ENERGY SAVING ANALYSIS OF PRESSURE DIFFERENCE CONTROL OF FREQUENCY CONVERSION VARIABLE WATER FLOW SYSTEM

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ABSTRACT

This paper discusses the energy saving principle of frequency conversion chilled water system. Analyzes the energy saving failure reason in actual engineering from the pipe lines and the pump two aspects and gets out the reason is adopting the constant pressure difference control method. Through a simplified chilled water system, compares the pump energy saving efficiencies under constant and variable pressure difference control methods. Get out that the frequency conversion system can reach the maximum energy saving efficiency under variable pressure difference control method. And put forward that the operable minimum pressure difference control method can be adopted in actual engineering.

INDEX TERMS

Frequency conversion, energy saving, constant pressure difference, variable pressure difference control method, minimum pressure difference control

INTRODUCTION

With the constant rise of utility costs and rapid increase of energy sources demand, energy saving has been put forward as a policy in our country. The total energy consumed by heating and air conditioning has exceeded 20% of primary total energy consumption. So save energy consumption and improve energy utilization of air conditioning system has become more and more important.

A distinct characteristic of air conditioning system is that most of them are working under part load. The annual cooling load time frequency of one typical public building is shown in Figure 1 (Li SL et al.2005), from which we can see that the time below 70% of the load ratio in a whole year is more than 90%. So keep the cooling efficiency of air conditioning system under part load conditions has great significance for energy saving.
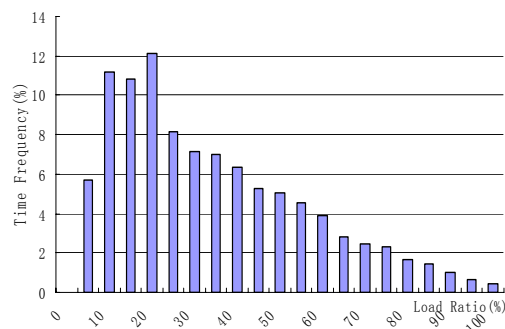

Figure 1 Time frequency of part load ratio

PARTS OF THE PAPER

Frequency conversion energy saving of the pump

Energy saving of air conditioning system under part load condition is mainly achieved by improving COP value of refrigerating machine under low load and reducing the electric consumption of pumps and fans in part load. The former is mainly depending on the factories' technical innovation, while the latter is mainly by adopting appropriate technology measures. The demand of chilled water flow will be down when the air conditioning load reduce, so saving the pumps' energy consumption can be realized by reducing the chilled water flow. At present, the respectable and applied widely technique is frequency conversion variable flow technique.

The rotation rate of the electric machine is calculated by the following formula:

$$n = 60 f (1 - s) / P$$

In the formula, f is current frequency, s is slip, P is the number of the electrode pairs.

We can see that stepless speed regulation of the electric machine can be achieved by frequency conversion technique in theory and so the stepless adjustment of the pump flow can be achieved. Based on the similarity principle in fluid mechanics (Zhou MR 1994), under the similarity operating conditions:

$$\frac{Q_1}{Q_0} = \frac{n_1}{n_0}$$

$$\frac{H_1}{H_0} = \left(\frac{n_1}{n_0}\right)^2 = \left(\frac{Q_1}{Q_0}\right)^2$$

$$\frac{N_1}{N_0} = \left(\frac{n_1}{n_0}\right)^3 = \left(\frac{Q_1}{Q_0}\right)^3$$

In the formulas, Q is the flow of the pump, H is the pressure head of the pump, N is the shaft power of the pump, and n is the number of turns. The subscript 0 stands for the value under the rated condition and the suffix 1 stands for the value under the conditions with n_1 turns.

From the formulas we can see that the pump's shaft power is proportional to the cube of the flow, and the shaft power decreases rapidly with the decrease of the flow. And the changing conditions are shown in Table 1.

Table 1 The pump's shaft power in part flow

Flow (q_1/q_0) %	100	90	80	70	60	50
Power (N_1/N_0) %	100	72.9	51.2	34.3	21.6	12.5

We can see that in the condition of frequency conversion variable flow, the pump's power consumption decreases quickly and energy saving effect is obvious in theory. But in many actual air conditioning systems with frequency conversion variable flow, especially in reform system, the energy saving effect is inapparent and even not by a long sight sometimes. What are the reasons? We analyze it from the pipe lines and the pump two aspects in the following (Zeng ZW and Li C 2005).

Influencing factors of the frequency conversion energy saving

Influence of the pipeline system changing

Figure 2 shows the characteristic curve of pump and pipeline of one chilled water system in design operating condition. In the figure, o is the pump's design working point, in which the pump's rotating speed is n_0 and the flow is Q_0. When the flow reduces to Q_1, the pump's rotating speed will fall to n_1 in theory. But in practical situations, many operators will cut down the flow by turning down the valves when the load reduces, and the pipeline's characteristic curve will become steep.
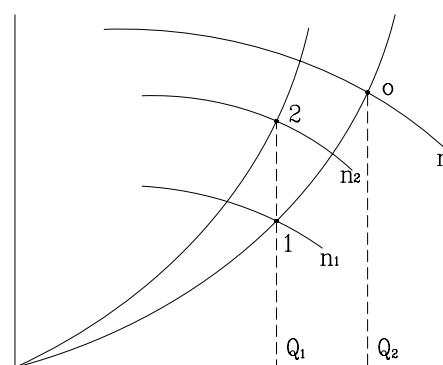

Figure 2 Running speed and operating point of the pump in actual system

We can see that the pump's rotating speed will fall to n_2 in actual system and the pump's working point is 2 by now. Because the value n_2 is bigger than n_1, the pump's energy saving effect decreases. So in the system with frequency conversion adjusting, it is not suggested to adjust flow by adjusting valves firstly but suggested to make use of various flow ability of frequency conversion equipment to the full.

In actual frequency conversion system, constant pressure difference control mode is usually adopted, that is, to keep the pressure difference ΔP between water supply main pipes and return ones unchanged. When the flow reduces, we can consider that the pump's lift $H = \Delta P + \Delta P'$ keeping unchanged generally. In the formula, $\Delta P'$ is the pressure drop of chilling room in the chilled water system. According to the formula $N = \rho g Q H$ (ρ and g are constant) of pump's effective power, the pump's power is only proportional to the simple of the flow, and the energy saving effective will make a discount (Zeng ZW and Li C 2005).

Influence of pumps parallel connection

In actual systems, several pumps are usually connected in parallel. To save cost, many projects adopt the method of making only one pump frequency conversion, which is the form of "one transducer and many changeless". The characteristic curve of centrifugal pump used in the water system of air conditioning is usually flat relatively (Yuan JZ 2002). And the characteristic curve will become more flat after several pumps being connected in parallel (as shown in Figure3). Right now, if the constant speed pump connects the frequency conversion pump in parallel again, the pump's lift will have to be considered. In Figure 3, the two constant speed pumps' lifts in design operating conditions are H_0, and keep constant during working. Then the frequency conversion pump connected in parallel with the constant speed pumps can bring into play really if its lift is not lower than H_0 (Li CC 2001). So

the pump's frequency conversion range will be limited greatly (Li SL et al.2003). To the frequency converter itself, its efficiency in low load will decrease and the frequency conversion range is not adapted for extending unboundedly (Huang WH et al.2004). Furthermore, the lift of the frequency conversion pump can only keep H_0. According to the previous analysis we know that the pump's efficiency is only proportional to the flow now, its frequency conversion effect is limited, and the energy saving effective is not obvious.
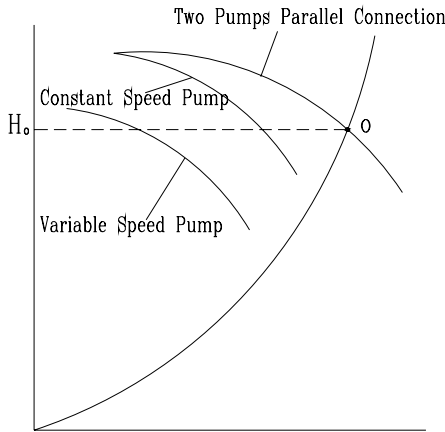

Figure 3 Characteristic curves of constant and variable speed pumps parallel connection

Energy saving effect comparison between the constant and variable pressure difference control methods

From the above analysis we can see that the main reason leading to bad energy saving effect of the frequency conversion variable water flow system is the pump's lift will not change after frequency conversion. Especially in the constant pressure difference system, to ensure the pressure difference between water supply main pipes and return ones, the pump must offer corresponding lift. The aim of constant pressure difference is only ensuring that every end has enough pressure head to ensure flow. But if the flow of every end can be ensured, the pressure difference can be changed, that is, variable pressure difference control method can be adopted. In the following, the energy saving effect is compared between the two methods with a simplified water system (see Figure 4).

We suppose the following conditions of the system:

(1) The pump can convert frequency freedom.

(2) The pipeline's resistance number of the chilling room is unchanged during flow changing.

(3) The pump and chiller have no limit to the flow.
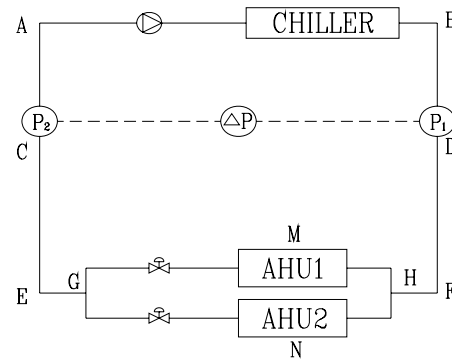

Figure 4 Simplified water system

In the design operating condition, the interrelated parameter data are as follows:

The pressure drop:

$$\Delta P_{CABD} = 80 kPa$$

$$\Delta P_{DFH} = \Delta P_{CEG} = 50 kPa$$

$$\Delta P_{HMG} = \Delta P_{HNG} = 70 kPa$$

The flow:

$$Q_0 = 20 L/s$$

$$Q_{HMG} = Q_{HNG} = 10 L/s$$

The pump's working lift:

$$H_0 = \Delta P_{CABD} + \Delta P_{DFH} + \Delta P_{CEG} + \Delta P_{GH} = 250 kPa$$

The effective power:

$$N_0 = \rho g Q_0 H_0 = 4.9 KW$$

We analysis the following two conditions: one is that the flows of the two branches change the same; the other is that they change separately.

Flows of the branches change the same

When the load reduces and the flow decreases, considering that the flows of the two branches change to 70% of the primary at the same time, if the constant pressure difference control method is adopted, then the pressure drops of $DFEC$ is unchanged. The pressure drops of $CABD$, the pump's working lift and the effective power are calculated by the following formulas (the superscript "'" stands for the values that flows of the branches change the same and the suffix "1" stands for the values under the constant pressure difference control)

$$\Delta P_{CABD}' = \Delta P_{CABD}(Q'/Q_0)^2 = 39.2 kPa$$

$$H_1' = \Delta P_{CABD}' + \Delta P_{DFH} + \Delta P_{CEG} + \Delta P_{GH} = 209.2 kPa$$

$$N_1' = \rho g Q' H_1' = 2.87 KW$$

We can see that the pump economizes 41.4% on energy compared with the primary.

If the variable pressure difference control method is adopted, because the change proportions of end loads are the same, we can only adjust the pump's rotate speed to decrease the flow to Q' and keep the pipeline unchanged. By this way we can make the flow of the end change to the value requested. Right now, the pump's working lift and the effective power are calculated by the following formulas (the suffix "2" stands for the values under the variable pressure difference control).

$$H_2' = sQ'^2 = H_0(Q'/Q_0)^2 = 122.5 kPa$$

$$N_2' = \rho g Q' H_2' = 1.68 KW$$

We can see that the pump economizes 65.7% on energy compared with the primary. And now, the power of the pump in the frequency conversion variable flow system can reach the theoretical level, that is, the pump's power is proportional to the cube of the flow.

The pump's power curves in constant and variable pressure difference control methods are shown in Figure 5 when the flow changes continuously. We can see that the energy saving effect of variable pressure difference control method is far more excelled than that of constant pressure difference control method.
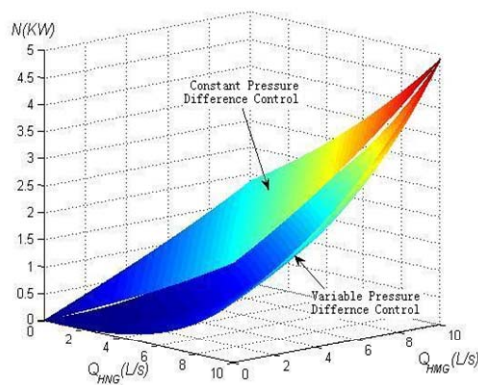

Figure 5 Pump power curves in two different control methods when the end's water flow vary separately

Flows of the branches change separately

We consider more general condition that the flows of the ends change differently. We suppose that the flow of M changes to 70% of the primary and the flow of N changes to 50% of the primary. When the constant

pressure difference control method is adopted, the correlative parameters are changing as follows. (The superscript " ' ' " stands for the values that flows of the branches change separately.)

$$\Delta P_{CABD}'' = \Delta P_{CABD}(Q''/Q_0)^2 = 28.8 kPa$$

$$H_1'' = \Delta P_{CABD}'' + \Delta P_{DFH} + \Delta P_{CEG} + \Delta P_{GH} = 198.8 kPa$$

$$N_1'' = \rho g Q'' H_1'' = 2.34 KW$$

We can see that the pump economizes 52.2% on energy compared with the primary.

If the variable pressure difference control method is adopted, the pressure head of the branch *HMG* should be satisfied firstly because of the bigger flow. Then:

$$\Delta P_{HMG}'' = \Delta P_{HMG}(Q_{HMG}''/Q_{HMG})^2 = 34.3 kPa$$

$$\Delta P_{CABD}'' = \Delta P_{CABD}(Q''/Q_0)^2 = 28.8 kPa$$

$$\Delta P_{DFH}'' = \Delta P_{CEG}'' = \Delta P_{DFH}(Q''/Q_0)^2 = 18 kPa$$

$$H_2'' = \Delta P_{CABD}'' + \Delta P_{DFH}'' + \Delta P_{CEG}'' + \Delta P_{GH}'' = 99.1 kPa$$

$$N_2'' = \rho g Q'' H_2'' = 1.17 KW$$

We can see that the pump economizes 76.1% on energy compared with the primary.

When the flows of the two branches change uniformly, the pump's power curves in constant and variable pressure difference control methods are shown in Figure 6.
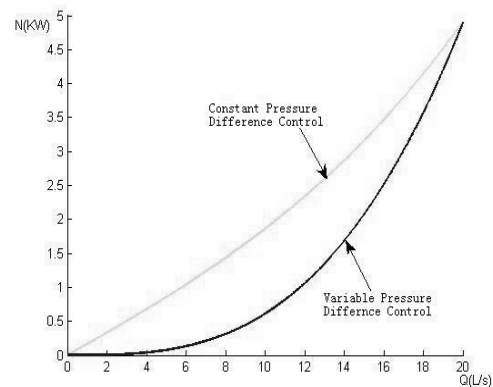

Figure 6 Pump power curves in two different control methods when the end's water flow vary uniformly

From the above calculating we can see that the energy saving effect of variable pressure difference control method is excelled than that of constant pressure difference control method no matter how the flows of the ends changes.

Minimum pressure difference control

In actual projects, the number and kinds of the ends are much more than the above simplified condition, the branches are coupled each other, and the flow of every end changes with no rules, so it is impossible to know the position of valves in every branch and lift supported by the pump of every condition with concrete calculating. The minimum pressure difference control method is operable actually (Cao Q et al. 2001). The exact operation is as follows: reduce the pressure difference between water supply main pipes and return ones according to definite rules when the flow changes, check every valve's opening at the same time; when the valves are open fully proportionally, we consider the pressure difference at this point is the minimum pressure difference. Although the most energy saving effect can not achieve in theory in this way, it can reduce the throttling loss caused by turning down valves as much as possible, and it is feasible in actual operating.

CONCLUSIONS

1. In similar operating conditions, the pump's effective power is proportional to the cube of the flow. And it has great energy saving space by frequency conversion variable flow.

2. The main reasons resulted in bad energy saving effect of frequency conversion variable flow technique in actual projects are as follows: one is adopting constant pressure difference control method; the other is that the frequency conversion pumps connect the constant speed pumps in parallel. The two points make the frequency conversion pump's lift not reduce accordingly when the frequency converts and cut down the energy saving effect greatly.

3. It is not requisite to adopting constant pressure difference control method. The pump's frequency conversion variable flow can obtain obvious energy saving effect when adopting variable pressure difference control method. In some conditions, the theoretic energy saving effect, which is the pump's power is proportional to the cube of the flow, can be achieved.

4. In actual projects, because the ends are complex and various, and the flow of every end changes with no rules, the operable minimum pressure difference control method can be adopted.

REFERENCES

Li SL, Zhu MB, and Zhang GQ. 2005. "Computer aided decision making for variable speed pump schemes," Heating Ventilating & Air Conditioning, 35(3):83-85

Zhou MR.1994. Hydromechanics & Pump and Fan (Third Edition). Beijing: China Architecture & Building Press. 316-318

Zeng ZW, Li C.2005. "Energy saving analysis for variable primary flow," Refrigeration, 24(4):80-83

Yuan JZ. 2002. "Energy-saving measures for central air conditioning system," Nonferrous Metals Engineering & Research. 23(2):35-36

Li CC. 2001. "Design of frequency control of primary-secondary pumping in air-conditioning water systems," Heating Ventilating & Air Conditioning, 31(6):51-54

Li SL, Zhu MB, Zhang GQ, and Zhang SC.2003. "Some Issues in Reforming Water System for a Central Air Conditioning," Automation Panorama, 20(5):53-55

Huang WH, Li EF, and Pan YG. 2004. "VWV control strategies of chillers in primary pump systems," Heating Ventilating & Air Conditioning, 34(4):65-69

Cao Q, Fu MX, and Xie MH. 2001. "Energy Save Variable-frequency Control for Air-conditioning Water System," Automation Panorama, 18(5):31-32