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(54) ## Improvements in or relating to defrosting of heat exchangers.

(57) An adaptive heat exchanger defrost system e.g. for a heat pump evaporator, incorporates a system controller which adapts the intervals between defrost cycles to prevailing conditions in order to improve overall efficiency. The time taken to complete a defrost cycle is measured and compared with the time taken for the preceding defrost cycle to determine whether it is appropriate to increase or decrease the interval between samplings of the operating parameter used to determine whether a defrost cycle is required.

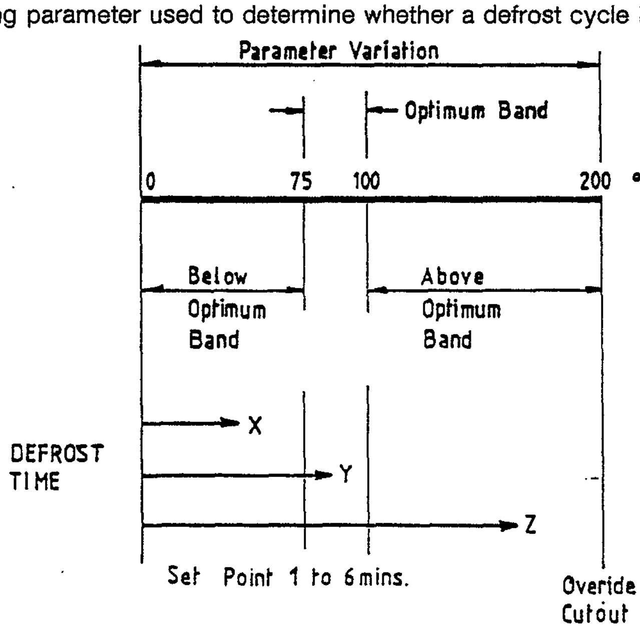

fig3

EP 0 278 701 A2

IMPROVEMENTS IN OR RELATING TO DEFROSTING OF HEAT EXCHANGERS

The present invention relates to the defrosting of heat exchangers particularly, but not exclusively, to the defrosting of a heat pump system.

A fin-and-tube air-to-refrigerant heat exchanger is used as an evaporator in heat pump systems to collect heat from the air. At low ambient temperatures frosting or icing up of the heat exchanger may occur. Such frosting both lowers (and, indeed, may stop) the throughput of air and acts as a barrier to the transfer of heat between the air and the primary and secondary surface material of the heat exchanger. It is conventional, therefore, to make provision for the heat exchanger to be defrosted from time to time where it is operating in low temperature humid air conditions where frosting occurs.

A typical defrosting technique used with heat exchangers is the "hot-gas" technique; in this, by operation of suitable valving in the refrigerant circuit, the heat exchanger is injected with hot compressor discharge gas, the air-to-refrigerant evaporator thus operating temporarily as a condenser, thereby rejecting heat to the outside and causing the frosting or ice to be melted. Operation in this way obviously detracts from the overall efficiency of the heat pump since while the defrost cycle is in operation the evaporator is not able to fulfil its normal function of collecting heat from the surrounding air. Conventionally, a sensor is provided to detect frosting or icing up of the evaporator - this may be done, for example, by measuring the temperature of the primary or secondary surface of the evaporator, the refrigerant temperature or pressure, the air pressure difference across the coil, the optical reflectivity of the evaporator and so on. Conventionally, a control circuit periodically samples the output of this sensor to determine whether a defrost cycle should be initiated. The defrosting cycle may either be of fixed duration or terminated by sensing that the frost or ice has been melted.

The present invention seeks to provide an improved defrosting system for heat exchangers such as air to refrigerant outdoor heat exchangers and proposes that the defrost cycle be adapted to prevailing conditions. More specifically, it is proposed that the timing of the defrost sampling intervals, that is the intervals at which the need (or otherwise) for defrosting is determined and, if necessary, defrosting is carried out, be varied in a manner such as to improve the overall operating efficiency of the system as compared with the system operating with fixed defrost sampling intervals. This can be done by varying the sampling intervals so that it is increased in circumstances where less defrosting is required and decreased where more defrosting is required. The requirement for more or less defrosting can be determined in a variety of ways. Preferably, however, it is done by recording the time taken for the defrost cycle to complete (as determined by whatever sensor determines the end of the defrost cycle) and using this information to increment or decrement the subsequent sampling interval as appropriate. The increments and decrements may be linear, step-wise, or follow any other suitable law appropriate to the particular circumstances in which the system is operated.

As will be apparent from the above, the present invention provides, inter alia, a defrost controller for a heat exchanger which is operative to adapt the defrosting operation to prevailing conditions by increasing or decreasing the intervals between defrosting cycles as appropriate.

The invention will further be described by non limitative example with reference to the accompanying drawings in which:-

Fig 1 is a somewhat schematic block diagram of a heat pump with which the present invention may be used.

Fig 2 is a functional block diagram showing the defrost controller.

Fig 3 shows how the defrost time may be varied by the controller of fig 2.

Fig 4 shows how the time interval between defrost may be adjusted as a percentage of a set-point value.

Fig 5 shows part of a multi-evaporator heat pump system with which the present invention may be employed.

Fig 6 shows how the defrost controller may operate with a system such as that shown in fig 5.

Fig 1 shows an example of a heat pump to which the present invention may be applied and which comprises a compressor 1 for driving refrigerant around a refrigerant circuit comprising an air-to-refrigerant fin-and-tube evaporator 2 which is exposed to outside air, a condenser 3 in which the refrigerant cools and rejects heat to another medium such as water in a hot-water supply circuit or space air, a refrigerant expansion device 4 which may be a thermostatic expansion valve or an electronically controlled expansion valve and a hot gas injection valve 12.

The system has associated with it a system controller 5 which incorporates electronic circuitry and appropriate interfaces to enable the system to operate under the control of one or more inputs generally designated 6 which may, for example, be used to signal to the system controller 5 a set point value for one or more relevant operating parameters of the system. An example of such a parameter is the temperature of the secondary medium leaving the condenser 3 where the system is intended primarily for heating purposes. Of course, where a cooling demand is to be serviced by the evaporator, a set point for air or water leaving the evaporator can be applied by one of the inputs 6 to the system controller 5. As is conventional, the system controller 5 has various sensors associated with it and distributed around the elements of the refrigerant circuit are electro-mechanical devices such as solenoid valves for controlling the refrigerant flow around the refrigerant circuit and to control the progressive loading and unloading of the compressor 1 in response to increasing and decreasing cooling or heating demands.

One of the functions of the system controller 5 is, in appropriate operating conditions, periodically to determine whether defrosting of the evaporator 2 is required and, if so, to initiate and control a defrosting cycle. For this purpose, the evaporator 2 (or each evaporator where there is a number of them) has associated with it a sensor 7 which can supply to the system controller 5 a signal (such as an analogue voltage) which when compared with a reference value is indicative of the need or otherwise for the initiation of a defrost cycle. As mentioned above, the sensor 7 may detect the temperature of the primary or secondary surface of the evaporator 2, the air pressure difference across the evaporator coil (which will increase as the evaporator coil frosts up), the pressure in, or pressure difference across, an appropriate part of the refrigerant system (such as at the exit of the evaporator 2), the optical reflectivity of the exterior of the evaporator or by any other variable indicative of the actual or likely occurrence of frosting.

The system controller 5 may be implemented using discrete electronic components, IC digital logic circuits or be based around a suitably programmed micro-computer. In the following, it will be assumed that the system controller 5 is to be implemented using a microprocessor (MPU) and associated interfacing and support circuitry. Thus the MPU 10 will execute a suitable program stored in a non-volatile, usually read only memory (ROM), have random access memory (RAM) available as program workspace and be provided with suitable interfaces to accept control and information signals and emit data and commands signals in a form electrically compatible with the controlled or controlling equipment of the heat pump system. The program for the MPU 10 will be such as to cause a desired control algorithm for the heat pump to be carried into effect. In particular, this program may be used in implementing the present invention.

In the following description given with reference to fig 2, two timer registers (8 and 11) are shown which in operation store counts associated with and determining the execution of the defrost cycle. Depending on the implementation of the system controller 5, these may again be in the form of discrete electronic components, digital logic ICs such as digital counters or could be program variables in the execution of the system controller's control program. The system controller 5 includes a defrost interval timer 8 which is used to generate a defrost-enable signal 9 which is used to signal the microprocessor 10 that the time has been reached at which a determination is to be made of whether a defrost cycle should be initiated. In the case of the system controller 5 being based round a MPU 10, the timer 8 may be implemented by means of a MPU register or RAM memory location in which a timing count is loaded, its value being incremented or decremented at appropriate intervals and a time-out determination made i.e. by the start of the timing interval, the time 8 can be loaded with a number representing the interval in, say, minutes or seconds with this value then being decremented periodically (for example every second or minute as appropriate) and then a determination be made by the microprocessor 10 to whether the count has reached zero.

When a defrost interval time-out has occurred, the MPU 10 makes a determination, from the output of one of more of the sensors 7, as to whether a defrost cycle is to be initiated. If the determination is that a defrost cycle is required, the system controller 5 sends the appropriate control signals to the electro-mechanical devices controlling operation of the heat pump to initiate a hot-gas defrost cycle, in this case by the hot gas defrost in which hot, gaseous refrigerant is delivered to the evaporator 2 via valve 12.

At the start of a defrost cycle, the defrost cycle length timer 11 is activated and this is used to record the time that the defrost cycle actually takes to complete. This may be achieved by initially storing a count of zero in the timer 11 and having the MPU 10 increment this at regular intervals. At appropriate intervals during the defrost cycle the MPU checks the output of the sensor(s) 7 to determine whether the defrost cycle is completed. At the end of the defrost cycle, the timer 11 will contain information as to the time which was taken to carry out the defrost cycle. This value is then used to determine whether an adjustment needs to be made of the defrost sampling interval in the next cycle. This determination can be made on the basis that a long defrost time suggest adverse operating conditions making more frequent defrost cycles desirable while a shorter than expected defrost cycle, indicating that defrosting is completing in less time than was expected, suggests that a longer defrost interval can be tolerated (and in the interests of efficiency this determination should be followed by an increase in the defrost interval). As mentioned above, the adjustment of the defrost interval can be done in a step-wise or linear manner or, indeed, in accordance with any other law appropriate to the circumstances.

Figures 3 and 4 illustrate one arrangement in which adjustment is made in a series of steps.

Having detected that defrost is necessary, the controller 5 issues a command for defrost to be carried out. It may be carried out by any of the standard methods such as the hot gas mentioned above, electric heating elements, warm water, etc, until defrost completion is detected by any one of the sensing methods described above.

In the illustrated system described above the initiation and termination of the defrost cycle are achieved using a temperature sensor 7. In this case, the controller 5 can provide control facilities through which each of the parameter set points may be varied, for example, defrost initiation occurring between 3°C and 9°C, the higher value enabling evaporator coil secondary surface temperatures to be effectively monitored; in the case of defrost termination temperatures between 5°C and 15°C may be selected.

The controller 5 includes a control facility in which the maximum optimum defrost period may be preset, for example between 1 and 6 minutes in the example shown in fig 3, and as described below.

Below optimum band, 0 to 75% of preset maximum optimum defrost period

Optimum band within 75% to 100% of the present maximum optimum defrost period,

Above optimum band 100% to 200% of preset maximum optimum defrost period.

The actual defrost time taken as established by the defrost duration timer 11 is compared by the controller 5 with those defined parameters in fig 3 to determine in which band the defrost termination signal occurred.

In addition the controller 5 has a control facility in which the 100% parameter for the interval time between defrost initiations may be set, for example between 30 and 90 minutes as another set point. In the event of the actual defrost period terminating within the "below optimum band" as shown in fig 3 (period X) then the subsequent interval between defrost will be incremented by a discrete percentage value i.e. to 120% of the original preset interval. If the system interval time for a defrost initiation is reached and the defrost initiation sensor temperature is greater than that at which defrost is required then no defrosting will take place and the control system will automatically increment the control defrost interval time. If subsequent defrost period is still within the "below optimum band" then the interval between defrost is again incremented to a longer time interval until a maximum value is reached, for example if fig 4, up to 160%. If the actual defrost period terminates within the "optimum band", in the illustrated example 75 to 100% of the set point (period Y), then no change will occur to the controlled interval time between defrost initiations. Thus, in this condition the controller 5 takes account of the defrost times necessary and the time interval between defrosts to achieve an optimum operating condition.

If the actual defrost period terminates in the "above optimum band", i.e. in the illustrated example 100% to 200% of the preset datum point (period Z), then the subsequent interval between defrost will be decremented and if necessary after subsequent defrosts further decremented, until a minimum time between defrosts is reached.

At 200% of maximum optimum defrost period, defrost termination will occur irrespective of the signal from the defrost termination sensor, i.e. this is a maximum defrost time override condition.

Depending upon the particular application in question, after compressor shut-down the defrost interval time can return to the 100% set point or remain at the previous operating set point.

At any start-up of the compressor 1 following normal, controlled shutdown, 5 minutes is added to the remaining defrost interval time by adding 5 minutes to the time value stored in time 8, to inhibit early defrost initiation and to ensure stable running operating conditions are achieved.

The above logic is applicable to any evaporator coil circuit that is defrosted in total.

The invention is, however, equally applicable to a system having a number of heat exchangers subject to defrosting. Fig 5, for example, shows part of a heat-pump system having a number of evaporators EVAP1, EVAP2, EVAPN, with associated solenoid valves SV, refrigerant expansion devices tev and defrost sensors SI...SN. In such multi-coil circuits, the controller 5 can cause defrosting of some circuits while others continue operation as evaporators.

In such an arrangement, the controller 5 is arranged to have the capability of dictating the defrost logic such that coincident defrosting of all the evaporators is inhibited.

The defrost cycle for this type of evaporator coil arrangement is determined on the basis of previous defrost times.

For example:

At the conclusion of a defrost, the actual defrost time for a particular evaporator EVAPX is compared to the parameters as defined in fig 2 to determine in which band the defrost termination signal occurred. This information is then related to the information obtained for the previous defrost time on the other coil(s) and the following decision table can be used to update the defrost interval time:-

TABLE 1

LAST DEFROST	THIS DEFROST	INTERVAL RESET
any band	above optimum band	Decrement
any band	within optimum band	NO CHANGE
below optimum band	below optimum band	Increment
within optimum band	below optimum band	NO CHANGE
above optimum band	below optimum band	NO CHANGE

To ensure maximum energy is available for the defrost cycle when multiple evaporator coil circuits are involved the controller 5 dictates that each circuit is sensed for defrost in sequence within the time interval between defrost as shown in fig 6.

At the termination of a defrost the time interval at which the next coil defrost cycle is initiated, in the case of two coils, will be half the defrost time interval determined by fig 4.

In case of additional multiple evaporator coils the actual time interval is divided evenly amongst the number of coils involved.

Referring back to the illustration in fig 5, each evaporator has its own sensor designated S1...Sn; when evaporator EVAP1 has terminated its defrost, the time taken D1, is used for the controller 5 to select the time interval T1 between defrosts (fig 4) based on table 1. The time then allocated before defrost initiation of the next evaporator EVAP2, is in the case shown in, T1/2 (fig 6). After the second evaporator EVAP2 has defrosted then the defrost time D2 is used for the controller to select the revised time interval T2 between defrost initiation (fig 4) based on table 1. In the case of only two evaporators, the revised time before defrost initiation of the first evaporator EVAP1 again is T2/2. Thus it can be seen that the time between defrost initiation of evaporation in turn is constantly varied but is always biased towards a maximum value in order to restrict the number of defrost cycles to a minimum.

In the case of implementations of the sensor 7 such as by temperature detection or reflectivity detection, to account for variables such as differences in prevailing winds, two such sensors may be provided at opposite sides (in the direction of air flow through the evaporator) of the evaporator and means may be provided to select for monitoring purposes, whichever of those sensors whose output indicates the greater likelihood of frosting. In other words, in the case of temperature monitoring, the output used would be the one from the sensor 7 indicating the lower evaporator temperature.

The principle described above for using multiple sensors may be accepted on a single evaporator coil to overcome the problem associated with variable conditions existing on either side of the coil due to wind/sleet etc.

Significant aspects of the above described system controller include the following:

1. It varies the time interval between initiations of a defrost cycle.

2. It utilises the time taken to achieve a satisfactory defrost to determine selectively the time interval at which the next defrost should be initiated if required.

3. The defrost interval time may be either incremented or decremented.

4. By measuring the defrost time, the controller effectively compensates for the type and degree of frost or ice that has accumulated on the heat exchanger surface.

5. By virtue of 4, the controller effectively takes into account the moisture content of the air passing over the heat exchanger, the prevailing refrigerant evaporating temperature, the air temperature and the capacity load on the heat exchanger. If the coil is cold but no ice is forming, the defrost time will be very short; the system recognises that the latent heat requirement is low (i.e. the relative humidity of the air is low) and thus increments the time between defrosts. The system also takes into account the amount of heat available to carry out defrost.

6. Any or all of the following system set points are variable.

(i) defrost time

(ii) defrost interval time

(iii) defrost initiation parameter (eg coil temperature)

(iv) defrost termination parameter (eg coil temperature)

7. The defrost time interval is incremented or decremented by a percentage of the interval time set point.

8. By restricting to a minimum the time during which defrost is recurring the EER (energy efficiency ratio) or COP (coefficient of performance) is held at a maximum value for the prevailing ambient conditions.

9. When multiple evaporator circuits are involved, equally time spaced defrosts are initiated in sequence. No two coils can be defrosted simultaneously.

10. The coil demanding maximum defrost capability takes priority.

11. On start up the controller will not initiate any defrost cycle prematurely to ensure stable conditions are established.

12. It ensures equal number of defrosts per evaporator.

13. It provides a time delay at start of operation before timing of the defrost initiation sampling interval can commence (eg 5 minutes).

It will be apparent from the above that the system is applicable to a wide variety of heat pump systems including unidirectional and reversible ones and ones with refrigerant/air as well as to other types of heat exchanger in use of which frosting and icing problems occur.

The time to defrost is variable dependent upon the capacity load being generated at that time (eg 1/2 or 1/4 load) - the greater the unloading, the higher the evaporating temperature which in turn reduces the likelihood of frost formation.

Claims

1. A heat exchanger defrosting system comprising a heat exchanger liable to frosting, means operable to carry out a defrost cycle of the heat exchanger and a controller for controlling defrosting comprising means for initiating a defrost cycle on detection of an operating parameter having a value indicative of the need for defrosting of the heat exchanger, characterised in that the controller is operative to adapt the defrost cycle to prevailing conditions in a manner such as to improve the overall operating efficiency of the system.

2. A system according to claim 1 in which the controller is operative to increase or decrease the intervals between defrosting cycles as appropriate to the prevailing conditions.

3. A system according to claim 1 or 2 in which the controller samples the values of one or more operating parameters of the system at intervals to determine whether a defrost cycle is required and is operative to vary the intervals between taking such samples such that the conditions where the defrosting requirement is likely to be increased, the interval between samples is reduced and vice versa.

4. A system according to claim 3, wherein the controller is operative to measure the time taken for a defrost cycle to complete.

5. A system according to claims 3 and 4, wherein the controller is operative to use the measured defrost time to adjust the sampling interval as specified in claim 3.

6. A system according to claim 5, wherein the controller is operative to increment or decrement the defrost cycle length by a fraction dependent upon the measured defrost time.

7. A system according to any one of claims 3 to 6 wherein the controller is operative to determine an adjustment required of the sampling time on the basis of the lengths of the two most recent defrost cycles.

8. A system according to any one of the preceding claims wherein the controller includes at least one sensor for measuring the heat exchanger air surface temperature or optical reflectivity or the air pressure difference across the heat exchange.

9. A system according to any one of the preceding claims and wherein the heat exchanger has two sides, each of which is more liable to frosting depending on prevailing conditions, and wherein sensors are provided at both such sides of the heat exchanger, in order to ensure that the defrost interval will be dictated by the sensor that is located in that position where frost formation is dominant.

10. A heat pump system comprising a refrigerant circuit having a refrigerant compressor, a refrigerant condensor and at least one refrigerant evaporator comprising a heat exchanger defrosting system according to any one of the preceding claims.

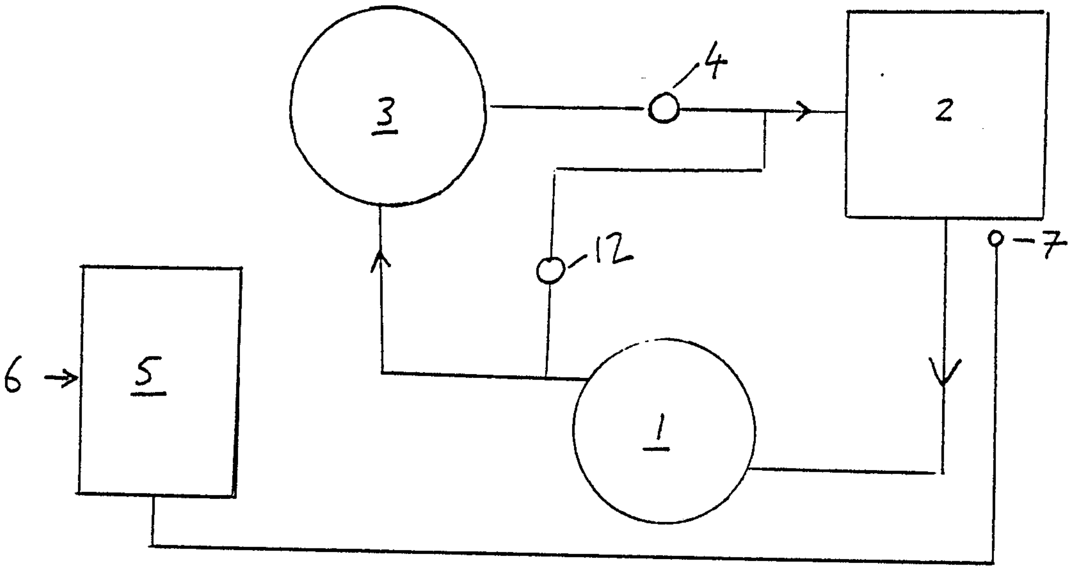

FIG 1

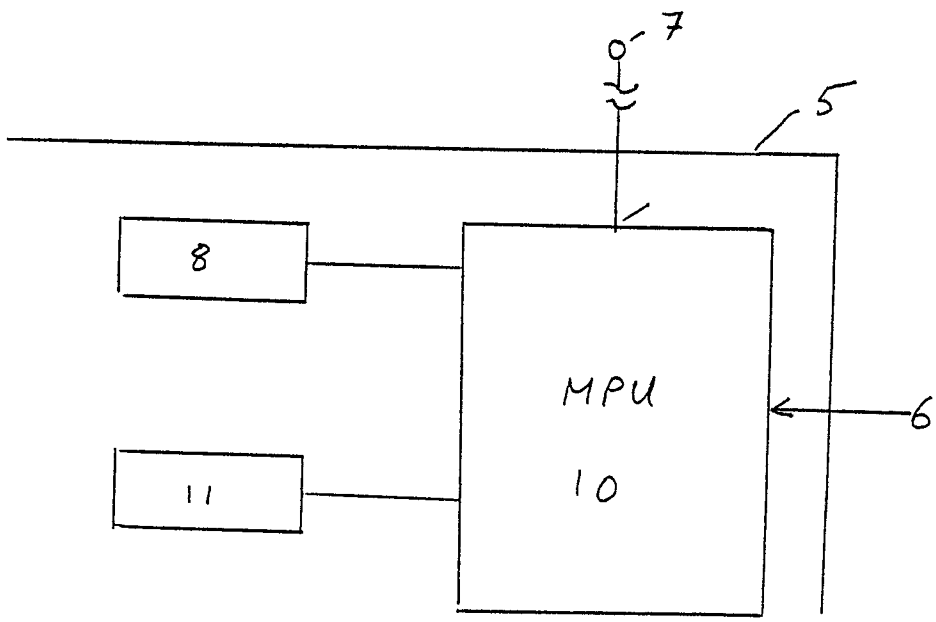

FIG 2

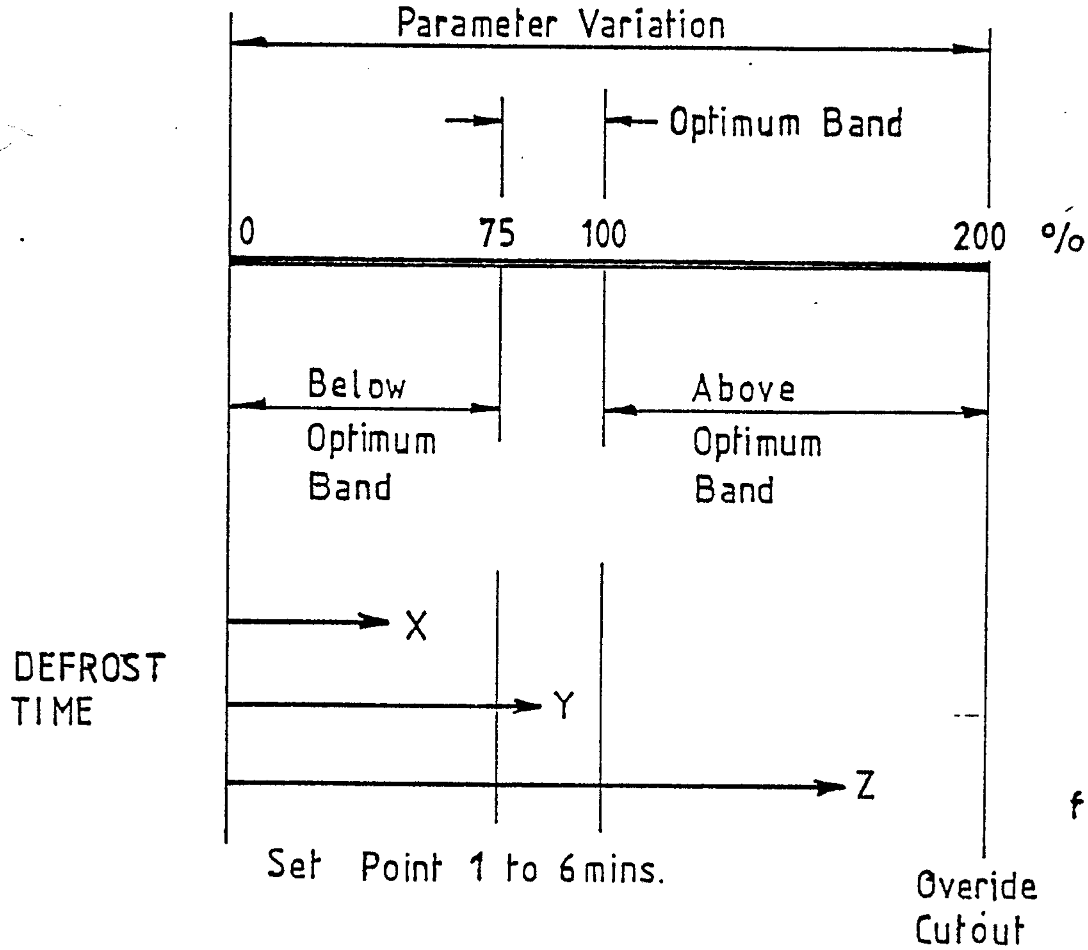
Parameter Variation
Optimum Band
0
75
100
200 %
Below Optimum Band
Above Optimum Band
X
DEFROST TIME
Y
Z
Set Point 1 to 6mins.
Overide Cutout

fig3

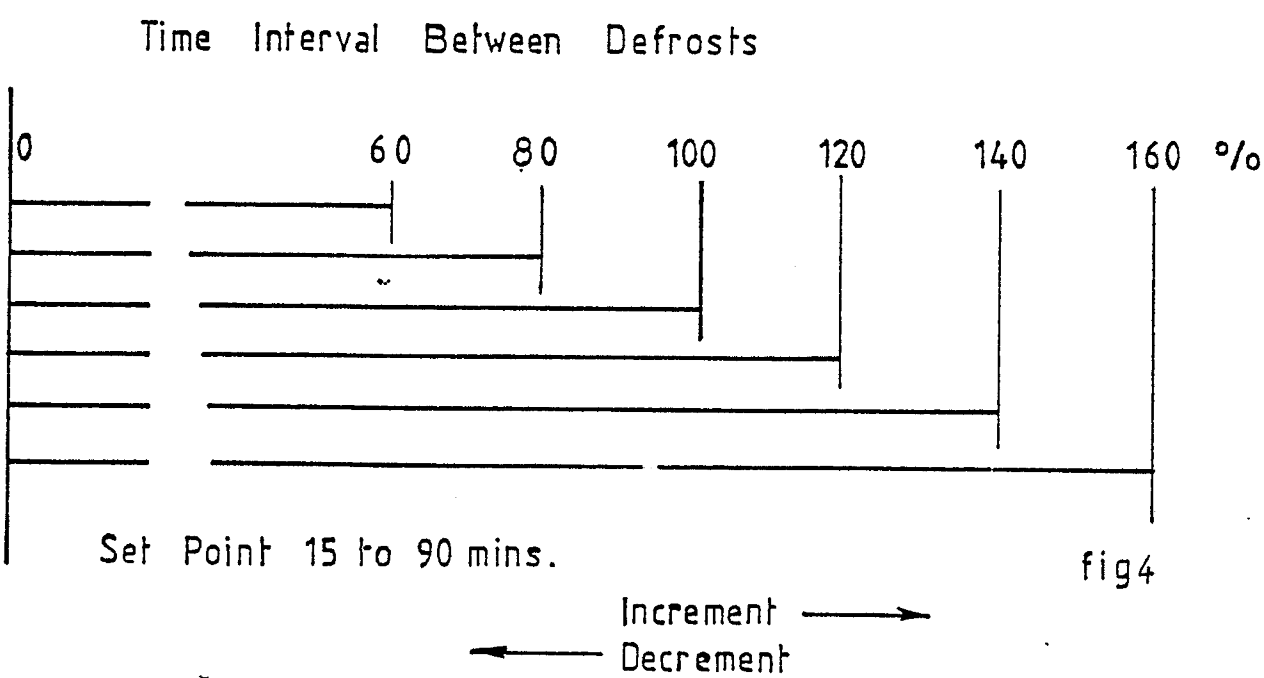
Time Interval Between Defrosts
0
60
80
100
120
140
160 %
Set Point 15 to 90 mins.
Increment
Decrement

fig4

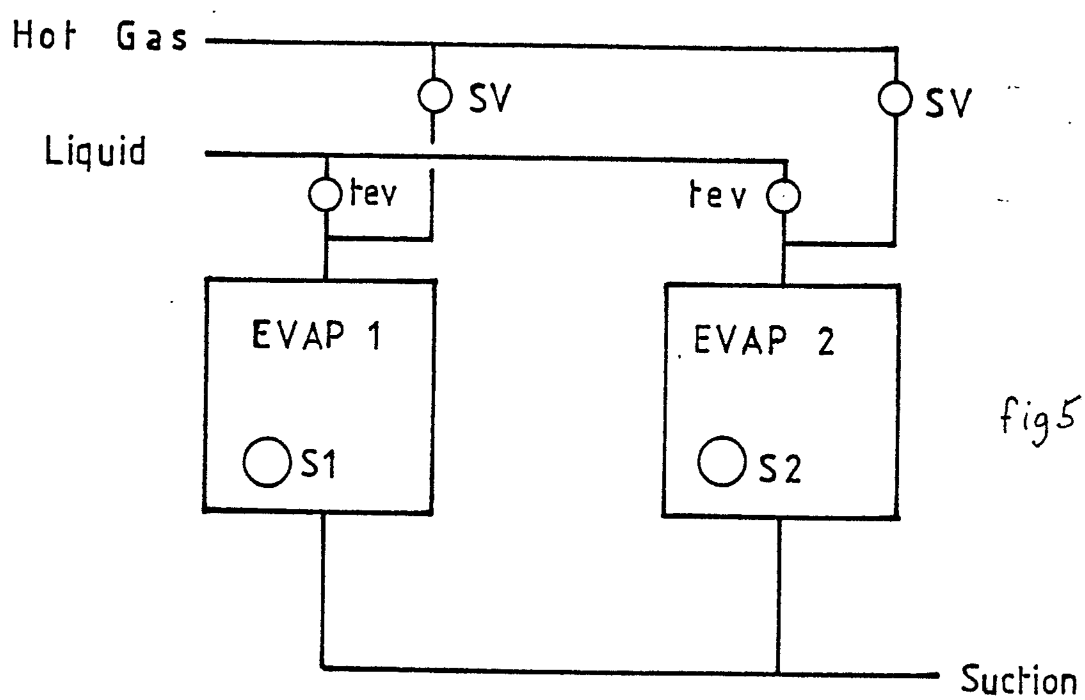
Hot Gas
SV
SV
Liquid
tev
tev
EVAP 1
S1
EVAP 2
S2
Suction

fig5

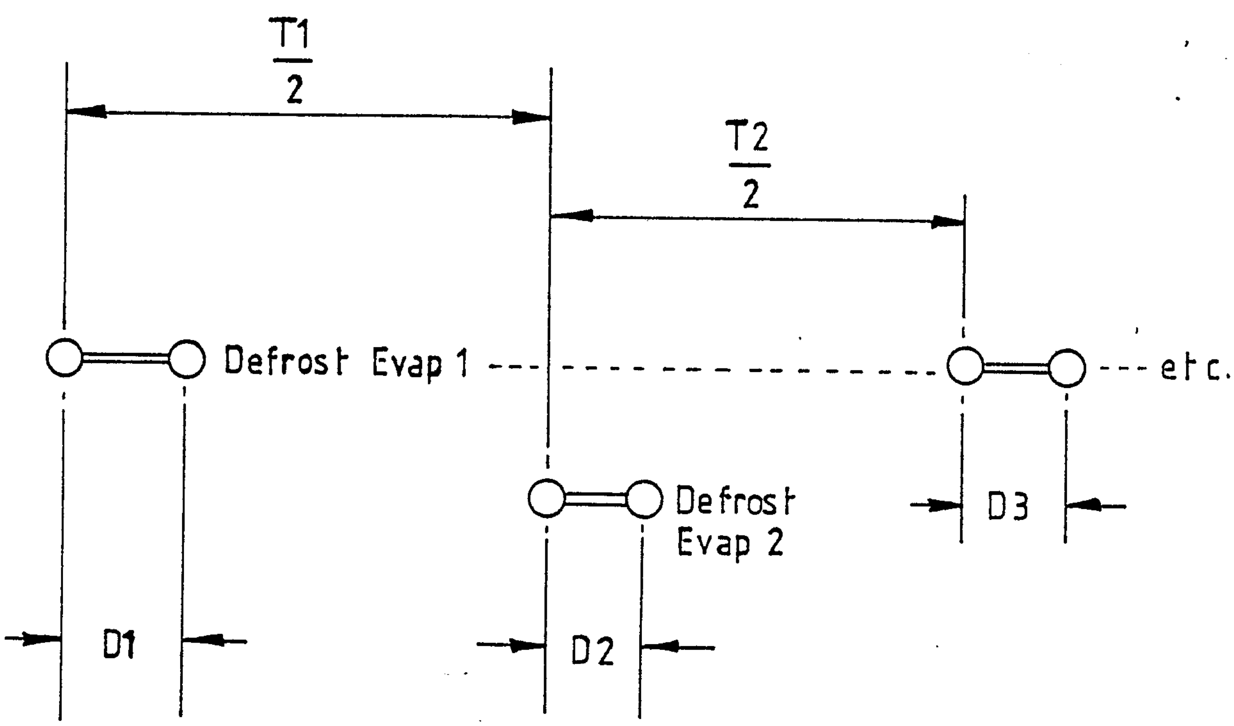
T1
2
T2
2
Defrost Evap 1
etc.
Defrost
Evap 2
D3
D1
D2

fig6