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Development of a dynamic model of a heat pump system and fault detection

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Abstract

Progressive fault such as refrigerant leakage in a heat pump system is difficult to diagnose at an early stage. If the faulty system is operated for a long time, it may lead to serious fault such as compressor break down as well as performance deterioration. If the dynamic characteristics of the system caused by refrigerant leakage can be predicted, it is possible to prevent the progress of faults and to reduce maintenance cost by early fault detection. This study presents a dynamic model to analyze the dynamic characteristics of the heat pump system. Experiments were conducted by varying the operating conditions such as indoor and outdoor air temperatures, cooling load, and refrigerant charge amount. The developed model can predict the temperature variations of the condenser and evaporator and the dynamic characteristics of the system due to load change under normal or faulty operating conditions. It is expected that the control performance of the system can be enhanced, and refrigerant leakage can be quantitatively diagnosed by predicting the dynamic characteristics using developed model in this study.

Keywords: Heat Pump, Refrigerant charge amount, Dynamic characteristics, Dynamic model, Fault detection;

1. Introduction

Recent advances in variable-speed compressor opened new possibilities in improving system performance and energy efficiency. The compressor speed can be continuously changed to meet the target capacity, and the expansion valve opening is adjusted to maintain the optimized system efficiency. [1]

Various researches for capacity and optimum control of a heat pump system have been carried out. Shah et al. [2] developed a novel controller based on system identification in which a simulation model for a practical air-handling system was developed. He et al. [3] reported on the use of MIMO control of a vapor compression cycle that had multiple actuators and sensors for regulating multiple outputs. They used a low-order dynamic model of the vapor compression cycle that produced a physical meaning to model order reduction.

Faults of heat pump system can be divided into two categories; hard failures and soft failures.[4] Hard failures occur abruptly and cause the system to stop functioning such as compressor and electrical faults. These kinds of faults can be easily detected and diagnosed by electrical on/off relay and alarm signals. However, soft failure such as improper refrigerant charge is more difficult to detect and diagnose. Even though soft faults do not stop a system from working, they lead to decrease in energy efficiency and finally, a fatal failure of the system.[5]

It is required to adopt control methods considering dynamic characteristics of the system models for overall operating region. And, it is needed to develop new control algorithm, which can discriminate dynamic characteristics of heat pump system and indoor load and fault detection. In this study dynamic characteristics of heat pump system and fault detection study were carried out and performed sensitivity analysis of fault detection for improper refrigerant charge of heat pump system.

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2. Test apparatus and conditions

Figure 1 shows the inverter type heat pump system. Rated cooling and heating capacity of the heat pump system is 3.5 kW and 4.0 kW, respectively. The heat pump system has an outdoor unit and an indoor unit with fin-tube type heat exchangers and variable speed rotary type compressor using R410A refrigerant. Fin-tube type heat exchanger of the outdoor unit consists of wavy fin and smooth tube. Fin-tube type heat exchanger of an indoor unit is consisted of strip fin and smooth tube. Figure 2 shows schematic diagram of test equipment for the heat pump system. Heat pump system was installed in 3RT capacity of environmental chambers. 16 temperatures, 3 pressures, relative humidity and refrigerant flow rate were measured.

Table 1 shows test conditions for obtaining dynamic characteristics of the heat pump system using central composite design method. 25 test conditions were selected by varying outdoor and indoor air temperature, compressor speed and indoor fan speed.

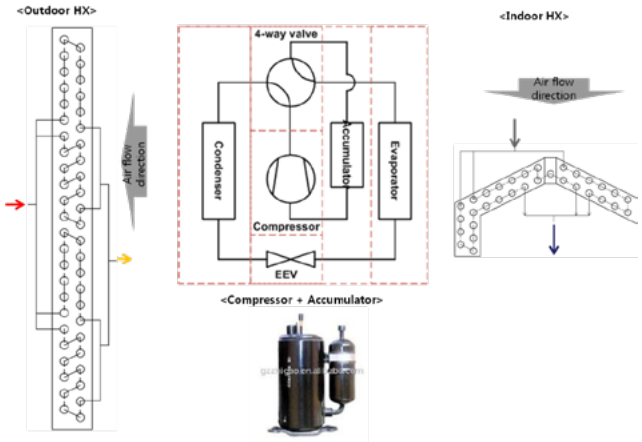


Fig. 1. Inverter type heat pump system.

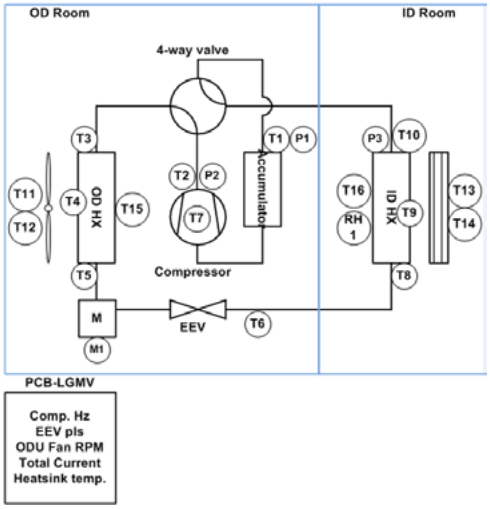


Fig. 2. Schematic diagram of the operation characteristics test equipment for the heat pump system

Table 1 Operation characteristics test condition using central composite design method

Parameter	+α	+1	0	-1	- α
OD temp. (DB/WB, ℃)	48/29	41/50%RH	35/24	28/50%RH	21/15
(ODU Fan speed (RPM))	(810)	(760)	(710)	(660)	(610)
ID temp. (DB/WB, ℃)	32/23	30/40%RH	27/19	24/40%RH	21/15
IDU Fan speed (mode)	Fast	Fast	Middle	Slow	Slow
Comp. Speed (Hz)			25 ~ 100		

Table 2 shows experimental condition for a development of fault-free reference model and for simulated fault mode of improper refrigerant charge. The rated refrigerant charge is 1000g, and the refrigerant charge is varied from 600g to 1100g at intervals of 100g and the experiment was conducted under various operation conditions.

Table 2 Experimental condition for a development of fault-free reference model

Parameter	Experimental condition
Outdoor air temperature (DB/WB)	21/15, 35/24, 48/29
Indoor air temperature (DB/WB)	21/15, 27/19, 32/23
Compressor Hz	Min~Max (5point)
Refrigerant charge	600, 700, 800, 900, 1100g

3. Development of the dynamic model of the system

In this study, the independent variable of the dynamic characteristic model is compressor speed and condensing and evaporating temperatures are considered as input variables that represent external influences on the system according to operating condition. The control variables include compressor discharge temperature, evaporating temperature, condensing temperature, and total current of heat pump system that show the effect of the system by the input variables.

Dynamic model that approximates dynamic characteristics of the system with compressor speed variation was developed using MATLAB. Figure 4 shows system response of four control variables such as compressor discharge temperature, condensing temperature, evaporating temperature and total current by compressor speed change. The dynamic characteristic of control variables was modelled and model outputs for four control variables are compared to actual responses in Fig. 4

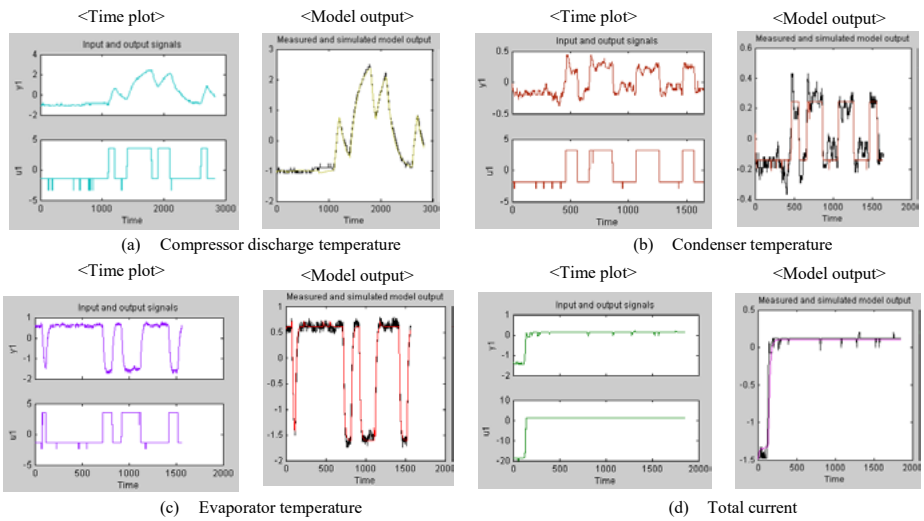


Fig. 3. Development of the dynamic characteristics model

4. Sensitivity analysis according to refrigerant charge

In this study, sensitivity analysis of fault detection was carried out with respect of fault progress. Figure 4 shows the variation of normalized distance according to refrigerant inventory of heat pump system. When refrigerant charge amount is normal, normalized distance is below 6. When fault progress increasingly, normalized distance is over 6 and built up. Fault detection using normalized distance method [6] proposed in this study predicts accurately failure mode for improper refrigerant charge.

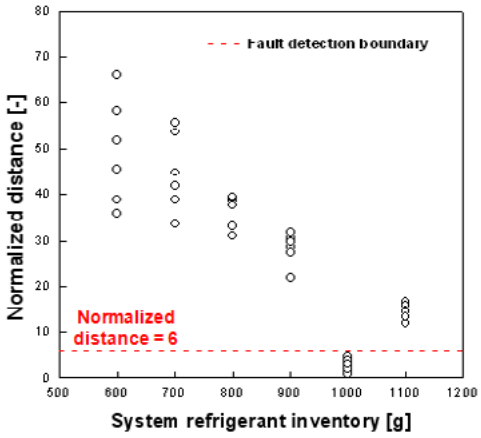


Fig. 4. Fault detection for a fault mode of refrigerant charge

5. Conclusion

In this study, a dynamic model was developed to analyze the dynamic characteristics of the heat pump system. The developed model can predict the temperature variations of the condenser and evaporator and the dynamic characteristics of the system due to load change under normal or faulty operating conditions. It is expected that the control performance of the system can be enhanced, and refrigerant leakage can be quantitatively diagnosed by predicting the dynamic characteristics using developed model.

Acknowledgements

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