Study on Refrigeratory Compressor with Frequency Conversion and its Economical Efficiency

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Abstract. The energy regulation on the refrigeratory compressor is described. Both the energy-saving principle and performance of conversion compressor are discussed in detail. Two different modes of the control for compressor, frequency conversion cooling and full-frequency run, are compared here. It is concluded that frequency conversion is better than full-frequency on energy-saving. The energy saving and the most economical way of the conversion technology in refrigeration system are demonstrated by an example. Rate of return on investment is higher to apply frequency conversion for compressor in cold storage.

Keywords: Compressor Frequency Conversion Refrigeratory Energy-saving

1. Introduction

It is essential that the quality of fruits and vegetables is sustained by pre-cooling and cold storage. Compressor in cold storage is the most energy-consuming unit in the refrigeration system, which consumes 30% of the input power of the electric machinery[1]. The property of the compressor is the most important in the whole refrigeration system. Now more researchers focus on frequency conversion applied on compressor, and propose better advice[2]~[5].Those compressor are mainly applied on air conditioning, some on electric refrigerator. There are few literatures about cold storage with frequency conversion. Now the main mode for temperature control is on-off full-frequency in pre-cooling and cold storage. The control precision of temperature and humidity by full-frequency is less than that by frequency conversion, even more energy is wasted[6]. In the paper, energy-saving by frequency conversion on compressor is discussed in pre-cooling and cold storage and its prospect is analyzed in detail.

2. Energy-regulating and Energy-consuming

The choice of compressor is based on the refrigerating output. The environmental temperature of the refrigeration system is between the extreme high one in summer and the extreme low one in winter. It fluctuates more than that of the air conditioning system. It is shown by literature [7] that cold container works in its partial condition during most time. There is a great difference between actual application and ISO criteria for cold container. The common cold storage is even so. So it is necessary to regulate energy in order to match the refrigerating output with thermal loading and make the compressor serve the more conditions.

Table 1. Regulating means and its energy-consuming

regulating means	Feature	Power-consuming rate at 60% load (%)
On/off	simple structure, low price, low accuracy control, commonly used in compact units with partly thermal loading, and much energy-consuming at enablement.	63%
cylinder off-bear	Step regulation, used in units with several cylinders and low efficiency at partly thermal loading	-----
inspiration throttle	stepless regulation, simple structure, regulation range limited, and low efficiency	70%
hot gas by-pass	stepless regulation, complicated constructure, and low efficiency	100%
frequency conversion	stepless regulation, simple constructure, high accuracy control, high efficiency, and high cost	60%

There are several regulation means for compressor to control the energy-consuming, such as On/off, inspiration throttle, cylinder off-bear, hot gas by-pass and frequency conversion. Refrigeration compressor in cold storage mostly depends on On/off to control the energy-consuming. When temperature in cold storage is higher than that of the upper limit set, compressor starts to decrease the temperature. While temperature in cold storage is lower than that of the low limit set, compressor stops. Therefore, temperature in the cold storage fluctuates between the low limit set and the up limit set. On/off is suitable for the thermal loading fluctuating little. In fact, thermal loading of cold storage varies much due of the season. In addition, the load of the portable cold storage and the cold container is influenced by the climate in different place. The compressor works in varying condition, enables and closes down frequently. This results in energy-consuming and leads to reduction of service life of the compressor at the same time. So On/off has much limitation. With the development of frequency conversion, it is widely used in air conditioning compressor, which provides much information to apply it on refrigeration compressor in cold storage. The features[5][7] of stepless regulation, simple construction, high accuracy control and high efficiency of frequency conversion make frequency conversion have a good prospect in application on cold storage.

3. Theoretical Analysis of Energy-saving of Compressor with Frequency Conversion

Given a certain condition, refrigerating output is ratio to mass flux of refrigerant. The basic theory of frequency conversion is based on rotating speed of compressor to obtain different mass flux of refrigerant and to gain refrigerating output expected.

Energy-consuming is obtained by theoretical analysis as follows:

$$N = \frac{Q}{\eta_1 \eta_2} \frac{1}{\varepsilon} = \frac{Q}{\eta_1 \eta_2} \frac{H_2 - H_1}{H_1 - H_4} = QK \quad (1)$$

$$K = \frac{1}{\eta_1 \eta_2} \frac{H_2 - H_1}{H_1 - H_4} \quad (2)$$

$$Q = Cn\lambda q_v \quad (3)$$

where K-effective power consumption per refrigerating output

C-structural coefficient of compressor

Q-refrigerating output

q_v-refrigerating output per volume

λ-transfer coefficient ε-EER

n-number of speeds $H_{1\sim4}$-enthalpy

η_1-mechanical efficiency η_2-adiabatic efficiency

It is concluded from the equation (1)-(3) that power consumption is related to both K of effective power consumption per refrigerating output and Q of effective power consumption per refrigerating output. When the thermal loading decreases, rotating speed of compressor is reduced by transducer. It can be seen from Fig.1. This leads to the reduction of mass flux. So the condensing temperature of refrigerant increases, the evaporating temperature of it decreases, the value of (H2-H1)/(H1-H4) decreases, and the refrigerating output decreases. On the other hand, it is showed in Fig.2 that reduction of rotating speed will lead to the reduction of friction work and increase of adiabatic efficiency. It decreases K. The power consumption is greatly reduced by decreasing rotating speed of compressor at partial loading. The power consumption versus mass flux of refrigerant is nearly linear[8][9]. Conclusions can be drawn from Fig.3 that EER is 40%~90% of high rate of rotating speed. The effect of energy-saving is very obvious.

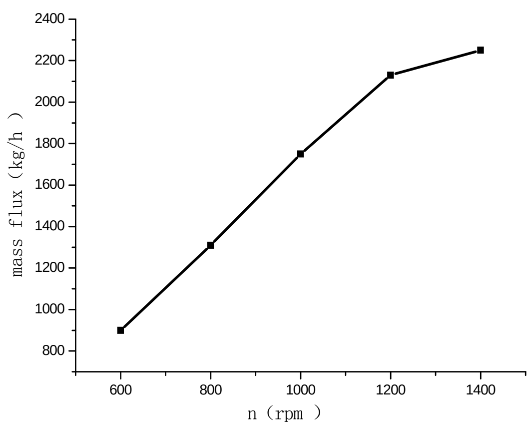

Fig. 1. Relations between mass flux and rotating speed

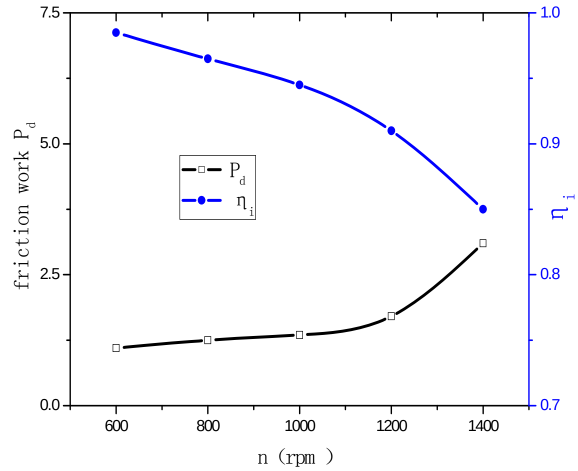

Fig. 2. Relations between friction work, adiabatic efficiency and rotating speed

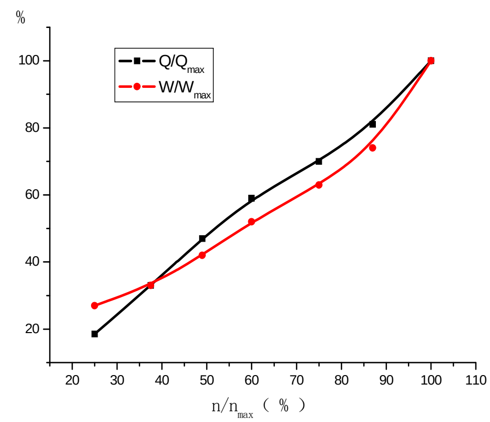

Fig. 3. Relations between the rates of refrigerating output, power consumption and rotate speed

4. Analysis of Energy-saving of Frequency Conversion and its Economical Efficiency

The portable cold storage is examined in the fruits and vegetables place of origin. There are two compressors in a cold storage. The power of one compressor is 2.2kw, air exhaust of it is 9.38m3/h, and rotating speed of it is 2950rpm.

4.1 Thermal Loading of the Portable Cold Storage

1 Thermal loading from cold storage wall

The surrounding T1 is 40℃, the extreme high temperature, temperature T2 is 0 in cold storage, and the thermal conductivity λ of the cold storage wall with 100mm is 0.032W/(m·K) ,the heat transfer area A is $46m^2$, and the inner volume V of the cold storage is 15.625m3 The thermal loading q1 is 563w, which is obtained according to Fourier equation as follows:

$$q1=\lambda\times A\times(T1-T2)/\ \delta=0.032\times44\times40/0.1=563(w) \quad (4)$$

The thermal loading q2 caused by gas exchanger for fresh air in cold storage is 50w.

2 Thermal loading of fruits and vegetables

It is presumed that specific heat of grapes is 3.6kJ/kg•℃ and density is 300kg/m^3. It is supposed that the body temperature decreases from 30 of T3 to 0 of T4 within 8 hours and the capacity coefficient of the cold storage is 0.4, which demonstrates the ratio of volume of grapes to volume of cold storage. Thermal loading q3 of fruits and vegetables is 7031w, which is calculated as follows:

$$q3=C\times\rho\times0.4\times V\times(T3-4)/t=3600\times300\times0.4\times15.625(30-0)/(8\times3600)= 7031w \quad (5)$$

3 Thermal loading caused by respiration of grapes

At 30℃, the coefficient q40 of respiration heat is 420kJ/(T·h) The overall thermal loading q4 caused by respiration of grapes is 218.75w, which is calculated as follows:

$$q4=\rho\times0.4\times V\times q40= 300\times0.4\times15.625\times420/3600=218.75(w) \quad (6)$$

4 Total thermal loading q5 calculates as follows:

$$q=q1+q2+q3+q4+q5=563+50+7031+218.75=7862.75w \quad (7)$$

The total thermal loading is taken to be 8000w.

The power of compressor is 4.4kw if EER is 2

4.2 Energy Calculation and Economics Analysis

Table 2. thermal loading and energy-consuming

thermal loading(%)	energy-consuming of compressor(w.h)		energy-saving rate(%)
	Frequency conversion	ON/OFF	
20	300	522	43
30	496	687	28
50	886	1016	13
70	1277	1345	5
80	1472	1509	2
100	1863	2200	0

According to Tab.2, power-consuming in a month between frequency conversion and ON-OF is compared after initial stages of pre-cooling at the total thermal loading 20%.

The amount of electricity is saved by 94376.8 w·h of H_s,

$$H_s=2\times(522-300)\times30\times24\times2200/1863=94376.8(w.h) \quad (8)$$

The weight of grapes being pre-cooled in a cold storage, W

$$W=300\times15.625\times0.4=1875(kg) \quad (9)$$

If the weight of grapes is 20000kg, the total amount of electricity will be saved by H_t.

$$Ht =94376.8\times20000/1875/1000=1006.686(kw.h) \quad (10)$$

The profit of ￥503.3 will be obtained in a month considered the common electricity price of ￥0.5/(kw.h). A common transducer is ￥2000-3000.

So rate of return on investment is higher to apply frequency conversion for compressor in cold storage.

5. Conclusions

The energy regulation on the refrigeratory compressor by frequency conversion is better than that by full-frequency. On/off is suitable for the thermal loading fluctuating little. It is favorable for compressors by frequency conversion to work in varying condition, which can enable and close down frequently. The most economical way for energy-saving are demonstrated by an example. Rate of return on investment is higher to apply frequency conversion for compressor in cold storage.

High efficiency and energy-saving, environmental protection, stepless regulating, and little noises will be the future features of the refrigeration compressor in cold storage. Compared with other means for energy regulation, frequency conversion application has a new broad prospect because of its features.

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