March 3, 1970 W. J. LEVEDAHL 3,498,369

HEAT PIPES WITH PREFABRICATED GROOVED CAPILLARIES AND METHOD OF MAKING

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FIG. 1

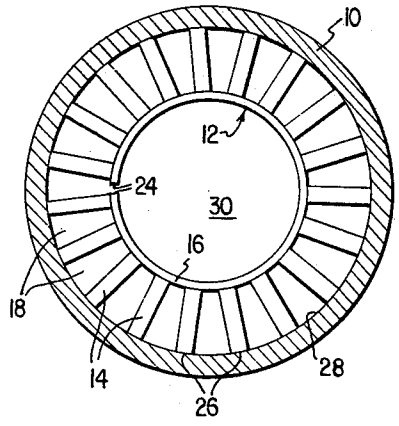


FIG. 2

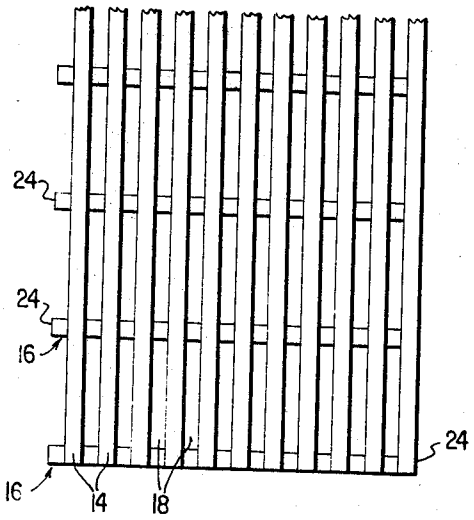
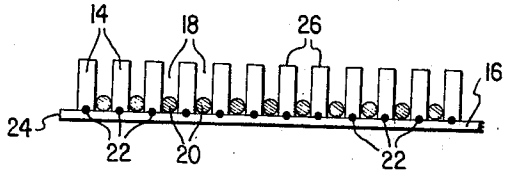


FIG. 3



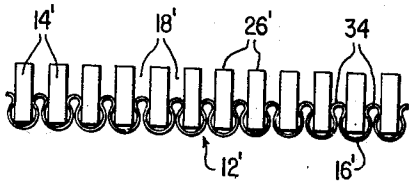
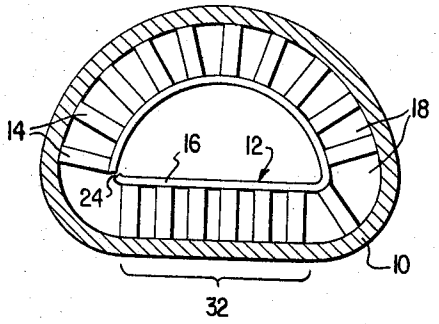


FIG. 5

FIG. 4



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HEAT PIPES WITH PREFABRICATED GROOVED CAPILLARIES AND METHOD OF MAKING

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U.S. Cl. 165—105 5 Claims

ABSTRACT OF THE DISCLOSURE

A prefabricated, flexible, grooved capillary structure inserted within a heat pipe enclosure to conform to the heat pipe cross-sectional configuration.

A heat pipe in its simplest form comprises a closed container, normally metallic, employing on the inner surface, a capillary structure which is essentially saturated with a vaporizable fluid. The heat pipe transfers heat, almost isothermally from one point on the external surface to any other point by a vaporization-condensation cycle. A vast majority of the heat pipes fabricated to date, contained wire-screen wicks as the capillary structure, the wicks extending throughout the length of the heat pipe with corresponding limited capability.

Grooved heat pipes have been fabricated by extensive machinery methods requiring removal of the large quantity of material with some precision. In an attempt to reduce the cost and time necessary to provide capillary means in the form of grooves, a recent technique involves machining of a banded axially grooved insert which fits closely to the heat pipe and may be swaged down onto it. Alternatively, grooves have been milled into flat plates which are then seam-welded into cylindrical form.

Optimum configurations have been disclosed for respective evaporator, transport and condenser regions of the heat pipe, but the grooved capillary structures of such optimum configuration are not easily fabricated by any of the above-described methods.

Where the heat pipes are employed for cooling, heating or temperature control of spacecraft, power sources and allied systems may be made smaller, lighter and more effective if the capillary configurations can be separately chosen to meet the flow and heat transfer requirements of each point of the heat pipe. Changes in direction or cross-section of the heat pipe may be necessary in certain applications. Theoretical considerations show that the inner surface of the pipe wall should consist of alternating grooves and curved-cross-section lands in some regions, of an outer "annular," "peripheral" or "circumferential" capillary, separated from the vapor flow in others. The container wall should be thin to minimize temperature drop and weight, while retaining the strength and rigidity necessary to remain integral and leak tight under stress caused by pressure differentials, accelerations, vibrations and other mechanical stresses.

When a heat pipe is designed with a configuration providing minimum weight and/or size and based on theoretical considerations, it will frequently have longitudinal grooves or thin peripheral capillary cross-sections. The shapes of the grooves and of the lands between them will likely be non-rectangular in cross-section, and the ideal configuration is unlikely to be constant throughout the length of the heat pipe. Thus, the already-difficult problem of shaping an interior surface is complicated greatly by attempts to optimize the design at any point along the heat pipe. Another problem of considerable significance is that of maintaining the container wall at constant thickness and eliminating stress concentrations when deep grooves are to be introduced along the inner pipe surface.

It is, therefore, a primary object of this invention to provide an improved heat pipe configuration which employs a grooved capillary structure which is inexpensive, easily made, may be used with heat pipes of varying configurations and which readily allows optimizing of the capillary means at any point along the heat pipe.

It is a further object of this invention to provide an improved heat pipe configuration in which the grooved capillary structure is removably carried by the heat pipe container and which, after insertion, readily conforms to the interior wall configuration.

It is a further object of the invention to provide a prefabricated, flexible grooved capillary structure for use with heat pipes, allowing the grooved capillary structure to be readily mass produced with great reduction in cost.

Other objects of the invention will be pointed out in the following detailed description and claims and illustrated in the accompanying drawing which discloses, by way of example, the principle of the invention and the best mode which has been contemplated of applying that principle.

In the drawing:

FIGURE 1 is a sectional view of a heat pipe employing the prefabricated, flexible, grooved capillary structure of the present invention.

FIGURE 2 is a plan view of a portion of the grooved capillary structure employed in the heat pipe of FIGURE 1.

FIGURE 3 is an elevational view of the flexible, grooved capillary structure of FIGURE 2 during manufacture.

FIGURE 4 is a sectional view of a portion of the heat pipe of FIGURE 1 at the point where the heat pipe has been bent and flattened along one side.

FIGURE 5 is an end elevation of yet another embodiment of the prefabricated, flexible grooved capillary structure of the present invention for use in heat pipe applications.

In general, the present invention is directed to a prefabricated, flexible, grooved capillary structure which may be inserted within a conventional tubular heat pipe enclosure whereby the flexibility of the capillary structure allows it to conform to the heat pipe cross-sectional configuration at any point along the heat pipe, regardless of change in this configuration.

In one form, a series of spaced rigid lands are welded to right angle, spaced flexible metal strips. In an alternate configuration, the individual rectangular strips are supported by undulating, preformed bands of spring metal which space and grip the lands. In each case, the circumferential bands have their ends bent back towards each other with the lands spread radially outward prior to and after insertion into the heat pipe container. After insertion, the circumferential strips tend to expand forcing the free ends of the lands into contact with the container inner wall.

FIGURE 1 shows in cross-section, a typical heat pipe of cylindrical configuration including a container or casing **10** which carries an inserted prefabricated, flexible grooved capillary structure **12** along with a vaporizable liquid (not shown) which acts as the heat pipe working fluid.

The grooved capillary structure **12** is prefabricated in a manner best seen in FIGURE 3. A plurality of rectangularly configured strips of metal or other material to form the desired lands **14** are positioned on a number of spaced circumferential bands **16**, the bands being relatively thin and flexible and formed of a material compatible with strips **14** forming the capillary lands. For proper spacing and the formation of grooves **18** of preferred width, a number of removable spacers **20** are inserted between land strips to achieve the desired

equal spacing and proper location of the lands **14** onto the flexible circumferential bands **16**. The lands **14** are then welded to the base strip as indicated by weld points **22** whereupon the individual spacers **20** may be removed. This produces a preformed assembly as indicated in FIGURE 2.

If the circumferential bands **16** are formed of spring stock, for instance, upon curving of these bands and insertion of the flexible grooved capillary structure **12** into the heat pipe casing or container **10**, the ends **24** of the circumferential bands move almost into abutting contact as indicated in FIGURE 1 with the resiliency of the bands tending to force the free or tip ends **26** of the lands into abutting contact with the inner wall **28** of the heat pipe container **10**. Thus, while the capillary grooves **18** formed thereby are irregular rectangles, they function adequately as flow channels for the liquid phase working fluid. Further, since the circumferential bands **16** are spaced from each other there is no interference in the movement of vapor phase working fluid from the capillary grooves **18** to the vapor channel **30**, nor, in condensed state moving from the vapor channel **30** into the capillary grooves **18**. Thus, the present invention consists essentially of the assembly of a number of simple, prefabricated parts into one or more flexible subassemblies for subsequent introduction into the heat pipe container walls. Spring and frictional forces then maintain the subassemblies in proper juxtaposition to the container wall **28**. While the lands in the embodiment of FIGURE 1 are shown as being held against the inner wall **28** by the spaced spring metal bands **16**, these members may be formed of non-resilient material and may be supplanted in this function, by spiral wire springs, screen material or thin sheet material or a combination of these elements incorporating the desired resiliency.

The improved heat pipe of the present invention has applicability to those situations in which the heat pipe must be flattened, or the configuration otherwise changed as a result of bending around a corner, for instance. In FIGURE 4, the heat pipe container **10** has been flattened along its face **32** which results in a change in configuration of the spring bands **16**. This forces the attached lands **14** to conform to the change in wall configuration and remain in abutting contact therewith without materially affecting the function of the capillary grooves **18** in transporting liquid phase working fluid. Thus, any change in cross-sectional configuration, either accidental or deliberate, will not impair the function of the heat pipe to transport heat isothermally.

Reference to FIGURE 5 shows a simplified, preassembled, flexible, grooved capillary structure **12'** comprising a series of spaced strips of material of rectangular configuration forming lands **14'**, the lands **14'** being separated by capillary grooves **18'**. In this case, the circumferential flexible strip members **16'** comprise convoluted springs in which case, opposing spring forces are set up by the curved strip sections **34** which act on respective lands **14'** to maintain them in position prior to, and subsequent to insertion within a heat pipe casing (not shown). Thus, the convoluted spring bands **16'** space and frictionally grip the lands **14'** without the need for spot welding. In similar fashion to the previous embodiment, the preassembled lands and their convoluted spring bands are then rolled into cylindrical configuration with the spaced bands internally positioned and are inserted into the heat pipe containing wall. Once inserted, the free ends **261** are forced against the container wall by the spring force set up within the spacing bands although this spring force may be suitably amplified by the subsequent insertion of spiral springs or the like if needed.

If the prefabricated or performed flexible grooved capillary structure is to be employed either within the condenser or evaporator sections of the heat pipe, the materials employed in the fabrication of the grooved capillary structures, such as **12** or **12'**, should be formed of conductive material, such as, lightweight metal although if the structure is to be employed in a portion of the heat pipe which performs only a transport function for the liquid phase working fluid, the materials may be rather poor conductors of thermal energy.

From the above description, it is obvious the container can have a circular cross-section, or may be bent to change direction without compromise to the capillary transport function. The container cross-section or direction may be changed either before or after insertion of the capillary-forming structure or structures. Since the capillary-forming structure need not be bonded to the container wall, forces transmitted to the wall can be predominantly normal to its surface, thereby permitting bending of the wall subsequent to assembly. This concept permits great flexibility in configuration of the entire heat pipe, while minimizing the danger of loss of container integrity. The prefabrication of the flexible grooved capillary structure decreases the cost, difficulty and uncertainty of capillary groove fabrication. Each section of the heat pipe can be individually optimized, the container wall may be made thinner without danger of rupture due to the continued flexibility of the capillary structure which readily conform to wall configuration change. The bands have negligible effect on the capillary action and the lands and grooves may have any desired cross-section. In their manufacture, no special equipment is needed and manufacturing costs may be kept quite low. The size and the shape of a capillary structure may be readily changed without the need of new tooling.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. In a heat pipe structure having casing means defining a closed container and a vaporizable liquid carried thereby, the improvement comprising: a plurality of rigid, land-forming strips and flexible support means interiorly coupled to said lands for maintaining said lands in longitudinally spaced parallel position with their free ends in contact with the interior wall of said heat pipe container and with the space between the strips being such as to maintain capillarity.

2. The heat pipe structure as claimed in claim **1** wherein said flexible support means comprises a plurality of longitudinally spaced, circumferentially positioned resilient bands welded to the inner ends of said lands.

3. The heat pipe structure as claimed in claim **1** wherein said flexible support means comprises a plurality of longitudinally spaced, convoluted spring bands, with said convolutions separating said strips and frictionally gripping the same.

4. An inexpensive method of forming a tubular heat pipe structure comprising: flexibly mounting a plurality of land forming strips in spaced parallel relationship to form a thin rectangular mat, curling the ends of said mat toward each other, deforming said mat into cylindrical form, inserting the same into a heat pipe tube and expanding said cylindrical configured mat to cause the surfaces of the land forming strips to contact the interior of the heat pipe tube to form a completed heat pipe structure.

5. A method of forming a longitudinally curved and flattened heat pipe member comprising inserting a rolled mat formed of a plurality of land forming strips on flexible mounting means within a heat pipe tube, expanding said rolled mat to cause said plurality of spaced parallel land forming strips to contact the interior of

said heat pipe tube and curving said heat pipe tube subsequent to mat insertion whereby said tube in flattening in the area of said bend fails to affect the capillary transport function of said spaced parallel land because of said flexible mounting means.

References Cited

UNITED STATES PATENTS

3,305,005	2/1967	Grover et al.	165—105
3,414,475	12/1968	Fiebelmann	165—105 X

OTHER REFERENCES

Deverall, J. E., et al.: High Thermal Conductance Devices, Los Alamos Scientific Laboratory (LA–3211), April 1965, p. 29.

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