United States Patent

Richardson

[15] **3,648,479**

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[54] REFRIGERATION SYSTEM WITH MULTIPLE CENTRIFUGAL COMPRESSORS AND LOAD BALANCING CONTROL

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[52] **U.S. Cl.**.....**62/217,** 62/230, 62/510, 417/3, 417/45

[51] **Int. Cl.**.....**F25b 41/04**

[58] **Field of Search**.....62/217, 227, 228, 230, 510; 417/3, 44, 45

[56] **References Cited**

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[57] **ABSTRACT**

A refrigeration system with two or more electric motor driven centrifugal gas compressors to a single common load circuit is provided with electric circuit interconnections for the respective electric controls of the movable capacity controlling means of the respective compressors such that increased current drawn by the electric motor of a more heavily loaded one of the compressors is effective to adjust the respective capacity control means and reduce the capacity of that compressor to balance the current drawn by the other motors and compressors and thus evenly divide the single load between the two or more compressors.

8 Claims, 6 Drawing Figures

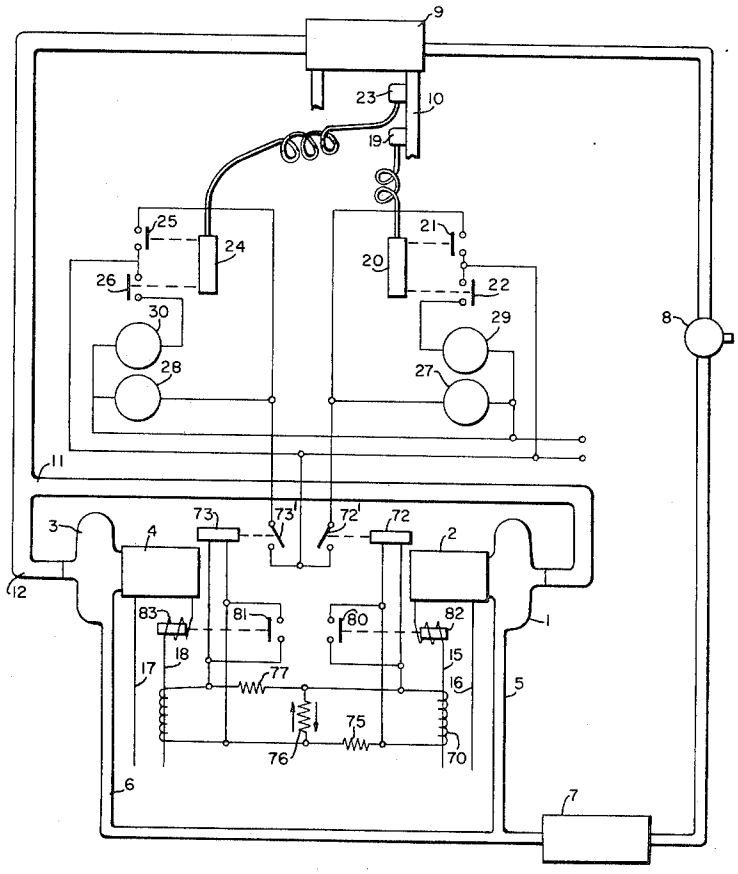
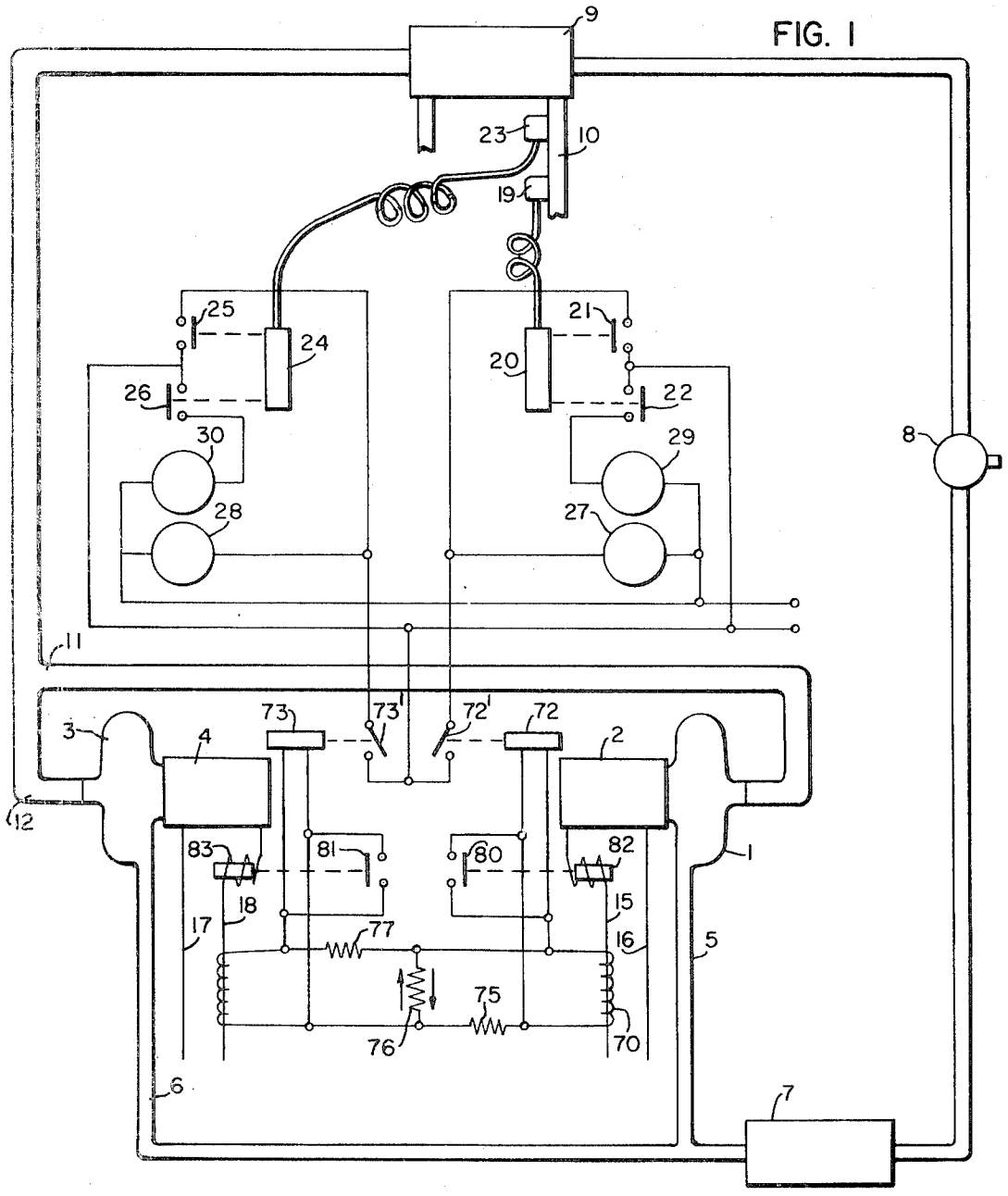


FIG. 1



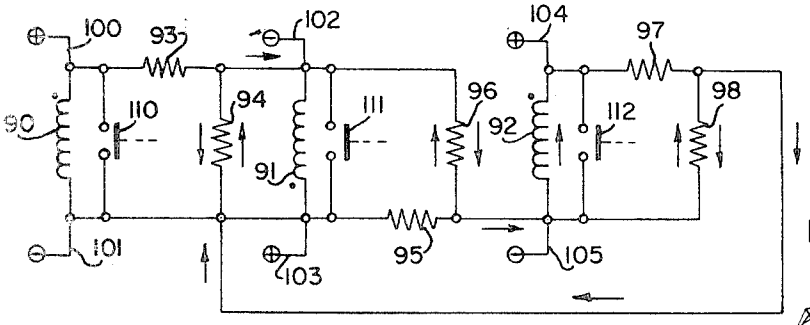


FIG. 6

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FIG. 2

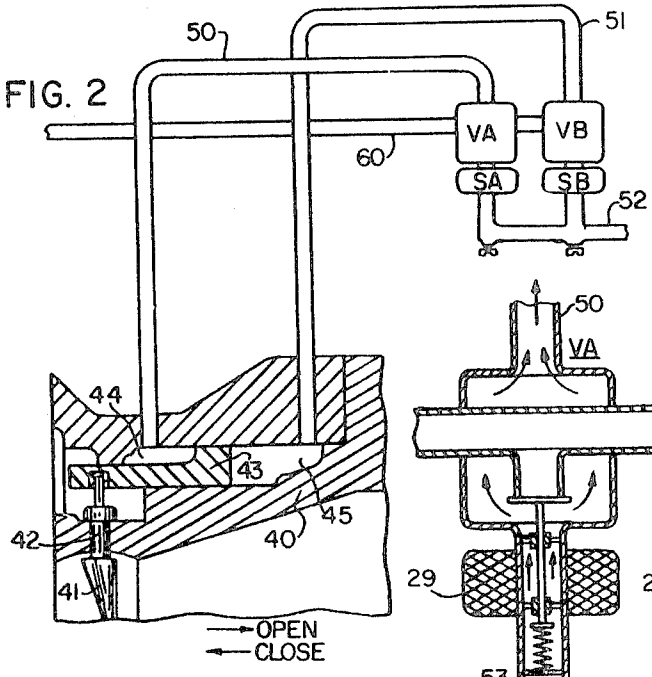
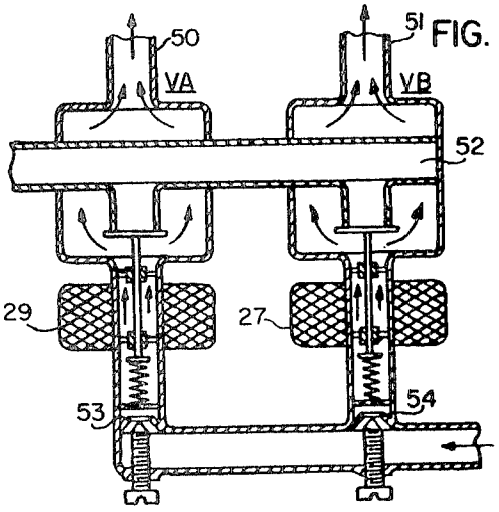


FIG. 3



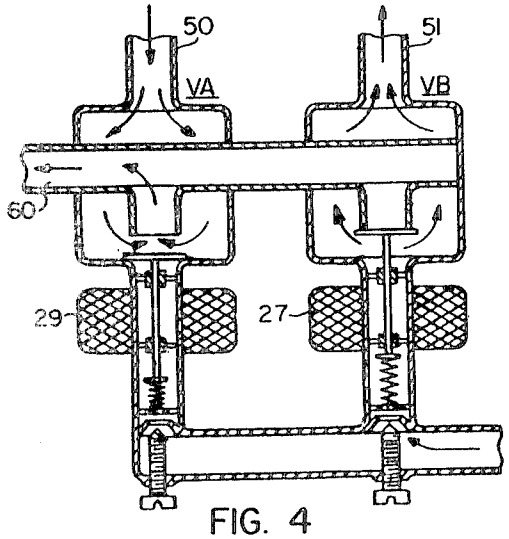


FIG. 4

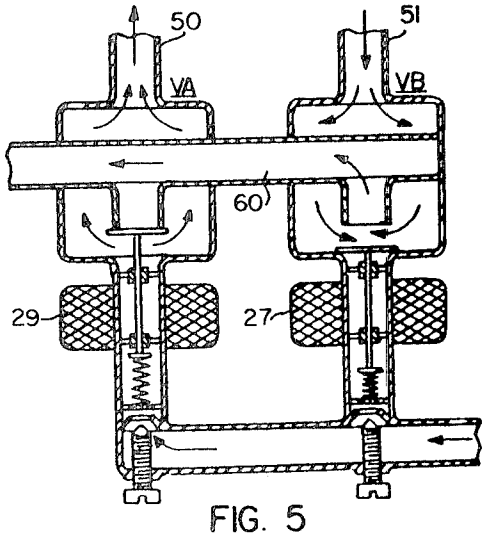


FIG. 5

REFRIGERATION SYSTEM WITH MULTIPLE CENTRIFUGAL COMPRESSORS AND LOAD BALANCING CONTROL

CROSS REFERENCES TO RELATED PATENT APPLICATIONS

A refrigeration capacity control for a system having a single centrifugal compressor is shown in my copending patent application Ser. No. 28,678, filed Apr. 15, 1970. This invention relates to the specific electrical interconnection of two or more such capacity controls when two or more centrifugal gas compressors are to be used in a single refrigeration load circuit.

BACKGROUND OF THE INVENTION

It is known that an electric motor driven centrifugal gas compressor is capable of overloading the motor if allowed to seek loads higher than standard design conditions. Centrifugal gas compressors, when used to compress a refrigerant gas are therefor required to have movable capacity controls and one such control determines the positions of movable suction inlet pre-rotation vanes for the compressor to vary the compressor capacity. An electrical control circuit for automatically positioning such inlet vanes to provide a predetermined control of refrigeration of air conditioning system parameters such as for example the chilled outlet water temperature is disclosed in my copending patent application as previously referred to. In that disclosure, a current sensing coil is also provided to operate an overload relay whenever the current drawn by the electric motor driving the compressors exceeds a predetermined amount corresponding to an overload condition. The operation of the overload relay causes the inlet vanes of the associated compressor to move in a decrease capacity direction until the sensed overload current is reduced to a safe value at which the operated overload relay restores to the non-operated condition upon which the movement of the inlet vanes towards a decreased capacity position is stopped.

It is sometimes desirable to have two or more centrifugal gas compressors connected to the same common refrigerant load circuit and each gas compressor should have its own capacity control circuit responding to the common system condition such as chilled water temperature or the like. A problem exists with such an arrangement in that one of the compressors tends to work harder than the other compressors in the system and therefore it is desirable to provide a load balancing capacity control to evenly divide the common load among all of the operating compressors. Of course such a control should be simple, reliable and also inexpensive.

PRIOR ART

Applicant is not aware of any prior patents showing load sharing circuits for capacity controls of two or more centrifugal gas compressors connected to a single common load refrigeration system. The U.S. Pat. No. 3,350,897 to Plaster issued Nov. 7, 1967 describes a capacity control for a single centrifugal compressor refrigeration system.

SUMMARY

According to the invention, a refrigeration system is provided with at least two centrifugal gas compressors supplying compressed refrigerant gas to a single common refrigerant load circuit and each compressor is provided with an inlet capacity control and an electrical control circuit therefor. Each control circuit includes a solenoid valve which, when energized, causes the capacity control to move in the decrease capacity direction. The power supply to each compressor motor includes circuit means having a current responsive device such as a current sensing coil and a respective relay connected to the respective coil to be operated when the current drawn by the associated compressor motor is more than a predetermined amount. An electrical circuit interconnection between the sensing coils for each compressor motor is such that the respective relay for the motor drawing the most current will be operated to decrease the compressor capacity until the current drawn by that motor is reduced to an amount balancing the respective current drawn by the other compressor motor. Such electrical interconnection according to the invention is very simply effected by a particular interconnection of conductors and or resistors between the current sensing coils so that the current sensed by one coil will flow through a resistor in opposition to the current sensed by another coil and so forth. By suitably choosing the values of the resistors, the sensing coils, and the relays, both a load sharing control function and an overload protection for each electric compressor motor can be provided.

This invention also provides respective circuit means including resistors and contactors responsive to energization of each compressor motor to short circuit the associated current sensing coil and relay when that respective compressor and motor are not energized and operating. Thus the associated capacity control system for a remaining operating compressor and motor in the system may still be operable. Other features and advantages of the invention will be apparent with reference to the following specification and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic view of the refrigeration system having two compressors and a load balancing circuit of the invention;

FIG. 2 is a diagrammatic and fragmentary sectional view of the mechanism for adjustment of a capacity control vanes of one of the centrifugal gas compressors such as shown in FIG. 1 of the drawings;

FIG. 3 is an enlarged sectional view of the two interconnected solenoid adjusted valves of FIG. 2, the piston of the valves being shown in the positions they take when the solenoid coils of the two valves are deenergized;

FIG. 4 is a view similar to FIG. 3 except that one solenoid coil, the left one, is energized;

FIG. 5 is a view similar to FIG. 4 except that the other solenoid coil, the right one is energized;

FIG. 6 is a circuit diagram of the load sharing capacity control system of the invention as may be used with three electric motor driven compressors.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring first to FIG. 1 of the drawings, a centrifugal gas compressor 1 driven by an electric motor 2 and a second centrifugal gas compressor 3 driven by the electric motor 4 are connected in parallel in a refrigeration circuit including compressed gas conduits 5 and 6 to the condenser 7. The condenser 7 is connected through an expansion valve 8 to the evaporator chiller 9 having a chilled water outlet at 10. The evaporated refrigerant gas from the chiller 9 is connected through the suction pipes 11 and 12 in parallel to the inlets of the respective centrifugal gas compressors 1 and 3. Each of the centrifugal gas compressors 1 and 3 is provided with inlet vanes which are movable to vary the capacity of the compressor, and these inlet vanes are of the well known pre-rotation type which will be shown and described in some detail in connection with FIG. 2 of the drawings. It should be understood that this invention would apply to any refrigeration system having two or more compressors connected to a common refrigeration load whether or not the load includes a common refrigerant gas circuit. In other words a plurality of refrigerant gas circuits may be connected to chill a common water load or the like.

As previously mentioned, when a common refrigerant circuit system such as has been described is provided with two or more centrifugal gas compressors, there is a tendency for one of the gas compressors to undertake more of the load than the other and therefore it is desirable to provide automatic circuits for adjusting the capacities of the respective centrifugal compressors so as to evenly divide the load between all of the operating compressors. The electric motor 12 is supplied with

operating current by means of the conductors **15** and **16** while similarly the electric motor **4** is supplied with operating current by means of conductors **17** and **18**. The gas compressor **1** is provided with a capacity control mechanism including a chilled water temperature sensing device **19** connected to the condition sensor **20** to actuate switches **21** or **22** according to sensed chilled water temperature. Similarly the centrifugal gas compressor **3** is provided with a capacity control including the chilled water temperatures. Similarly the centrifugal gas compressor **3** is provided with a capacity control including the chilled water temperature sensing element **23** connected to the condition sensor **24** to actuate switches **25** or **26** to maintain a desired chilled water temperature. The details of the condition sensors **20** and **24** will not be described herein as they are not necessary to an understanding of the present invention but if more information is desired reference may be made to the aforementioned copending patent application Ser. No. 28678, filed Apr. 15, 1970 It should be mentioned, however, that if the chilled water temperature is lower than desired, the condition sensors **20** and **24** will respond to close contacts **21** and **25** respectively to energize the decrease capacity solenoid valve coils **27** and **28** respectively. Similarly if the chilled water temperature is higher than desired the condition sensors **20**, **24** respectively will respond to close switch contacts **22**, **26** respectively and energize the increase capacity solenoid valve coils **29** and **30**. When either of the solenoid valve coils **27** or **28** is energized the inlet vanes for the associated centrifugal gas compressor **1** or **3** will be moving in the decrease capacity direction. On the other hand when either of the increased capacity solenoids **29** or **30** is energized, the associated inlet vanes for the gas compressor **1**, **3** will be moving in the increased capacity direction. When neither of the solenoid valve coils **27**, **28**, **29** or **30** are energized, which would be a condition where the chilled water is at the desired temperature, the associated inlet vanes for the respective gas compressors **1** and **3** would be maintained in their particular set positions maintaining the desired capacity to produce the desired temperature of chilled water.

For a more detailed understanding of the hydraulic circuits and the inlet vanes for controlling the capacity of the associated compressor, reference will be briefly made to FIGS. **2–5** of the drawings. A fluid pressure system for actuating or operating a centrifugal capacity control as is to be provided for each of the gas compressors **1** or **3** will not be described although if a more detailed understanding of such a system is desired, reference may be made to the aforementioned U.S. Pat. No. 3,350,897. The inlet cone **40** of the associated centrifugal compressor is provided with a plurality of movable pre-rotation spin vanes such as shown at **41** and it should be understood that the rotatable position of the spin vane **41** as it may be rotated about its axis **42** will vary the capacity of the centrifugal compressor in a manner well known to those skilled in the art. A piston **43** is slidable within a cylinder having cylinder portions **44** and **45**. When fluid under pressure is supplied to cylinder portion **44** and drained from cylinder portion **45**, the piston **43** will move to the right in a manner to rotate the capacity control means or vane **41** toward the position opening the intake and increasing the capacity of the compressor. If on the other hand, fluid under pressure is supplied to a cylinder portion **45** and drained from the cylinder portion **44**, the piston **43** will move to the left of the drawings and its mechanical coupling to the capacity control at vane **41** will be such as to rotate the vane to a position corresponding to the closing of the centrifugal compressor intake and decreasing the compressor capacity. When fluid under pressure is supplied equally to both cylinder portions **44** and **45**, the capacity control piston **43** will remain in a given position corresponding to a given capacity of the compressor. Solenoid operating valves such as valves VA and VB are double acting valves as shown more in detail by FIGS. **3–5** of the drawings for supplying fluid under pressure selectively to either or both of the cylinder areas **44** and **45** and for selectively draining fluid under pressure from either cylinder areas **44** or **45**.

As shown by FIG. **3** of the drawings both solenoid valves VA and VB are shown in their deenergized position with their solenoids coils **29** and **27** not connected to a source of electric energizing potential. When the valves VA and VB are in the deenergized position as shown by FIG. **3** of the drawings, fluid under pressure in the line **52** is passed through needle valves **53** and **54** through conduits **50** and **51** to both respective cylinder portions **44** and **45** thus balancing the capacity control piston **43** at a predetermined position.

As shown by FIG. **4** of the drawings, if the solenoid coil **29** is energized the associated valve VA will be operated to allow the pressure of the cylinder area **44** to drain through conduit **50** into the drain conduit **60** thus allowing the fluid under pressure in the cylinder area **45** to overbalance the fluid pressure in the cylinder area **44** and move the pistons **43** to the left in a decrease capacity direction in a manner to change the capacity control to a lower capacity or closed position.

As shown by FIG. **5** of the drawing, when solenoid coil **27** is energized, valve VB will be operated to allow the fluid under pressure in the cylinder area **45** to drain to the conduit **51** to the fluid pressure return conduit **60**, thus allowing the pressure in the cylinder area **44** to overcome the pressure in the cylinder area **45** and move the pistons to the right in an increase capacity direction to change the capacity control to increase the capacity and open the intake valve.

Referring again to FIG. **1** of the drawings it is not believed necessary to describe any more details of the capacity controls system as they may be used with the load balancing circuits of the invention. A current sensing coil **70** is positioned in inductive relation to the conductor **15** supplying current to the electric motor **2** for the gas compressor **1**. Similarly, a current sensing coil **71** is provided in an inductive relation to the conductor **18** supplying the operating current to the electric motor **4** for this second gas compressor **3**. An overload relay **72** is connected across the terminals of the current sensing coil **70** and similarly an overload relay **73** is connected across the terminals of the current sensing coil **71**. If the current drawn by either electric motor **2** or **4** should exceed a predetermined maximum representative of an overload condition, the potential induced in the respective sensing coil **70** or **71** will cause the respective voltage sensitive overload relay **72** or **73** to operate. For example if the overload relay **72** is operated by an overloaded condition for the electric motor **2** and gas compressor **1**, the contact **72'** will be closed to energize the down capacity solenoid valve coil **27** thus moving the inlet vanes for the gas compressor **1** in a decrease capacity direction. As soon as the capacity of the gas compressor **1** is reduced to a safe, no-overload condition, the current drawn by the associated electric motor **2** will be reduced such as to cause the overload relay **72** to be restored to a non-operated condition, thus deenergizing the decrease capacity solenoid coil **27**. Similarly, when the overload relay **73** is energized, its contact **73'** will be closed to operate the decrease capacity solenoid coil **28**.

In accordance with the invention, the current sensing coil **70** is interconnected with the current sensing coil **71** through resistors **75**, **76** and **77**. These interconnections and coils are of a polarity to result in opposing currents flowing through the resistor **76**, one current flowing in one direction being the current induced in sensing coil **70** and the other current flowing in the opposite direction being the current induced in the sensing coil **71**. By suitably choosing the values of the resistors **75**, **76** and **77** in relation to the parameters of the coils **70**, **71** and overload relays **72** and **73** as will be obvious to any one skilled in the art, the associated overload relay **72** or **73** can be caused to be operated when the current drawn by one of the electric motors **2** or **4** appreciably differs from the current drawn by the other electric motor **2** or **4**. The connections are such that should the electric motor **2**, for example, draw more current than the electric motor **4**, indicating that the gas compressor **1** is working at higher capacity than the gas compressor **3**, the overload relay **72** would be energized to close its contacts **72'** and actuate the decrease capacity solenoid coil **27** to adjust the inlet vanes for the gas compressor **1** in a

direction to reduce its capacity until its capacity approximates that of the capacity of the gas compressor 3 as may be indicated by a current flow through the conductor 15 approximately the same as the current flow through conductor 18. In other words, when the currents flowing through the conductors 15 and 18 are equal, the opposing currents flowing in the resistor 76 will balance so that there will be no effective potential, adding or subtracting, to cause a preferential operation of either the overload relay 72 or 73 intended to be responsive to the detected unbalance of the load division between the two electric motors 2 and 4 and compressors 1 and 3.

Another feature of the invention is the provision of shorting contactors 80 and 81 respectively for the associated current sensing contactor coils 70 and 71. The shorting contactor 80 is normally open but is operated to be closed when current is not supplied to operate the electric motor 2 and energize the shorting contactor coil 82. Similarly the shorting contactor 81 is normally opened but will be closed and operated when current is not passing through the shorting contactor coil 83 to the electric motor 4. Thus if either electric motor 2 or 4 is deenergized and not operating, the respective overload sensing coils 70 or 71 associated therewith will be shorted. However the provision of the resistors 75 and 77 will enable the capacity control and the overload responsive circuit for the operating one of the electric motors 2 or 4 to continue to function even though another one of them may be deenergized with its current sensing overload detecting coil shorted.

Referring now to FIG. 6 of the drawings a wiring diagram showing the additional resistor interconnections for the system of the invention as applied to three electric motor driven centrifugal gas compressors will be described. Sensing coil 90 is inductively related to the current leads for the electric motor of a first gas compressor not shown. Similarly sensing coil 91 is associated with the current leads to the electric motor for a second centrifugal gas compressor while the current sensing coil 92 is associated with the current leads to a third electric motor driving a third centrifugal gas compressor not shown. Resistors 93, 94, 95, 96, 97 and 98 are connected in the arrangement shown to provide the desired bridge circuit interconnections so that opposing currents flow through the resistors 94, 96 and 98 associated with a respective sensing coil 90, 91 and 92. The sensing coils 90, 91 and 92 are poled as shown respectively to produce the desired opposing currents flowing in the sensing resistors 94, 96 and 98 as previously described. Each overload relay controlling the associated decrease capacity solenoid valve is connected to the terminals of the respective sensing coils 90–93 as shown at 100, 101, 102, 103 and 104, 105 respectively. A shorting contactor 110 is associated with the current sensing coil 90 and a similar shorting contactor 111 is associated with sensing coil 91 and shorting contactor 112 is associated with sensing coil 92. Each of the shorting contactors 110–112 are operated by associated shorting contactor coils similar to the contactor coils 82 or 83 previously described in connection with FIG. 1 of the drawings. The provision of the respective shorting contact 110–112 enables any one of the electrically driven compressors associated with the respective current sensing coils 90–92 to be deenergized and not operating while the remainder of the compressors that are connected in parallel in the common refrigerant system remain operated and the arrangement is such that the load sharing would be evenly divided between the total number of operating compressors regardless of how many of the other compressors are not energized for any reason whatsoever.

It should be understood that the chain circuit of FIG. 6 may be expanded indefinitely to include as many parallel connected electric motor driven centrifugal compressors as would be desired for a given refrigeration system. Although the load sharing circuit of the invention has been described in connection with a particular type of capacity control designed to operate with inlet pre-rotation capacity controlling vanes for centrifugal compressors, it should be obvious that the load sharing circuit could be used with other forms of capacity controls and centrifugal compressor systems. Various modifications will occur to those skilled in the art.

I claim:

1. A refrigeration system comprising, a refrigerant load, at least two electric motor driven centrifugal gas compressors connected in parallel to said load and each having movable capacity control means, respective electric control means to be energized to move the capacity control means of each compressor in the decrease capacity direction, respective electric circuit means responsive to current drawn by the respective electric motor of each compressor to energize the respective electric control means for reducing the capacity of the associated compressor, and means electrically interconnecting the respective electric circuit means of each compressor to decrease the capacity of a particular compressor as its electric motor current tends to increase above the current drawn by the other electric motors for the other compressors connected to the refrigerant load thus balancing the loads on all compressors.

2. The invention of claim 1 in which each of said respective electric circuit means is overload responsive to energize the respective control means when the electric current drawn by the associated compressor motor exceeds a predetermined amount.

3. The invention of claim 2 in which the means electrically interconnecting the respective electric circuit means is comprised of at least one resistor in which are passed in opposition respective electric currents corresponding to the respective currents drawn by one electric motor associated with one compressor and another electric motor associated with another compressor.

4. The invention of claim 2 in which said respective electric circuit means includes a current sensing coil associated with a power conductor for the respective electric motor and there is provided means for short circuiting the respective coil when the associated electric motor is not energized

5. The invention of claim 3 in which said respective electric circuit means includes a current sensing coil associated with a power conductor for the respective electric motor and there is provided means for short circuiting the respective coil when the associated electric motor is not energized.

6. The invention of claim 1 in which the means electrically interconnecting the respective electric circuit means is comprised of at least one resistor in which are passed in opposition respective electric currents corresponding to the respective currents drawn by one electric motor associated with one compressor and another electric motor associated with another compressor.

7. The invention of claim 6 in which said respective electric circuit means includes a current sensing coil associated with a power conductor for the respective electric motor and there is provided means for short circuiting the respective coil when the associated electric motor is not energized.

8. The invention of claim 1 in which said respective electric circuit means includes a current sensing coil associated with a power conductor for the respective electric motor and there is provided means for short circuiting the respective coil when the associated electric motor is not energized.

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