CONTROLLABLE HEAT PIPE

Filed March 15, 1967 8 Sheets-Sheet 1

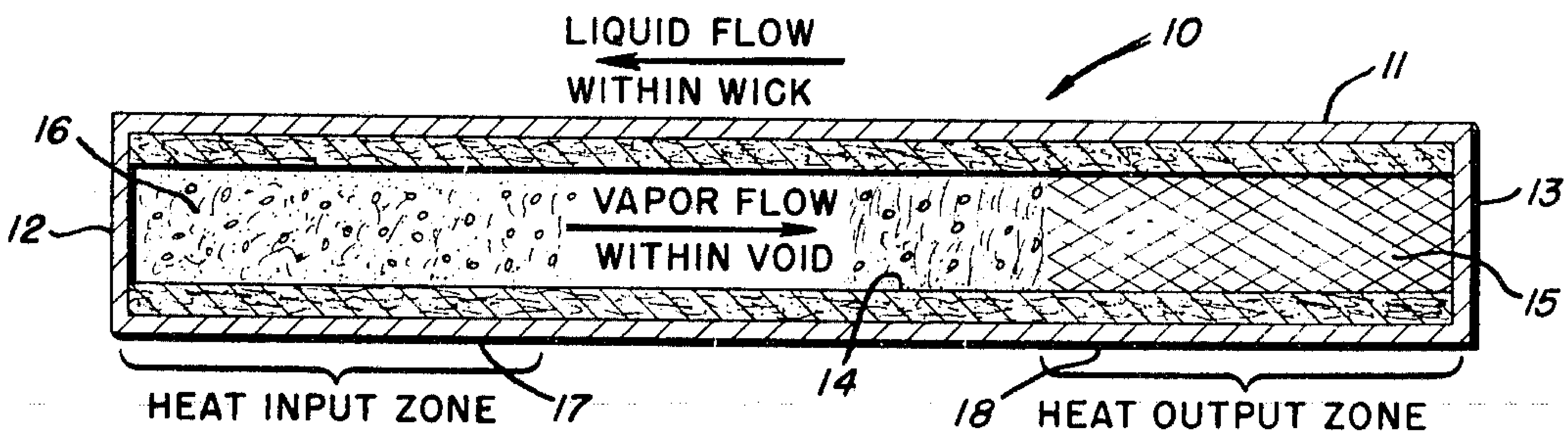

FIG. 1

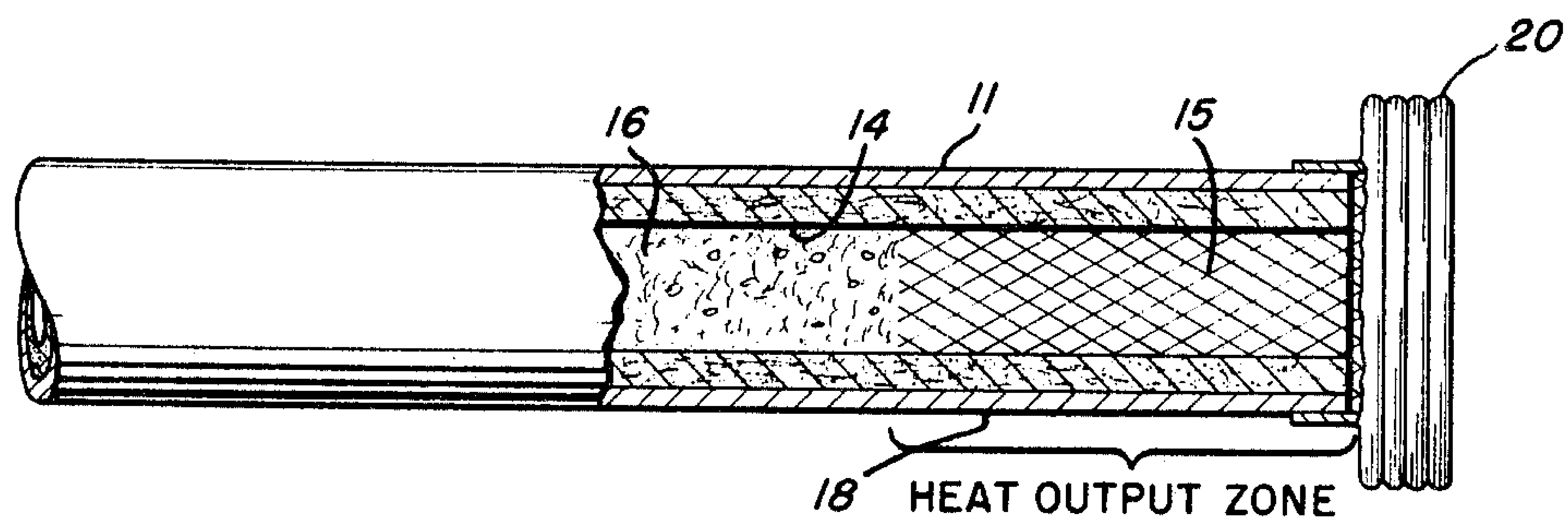

FIG. 2

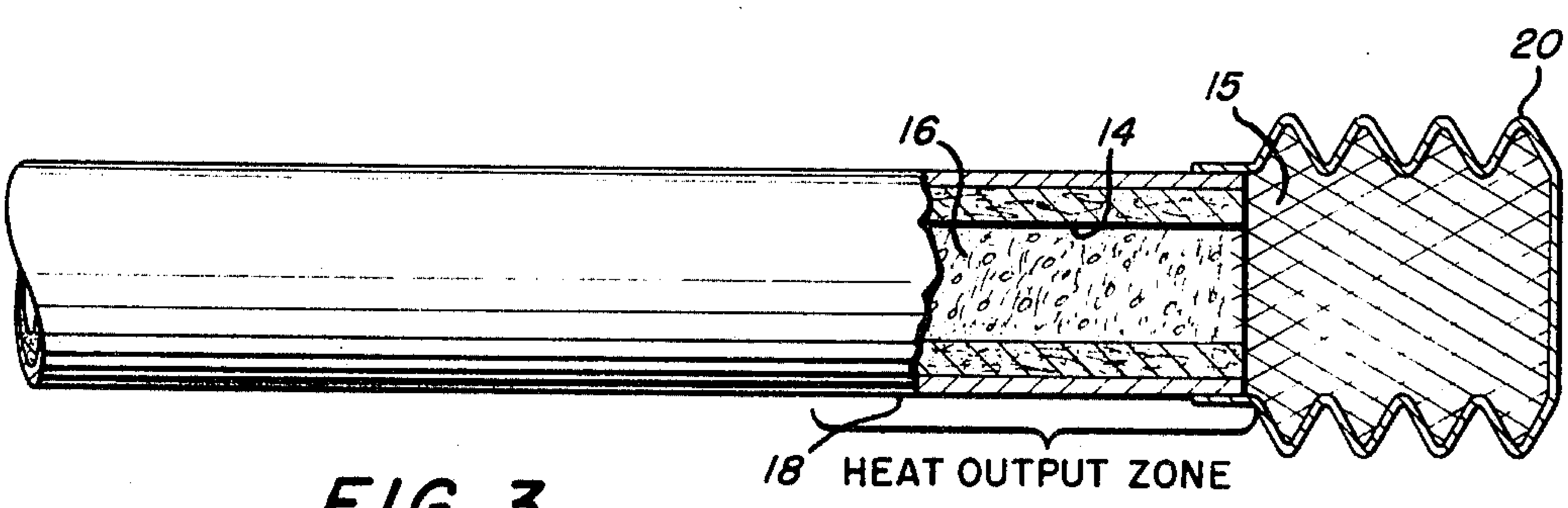

FIG. 3

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ATTORNEY

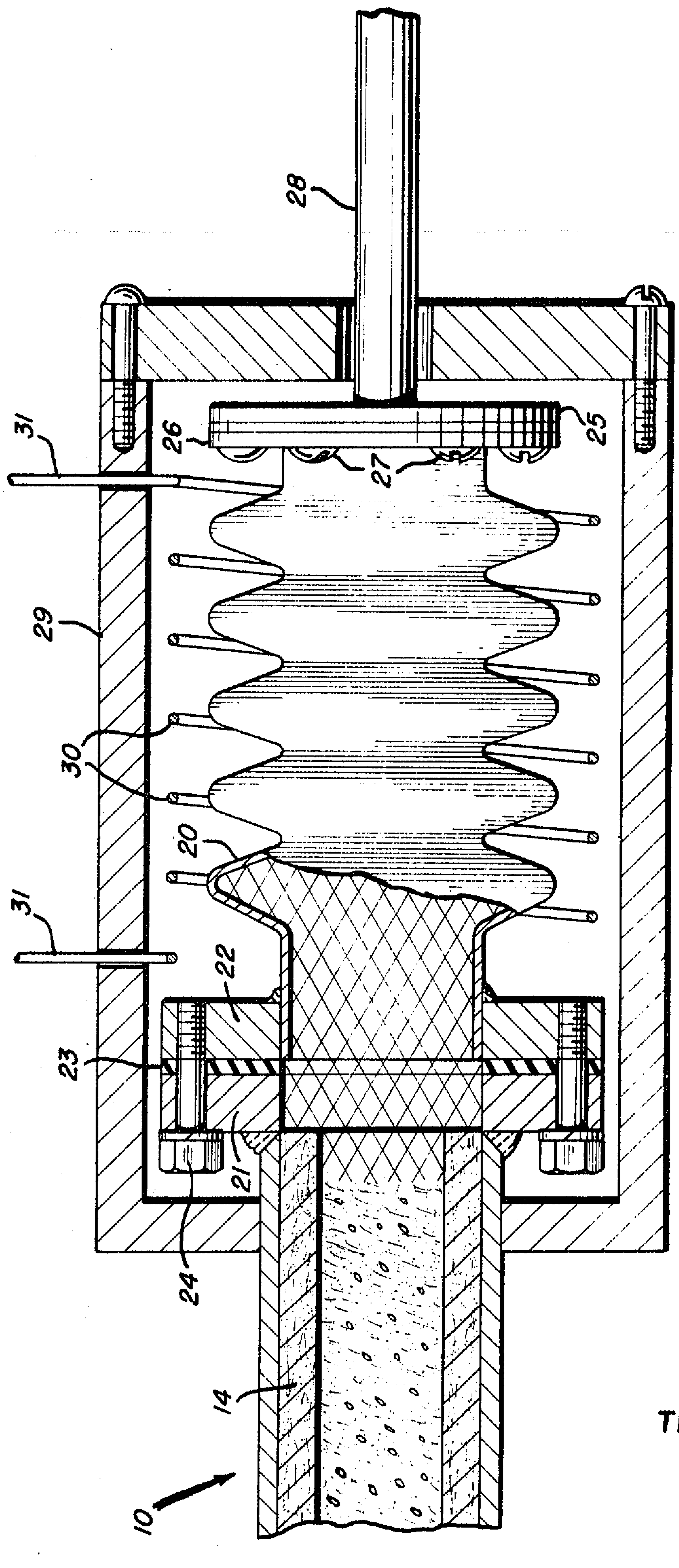

FIG. 4

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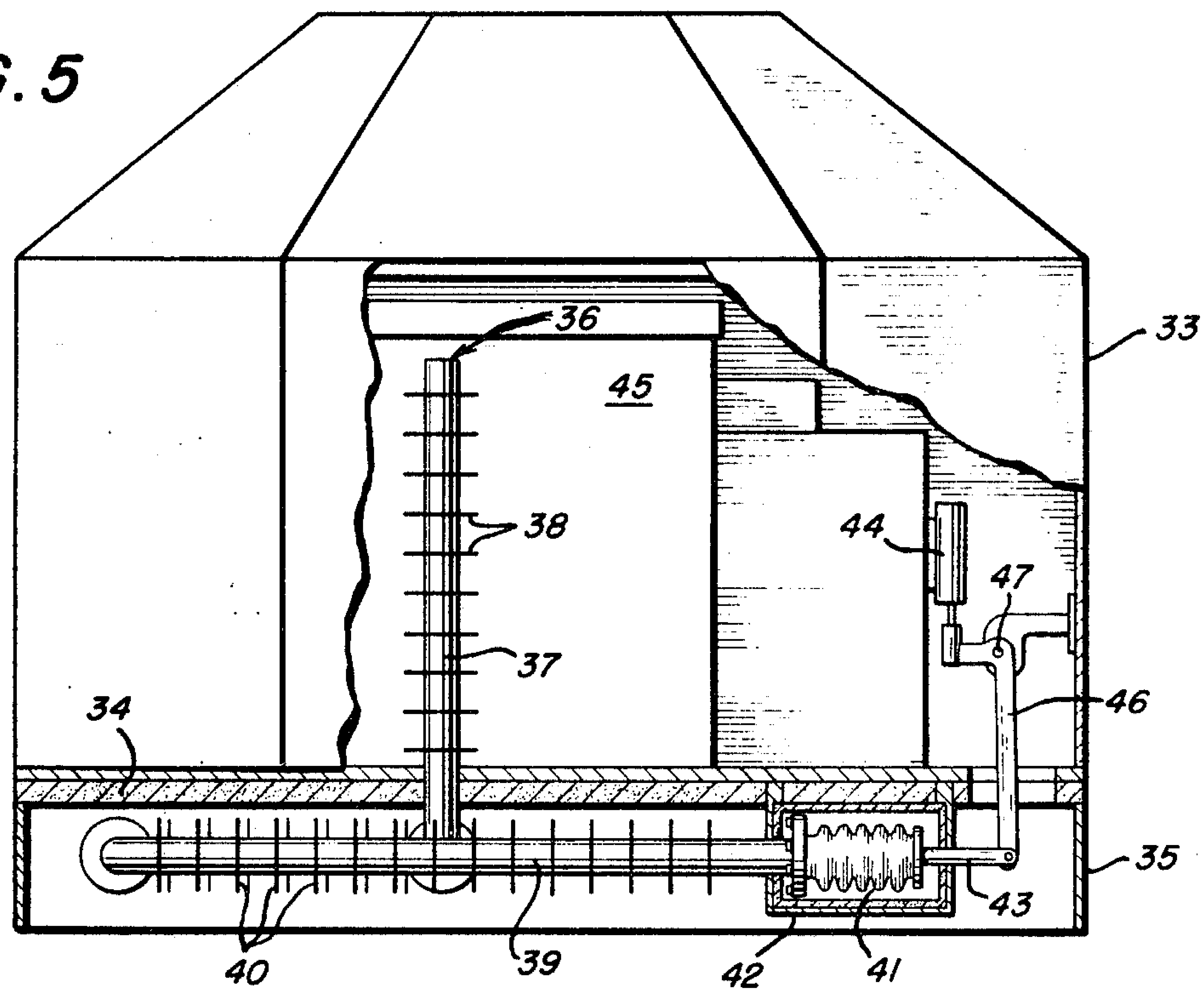
FIG. 5



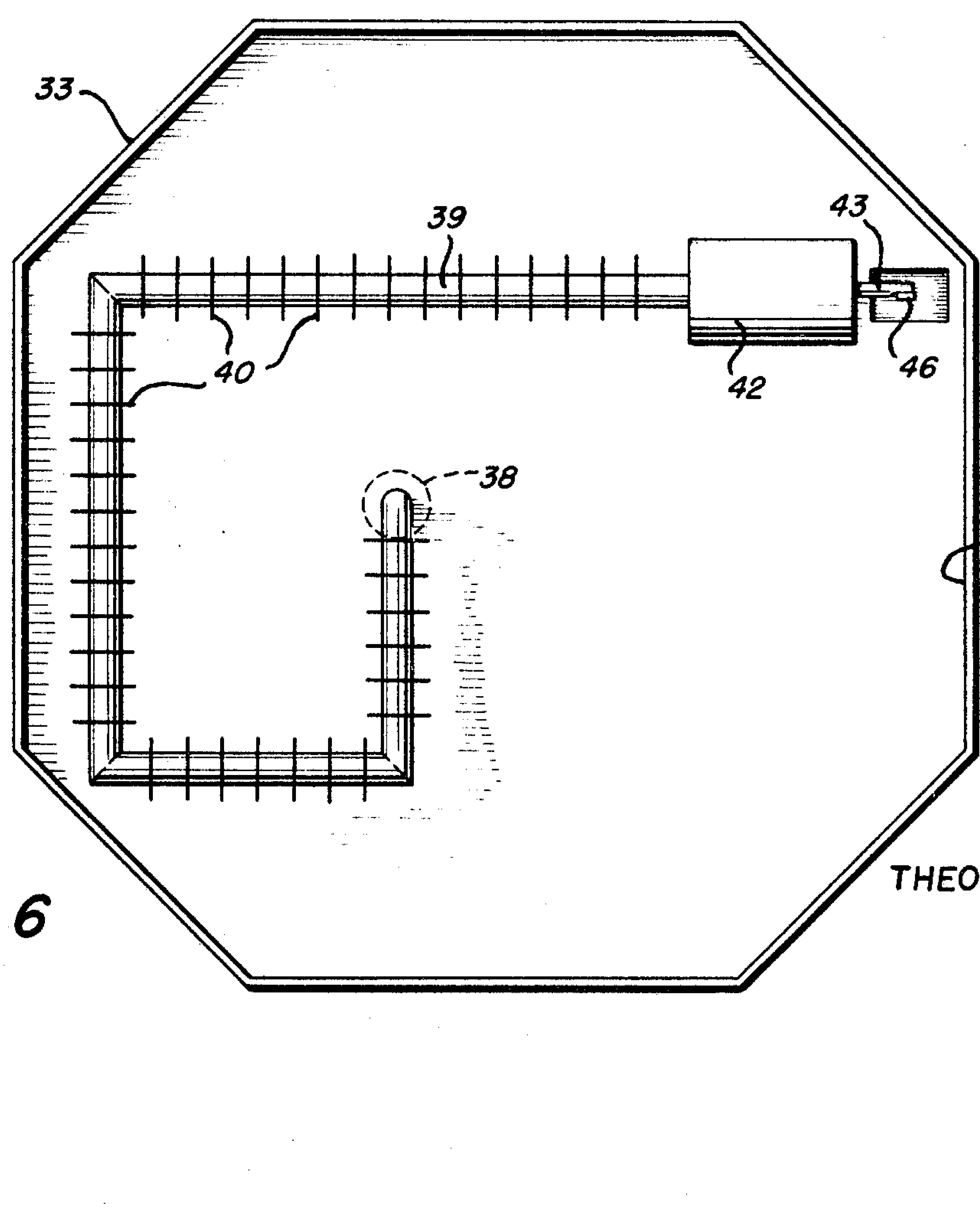


FIG. 6

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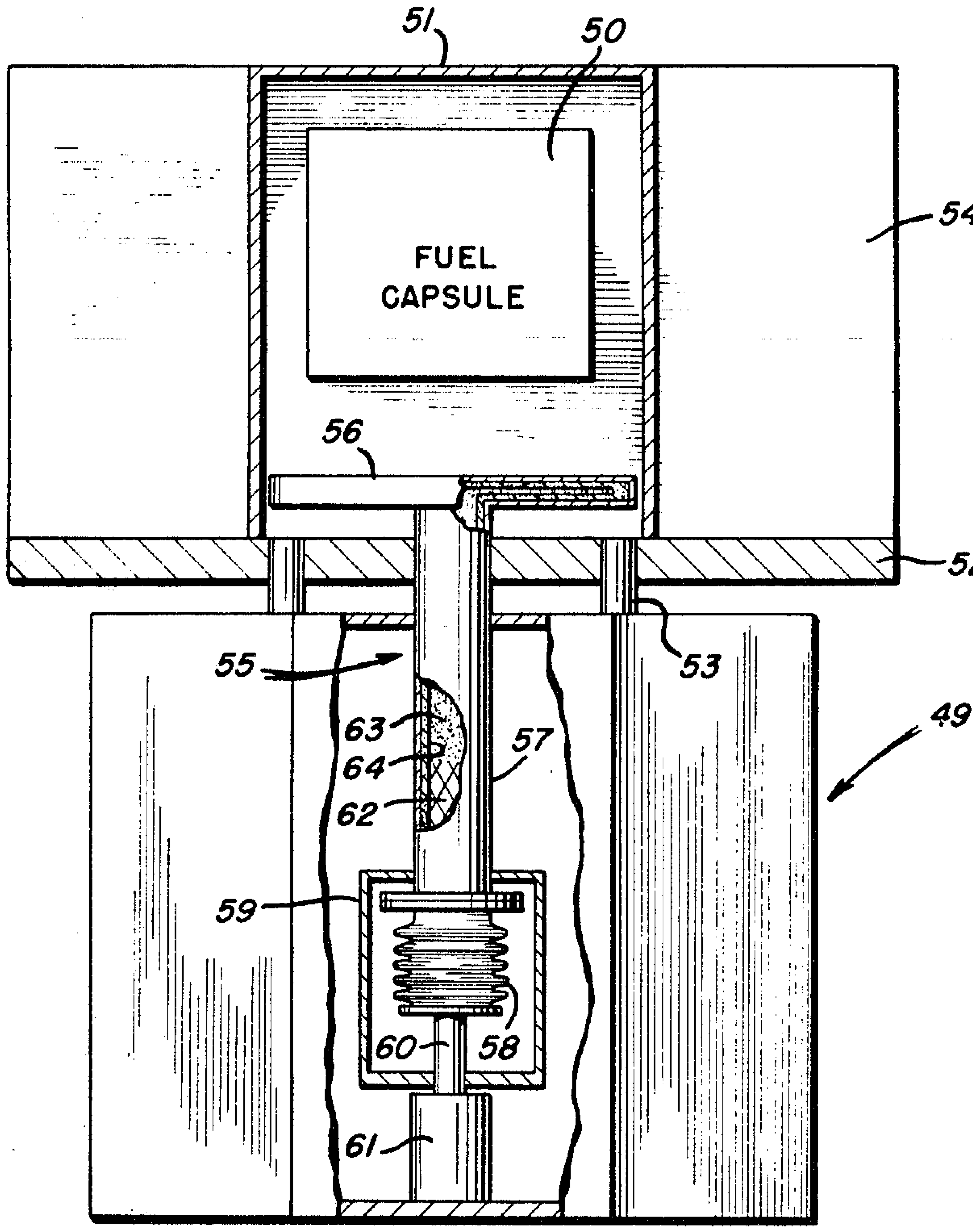

FIG. 7

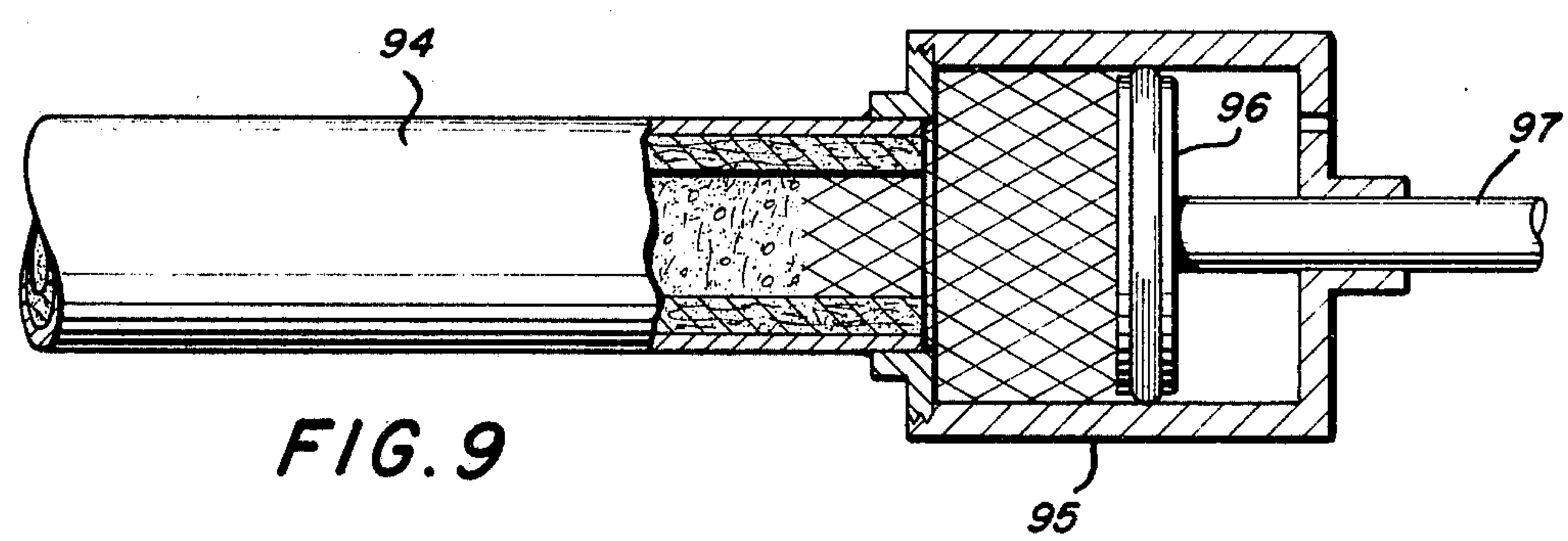

FIG. 9

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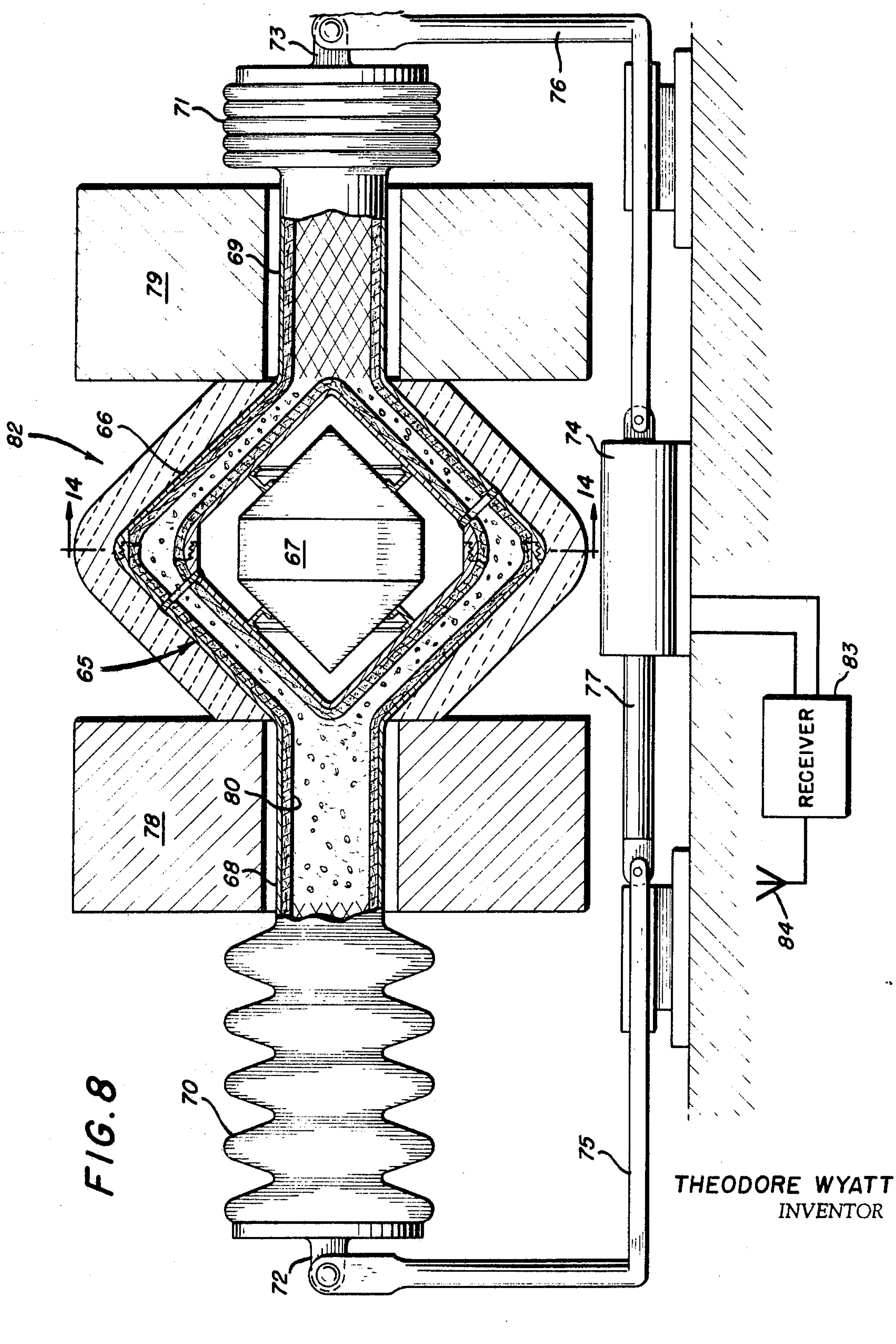

FIG. 8

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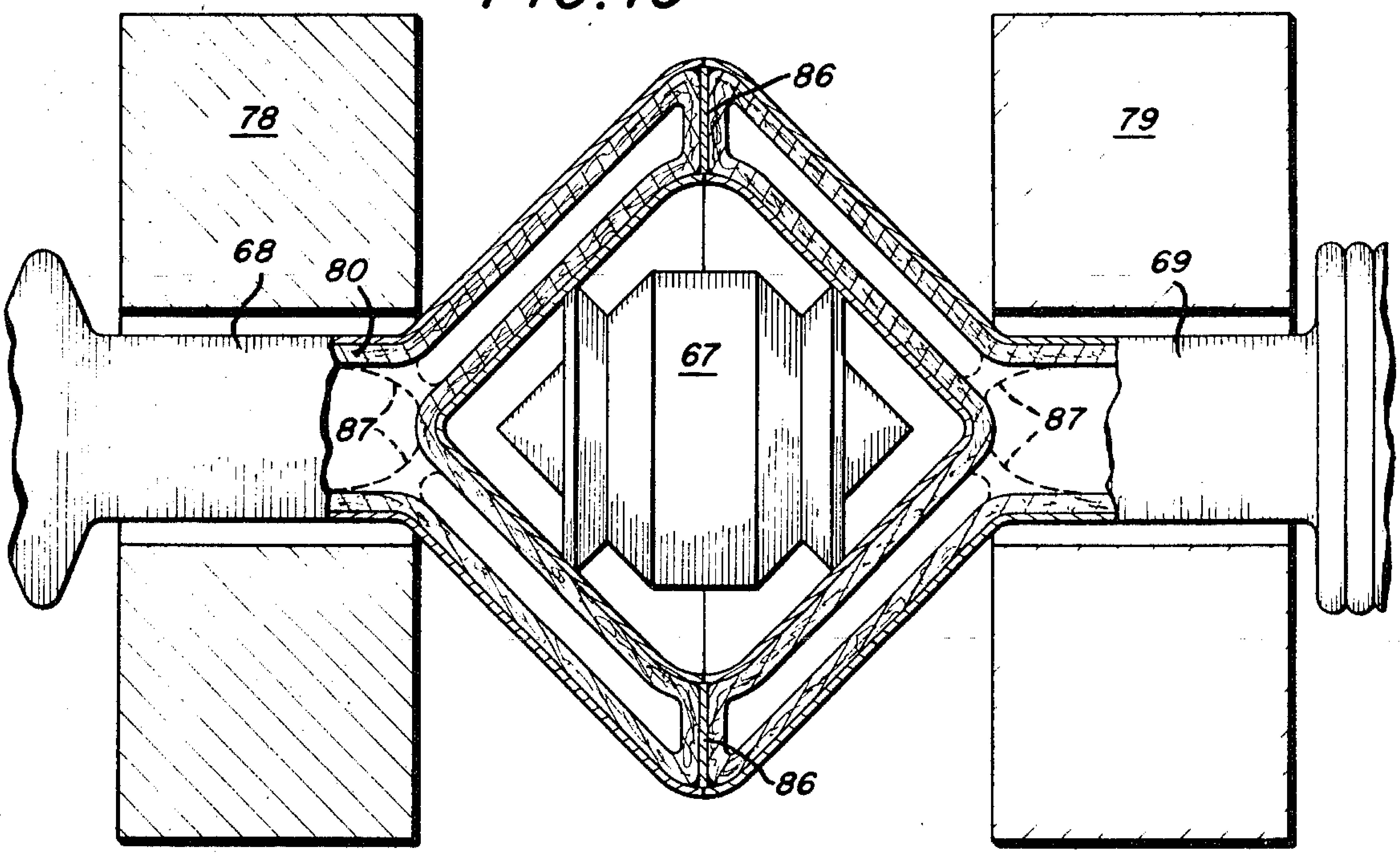
FIG. 10



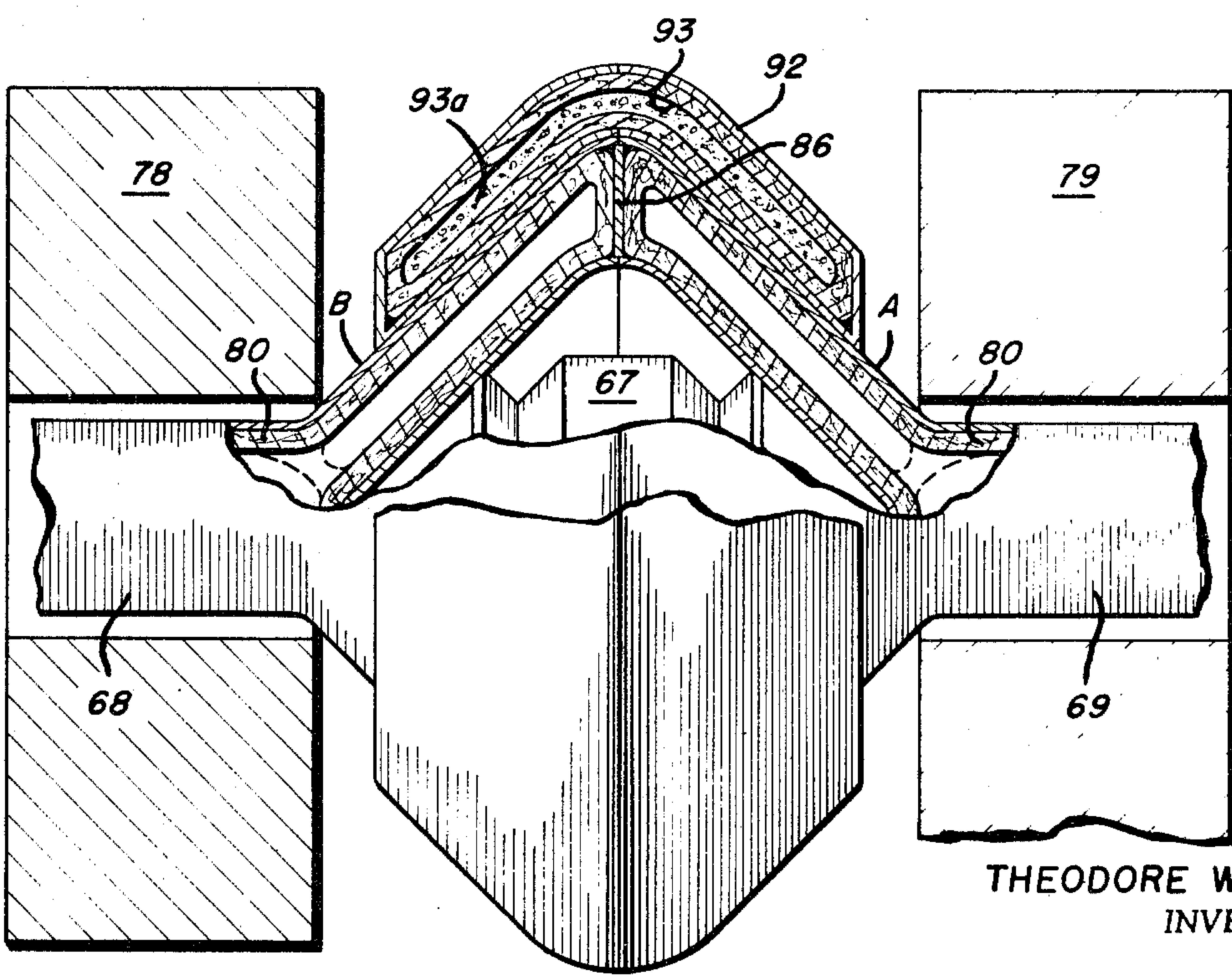


FIG. 12

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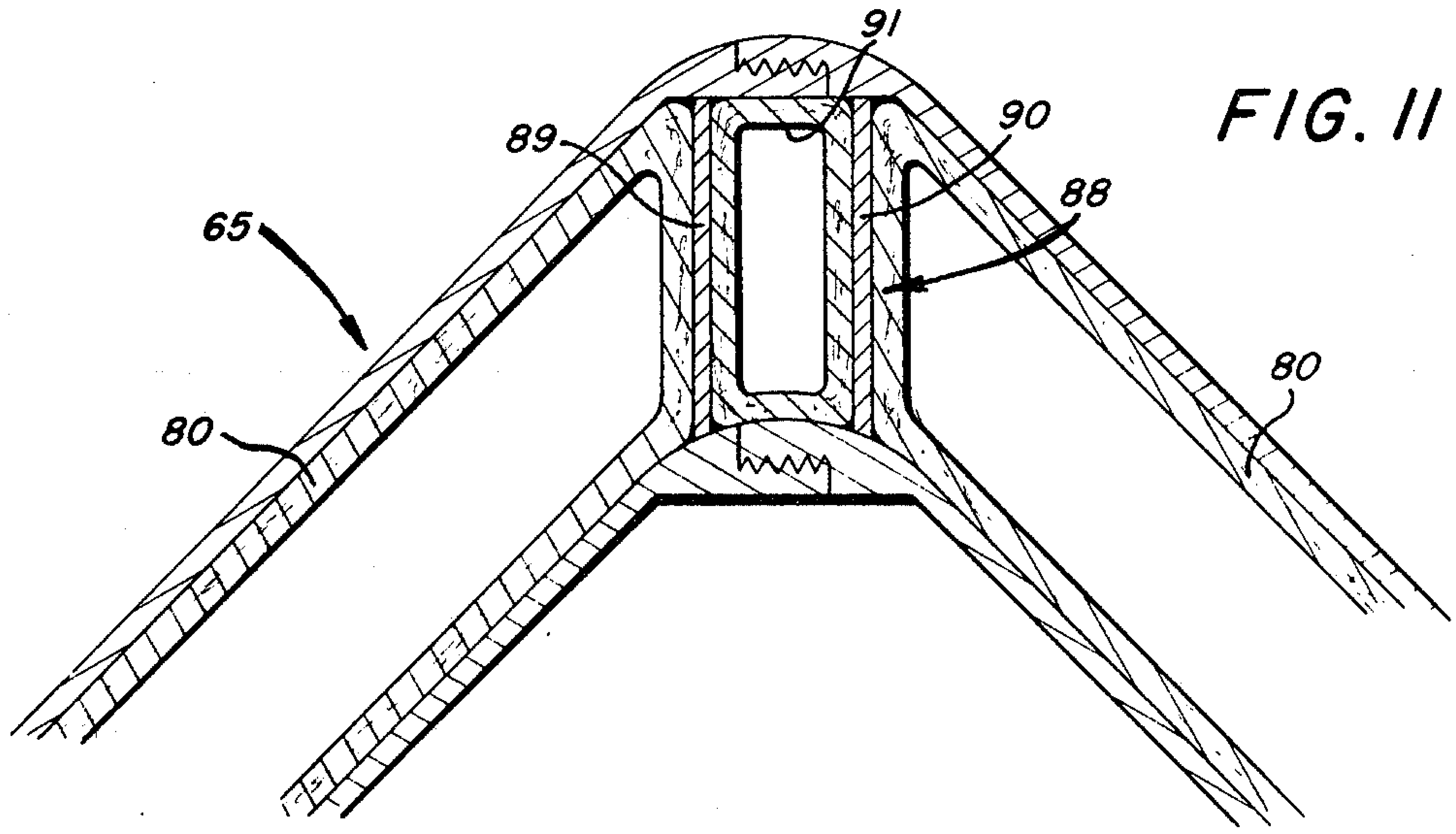

FIG. 11

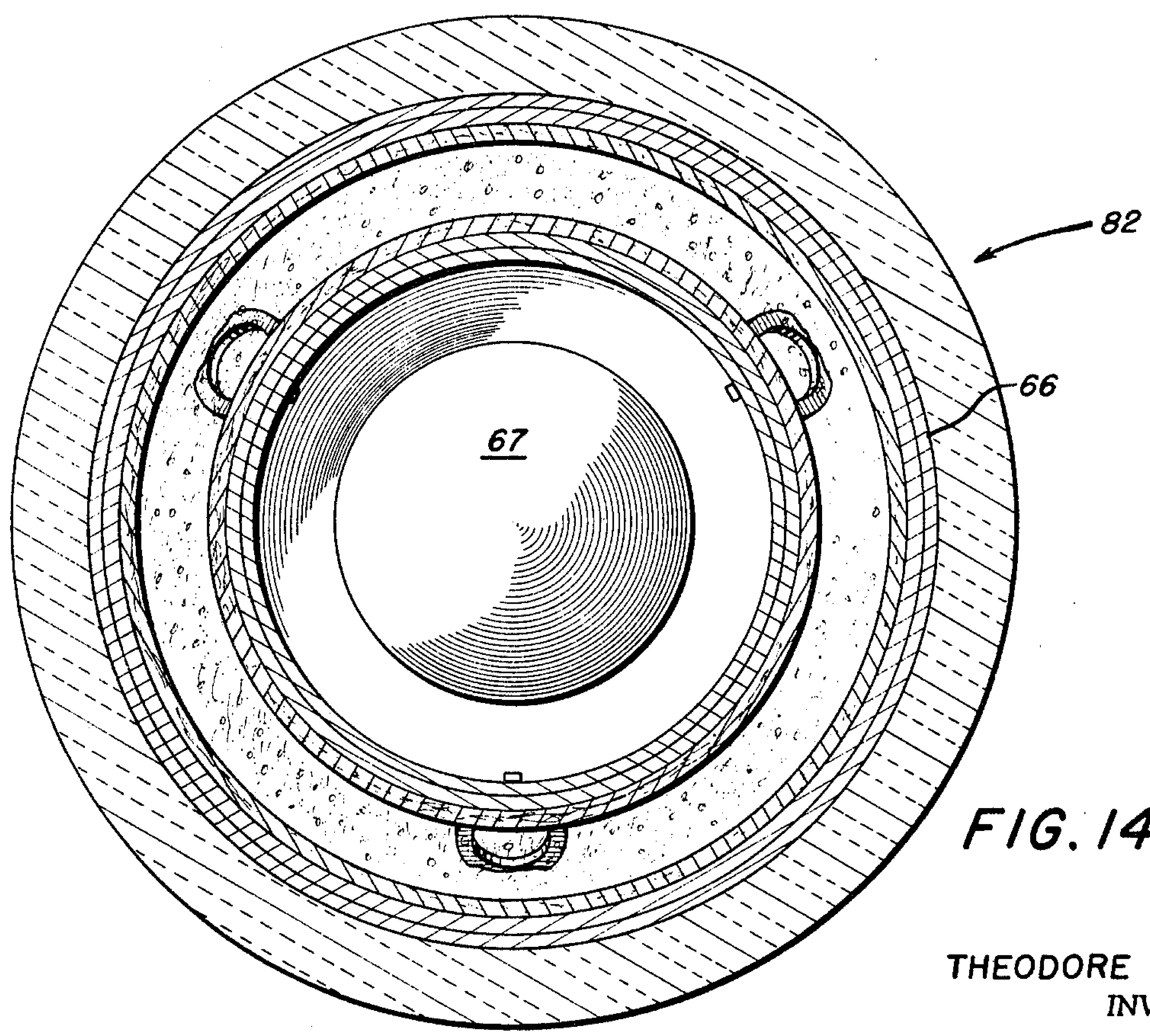

FIG. 14

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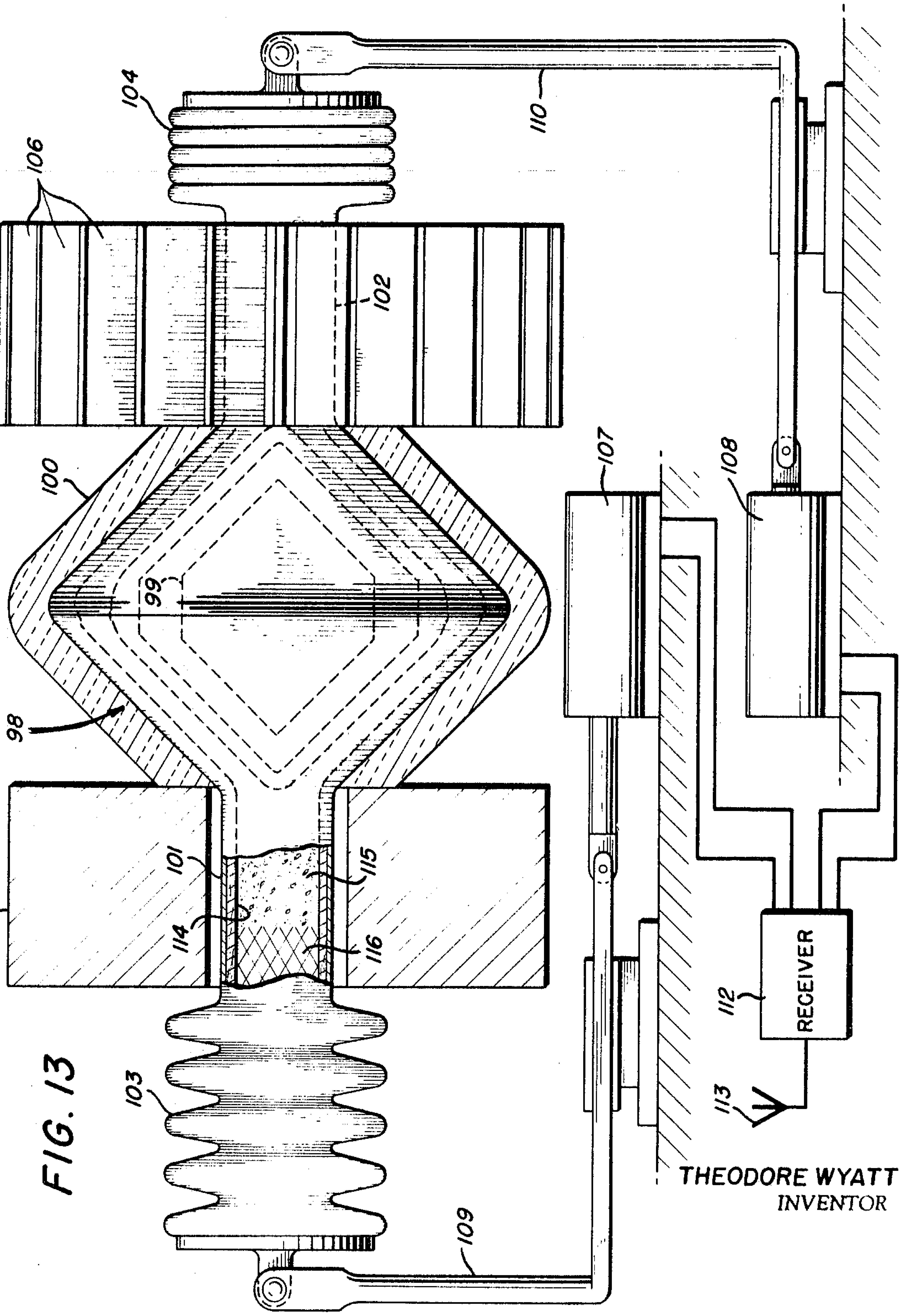

FIG. 13

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United States Patent Office

3,517,730
Patented June 30, 1970

3,517,730
CONTROLLABLE HEAT PIPE

Theodore Wyatt, Union Bridge, Md., assignor to the United States of America as represented by the Secretary of the Navy

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Int. Cl. F28d *15/00;* G21h *1/10*
U.S. Cl. 165—32 23 Claims

ABSTRACT OF THE DISCLOSURE

The object of the present invention is to provide apparatus for controlling the temperature within a space vehicle such as an earth satellite. The invention utilizes a heat pipe having a portion within the satellite and a portion extending exteriorly thereof, and having condensable and non-condensable gasses therein. The condensable gas is vaporized by heat from within the satellite and forced by pressure into the portion of the pipe that extends exteriorly of the satellite, at the same time forcing the non-condensable gas into a bellows (or cylinder) connected to the outer end of the pipe. Vapor reaching the exterior portion of the pipe conducts heat from the satellite into free space. Vapor in the exterior portion of the pipe is condensed and returned to the interior portion thereof by a wick. The bellows may be compressed (or a piston in the cylinder moved), by remotely controlled means, for forcing non-condensable gas into the pipe for limiting vapor flow and thus heat discharge from the satellite.

In modified embodiments the invention is used for controlling the output of one or more thermoelectric generators.

This invention relates generally to heat transfer devices of the type known as heat pipes. More particularly it pertains to an improved heat pipe having a controllable output.

Heat pipes, in their broadest aspects, are well-known and have been found to be quite useful for disposing of waste heat in space vehicles such as earth satellites. One such heat pipe is shown and described in my U.S. Pat. No. 3,152,774, assigned to the U.S. Government. In heat pipes in use up to the present time, however, no means has been employed for controlling their outputs.

An important object of the present invention, therefore, is to provide a heat pipe having simple and highly efficient means for controlling thermal flow therethrough without significantly varying the temperature level at which the heat is transferred and without requiring any variation of the quantity of heat or the temperature of the heat input source.

Another object of the invention resides in the provision of a controllable heat pipe by the use of which it will be possible to maintain a uniform temperature in the environment representative of either the input or the output end of the pipe, or the difference between them, or the difference between either end of said pipe and a reference temperature.

As a further object the invention provides a heat pipe which lends itself particularly well for use with nuclear power supplies, for transferring heat produced thereby selectively and controllably to one or more apparatuses provided for the conversion of heat to electricity.

Other objects and many of the attendant advantages of the invention will be readily appreciated as the same becomes better understood by reference to the following description when considered in connection with the accompanying drawings, wherein:

FIG. 1 is a diagrammatic view showing a heat pipe in an equilibrium condition;

FIG. 2 is a diagrammatic view illustrating a heat pipe with a bellows at the output end thereof for controlling heat output, the view showing the bellows contracted, for providing minimum heat conduction;

FIG. 3 is a view similar to FIG. 2 but showing the bellows extended for providing maximum heat conduction;

FIG. 4 is a detail longitudinal section, partly in elevation, showing one embodiment of a bellows and its associated mounting structure;

FIG. 5 is a side elevation, partly in section illustrating the invention as applied to a satellite;

FIG. 6 is a bottom view of the invention shown in FIG. 5;

FIG. 7 is a diagrammatic view showing a modification of the invention, as used in a space vehicle employing waste heat from a radioactive isotope thermoelectric generator;

FIG. 8 is a diagrammatic view of a further modification of the invention, utilizing heat from a radioactive isotope fuel capsule to activate alternatively either of a pair of thermoelectric generators;

FIG. 9 is a diagrammatic view showing a modified means for varying the position of the non-condensable gas employed for controlling heat flow;

FIG. 10 is a fragmentary diagrammatic view showing a modified version of the invention illustrated in FIG. 8;

FIG. 11 is a fragmentary diagrammatic view showing a further modification of the invention of FIG. 8;

FIG. 12 is a detail diagrammatic view showing still another modified form of the invention of FIG. 8;

FIG. 13 is a diagrammatic view showing a still further modified embodiment of the invention; and

FIG. 14 is a section on the line **14—14** of FIG. 8.

It is well-known in steam power plant practice that, if a non-condensable gas (commonly air dissolved in the feedwater) is admitted to the boiler or any other part of the system, the non-condensable gas is concentrated within the steam condenser. The effect of this accumulation within the condenser is to reduce the heat transfer accomplished within the condenser and is evidenced by a reduction in temperature in that portion of the condenser occupied by the non-condensable gas. Consequently, means are commonly provided to remove the non-condensable gas so as to maintain the heat transfer at the desired maximum rate.

With knowledge of the above-mentioned steam plant characteristic and of the similarity between a steam plant and a heat pipe, it became evident that by varying the amount of non-condensable gas present in a heat pipe the heat transfer accomplished might be controlled.

In addition, an experiment was reported wherein sodium was employed as the condensable gas or working fluid. After noting a temperature discontinuity in the heat output zone the explanation was offered that hydrogen gas was unintentionally present. Under the conditions of the experiment hydrogen would have been a non-condensable gas.

Thereafter an experiment was performed using ethyl alcohol as the working fluid and air as the non-condensable gas. The expected temeperature discontinuity in the heat output zone and reduction in heat flow was found to be present, as compared to the same heat pipe when operated under identical conditions except with the air absent.

The following explanation is postulated. Assume an inoperative heat pipe containing a working fluid and a gas which are chemically inert with respect to each other and their surroundings and differing greatly in their boiling points—the gas having the lower and being well above its dew point when the heat pipe is operating. The gas and the vapor of the fluid will be uniformly distributed and mixed throughout the heat pipe. If a constant amount of heat is now applied at one end of the heat pipe and withdrawn at the other end an equilibrium in temperature and pressure will be attained within the heat pipe. Liquid will be evaporated at the heat input zone and the resulting vapor will flow to the heat output zone, where the vapor will be condensed to the liquid state. The liquid thus produced will flow by capillary action through a wick back to the heat input zone. The continuing flow of vapor, always being in the same direction, sweeps essentially all of the non-condensable gas to the heat output zone and continually returns any gas molecules tending to migrate from this zone. FIG. 1 illustrates diagrammatically the equilibrium situation thus created. The non-condensable gas is confined to that portion of the heat output zone most remote from the heat input zone and gradually loses heat through the surrounding heat output zone. Consequently, the gas is cooler than the vapor and the portion of the heat pipe occupied by gas has a lower temperature than the portion occupied by vapor. Furthermore, the heat extracted from the output zone is reduced in proportion to the extent that the zone is occupied by non-condensable gas.

Thus the experimental observations and the postulated explanation seem to agree.

From the above it will be understood that thermal flow through a heat pipe can be controlled by varying the amount of non-condensable gas present. Such control may be effected reversibly by introducing or withdrawing the non-condensable "control" gas, as by a bellows or a piston. Various manual or automatic means may be used to adjust the position of the bellows or piston and hence the heat flow through the pipe. A suitable automatic device for, say, satellite temperature control would be the "Vernatherm" manufactured by the American Radiator and Standard Sanitary Corporation. An example wherein the "Vernatherm" would be useful is a satellite with internal heat dissipation, as from electrical loads or nuclear decay, sufficiently large compared to the solar input that regulation of the flow of such internal heat to surfaces substantially shielded from the sun, e.g., the base plate of a gravity stabilized satellite, and radiating to space would permit maintenance of a desired nearly constant internal temperature.

It should be understood that the internal pressure of a heat pipe is merely the vapor pressure of the working liquid at the temperature of the input zone. The same pressure prevails throughout, except for small flow losses, and, since the vapor and liquid phases of the working fluid are in temperature—pressure equilibrium throughout, the temperatures in all portions occupied by the condensable vapor are essentially the same. Furthermore, in the applications described herein the temperature of the heat input zone is very nearly the same as the temperature of the source of the heat. As a consequence, even though the operation of the bellows, or cylinder and piston, changes the internal volume of the heat pipe, there is no associated change in the internal pressure and temperature of the heat pipe.

Referring now more particularly to the drawings, and first to FIG. 1 thereof, a basic heat pipe according to the invention is shown. The heat pipe includes a cylindrical pipe section **10** having a side wall **11** which is closed at both ends by walls **12** and **13** and includes a sleeve **14** of suitable wicking material. The sleeve **14** extends throughout the length of the pipe section and engages the inner surface of the side wall **11**.

The heat pipe contains a non-condensable gas, such as air or hydrogen, indicated at **15**, and a condsenable working fluid such as water or ethyl alcohol, shown at **16**. The portion of the pipe shown within the bracket **17** is the heat input zone and is normally located near a source of heat, such as the interior of a space satellite, whereas

the portion of the pipe within the bracket **18** is the heat output zone and is located in a position to discharge heat produced, say, within the satellite by radiation to space.

As heat is applied to the pipe section **10** at the input zone **17** thereof, the working fluid **16** is caused to boil and the resulting vapor flows toward the heat output zone **18** for discharge therefrom. As pointed out hereinabove, as long as heat is supplied to the input zone **17**, any molecules of the non-condensable gas **15** that tend to migrate from the output zone **18** are returned to said output zone by the flow of the condensable vapor of the working fluid **16**, so that an equilibrium condition will be maintained. A sharp interface exists between the fluids **15** and **16**, and heat discharge from the output zone **18** will not take place if said zone is occupied by said non-condensable gas **16**.

Attention is now directed to FIGS. 2 and 3, wherein there is shown diagrammatically a means for controlling the heat output of a heat pipe by varying the position of the non-condensable gas therein. In these views the pipe section **10** is provided with an open end adjacent the heat output zone **18**, and secured to said open end is a bellows **20** which is formed of a suitable heat-resistant material. In FIG. 2 the bellows is shown compressed, for forcing the non-condensable gas **15** into the pipe section for occupying the heat output zone thereof and preventing flow of condensable vapor **16** into said output zone, with the result that heat discharge from the pipe section will be arrested. In FIG. 3 the bellows is shown expanded. In this position the non-condensable gas **15** will be withdrawn from the pipe section, when the condensable vapor **16** will be allowed to conduct heat to the heat output zone **18** for discharge therefrom. As will be obvious, the bellows may be adjusted, either manually or automatically, for positioning the non-condensable gas as desired, for regulating the heat flow from the output zone **18**. A satisfactory bellows adjusting means is shown in FIG. 5, to be described hereinafter.

To assure that stray molecules of the working fluid vapor will not condense in the bellows **20**, the structure shown in FIG. 4 may be employed. Referring to this view, the pipe section **10** is open at its end adjacent the heat output zone and is provided with a coupling flange **21** which mates with a coupling flange **22** secured to the open inner end of the bellows **20**. A suitable sealing gasket **23** is disposed between the flanges **21** and **22** and coupling bolts **24** secure the flanges and gasket in proper operative relationship for coupling the bellows to the pipe section. At its outer end, which is closed, the bellows **20** is secured to an actuator plate **25** by a clamping ring **26** and screws **27**, the actuator plate having an actuator rod **28** for connection to a manual or an automatic actuator (not shown). Surrounding the bellows and secured to the outer end portion of the pipe section **10** is a casing **29** of thermal insulating material, and surrounding the bellows within the casing is a heating element **30** having terminals **31** for connection to a source of electric power.

In the arrangement shown in FIG. 4, the casing **29** and heating element **30** cooperate to maintain the bellows **20** at a temperature slightly higher than that of the pipe section **10** at the heat output zone **18** thereof, to prevent the aforementioned condensation in said bellows.

FIGS. 5 and 6 illustrate the invention as applied to a gravity-gradient stabilized, earth orbiting satellite and with means for automatically controlling the bellows. In these views a satellite body is shown at **33**. A skirt is secured to the base of the body, and a layer of thermal insulation **34** is positioned adjacent said base. The skirt defines a sun shroud **35**. The heat pipe of this embodiment of the invention is shown generally at **36** and includes a heat input portion **37** which extends into the interior of the satellite body and includes fins **38**, and a heat output portion **39** which is positioned within the shroud **35** and includes fins **40**. At its outer end the output portion is provided with a bellows **41** which is similar to the bellows **20**. The bellows **41** is mounted in a casing **42** of thermal insulating material, and includes an actuator rod **43**. The output portion **39** is of angular configuration, as shown in FIG. 6. It should be understood, however, that said output portion may be of any desired configuration.

For controlling the output of the heat pipe of the embodiment of FIGS. 5 and 6, a heat-responsive device **44** is mounted within the satellite body **33**. The heat responsive device may conveniently be of the type known as "Vernatherm," manufactured by the American Radiator and Standard Sanitary Corporation. The heat responsive device and the heat input portion **37** of the pipe **36** are mounted in such a position within said body **33** that they will be exposed to heat from, say, operating electronic equipment such as is shown diagrammatically at **45**. The heat responsive device **44** is operatively connected to the actuator rod **43** of the bellows **41** by a linkage **46** which is pivotally connected to the body **33** by a pin **47**. The linkage **46** is shown as being of inverted L shape, but it should be understood that other configurations, or even a direct connection between the rod **43** and the device **44**, may be used if desired.

The operation of the embodiment shown in FIGS. 5 and 6 is briefly as follows. An increase in temperature within the body **33** causes the heat responsive device **44** to extend, thus shifting the linkage **46** for extending the bellows **41** and withdrawing non-condensable gas in the heat pipe into said bellows, when condensable vapor will flow into the output portion **39** for discharge therefrom. The fins **38** and **40** function in their normal way to provide increased heat collection and discharge surfaces. When the temperature of the interior of the satellite body **33** has been lowered to a desired predetermined value, the heat responsive device **44** will operate to compress the bellows **41** for forcing non-condensable gas into the output portion **39** for limiting discharge of heat therefrom.

To assure proper operation of the invention as shown in FIGS 5 and 6, the earth-orbiting satellite may be gravity stabilized, so that the shroud **35** will predominantly shield the output portion **39** of the heat pipe **36** from the sun. When used with a gravity stabilized satellite, the invention will maintain the interior of said satellite at a desired nearly constant temperature.

Referring now to the modification of the invention shown in FIG. 7, a satellite **49** is powered by a fuel capsule **50** which may conveniently be a radioactive isotope supplying heat to a thermoelectric generator. The fuel capsule is mounted in a suitable housing **51** having a base **52** of thermal insulating material, and said housing is connected to the satellite by legs **53**. Fins **54** radiate heat generated by the heat capsule.

Mounted in the satellite **49** and extending into the housing is a heat pipe **55** which includes a heat input portion **56** of "pancake" configuration and a tubular heat output portion **57**. As will be seen, the heat input portion **56** is disposed within the housing **51** to receive heat from the capsule **50**, and the output portion **57**, which extends through the base **52**, is positioned to discharge heat to the interior of the satellite **49**. Connected to the lower end of the heat pipe **55** is a bellows **58** which is mounted in an insulated enclosure **59**. The bellows **58** is provided with an actuating rod **60** which is directly connected to a heat responsive device **61** that is mounted in the satellite. The heat responsive device may be the "Vernatherm" mentioned in the description of FIGS. 5 and 6 hereinabove.

As in the previously described modifications of the invention, the heat pipe **55** of FIG. 7 contains a non-condensable gas **62** and a condensable vapor **63** and a wick **64**. Movement of the bellows by action of the heat responsive device **61** in accordance with heat requirements of the satellite will position the non-condensable gas in the output portion **57** for admitting condensed fluid from the heat input portion **56** to a relatively large or relatively small area of the output portion **57**, whereby relatively large or relatively small amounts of heat generated by the fuel capsule will be transferred to the interior of the satellite, thereby maintaining some predetermined desired temperature.

In FIGS. 8 and 14 the invention is shown applied to a thermoelectric power generating system. In FIG. 8, which is partly diagrammatic, a heat pipe is shown at **65**. The heat pipe **65** includes a sectionalized central heat input housing **66** which surrounds a radioactive isotope fuel capsule **67**, and tubular heat output end portions **68** and **69**. The outer ends of the portions **68** and **69** are open and have secured thereto bellows **70** and **71**, respectively, the bellows being closed at their outer ends and fitted with actuating rods **72** and **73**. A control device **74** is connected to the actuating rods **72** and **73** by links **75** and **76** respectively, and in such a manner that movement of an actuator rod **77** of the device **74** in one direction will cause the bellows **70** to expand and the bellows **71** to compress. Movement of the actuator rod **77** in the opposite direction will, as will be obvious, bring about compression of the bellows **70** and expansion of the bellows **71**.

Surrounding the heat output portions **68** and **69** are, respectively, thermoelectric arrays **78** and **79**, said arrays being of well-known construction. The heat pipe **65**, like the heat pipes of the other embodiments described hereinabove, is provided with a wick **80** which extends throughout the lengths of the output end portions **68** and **69** and adjacent the interior surfaces of the housing **66**. Also as in the previously described embodiments of the invention, the heat pipe **65** has condensable and non-condensable fluids therein. Surrounding the housing **66** is a thermal insulating jacket **82** to minimize heat loss.

It will be clear from the above description that expansion of one or the other bellows will withdraw non-condensable gas from its associated heat output portion for admitting condensable vapor thereto for transfer to the adjacent thermoelectric array for generating power. Thus one of the arrays will be on inoperative stand-by when the other is operating. The control device **74** is a conventional solenoid which, when the invention of this embodiment is mounted in a satellite, may be operated on command from the ground or another satellite. A command receiver and antenna therefor are shown diagrammatically at **83** and **84**.

A variation of the application of the controllable heat pipe to the thermoelectric power generator, as shown in FIG. 8, is illustrated in FIG. 10 and may be preferable to insure reliable operation. Where applicable the numerals used in FIG. 8 are also employed in FIG. 10, in the interest of simplicity. There is some concern that the non-condensable gas, although initially divided into equal parts assigned to the left and right halves of the heat pipe, might become redistributed so that a preponderance permanently or temporarily would occupy one or the other half. This occurrence would interfere with proper operation. To preserve the desired distribution of equal portions of non-condensable gas in each half an annular metal bulkhead **86** is provided between the sections of the housing **66** to seal off the left and right halves of the heat pipe from each other. The wick **80** provides a continuous path for the flow of the liquid phase of the condensable fluid along the circular portion of one-half of the heat pipe, within one-half of the heat input housing and along the bulkhead **86**. Heat transfer across the bulkhead to the other half of the heat pipe is accomplished by the same vaporization and condensation process as within a conventional heat pipe. If it is desired to shorten the length of the path of capillary flow, bridges **87** of wicking material, shown in dotted lines, can be provided, so long as care is taken to avoid obstructing seriously the flow of vapor from the input to the output ends of the pipe.

Another way of obtaining the same effect is illustrated in FIG. 11, wherein, as in FIG. 10, the numerals of FIG. 8 are employed where applicable. FIG. 11 shows in larger scale a modified annular bulkhead. In FIG. 11 the bulkhead, shown at **88**, has two metal walls **89** and **90**, is provided on each side with wicking material **91**, and contains the vapor and liquid of a condensable fluid. The bulkhead **88** does not contain non-condensable fluid. The edges of the plates **89** and **90** are sealed, so that the above-mentioned gas isolation of the two halves of the main heat pipe is provided. By its construction the bulkhead **88** also functions as a heat pipe, thus providing the desired ease of heat flow from one to the other halves of the main heat pipe.

If the allowable dimensions do not permit sufficient heat transfer across the bulkhead **86**, the input section of the housing **66** on the right in FIG. 10 will attain a higher temperature and pressure than that on the left, and the heat liberated from the fuel capsule **67** in the right half of the heat pipe will not aid the operation of thermal-electric array **78** on the left. Accordingly, as shown in FIG. 12, wherein the numerals of FIGS. 8 and 10 are used where applicable, an annular sectional separately sealed heat pipe **92** is provided to transfer most of the heat from the electrically inoperative half (in FIG. 10 the right half) to the operative (left) half. By this means the above-mentioned temperature and pressure difference is prevented and nearly all available heat is transferred to the operating thermal-electric array. Since a heat pipe is equally capable of transmitting heat in either direction, movement of actuator **77** (FIG. 8) to the position opposite to that shown does not impair the above uniformity of temperature and pressure and the utilization of available heat. The annular heat pipe **92** includes a sealed hollow body and is similar to the heat pipe **65** to the extent that it contains wicking **93** and a condensable fluid **93*a***, the non-condensable fluid being omitted.

If desired, a cylinder and piston arrangement may be substituted for the bellows in each of the embodiments described hereinabove. Such an arrangement is shown in FIG. 9, wherein the heat pipe is shown at **94**, a cylinder attached to the outer end thereof at **95**, and a piston in the cylinder at **96**. A piston rod **97** connects the piston to a linkage, such as the linkage **46** shown in FIG. 5, or to the solenoid actuator **77**. Other variations of this switching technique, such as switching among three or more outputs instead of the two outputs described, or switching partially rather than completely, are apparent.

The objective of the provision of a controllable heat pipe for the radioactive isotope fueled thermoelectric power generator is to obtain a better match in the useful operating life of the fuel capsule and of the thermoelectric array so as to attain an improvement in overall generator longevity and in economy of usage of isotope fuel. One way to attain this desired improvement is to provide means of exploiting a redundancy of thermoelectric arrays so that the presently imperfect reliability or the commonly experienced gradual degradation of thermo-electric arrays can be mitigated by directing the heat to a selected one of two or more alternative arrays, each array having been designed to sustain the entire electrical load by itself if in proper operating condition. Since the evolution of heat in konwn amount from a radioactive isotope fueled capsule is highly predictable and dependable, this provision will extend the probable life of the overall generator in proportion to the degree of redundancy.

Another way of attaining improvement is to provide means of utilizing the changing thermal emission properties of the cheaper and more available relatively shortlived radioactive isotopes. If, as shown in FIG. 13, one array were removed and replaced with radiating fins and if provisions were made to operate the two bellows independently, then at the start of life with an excess of shortlived isotope the excess heat, which would otherwise destroy the array, could be harmlessly radiated to space by fully extending the bellows controlling the radiating fins. As the isotope progressively deteriorates in its heat output, the bellows is gradually compressed to reduce the amount of heat radiated to space and to maintain constant the amount of heat directed to the array. By sizing the bellows and radiating fins properly the required constant amount of heat can be provided to the array during several half-lives of the isotope.

More specifically, as shown in FIG. 13, a heat pipe similar to that illustrated in FIG. 8 is shown. The heat pipe of FIG. 13 includes a heat input housing **98** having a short-lived radioactive isotope **99** positioned therein. Insulation **100** surrounds the input housing. Heat output portions **101** and **102** extend from the opposite ends of the input housing, and connected to the outer ends of the heat output portions **101** and **102**, respectively, are bellows **103** and **104**. A thermoelectric generator **105** surrounds the heat output portion **101** and a fin assembly **106**, comprising a plurality of radially directed fins, is fitted about the heat output portion **102**. Actuators **107** and **108** are connected, respectively, to the bellows **103** and **104** through suitable linkages **109** and **110**, and the actuators are connected to a receiver **112** which has an antenna **113** connected thereto. The receiver is responsive to pulse coded signals so that the actuators may be operated independently or simultaneously, for controlling the bellows.

The heat pipe **98** is provided with wicking **114** and condensable and non-condensable gases **115** and **116**, respectively. Thus, on expansion of the bellows **104**, the non-condensable gas will be drawn into said bellows, allowing the heat-conducting condensable gas to enter the heat output portion **102**. Heat conducted by the condensable gas will be radiated by the fin assembly **106**. Conversely, as the heat output of the isotope deteriorates, the bellows **104** may be compressed, for limiting heat radiation by the fin assembly **106**. Output of the thermoelectric generator **105** may likewise be controlled by operation of the bellows **103**, for admitting a desired amount of condensable gas into the heat output portion **101**.

It is apparent from the above descriptions that by the use of redundant arrays, several branches to the heat pipe and excess heat radiating provisions, the combination of features affording long array life with relatively short-lived isotopes can be employed to advantage.

If desired, the cylinder and piston arrangement shown in FIG. 9 may be substituted for the bellows in each of the embodiments described hereinabove.

Other variations of this switching technique, such as switching among three or more outputs instead of the two outputs described, or switching partially rather than completely, are apparent.

Obviously, many modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood at this time that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A controllable heat pipe comprising:

a pipe section having a heat input end portion and a heat output end portion, the heat input end portion of the pipe being positioned for exposure to a source of heat external of the pipe and the heat output end portion of said pipe being positioned to discharge such heat to an area remote from the heat input end portion of the pipe,

fluid conducting means in the pipe section,

a condensable fluid in the pipe section and movable as vapor under the influence of heat toward the heat output end portion of the pipe,

a non-condensable gas in the pipe section and limiting flow of said vapor toward said output end portion, and

volumetric means connected to the pipe section at the heat output end portion thereof and adjustable for withdrawing therefrom and returning thereto non-condensable gas whereby heat conducted by the vapor will be permitted to flow toward and away from said output end portion of the pipe for discharge therefrom,

said fluid conducting means returning as liquid the vapor condensed at the heat output end portion of the pipe to the heat input end portion thereof.

2. A controllable heat pipe as recited in claim **1**, wherein

said fluid conducting means in the pipe section comprises wicking material.

3. A controllable heat pipe as recited in claim **1**, wherein

said last-mentioned means comprises a bellows.

4. A controllable heat pipe as recited in claim **1**, wherein

said last-mentioned means comprises a cylinder connected to the output end portion of the pipe section, and

a piston movable in the cylinder.

5. A controllable heat pipe as recited in claim **3**, including additionally

heat-responsive actuating means positioned in the environment of the input end portion of the pipe section, and

means operatively connecting the heat-responsive actuating means to the bellows.

6. In combination with a heat source,

a controllable heat pipe including a pipe section having a heat input end portion positioned for exposure to the heat source and a heat output end portion positioned remote from said heat source,

a condensable gas in the pipe section and movable by heat from the source toward the heat output end portion of the pipe where the heat of condensation is released,

a non-condensable gas in the pipe section and limiting flow of said condensable gas toward said output end portion of the pipe,

a bellows connected to the heat output end of the pipe section,

heat-responsive actuating means positioned adjacent the heat source,

said actuating means so positioning the bellows that the amount of non-condensable gas admitted to the heat output end portion of the pipe will be regulated, whereby the area surrounding the input end portion of the pipe section will be maintained at a nearly constant temperature, and

fluid conducting means in the pipe section for returning as liquid the condensable gas condensed at the heat output end portion of the pipe to the heat input end portion thereof.

7. The combination recited in claim **6**, wherein the conducting means in the pipe section consists of wicking material.

8. The combination recited in claim **6**,

including additionally link means connected between the bellows and the actuating means.

9. The invention as recited in claim **1**, wherein

the condensable fluid is water, and the non-condensable gas is hydrogen.

10. The invention as recited in claim **1**, wherein

the condensable fluid is ethyl alcohol, and the non-condensable gas is hydrogen.

11. The invention as recited in claim **1**, wherein

the condensable fluid is sodium gas, and the non-condensable gas is hydrogen.

12. The invention as recited in claim **1**, wherein

the condensable fluid is water, and the non-condensable gas is air.

13. The invention as recited in claim **1**, wherein

the condensable fluid is ethyl alcohol, and the non-condensable gas is air.

14. The invention as recited in claim **6**,

including additionally an insulated casing enclosing the bellows, and

heat means surrounding the bellows within the casing for preventing condensation within the bellows of any stray molecules of condensable gas.

15. In combination with a space satellite having heat producing means therein,

a controllable heat pipe comprising:

a pipe section having a heat input end portion mounted within the satellite and in the environment of the heat producing means and a heat output portion mounted exteriorly of the satellite,

a condensable gas in the pipe section and movable by heat from the heat producing means toward the heat output end portion of the pipe,

a non-condensable gas in the pipe section and limiting flow of said condensable gas toward said output end portion,

volumetric means connected to the pipe section at the heat output end portion thereof and exteriorly of the satellite and being adjustable for withdrawing therefrom and returning thereto non-condensable gas whereby heat conducted by the condensable gas will be permitted to flow toward and away from said output end portion of the pipe for discharge exteriorly of the satellite, and

fluid conducting means in the pipe section for returning liquid produced by condensation of the condensable gas at the heat output end portion of the pipe section to the heat input end portion thereof.

16. The combination recited in claim **15**, wherein

the satellite has a body, a shroud extending below the body and a wall of insulating material between the body and the shroud.

wherein the heat producing means and the heat input end portion of the pipe section are mounted within the body, and

wherein the heat output portion of the pipe section and the second mentioned means are mounted exteriorly of the body adjacent the wall of insulating material and within the shroud.

17. In combination with a satellite having a body, a heat generating fuel capsule, and means insulating the fuel capsule from the body,

a controllable heat pipe including a pipe section having a heat input end portion mounted in the environment of the fuel capsule and a heat output portion extending through the insulating means and within the body,

a condensable gas in the pipe section and movable by heat toward the heat output end portion thereof,

a non-condensable gas in the pipe section and limiting flow of said condensable gas toward said output end portion,

volumetric means connected to the pipe section at the heat output end portion thereof and adjustable for withdrawing therefrom and returning thereto non-condensable gas whereby heat conducted by the condensable gas will flow into and away from said output end portion of the pipe for discharge therefrom,

means for actuating said last-mentioned means in response to temperature changes in the body, and

liquid conducting means in the pipe section and returning as liquid condensable gas condensed at the heat output end portion of the pipe section to the heat input portion thereof.

18. In combination with a heat generating fuel capsule, and a pair of thermoelectric generators, a controllable heat pipe including a pipe section having a centrally located heat input housing and heat output end portions,

said housing having said capsule therein,

one of said heat output end portions being positioned adjacent each of said generators,

a bellows connected to the outer end of each of said heat output end portions,

a condensable gas in the pipe section and movable by heat from the capsule toward the heat output end portions of the pipe section,

a non-condensable gas in the pipe section and limiting flow of said condensable gas toward said output end portions,

means connected to said bellows for alternately expanding one thereof while compressing the other for alternately withdrawing non-condensable gas from one output end portion and forcing non-condensable gas into the other said output end portion, the with-drawal of non-condensable gas from one output end portion permitting the flow of condensable gas therein, whereby heat wil be transferred to the thermoelectric generator adjacent thereto for generating electric power, the forcing of non-condensable gas into the other of said heat output end portions arresting flow of condensable gas into said other heat output end portion for limiting heat transfer to the thermoelectric generator adjacent thereto, and

conducting means in the pipe section for returning as liquid the condensable gas condensed in the heat output end portions of said pipe section to the heat input housing thereof.

19. The combination recited in claim **18**,

wherein the heat input housing comprises a pair of mating sections, and

including additionally a bulkhead between the housing sections and dividing the heat pipe into independently operating halves,

said bulkhead conducting heat between said halves.

20. The combination recited in claim **18**,

wherein the heat input housing comprises a pair of mating sections, and

including additionally an annular heat pipe between the housing sections and dividing the heat pipe into independently operating halves,

said annular heat pipe conducting heat between said halves and including a pair of spaced walls cooperating with said housing sections to define a closed chamber, wicking material between the walls, and a condensable gas in the chamber.

21. The combination recited in claim **18**,

wherein the heat input housing comprises a pair of mating sections, and

including additionally an annular heat pipe surrounding the housing sections and conducting heat between the sections,

said annular heat pipe having wicking and a condensable gas therein.

22. A controllable heat pipe including a pipe section having a centrally located heat input housing and first and second heat output end portions,

a fuel capsule in the housing,

a thermoelectric generator on said first heat output end portion,

a fin assembly on said heat output end portion,

a first bellows connected to the outer end of said first heat output end portion,

a second bellows connected to the outer end of said second heat output end portion,

a condensable gas in the pipe section and movable by heat produced by the capsule from the housing toward said heat output end portions,

a non-condensable gas in the pipe section and limiting flow of said condensable gas toward said heat output end portions,

means for actuating said first bellows for regulating the flow of condensable gas into said first heat output end portion for controlling heat discharge therefrom to said thermoelectric generator,

means for actuating said second bellows for regulating the flow of condensable gas into said second heat output end portion for controlling heat discharge therefrom to said fin assembly, and

means for supplying control signals to said penultimate and last mentioned means for operating the same independently, whereby the heat supplied by the fuel capsule to the thermoelectric generator may be maintained substantially constant.

23. A controllable heat pipe including a pipe section having a centrally located heat input housing and first and second heat output end portions,

a fuel capsule in the housing,

a thermoelectric generator on said first heat output end portion,

a fin assembly on said heat output end portion,

a first bellows connected to the outer end of said first heat output end portion,

a second bellows connected to the outer end of said second heat output end portion,

a condensable gas in the pipe section and movable by heat produced by the capsule from the housing toward said heat output end portions,

a non-condensable gas in the pipe section and limiting flow of said condensable gas toward said heat output end portions,

means for actuating said first bellows for regulating the flow of condensable gas into said first heat output end portion for controlling heat discharge therefrom to said thermoelectric generator,

means for actuating said second bellows for regulating the flow of condensable gas into said second heat output end portion for controlling heat discharge therefrom to said fin assembly, and

means for supplying control signals to said penultimate and last mentioned means for operating the same simultaneously, whereby the heat supplied by the fuel capsule to the thermoelectric generator may be maintained substantially constant.

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