STANDBY VARIABLE FREQUENCY COMPRESSOR DRIVE

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A transport refrigeration system is provided with a variable speed compressor which is operated only in the low capacity perishable range of operation. In this way, the line voltage and frequency power can be used during high capacity operation and a relatively small inverter can be used to provide variable voltage and frequency for the variable speed operation. The variable voltage and frequency can also be provided to a variable speed condenser motor to provide additional condensing capacity during economized operation. It can also be used to provide DC voltage to the compressor for heating purposes.
TEMPERATURE °F

CARGO TEMPERATURE

SUPPLY TEMPERATURE

SETPOINT

TIME

FREQUENCY/RPM COMPRESSOR

MODE 4 = F–E = ECONOMIZED
MODE 3 = E–D = STANDARD
MODE 2 = D–C = UNLOADED WITH SUCTION MODULATION
MODE 1 = C–A = UNLOADED, SMU, VARIABLE SPEED

FIG. 3
STANDBY VARIABLE FREQUENCY COMPRESSOR DRIVE

BACKGROUND OF THE INVENTION

0001. This invention relates generally to refrigeration systems and, more particularly, to selected use of a variable speed drive for the compressor during unloaded modes of operation.

0002. Transport refrigeration systems include a cargo space to be cooled and a refrigeration system for providing the heat exchange capabilities for maintaining the controlled temperature range within the cargo space. A temperature sensor and a controller are operatively connected to the cooling circuit in order to modulate the output thereof in order to maintain the desired temperature levels.

0003. The cooling circuit is designed for a capacity that is sufficient for accommodating maximum heat losses into and through the transportable cooling unit, with the losses being directly proportioned to the outside ambient temperature.

0004. At frozen conditions, the controller adjusts the cooling circuit by turning the cooling circuit on and off in response to the sensed temperature in the cargo space. That is, the cooling circuit is turned off when the sensed temperature reaches a lower set point and is turned on when the sensed temperature reaches a predetermined upper set point. However, when the temperature of the ambient air approaches that of the transport volume (i.e. at part load or so-called chilled conditions), then the cooling circuit has more capacity than is needed and the deficiency of the system is substantially reduced during such chilled conditions. That is, in such chilled conditions, although the cooling circuit has too much capacity, it needs to run continuously in order to maintain temperature control on a transport volume.

0005. The on/off mode of operation for frozen conditions (i.e. for pull down, frozen and fully loaded chilled conditions), comprises an estimated 60% of the market demand, whereas the chilled part-load conditions comprises about 40% of the market demand. Thus, there is a substantial inefficiency using present methods of modulating or throttling the suction pressure to shed capacity while running the compressor motor at full speed. On the other hand, if a variable speed compressor is used at all times, the power consumption will be excessive during periods of on/off and pull down modes of operation because of drive losses.

SUMMARY OF THE INVENTION

0006. Briefly, in accordance with one aspect of the invention, provision is made for driving the compressor at variable speeds during periods in which the system is operating at chilled conditions. In this way, continuous operation can be maintained while maximizing power efficiency.

0007. In accordance with another aspect of the invention, compressor power is reduced by conventional methods to a range where variable speed can be effectively and efficiently used by way of a relatively small inverter.

0008. By yet another aspect of the invention, an inverter is provided such that at times when operating under part load conditions, the inverter is selectively applied to provide variable voltage and frequency to the compressor drive motor so that it can be run at selectively variable speeds on a continuous basis thereby achieving high operating efficiencies.

0009. By another aspect of the invention, during periods of variable speed operation, an evaporator flow control apparatus is also applied if the system capacity remains higher than the load requirements.

0010. In accordance with another aspect of the invention, during chilled conditions, the system will operate with line voltage and frequency until the temperature demand is stable, at which point the power source will be switched from line voltage and frequency to a variable voltage and frequency.

0011. In the drawings hereinafter described, a preferred embodiment is depicted; however, various other modifications and alternate constructions can be made thereto without departing from the spirit and scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

0012. FIG. 1 is a schematic illustration of a vapor compression system in accordance with the prior art.

0013. FIG. 2 is a schematic illustration of a vapor compression system in accordance with the present invention.

0014. FIG. 3 is a schematic illustration of a vapor compression system in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

0015. FIG. 1 shows a vapor compression system 10 in accordance with the prior art. Vapor compression system 10 includes a main vapor compression circuit including a compressor 12, a condenser 14, an expansion device 16 and an evaporator 18. These components are serially connected by main refrigerant lines to provide refrigerant flow from discharge port 13 of a compressor 12 through line 19 to condenser 14, from condenser 14 through line 22 to expansion device 16, from expansion device 16 through line 24 to evaporator 18, and from evaporator 18 through line 26 back to a suction port 15 of a compressor 12.

0016. An economizer circuit is also provided and is connected between condenser 14 and at least one of an intermediate pressure port 28 and suction port 15 of compressor 12. This circuit is preferably provided in the form of an economizer refrigerant line 40 leading from condenser 14 to an auxiliary expansion device 42, and from expansion device 42 through economizer refrigerant line 44 to heat exchanger 32. In a typical mode of operation of the economizer circuit, the economizer circuit extends from heat exchanger 32 through line 38 to an intermediate pressure port 28 of compressor 12.

0017. An economizer shutoff valve 46 can advantageously be positioned along economizer refrigerant lines, for example, along line 40, for selectively allowing and blocking flow through the economizer circuit as well. Alternatively, if expansion device 42 is an electronic expansion device, then valve 46 is not needed.

0018. In further accordance with the prior art, system 10 also includes a bypass circuit which is connected between an intermediate pressure port 28 of compressor 12 and suction port 15 of compressor 12. The bypass circuit allows for unloaded operation of compressor 12. The bypass circuit is adapted to flow through economizer heat exchanger 32 so as to sub-cool the main refrigerant flow with flow from the bypass circuit, thus utilizing economizer heat exchanger 32, and improving efficiency, during unloaded operation. Thus, bypass refrigerant line 38 advantageously leads to economizer heat exchanger 32, and from heat exchanger 32 through line 36 and back to suction port 15 of compressor 12. A bypass shutoff valve 34 is advantageously positioned along
bypass line 36 leading from heat exchanger 32 to suction port 15, for selectively allowing and blocking flow through the bypass circuit.

[0019] It should be noted that reference is made throughout this text to blocking flow through certain circuits or components. As used herein, this term means substantially blocking of flow, such that the circuit in question is substantially inactive, or such that the substantial portion of flow through that circuit is blocked.

[0020] Main refrigerant line 22 flows through economizer heat exchanger 32 so as to be exposed to heat transfer relationship with flow in line 38 in heat exchanger 32. Thus, heat exchanger 32 is adapted to receive a first flow from main refrigerant line 22 and a second flow from at least one of the economizer circuit and the bypass circuit, and heat transfer occurs in both full-load economized operation, and advantageously in part-load operation as well.

[0021] With this configuration, when compressor 12 is to be operated in an unloaded state, valve 34 is open to pass a portion of the refrigerant through intermediate pressure port 28, representing a portion of refrigerant flowing through compressor 12 which is compressed to an intermediate pressure, thereby unloading compressor 12.

[0022] In the unloaded mode of operation, main refrigerant flow is sub-cooled in economizer heat exchanger 32 to provide performance enhancement of the system in this mode of operation. In this regard, depending upon location of intermediate pressure port 28, the intermediate pressure of flow exiting this port is relatively close to suction pressure, thereby increasing available temperature difference for heat transfer interaction in economizer heat exchanger 32.

[0023] A control member 48 may advantageously be provided and operatively associated with shutoff valves 34, 46, or expansion device 42 if electronically controlled, for selectively positioning either of these valves in the closed or open position so as to allow or for operation of system 10 as desired, in the full load economized mode or in the unloaded mode, with heat exchanger 32 still active and functional to enhance system performance. Of course, system 10 can also operate in a full load non-economized mode with both valves 34, 46 closed.

[0024] As an alternative or in addition to the bypass feature used in the unloaded operation, an evaporator flow control apparatus 49 may be brought into use as the load on the system decreases. The evaporator flow control apparatus 49 may provide various types such as a suction modulation valve or a pulse width modulation valve, the purpose of which is to decrease flow of refrigerant to the compressor and in doing so balancing the compressor capacity with the load to prevent operation with low coil temperatures. The evaporator flow control apparatus may also be a PWM (pulse width modulated) compressor which is a scroll type compressor with an integral unloading system that utilizes a pulse width modulated demand signal to engage and disengage the intermeshing scroll wraps. Compressor unloading is accomplished via separation/lifting of the non-rotating scroll set from the orbiting scroll set. This separation is controlled via a fluid bypass PWM solenoid valve. Capacity modulation is ultimately controlled by pulsing this solenoid valve switching the compressor from high capacity to low capacity operation.

[0025] Referring now to FIG. 2, the compressor 12 of the FIG. 1 embodiment is replaced with a compressor 51 which is capable of selectively operating at either a fixed speed mode of operation or at a variable speed mode of operation. The compressor 51 may be a reciprocating compressor, but it could also be of another type, such as a scroll compressor or a rotary compressor.

[0026] The compressor 51 is electrically connected directly to the control 52 by a plurality of power connectors 53. The compressor 51 is also electrically connected by a plurality of power connectors 54 to an inverter 56, which is in turn connected to the control 52 by the connectors 57. Control of the inverter 56 is brought about by the control 52 through the connector 58. Line power is fed to the control 52 by way of the lines 59.

[0027] With the apparatus as shown, the compressor 51 can be selectively operated by operation of the contactors 61 and 62 to provide either line voltage and frequency to the compressor 51 or variable voltage and frequency. That is, with the contactors 61 closed and the contactors 62 open, line voltage will be provided to the compressor by way of connectors 53. Alternatively, with the contactors 62 closed and contactors 61 open, line voltage and frequency will be provided to the inverter 56, and the inverter 56 will then provide variable voltage and frequency to the compressor 51 by way of connectors 54.

[0028] In the FIG. 2 embodiment, the modulation valve 49 is provided in the same manner as the FIG. 1 embodiment, but the bypass circuit shown in the FIG. 1 embodiment has been removed. Thus, the present invention will be described in terms of use with a modulation valve and with no bypass circuit. However, it should be understood that the present invention could be equally useful in systems wherein a bypass circuit is provided.

[0029] Referring now to FIG. 3, there is shown a typical illustration of the variation of both cargo temperature and supply temperature as they vary with time as the system operation tends toward operating in an unloaded condition. As will be seen, with the passing of time, the cargo temperature is gradually brought down to a temperature that is closer to the supply temperature and will eventually reach the set point.

[0030] In the lower portion of FIG. 3, there is shown a sequence of various modes of operation when operating at part load and unloaded conditions. These modes of operation correspond to the temperature conditions directly above. That is, for part load conditions, wherein the difference between the cargo temperature and the supply temperature is substantially constant, the compressor 51 is operated in an economized mode using line voltage and frequency. This is shown by the line F-E.

[0031] As the difference between the cargo temperature and supply temperature commences to decrease, the compressor is switched out of the economized mode and into a standard mode of operating using line voltage and frequency. This mode is used when the load is being pulled down to the perishable range. This mode operation is shown at E-D in FIG. 3.

[0032] In mode 2 operation, which is used for start up on frozen and when a chilled load is being pulled down to the perishable range, the compressor is operated in the unloaded mode using line voltage and use of the evaporator flow control apparatus 49 as described hereinabove.

[0033] It will thus be seen that in each of the modes 2, 3 and 4 of operation, the compressor speed will remain constant. However when going from the economized mode to the standard mode to an unloaded mode with the evaporator flow control apparatus, it will be recognized that the amount of
power used by the compressor is being substantially reduced. As a result, when the inverter 56 is brought in by the contactors 62, for operation in mode 1 as represented by the lines CBA, the power required has been reduced to such an extent that the size of the inverter 56 that is required is substantially reduced from that which would otherwise be required. For example, rather than being sized for operation with 10-11 kilowatts, the inverter is sized for 5 kilowatts. That is, the drive can be sized much smaller when used only in mode 1 because the thermodynamics of a vapor compression, closed cooling system provides a fairly linear reduction in system compression power due to inherent suction gas density changes with substantially lower box temperatures in the perishable range. The reduction in suction gas density and mass flow after pull down allows for significantly smaller variable speed drive when near set point.

[0034] The mode 1 operation is used for perishable products when the system has more capacity than is needed. Perishable products require tight temperature control which is best achieved when the system can operate continuously.

[0035] In mode 1, the system will run using line voltage and frequency in the unloaded compressor mode of operation and then the evaporator flow control apparatus 49 will engage until the temperature demand is stable. At some point between the time when the modulation valve starts to close and is fully closed, the controller 52 will decide to switch the contactors 61 and 62 to turn off the line voltage and frequency and switch to a variable voltage and frequency to operate the compressor 51 on a variable speed basis. In that mode, the controller 52 will precisely control the compressor speed to provide the correct temperature of the transport load for all perishable conditions. The variable speed will run to a minimum optimized speed and will then operate the evaporator flow control apparatus 49 if the system capacity remains higher than the transport load requirement until steady temperature control is obtained. Conversely, when the optimum highest speed is achieved in the unloaded mode of operation and more cooling power is required the system will switch the contactors 61 and 62 to resume fixed speed operation with line voltage and frequency.

[0036] Because the variable speed drive is not used on the compressor at high capacity conditions, it may be advantageous to switch the variable speed drive to the condenser fan motor to increase fan speed for added condenser fan performance where the condenser capacity is limited. This would provide a cost advantage by keeping the condenser size at its minimum but allowing the system to be more effective at high temperature pull down conditions, increase compressor reliability by reducing discharge temperature and pressure, and utilize a critical component not being used.

[0037] It is advantageous to apply the variable speed drive in mode 1 only because it provides a redundant system. That is, if for some reason the drive failed during transportation, the system can successfully operate without the variable speed drive and there would be no loss of load by using current control strategy. In addition, drive reliability will be better because it will operate in lightly loaded conditions.

[0038] The variable speed drive can be used to heat the compressor motor by applying a small DC voltage to the compressor for arctic applications where crankcase heaters are applied and purchased separately. The variable speed drive can replace the heaters and can be offered as a standard package to all customers reducing cost and reliability. With this, the invention will allow the cooling system to have the ability to work in all regions of the world without special modifications or options.

We claim:

1. A method of operating a transport refrigeration system of the type having a compressor and associated vapor compression circuitry, an economizer circuit, and an evaporator flow control apparatus, comprising the steps of:
   - providing a variable speed capability to the compressor;
   - providing an inverter for selectively providing either line voltage and frequency or variable voltage and variable frequency power to said compressor;
   - operating said compressor at fixed speeds during high capacity operation to pull down the load to the perishable range; and
   - operating said compressor at variable speeds during low capacity operation in the perishable range.

2. A method as set forth in claim 1 wherein, during fixed speed operation, the vapor compression circuit is used in combination with the economizer circuit.

3. A method as set forth in claim 1 wherein, during fixed speed operation, the vapor compression circuit is used without the economizer circuit.

4. A method as set forth in claim 1 wherein, during fixed speed operation, the vapor compression circuit is used in combination with the evaporator flow control apparatus.

5. A method as set forth in claim 1 wherein, during fixed speed operation, the vapor compression circuit is used in combination with the evaporator flow control apparatus.

6. A method as set forth in claim 1 wherein the evaporator flow control apparatus is used until the temperature demand is stable.

7. A method as set forth in claim 6 wherein, when the evaporator flow control apparatus valve starts to close, the line voltage and frequency power will be switched to variable frequency voltage and frequency power to drive the compressor at variable speed.

8. A method as set forth in claim 1 and including the further step of providing a variable speed condenser fan motor and selectively applying variable voltage and frequency power thereto when operating with the economizer.

9. A method as set forth in claim 1 and including the step of using the variable frequency and voltage power to provide a DC voltage to the compressor for heating purposes.

10. A method of operating a transport refrigeration system of the type having a vapor compression circuit with an economizer, an evaporator flow control apparatus, and a compressor receiving power from a power source by way of controller and adapted to operate, at times, under part load conditions comprising:
   - providing an inverter for receiving a fixed voltage and frequency from the power source and converting it to a variable voltage and frequency power output;
   - providing a compressor that is capable of operating at either fixed or variable speed operation;
   - providing a switch to selectively include or exclude said inverter from the circuit to provide either a fixed voltage and frequency or a variable voltage and frequency to said variable speed compressor; and
   - using said variable voltage and frequency only during periods of part load operating conditions.

11. A method as set forth in claim 10 wherein, during fixed speed operation, the vapor compression circuit is used in combination with the economizer circuit.
12. A method as set forth in claim 10 wherein, during fixed speed operation, the vapor compression circuit is used without the economizer circuit.

13. A method as set forth in claim 10 wherein, during fixed speed operation, the vapor compression circuit is used in combination with the evaporator flow control apparatus.

14. A method as set forth in claim 10 wherein, during low capacity operation, fixed voltage and frequency power is provided to the compressor.

15. A method as set forth in claim 14 wherein the evaporator flow control apparatus is used until the temperature demand is stable.

16. A method as set forth in claim 15 wherein when the evaporator flow control apparatus starts to close, the line voltage and frequency power will be switched to variable frequency voltage and frequency power to drive the compressor at variable speed.

17. A method as set forth in claim 10 and including the further step of providing a variable speed condenser fan motor and selectively applying variable voltage and frequency power thereto when operating with the economizer.

18. A method as set forth in claim 10 and including the step of using the variable frequency and voltage power to provide a DC voltage to the compressor for heating purposes.

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