exchange unit as defined in claim 14, wherein the widths of said grooves are substantially the same in the longitudinal direction of the fins as the average fin thickness.

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