STUDY ON INTELLIGENT DEFROST TIME OF AIR-COOLED HEAT PUMP

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ABSTRACT

Air-Cooled heat pumps have numerous advantages in many applications over other heating equipment with regard to energy efficiency, operation, and safety. However, some problems are accompanied with it in winter, such as heating capacity decreasing, too much low pressure protecting, compressor damaging, and so on.

After investigation and analyses, it is found that the unsuitable defrost control is the key reason. Now, most heat pumps have temperature-time controller, and can't adapt to different areas because of different weather conditions. For lack of details of the climates, the manufactory's field test and modulation is not available. In order to overcome this problem, intelligent defrosting is dead in need.

In this paper, the reasons causing unreliable running of air-cooled heat pump in winter are firstly analyzed and then some improvements are discussed. At last, the research and development of intelligent defrost control is given in detail. Simulation results show that the fuzzy controller is a very effective way to improve the performance of air-cooled heat pump in winter.

INTRODUCTION

The number of heat pump in china has been increasing in recent years. Their safety, cleanliness, and reduction of energy and space have made them very popular, and many efforts have been made to improve their performance and quality.

When a heat pump is operated at temperature below 4°C or 5°C, the surface temperature of outdoor coil falls below 0°C and frost is formed on the surface of the coil. As the frost forms, it can decrease the airflows areas and eventually begins to insulate the cold heat exchanger and decreases the capacity of the unit and its efficiency. So under such conditions, to ensure a reasonably good performance from the unit, a periodical defrost is required. This defrost extracts an additional penalty in terms of energy consumption. This paper presents a novel intelligent defrost methods of heat pump.

1. DEFROST ANALYSIS OF THE AIR-COOLED HEAT PUMP

At present, the popular hot-gas defrost method are (Jianghang and Xiaojiang 1998): timer method, differential pressure method, and time-temperature method.

The most straightforward method of defrost is the simple timer method, that is after a fixed length of running time, the defrosting is beginning at no consideration of the climate and situation of heat pump. But in practice, the defrost time is designed for the safe operation in the worse badly weather. The timer method is the simplest way to accomplish defrost, and it has obvious disadvantages. It initiates defrost at regular intervals, even though the heat pump could operate under favorable conditions for long periods without frost buildup. It also holds the system in defrost for a fixed time during each cycle, even though a shorter time could be adequate in defrost removal. The result is a loss of efficiency as well as excessive cycling of components.

The differential pressure method takes account of the effect of the frost. As we know, the frost and growth of frost can enlarge friction of the air flowing through the evaporator. After detecting the differential pressure of evaporator, it is possible to implement the defrost on demand theoretically. However this method is not always valid because of unknown factors that can affect the differential pressure. For example, the dirty buildup can enlarge the friction too.

The time-temperature method have sought to minimize the above disadvantages by integrating temperature with time to determine both the need for defrost initiation and the duration of the defrost cycle. In a typical circuit, this method utilizes a timer with two contacts in series with a temperature-actuated switch (thermostat). The thermostat is mounted on the outdoor coil and is always closed when the coil temperature is below some constant (-5°C or so), open when above other constant (15°C or so). One contact of the timer closes for, say 20 seconds every an hour or so. If during that 20 seconds the thermostat is also closed, the defrost relay will be energized, initial defrost. A holding contact on the defrost relay maintains this condition until one of two thing happens: the coil thermostat opens, meaning defrost is completed, or the second timer contact opens after sometimes to assure defrost termination.

The timer-temperature method overcomes the disadvantages of the timer-only method by preventing unnecessary defrost cycles and limiting their durations. But as we know, the time between defrosts can be lengthened or shortened in response to parameters measured during defrost. For example, the defrost time in Changsha district is different from that of Xi’an district. So an intelligent defrost method that can adapt to different environments is required to optimize the heat pump’s performance.

2. FROST PROPERTIES ON THE EVAPORATOR

Frost formation is a non-linear transient and coupled heat and mass problem with a moving boundary. It is also experimentally hard to investigation due to the unstable and brittle nature of the deposit.

Hayashi et al (Hayashi et al 1977) considered three periods which describe the evolution of a frost layer, and are now widely accepted. From the beginning, when the clean cold plate is exposed to the ambient moist airstream, the noticed: the crystal growth period, the frost layer growth period and the frost layer full-growth period. The first and rather short period is characterized by the condensation and subsequent freezing of small water droplets. Next, frost crystal are generated on the ice nuclei, and grow in a vertical direction at about the same rate. During these two periods, the frost layer is characterized by a more uniform aspect due to the branching and interconnecting of ice crystals. The frost layer becomes like an homogeneous porous material made of a solid ice matrix and pores filled with moist air. The frost layer full-growth period arises when the surface temperature becomes equal to the water triple-point temperature due to increased frost thermal resistance. Water vapor condensing at the top of the frost layer forms a liquid film that soaks into the frost layer, and freezes in the coldest areas towards the coil wall. Then, a cycle process of melting, freezing and growth occurs until thermal equilibrium of the entire frost layer is reached.

For air-cooled heat pump, the frost temperature range is –12.8°C~5.8°C.When the temperature is above 5.8°C, or the temperature is below 5.8°C and the humidity is below 67%, no frost is considered. When the temperature is below –12.8°C, frost is not considered too due to the very low humidity. The frost on the evaporator can degrade the heat capacity of the heat pump. From a lot of investigation, the heating capacity, energy consumption and efficiency of heat pump are deteriorating with the time of frost and the degree to that, 75%~95% as a general, is related with the climate.

3. INTELLIGENT DEFOST TIME CONTROL USING FUZZY LOGIC

From above, we know that the best defrost method is on demand defrost, which means we should detect the thermal property of the frost and decide when to initiate the defrost and terminate it. But this is very hard to do because the property of frost is very difficult to measure in practice even in laboratory. For these reason, an intelligent defrost method, using the fuzzy logic and taking account of the temperature and humidity, is brought forward. Also it can work harmoniously with the present method as well.

Since the inception of fuzzy logic by Zadeh in 1965, the fuzzy logic has found extensive applications in the areas of industrial systems and consumer products. Its success derives from the fact that problems that are treated by human beings on the basis of their experienced knowledge often lack an exact mathematics description and therefore, can hardly be handled by conventional methods. The basic configuration of the fuzzy logic system is depicted in Fig. 1, which is constructed from the fuzzy IF-THEN rules using some specific inference, fuzzification, and defuzification strategies.

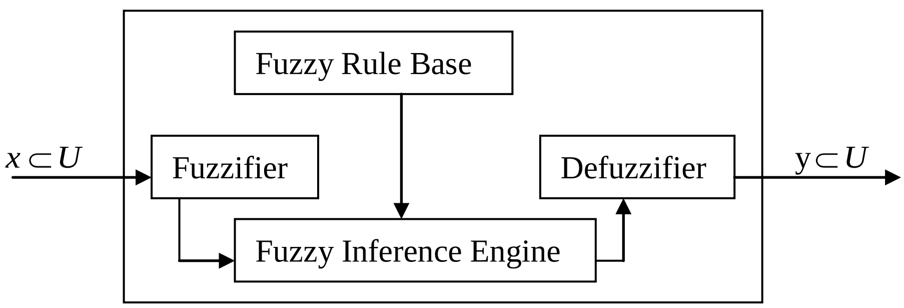

Fig. 1 basic configuration of the fuzzy logic system

The fuzzy logic system performs a mapping from $U \subset R^n$ to $V \subset R$. Let $U = U_1 \times \cdots \times U_N$, where $U_i \subset R, i = 1,2,\cdots,N$. The fuzzifier maps a crisp point in U into a fuzzy set in U . The fuzzy rules base consists of a collection of fuzzy IF-THEN rules:

$$R^{(l)} \quad : \text{if } x_1 \text{ is } F_1^l, \cdots \text{ and } x_n \text{ is } F_n^l, \text{ then } y \text{ is } G^l .$$

In which $x = (x_1, \cdots, x_n)^T \subset U$ and $y \in V \subset R$ are the input and output of the fuzzy logic system, respectively, and $l = 1, \cdots, M$, where M denotes the number of fuzzy IF-THEN rules. The fuzzy inference engine performs a mapping from fuzzy set in U to fuzzy set in V , based upon the fuzzy IF-THEN rules in the fuzzy rules base and the compositional rule of inference. The defuzzifier maps a fuzzy set in V to a crisp point in V .

(1) Considering the main factors that affect the growth of frost is temperature and humidity, we take set A as temperature, set B as humidity and set C as defrost time. Following is the fuzzy variables:

$$A = \{PB, PS, PZ, NZ, NS, NB\}, \quad A = \{-3, -2, -1, -0, 0, 1, 2, 3\};$$

$$B = \{PB, PZ, AZ, NS, NB\}, \quad B = \{-3, -2, -1, 0, 1, 2, 3\};$$

$$C = \{PB, PS, AZ, NS, NB\}, \quad C = \{-4, -3, -2, -1, 0, 1, 2, 3, 4\}.$$

(2) The following control rules come from the experts and manufacture's data. In general, the lower temperature and the higher humidity, the longer defrosting time. That is:

IF $A = NB$ and $B = PB$ THEN $C = PB$

And so on.

Table 1. The Control Rules of Fuzzy Reasoning

		B				
	C	NB	NS	AZ	PS	PB
A	PB	PB	PB	PB	PS	PZ
	PS	PB	PS	PS	AZ	NS
	PZ	PB	PS	AZ	AZ	NB
	NZ	PB	AZ	AZ	NS	NB
	NS	PB	AZ	NS	NS	NB
	NB	AZ	NS	NS	NS	NB

(3) The following is the member function of fuzzy subsets:

Table 2. The Member Function of Temperature:

fuzzy status	fuzzy variables of set A							
	−3	−2	−1	0	0	1	2	3
PB	0	0	0	0	0	0	0. 5	0
PS	0	0	0	0	0. 5	1	0. 5	0
PZ	0	0	0	0. 5	1	0. 5	0	0
NZ	0	0	0. 5	1	0. 5	0	0	0
NS	0	0. 5	1	0. 5	0	0	0	0
NB	1	0. 5	0	0	0	0	0	0

Table 2. The Member Function of Humidity

fuzzy status	fuzzy variables of set B						
	−3	−2	−1	0	1	2	3
PB	0	0	0	0	0	0.5	1
PS	0	0	0	0. 5	1	0. 5	0
AZ	0	0	0. 5	1	0. 5	0	0
NS	0	0. 5	1	0. 5	0	0	0
NB	1	0. 5	0	0	0	0	0

Table 3. The Member Function of Defrost Time

fuzzy status	fuzzy variables of set C								
	−4	−3	−2	−1	0	1	2	3	4
PB	0	0	0	0	0	0	0. 2	0. 7	1
PS	0	0	0	0	0	0. 5	1	0. 5	0
AZ	0	0	0	0. 5	1	0. 5	0	0	0
NS	0	0. 5	1	0. 5	0	0	0	0	0
NB	1	0. 7	0. 2	0	0	0	0	0	0

(4) From above fuzzy relation, the table 5 is got by the fuzzy algorithm, fuzzy reasoning and center-average defuzzification:

Table 5. The Strategies of Fuzzy Control

fuzzy variables of set B	fuzzy variables of set A							
	−3	−2	−1	0	0	1	2	3
−3	0	0	−1	−1	−3	−3	−4	−4
−2	0	0	−1	−1	−3	−3	−4	−4
−1	2	1	0	−1	−1	−1	−4	−4
0	4	2	1	0	0	−1	−2	−4
1	4	4	3	1	1	0	−1	−2
2	4	4	3	3	1	1	0	0
3	4	4	3	3	1	1	0	0

4. DISCUSSION

In our simulation to validate the fuzzy control logic, we take the frosting temperature is (-12.8~5.8°C) and the humidity is (65~95%). The defrosting time is set as (1~10) minutes. The air-cooled heat pump is made in china that consisted of a reciprocating compressor that was made in Italy, ALCO thermal expansion valve, shell-tube condenser and FMV shaft fan. The evaporator's surface is processed by hydrophilic aluminum foil. The following is the typical simulation results and coincide with the investigation of Li Zhou (Li 1995) and Zhiwei Lian (Zhiwei 1998):

Table 6. The Typical Results of Simulation

climate	temperature (°C)	0	1	0	3
	humidity（%）	85	65	95	65
defrost time	（seconds)	360	180	420	120

For limited by the experimental field, we didn't test the system in situation. We will put it in practice t test in future.

5. CONCLUSION

The fuzzy defrost time of air-cooled heat pump that can adapt to different climate is investigated and it is valid by the simulation. We can embed the fuzzy controller into exiting control system easily to improve the performance of heat pump in heating model. We can extend the fuzzy logic technology to interval times, the initial value and terminated value of defrost and so on. It is possible eventually to solve the problem of unstable and low efficiency of air-cooled heat pump by this way.

ACKNOWLEDGMENT

This research work has been supported by Hongtai air-conditioner limit company and Nanhua University, whose assistance is hereby acknowledged.

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KEY WORDS

Air-cooled heat pump, defrost intelligence control, simulation, fuzzy controller