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AIR CONDITIONING APPARATUS

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2 Sheets-Sheet 1

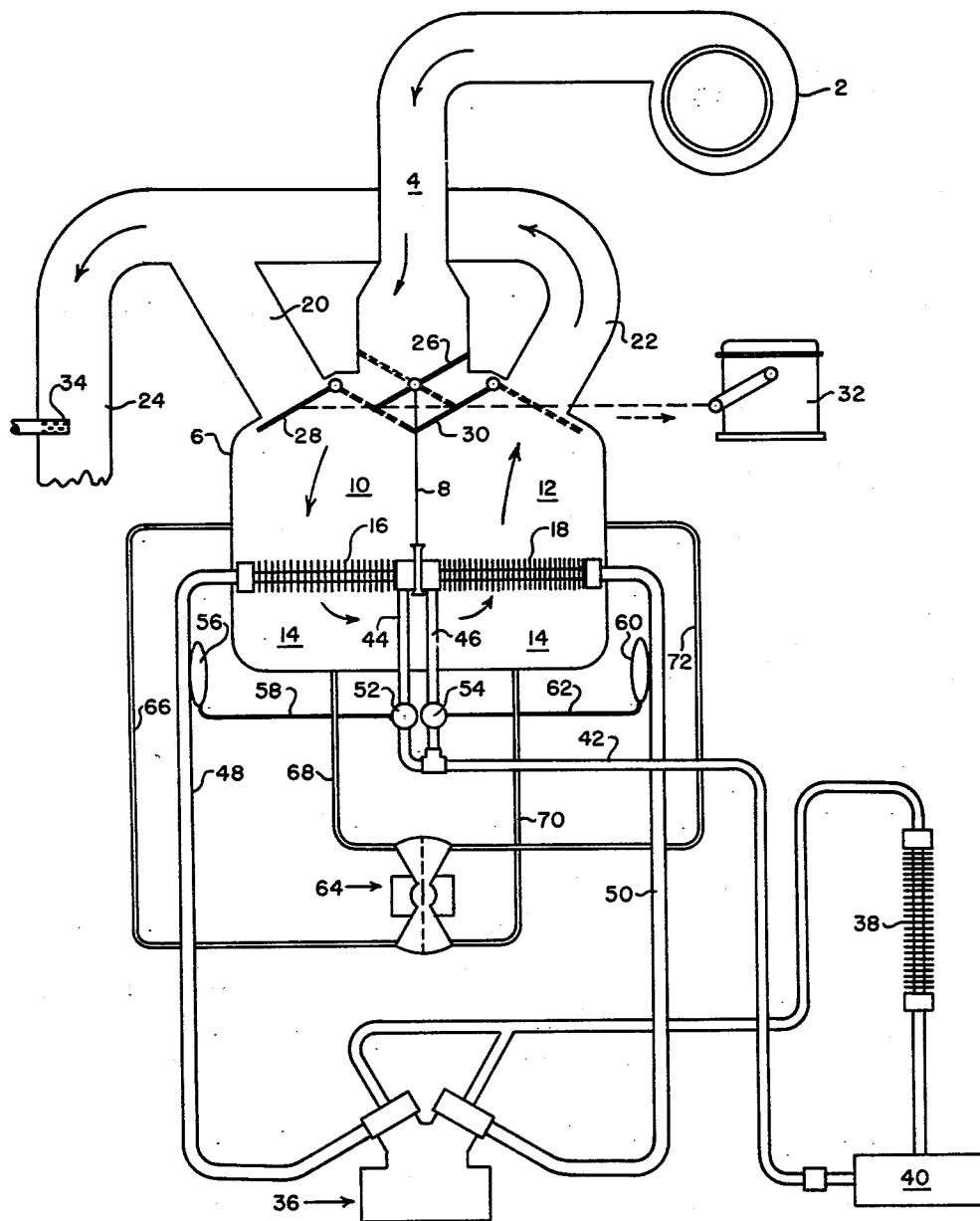


FIG. 1

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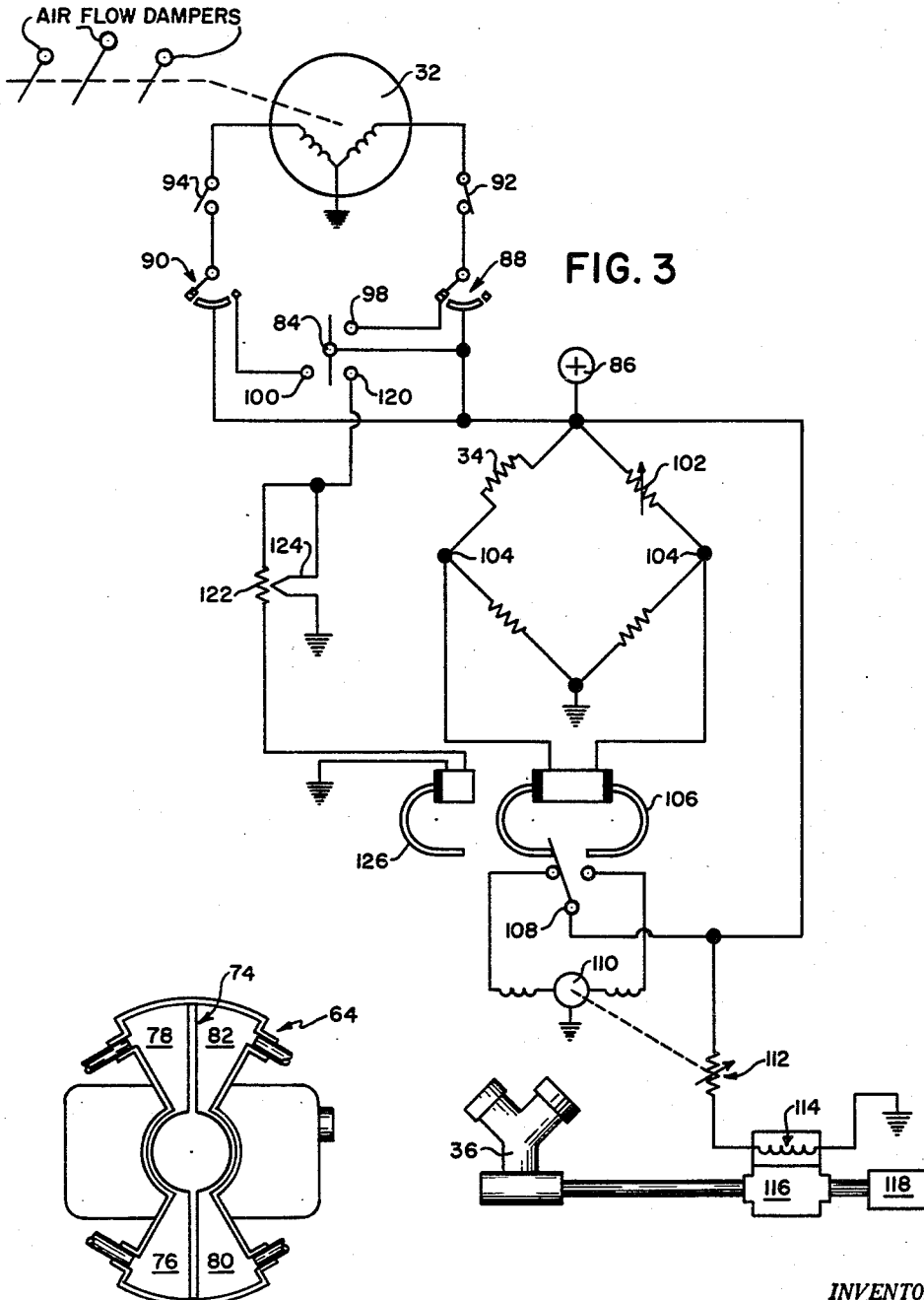


FIG. 2

FIG. 3

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AIR CONDITIONING APPARATUS

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9 Claims. (Cl. 62—140)

This invention relates to air conditioning apparatus of the type particularly adapted to provide cooled air for use in ground support of aircraft and the like. Specifically, the invention relates to an air conditioner having several air cooling coils or evaporators arranged in series or tandem to obtain relatively low air temperatures, and having means for automatically controlling the direction of air flow and supply of refrigerant to defrost the coil upon which frost accumulates.

It is known to utilize two or more coils in a tandem arrangement wherein the air flows in one direction until the downstream coil accumulates an objectionable load of frost, and then to reverse the air flow so that the previously downstream coil is defrosted by the flow of unconditioned or relatively warm air.

It has been suggested that the need for a reversal of air flow can be sensed by using a temperature sensitive element in the discharge air stream. One such arrangement apparently is based upon a theory that an increase in air outlet temperature indicates a decreased effectiveness of heat transfer of the frosted coil and a consequent need of defrosting. Another such arrangement apparently is based upon a theory that a decrease in air outlet temperature indicates a decreased air flow giving more heat transfer per unit volume of air, the decreased air flow resulting from the increased resistance to air flow exerted by a frosted coil and consequently signalling for a need to defrost. While no judgment is made as to the correctness of either of these seemingly contradictory concepts, it is at least apparent that substantial difficulties would be encountered in the adaptation of such control to an air conditioner required to provide air at selected low temperatures within a range of temperatures.

It has also been taught that the supply of refrigerant to the frosted coil should be cut off to increase the speed of defrosting. While rapid defrosting can thus be accomplished, it is obvious that one "spare" coil must be provided in addition to the number of coils necessary to give the desired cooling capacity. This "spare" coil adds expense and poses space requirement problems; particularly with air conditioners of the portable type.

Therefore, one object of the present invention is the provision of an air conditioner having a plurality of cooling coils arranged in series and wherein the direction of air flow is controlled in response to the difference in air flow resistance or static air pressure drop across each of the coils.

Another object is the provision of an air conditioner wherein refrigerant will normally continue to be supplied to the frosted coil after reversal of air flow.

Still another object is the provision of an air conditioner having means for detecting a failure of the frosted coil to defrost with sufficient rapidity, and having means to control the air conditioner in a manner to increase the rate of defrosting in response to such a condition.

Still another object of the present invention is the integration of the foregoing into a temperature control

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system of the type which permits the selection of a desired outlet temperature within a range of temperatures.

In accordance with the present invention, there is provided switch means responsive to the difference in air pressure drop across, or resistance to air flow exerted by, each of the coils arranged in series, the switch being operable in response to a predetermined differential between the pressure drop of the two coils to actuate means for operating suitable damper means to reverse the direction of air flow through the coils. The damper operating means is arranged so that the movement of the dampers to an opposite extreme position continues after damper reversal starts irrespective of the changing pressure differential during the damper movement, and irrespective of the reversed pressure differential when the dampers have been reversed.

In accordance with another feature of the invention, if the pressure responsive switch means remains, for a sufficiently long period, in a position opposite to that position which causes reversal of the damper means, thereby indicating that the frosted coil is not being defrosted at a sufficiently rapid rate, that this condition be utilized to reduce temporarily the refrigerant supply so that the frosted coil will more quickly defrost. Further in accordance with the invention, the refrigerant system includes separate suction lines connected to an isolated bank compressor so that thermostatic expansion valves in the refrigerant supply lines can function to distribute the refrigerant supply to the coils in dependence upon the heat load imposed upon the individual coils.

The invention is described in connection with the accompanying drawing which illustrates one embodiment of the invention by way of example, and wherein:

Figure 1 is a diagrammatic view of an air conditioner embodying the present invention;

Figure 2 is a view of a suitable pressure responsive switch with the cover thereof removed;

Figure 3 is an electrical circuit diagram of a control system for the air conditioner.

Referring to Figure 1, a suitable air blower 2 supplies unconditioned or ambient air through inlet duct 4 to one side of cooling tank 6 which is divided by a partition 8 into chambers 10 and 12 and which has an intermediate chamber designated 14. Cooling or evaporator coils 16 and 18 are mounted to extend horizontally and transversely across chamber 10 and 12 respectively. Each of the chambers 10 and 12 is connected by ducts 20 and 22 respectively, to a common air outlet duct 24.

At the inlet and outlets of cooling tank 6, a set of dampers including air inlet damper 26 and cooling tank air outlet dampers 28 and 30 are suitably linked as indicated by the dotted line to be operated simultaneously to close off the outlet of one chamber and the inlet of the other. With the dampers positioned as shown by solid lines in Figure 1, the incoming air is directed by damper 26 into chamber 10, through coil 16, chamber 14, coil 18, chamber 12, and thence through duct 22 to the outlet 24. It will be apparent that if the dampers are displaced to their opposite extreme position (dotted line positions), the air will flow into the tank by way of chamber 12 and leave the tank by way of duct 20 from chamber 10. The position of the dampers is controlled by damper operator 32. An outlet temperature sensing element 34 disposed in the outlet 24 is a part of a temperature control system to be hereinafter described.

The refrigeration system includes an isolated bank compressor 36, a condenser 38, a receiver 40 from which liquid refrigerant is supplied through line 42 to separate coil supply lines 44 and 46, and separate suction lines 48 and 50 which carry gasified refrigerant back to the individual cylinders or banks of cylinders of compressor 36.

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Refrigerant flow to coils 16 and 18 is controlled by conventional thermostatic expansion valves 52 and 54 in the separate coil supply lines 44 and 46 respectively. These valves are responsive to the refrigerant gas temperature in the suction lines 48 and 50. To this end, a temperature responsive element 56 is disposed adjacent suction line 48 and is connected by capillary tube 58 to valve 52, and temperature responsive element 60 is likewise disposed adjacent suction line 50 and is connected to valve 54 by capillary tube 62.

As is well known in the art, such expansion valves respond to degrees of superheat of refrigerant gas leaving the coils and tend to open in response to a starved condition in the coils and tend to close in response to a flooded condition. The condition of the refrigerant gas leaving the coils is a function of the heat load imposed thereon. That is, with an increased heat load imposed on a coil the gas has an increased degree of superheat, and conversely, with a decreased heat load imposed on a coil the gas has a decreased degree of superheat. Thus, the valves 52 and 54 are effectively controlled by the imposed heat load on each coil.

This faculty of thermostatic expansion valves is employed to advantage in accordance with the invention by utilizing separate suction lines connected to separate cylinders or banks of cylinders of the compressor 36 so that the pressures and consequently superheat, in the gas leaving the coils, can differ from one suction line to the next.

Assuming the required final outlet air temperature is not below a certain limit, the heat load imposed upon the upstream coil is greater than that imposed upon the downstream coil. Therefore, the refrigerant in the upstream coil boils or evaporates at a faster rate than the refrigerant in the downstream coil, and the upstream coil temperature will be higher than the downstream coil temperature.

Since with separate suction lines the compressor displacement offered to each coil is identical, the compressor operation "pulls down" or increases the suction pressure in the downstream coil to a pressure below that pressure possible if a common suction line were used. Hence the downstream coil temperature is depressed to a value below that attainable with a common suction line. In this way it is possible to operate with a downstream coil temperature well below freezing and an upstream coil temperature above freezing. Thus air can be cooled to a temperature below freezing while the rate of frosting on the downstream coil is suppressed and frosting on the upstream coil is prevented.

Referring further to Figure 1, a pressure responsive switch designated 64 has four separate interior chambers in communication through pressure lines with selected portions of the cooling tank 6. Pressure line 66 connects the switch with the chamber 10 of the tank, lines 68 and 70 connect intermediate chamber 14 of the tank to the switch, and line 72 connects the switch to chamber 12 of the tank. Thus, the static pressures in the chambers 10, 12, and 14 of the cooling tank are transmitted to the pressure switch 64 which operates in response to changes in the relationship of these pressures. In other words, the static pressure drops across the coils are placed in opposition to each other in the switch 64 whereby an imbalance of at least a predetermined magnitude between the pressure drops will result in movement of the vane piston 74.

The pressure switch 64 is shown in Figure 2 with its front cover removed to show internal construction. The rotatably mounted vane piston 74 divides the interior of the switch into the four interior chambers sealed from each other and designated as 76, 78, 80 and 82. The vane 74 is suitably biased to an intermediate position. Each of the pressure switch chambers is in communication with a selected part of a cooling tank by means of the aforementioned pressure lines 66, 68, 70 and 72, so

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that the static pressure in each pressure switch chamber will be the same as in the cooling tank chamber connected therewith.

Referring to both Figures 1 and 2, and assuming air flow through the cooling tank in the direction shown by the arrows in Figure 1, it will be apparent that the static pressure in chamber 10 will exceed the static pressure in chamber 14 because of the resistance to air flow exerted by coil 16, and the static pressure in chamber 14 will exceed the static pressure in chamber 12, due to the resistance to the same air flow exerted by coil 18. Assuming that neither coil is frosted, the pressure drop across coils 16 and 18 will be substantially the same and the neutrally biased vane piston 74 will be in an intermediate position as shown in Figure 2. As the downstream coil 18 accumulates frost, its resistance to air flow rises and the pressure drop thereacross consequently increases. The upstream coil 16, which is operating with its cooling surfaces above freezing, does not frost up and therefore has less resistance to air flow and a lower pressure drop thereacross than coil 18.

The operation of the pressure switch 64 in response to such variations in cooling tank chambers 12, 14 and 16 will now be described. Since the static pressure in switch chamber 76 exceeds the static pressure in switch chamber 78, this differential tends to move the vane piston in a counterclockwise direction. However, the static pressure in switch chamber 80 exceeds the static pressure in switch chamber 82 by an even greater amount and this greater differential tends to rotate the vane piston in a clockwise direction. When the differential is great enough to overcome the means biasing the vane piston to a neutral position, the vane piston will rotate in a clockwise direction to a degree corresponding to this differential. As the coil 18 continues to frost, this force will correspondingly increase until a predetermined frosted condition, the vane piston will be rotated to its extreme clockwise position. The displacement of the vane piston to its extreme clockwise position is used, in accordance with the present invention, to indicate that the downstream coil 18 should be defrosted to prevent further obstruction to air flow, the defrosting being accomplished by reversing the damper positions to reverse the direction of air flow through the cooling tank.

The operation of the dampers for reversing the air flow in response to predetermined displacement of the vane piston is accomplished through the circuit shown in Figure 3. A vane switch designated 84, and connected to electrical power source 86, is linked for operation with vane piston 74 so that as vane piston rotates in either direction, the vane switch 84 correspondingly rotates. The vane switch 84 may suitably be a mercury switch mounted on the axis of the vane piston 74 for a tilting rotation in one direction or another with rotation of the vane piston. In addition to being connected to the common moving terminal of vane switch 84, power source 86 is also directly connected to intermediate contact segments of motor reset switches 88 and 90 which form part of the circuit for controlling operation of the servomotor damper operator 32. This circuit also includes limit switches 92 and 94 which are controlled by the displacement of the damper operator 32, limit switch 94 opening when the damper operator is operated to its extreme position corresponding to the position of dampers in Figure 1, and limit switch 92 opening at the opposite extreme position. It is to be understood that the wiping contacts or arms of reset switches 88 and 90 are also rotatably displaced as servomotor 32 is operated. For purposes of clarity in explanation, the angular disposition of these wiping contacts will generally correspond with the angular disposition of the dampers 26, 28 and 30.

When vane piston 74 assumes its clockwise position due to the aforementioned static pressures being imposed on the vane piston faces, vane switch 84 assumes a cor-

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responding clockwise position and power is delivered to terminals 98 and 100 of the vane switch. The power delivered to terminal 98 energizes the servomotor 32 through the left end segment of motor reset switch 88, the limit switch 92, and causes the servomotor to operate in a direction to displace the dampers from the solid line position shown in Figure 1, to the dotted line extreme opposite position. As the servomotor displaces the dampers in this direction the static pressure conditions initially causing the energization of the servomotor are disturbed. Thus, the vane piston 74 moves from its extreme clockwise position and consequently the vane switch 84 breaks contact with terminals 98 and 100. However, the servomotor remains energized through the middle contact segment of reset switch 88 and continues the displacement of the dampers until they are displaced to their opposite extreme position whereupon limit switch 92 and motor reset switch 88 open to de-energize the servomotor, and limit switch 94 closes to permit subsequent energization of the servomotor for operation in the opposite direction.

Since the frosted coil 18 is now the upstream coil and has a resistance exceeding the resistance across coil 16, the vane piston 74 and vane switch 84 will have responded to the reversed pressure conditions by assuming extreme counterclockwise positions. The unconditioned or relatively warmer air now passes through the upstream coil 18 first and serves to defrost it. As the coil 18 defrosts, the vane piston 74 and vane switch 84 will correspondingly move towards an intermediate position from the extreme counterclockwise position. When the upstream coil 18 has completely defrosted and the now downstream coil 16 accumulates sufficient frost that the pressure drop across the downstream coil exceeds the pressure drop across the upstream coil by a value sufficient to cause the vane piston 74 to move again to an extreme clockwise position, power to operate the servomotor 32 will be delivered through switch terminal 100 connected to right end contact segment of motor reset switch 90, and the closed limit switch 94. Thus, the dampers will be displaced to their original positions as shown in Figure 1 and frosted coil 16 again becomes the upstream coil and coil 18 the downstream coil. This manner of reversing air flow will continue so long as the coil which is downstream with respect to air flow continues to accumulate sufficient frost to displace vane piston 74 to its clockwise position.

While the foregoing arrangement normally permits both coils 16 and 18 to remain in service continuously to provide cooling air, certain conditions may be encountered which prevent the upstream coil from defrosting as rapidly as is desired. Such a condition may arise, for example, when the ambient air being conditioned is relatively humid and of a low temperature. In such a case, it would be possible that the upstream coil would retain a substantial quantity of frost while the downstream coil also accumulated frost. This would hinder proper control and also impose an additional resistance to air flow. Thus, under certain conditions it may be desirable to defrost the upstream coil more rapidly than is possible by simply utilizing the unconditioned air passing the coil. This is accomplished by reducing the available refrigerant supply to the coils until the frosted condition of the upstream coil is relieved. One preferred way of doing this is by reducing compressor speed. While control of outlet air temperature is temporarily sacrificed by unbalancing the temperature control system, the temperature control is affected for a short time only.

Referring to Figure 3, there is shown a conventional Wheatstone bridge which includes the air flow outlet temperature sensing resistor 34 in one leg, an air flow temperature selecting resistor 102 in another leg, and several balancing resistors in the opposite legs. The out-

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put terminals 104 of the Wheatstone bridge are connected to a polarized relay 106 which controls a single pole, double throw switch 108 suitably biased to an intermediate position. The switch 108 controls the energization of the servomotor 110 which in turn controls the position of a variable resistor 112 in series with a field coil 114 of a magnetic particle clutch 116. The clutch 116 controls the degree of coupling between the driven compressor 36 and the driving prime mover 118.

The operation of the Wheatstone bridge in controlling the speed of the compressor through the magnetic clutch will now be described. If the outlet temperature sensed by resistor 34 exceeds the selected temperature established by resistor 102 by at least a predetermined value, the imbalance in the Wheatstone bridge will cause current to flow through polarized relay 106 in a direction to close the switch 108 to the terminal which energizes servomotor 110 for operation in a direction to decrease the resistance of resistor 112. Thus, the current flow through coil 114 increases and the degree of coupling effected by clutch 116 consequently increases, thereby increasing the speed of the compressor 36. The increase in the speed of the compressor 36 will provide the additional refrigerating capacity to reduce the outlet temperature to that established by resistor 102.

Conversely, if the temperature sensed by resistor 34 is sufficiently below that established by resistor 102, the current flow through the polarized relay 106 will be in the opposite direction, the switch 108 will close to the opposite terminal and servomotor 110 will be operated to increase the resistance of resistor 112. The decrease in current through field coil 114 decreases the coupling of clutch 116 so that the compressor speed is reduced and the refrigerating capacity of the coils is decreased.

This temperature control system is utilized in connection with the air flow reversing system to provide rapid defrosting when required. To this end, the vane switch 84 is arranged so that it is in its extreme counterclockwise position (corresponding to a reversal of air flow dampers so that the frosted coil is now upstream), the switch 84 will close to terminal 120 to provide current flow to a resistor 122, a heating element 124 associated with the resistor 122, and a bias relay 126 disposed, along with polarized relay 106, to exert control over switch 108.

The resistor 122 is chosen so that its resistance in an unheated condition is relatively high and current flow to relay 126 is negligible. Thus, switch 108 is normally controlled by the Wheatstone bridge circuit only. However, as resistor 122 is heated by its associated heating element 124, its resistance decreases and current flow therethrough correspondingly increases. Thus, when vane switch 84 is displaced to its extreme counterclockwise position the heating element 124 is energized and begins to heat the resistor 122. If the vane switch 84 remains in its counterclockwise position for at least a predetermined period (thus indicating that for some reason the frosted upstream coil is not being defrosted rapidly enough), the resistance of resistor 122 will have decreased enough that the current flow to bias relay 126 actuates switch 108 to a position causing a reduction in compressor speed through the servomotor 110, its controlled resistor 112 and the magnetic particle clutch coil 114.

While control of outlet temperature by the Wheatstone bridge is disturbed when bias relay 126 actuates switch 108, the defrosting of the upstream coil is accomplished more rapidly and loss of temperature control is for a short time only. The control is of course restored to the Wheatstone bridge as soon as the upstream coil defrosts to a degree causing switch 84 to move from its extreme counterclockwise position and break contact with terminal 120.

The embodiment of the invention herein described by

way of example is particularly suited for use as the air cooling part of an all weather air conditioner adapted to provide either heated or cooled air, or both. Such all weather air conditioners may be required to operate in diverse geographical areas having ambient temperatures as low as -65° F. and as high as 120° F. Further, the air conditioners may be required to provide high pressure, low temperature air to a missile or aircraft ventilating system. Because of the need at times for cooling air at a high pressure, the cooling system may be required to operate when the ambient air is below freezing since the pressurizing of air increases its temperature considerably. Thus, it will be clear how the air conditioner can be required to provide cooling air when the ambient temperature is below freezing. It is only necessary that the temperature of the pressurized air passing through the upstream coil is warm enough to melt accumulated frost.

Having described my invention, I claim:

1. In an air conditioner: a plurality of air cooling coils arranged to receive air flow in series sequence; a refrigerant system including means for supplying refrigerant to said coils; damper means displaceable to alternate positions for reversing the sequence in which air flows through said coils; means for detecting an imbalance in resistance to air flow exerted by each of said coils occupying the downstream and upstream position; and means responsive to an imbalance in one direction corresponding to the air flow resistance exerted by said downstream coil exceeding the air flow resistance exerted by said upstream coil by a predetermined value for displacing said damper means to an alternate position, whereby the sequence in which air flows through said coils is reversed.

2. In an air conditioner as specified in claim 1: said means responsive to said imbalance in said one direction includes means responsive to a sustained predetermined imbalance in the opposite direction for reducing the supply of refrigerant to said coils until said imbalance in said opposite direction decreases.

3. In an air conditioner as specified in claim 1: said refrigerant system includes, an isolated bank compressor having each of said isolated banks connected by separate refrigerant suction lines to said coils, and thermostatic expansion valves in the supply line of each of said coils for distributing the supply of available refrigerant in accordance with the heat load imposed on each of said coils.

4. In an air conditioner: a plurality of series-arranged air cooling coils including an upstream and downstream coil; a refrigerating system for supplying liquified refrigerant to said coils and receiving said gasified refrigerant therefrom; damper means operable to reverse the direction of air flow through said coils so that the sequence in which said coils receive said air flow is reversed; air pressure responsive switch means displaceable in a first direction in response to a static air pressure drop across said coil occupying the downstream position exceeding a static air pressure drop across said coil occupying the upstream position, and in the opposite direction in response to a reversed differential in static pressure drop across said coil; and, means for operating said damper means to reverse the direction of air flow in response to displacement of said air pressure switch means a predetermined degree in said first direction cor-

responding to a predetermined frosted condition of said downstream coil.

5. An air conditioner as specified in claim 4 including: means for reducing said refrigerant supply to said coil in response to displacement of said air pressure responsive switch means a predetermined degree in said opposite direction for a predetermined sustained period indicating failure of said coil occupying the upstream position to defrost sufficiently rapidly.

6. In an air conditioner: a housing defining an air flow passageway; a plurality of series-arranged air cooling coils in said housing; damper means for reversing the direction of air flow through said housing; pressure responsive means placing the static air pressure drop across the downstream coil and across the upstream coil of said series-arranged coils in opposition; and means for operating said damper means to a reversed position in response to a condition of said pressure responsive means corresponding to said static air pressure drop across said downstream coil exceeding said static air pressure drop across said upstream coil by a predetermined value indicating a corresponding degree of frosting of said downstream coil.

7. An air conditioner comprising: blower means providing a flow of air to be tempered; a housing defining a passageway for the air flow from said blower means; a plurality of series-arranged air cooling coils in said housing; a refrigerant system for supplying refrigerant to said coils; air temperature control means operable to vary the supply of refrigerant to said coils in response to variations in the outlet temperature of said air flow; damper means operable to reverse the direction of air flow through said housing; means responsive to a predetermined differential in static air pressure drop across the upstream and across the downstream coil respectively corresponding to a predetermined frosted condition of said downstream coil to operate said damper means to reverse the direction of air flow; and means for overriding said temperature control means to reduce the supply of refrigerant to said coils in response to a sustained reversal of said predetermined differential in said static air pressure drop corresponding to a sustained frosted condition of said upstream coil.

8. The air conditioner of claim 7 wherein: said means responsive to the differential in static air pressure drop across said coils includes switch means operable, in one position, to reverse said damper means, and in an opposite position, to energize said overriding means.

9. The air conditioner of claim 8 wherein: said air temperature control means includes a bridge circuit operative to produce an output signal in accordance with a departure in outlet air temperature from a selected air temperature, said output signal being operative to exert control over refrigerant compressor speed switch means; and, said overriding means includes means operative to override control of said refrigerant compressor speed switch means by said bridge circuit output signal in response to a predetermined sustained displacement of said air pressure switch means in said opposite position.

References Cited in the file of this patent

UNITED STATES PATENTS

2,481,348	Ringquist	Sept. 6, 1949
2,710,724	McMahon	June 14, 1955
2,763,132	Jue	Sept. 18, 1956