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(54) METHOD FOR CONTROLLING A PULSED EXPANSION VALVE

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(57) ABSTRACT

A method of controlling the duty cycle of a pulse width modulated expansion valve in order to achieve low and stable evaporator superheat is disclosed. Duty cycle is incremented/decremented if superheat is above/below a dead band, and, in a preferred embodiment, incremented/decremented if the time derivative of superheat is above/below a preset value.

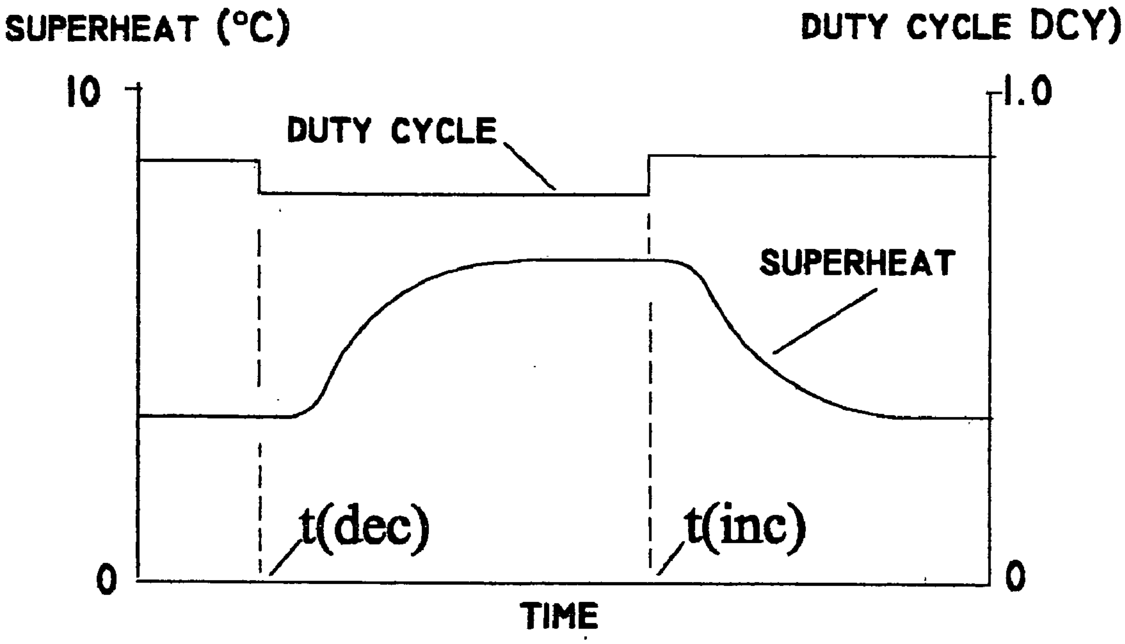


FIGURE 1

PRIOR ART

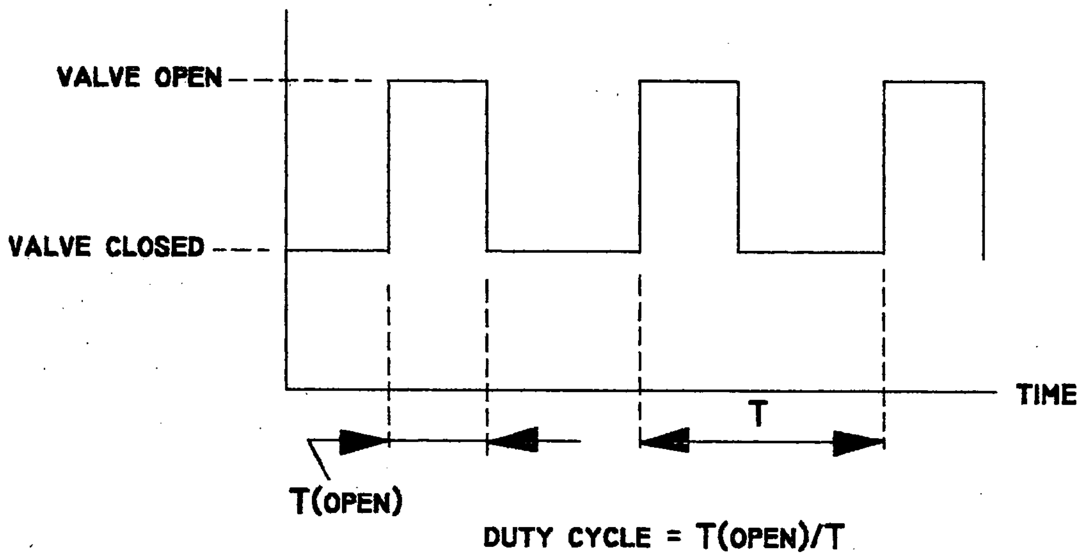


FIGURE 2

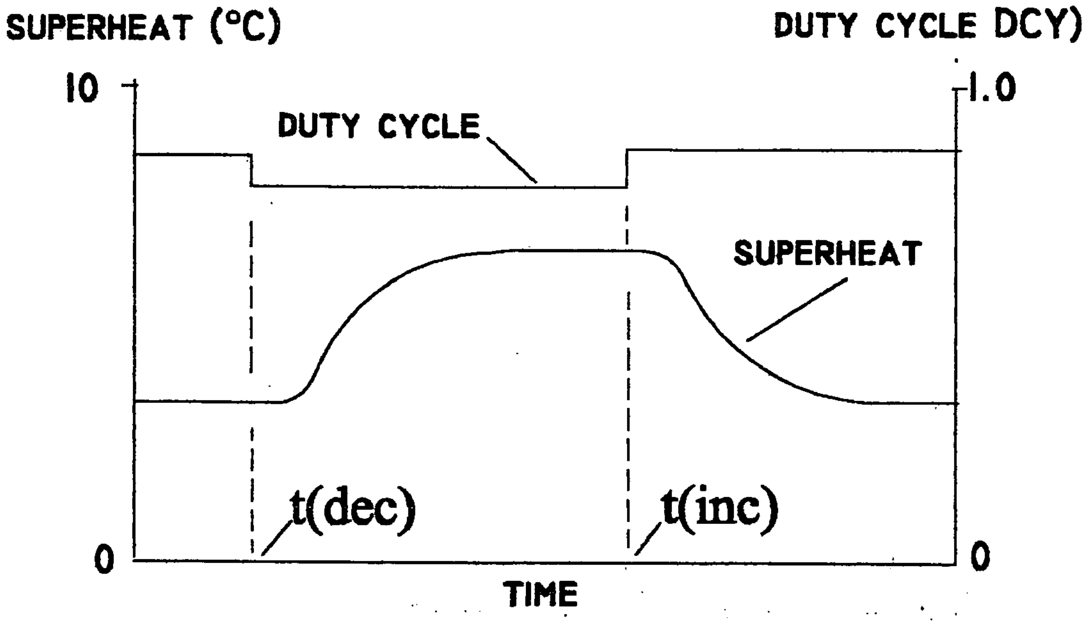

SUPERHEAT (°C)
DUTY CYCLE DCY)
10
1.0
DUTY CYCLE
SUPERHEAT
t(dec)
t(inc)
0
0
TIME

FIGURE 3

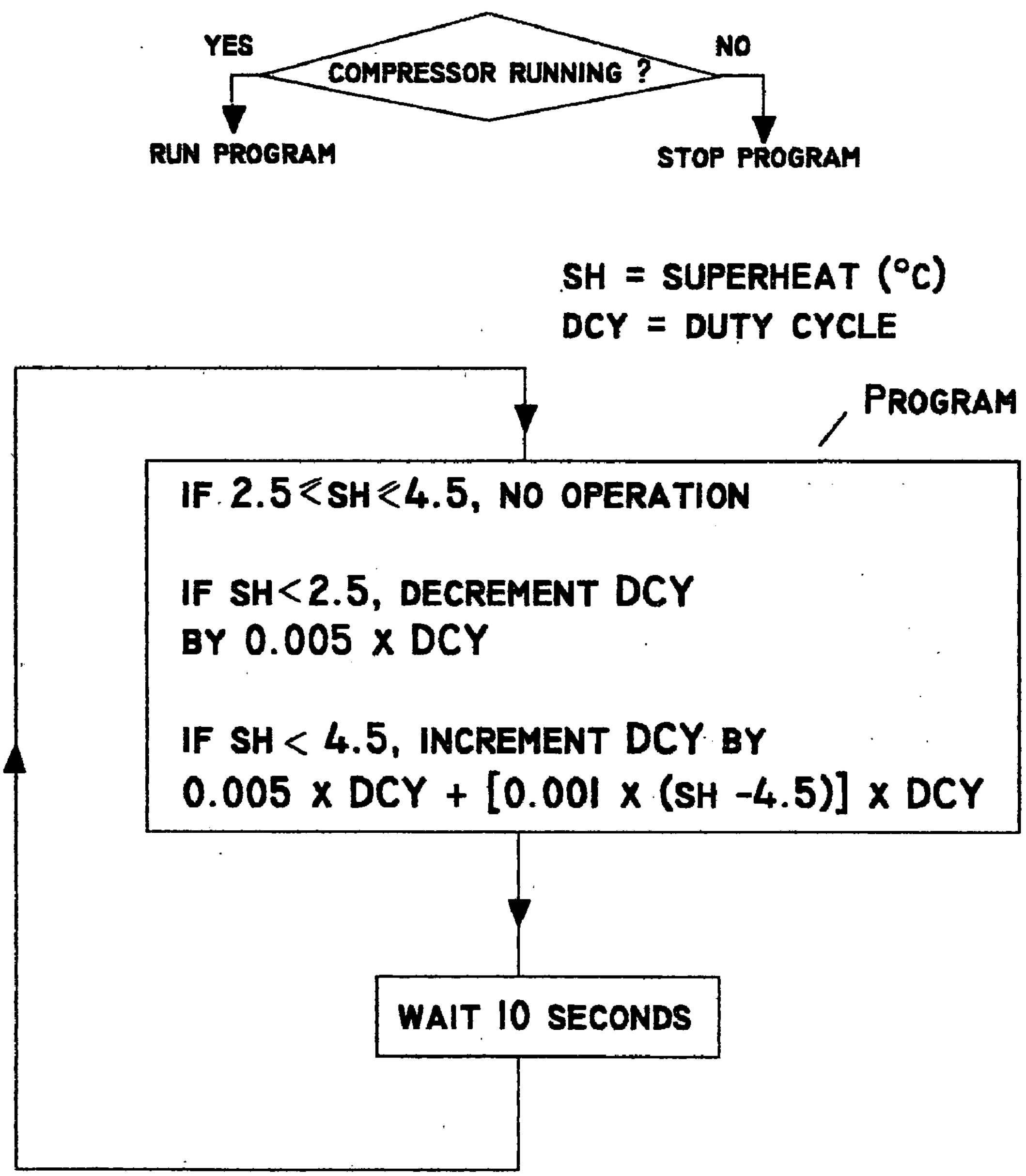

YES
COMPRESSOR RUNNING ?
NO
RUN PROGRAM
STOP PROGRAM
SH = SUPERHEAT (°C)
DCY = DUTY CYCLE
PROGRAM
IF 2.5≤SH≤4.5, NO OPERATION
IF SH<2.5, DECREMENT DCY BY 0.005 x DCY
IF SH< 4.5, INCREMENT DCY BY 0.005 x DCY + [0.001 x (SH -4.5)] x DCY
WAIT 10 SECONDS

FIGURE 4

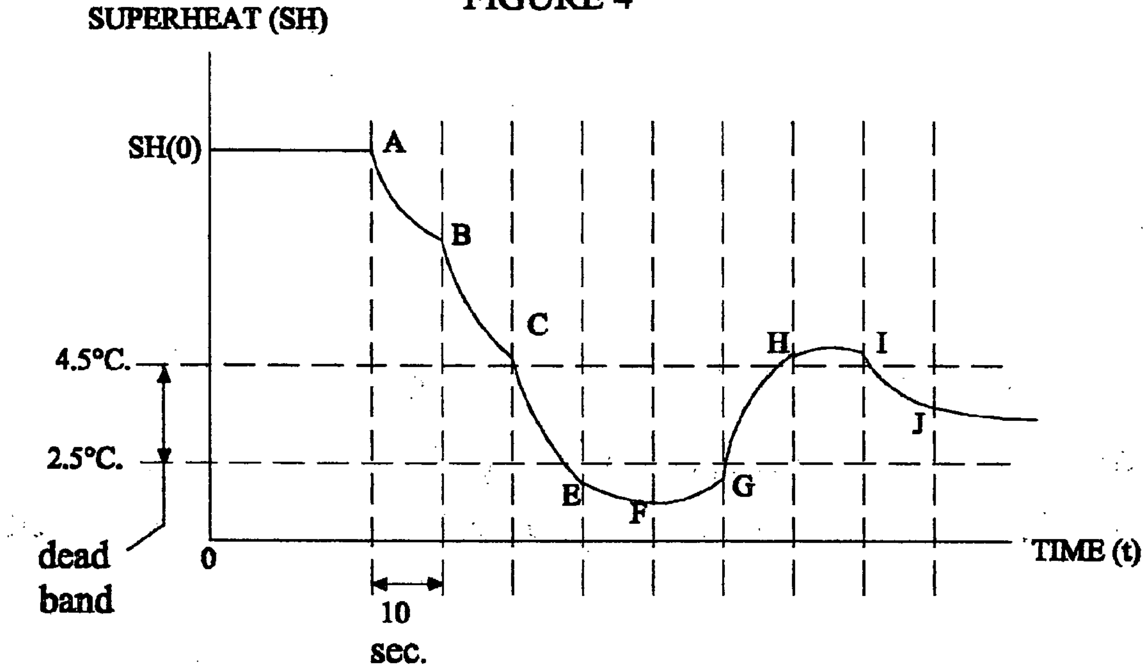


FIGURE 5

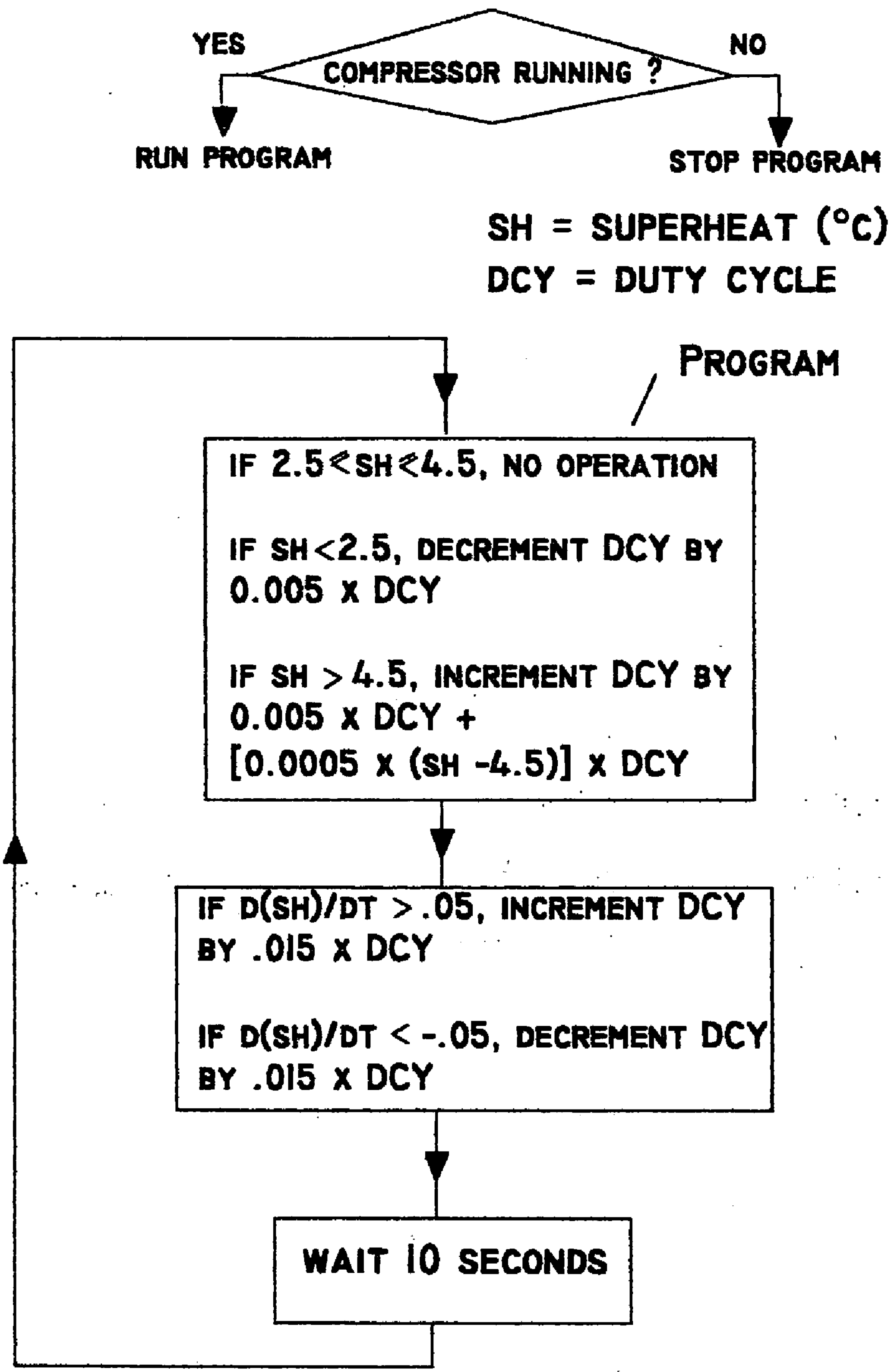
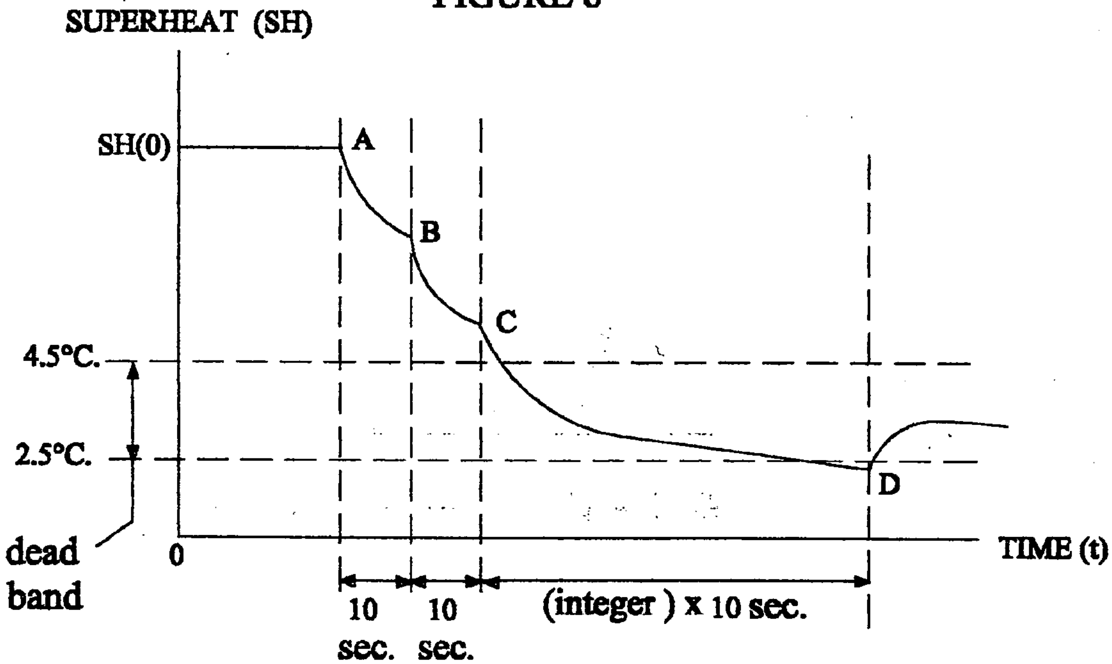

YES
COMPRESSOR RUNNING ?
NO
RUN PROGRAM
STOP PROGRAM
SH = SUPERHEAT (°C)
DCY = DUTY CYCLE
PROGRAM
IF 2.5<SH<4.5, NO OPERATION
IF SH<2.5, DECREMENT DCY BY 0.005 x DCY
IF SH >4.5, INCREMENT DCY BY 0.005 x DCY + [0.0005 x (SH -4.5)] x DCY
IF D(SH)/DT >.05, INCREMENT DCY BY .015 x DCY
IF D(SH)/DT < -.05, DECREMENT DCY BY .015 x DCY
WAIT 10 SECONDS

FIGURE 6


SUPERHEAT (SH)
SH(0)
A
B
C
4.5°C.
2.5°C.
D
dead band
0
TIME (t)
10 sec.
10 sec.
(integer) x 10 sec.

METHOD FOR CONTROLLING A PULSED EXPANSION VALVE

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] This invention relates generally to vapor compression refrigeration in which the flow rate of refrigerant is controlled by a pulse width modulated expansion valve.

[0003] 2. Description of Related Art

[0004] It is well known in the field of the invention that refrigeration efficiency increases as evaporator superheat decreases. To realize high efficiency, expansion valves are commonly used in feedback systems that achieve low superheat by increasing the flow of refrigerant when superheat increases above a design value and decreasing flow when superheat falls below the design value. Such systems are prone to superheat oscillation because of the thermal time constant of evaporator temperature in response to changing flow rate, and also because of transit time delay between a change in flow rate at the evaporator inlet and consequent change in flow at the evaporator outlet. Stability commonly requires relatively expensive controls, and may only be achieved if superheat is relatively high. The present invention is a method according to which an inexpensive control, used with a pulse width modulated expansion valve, can provide superheat that is both stable and lower than is realized in existing art.

BRIEF SUMMARY OF THE INVENTION

[0005] A pulse width modulated expansion valve, when used to control refrigerant flow, is opened at constant frequency and held open for a controllable time. "Duty Cycle", abbreviated hereafter by DCY, is the ratio of the time the valve is open to the interval between successive openings of the valve. Generally, evaporator superheat control with a pulse width modulated expansion valve comprises lowering DCY when superheat decreases and conversely. This constitutes negative feedback since reduced DCY raises superheat. Thus, if the system is stable, superheat will be maintained near a constant value. Unless measures are taken to prevent it, instability will occur, particularly at low superheat because the ratio [(change in superheat/change in DCY)] increases rapidly as superheat approaches zero. Thus, in existing art, it is difficult to maintain average superheat below 5° C. A controller according to the method of the invention achieves stable average superheat of about 3° C. with the following basic method;

[0006] a) Creation of a superheat "dead band", typically from 2.5° C. to 4.5° C. If superheat is within this dead band, the controller maintains the existing DCY.

[0007] b) If superheat is outside the dead band, the controller, at time intervals Δt, increments existing DCY if superheat is above the dead band and decrements existing DCY if superheat is above the dead band.

[0008] It can be shown that a system controlled according to the above method is stable within wide ranges of Δt, increments of DCY, and decrements of DCY, and when used in a conventional refrigerator in which the compressor is turned on and off by a thermostat, can maintain average superheat close to the center of the dead band.

[0009] Superheat excursions outside the dead band can be reduced in amplitude and number of occurrences by augmenting the basic method with a "rate correction" as follows;

$$\text{if } \frac{d(SH)}{dt} \geq \text{first preset value, increment } DCY\ (t = \text{time, } SH = \text{superheat})$$

$$\text{if } \frac{d(SH)}{dt} \leq \text{second preset value, decrement } DCY$$

g) BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0010] FIG. **1** illustrates operation of a pulse width modulated expansion valve, and defines "duty cycle".

[0011] FIG. **2** illustrates response of superheat to an increment and a decrement of duty cycle.

[0012] FIG. **3** illustrates a basic embodiment of the method of the invention, in the form of an operations flow chart that can be implemented with a microprocessor.

[0013] FIG. **4** shows how application of the basic method of the invention causes superheat to decrease from a value above the dead band to a value within the dead band.

[0014] FIG. **5** illustrates a preferred embodiment of the method of the invention, in the form of an operations flow chart that can be implemented with a microprocessor.

[0015] FIG. **6** shows how application of the preferred method of the invention causes superheat to decrease from a value above the dead band to a value within the dead band.

[0016] In describing the preferred embodiment of the invention which is illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, it is not intended that the invention be limited to the specific term so selected and it is to be understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar purpose.

h) DETAILED DESCRIPTION OF THE INVENTION

[0017] FIG. **1** illustrates the definition of the "duty cycle" (symbolized herein as DCY) of a pulse width modulated expansion valve. Referring to FIG. **1**, the valve is opened at successive times separated by a constant interval T, and is held open for a controllable interval T (open). DCY is defined as;

$$DCY = \frac{T(\text{open})}{T}$$

[0018] FIG. **2** illustrates how evaporator superheat, symbolized herein by SH, and defined as;

[0019] SH =(Temperature of Evaporator Outlet—Temperature of Evaporator Inlet), responds to decrements and increments of DCY.

[0020] Referring to FIG. **2**, DCY is decremented at time t(dec). Decrementing DCY causes the average refrigerant flow at the evaporator inlet, where the expansion valve is located, to decrease. Decreased flow at the evaporator outlet commences after a transit time interval required for refrigerant to move from the inlet to the outlet of the evaporator. Following the transit time interval, SH rises exponentially toward a new equilibrium, with a thermal time constant dependent on the heat capacity of the evaporator.

[0021] Again referring to FIG. 2, DCY is incremented at time t(inc). Incrementing DCY causes the average refrigerant flow at the evaporator inlet, where the expansion valve is located, to increase. Increased flow at the evaporator outlet commences after a transit time interval required for refrigerant to move from the inlet to the outlet of the evaporator. Following the transit time interval, SH falls exponentially toward a new equilibrium, with a thermal time constant dependent on the heat capacity of the evaporator.

[0022] From the above, it follows that SH can be controlled by periodically either incrementing DCY if SH is above a specified value SH(design) or decrementing DCY if SH is below SH(design). However, such a control would not cause SH to converge to SH (design). Rather, SH would oscillate around SH (design) because of the thermal time constant of the evaporator and the evaporator transit time.

[0023] The basic invention overcomes instability by periodically, at time intervals Δt, incrementing or decrementing DCY if SH is respectively above or below a range of SH referred to herein as the "dead band", and maintaining existing DCY if SH is within the dead band. For example, if the dead band is 2.5° C. ≦SH ≦4.5° C., SH is incremented if SH exceeds 4.5° C., decremented if SH is less than 2.5° C., and maintained at the existing DCY if SH is within the dead band. It can be shown that SH will stabilize within the dead band over wide ranges of Δt, DCY increment, and DCY decrement.

[0024] FIG. 3 shows an operations flow chart implementing the basic invention. The operations shown can be controlled by an appropriately programmed microprocessor. In FIG. 3:

[0025] dead band is 2.5° C. ≦SH ≦4.5° C. and;

[0026] Δt=10 seconds,

[0027] Decrement of DCY=0.005×DCY

[0028] Increment of DCY=0.005×DCY +[0.001×(SH−4.5)]×DCY

[0029] The term [0.001×(SH−4.5)]×DCY is included in the increment of DCY to hasten reduction of SH from high values such as 15-20° C. to the dead band.

[0030] FIG. 4 shows reduction of SH from a value SH(0) to values within the dead band. DCY is incremented at points A.B, and C, causing SH to overshoot the lower limit of the dead band. To correct the overshoot, DCY is decremented at points E, F, and G, causing SH to overshoot the upper limit of the dead band. This overshoot is corrected by incrementing DCY at points H and I, thus bringing SH into the dead band at point J. The value of DCY that exists at point H is maintained, and SH drifts downward as the interior of the refrigerated space cools. Eventually SH will reach the lower limit of the dead band, and will be decremented to bring it within the dead band (this process is not shown in FIG. 4).

[0031] A preferred method which will reduce the number of occurrences and the amplitude of overshoots is shown in FIG. 5. In addition to the basic method, it incorporates "rate correction" as follows;

$$\text{if } \frac{d(SH)}{dt} \geq \text{first preset value, increment } DCY\ (t = \text{time})$$

$$\text{if } \frac{d(SH)}{dt} \leq \text{second preset value, decrement } DCY$$

[0032] In FIG. 5, the first preset value is 0.05 degrees per second and the second preset value is −0.05 degrees per second.

[0033] Rate correction corrects for trends in SH. Its effect is shown in FIG. 6, which may be contrasted with FIG. 4. A rate induced decrement is applied at point C,

$$\text{where } \frac{d(SH)}{dt} \leq -.05, \text{ and a rate increment is applied at point } D,$$

$$\text{where } \frac{d(SH)}{dt} \geq .05.$$

The effect of the rate correction is to substantially reduce time during which SH is outside the dead band.

[0034] Wide ranges of values of values of the parameters Δt, increment, decrement, and rate correction will result in acceptable control of superheat according to the method of the invention. Any practically useful set of values of these parameters, when used with the method of the invention, is considered to be within the scope of the invention.

1. A method for stable control of evaporator superheat in a vapor compression refrigerator, evaporator superheat symbolized herein by SH, SH defined as the difference between evaporator outlet and inlet temperatures, the refrigerator including a compressor, a condenser, a pulse width modulated expansion valve, an evaporator, and a thermostatic control for turning the compressor on when the temperature of the interior of the refrigerator rises above a preset value and turning it off when the interior temperature falls below a preset limit, the method consisting generally of controlling the duty cycle of the pulse width modulated expansion valve in response to evaporator superheat, duty cycle defined as the ratio of the time the expansion valve is open to the time interval between successive openings of the expansion valve, duty cycle symbolized herein by DCY, the method specifically comprising the following elements,

1) temperature sensors responsive to SH,

2) an electronic control which periodically responds to SH signal from the temperature sensors by adjusting DCY as follows:

if SH is within a preset range referred to herein as the "dead band",

the control does not change existing DCY;

if SH is above the dead band, the control increments DC; and

if superheat is below the dead band, the control decrements DCY.

2. A method according to claim 1, in combination with the following additional operations,

$$\text{if } \frac{d(SH)}{dt} \geq \text{first preset value, increment } DCY,$$

$$\text{if } \frac{d(SH)}{dt} \leq \text{second preset value, decrement DCY},$$

where, in the above, t represents time.

* * * * *