OPTIMAL CONFIGURATION OF COMPRESSORS IN INDUSTRIAL REFRIGERATION SYSTEMS BASED ON PART-LOAD

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ABSTRACT

A typical industrial refrigerating plant is selected for analysis. The operational regulation of the compressors over an annual period is determined. The ratio between refrigerating capacity of the operating compressors and total compressor capacity is calculated and defined as the part-load ratio of the plant. It is found that the plant was operating at 30% part-load for 66.4% of the annual operating time. Some measures for optimal configuration of compressors based on part-load are proposed to improve annual energy efficiency. A case study further reveals that optimal configuration of compressors will not only decrease operational costs, but also decrease capital investment requirements of the plant.

1. INTRODUCTION

Industrial refrigerating systems are usually designed based on their maximum load. However, the operating time under maximum load is usually less than 5% of total operating time (EECA, 2010). IPLV（integrated part-load value）has been proposed as a measure to evaluate annual operating efficiency in air-conditioning systems, but annual operating efficiency is still neglected in industrial refrigerating systems. The relationship between part-load and compressor selection is discussed in this paper.

2. PART-LOAD ANALYSIS OF A TYPICAL INDUSTRIAL REFRIGERATING PLANT

2.1. Basic Facts For The Observed Plant

A typical refrigerating plant is selected for analysis. The plant is a refrigerated warehouse in Xiamen, a sub-tropical city in China. The basic facts of the cold stores are shown in Table 1. Technical parameters of the compressors used are listed in Table 2.

Table 1. Basic facts of observed cold stores

	Evaporating temp. (℃)	Capacity (m^3)	Compressor No.
Building 1	-15	6000	1, 2
Building 2	-28	18000	3, 5
Building 3	-30	14000	6, 7

Table 2. Technical parameters of the compressors used

Compressor No.	Compressor	Model	Rated Refrig. Cap. kW	Motor power kW
1, 2	piston	4V-12.5	130	55
3-7	piston	S8-12.5	95	75

Note: Rated operating condition of compressor S8-12.5 is +30℃/-30℃ ; Compressor 4V-12.5 is +30℃/-15℃

2.2. Analysis Of Regulation Of Part-Load For The Observed Plant

The operating parameters of the observed plant are recorded in its diary, including operating currents, operating time, etc. Records of the compressor operation for a whole year were collected and analyzed. The operational regulation of the compressors was calculated from the records. Equation 1 (θ) defines the ratio of part-load for the plant.

$$\theta = \frac{\alpha}{\beta}\% \qquad (1)$$

where

θ = Ratio of part-load for the plant,
α = Rated refrigerating capacity of running compressors, kW,
β = Rated refrigerating capacity of total compressors in a plant, kW

The annual operating time of the plant is 4550 hours. The ratio of part-load and the annual operating time are listed in Table 3 and Figure 1, based on Equation 1. From Table 3, it can be seen that the plant operated at 30% part-load for 66.4% of the annual operating time.

Table 3. Annual regulation of part-load for the observed plant

Ratio of part-load (%)	15	30	50	60	70
Actual operating hours (h)	380	3020	780	250	120
Percentage of annual operation (%)	8.4	66.4	17.1	5.5	2.6

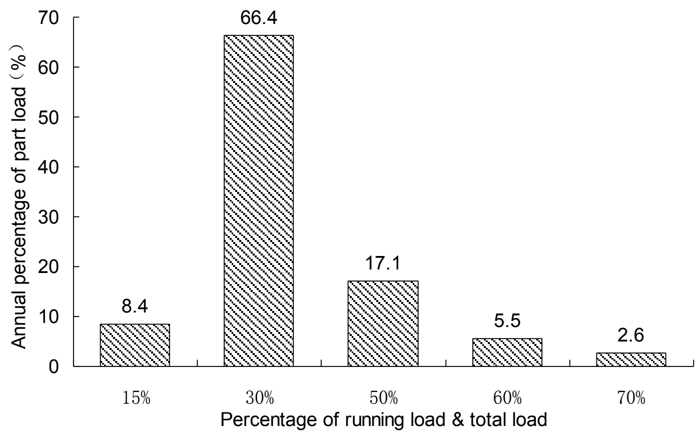

Fig. 1 Annual percentage of part-load for the observed plant

Based on a survey by the author, the total refrigerating capacity of installed compressors in most plants in China is greater than their maximum load. Therefore, most plants run under part-load for most of the time, and consequently their annual operating efficiency is low. Annual operating efficiency could be greatly improved if the regulation of part-load is considered during the design of a plant.

3. OPTIMAL CONFIGURATION OF COMPRESSORS BASED ON PART-LOAD

3.1. Selecting The Number Of Compressors Based On The Regulation Of Part-Load

Obviously, the regulation of part-load in refrigerating plants is related to the service objectives, operational status, weather conditions, etc. The designer will have difficulty considering all factors during the design phase.
In fact, the owner/designer of a new plant could consider a currently operational plant with similar conditions. The method in Section 2 could be used to determine the annual regulation of part-load for that plant, and the results used to guide selection of the number of compressors for the new plant. This should lead to an improvement in the part-load performance of the plant. It may take some time to calculate the annual regulation of part-load, but it is easy to do so. In this way, the annual energy efficiency of the refrigerating plant will be improved.
Recently, computerised automatic control systems are increasingly used in refrigerating plants in China. It is easy to extract the operating parameters for analysis of part-load from such plants.

3.2. Selecting The Number Of Compressors By Golden Section

When the annual regulation of part-load cannot be obtained, annual energy efficiency can still be improved if the owner/designer of a plant carefully considers the optimal configuration of compressors and their adjustment in part-load.
The Golden Section (Golden ratio) is a mathematical ratio (0.618) which can be adopted in this application. It is a useful factor for division of the total load in order to select the number of compressors. If compressors are configured for both 1/3 and 2/3 of total refrigerating capacity, the plant can operate efficiently under both conditions. The refrigerating system will then be easy to adjust and operate at near high-efficiency even though the active load is not exactly 1/3 or 2/3 of the total load.

3.3. Selecting Screw Compressors

The refrigerating capacity of screw compressors is continuously-variable. Therefore, screw compressors will provide better efficiency under part-load. Screw compressors have been widely used in industrialised countries, and have been increasingly accepted by plants in China in recent years. Some analysis (Zhang, 2013) showed that the average COP of typical screw compressors is 11.4% higher than that of piston compressors in the current market in China.
Therefore, selection of screw compressors is a simple step for improving the annual efficiency, especially for a plant with large fluctuations in load.

3.4. Selecting Different Capacity/Series Of Compressor

Traditionally, the same series/capacity of compressors is selected when a new refrigerating plant is designed in China. The reason is that piston compressors are usually adopted. The compressors will have common parts requiring replacement due to wear, which eases maintenance.
Screw compressors do not have wearing parts compared to piston compressors, so there is no maintenance benefit in selecting the same series/capacity of compressors. The operation of a plant will more easily be adjusted for higher efficiency if different capacities of compressors are adopted. In this way, the annual operating efficiency will be improved.

4. CASE STUDY ON OPTIMAL CONFIGURATION BOTH COMPRESSORS & MOTORS

A company plans to build a cold store, the required refrigerating capacity is 426kW, evaporating temperature is -31℃, and condensing temperature is 40℃. Optimal configuration of both compressors and motors for this case are analyzed as follows.

4.1. Options For Compressors And Motors

Various piston compressors and screw compressors are selected and analyzed based on typical products available in the current market. Parameters of five options with different compressors and motors are listed in Table 4.

Table 4 Parameters of five options with different compressors

Option	Compressor	Model	Rated refrig. Cap. kW	Shaft power kW	Motor power kW	COP	Number
1	Piston	S812.5	95	47	75	2.02	5
2	Piston	JZY8ASJ17	163	83.9	132	1.94	2
		S812.5	95	47	75	2.02	1
3	Screw	RXF-85E	229	120	132	1.90	2
4	Screw	SLG16/12.5CS	144.1	71.5	100	2.02	1
		SLG20/16CS	298.6	143.2	200	2.09	1
5	Screw	HSN7471-75-40P	75	49	55	1.53	6

Note: Refrigerating capacities taken from catalog, COPs are calculated by catalog.

4.2 COP Analyses Of Five Options For Compressors

The total refrigerating capacities, COPs and total motor powers of the five options are shown in Figure 2. The COP uses the average value for compressors with different models in one option. From Table 4, the COP of screw compressors (Option 4) is higher than that of piston compressors (Option 1 and 2). The COP of Option 4 is 4% higher than that of Option 2.

The COP of Option 4 is 34.6% higher than that of Option 5 among screw compressors. Therefore, it is necessary to compare the COP of different compressors at full load, to optimize the selection within an option of compressor.

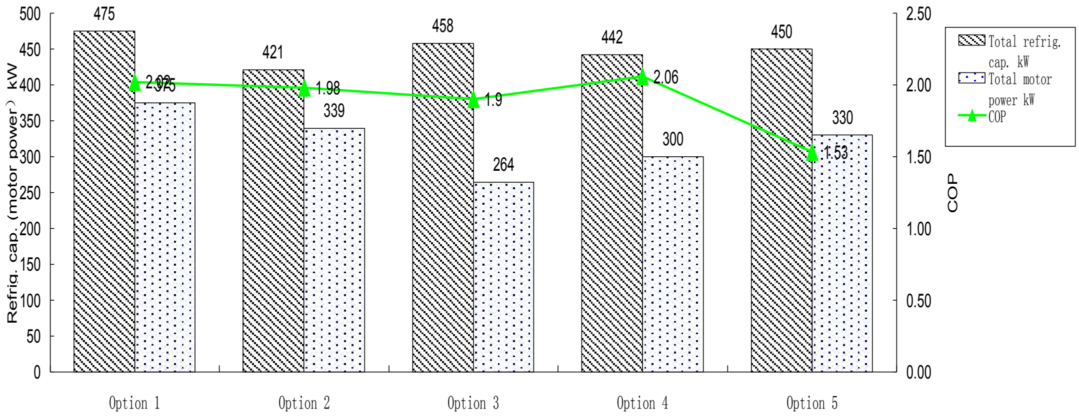

Fig. 2. Total refrigerating capacity/motor power and COP among five options

4.3 Analyses Of Total Motor Power Of The Options

The motor powers of compressors should be calculated and selected based on the actual operating condition, from the provisions of the national standard (Xu *et al.*, 2010). However, most users do not check and calculate the motor powers of compressors.

It is a remarkable fact that motor power will vary greatly among different options of compressors. From Table 4, the average motor power of piston compressors is 20% higher than that of screw compressors. The total motor power of Option 1 (piston compressor) is 42% higher than that of Option 3 (screw compressor). Therefore, it is necessary to compare total motor power, to optimize the compressor selection.

The energy cost of a plant can be calculated by Equation 2 (Zhang and Li, 2011) in China.

$$S = A + B + C \quad (2)$$

where

S = total power cost, Yuan,

A = power consumed, Yuan/kW·h,
B = capacity cost of transformer , Yuan/month,
C = regulation fees of power factor

If the total motor power is larger, the transformer required for a plant will be larger. At the same time, the capacity cost of plant power will be larger from Equation (2). That is, both the initial investment and operating cost of a plant will be increased.
Therefore, the optimal configuration of compressors in industrial refrigeration systems is not only related to the annual operating efficiency of a plant, but also to the initial investment and operating cost of a plant's electrical system.

5. CONCLUSIONS

Some conclusions can be drawn from the analyses above. Different options of compressors under the same conditions will result in different COPs and annual operating efficiencies. The optimal configuration of compressors will not only decrease operational costs, but also decrease the investment in a plant. The annual part-load regulation should be carefully considered. There are different ways to optimize the configuration of compressors based on part-load in industrial refrigeration systems during the design phase.

6. REFERENCES

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