

Jan. 6, 1970

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3,487,670

METHOD OF FORMING INDENTATIONS IN FINS
EXTENDING FROM A HEAT TRANSFER SURFACE

Original Filed March 29, 1965

2 Sheets-Sheet 1

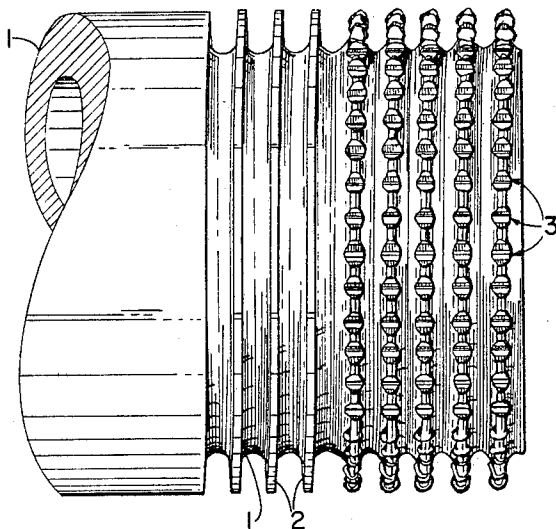


FIG. 1

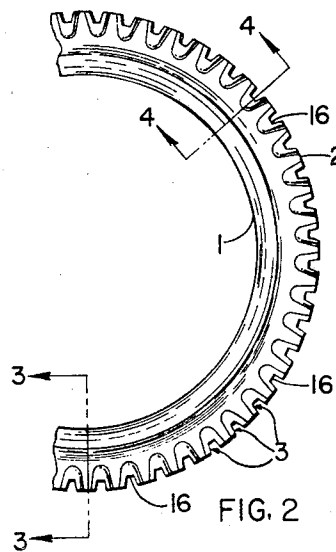


FIG. 2

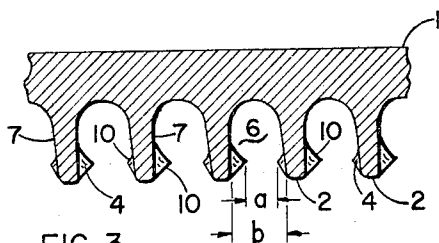


FIG. 3

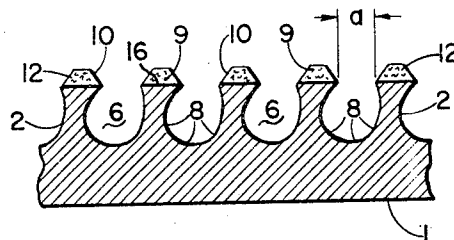


FIG. 4

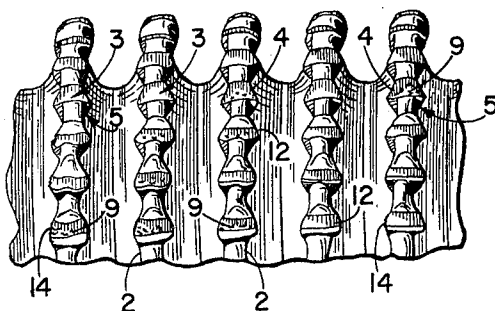


FIG. 5

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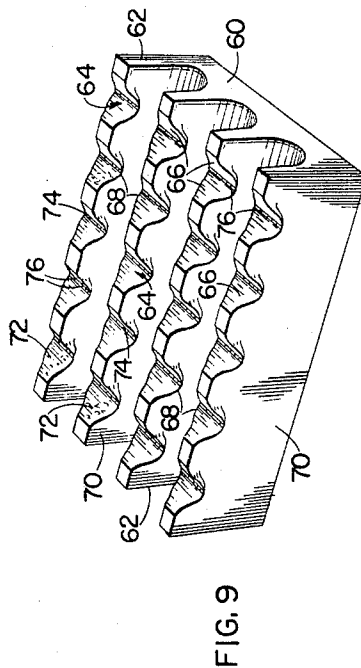
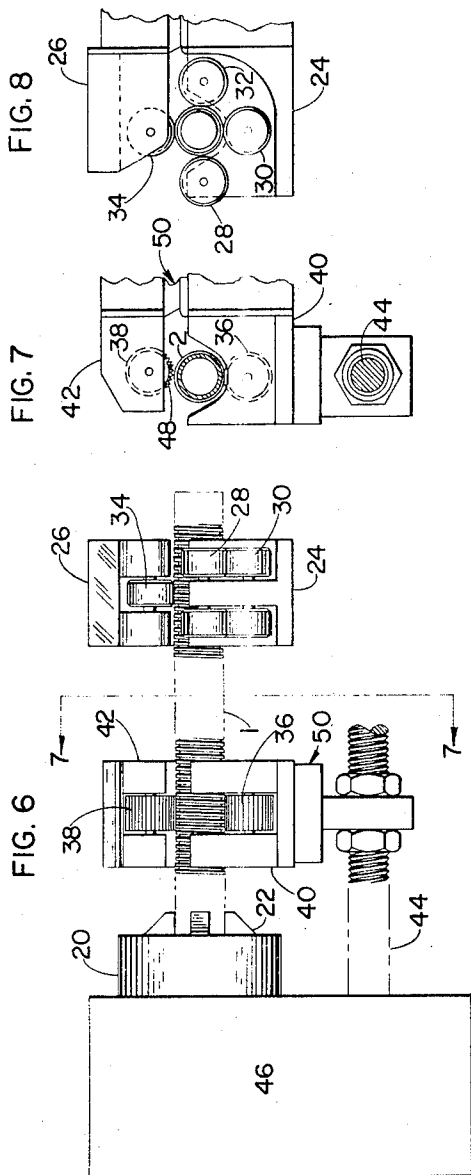
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METHOD OF FORMING INDENTATIONS IN FINS EXTENDING FROM A HEAT TRANSFER SURFACE

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Original application Mar. 29, 1965, Ser. No. 443,264, now Patent No. 3,326,283. Divided and this application
Apr. 17, 1967, Ser. No. 654,287

Int. Cl. B21d 17/04

U.S. Cl. 72-108

3 Claims

ABSTRACT OF THE DISCLOSURE

An improvement in heat transfer characteristics of a helically finned heat exchange tube is achieved by deforming the periphery of the fin to produce from 14 to 33 V-shaped cavities per circumferential inch. The cavities are impressed by contacting a helically finned tube with a serrated cylindrical machine tool to deform the periphery of the fins to less than the full depth thereof and to simultaneously flare peripheral fin material beyond each of the side walls of the fins.

This is a division of application Ser. No. 443,264, filed Mar. 29, 1965, now U.S. Patent 3,326,283.

This invention relates to an improved heat transfer surface, and more particularly to a heat transfer surface provided with fins or projections for transferring heat from the relatively warm surface to a fluid.

One method of transferring heat from such a surface to a liquid in contact with the surface is nucleate boiling. This is the well known phenomenon according to which vapor bubbles are formed (nucleation) and rise from active spots on the heat transfer surface known as nucleate boiling sites, as the surface temperature rises above the saturation temperature of the liquid. The precise nature of nucleate boiling sites is not known. However, it is generally recognized that nucleation takes place most often and most vigorously at surface irregularities or imperfections in which vapor forming the nucleus of a bubble may be trapped. The rapid emission of bubbles from these sites agitates the liquid adjacent the heat transfer surface, and this is, in part, the reason for the high rate of heat transfer associated with nucleate boiling.

The present invention is based on the premise that the rate of heat transfer will be increased as the number of nucleate boiling sites is increased. The improvement lies in the provision of a large number of incipient nucleate boiling sites on a heat transfer surface by forming the surface into a unique shape in a simple and inexpensive manner.

More particularly, the invention has as its object the formation of indentations in fins or projections extending from a solid heat transfer surface, said indentations having the ability to initiate and support nucleate boiling.

A further object is to provide indentations in the fin tip material extending from a heat transfer surface by mechanically rearranging the material without actually removing any material.

A third object of the invention is to provide indented fins as in the immediately preceding object wherein the indented tip material is flared out beyond the side walls of the fin so that the indentations take the form of cavities.

A fourth object is to form the indentations of the immediately preceding object by means of a knurling process.

These and other objects and advantages of the invention will become readily apparent as the following description is read in conjunction with the accompanying drawings, of which:

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FIGURE 1 is a front elevation view of a tube embodying the improved heat transfer fins of the invention;

FIGURE 2 is an end view of the tube of FIGURE 1;

FIGURE 3 is a longitudinal sectional view of a portion of the tube of FIGURE 1 taken along line 3-3 of FIGURE 2;

FIGURE 4 is a longitudinal sectional view of a portion of the tube of FIGURE 1 taken along line 4-4 of FIGURE 2;

FIGURE 5 is an enlarged, front elevation view of a section of the tube of FIGURE 1 more clearly showing the contour of the indentations in the fins;

FIGURE 6 is a front elevation view of the machine apparatus for forming indentations in the fins extending from a tube;

FIGURE 7 is a transverse sectional view of the apparatus of FIGURE 6 taken along the plane indicated by line 7-7;

FIGURE 8 is an end view of the apparatus of FIGURE 6 showing only the roller support for the tubular work piece; and

FIGURE 9 is a perspective view of a flat plate provided with the indented fins of the invention.

The improved heat transfer surface of this invention may be provided on a flat plate having spaced fins or projections on its surface, or on the well known integrally finned tubing commonly employed in evaporators and heat exchangers of the shell and tube type. FIGURES 1 thru 5 illustrate the application of this invention to an integrally finned tube. A plurality of spaced fins 2 extend in a helix along the surface of the tube 1, a number of the fins 2 on the left side of the tube being shown as they exist before being formed into my improved heat transfer surface. Superimposed upon the tip metal around the circumference of the fins 2 on the right side of the tube are a number of indentations generally indicated by reference numeral 3, which may preferably take the form of V-shaped cavities. The cavities 3 are preferably formed by mechanically indenting the fin tip metal at spaced intervals in such a way that no metal is actually removed. The metal is simply rearranged in a flared or "flowered out" cavity, the flared portions of the cavities 3 being indicated by reference numeral 4 in FIGURES 3 and 5. It is important with respect to the improved heat transfer effect to be obtained that the fin tip metal be "flowered out" transversely by the indenting tool beyond the side wall of the fin as shown at 4. By rearranging the metal of the fins in such a manner, as opposed to actually removing the metal in a cutting operation, a number of nucleate boiling sites in the form of cavities 3 are provided. The indenting operation is preferably performed by knurling the fins of the tube in a manner to be described below. The impact of the knurling tool displaces the fin tip metal transversely beyond the opposite side walls of each fin to form cavities 3 of the configuration best shown in FIGURE 5. Since the knurling tool has a flat rather than a sharp, V-shaped bottom, the bottom 16 of cavities 3 is also flat as is best shown in FIGURE 2.

It is recognized that the indenting tool could be directed against the fins at such an angle as to displace the fin tip metal transversely outwards beyond only one side wall of the fins, as by a broaching operation. Such a process would produce cavities similar to those shown at 3 in FIGURE 5 except that the cavity would be flared out on only one side of the fin by the action of the broaching tool moving transversely against the fin.

Since the face of the indenting tool will not normally be a perfectly smooth surface, the impact of the tool striking the fin peripheral edge in a direction normal to the axis of the tube will also form a plurality of minute pockets 9 in the top surfaces of the side walls 12 of cavities 3, as is

indicated in FIGURES 4 and 5. Furthermore, the fin tip metal, having been hardened initially by the fin forming operation, will be torn into seams 14 (FIGURE 5) of extremely small size along the edges 10 of flared out portions 4. The edges 10 are very thin and very sharp, and thus are split or torn to a certain extent at the bottom 16 of cavities 3 by the indenting operation. Nucleate boiling is actively induced by pockets 9 and seams 14, in which vapor forming the nucleus of a bubble may be trapped. Sharp edges 10 serve the useful purpose of causing cavitation in the liquid flowing adjacent the external surface of tube 1. This results in the formation of small bubbles which initiate nucleate boiling.

The cavities 3 terminate short of the base of the fins 2, as is clearly indicated in FIGURES 3 and 4. This results in the formation of additional, relatively large cavities 5 in the space between the underside of flared out portions 4 and the side walls 7 of fins 2 (FIGURES 3 and 5). Cavities 5 also serve as nucleate boiling sites.

Nucleate boiling also takes place from points 8 on the surface of tube 1 between adjacent fins 2 in cavities 6. Nucleate boiling at points 8 and the attendant high heat transfer will be rapid and continuous so long as the vapor bubbles produced at these points have an unimpeded discharge path. For this reason, gap *a* between adjacent edges 10 of flared out portions 4 is controlled so as not to unduly restrict the flow of liquid to and vapor bubbles from points 8 on the surface of tube 1 (FIGURE 4). This is done by regulating the depth of cavities 3, and thus limiting the extent of flaring or "flowering out" of edges 10 during the indenting process. Satisfactory results in the form of substantial nucleate boiling and improved heat transfer have been obtained with gaps *a* within a range of 35% to 75% of the initial distance *b* (FIGURE 3) between the side walls 7 of adjacent fins 2 at the top thereof. Optimum results were obtained with gaps *a* held within a range of 0.020 to 0.025 inch. A range of 0.015 to 0.030 inch would also be workable, but not as satisfactory as the more limited range for gaps *a*. With the gaps *a* controlled in this manner, the depth of cavities 3 will always be less than one-half of the height of fins 2. The size of gaps *a* becomes a particular problem under conditions where there is a high temperature differential between the external surface of tube 1 and the boiling liquid. Under such conditions bubbles will form at a very rapid rate, and too small a gap *a* would cause vapor to be locked in the space 6 beneath adjacent edges 10 of flared out portions 4; and the flow of additional liquid to boiling points 8 on the tube 1 would be impeded.

The gap control problem discussed above could be substantially eliminated by randomly spacing cavities 3 so that flared out portions 4 of adjacent fins are not in axial alignment. With such an arrangement, there would be no problem of forming relatively narrow gaps *a* between adjacent fins 2.

The preferred machining arrangement for forming the indentations 3 in the fins 2 of the tube 1 of FIGURES 1 thru 5 is shown in FIGURES 6 thru 8. The finned copper tube work piece 1 is supported at one end in the clamping teeth 22 of chuck 20. Finned tube 1 is supported at its other end by means of a roller assembly comprised of a base portion 24 and a head portion 26. Three roller wheels 28, 30, and 32 are mounted in the base 24 for rotation about their longitudinal axis. A single roller wheel 34 is similarly mounted in head 26. Head 26 is slidably mounted for transverse movement by means of pneumatic or hydraulic means not shown. Thus tube 1 may be placed in base portion 24 in contact with roller wheels 28, 30, and 32; and then head 26 may be moved transversely into the position shown, whereby roller wheel 34 will come into contact with the top of tube 1.

A knurling tool assembly generally indicated by reference numeral 50 is provided for forming the indentations 3 in the fins 2 of tube 1. Knurling wheel 36 is mounted in base 40 of assembly 50 for free rotation about its longi-

tudinal axis, and knurling wheel 38 is similarly mounted in transversely movable head 42. Head 42 is fixedly mounted on base 40 for movement therewith, longitudinal movement being imparted to knurling assembly 50 by means of lead screw 44. Head 42 may also be moved transversely with respect to base 40 by hydraulic or pneumatic means not shown. As may readily be seen in FIGURE 7, the axis of rotation of knurling wheel 38 is slightly laterally offset with respect to longitudinal axis of tube 1. By virtue of this arrangement, the teeth 48 of knurling wheel 38 will advance into contact with the peripheral surface of fins 2 and force tube 1 downwardly against the teeth of knurling wheel 36 as head 42 is moved transversely into the position shown. The depth of cavities 3, and thus the size of gap *a* between flared out portions 4 of adjacent fins 2 (FIGURES 3 and 4) is determined by adjusting the ram force applied to head 42. It is noted that when a relatively long piece of finned tubing is to be knurled, a number of roller assemblies 24-26 may be positioned at spaced intervals along the tube in order to properly support it. A plurality of knurling assemblies 50 may then be employed to knurl the portions of the finned tube between roller supports.

As a matter of convenience in producing finned tubes with the peripheral edges of the fins indented in accordance with my invention, knurling tool assembly 50 could be mounted on a standard fin forming machine. Apparatus as is conventionally employed for rolling fins in the wall of a tube is shown in United States Patent No. 1,865,575, issued on July 5, 1932, to Locke. As is indicated in that patent, the fins are formed integrally with the tube wall by means of roller dies moving radially against the tube as the tube is propelled longitudinally past the roller. Knurling wheels 36 and 38 could be positioned radially outwards from the path of longitudinal movement of the tubular work piece, and adjacent the roller dies beyond the final forming stage thereof so that as the rotating tube moves longitudinally forward, the fins will first be formed in the tube and then the fins will be indented by the knurling wheels. In such a machining arrangement, the knurling wheels 36 and 38 would not move longitudinally as in the process illustrated in FIGURES 6-8, but rather the knurling wheels would be mounted at fixed stations positioned circumferentially about the longitudinally moving tube.

In operation, tube 1 is placed in position with one end in chuck 20 and the other end supported in roller base portion 24. Roller head 26 is then moved transversely into the position shown in FIGURE 8. A rotational force is applied to chuck 20, and to lead screw 44 by power transmission means within headstock 46, and motor means drivingly connected thereto (not shown). Tube 1 will thus be caused to rotate with chuck 20. At the same time, knurling tool 38 is advanced into contact with fins 2 by transverse movement of head 42. Knurling tools 36 and 38 are rotated against fins 2 as a result of being in frictional contact with rotating tube 1. Thus teeth 48 of knurling tools 38 and 36 will deliver a series of impacts against the peripheral surface of fins 2 so as to displace the fin tip metal into the shape of cavities 3 shown in FIGURES 1, 2 and 5. Cavities 3 will be formed in fins 2 along the length of tube 1 as the knurling assembly 50 is moved parallel to the longitudinal axis of tube 1 by rotation of lead screw 44. This longitudinal movement of knurling assembly 50 causes more of the fin tip metal in cavities 3 to be displaced in the direction in which knurling assembly 50 is moving. Thus, as is most clearly shown in FIGURE 3, flared out portions 4 will extend farther beyond one side wall 7 of fins 2 than the other.

Knurling wheels 36 and 38 are so constructed and arranged that the teeth of lower wheel 36 strike fins 2 in generally, but not precisely, the same cavities 3 formed by the teeth of upper wheel 38. This causes cavities 3 to have roughened walls, the rough spots serving to induce nucleate boiling.

With reference to FIGURE 6, it is noted that knurling wheels 36 and 38 have straight teeth parallel to the wheel axis. Tools of this type will form cavities 3 of the shape most clearly shown in FIGURE 5. Knurling tools having teeth in a herringbone or diamond pattern may also be employed. Such tools would of course produce cavities in fins 2 having a herringbone pattern. In the course of knurling finned tubes by the process described with respect to FIGURES 6 thru 8, I have discovered that the pitch (number of teeth per inch of circumference) of the knurling wheel is quite critical. Thus, if too coarse a knurling tool having less than 14 teeth per circumferential inch is used, the resulting low number of cavities formed will not produce a significant increase in heat transfer. On the other hand, if too fine a knurling tool having a pitch greater than 33 is used, the knurling process becomes very difficult to control. The teeth of bottom tool 36 tend to strike the periphery of fins 2 between, rather than within the cavities formed by upper wheel 38 and an excessive number of cavities in an irregular pattern are formed. Optimum results in the form of a substantial number of uniformly spaced cavities 3 providing a significant increase in heat transfer have been achieved using a 21 pinch knurling wheel.

An integrally finned copper tube having an inside diameter of $\frac{9}{16}$ ", a root diameter (between fins) of $\frac{5}{8}$ " and an outside fin diameter of $\frac{3}{4}$ " has been successfully knurled by the above described process. Such finned tubes provided with a plurality of cavities 3 in the peripheral fin surfaces by this knurling process have been tested in both a relatively placid pool of refrigerant liquid, such as Refrigerant-113 or Refrigerant-11 and in the shell and tube evaporator of an operating centrifugal refrigeration system. In both cases relatively warm water was circulated through the tubes in heat exchange with boiling refrigerant liquid adjacent the outside surface of the tubes. In the pool boiling setup, the number of streams of bubbles rising from active nucleation sites on the finned tube was seen to increase as much as ten times in comparison with an ordinary finned tube. The operation of the shell and tube evaporator with my improved heat transfer surface resulted in a seven percent increase in overall heat transfer for a given temperature differential between the water and the refrigerant.

FIGURE 9 illustrates the application of my improved heat transfer surface to fins 62 extending from a flat plate 60. Such a plate would normally be used in an application where boiling liquid is in contact with the fins 62 and the top of the plate 60, and a relatively warmer fluid is in contact with the bottom of the plate. Cavities 64 of a configuration similar to that of cavities 3 shown in FIGURES 1 thru 5 are formed in fins 2 by placing plate 60 on the bed plate of a milling machine and moving a rotating knurling or milling tool over the finned surface in a horizontal direction parallel to the plane of plate 60. Edges 68 of side walls 66 of cavities 64 are flared out beyond side walls 70 of fins 62 for the purpose described above with respect to flared out portions 4 of cavities 3.

The imperfect surface of the indenting tool forming the cavities 64 will also form a plurality of minute pockets 72 similar to pockets 9 of cavities 3 in FIGURES 4 and 5. The base 74 of cavities 64 will also be split into a number of extremely small seams 76 by the impact of the indenting tool on the fin surface. The cavities 64, aided by pockets 72 and seams 76 in the surface thereof, serve to initiate and sustain nucleate boiling. As a result heat transfer to the liquid in contact with fins 62 is greatly increased. The gap between adjacent flared-out edges 68 must be controlled in the manner described above with respect to gap a by regulating the depth of cavities 64 so

as not to unduly restrict the flow of bubbles rising from the top surface of plate 60 between fins 62.

On the basis of the foregoing description and discussion, it will be readily apparent that I have provided a unique heat transfer surface which functions to permit heat transfer at a much higher rate than normal by virtue of the large number of nucleate boiling sites formed on the surface. As a result of the large number of active nucleation sites on my improved surface, the heat transfer rate to a boiling liquid in contact with the surface is greatly increased for a given driving force in the form of a particular temperature differential.

I do not desire to limit my invention to the particular embodiments shown and described, which are illustrative only. It is contemplated that changes may be made without departing from the spirit and scope of the invention as defined by the following claims.

I claim:

1. The method of providing a heat exchange tube having continuous helical fins thereon with a plurality of V-shaped cavities in the periphery of said fins comprising the steps of:

- (a) deforming the periphery of said fins to less than the full depth thereof to form a cavity therein,
- (b) simultaneously flaring peripheral fin material beyond each of the sidewalls of said fins,
- (c) successively deforming and flaring the periphery of said fins to produce from 14 to 33 cavities per circumferential inch.

2. A method of providing a heat exchange tube having continuous helical fins thereon with a plurality of V-shaped cavities in the peripheries of said fins comprising the steps of:

- (a) mounting said tube for rotational motion about its longitudinal axis on a suitable base,
- (b) applying the surface of a first longitudinally serrated cylindrical tool mounted for rotation about an axis parallel to the longitudinal axis of said tube to the periphery of said fins,
- (c) rotating said tube about its longitudinal axis,
- (d) applying the surface of a second longitudinally serrated cylindrical tool substantially identical to said first tool mounted for rotation about an axis parallel to the longitudinal axis of said tube to the periphery of said fins,
- (e) applying sufficient force to said tools to form an indentation in the periphery of said fins which has a depth less than the depth of said fins, said first and second tools having sufficient serrations to form from 14 to 33 cavities per circumferential inch of said tube,
- (f) moving said serrated tools in a longitudinal direction with respect to said tube axis as said tube is rotated.

3. The method of claim 2 wherein said second tool is offset with respect to said tube from a position diametric to the position of said first tool.

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MILTON S. MEHR, Primary Examiner

U.S. Cl. X.R.

29—157.3; 72—703