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AUTONOMIC DISTRIBUTED COORDINATIVE CONTROL "F-VPM" FOR MULTIPLE AIR CONDITIONERS WITH CONCURRENT COOLING AND HEATING OPERATION

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Abstract

This paper describes the configuration of the multiple air conditioners with concurrent heating and cooling operation, and the algorithm of the autonomic distributed coordinative control system named "F-VPM;Fuzzy-Vector Pattern Matching". Furthermore, the method and results of dynamic simulation incorporating F-VPM are mentioned. This F-VPM system can control the capacity of a compressor and the performance of the outdoor heat exchanger by way of sensing the suction pressure and discharge pressure of the compressor. It verified by dynamic simulation that the air conditioner with F-VPM control system gets higher control stability in case of concurrent heating and cooling operation.

1. Introduction

Recently in Japan, multiple air conditioner system consisting of distributed individual units have become popular for large buildings. Because they have advantages to respond economically and safely to the requirement of each tenant, and to be reliable, easy to install, and simple to maintain. As buildings become more intelligent and the office automation equipment increases in offices, the thermal load for air conditioner systems grows. Subsequently, it might be necessary to cool offices even during the winter period. There is therefore a growing demand for air-conditioning systems not only to improve the comfort of the residential and working areas with conserving energy but also to respond flexibly to installation and removal of the office automation equipment.

To meet this demand, Authors have developed the multiple air conditioner with concurrent heating and cooling operations. The multiple air conditioner uses three refrigerant pipes to connect each indoor unit to an outdoor unit.

In case of setting the desired cooling or heating operation for each indoor unit, it is difficult to balance the heat load of the indoor unit with the capacity of the outdoor unit. One way of solving this problem is to use the autonomic distributed coordinative control algorithm that we have developed F-VPM:fuzzy-vector pattern matching. This method which differs from conventional control algorithms is that the capacity of the outdoor unit is controlled in a completely self-contained way, regardless of the operating capacity of each indoor unit.

We have also developed a dynamic simulation program to analyze the behavior of refrigerant cycle in case of applying the F-VPM autonomic distributed coordinative control method for concurrent heating and/or cooling modes.

This article introduces details of this control method and dynamic simulation applied to the multiple air conditioner.

2. Multiple air-conditioner with concurrent heating and cooling operations

2-1 Configuration

The basic refrigerant circuit of the three-pipe system is shown in Fig.1. It is divided as follows; an outdoor unit consisting of a pole change control type compressor, an outdoor heat exchanger with the inverter driven fan controller and an accumulator. And several indoor units equip with an indoor heat exchanger. Three pipes consisting of high pressure gas pipe, high pressure liquid pipe and low pressure gas pipe are connected with the outdoor unit and the indoor units. Expansion valves are installed for each heat exchanger on the T branched high pressure liquid pipe. The high pressure gas pipe and low pressure gas pipe are connected to each heat exchangers with solenoid valves.

2-2 Mainly heating operation

In case of heating dominant mode of indoor unit (i.e.,heating load of indoor units is greater than cooling load),refrigerant gas discharged from the compressor flows through the high pressure gas pipe into the indoor units that are operating as a heater, and it exits as a condensed liquid. This liquid refrigerant flows into the high pressure liquid pipe. A part of it flows through the expansion valve into another indoor unit operating as a cooler and then flows as vaporized gas into the low pressure gas pipe. And also the remaining liquid refrigerant flows through the expansion valve and it is vaporized by the outdoor heat exchanger, and then drawn into the compressor.

2-3 Mainly cooling operation

In case of cooling dominant mode of indoor unit (i.e.,cooling load of indoor units is greater than the heating load), refrigerant gas discharged from the compressor flows through the high pressure gas pipe, and it flows into the outdoor unit and the indoor unit as a heater. The condensed liquid flows through the high pressure liquid pipe and also the expansion valve into another indoor units operating as a cooler and then it is vaporized.This vaporized refrigerant flows through the low pressure gas pipe into the compressor.

3.Autonomous Distributed Coordinative Control "F-VPM"

In conventional control method of multiple air-conditioners, the operating number of units and necessarily temperatures of indoor units are monitored for smooth control of the entire air conditioning system. However, the combination of the indoor units and the outdoor units is not possible to be fixed due to the various application. And also the installed system might be changed according to future requirement. In any case, control parameter setting or program changes are required to be adjusted or modified, at time to time.

In order to solve this problem,the F-VPM method is developed to adjust the entire air-conditioning system by controlling the outdoor unit in a completely self-contained manner. Control is based on only two items of data:the discharge pressure(Pd) and suction pressure(Ps) of the compressor. In order to obtain the full performance of each indoor units in case of operating concurrent cooling and/or heating mode, it is necessary to shift the current operating state Pd and Ps to a target high pressure(Pdt) and low pressure(Pst).

The basic concept of F-VPM is described below. The operating states of an air-conditioner are trapezoidal, as shown in the Mollier charts of Fig.2. In these charts, if the capacity(Qcomp) of the compressor increases with ΔQcomp, the trapezoid expands (high-pressure side rises, low pressure side falls). Conversely, if it decreases with ΔQcomp, the trapezoid contracts(high-pressure side falls, low-pressure side rises). If the outdoor heat exchanged performance(AK) in case of an evaporator, increases with Δ AK, the trapezoid moves in parallel toward the high-pressure side rises. Conversely, if it decreases with ΔAK, the trapezoid moves in parallel toward the low-pressure side (high-pressure side rises,low-pressure side falls). On the other hand, when the outdoor heat exchanger is a condenser, the trapezoid will move in the opposite direction. This can be expressed in the following equations.

$$\begin{bmatrix}\Delta Pd\\ \Delta Ps\end{bmatrix} = \begin{bmatrix}a & c\\ -b & d\end{bmatrix}\cdot\begin{bmatrix}\Delta Qcomp\\ \Delta AK\end{bmatrix} \quad \text{-- Eq.1}$$

where Pd: increase in discharge pressure(Pd)
Ps: increase in suction pressure(Ps)
a,b,c,and d : coefficients

If the characteristics of the air-conditioner are defined in the above equation, the high and low pressure of the refrigeration cycle can be assumed by the Pd and Ps pressures of the compressor.

In this way, the entire air-conditioner system can be operated in almost optimum setting. (See a graph at the center of Fig.3 indicating the normal heating/cooling performances of all indoor units. The surrounding graphs indicate non-ideal conditions.)

F-VPM control uses fuzzy theory in which the following rules based on everyday common sense are established beforehand:

(1)Make Pd and Ps matching the target pressure settings to ensure that the indoor heat exchangers operate efficiently.
(2)Prevent the change in a minimum increases or decrease of Qcomp and AK.
(3)Accelerate start-up.
(4)Prevent high-pressure cut.
(5)Make the power input as small as possible.
(6)In case of using the indoor units in concurrent heating and cooling mode,operate the fan speed of the outdoor heat exchanger as little as possible.
(7)In case of using the indoor units in only cooling or only heating mode, operate the fan speed of the outdoor heat exchanger at full capacity.

The most suitable combination of Qcomp and AK is evaluated with reference to these rules.

An example of applying fuzzy rule describes hereafter; The predict values(Pdi and Psi,where i=1 to n) are obtained from Eq.1 using the combinations of Qcomp and AK at the current states. Following equation evaluates the difference between the target pressures and the predict pressures.

$$Ji=1 - G\ (a(Pdt-Pdi)^2+b(Pst-Psi)^2) \qquad \text{-- Eq.2}$$

where G: constant value
a: High pressure weighting coefficient
b: Low pressure weighting coefficient
Ji: Evaluating value

By this evaluating equation, the combinations of Qcomp and Ak at the large evaluating values(Ji) are selected for nominated control parameters. Consequently, the fuzzy rules are applied by the end. The feasible combination of Qcomp and AK is finally determined for optimum control parameter.

4.Simulation

4-1 Simulation method

In order to established the control algorithm, the following procedure of dynamic simulation method were taken. At first, the stable pressure and temperature level of the refrigerant cycle are obtained by static simulation under the condition that refrigerant flow rate of the evaporator and condenser heat exchanger is equal to the flow rate from compressor. The refrigerant flow rate is obtained from the heat balance of the refrigerant and air heat exchanger given with the assumed Pd and Ps. The dynamics of Pd and Ps is expressed with the dead time and time constant as follows.

$$P = Po + Ga(1 - \exp(-(t-to)/Tj)) \qquad \text{-- Eq.3}$$

Po:Initial pressure (Pa)
Ga:Pressure gain(Pa)
Tj:Time constant(s)
to:Dead time(s)
t :time(s)

4-2 An example of simulation result

Table.1 shows the input conditions. The equipment model consisting of four heat exchangers operates cyclically with 10 minutes intervals from heating to concurrent cooling and heating modes,as shown in Table.2.

The above simulation results were shown in Fig.4 and 5. It evidenced that the quick response of the pressure from start up to the preset pressure value is controlled as expected in accordance with the fuzzy rule "Accelerate start-up". After reaching within the preset values, the pressure Qcomp is precisely controlled according to the rule "Make the power input as small as possible" and "Operate the fan speed of the outdoor heat exchanger at full capacity". At the 30 minutes, the cooling unit is added in operation so that the concurrent heating and cooling operation is achieved. Under this operation, the fuzzy rule "Operate the fan speed of the outdoor heat exchanger as little as possible" becomes effective, and then Ak becomes 0(%) due to preventing the pressure increase. It means that the heat exchanger in cooling mode recover the wasted heat and use it for heating as if it is from the heat source. It appears more characteristic at the 40 to 50 minutes. The input power for two heating equipment capacity covers the one for two heating and one cooling equipment capacity as a result, and the energy conservation was proved by the waste heat recovery system.

5. Conclusion

As a result of the dynamic simulation, the F-VPM control algorithm for the multiple air conditioner with concurrent heating and cooling works properly and effectively in terms of energy conservation, and copes with the variable load smoothly.

Reference

S.Inoue,et.al "Development of Sprit-type Multiunit Air-conditioning Systems with Simulataneous Heating and Cooling Function",'91 Symposium on Environmental Engineering(JSME),Japan.

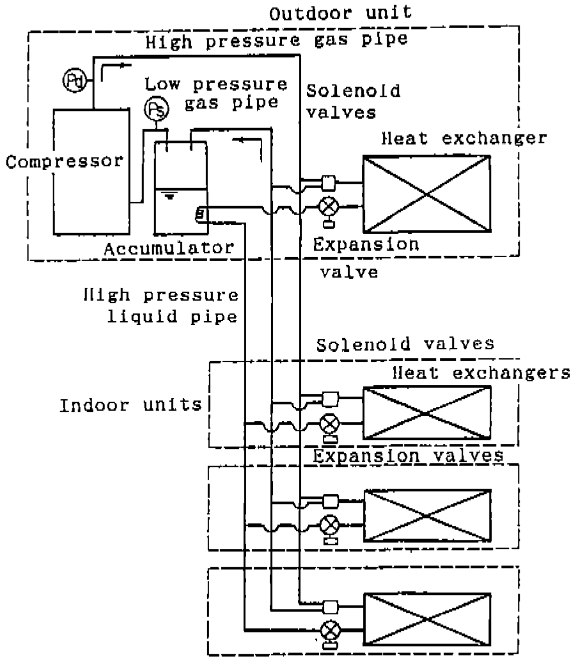

Fig.1 The basic refrigerant circuit of the three-pipe multi-unit,split-type air-conditioner with concurrent heating and cooling operations.

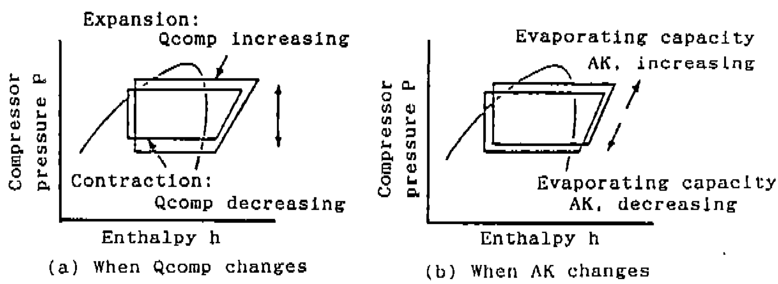

Fig.2 The transitions in operating states, shown in Molier charts.

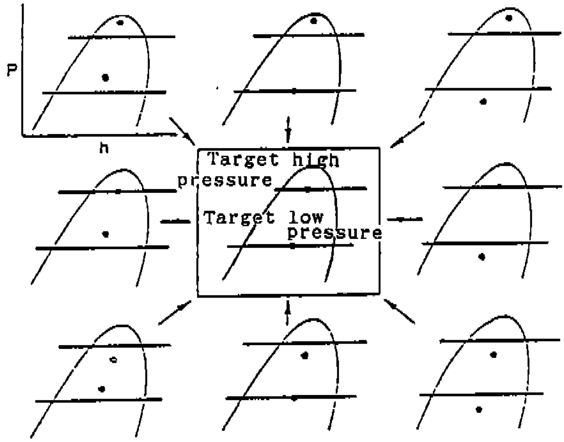

Fig.3 The operating states of the refrigeration cycle.

Table.1 Simulated conditions

Compressor	Power input	25.74(kW)
	Steps of capacity control	0,33,50, 67,100(%)
Heat exchanger	Heat transfer Area	
	Outdoor unit	378.5(m^2)
	Indoor units	45.6(m^2)×4
Outdoor side temperature		280(K)
Indoor side temperature	heating	293(K)
	cooling	303(K)
Target high pressure		2.0(MPa)
Target low pressure		0.6(MPa)
Control timing		30 (minute)
Refrigerant		HCFC 22

Table. 2 Simulated heat loads model of indoor units.
(Indoor units changing in operation or stop-status)

Time(minute)	0 - 10	10 - 20	20 - 30	30 - 40	40 - 50
Number of indoor units	heating1	heating2	heating3	heating3 cooling1	heating2 cooling1

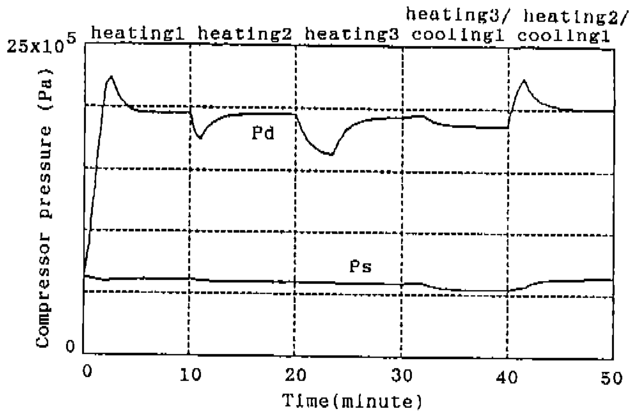

Fig.4 Simulation results of high pressure (Pd) and low pressure(Ps)

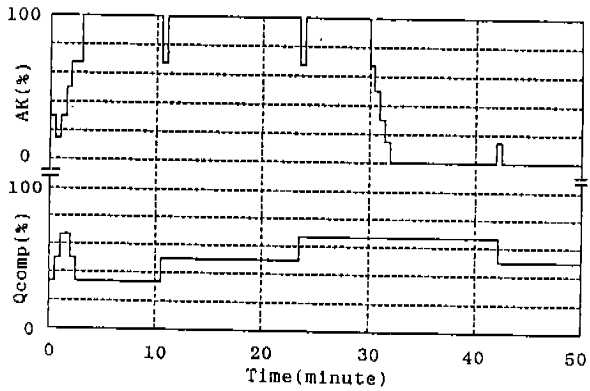

Fig.5 Simulation results of Compressor capacity(Qcomp) and Evaporating performance (AK)