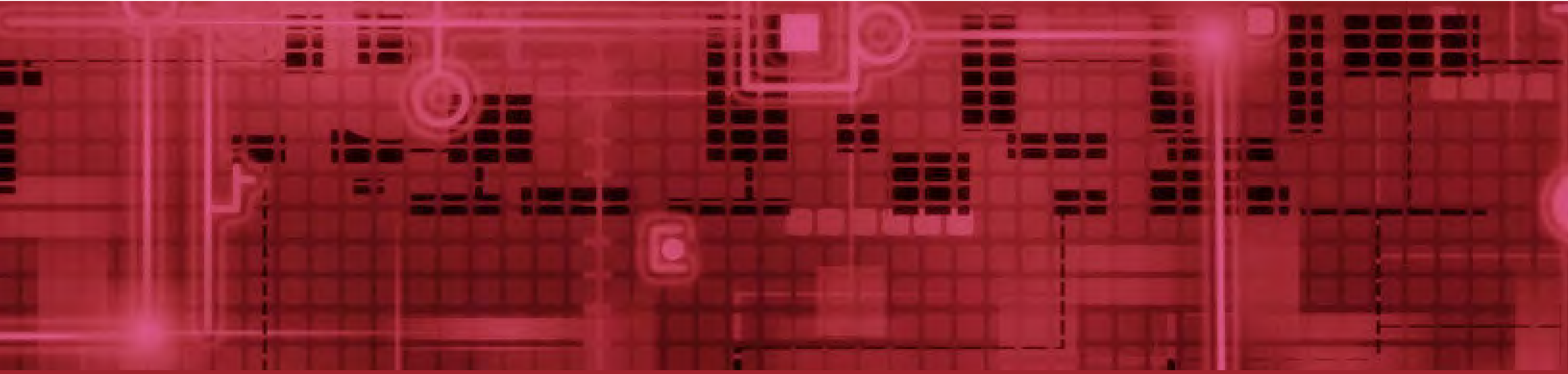


Technology Review: Techniques for Measuring the Thermal Performance of Heat Pipes, 2006 to 2012

Qpedia continues its review of technologies developed for electronics cooling applications. We are presenting selected patents that were awarded to developers around the world to address cooling challenges. After reading the series, you will be more aware of both the historic developments and the latest breakthroughs in both product design and applications. We are specifically focusing on patented technologies to show the breadth of development in thermal management product sectors. Please note that there are many patents within these areas. Limited by article space, we are presenting a small number to offer as a representation of the entire field. You are encouraged to do your own patent investigation. Further, if you have been awarded a patent and would like to have it included in these reviews, please send us your patent number or patent application.

In this issue, our spotlight is on techniques for measuring thermal performance of heat pipes. There is much discussion on this subject with respect to the electronics industry, and these patents show some of the salient features that are the focus of different inventors.

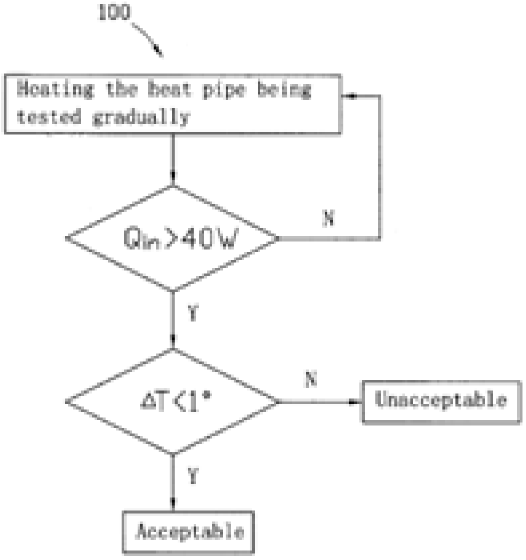
Method and Apparatus for Conducting Performance Test to Heat Pipe

US 2006/0256834 A1, Chang., C. et al.

As scientific technology continues to advance in electronic industry, a variety of electronic components such as central processing units (CPUs) of computers are currently suffering serious heat-dissipating problem with which conventional heat dissipation devices, for example, heat sinks and fans, are difficult to deal. Now, in order to solve this problem, heat pipes are often incorporated into these conventional heat dissipation devices so as to dissipate heat from the electronic components more rapidly and effectively. Heat pipes have excellent heat transfer performance due to their low thermal resistance, thus providing an effective means for overcoming overheating problem of advanced electronic components.

A heat pipe is usually a vacuum vessel which defines therein a chamber for containing a working fluid such as water. The working fluid is employed to carry heat from one end of the heat pipe, typically referred to as “evaporating section”, to the other end of the heat pipe, typically referred to as

PATENT NUMBER	TITLE	INVENTORS	DATE OF AWARD
US 2006/0256834 A1	METHOD AND APPARATUS FOR CONDUCTING PERFORMANCE TEST TO HEAT PIPE	Chang,. C. et al.	Nov 16, 2006
US 7,594,749 B2	PERFORMANCE TESTING APPARATUS FOR HEAT PIPES	Liu., T. et al.	Sep 29, 2009
US 8,322,917 B2	METHOD FOR TESTING A HEAT PIPE AND CORRESPONDING TEST DEVICE	Gatti, M., et al.	Dec 4, 2012



"condensing section". Preferably, a wick structure, such as mesh or sintered powder, is provided in the chamber, lining the inside walls of the vessel. In application, conventional heat dissipation devices such as fins are coupled to the condensing section of the heat pipe to thereby form a cooling assembly. As the evaporating section of the heat pipe is maintained in thermal contact with a heat-generating component, heat is absorbed in the evaporating section and the working fluid contained therein evaporates into vapor. The vapor moves towards the condensing section of the heat pipe under the vapor pressure gradient between the two sections. In the condensing section, the vapor releases its latent heat to atmosphere environment by the fins, and then is condensed into liquid. The condensed liquid then returns back to the evaporating section rapidly via capillary action provided by the wick structure. Thus, the heat generated by the heat-generating component is removed.

In order to ensure that the heat is rapidly and effectively removed from the heat-generating component, the heat pipe is generally required to be tested before sent for application in order to find whether or not its performance satisfies the cooling requirement of the heat-generating component. The thermal resistance (R_{th}), the maximum heat transfer capacity (Q_{max}) and the temperature difference (ΔT) between two ends are three parameters that are commonly used to evaluate the performance of a heat pipe. The relationship between these parameters Q_{max}, R_{th} and ΔT is $R_{th}=\Delta T/Q_{max.}$ As a competent heat pipe to the heat-generating component, the general rule is that its thermal resistance R_{th} and temperature difference ΔT between its two ends should be as low as possible and its maximum heat transfer capacity Q_{max} should be higher than the thermal design power of the heat-generating component, if only one heat pipe is used in the cooling assembly. The heat pipe 1 is partially inserted into a constant temperature water bath 2 containing hot water. After a specified time period, the respective temperatures T1, T2 at two ends of the heat pipe 1 are detected, and if the temperature difference ΔT between the two ends is lower than a predetermined value, for example, 1 degree centigrade, the heat pipe 1 being tested will be deemed as acceptable to the heat-generating component. However, this method cannot obtain the quantity of heat actually transferred from the hot water to the heat pipe 1. Thus, on some occasions, it may lead that for some heat pipes their maximum heat transfer capacity is lower than the thermal design power of the heat-generating component, but they are judged as acceptable to the heat-generating component through this method.

In view of the above-mentioned disadvantage of the conventional art, there is a need for a method which can be applied to evaluate the performance of a heat pipe more accurately. What is also needed is an apparatus for conducting the performance test to the heat pipe.

The flow chart shows the main steps of a preferred method 100 of the present invention for testing the performance of a heat pipe 40. This method 100 is directed to obtain two parameters, i.e., Q_{in} and ΔT, from the heat pipe 40. The first parameter Q_{in} is the quantity of heat energy transferred to the heat pipe 40. The first parameter Q_{in} is typically used to reflect the heat transfer capacity of the heat pipe 40. The second parameter ΔT is the temperature difference between two ends of the heat pipe 40. Firstly, the heat pipe 40 is heated gradually until the heat pipe 40 begins to work. Then, the first parameter Q_{in} is obtained, and if it exceeds a first value, a following procedure is commenced to obtain the second parameter ΔT. If the obtained parameter ΔT is lower than a second value, the heat pipe 40 being tested will be deemed as acceptable. The selection of the first and second values is based on a case-by-case basis. For example, the first and second values may be determined according to the cooling requirement of a specific heat-generating component to which the heat pipe 40 is applied to remove heat therefrom. In this case, it is assumed that, as a competent heat pipe, the first parameter Q_{in} of the heat pipe 40 should be higher than a value of 40 watts and the second parameter ΔT should be lower than a value of 1 degree centigrade. Through this method 100, those heat pipes with their maximum heat transfer capacity being lower than 40 watts will not be accepted, thereby overcoming the disadvantage of the conventional test method depending only on ΔT.

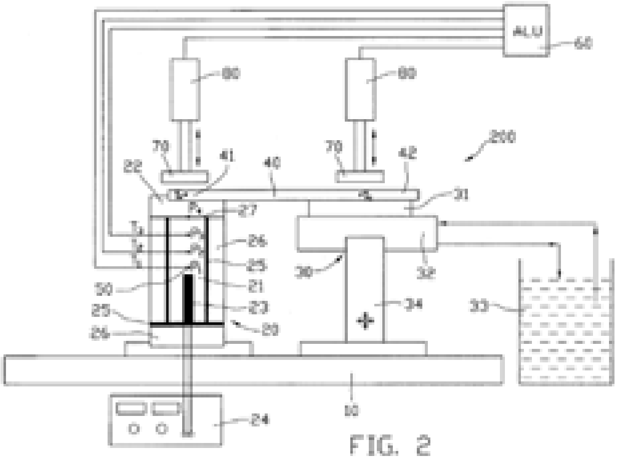
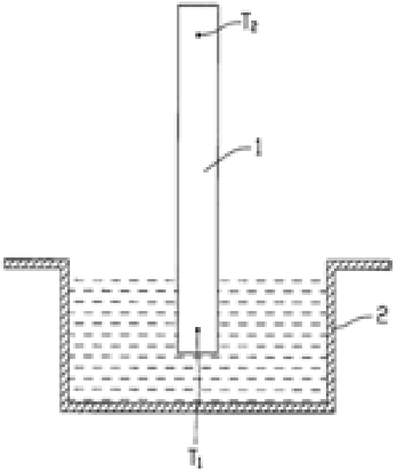


FIG. 2

The schematic illustrates an apparatus 200 for conducting the performance test to the heat pipe 40 by applying the method 100. The apparatus 200 includes a supporting base 10, a heating device 20 and a cooling device 30. The heating device 20 and the cooling device 30 are mounted on the supporting base 10 and are spaced from each other. The heating device 20 includes a heat-transferring block 21, a heating block 22 located above and thermally connected with the heat-transferring block 21 and an electric heater 23 completely received in a lower portion of the heat-transferring block 21. The electric heater 23 is inserted into the heat-transferring block 21 along a longitudinal direction thereof. The heat-transferring block 21 and heating block 22 may be integrally formed, and preferably, the heating block 22 has a larger cross-sectional area than the heat-transferring block 21.

The heat-transferring block 21 and heating block 22 are preferably made of copper or other materials with excellent thermal conductivity. The electric heater 23 is connected with a direct-current power supply 24 so as to supply thermal energy to the heat-transferring block 21. The thermal energy supplied by the electric heater 23 is then transferred upwardly from the heat-transferring block 21 along its longitudinal direction to the heating block 22, and is further transferred to the heat pipe 40 from the heating block 22. In order to prevent the thermal energy supplied by the electric heater 23 from dissipating into ambient environment, first and second heat insulation layers 25, 26 are provided to surround the heat-transferring block 21. The heat insulation layers 25, 26 are made of heat-insulating materials such as fiber glass, Bakelite or asbestos. Thus, the thermal energy supplied by the electric heater 23 is generally considered to be fully transferred to the heating block 22 from the heat-transferring block 21.

The cooling device 30 includes a cooling block 31, a cooling jacket 32 and a low temperature water tank 33. The cooling jacket 32 is located below and thermally connected with the cooling block 31. The cooling device 30 employs water circulating through the cooling jacket 32 to thereby remove heat from the cooling block 31 which is in thermal contact with the heat pipe 40. Preferably, an adjustment mechanism 34 is provided between the cooling jacket 32 and the supporting base 10 to adjust the positions of the cooling jacket 32 and the cooling



block 31 so that the apparatus 200 can be suitably applied to test heat pipes with different lengths or configurations.

Before the performance test to the heat pipe 40 is conducted, two ends of the heat pipe 40, i.e., the evaporating section 41 and the condensing section 42, are placed to thermally contact with the heating block 22 and the cooling block 31, respectively.

Preferably, the evaporating section 41 is arranged to be partially or fully received in the heating block 22 from a top surface thereof so as to increase the contact surface between the heating block 22 and the heat pipe 40. Then, the supply power 24 is controlled to gradually supply thermal energy to the heat-transferring block 21 via the electric heater 23. Meanwhile, at least one temperature detector 50 is used to detect the respective temperatures T1, T2, T3 at three spaced points P1, P2, P3 selected from an upper portion of the heat-transferring block 21. The three points P1, P2, P3 are linearly located between the heating block 22 and the electric heater 23 along the longitudinal direction of the heat-transferring block 21. The temperature detector 50 may be a thermal couple or a thermometer to be connected with a corresponding point P1, P2 or P3. For example, three thermal couples may simultaneously be used to measure the temperatures T1, T2, T3 of the three points P1, P2, P3, respectively. The temperature detector 50 is electrically connected with an electronic module 60 such as an Arithmetic/Logic Unit (ALU) or a central processing unit (CPU) of a computer, so that the numerical values of the temperatures T1, T2, T3 can be inputted into the electronic module 60 for calculations. As the thermal energy supplied by the electric heater 23 is generally considered be fully transferred to the heating block 22, thus, at a given time point, the temperature distribution in the upper portion of the heat-transferring block 21 can be shown in the following relationship:

$$T(x)=a*x^2+b*x+c \qquad (1)$$

Where x represents the distance between the electric heater 23 and a point selected from the upper portion of the heat-transferring block 21, T(x) represents the temperature value of the selected point, and a, b and c are constants at the given time point.

From Equation (1), the quantity of thermal energy transferred through a horizontal cross-sectional surface of the upper portion of the heat-transferring block 21 at the given time point can therefore be described as follows:

$$Q(x)=k*A*dT(x)/dx=k*A*(2*a*x+b) \qquad (2)$$

Where k is the heat transfer coefficient of the heat-transferring block 21, A is the surface area of the horizontal cross-sectional surface, and Q(x) represents the quantity of thermal energy transferred through the horizontal cross-sectional surface at the given time point. Both the coefficient k and the surface area A are constants.

If the distances x1, x2, x3 between each of the three points P1, P2, P3 and the electric heater 23 and the corresponding temperatures T1, T2, T3 of the three points P1, P2, P3 are respectively introduced into Equation (1), the numerical values of the constants a, b, c at this given time point can be accordingly determined. After the constants a, b, c are determined, the temperature T_{case} at a fourth point P4 selected from a top surface 27 of the heat-transferring block 21, i.e., the contacting surface between the heating block 22 and the heat-transferring block 21, can easily be obtained at this given time point by introducing the distance X_{case}, i.e., the distance between the contacting surface and the electric heater 23, into Equation (1). Similarly, the quantity of thermal energy Q_{case} transferred through the contacting surface from the heat-transferring block 21 to the heating block 22 at this given time point also can be easily obtained by introducing the distance X_{case} into Equation (2). In this embodiment, all of the resulting data, including a, b, c, T_{case} and Q_{case}, are obtained from the electronic module 60 by calculation based on the original data including T1, T2, T3, x1, x2, x3, X_{case}, k and A.

As the power supply 24 is further controlled to input thermal energy to the heating device 20 in an increasing manner, the portion of thermal energy transferred by the heat pipe 40 will gradually increase in amount so long as the quantity of thermal energy transferred to the heat pipe 40 is under the maximum heat transfer capacity of the heat pipe 40. Thus, the temperature of the heating block 22 is basically maintained at 60 degrees centigrade since the heat pipe 40 is still maintained in working condition. Consequently, the quantity of thermal energy transferred to the heat pipe 40, i.e., the parameter Q_{in}, can therefore be easily determined from the following equation:

$$Q_{in} = Q_{case} - Q' \qquad (3)$$

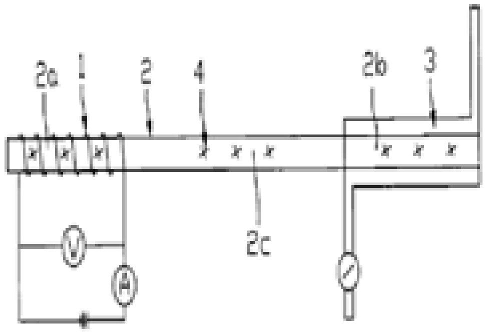
Where Q_{case} is the quantity of thermal energy transferred through the top surface 27 at a given time point, and Q' is the quantity of thermal energy dissipated into ambient environment by the heating block 22 at 60 degrees centigrade.

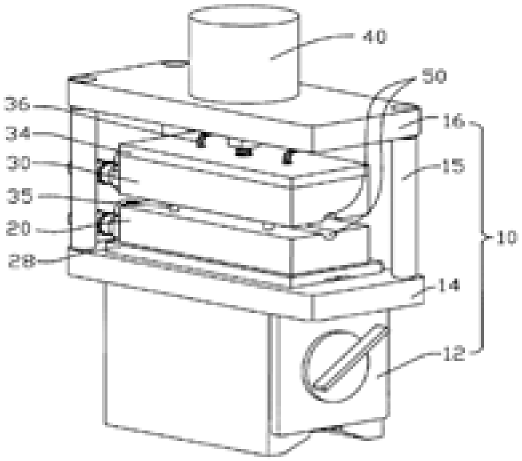
In accordance with the present invention, the performance test to the heat pipe 40 can be finished in a short time period, only about 90 seconds. In addition, if the maximum heat transfer capacity of a heat pipe is lower than 40 watts, the heat pipe will not be passed as acceptable through this method 100, thereby increasing accuracy to the performance test. We take a heat pipe with a maximum heat transfer capacity of 35 watts for example. When the value of Q_{in} obtained from Equation (3) at a time point reaches to 35 watts, after this time point, the temperature of the heating block 22 will begin to rise, since additional thermal energy is continued to be supplied to the heating block 22 by the electric heater 23 and this portion of additional thermal energy cannot further be removed by the heat pipe 40 because the heat pipe 40 has reached to its maximum heat transfer capacity. Accordingly, the temperature at the evaporating section of the heat pipe will also begin to rise and as a result, the subsequently obtained parameter ΔT, i.e., the temperature difference between two ends of the heat pipe, will exceed 1 degree centigrade. Therefore, those heat pipes with maximum heat transfer capacity lower than 40 watts will not pass the test to be deemed as an acceptable heat pipe.

Performance Testing Apparatus for Heat Pipes

US 7,594,749 B2, Liu., T. et al.

It is well known that a heat pipe is generally a vacuum-sealed pipe. A porous wick structure is provided on an inner face of the pipe, and at least a phase changeable working media employed to carry heat is contained in the pipe. Generally, according to positions from which heat is input or output, a heat pipe has three sections, an evaporating section, a condensing section and an adiabatic section between the evaporating section and the condensing section.



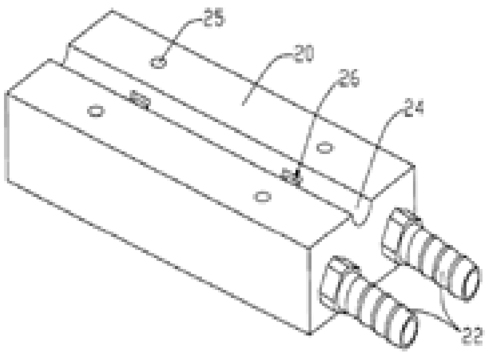


In use, the heat pipe transfers heat from one place to another place mainly by exchanging heat through phase change of the working media. Generally, the working media is a liquid such as alcohol or water and so on. When the working media in the evaporating section of the heat pipe is heated up, it evaporates, and a pressure difference is thus produced between the evaporating section and the condensing section in the heat pipe. The resultant vapor with high enthalpy rushes to the condensing section and condenses there. Then the condensed liquid reflows to the evaporating section along the wick structure. This evaporating/condensing cycle continually transfers heat from the evaporating section to the condensing section. Due to the continual phase change of the working media, the evaporating section is kept at or near the same temperature as the condensing section of the heat pipe. Heat pipes are used widely owing to their great heat-transfer capability.

In order to ensure the effective working of the heat pipe, the heat pipe generally requires test before being used. The maximum heat transfer capacity (Qmax) and the temperature difference (ΔT) between the evaporating section and the condensing section are two important parameters for evaluating performance of the heat pipe. When a predetermined quantity of heat is input into the heat pipe through the evaporating section thereof, thermal resistance (Rth) of the heat pipe can be obtained from ΔT, and the performance of the heat pipe can be evaluated. The relationship between these parameters Qmax, Rth and ΔT is Rth=ΔT/Qmax. When the input quantity of heat exceeds the maximum heat transfer capacity (Qmax), the heat cannot be timely transferred from the evaporating section to the condensing section, and the temperature of the evaporating section increases rapidly.

Conventionally, a method for testing the performance of a heat pipe is first to insert the evaporating section of the heat pipe into liquid at constant temperature; after a predetermined period of time, temperature of the heat pipe will become stable and then a temperature sensor such as a thermocouple, a resistance thermometer detector (RTD) or the like is used to measure ΔT between the liquid and the condensing section of the heat pipe to evaluate the performance of the heat pipe. However, Rth and Qmax cannot be obtained from this test, and the performance of the heat pipe cannot be reflected exactly by this test.

A conventional performance testing apparatus for heat pipes is shown. The apparatus has a resistance wire 1 coiling round an evaporating section 2 a of a heat pipe 2, and a water cooling sleeve 3 functioning as a heat sink and enclosing a condensing section 2 b of the heat pipe 2. In use, electrical power controlled by a voltmeter and an ammeter flows through the resistance wire 1, whereby the resistance wire 1 heats the evaporating section 2 a of the heat pipe 2. Simultaneously, by controlling flow rate and temperature of cooling liquid flowing through the cooling sleeve 3, the heat input at the evaporating



section 2 a can be removed from the heat pipe 2 by the cooling liquid at the condensing section 2 b, whereby a stable operating temperature of adiabatic section 2 c of the heat pipe 2 is obtained. Therefore, Qmax of the heat pipe 2 and ΔT between the evaporating section 2 a and the condensing section 2 b can be obtained by temperature sensors 4 at different positions of the heat pipe 2.

However, in the test, the conventional testing apparatus has drawbacks as follows: a) it is difficult to accurately determine lengths of the evaporating section 2 a and the condensing section 2 b which are important factors in determining the performance of the heat pipe 2; b) heat transference and temperature measurement may easily be affected by environmental conditions; c) it is difficult to achieve sufficiently intimate contact between the heat pipe and the heat source and between the heat pipe and the heat sink, which results in unsteady performance test results of the heat pipes. Furthermore, due to fussy and laborious assembly and disassembly in the test, the testing apparatus can be only used in the laboratory, and cannot be used in the mass production of heat pipes.

In mass production of heat pipes, a large number of performance tests are needed, and the apparatus is used frequently over a long period of time; thus, the apparatuses not only requires good testing accuracy, but also requires easy and accurate assembly to the heat pipes to be tested. The testing apparatus affects the yield and cost of the heat pipes directly; thus testing accuracy, facility, speed, consistency, reproducibility and reliability need to be considered when choosing the testing apparatus.

Method for Testing a Heat Pipe and Corresponding Test Device

US 8,322,917 B2, Gatti, M., et al.

A board 100 of a computer or electronic module, of which a component 101 is in thermal contact with one end 202 of a heat pipe 200. The other end 201 of the heat pipe 200 is in thermal contact with a heat exchanger 300.

In practice, several boards such as the board 100 are placed inside an electronic module or computer, with one or more heat pipes, making it possible to carry the heat emitted by one or more components of these boards. The heat exchanger 300 is on the outside of this electronic module, passages being arranged in a wall of the computer to allow the heat pipe(s) to pass through.

The test is advantageously carried out once the computer is fully assembled, with all its boards and all its heat pipes, and prior to its first power-up.

In operation, the heat exchanger 300 is the cold portion of the heat pipe 200 and the component 101 is the hot portion: the heat pipe carries the calories dissipated by the component to the heat exchanger.

According to embodiments of the invention, during the test procedure, the heat pipe is used in the reverse direction, bringing energy in the form of heat to the exchanger, in order to verify that the heat is carried to the component 101, and to measure how long it takes.

A device 400 for testing the heat pipe 200 therefore comprises:

o means 401 for heating the heat exchanger 300, or at least a portion 301 of the exchanger covering the zone of thermal contact with the heat pipe,

o means 402 for detecting heat (that is to say an increase in temperature) on the component 101, in order to measure the elapsed time between the provision of heat on the exchanger and the detection of heat on the component.

In one embodiment of such a test device as illustrated in FIG. 1, the heating means 401 comprise a current loop 401.a supplying with current IC a resistor R2 placed in good thermal contact with the heat exchanger, in the zone 301 of thermal contact with the heat pipe tested. Advantageously, the resistor is incorporated into the heat exchanger, such that the only thing left to do is

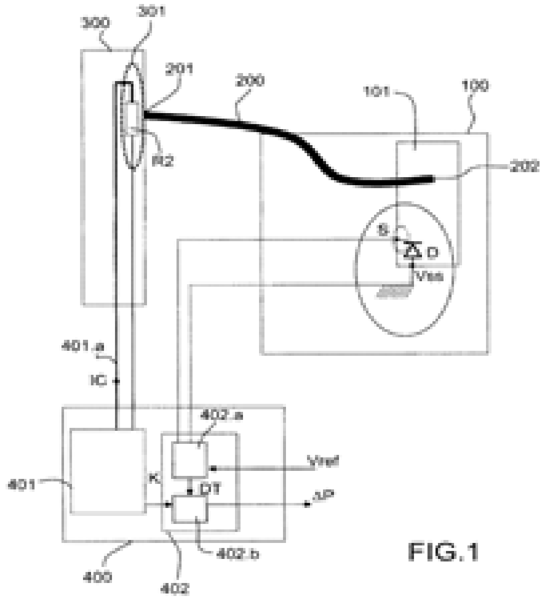
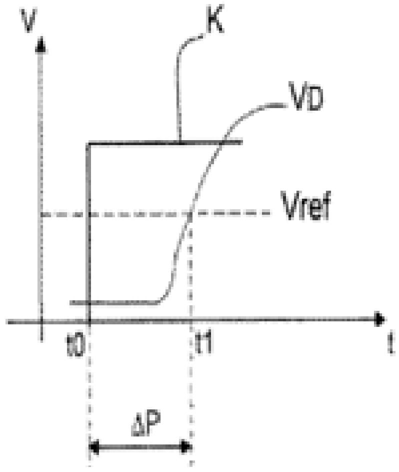


FIG.1

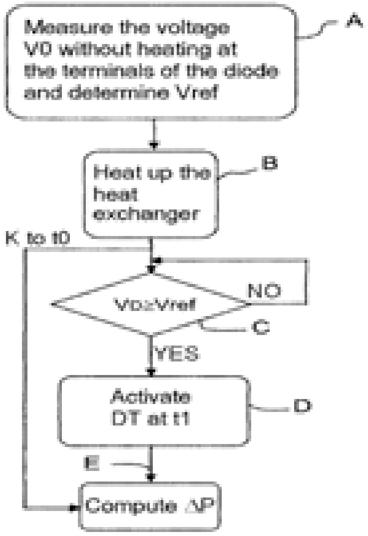


to connect it into the current loop, during the test. Such heating means are simple and not very costly to apply, and they make it possible to control precisely the power supplied, without requiring a high-precision resistor. Specifically it is known how to easily measure the precise current IC injected into the loop and the voltage at the terminals of the resistor, which makes it possible to control the supplied power precisely. The heat detection means 402 may use a temperature sensor fitted to the component. In a preferred embodiment, the heat detection means 402 advantageously use as a detection means a protection diode D, for protection against electrostatic discharges, that is usually provided on the connector pins of an electronic component. Notably, the electronic components of the CMOS type largely used today in computers comprise such protection diodes on both the input and output connector pins.

In a known manner, the electrical characteristics of a diode vary according to the temperature of the junction. As a reminder, the relation that links the direct current I of a diode at the voltage V to its terminals is as follows:

$I=Ise^{(V/KT)}$

where k is a physical characteristic of the material, Is is the saturation current characteristic of the diode, and T is the absolute temperature in ° Kelvin. Typically, for a silicon technology diode, kT=25 mV at 25° C. (or 297° Kelvin). From Eq. 1 comes: V=kT Log(I/Is) and dV/dT=k Log(I/Is).



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