Control system for heat exchangers fans in a refrigeration system

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Abstract: The paper presents a method for controlling evaporator and condenser fans in a refrigeration system. The refrigeration system includes a refrigerant circuit defined by a compressor, a condenser, a throttling device, and an evaporator. The system includes an evaporator fan and a condenser fan and a variable frequency drive unit controller coupled to the fans, which controlls the speed of the fans.

Key-Words: Fan, Controlling, Refrigeration system, Variable frequency drive unit.

1 Background

The paper relates to the operation of a refrigeration system, and more specifically to the control of the evaporator and condenser fans in a refrigeration system.

Air is circulated over the condenser by a condenser fan. The condenser fan in refrigeration systems is commonly powered by cycling between a power source and a ground, i.e. by turning the fan on and off. When the condenser fan is cycled equally between on and off, the condenser fan consumes half as much power as when the condenser fan is always on [1-5].

Air is circulated over the evaporator and through the conditioned space by one or more evaporator fans. The evaporator fans in refrigeration systems are physically located in the air stream of the air being circulated through the conditioned space. Due to the physical location of the evaporator fans, the power supplied to the evaporator fans is ultimately added to conditioned space as unwanted heat. The unwanted heat added to the conditioned space by the evaporator fans must be compensated for by increasing the amount of cooling that the refrigeration system must do. Thus, evaporator fans require the refrigeration system to consume power to compensate for the unwanted heat, in addition to the power required to operate the evaporator fans. The net effect is that the electric power used to move air within the conditioned space is ultimately counted twice as non-cooling power.

In refrigeration systems with two-speed evaporator fans, the higher speed is typically used when the conditioned space is above freezing, while the lower speed is used when the conditioned space is below freezing. When keeping the conditioned space above freezing, it is more acceptable to add unwanted heat to the conditioned space. As a result, the evaporator fans can be operated at the higher speed, even though the evaporator fans emit more heat at the higher speed. When keeping the conditioned space below freezing, it is less acceptable to add unwanted heat to the conditioned space. As a result, the evaporator fans are operated at the lower speed in order to minimize the heat generated by the evaporator fans.

2 Summary

The use of two-speed condenser and evaporator fans in refrigeration systems has several limitations. Since the fans must be operated at one of two speeds, the fans cannot be operated at their most energy efficient speed. This results in more power being consumed by the fans and higher operating costs for the refrigeration system. Moreover, when the refrigeration system requires more power to operate, the refrigeration system consumes more non-renewable fossil fuel and the refrigeration system creates more air pollution. Specifically regarding the evaporator fans in refrigeration systems, since the fans must be operated at one of two speeds, more unwanted heat is often added to the conditioned space than is necessary. When more unwanted heat is added to the conditioned space, the time period for the refrigeration system to cool the conditioned space to within the desired temperature range is extended. Moreover, when the evaporator fans are operated at the higher speed, more air is circulated through the conditioned space which may result in the undesirable dehydration of the goods stored within the conditioned space.

The present paper provides a method for controlling continuously-variable speed evaporator and condenser fans in a refrigeration system in order to minimize:

- the power consumed by the evaporator and condenser fans, therefore the unwanted heat added to the conditioned space by the evaporator fans, and
- the quantity of air circulated through the conditioned space by the evaporator fans in order to reduce the dehydration of the goods stored within the conditioned space.

The apparatus is a refrigeration system including a refrigerant circuit defined by a compressor, a condenser, a throttling device, and an evaporator. The refrigeration system includes at least one evaporator fan and at least one condenser fan and a controller coupled to the fans. The controller includes a variable frequency drive unit for providing variable frequency power to the fans. The speed of the evaporator fan can be precisely controlled so that the fan only operates at the desired speed, thus saving power, reducing unwanted heat, and reducing dehydration of the goods.

The speed of at least one evaporator fan and of at least one condenser fan is controlled in a refrigeration system including a compressor, a condenser, a throttling device, and an evaporator. For the evaporator, the method includes providing a desired temperature for a conditioned space, measuring temperature at the inlet to the evaporator, and measuring temperature at the outlet to the evaporator. The method also includes calculating an actual temperature differential and adjusting an evaporator fan speed based on the desired temperature differential and the actual temperature differential.

For the condenser, the method includes providing a condenser temperature threshold value and measuring an actual temperature of the condenser. The method also includes adjusting a condenser fan speed based on the condenser temperature threshold value and the actual temperature.

3 Detailed description of the system

The refrigeration system includes a refrigerant circuit, an evaporator fan, a condenser fan, and a controller circuit.

One evaporator fan forces air into the evaporator and the conditioned space. However, more than one evaporator fan may be used. Usually the evaporator fan is physically located within the air stream of the air used to cool the conditioned space. Due to the physical location of the evaporator fan, the power supplied to the evaporator fan is transferred to the conditioned space in the form of heat. In the preferred embodiment of the paper, the evaporator fan is a continuously-variable speed fan.

The refrigeration system also includes a controller circuit. The controller circuit includes a plurality of sensors and a controller. These sensors includes at least:

- an evaporator input temperature ($T_{evap,in}$) sensor,
- an evaporator output temperature ($T_{evap,out}$) sensor,
- a condenser temperature (T_{cond}) sensor,

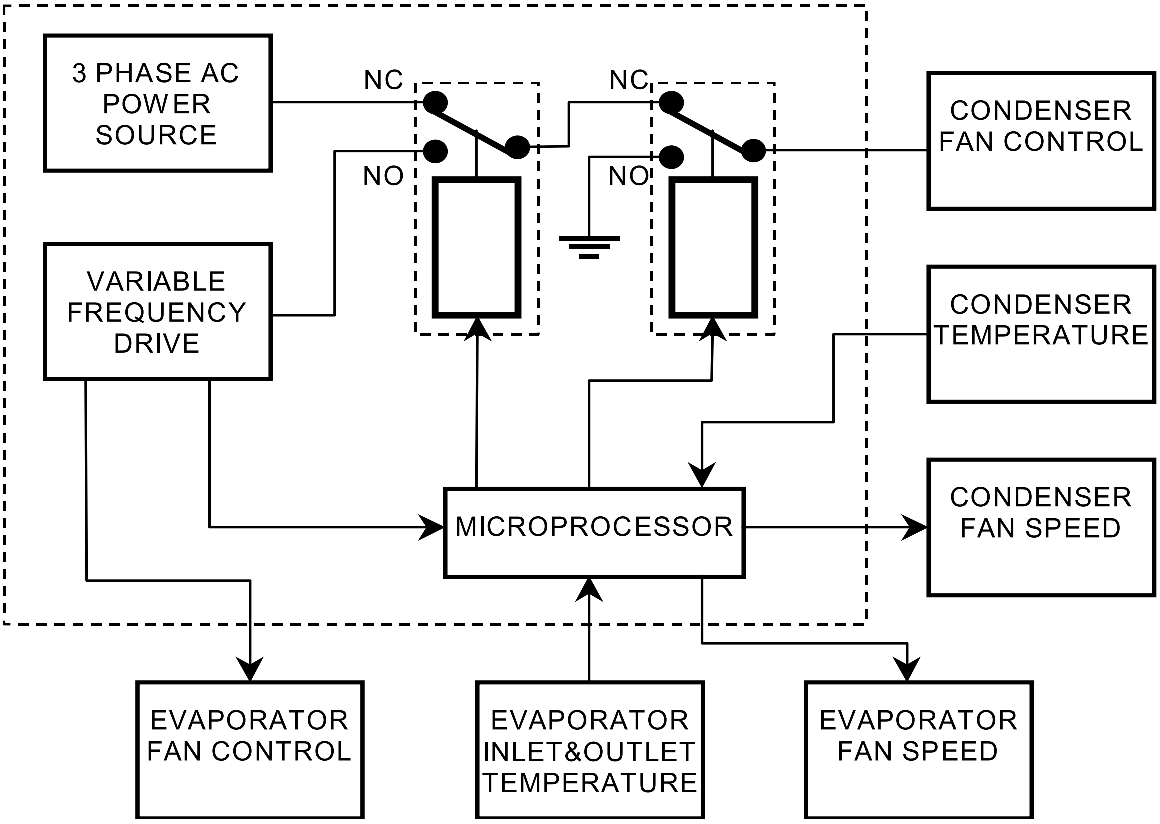

Fig. 1 Schematic representation of the controller of the refrigeration system

- an evaporator fan speed sensor, and
- a condenser fan speed sensor.

The plurality of sensors may include[6-8]:

- a compressor discharge temperature sensor,
- a compressor discharge pressure sensor,
- a suction temperature sensor, or a suction pressure sensor.

As illustrated in Fig. 1, the controller includes a three-phase, alternating current (AC) power source, a variable frequency drive (VFD) unit, two switches, and a microprocessor.

Referring to Fig. 1 one VFD unit provides power to both the evaporator fan and the condenser fan. However, two separate VFD units (not shown) may provide power to each one of the evaporator fan and the condenser fan. The VFD unit is a device used to convert conventional, three-phase, AC power at a voltage of 220 to 500 Volts and a frequency of 50 to 60 Hertz into power with a desired voltage and a desired frequency. VFD devices are conventionally known, and generally consist of a full wave rectifier circuit, a filter circuit, and a transistor circuit. The full wave rectifier circuit converts the three phase, AC power into DC power. The filter circuit generally includes large electrolytic capacitors that filter the DC power. The transistor circuit generally includes an insulated gate bipolar transistor (IGBT) which converts the DC power into AC power with a desired voltage and a desired frequency. The VFD unit is coupled to the microprocessor, which controls the power output of the VFD unit. As the frequency of the power output of the VFD unit is reduced, the AC voltage of the power output of the VFD unit is also reduced. The AC voltage of the power output is reduced in order to compensate for the decrease in the inductive reactance (AC resistance) that results as the applied frequency of the fan motor decreases.

The VFD unit is physically located inside the conditioned space and the microprocessor is physically located in a control box outside the conditioned space. In operation, the VFD unit emits heat and requires a heat sink. If the VFD unit is positioned within the conditioned space, a smaller, less complex heat sink can be used due to the colder temperatures in the conditioned space.If the VFD unit is positioned within the conditioned space, a fiat piece of aluminum can be used for the heat sink. Due to the colder temperatures in the conditioned space, positioning the VFD unit in the conditioned space also improves the current handling abilities of the VFD unit.

In order to provide power to the evaporator fan, the AC power source is electrically coupled to the VFD unit. The VFD unit is electrically coupled to the evaporator fan by the evaporator fan control line. The VFD unit is also electrically coupled to the microprocessor. The microprocessor provides a control signal to the VFD unit, and the VFD unit provides variable frequency power to the evaporator fan via evaporator fan control line [9].

In order to provide power to the condenser fan, the AC power source is electrically coupled to a first input of the first switch. The VFD unit is electrically coupled to a second input of the first switch. The first switch is a relay-type device designed for high current applications. The first switch includes a first contactor including a normally closed (NC) position and a normally open (NO) position. The NC position for the first switch corresponds to the first input, while the NO position corresponds to the second input. An output of the first switch is electrically coupled to a first input of the second switch. A second input of the second switch is coupled to a ground. The second switch is also a relay-type device designed for high current applications. The second switch includes a second contactor including a NC position and a NO position. The NC position for the second switch corresponds to the first input, while the NO position corresponds to the second input. An output of the second switch is electrically coupled to the condenser fan by the condenser fan control line. In addition, the first contactor of the first switch and the second contactor of the second switch are each electrically coupled to the microprocessor. The microprocessor provides control signals to the first switch and the second switch in order to provide power to the condenser fan via the condenser fan control line.

4 Operating the evaporator fan

Fig 2 illustrate a method of operating the evaporator fan of the refrigeration system presented by the paper. Referring to Fig. 1 and Fig 2, the microprocessor reads the evaporator input temperature ($T_{evap,in}$) sensor via the evaporator input temperature line. The microprocessor reads the evaporator output temperature ($T_{evap,out}$) sensor via the evaporator output temperature line. $T_{evap,in}$ and $T_{evap,out}$ vary depending on the ambient temperature of the air outside the conditioned space. For example, if the temperature is higher outside the conditioned space than inside the conditioned space, $T_{evap,in}$ will be higher than $T_{evap,out}$. Similarly, if the temperature is lower outside the conditioned space than inside the conditioned space, $T_{evap,in}$ will be lower than $T_{evap,out}$. The microprocessor then calculates the actual evaporator temperature differential (ΔT_{act}) by calculating the difference between $T_{evap,in}$ and $T_{evap,out}$. An operator of the refrigeration system may provide a desired temperature differential ($\Delta T_{desired}$) for the conditioned space, which is also referred to as the delta of the conditioned space. Referring to Fig. 1 and Fig 2, the microprocessor determines whether ΔT_{actual} is greater than, less than, or equal to $\Delta T_{desired}$. If **ΔT_{actual} is less than $\Delta T_{desired}$**, the microprocessor sends a signal to the evaporator fan via the evaporator fan control line to decrease the speed of the evaporator fan. Once the microprocessor sends the signal to decrease the speed of the evaporator fan, the microprocessor begins the sequence again.

If **ΔT_{actual} is approximately equal to $\Delta T_{desired}$**, the microprocessor sends a signal to the evaporator fan via the evaporator fan control line to maintain the speed of the evaporator fan. Once the microprocessor sends the signal to maintain the speed of the evaporator fan, the microprocessor begins the sequence again.

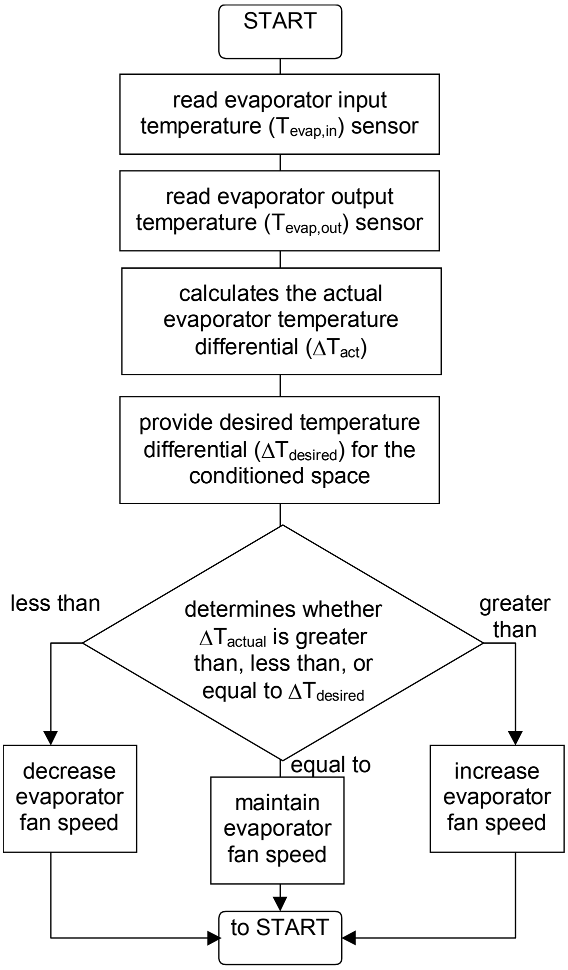

Fig 2 Method of controlling the evaporator fan of the refrigeration system

When ΔT_{actual} is approximately equal to $\Delta T_{desired}$, the VFD unit may also vary the frequency and voltage of the power provided to the evaporator fan. Varying the frequency and voltage of the power provided to the evaporator fan when ΔT_{actual} is approximately equal to $\Delta T_{desired}$ has several benefits:

- First, the power required to operate the evaporator fan is greatly reduced. The power consumed by the evaporator fan is a cubic function of the fan speed. As a result, when the evaporator fan is operated at half speed, the evaporator fan consumes one-eighth as much power as when the evaporator fan is operated at full speed.
- Second, the heat added to the conditioned space by the evaporator fan is minimized, which reduces the amount of power necessary to maintain the conditioned space within the $\Delta T_{desired}$ range.
- Third, varying the frequency and the voltage of the power provided to the evaporator fan minimizes the air flow through the conditioned space. When the air flow through the conditioned space is minimized, less moisture is carried away from the goods. When less moisture is carried away from the goods, less dehydration of the goods results. For the transportation of produce in refrigerated container units, produce that is less dehydrated has a better appearance, a higher product-weight, and a longer shelf-life.

Finally, if **ΔT_{actual} is greater than $\Delta T_{desired}$**, the microprocessor sends a signal to the evaporator fan via the evaporator fan control line to increase the speed of the evaporator fan. Once the microprocessor sends the signal to increase the speed of the evaporator fan, the microprocessor begins the sequence again by performing act. This period of operation during which the temperature of the conditioned space must be reduced is referred to as pulldown. The evaporator fan is generally operated at full speed during pulldown in order to remove heat from the conditioned space as rapidly as possible. In order to operate the evaporator fan at full speed, the VFD unit generally provides three-phase, AC power to the evaporator fan from the AC power source.

5 Operating the condenser fan

Fig 3 illustrate a method of operating the condenser fan of the described refrigeration system. The microprocessor reads the condenser temperature (T_{cond}) sensor. In the preferred embodiment of the paper, the condenser temperature (T_{cond}) sensor is physically located within the fins of the condenser. Thus, the sensor measures the temperature of the metal exterior of the condenser that correlates closely to the temperature of the refrigerant within the condenser.

A condenser temperature threshold value ($T_{threshold}$) is provided to the microprocessor. The $T_{threshold}$ value is based on the specific condenser unit and the specific type of refrigerant being used in the refrigeration system. The $T_{threshold}$ value corresponds to the temperature necessary to keep the pressure of the specific type of refrigerant in the condenser high enough so that the valves within the compressor remain closed and sealed.

Moreover, a minimum pressure in the condenser must be maintained for the proper operation of the throttling device. Alternatively, the $T_{threshold}$ value may be a temperature range ($\Delta T_{threshold}$). The $T_{threshold}$ value may be stored in a memory location accessible by the microprocessor [10-12].

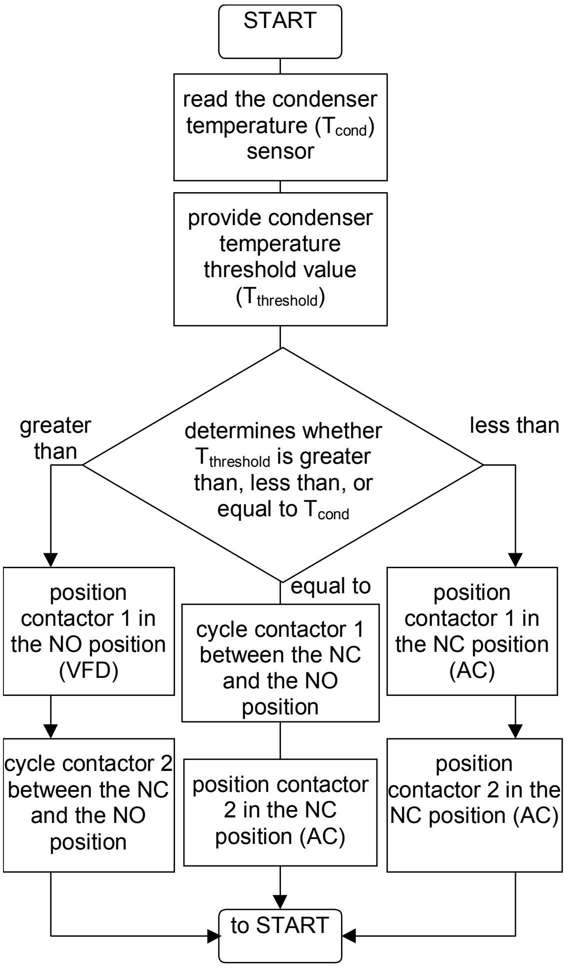

Fig 3 Method of controlling the condenser fan of the refrigeration system

Referring to Fig. 1 and Fig 3, the microprocessor determines whether $T_{threshold}$ is greater than, less than, or equal to T_{cond}.

If **$T_{threshold}$ is greater than T_{cond}**, the condenser fan speed must be decreased. To decrease the condenser fan speed, the microprocessor sends a first signal to the first switch in order to position the first contactor in the NO position corresponding to the second input of the first switch. The positioning of the first contactor in the NO position results in variable frequency power being provided to the output of the first switch. The microprocessor then sends a second signal to the second switch in order to cycle the second contactor between the NC position corresponding to the first input and the NO position corresponding to the second input. The cycling of the second contactor between the NC position and the NO position results in variable frequency power cycled with no power being provided to the output of the second switch. Variable frequency power cycled with no power is then provided to the condenser fan via the condenser fan control line, in order to decrease the speed of the condenser fan.

If **$T_{threshold}$ is approximately equal to T_{cond}**, the current condenser fan speed is maintained. In order to maintain the current condenser fan speed, the microprocessor sends a first signal to the first switch in order to cycle the first contactor between the NC position corresponding to the first input and the NO position corresponding to the second input. The cycling of the first contactor between the NC position and the NO position results in three-phase, AC power cycled with variable frequency power being provided to the output of the first switch. The microprocessor then sends a second signal to the second switch in order to position the second contactor in the NC position corresponding to the first input of the second switch. The positioning of the second contactor in the NC position results in three-phase, AC power cycled with variable frequency power being provided to the output of the second switch. Three-phase, AC power cycled with variable frequency power is then provided to the condenser fan via the condenser fan control line, in order to generally maintain the current speed of the condenser fan.

If **$T_{threshold}$ is less than T_{cond}**, the condenser fan speed must be increased. In order to increase the condenser fan speed, the microprocessor sends a first signal to the first switch in order to position the first contactor in the NC position corresponding to the first input. The positioning of the first contactor in the NC position results in three-phase, AC power being provided to the output of the first switch. The microprocessor then sends a second signal to the second switch in order to position the second contactor in the NC position corresponding to the first input. The positioning of the second contactor in the NC position results in three phase, AC power being provided to the output of the second switch. Three-phase, AC power is then provided to the condenser fan via the condenser fan control line, in order to increase the speed of the condenser fan.

The power consumed by the condenser fan is greatly reduced when the condenser fan is operated below full speed, because the power consumed by the condenser fan is a cubic function of the fan speed. As a result, when the condenser fan is operated at half speed, the condenser fan consumes one-eighth as much power as when the condenser fan is operated at full speed.

6 Implementation

This control method was implemented on a refrigeration system used in the refrigeration laboratory of Dept. of Thermal systems and Environmental Engineering.

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References:

[1] P. Niculiţă, E. Ceangă, S. Bumbaru, *Automatizarea în tehnica frigului*, Ed. Teora, Bucureşti, 1999.

[2] I. Cerepnalkovski, *Modern Refrigerating Machines*. 12/1991. ISBN 0-444-88963-9 Elsevier Publ.

[3] W.C. Whitman, W.M. Johnson, *Refrigeration and Air Conditioning Technology*, Delmar Publishers Inc., 1988, ISBN 0-8273-3478-8.

[4] C.P. Arora, *Refrigeration and Air Conditioning*, Tata-McGraw Hill Publ. Company Ltd., New Delhi 1987.

[5] Cr. Iosifescu, *Determinarea caracteristicilor de funcționare ale instalațiilor frigorifice cu comprimare mecanicã de vapori*, Ph.D. Thesis, Galati, 2000.

[6] N.I. Shaikh, V. Prabhu, Mathematical Modeling and Simulation of Cryogenic Tunnel Freezers, *Journal of Food Engineering*, No.80, 2007, pp.701-710.

[7] L.Ferrarini, A new approach to modular liveness analysis conceived for large logic controllers design*,* *IEEE Trans. Robot. Automat*, vol. 10, 1994, pp.169-184

[8] J. Zaitoon, Specification and design of logic controllers for automated manufacturing systems, *Robot. Comput-Integr. Manufact.*, vol. 12, no. 4, 1996, pp. 353-366

[9] F. S. Hsich, S. Ch. Chang, Dispatching driven deadlock avoidance controller synthesis for flexible manufacturing systems, *IEEE Trans. On Rob. And Autom.*, no. 2, pp. 196-209, 1994

[10] C.Ciufudean, C.Filote, D.Amarandei, Measuring the Performance of Distributed Systems with Discrete Event Formalisms, In *Proc. of The 2nd IEEE –IAS Seminar for Advanced Industrial Control Applications, SAICA 2007*, pp.263-267, November 5-6, Madrid, Spain, (2007).

[11] Ciufudean, C., Larionescu, A., Safety criteria for production lines modeled with Petri nets, Advances in Electrical and Computer Engineering, no.2(18), pp.15-20, (2002).

[12] S.Hintea, P.Faragó, L.Festila, P.Söser, Reconfigurable Filter Design for Implantable Auditory Prosthesis, *Electronics and Electrical Engineering*, pp.7-12 (2010).