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An experimental research on temperature accuracy in the refrigerator system with a variable speed compressor

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Abstract

A precision of temperature control in the manufacturing process would be an important factor and become the main key to control production quality. Mostly manufacture machinery used oil as a coolant in their system so an accurate oil temperature control system become an absolute need in industrial field.

This paper presents a experiment research to control the oil temperature constant at target point, in this experiment is 35°C by using an inverter attached in compressor to varying the compressor speed. This control has been completed and tested through an experiment with different heat load of 4kW, 6kW, 7kW, 8kW and 10kW given under temperature constant room conditioned as 25°C.

The results had shown the temperature deviation in the refrigerator has around 0.2°C and the COP is 2.5 gained at 8kW and 10kW.

Key words : Variable speed, Control system, Refrigeration system, Compressor, Inverter

1. Introduction

In the conventional system, refrigeration capacity only controlled by adjusting the opening angle of EEV. Adjusting opening degree of the EEV can control the superheat value. But with only controlling the opening degree of EEV, energy efficiency is small because compressor always running at full load.

This inefficient use of electrical energy to supply the compressor in cooling system is regarded into one of indirect contribution to the emission gas. New method is using capacity control which matched the target load system with heat load. Capacity control reduces the on/off cycling losses of the equipment and also improves the steady state efficiency of the plant due the lower pressure differential across the compressor at part load conditions [1]

Research held at Brunel University proved the best method from various capacity control techniques is variable speed method to save the energy load almost near the ideal value.

The application of inverter air conditioner for commercial and residential purpose becomes increasingly wide owing to its saving energy and maintaining comfort.

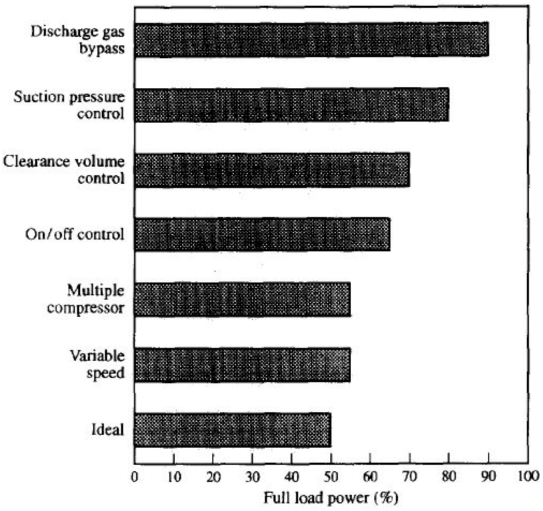

Fig. 1 Comparison of various capacity control techniques.[1]

The constant speed air conditioner, the dominant type in the air conditioner market in the past, is now gradually replaced by the inverter air conditioner. With the complicated heat and mass transfer inside, the compressor is the most complex component in a refrigeration system, for which it is difficult to setup a precise model [5]. On the other hand, as the performance of the air conditioner system is largely influenced by that of the The superheat and the refrigeration capacity are the main control variables of VSRS. The control method of superheat is adjusting the opening angle of EEV to maintain the superheat at a constant level. And the method of refrigeration capacity control is consisted in varying the compressor speed to continuously match the compressor refrigeration capacity to the thermal load [3~4], In fact, there exist several drawbacks in case of traditionally designed controllers for such a system. It is known that a basic refrigeration cycle consists of a compressor, heat exchangers, and expansions valve. Many studies focused on controlling the superheat or capacity and little of them studied up controlling both of them at the same time. It is noted that in the VSRS, the capacity and superheat cannot be controlled independently because of interfering loops when the compressor speed and electronic expansion valve opening angle are varied simultaneously.

2. COP (Coefficient of Performance)

In this experiment using single vapor-compression refrigeration system as show in Fig. 2, the vapor - compression uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled. This time experiment has used R-22 as refrigerant liquid.

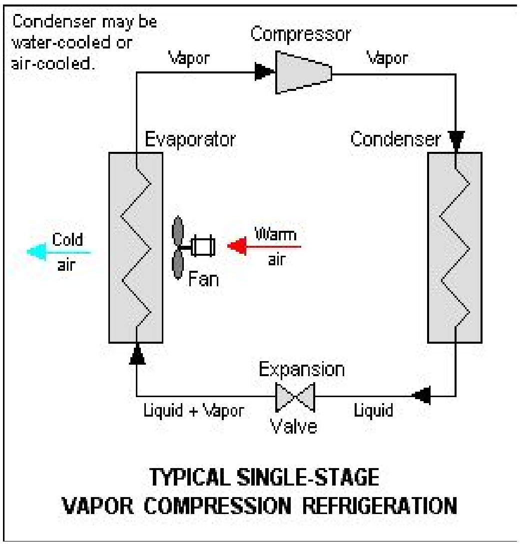

Fig. 2 Single-stage vapor compression refrigeration.(http://en.wikipedia.org)

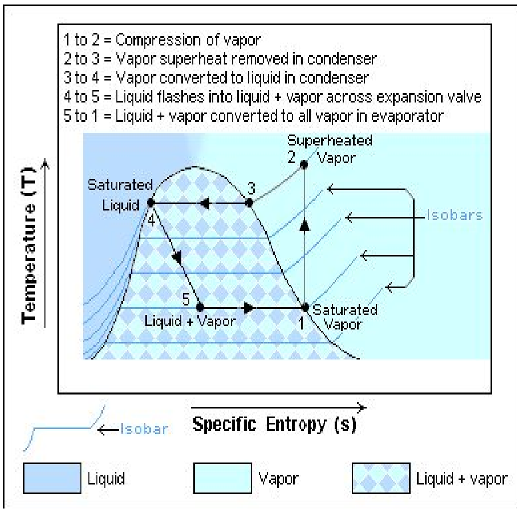

Fig. 3 Configuration of refrigeration cycle(http://en.wikipedia.org)

The conventional way expressing the effectiveness of refrigeration is Coefficient of Performance (COP). This is the ratio of cooling effect or heat extraction to electrical work supplied or energy input. The coefficient of performance is given by Eq. 1. The cooling effect and work of compression are formulated using Eq. 2 and Eq. 3 respectively.

$$COP = \frac{Cooling\,Effect}{Work\ supplied} \tag{1}$$

$$q_2 = (h_B - h_A) \tag{2}$$

$$w = (h_C - h_B) \tag{3}$$

3. Variable speed control

Changing the compressor frequency will change the refrigerant mass flow rate, and then it also changes the cooling capacity. In the experiment we have to measure the pressure, temperature and mass flow rate to get the empirical correlation between the compressor frequency and the cooling capacity. Fig. 3 show the control panel included an inverter connected to control variable speed compressor.

Fig. 4 View of control panel

In this study, the proportional gain is

taken from linearization of the frequency range of the compressor from zero until maximum and the maximum cooling effect result. In the Laplace domain, the PID equation to control the compression frequency is taken from Eq. 1.

$$U(s)=K\left(1+\frac{1}{T_I s}+\frac{T_D s}{1+\frac{T_D s}{N}}\right)E(s) \qquad (4)$$

$$U_p(k)=K_p e(k) \qquad (5)$$

$$U_I(k)=U_I(k-1)+\frac{K_p T}{T_1}e(k) \qquad (6)$$

$$U_D(k)=K_p N(e(k)-e(k-1))+$$

$$\exp\left(\frac{-TN}{T_D}\right)U_D(k-1) \qquad (7)$$

$$U_{total}(k)=U_p(k)+U_1(k)+U_p(k) \qquad (8)$$

U(s) and E(s) is the Laplace output and error, K is the proportional gain, TI is the integral, or reset, time, TD is the derivative time, and N is a constant for the filter in the derivative portion

From the experiment result, we get the frequency-cooling capacity correlation formula with the output is linear equation

$$y=Ax+B \qquad (9)$$

Where:

y, is the cooling capacity,

x ,is the compressor frequency,

A, is the slope and B, is the constant value got from experiment. With this formula we don't need to measure the mass flow rate to get the cooling capacity, this means we don't need to attached refrigerant mass flow rate sensor that are very expensive. And we can use this formula on logic control unit to control the cooling capacity.

4. Experiment apparatus

Fig. 5 show the experiment apparatus diagram. he compressor speed is controlled by inverter frequency and the superheat is controlled by EEV aperture. The compressor normal frequency range is 30Hz-60Hz. and the EEV aperture full open is 512 Step from fully closed.

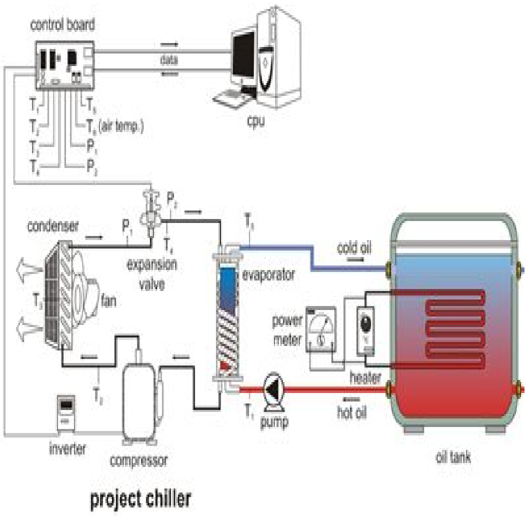

Fig. 5 Schematic of experiment apparatus

5. Results and discussions

Based on experiment result have done with load variation from 4kW until 10kW, Fig. 6 shows the controlled temperature. The Normal load is about 7kW-12kW, below those load, the compressor will run under below 30Hz.

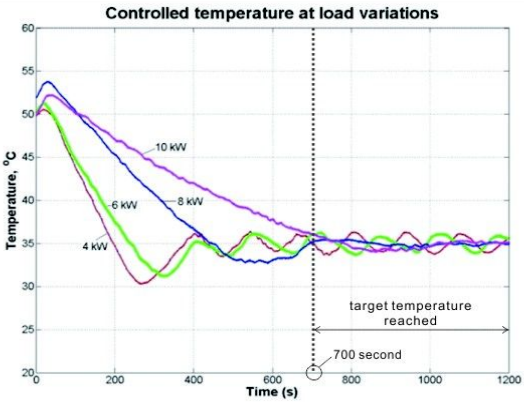

Fig. 6 Controlled temperature at different heat load

For measuring deviation the figure start after 700 second because the target temperature reached for all load variation ,Hence the deviation of the constant temperature is high as shown in Fig.7. In normal load condition the compressor is never turned off and deviation value shown 0.2℃ for 8kW and 10kW, therefore the cooling effect of 8kW. For abnormal condition, the lower load has higher deviation.

Fig. 8 shows the COP of VSRS in variation of cooling load. The average COP is around 2.5.

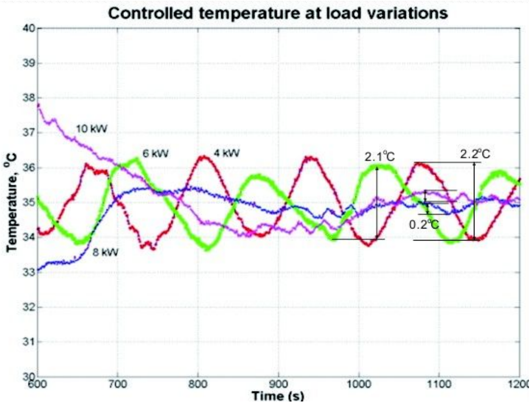

Fig. 7 Temperature Deviation from the targeted line

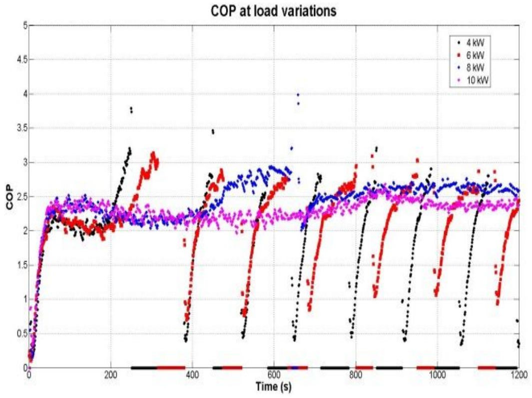

Fig. 8 Variations of the COP at the different range

6. Conclusions

Using linearization cooling capacity as the proportional gain in PID control results in a deviation around 0.2°C in normal load in this compressor type gain at 8kW and 10kW, and has higher deviation if the heat load below the compressor capacity or in abnormal load. The increased deviation is caused by the compressor has a band pass range of frequencies for the life time issue if compressor operated under band range. The COP of the cooling system almost constantly around 2.5 if we operated at normal load (8kW and 10kW).

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