Feb. 24, 1942. E. S. LAMMERS, JR 2,274,336

CONTROL SYSTEM FOR REFRIGERATING APPARATUS

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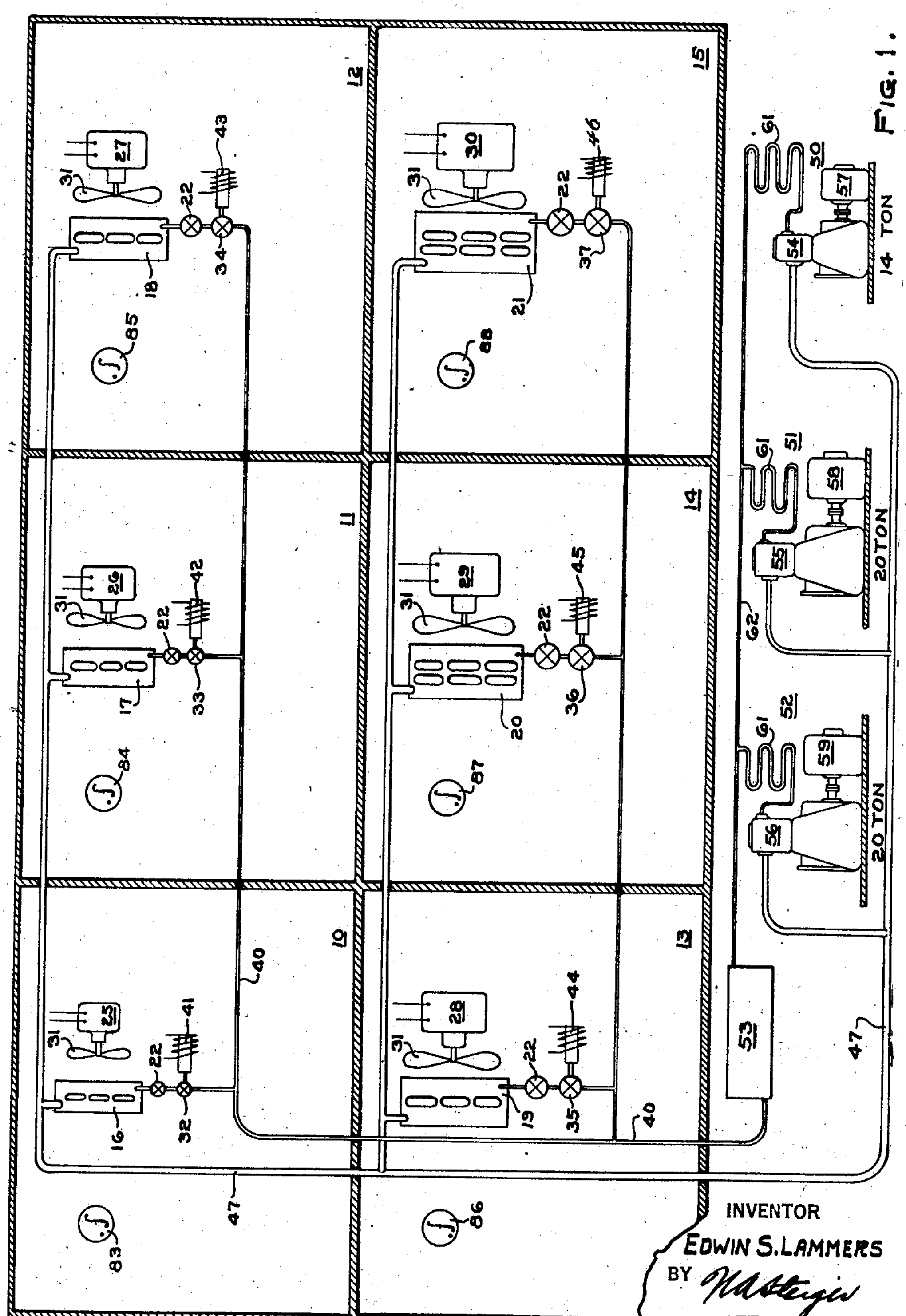

FIG. 1.

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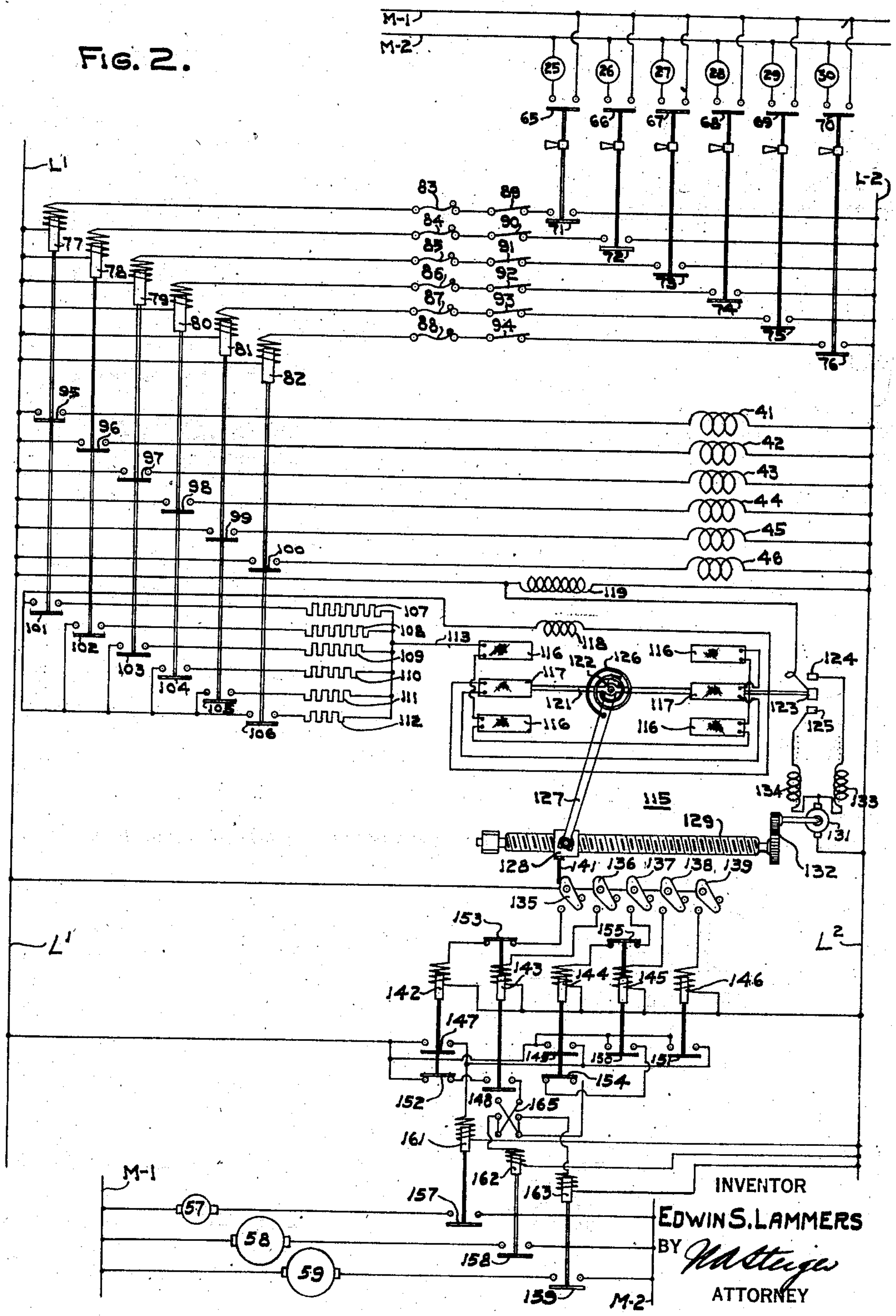
FIG. 2.



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CONTROL SYSTEM FOR REFRIGERATING APPARATUS

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3 Claims. (Cl. 62—4)

My invention relates to control systems for refrigerating apparatus, more particularly to a control system for refrigerating apparatus employing a plurality of refrigerant compressors, and it has for an object to provide an improved system of this kind.

A further object of my invention is to provide an improved method and apparatus for controlling refrigerating apparatus having a plurality of refrigerant compressor elements of equal or various capacities, wherein the compressor elements are selectively operated, individually or together, in accordance with the prevailing load and in such manner that the total capacity of the elements in operation is optimum for the prevailing load.

A further object of my invention is to regulate the operation of the refrigerant compressor elements in accordance with the total capacity of the evaporators that are operating.

My invention is particularly adaptable to air conditioning systems having a plurality of evaporators for cooling the air in a plurality of spaces and supplied with refrigerant by a plurality of parallel connected, refrigerant compressor elements which may be of various sizes. It is desirable in a system of this kind to operate the smallest size condensing unit that will carry the existing load, and, also, to operate the least number of units.

In accordance with my invention, I provide a control system for a plurality of parallel connected, refrigerant compressor elements, which may be of various sizes, wherein an electrical control circuit is employed. A characteristic of the circuit such as, for example, the current therein is varied in response to the load on the system or the total capacity of the evaporators which are operating. A current responsive device is connected in the circuit and operates to control the operation of the compressor elements in accordance with the current in the circuit and, therefore, the load on the system or the capacity of the evaporators in operation.

The current responsive device such as, for example, a Kelvin balance, is actuated by the current in the circuit and assumes various positions in response to the different values of current in the circuit. The various positions of the balance determine the size and number of the compressor elements to be operated for the existing load.

By operating the compressor elements, either individually or together, so that the total capacity thereof is of the lowest value sufficient for carrying the existing load, more efficient operation is obtained. Furthermore, the suction or evaporator pressure may be maintained more nearly at its proper value, so that freezing of moisture on the evaporator is prevented.

These and other objects are effected by my invention, as will be apparent from the following description and claims taken in connection with the accompanying drawings, forming a part of my invention, in which:

Fig. 1 is a diagrammatic view of a refrigerating system employing a plurality of refrigerant compressor elements and a plurality of evaporators; and,

Fig. 2 is a diagram of the apparatus and electrical connections for controlling the operation of the system shown in Fig. 1.

In Fig. 1, I have shown my improved refrigerating system applied to a plurality of enclosures 10 to 15, inclusive, for cooling the air therein. A plurality of refrigerant evaporators 16 to 21, inclusive, are provided for cooling the air in the enclosures 10 to 15, respectively, each of said evaporators 16 to 21 being provided with a suitable refrigerant expansion device 22 such as, for example, a conventional thermostatic expansion valve. Such a valve, which is well known in the art, controls the flow of refrigerant to the evaporator to maintain a constant degree of superheat of the refrigerant vapor exhausted from the evaporator, thereby supplying the evaporator substantially with such quantity as can be evaporated therein. A plurality of motors, 25 to 30, inclusive, are associated with the respective evaporators 16 to 21 and operate to drive fans or blowers 31 for the translation of air in heat exchanging relation with the evaporators prior to its delivery to the enclosures.

Operation of the various evaporators may be controlled by a plurality of valves 32 to 37, inclusive, which are connected between the expansion devices 22 and a common refrigerant supply conduit 40. The valves 32 to 37 are operated electrically, preferably by means of solenoids 41 to 46, inclusive. Vaporized refrigerant is conveyed from the evaporators 16 to 21 by means of a common suction conduit 47.

A plurality of refrigerant compressor elements generally indicated at 50, 51, and 52 are employed for compressing the refrigerant vapor withdrawn from the suction conduit 47. The compressor elements 50, 51, and 52 include a plurality of compressors 54, 55, and 56 driven, respectively, by motors 57, 58, and 59. Suitable condensing mechanism is provided for condensing the compressed refrigerant, either a common condenser or separate condensers being employed. Preferably, as shown in the illustrated embodiment, each compressor is provided with a condenser 61. Refrigerant condensed by the condensers 61 is delivered to a reservoir or liquid receiver 53 by means of a common conduit 62, said reservoir 53 being in communication with the liquid conduit 40. The heat load of the various enclosures 10 to 15 may be of various values, so that different sizes or capacities of evaporators are necessary. In the system disclosed, it will be assumed that the capacities of the evaporators 16 to 21, inclusive, are, respectively, 4, 6, 8, 10, 12, and 14 tons. As described hereinafter, the evaporators may be selectively operated either individually or together, so that it will be obvious that the load on the compressor elements 50, 51, and 52 may vary from 4 tons to a total load of 54 tons. The compressor elements are also operated singly or simultaneously in different combinations depending upon the load imposed thereon. It will be assumed in the present example that the capacities of the compressors 54, 55, and 56 are, respectively, 14 tons, 20 tons, and 20 tons.

In accordance with my invention, I provide means, as disclosed hereinafter, for automatically effecting operation of the smallest compressor element that will carry the prevailing load and, furthermore, which will effect operation of the least number of condensing units at all times. Reference will now be had to Fig. 2, wherein the control system for the apparatus shown in Fig. 1 is diagrammatically shown.

The source of power for the control devices is represented by the conductors L—1 and L—2. The compressor motors 57, 58, and 59 are energized from power mains M—1 and M—2 which may also represent the source of power for the fan motors 25 to 30, inclusive.

The fan motors 25 to 30, inclusive, are controlled by switches 65 to 70, inclusive, which may be manually opened and closed, preferably, from their respective enclosures 10 to 15. A plurality of switches 71 to 76, inclusive, are opened and closed simultaneously with the opening and closing of switches 65 to 70 and control circuits having a plurality of solenoids 77 to 82, inclusive, connected therein. The latter circuits are also controlled by respective thermostats 83 to 88, inclusive, arranged in the respective enclosures 10 to 15, as described hereinafter, control the operation of the evaporators in response to the temperature of the air in their associated enclosures. It will be apparent from the foregoing that energization of a fan motor is effected in order to render its associated evaporator operative, so that delivery of air to the evaporator is assured before refrigerant can be delivered to the evaporator. Operation of the fan motors 25 to 30 may be effected, without cooling of the air delivered thereby, in any suitable manner known in the art; for example, by providing a plurality of hand-operated switches 89 to 94 in circuit with the thermostats 83 to 88. Any of the circuits including the thermostats 83 to 88 may be rendered ineffective to permit the delivery of refrigerant to the evaporators by opening its associated hand switch 89 to 94.

The valve solenoids 41 to 46 are shown in Fig. 2 controlled by switches 95 to 100, inclusive; said switches being closed by their respective solenoids 77 to 82 when the latter are energized. The solenoids 77 to 82, when energized, also close respective switches 101 to 106, inclusive, which are respectively connected in series with resistors 107 to 112. The resistors 107 to 112 are connected in parallel in a circuit indicated by the reference numeral 113 and regulate the value of a characteristic thereof such as, for example, the value of the current flowing therein.

Control of the compressor motors 57, 58, and 59 is effected by a mechanism including a Kelvin balance, indicated generally at 115 and including series connected, stationary and movable coils 116 and 117, respectively, which are connected in the circuit 113. Energization of the circuit 113 may be effected by the secondary of a transformer 118, the primary 119 of which is energized from the conductors L—1 and L—2.

The moving coils 117 of the balance 115 are carried by a beam 121 pivoted at 122 and carrying a contact 123 connected to the conductor L—1. The latter contact is engageable with stationary contacts 124 and 125 and defines therewith a double-throw switch. A spring 126 is connected at one of its ends to the beam 121 and at its other end to a pivoted lever 127, the latter being rotated about the pivot point 122 by a travelling nut 128 carried by a screw 129. Rotation of the screw 129 is effected by a reversible motor, the armature of which is shown at 131. Preferably, a speed reducing device is employed between the armature 131 and the screw 129, which device is indicated at 132. The field of the reversible motor is split, the portions 133 and 134 of which are connected at one side to the stationary contacts 124 and 125, respectively. Both field portions 133 and 134 are connected at their opposite sides to the armature 131, the latter being connected to the conductor L—2 as shown.

From the foregoing, it will be apparent that the value of the current flowing in the circuit 113 and in the coils of the balance 115 will vary dependent upon the number and resistance values of the resistors 107 to 112 that are connected in circuit. The resistors 107 to 112 are connected in the circuit 113 simultaneously with the energization of their respective valve solenoids 41 to 46, so that, as refrigerant is admitted to an evaporator by its associated solenoid valve, a resistor is connected in the circuit 113 and the current therein is increased. The values of the resistances of the various resistors 107 to 112 are predetermined and are inversely proportional to the tonnage capacity of their respective evaporators, so that the values of the current flowing through the respective resistors are proportional to such tonnage capacity. The value of the current in the circuit 113 and the balance 115 is the sum of the current flowing through the several resistors and it is, therefore, proportional to the total capacity of the evaporators that are operating.

As the operation of a Kelvin balance is well understood, it will not be described here, other than to say that the current in the coils 116—117 bias the beam 121 in clockwise direction with a force proportional to the value of the current. A spring 126 biases the beam 121 in counterclockwise direction in opposition to the force of the coils. The spring is of such strength and scale that as the nut 128 reaches the proper position corresponding to the value of the current in the circuit 113, the spring exerts a bias on the beam 121 equal to the bias of the coils 116—117, causing the beam 121 to assume equilibrium position in which the contact 123 does not engage either of the contacts 124, 125.

As the current flowing in the balance 115 increases, due to an evaporator being rendered active, the beam 121 rotates in clockwise direction and causes engagement of the contacts 123 and 125. The armature 134 is, thereby, energized and effects rotation of the screw 129 in such manner that the nut 128 moves to the right. The pivoted lever 127 therefore rotates about the pivot point 122 in counterclockwise direction, adding bias to the spring 126 and returning the beam 121 to its neutral position. The contacts 123 and 125 are disengaged and the armature 131 stops.

A decrease in the current in the balance coils 116—117, due to the termination of flow of refrigerant to an evaporator and disconnection of its respective resistor from the circuit 113, effects a reverse operation of the balance mechanism 115, the beam 121 tilting in counterclockwise direction to engage contacts 123 and 124. Accordingly, the armature 131 effects a movement of the nut 128 to the left and clockwise movement of the lever 127 until the reduced bias of the spring permits the beam 121 and contact 123 to assume their neutral positions, as shown. It will be apparent, therefore, that the nut 128 assumes different positions along the screw 129 for different values of current in the circuit 113 and, incidentally, different values of the total tonnage of the evaporators that are operating.

The various positions of the nut 128 may be utilized for regulating the operation of the compressor motors 57, 58, and 59, which operation is thereby responsive to the total tonnage of the evaporators which are active. A plurality of mechanically operated switches 135 to 139, inclusive, may be disposed adjacent to the nut 128 and actuated thereby. A projection 141 carried by the nut 128 engages the switches 135 to 139 and effects closing and opening thereof as the nut 128 moves to the right and left, respectively. It will be understood that the switches 135 to 139 remain in the position to which they have been moved by the projection 141. The switches 135 to 139 that are engaged and closed by the projection 141 as it moves to the right, remain closed until engaged by the projection 141 as it moves to the left at which time they are opened.

A plurality of solenoids 142 to 146, inclusive, are connected between the conductors L—1 and L—2 and are controlled by the switches 135 to 139, inclusive. In the drawing, the solenoids 142 to 146, inclusive, are shown deenergized. When energized, they effect closing of respective switches 147 to 151. The solenoids 142 to 145, inclusive, open respective interlock switches 152 to 155, inclusive, when energized. The interlock switches 152, 153, 154, and 155 are, respectively, connected in series with the switch 148, the solenoid 142, the switch 150, and the solenoid 144. The various conductors interconnecting the various switches 147 to 155, inclusive, are clearly shown on the drawing and it is not deemed necessary to recite their specific connections.

The compressor motors 57, 58, and 59 are controlled by relay switches 157, 158, and 159 operated, respectively, by solenoids 161, 162, and 163. Energization of the latter solenoids is under the control of the switches 147 to 152, inclusive, and switch 154. As described hereinafter, the motors 57, 58, and 59 are started and stopped in a predetermined sequence and, as the motors 58 and 59, as disclosed, are of the same capacity, their relative sequence of operation may be periodically reversed in order to equalize the wear thereon and on their driven compressors. Accordingly, a conventional double pole reversing switch 165 may be interposed in the circuits of the solenoids 162 and 163, which switch is moved, periodically, from one position to the other, whereby the starting and stopping sequence of the motors 58 and 59 is reversed.

Operation

As shown in the drawings, the control system is in its shutdown position, due to the fact that the switches 71 to 76 are open. Assume it is desired to condition the control system for ventilating all of the enclosures 10 to 15, inclusive, and for maintaining the air therein at the temperature at which the thermostats are set. The switches 65 to 70, inclusive, are closed for initiating operation of the fans 25 and 30, inclusive. Switches 71 to 76, inclusive, are closed incidental to the closing of the switches 65 to 70, so that the circuits including the solenoids 77 to 82, inclusive, are conditioned for operation, that is, placed in condition to be energized upon closing of the thermostat contacts. As cooling of the air in all of the enclosures is to be effected, manually operated switches 89 to 94, inclusive, are closed. The operation of each evaporator will now be controlled by its associated thermostat.

Assume now that cooling is required in the enclosures 10 and 11 which include the 4 and 6 ton evaporators 16 and 17, respectively. The thermostats 83 and 84 are, therefore, closed while the remaining thermostats 85 to 88, inclusive, are in their open position. The solenoids 77 and 78 are, therefore, energized and switches 95, 96, 101, and 102 are closed. Accordingly, the valve solenoids 41 and 42 are open for the passage of refrigerant to the evaporators 16 and 17. Closing of the switches 101 and 102 connects the resistors 107 and 108 in circuit with the balance 115. The amount of current passed by the resistors 107 and 108 is proportional to 10 tons evaporator capacity, and the balance 115 responds to this current value in such manner that the nut 128 is moved to the right a sufficient distance to effect closing of switch 135. A circuit is established from the line conductor L—1 through the switch 135, interlock switch 153, solenoid 142, to the conductor L—2.

The switch 147 is thereby closed and the switch 152 opened. Closure of the switch 147 effects energization of the solenoid 161 which operates to close the switch 157. Closure of the switch 157 initiates operation of the motor 57 and the 14-ton compressor 54 driven thereby.

As recited heretofore, the capacity of the evaporators 16 and 17 is 4 and 6-tons respectively or a total of 10 tons. This load can readily be carried by the small or 14-ton compressor.

Assume now that the thermostat 85 closes for effecting cooling in the enclosure 12, the thermostats 83 and 84 remaining closed. This operation energizes the solenoid 79 which closes the switches 97 and 103. The solenoid 43 is energized by the closing of the switch 97 for permitting the flow of refrigerant to the evaporator 18. Closing of the switch 103 connects the resistor 109 in circuit so that there is an increased flow of current in the balance 115, the value of current now being proportionate to 18 tons evaporator capacity. As described heretofore, the contacts 123 and 125 engage and the armature 131 rotates to cause further movement of the nut 128 to the right. This movement causes the projection 141 to close the switch 136. A circuit is therefore established which effects energization of the solenoid 143, thereby closing the switch

148 and opening the interlocked switch 153. Opening of the latter deenergizes the solenoid 142 and switches 147 and 152 open and close respectively. Opening of the switch 147 deenergizes the solenoid 161 and terminates operation of the motor 57 and the 14-ton compressor driven thereby. Closing of the switches 152 and 148 establishes a circuit from the conductor L—1 through switches 152, 148, reversing switch 165, which is in its lower position, solenoid 162 to the line conductor L—2. Energization of the solenoid 162 closes the switch 158 and thereby initiates operation of the motor 58 and the 20-ton compressor 55 driven thereby.

It will be seen from the foregoing that the load on the compressor elements is now 18 tons which is greater than the capacity of the compressor 54 but within the capacity of the compressor 55.

Assume now that the enclosure 13 requires cooling and that the thermostat 86 closes. This will represent a load of 28 tons. Closing of the thermostat 86 effects energization of the valve solenoid 44 so that refrigerant is delivered to the evaporator 19. The resistor 110 is also inserted in the circuit 113 of the balance 115 which operates to effect the closing of switch 137. A circuit is therefore established from the line conductor L—1, switch 137, interlock switch 155, solenoid 144 to the other line conductor L—2. Energization of the solenoid 144 effects closing of the switch 149 and opening of the switch 154. The solenoid 161 is therefore energized by a circuit extending from the conductor L—1, switch 149, solenoid 161, to the line conductor L—2. The switch 157 is therefore closed for initiating operation of the motor 57 and the 14-ton compressor driven thereby. The total load of 28 tons is now carried by the 14 and 20-ton compressors 57 and 58.

Assume now that the enclosure 14 requires cooling and that the thermostat 87 closes. The solenoid valve 45 is energized to admit refrigerant to the evaporator 20 and the resistor 111 inserted in the circuit of the balance 115. The latter operates to close the switch 138 whereby the solenoid 145 is energized. The circuit is established from the conductor L—1 through the switch 138, solenoid 145 to the line conductor L—2. The solenoid 145 operates to open the switch 155 and to close the main switch 150. The opening of the switch 155 deenergizes the solenoid 144 thereby opening switch 149 and closing the switch 154. As the switch 149 opens, the solenoid 161 is deenergized so that switch 157 opens and operation of the motor 57 and the 14-ton compressor is terminated. Closing of the switch 150 establishes a circuit from the conductor L—1 through switch 150, switch 154, reversing switch 165, solenoid 163 to the line conductor L—2. The switch 159 is therefore closed as the solenoid 163 is energized and operation of the motor 59 and the 20-ton compressor 56 is initiated. It will be seen that the load on the compressor elements is now an even 40 tons which is within the capacity of the two 20-ton compressors which are operating.

With all of the enclosures demanding cooling, it will be apparent that all of the solenoid valves will be open and that the current flowing in the balance 115 is maximum due to the fact that all the resistors are in circuit. The travelling nut 128 is therefore at its extreme right position so that all of the switches 135 to 139, inclusive, are closed. As the latter switch 139 closes, the solenoid 146 is energized for closing the switch 151. The latter establishes a circuit through the solenoid 161 so that the switch 157 is closed for initiating operation of the motor 57 and the 14-ton compressor 54. All elements are now operating.

The foregoing is a description of the operation of the various elements of the control system as the compressors are started. A description of the operation of system as the load is decreased will now be given.

Assume the temperature of the air in enclosures 13 and 14 is depressed to the desired value. The thermostats 86 and 88 open and deenergize the solenoids 80 and 82 so that switches 98, 100, 104, and 106 open. Accordingly, the valve solenoids 44 and 46 are deenergized and the valves 35 and 37 close to terminate flow of refrigerant to the evaporators 19 and 21. As described heretofore, the fan motors 28 and 30 continue to operate for circulating untreated air in the enclosures 13 and 15. Opening of the switches 104 and 106 remove resistances 110 and 112 from the circuit 113, so that the current flowing through the Kelvin balance coils 116 and 117 is reduced to a value corresponding to 30 tons of evaporator capacity, which is the total capacity of the operating evaporators 16, 17, 18 and 20.

Reducing the current in the balance mechanism 115 effects counterclockwise movement of the beam 121 and engagement of the contacts 123 and 124. The motor armature 131 and field portion 133 are energized and rotation of the screw 129 is effected for moving the nut 128 and projection 141 to the left to a location corresponding to 30 tons of refrigeration load. This location is intermediate the switches 137 and 138. As the projection 141 passes from its extreme right position to the recited location, it moves, successively, the switches 139 and 138 to their open positions.

Accordingly, the solenoids 145 and 146 are deenergized, whereby the switches 150 and 151 open and the interlock switch 155 closes. Solenoid 144 is energized by switch 155 so that switch 149 closes and switch 154 opens. As switch 150 opens, the solenoid 163 is deenergized for opening switch 159. The motor 59 is, therefore, deenergized and operation of the 20-ton compressor 56 is terminated. Operation of the 14-ton compressor is maintained as switch 157 is held in its closed position by the solenoid 161, the latter being energized through closed switch 149.

As stated heretofore, the total load on the compressors is 30 tons, which load is carried by the 20- and 14-ton compressors 55 and 54, respectively.

It is to be understood that any of the many known expedients commonly used in the electrical control art may be employed wherever occasion for their use arises. For example, suitable time delay devices, such as dashpots, may be applied to the relay switches 157—159 to provide sequential starting of the motors 57—59 upon restoration of the electrical current after an interruption thereof.

From the foregoing, it will be apparent that I have provided an improved refrigerating system having a plurality of compressors which may be of various sizes connected with a plurality of evaporators, wherein the compressor to be operated is selected in accordance with the prevailing load and wherein a minimum number of compressors are operated at all times. It is to be understood that the present invention is also applicable where compressors of equal capacity are used. For example, the compressor 54 and the motor 57 may be omitted, in which case the relays 142, 144 and 146 would also be omitted.

Furthermore, it will be apparent that I provide an improved refrigerating system having a control or phantom circuit in which the value of an electrical characteristic is proportionately varied in accordance with the load on the system, and the compressor or compressors to be operated selected in accordance with the value of the electrical characteristic.

While I have shown my invention in but one form, it will be obvious to those skilled in the art that it is not so limited but is susceptible of various changes and modifications, without departing from the spirit thereof, and I desire, therefore, that only such limitations shall be placed thereupon as are imposed by the prior art or as are specifically set forth in the appended claims.

What I claim is:

1. In refrigerating apparatus, the combination of a plurality of evaporators, a control device associated with each evaporator for initiating and terminating operation thereof, variable capacity compressor means for serving said evaporators, and means for varying the compressor capacity in operation substantially in proportion to the total capacity of the evaporators that are controlled to operate, said last-mentioned means comprising a group of resistors respectively associated with the several evaporators and having resistance values inversely proportional to the capacities of the associated evaporators, each resistor being energized by the control device of the associated evaporator simultaneously with effecting operation of the latter, said resistors being connected in parallel when energized, and means responsive to the total current flowing through the resistors that are energized for varying the total compressor capacity substantially in proportion to such current and, therefore, substantially in proportion to the total capacity of the evaporators that are controlled to operate.

2. In refrigerating apparatus, the combination of evaporator means of variable capacity, control means for varying the evaporator capacity in operation, variable capacity compressor means for serving said evaporator means, and means for varying the compressor capacity in operation in response to the evaporator capacity that is controlled to operate, said last-mentioned means comprising a control circuit, a plurality of resistors adapted to be connected in said control circuit in parallel under control of said control means, the latter being operative to increase and decrease the current-carrying value of the resistors connected in said circuit upon increasing and decreasing, respectively, the evaporator capacity in operation, and means for increasing and decreasing the compressor capacity in operation in response to increase and decrease, respectively, in the total current flowing in said control circuit.

3. In a control system, the combination of a plurality of load-imposing elements, a control device associated with each element for initiating and terminating operation thereof, motor-actuated means for carrying the load imposed by said elements, and means for controlling said motor-actuated means comprising a group of resistors respectively associated with the load-imposing elements and having resistance values inversely proportional to the loads imposed by the associated elements, each resistor being energized by the control device of the associated element simultaneously with effecting operation of the latter, said resistors being connected in parallel when energized, and means responsive to the total current flowing through the resistors that are energized for controlling the operation of the motor-actuated means to assume a load substantially equal to the total load of the elements that are controlled to operate.

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