

A Heat Transfer System and Method

FIELD OF INVENTION

5 The present invention relates broadly to a heat transfer system and to a method of heat transfer for maintaining or controlling a temperature of a device under test with heat generating capability.

BACKGROUND

10

Typically, high-performance electronic devices are subjected to a 100% functional test prior to being shipped by a manufacturer. For example, high power microprocessor devices are typically subjected to a classification test to determine an effective operating speed of the devices. During the classification test, it is important to
15 keep a temperature of a die of the microprocessor device at a single prescribed temperature while the power of the device is varied from about 0% to about 100% of the power rating in a predetermined test sequence.

A thermal control unit (TCU) is usually used to facilitate heat exchange between
20 the device and the heat transfer medium such that the die temperature of the device can be subjected to a prescribed thermal cycle. The heating process of the device can be achieved by installing heaters within the TCU. For the cooling process, the TCU is coupled to a closed loop system whereby a heat transfer medium in fluid form is delivered through the TCU to remove heat generated by the devices such as the
25 microprocessors.

During the cooling process, the heat transfer medium can exist in either a single phase or a two-phase flow condition. The single phase flow removes heat by forced convection without changing the state of the heat transfer medium while the two-phase
30 flow experiences a phase change of state from liquid to vapour to remove heat largely by acquiring the latent heat of vaporization. For better cooling efficiency, the latter heat removal process is desired.

A system that is widely known to employ phase change of fluid in promoting heat transfer is a vapour-compression system. This system is widely used in the existing refrigeration system. A thermostatic expansion valve is positioned upstream of the evaporator to reduce the condensing pressure to the evaporating pressure of the fluid.

5 The thermostatic expansion valve operates its flow regulating function by sensing the superheat temperature of the refrigerant at the downstream of the evaporator. Thus, when the amount of heat absorbed by the evaporator varies, the thermostatic expansion valve restores the required superheat temperature but does not necessarily maintain a desired temperature of the heat source at the evaporator. Therefore, accurate control of
10 the temperature of the heat source may not be achieved. As it is widely known, temperature control at the evaporator employing a conventional thermostatic expansion valve is usually achieved via a compressor, either by start-stop control or speed variation. Therefore, with a conventional vapour-compression system as described, it is difficult if not impossible to provide a system comprising of a single compressor yet
15 having multiple TCUs with individual temperature control of each TCU.

Hence, there is a need to provide a heat transfer system which seeks to address at least one of the above-mentioned problems.

20 SUMMARY

In accordance with a first aspect of the present invention there is provided a heat transfer system for maintaining or controlling a temperature of a device under test (DUT) with heat generating capability, the heat transfer system comprising a
25 temperature control unit (TCU) for thermal coupling to the DUT, the TCU arranged for flow of a heat transfer medium therethrough; an automatic expansion valve disposed upstream of the TCU; a flow-regulating valve disposed downstream of the TCU; and a controller coupled to the TCU for receiving an input signal representative of a temperature of the DUT; wherein the controller is further coupled
30 to the flow-regulating valve to change a flow area of the flow-regulating valve based on the signal representative of the temperature of the DUT.

A predetermined downstream pressure of the automatic expansion valve may be adjustable by adjusting a pressure differential across the automatic expansion valve for changing a range of a cooling capacity adjustment of the heat transfer system.

- 5 The system may further comprise a receiver reservoir upstream from the automatic expansion valve for maintaining a substantially constant pressure upstream of the automatic expansion valve.

10 The system may comprise a plurality of TCUs, each TCU in fluid connection with one associated upstream automatic expansion valve and one associated downstream flow-regulating valve, the TCUs coupled to a single variable speed compressor, wherein the controller is coupled to each of the TCUs and to each of the flow-regulating valves for changing the flow areas of the respective flow-regulating valves based on signals representative of the temperatures of respective
15 DUTs.

The system may further comprise an accumulator in fluid connection with each of the flow-regulating valves at an input of the accumulator, and to the compressor for the heat transfer medium at an output of the accumulator, for de-coupling the flow-regulating valves from the compressor.
20

The controller may further be coupled to the accumulator for receiving a signal representative of a pressure in the accumulator, and the controller is further coupled to the compressor for adjusting a speed of the compressor based on the signal
25 representative of the pressure in the accumulator.

The system may further comprise a condenser for dissipating heat from the heat transfer medium.

30 The controller may further comprise a set-point adjustment unit for adjusting a set-point of the DUT.

The controller may change the flow area of the flow-regulating device based on a comparison of the signal representative of the temperature of the DUT and the set-point.

- 5 In an active operation mode, the set-point may be changed whereby a cooling capacity of the heat transfer system is changed as a result of said comparison, resulting in a change of the temperature of the DUT.

10 In accordance with a second aspect of the present invention there is provided a method of heat transfer for maintaining or controlling a temperature of a device under test (DUT) with heat generating capability, the method comprising the steps of thermally coupling a temperature control unit (TCU) to the DUT, the TCU arranged for flow of a heat transfer medium therethrough; disposing an automatic expansion valve upstream of the TCU; disposing a flow-regulating valve downstream of the TCU;
15 receiving an input signal representative of a temperature of the DUT; and changing a flow area of the flow-regulating valve based on the signal representative of the temperature of the DUT.

20 A predetermined downstream pressure of the automatic expansion valve may be adjusted by adjusting a pressure differential across the automatic expansion valve for changing a range of a cooling capacity adjustment of the heat transfer system.

The method may further comprise maintaining a substantially constant pressure upstream of the automatic expansion valve.

25 The method may comprise providing a plurality of TCUs, each TCU in fluid connection with one associated upstream automatic expansion valve and one associated downstream flow-regulating valve, coupling the TCUs to a single variable speed compressor, wherein the controller is coupled to each of the TCUs and to
30 each of the flow-regulating valves for changing the flow areas of the respective flow-regulating valves based on signals representative of the temperatures of respective DUTs.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

Figure 1 shows a schematic diagram of a single thermal control unit (TCU) system.

Figure 2 shows a schematic diagram of a multi-TCU system.

Figure 3 shows a flow-chart illustrating a method of heat transfer for maintaining or controlling the temperature of a device under test (DUT), with heat generating capability, according to an example embodiment.

DETAILED DESCRIPTION

Figure 1 shows a schematic diagram of a single thermal control unit (TCU) system 100. The single TCU system 100 is a vapour-compression system, which makes use of a phase change cooling process for heat removal. The single TCU system 100 firstly comprises a compressor 102 for driving a heat transfer medium in fluid form, a condenser 104 for dissipating heat to a heat reservoir, for example, the environment, and a heat transfer device in the form of a thermal control unit (TCU) 106 which absorbs heat from a heat generating device, thus performing the function of an evaporator. The TCU 106 may be provided in different designs and configurations, but generally includes a thermally conducting main body which is in thermal contact with a device under test (DUT) (not shown), and having the heat transfer medium flowing through one or more passages provided in the TCU 106.

The ends of the passage(s) of the TCU 106 are coupled to an automatic expansion valve 108 and a flow-regulating valve 110, respectively. The automatic expansion valve 108 is disposed at the upstream of the TCU 106. The automatic expansion valve 108 creates the pressure difference required to set the conditions for heat absorption at the TCU 106 and heat discharge at the condenser 104. The flow-

regulating valve 110 is disposed at the downstream of the TCU 106. The flow-regulating valve 110 is coupled to the compressor 102, the compressor 102 is coupled to the condenser 104 and the condenser 104 is coupled to the automatic expansion valve 108 to form a closed loop system. A controller 112 is coupled to the TCU 106 and the flow-regulating valve 110. The controller 112 controls the flow-regulating valve 110 through feedbacks from TCU.

During a steady operation mode, the TCU 106 absorbs a certain amount of heat generated by a device under test (not shown) and dissipates the heat to the environment through the condenser 104. The automatic expansion valve 108 maintains a steady flow area according to a set pressure difference across the automatic expansion valve 108. By having a receiver 118 upstream of the automatic expansion valve 108, the pressure upstream can be easily maintained constant and thus the automatic expansion valve 108 is able to maintain a constant pressure downstream at the TCU 106. The accumulator 120 downstream of the flow-regulating valve 110 also assists in maintaining a constant pressure at the receiver 118 and thus at the TCU 106. The flow-regulating valve 110 also maintains a constant flow area for enabling a steady flow across the TCU 106. The temperature of the device under test remains constant at a user-defined temperature during this steady operation mode. The user-defined temperature is also known as a set-point.

During a transient operation mode, e.g. when the heat generated by the device under test increases, there is an increase in the temperature of the device under test. The temperature of the device under test is detected by a temperature sensor, e.g. a thermocouple 113, which sends an electrical signal 114 in the form of voltage or current to the controller 112. The controller 112 then sends an output signal 116 to the flow-regulating valve 110 to increase the flow area at the flow-regulating valve 110, resulting in a larger flow rate across the TCU 106. At the same time, the pressure at the downstream of the automatic expansion valve 108 decreases. The automatic expansion valve 108 increases its flow area to increase the flow rate across the automatic expansion valve 108. The fluid pressure at the downstream of the automatic expansion valve 108 returns to the initial pressure corresponding to the initial set pressure difference across the automatic expansion valve 108. The combined action of the flow regulating valve 110 and the automatic expansion valve 108 results in an increased flow rate of the heat transfer medium across the TCU 106 and this sequence of event also

increases the cooling capacity of the TCU 106. Thus, an additional amount of heat generated by the device under test is removed and the temperature of the device under test is thus maintained at the set-point.

5 When there is a decrease in heat generated by the device under test, the opposite happens. The flow areas at the flow-regulating valve 110 and the automatic expansion valve 108 are reduced, resulting in a lower flow rate of the heat transfer medium across the TCU 106 and reducing the cooling capacity of the TCU 106 to maintain the temperature of the device under test at the set-point.

10

 The above describes a passive type of operation in which the function of the system 100 is to maintain the temperature of the device under test constant at the user-defined temperature. The system 100 can be advantageously arranged without additional complexities to implement an active type of operation, e.g. dynamically cause
15 variations in the temperature of the device under test. For example, the reliability of the device under test imposed by thermal shocks such as when a particular surface of the device under test is subjected to a sudden drop in temperature can be investigated by decreasing the set-point of the device under test fast enough to cause the desired rate of decrease in the temperature. When the set-point of the device under test is lowered
20 using an adjustment element, for example output signal 116, the system 100 responds in a manner similar to that when an increase in the temperature of the device under test is detected as described above. In consequence, the cooling capacity of the TCU increases and the temperature of the device under test decrease rapidly to simulate the occurrence of a thermal shock.

25

 Further, although there is a change in the flow rate of the heat transfer medium during the transient operation mode, the temperature of the heat transfer medium which also affects the cooling capacity of the TCU 106 remains unaltered by using the automatic expansion valve 108 disposed upstream of the TCU 106. Therefore, the
30 overall range of the cooling capacity which the TCU 106 is capable of operating as a result of the control of the flow-regulating valve 110 can be changed by selecting a different fluid pressure downstream of the automatic expansion valve 108 by selecting a corresponding pressure difference across the automatic expansion valve 108. In other words, by pre-selecting the pressure downstream of the automatic expansion valve 108,

which typically involves a manual adjustment of the automatic expansion valve 108, the absolute values of the cooling capacity within the variable range as a result of the control of the flow-regulating valve 110 can be adjusted, for example moving from a range from 10 Watt to 20 Watt, to a range of 20 Watt to 200 Watt.

5

The system 100 advantageously provides ease of control of the cooling capacity at the TCU 106, which only requires a single input signal (i.e. signal representative of the temperature of the device under test in the example embodiment) and a single output signal (i.e. flow area control of the flow-regulating valve in the example embodiment).

10 Active variation of cooling capacities can be advantageously achieved by changing the set-point of the device under test. The single TCU system 100 advantageously allows a testing process to be conducted on a single device at any one time. It is noted that for the single TCU system 100, the compressor 102 may be operated at a constant, optimized speed, chosen so as to be capable of handling the range of flows controlled using the flow-regulating valve 110 (and the automatic expansion valve 108) in the example embodiment.

15

For better productivity, it is preferred that several TCUs can be employed in a single main circuit having a compressor and a condenser with the capability of achieving individual control of each TCU. The single TCU system 100 can be advantageously modified into a multi-TCU system.

20

Figure 2 shows a schematic diagram of a multi-TCU system 200. The multi-TCU system comprises a receiver 202, an accumulator 204, multiple TCU lines 206, a condenser 208 and a variable speed compressor 210. Each TCU line 206 comprises an automatic expansion valve 212, a TCU 214 and a flow-regulating valve 216. The ends of the TCU 214 are coupled to the automatic expansion valve 212 and the flow-regulating valve 216 respectively. The automatic expansion valve 212 is disposed at the upstream of the TCU 214 and the flow-regulating valve 216 is disposed at the downstream of the TCU 214. Each TCU line 206 is coupled to the receiver 202 and the accumulator 204. The receiver 202 is disposed at the upstream of each TCU line 206 and the accumulator 204 is disposed at the downstream of each TCU line 206. The accumulator 204 is a reservoir for the heat transfer medium flowing through each TCU 214. The accumulator 204 is coupled to the compressor 210, the compressor coupled to the condenser 208

25

30

and the condenser coupled to the receiver 202. A controller 218 is coupled to the TCUs 214, the flow-regulating valves 216, the accumulator 204, the condenser 208 and the compressor 210. The pressure at the accumulator 204 is monitored by the controller 218 to ensure sufficient flow of refrigerant through each TCU 214.

5

When the heat absorbed by any one of the TCU(s) 214 increases, the flow areas at the respective flow-regulating valves 216 and the respective automatic expansion valves 212 are increased, resulting in an increase in the flow rate of the heat transfer medium across the relevant TCU(s) 214. Thus, there is a larger amount of heat transfer medium flowing into the accumulator 204, which results in an increase in the pressure in the accumulator 204. The increase in the pressure in the accumulator 204 is detected by a transducer 217, e.g. a piezo-electric or resistive pressure transducer, and the controller 218 sends a signal to the variable speed compressor 210 to drive the compressor 210 faster. Hence, more heat transfer medium is drawn out of the accumulator 204 and the prescribed pressure in the accumulator 204 is restored. Correspondingly, more heat is dissipated at the condenser 208 as the heat transfer medium channelling out of the compressor 210 increases. It is noted that the accumulator 204 advantageously avoids a situation where, if the flow-regulating valves 216 were each in direct fluid communication with the compressor 210, variation of the drive speed of the compressor 210 would affect the heat transfer medium flow in each of the TCUs 214. Thus, the accumulator 204 in the described example embodiment advantageously functions as a "buffer" which de-couples the compressor 210 from the flow-regulating valves 216. In a further modification of the embodiment shown in Figure 2, the controller 218 may further be coupled to the condenser 208, for control of e.g. a fan speed of the condenser, depending on the speed the variable speed compressor 210 set under the control of the controller 218.

The increased heat transfer medium eventually flows into the receiver 202, which is subsequently supplied to the respective TCUs 214. The additional heat generated by the device(s) under test is removed and the temperature of the device(s) under test is maintained at the set-point. The cooling capacity of each TCU 214 is independently controlled by the combined action of the flow-regulating valve 216 and the automatic expansion valve 218 as described above. Also, as described above, the absolute range of the cooling capacity in the respective TCUs 214 can be adjusted by selecting the

30

desired pressure downstream of the respective automatic expansion valves 212. Thus, even in a single multi-TCU system, the overall range of cooling capacity for each TCU can be individually selected, independent of other TCUs in the entire system.

5 When there is a decline in heat absorption by any one or more of the TCU(s) 214, the opposite happens. The flow areas at the respective flow-regulating valves 216 and the respective automatic expansion valves 212 are reduced, resulting in a lower flow rate of the heat transfer medium across the relevant TCU(s) 214. Thus, there is a smaller amount of heat transfer medium flowing into the accumulator 204, which results
10 in a decrease in the pressure in the accumulator 204. The decrease in pressure is detected, and the controller 218 sends a signal to the variable speed compressor 210 to drive the compressor slower. Less heat transfer medium is drawn out of the accumulator 204 and the prescribed pressure in the accumulator 204 is restored. Thus, the temperature of the device(s) under test is maintained at the set-point.

15 The multi-TCU system 200 advantageously provides independent control of each TCU 214. The use of a pressure set-point at the accumulator 204 means that one does not need to physically monitor and control the main flow circuit as changes are automatically made to ensure the proper operating conditions. In addition, the control
20 algorithm is easy to implement as the control of the main flow circuit and the individual evaporator lines are uncoupled. This advantageously provides controllability of the individual TCUs 214 with accuracy and short response time, as changes made to the main circuit do not have to correspond with control of the individual TCU lines. Further, the system 200 can advantageously accommodate a large number of the TCU lines as
25 pressure fluctuations at the accumulator is less likely to be affected by individual changes at the TCUs 214. Various individual different prescribed thermal conditions required at each TCU of the multi-TCU system 200 can be advantageously provided. The multi-TCU system 200 is simple and reliable and can be effective for all kinds of cooling processes.

30 Figure 3 shows a flow-chart 300 illustrating a method of heat transfer for maintaining or controlling a temperature of a device under test (DUT) with heat generating capability, according to an example embodiment. At step 302, a thermal control unit (TCU) is thermally coupled to the DUT, the TCU arranged for flow of a

heat transfer medium therethrough. At step 304, an automatic expansion valve is disposed upstream of the TCU. At step 306, a flow-regulating valve is disposed downstream of the TCU. At step 308, an input signal representative of a temperature of the DUT is received. At step 310, a flow area of the flow-regulating valve is changed based on the signal representative of the temperature of the DUT.

The components used to implement the control of the TCU(s) in the example embodiments described above are available standard components. Few components are required for the embodiments. Individual control of different thermal cycles of different heat loads is advantageously provided. Further, the designs of the embodiments are compact, which advantageously makes it easy to integrate the embodiments into a test handler system. The embodiments can be advantageously used in cooling applications.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A heat transfer system for maintaining or controlling a temperature of a device under test (DUT) with heat generating capability, the heat transfer system comprising:
 - 5 a temperature control unit (TCU) for thermal coupling to the DUT, the TCU arranged for flow of a heat transfer medium therethrough;
an automatic expansion valve disposed upstream of the TCU;
a flow-regulating valve disposed downstream of the TCU; and
a controller coupled to the TCU for receiving an input signal representative of
 - 10 a temperature of the DUT;
wherein the controller is further coupled to the flow-regulating valve to change a flow area of the flow-regulating valve based on the signal representative of the temperature of the DUT.
- 15 2. The system as claimed in claim 1, wherein a predetermined downstream pressure of the automatic expansion valve is adjustable by adjusting a pressure differential across the automatic expansion valve for changing a range of a cooling capacity adjustment of the heat transfer system.
- 20 3. The system as claimed in claim 2, further comprising a receiver reservoir upstream from the automatic expansion valve for maintaining a substantially constant pressure upstream of the automatic expansion valve.
4. The system as claimed in any one of claims 1 to 3, comprising a plurality of
25 TCUs, each TCU in fluid connection with one associated upstream automatic expansion valve and one associated downstream flow-regulating valve, the TCUs coupled to a single variable speed compressor, wherein the controller is coupled to each of the TCUs and to each of the flow-regulating valves for changing the flow areas of the respective flow-regulating valves based on signals representative of the
30 temperatures of respective DUTs.
5. The system as claimed in claim 4, further comprising an accumulator in fluid connection with each of the flow-regulating valves at an input of the accumulator,

and to the compressor for the heat transfer medium at an output of the accumulator, for de-coupling the flow-regulating valves from the compressor.

6. The system as claimed in claims 4 or 5, wherein the controller is further coupled to the accumulator for receiving a signal representative of a pressure in the accumulator, and the controller is further coupled to the compressor for adjusting a speed of the compressor based on the signal representative of the pressure in the accumulator.

7. The system as claimed in any one of the preceding claims, further comprising a condenser for dissipating heat from the heat transfer medium.

8. The system as claimed in any one of the preceding claims, wherein the controller further comprises a set-point adjustment unit for adjusting a set-point of the DUT.

9. The system as claimed in claim 8, wherein the controller changes the flow area of the flow-regulating device based on a comparison of the signal representative of the temperature of the DUT and the set-point.

10. The system as claimed in claim 9, wherein, in an active operation mode, the set-point is changed whereby a cooling capacity of the heat transfer system is changed as a result of said comparison, resulting in a change of the temperature of the DUT.

11. A method of heat transfer for maintaining or controlling a temperature of a device under test (DUT) with heat generating capability, the method comprising the steps of:

thermally coupling a temperature control unit (TCU) to the DUT, the TCU arranged for flow of a heat transfer medium therethrough;
disposing an automatic expansion valve upstream of the TCU;
disposing a flow-regulating valve downstream of the TCU;
receiving an input signal representative of a temperature of the DUT; and

changing a flow area of the flow-regulating valve based on the signal representative of the temperature of the DUT.

5 12. The method as claimed in claim 11, wherein a predetermined downstream pressure of the automatic expansion valve is adjusted by adjusting a pressure differential across the automatic expansion valve for changing a range of a cooling capacity adjustment of the heat transfer system.

10 13. The method as claimed in claim 12, further comprising maintaining a substantially constant pressure upstream of the automatic expansion valve.

14. The method as claimed in any one of claims 11 or 13, comprising providing a plurality of TCUs, each TCU in fluid connection with one associated upstream automatic expansion valve and one associated downstream flow-regulating valve,
15 coupling the TCUs to a single variable speed compressor, wherein the controller is coupled to each of the TCUs and to each of the flow-regulating valves for changing the flow areas of the respective flow-regulating valves based on signals representative of the temperatures of respective DUTs.