한국해양공학회 2006년도 추계학술대회 논문집 pp. 241~244

High Efficient Control Design for Refrigeration System of a Ship

LI HUA

Division of Mechanical Engineering, Yanbian University, No.977, Gongyuan Road, Yanji 133002, China

KEY WORDS: High efficient control, Decoupling model, Superheat, Capacity control, PI control law, Variable speed refrigeration system, Inverter.

ABSTRACT: *In this paper, we suggest the high efficient control method based on general PI control law to control the refrigeration system of the ship effectively. In the variable speed refrigeration system, the capacity and the superheat are controlled by inverters and electronic expansion valves respectively for saving energy and improving cost performance. Thus, we propose decoupling model to eliminate the interfering at first. Next, we design PI controller to control capacity and superheat independently. Finally the control performance was investigated through some experiments. The experiments results show that the PI control design can obtain good control performance deal with the varied control reference and thermal load.*

1. Introduction

As the surrounding environment will be varied when ships move to different region, it is very difficult to design for controlling refrigeration system of a ship effectively. It is inevitable to design practical controller in order to control the refrigeration system of ship for the purpose of saving energy and establishing high efficiency. A basic refrigeration cycle is composed of a compressor, heat exchangers and an expansion valve. Components of the cycle are deeply connected with pipes each other and have nonlinearity inherent. Hence, it is not easy to design a suitable controller.

The conventional control schemes of the refrigeration system are mainly focused on representative two control methods, superheat and capacity control. The superheat has been controlled by expansion device, and it plays an important role reduce evaporating pressure and to regulate the refrigerant mass flow rate. The superheat is controlled as a certain constant value by adjusting opening angle of the electronic expansion valve(EEV) to improve coefficient of performance(COP) of the refrigeration system. The capacity control is basically conducted to respond partial loading conditions on the purpose of energy saving. Usually, refrigeration machines operate under the partial loading conditions, conventional on/off control of a compressor for responding partial load influences to the compressor durability because of frequent switching actions. Therefore, the on/off control system is now gradually replaced by a variable speed compressor control system with inverters.

In the refrigeration system, the capacity and superheat can not be controlled independently because of interfering loop when the compressor speed and electronic expansion valve opening angle are varied.

Fig. 1 shows a block diagram of refrigeration system which has interfering loops inside the dash two dot lines. Because of the coupling characteristic of refrigeration system, the capacity and superheat were not controlled independently.

Choi suggested a superheat control method to control a variable speed heat pump system[1]. The compressor frequency, the reference of inverters, was calculated by the empirical equation with the varied thermal load. Also, the transfer function between superheat and EEV opening angle was expressed as first-order system with dead time. In the paper, the capacity control was considered only the steady state, the superheat controls had very big overshoot and undershoot when it only used PID controller.

In this paper, we suggest the high efficient control method based on general PI control law to control the refrigeration system of the ship effectively. Conventional coupling model makes the systematical design of PI controller difficult. Furthermore, it is a drawback to get good transient characteristics when control reference is changed. Thus, we propose decoupling model to eliminate the interfering loop and each transfer function is obtained from number of experiments at first.

Fig. 2 shows the decoupling control model, it does not have any interfering loop and each influence of operating variation such as VO and T_a is reflected feedforward to their reference input side. Next, we design PI controller with feedforward manner and prove that the PI controller

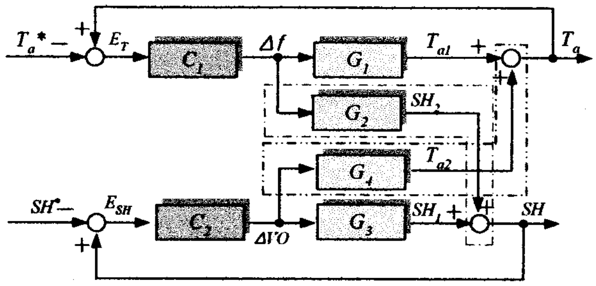


Fig. 1 Block diagram of refrigeration control system

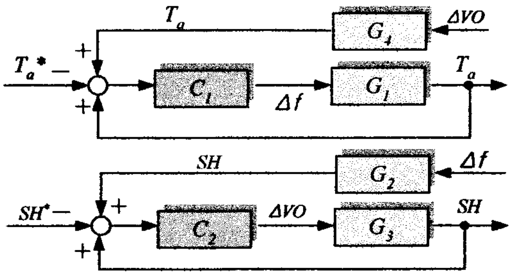


Fig. 2 Block diagram of decoupling control of refrigeration system

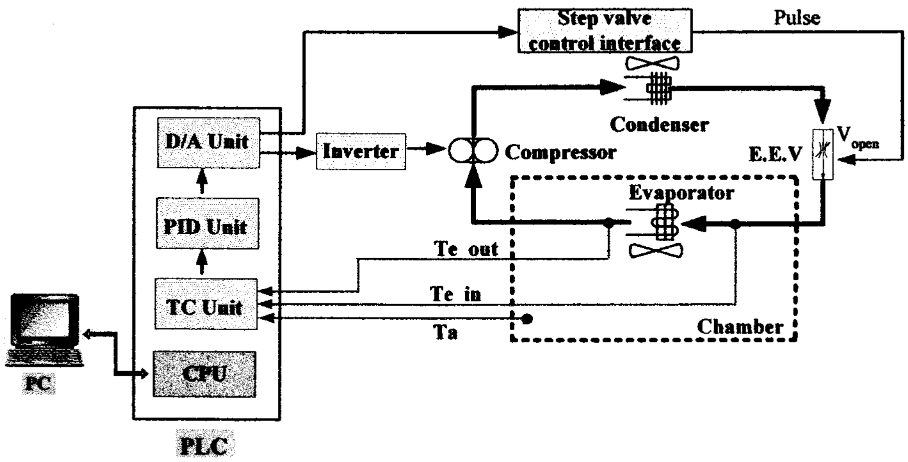


Fig. 3 Schematic diagram of the experimental system

Table 1 Specification of a test unit

Compressor	Type	Vertical, Reciprocating	Inverter	Type	PWM
	Power	220V, 60㎐, 1.5KW		HP	2
Condenser	Type	Fan fin type	Step valve control interface	Input voltage	DC 12V
	Capacity	3450 ㎉/h		Input signal	1-5VDC or 4-20㎃
Evaporator	Type	Fin-tube type		Output	0-400 step
	Capacity	680 ㎉/h	PLC	DC unit	32 CH
Expansion Valve Device	Type	EEV		Relay unit	32 CH
	Model	JHEV 14A		D/A unit	16 CH
	Port size	Φ14		PID unit	16 Loop
	Operating range	0 - 506 pulse		TC unit	16 CH
	Rated voltage	DC 12V		CPU	GM2
Refrigerant	Type	R22	Chamber	Size	1200 x 700 x 1650[㎜]

can establish not only precise control but also high COP of the variable speed refrigeration system through the experiments.

2. Experiment Equipments

Fig. 3 shows a schematic diagram of experimental system, and Table 1 represents the specification of a test unit of the experimental system. The experimental system was composed of basic refrigeration system and control system. The elements of control system were inverter, step valve control interface and PLC(Programmable Logic Controller).

The compressor is driven by the induction motor with a general V/f constant type inverter. The stepper motor to drive EEV is operated by a step valve control interface. The input control signal of inverter and step valve control interface is gotten from D/A unit of PLC. The PI control is performed by PID unit of PLC. All temperatures are measured by thermocouples(T-type). The temperature information is transmitted to TC(Thermocouple) unit of PLC with real time.

3. Experimental Result

Fig. 4 describes the PI control response of chamber temperature and superheat when the control reference of chamber temperature was abruptly varied from 5[℃] to 0 [℃]. The thermal load is 1.75[㎾] and the superheat control reference is 6[℃].

Fig. 4(a) shows the PI control response of chamber temperature when the reference varied. It takes about 500[sec] from change reference to get close set point value. Fig. 4(b) shows the response of compressor frequency to follow the reference of chamber temperature. It can be seen that the compressor set point frequency for controlling the capacity was very stabile.

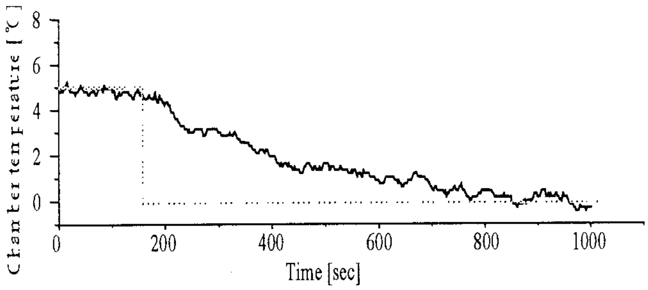
Fig. 4(c) presents the PI control response of superheat according to the chamber temperature reference. The superheat must be controlled when the compressor speed and chamber temperature was varied. The percent overshoot is observed about 30[%], but the maximum overshoot of superheat is below 8[℃]. It is permitted superheat degree in this system. Fig. 4(d) indicates the opening angle of EEV when the PI controller was operated. The set point value of EEV opening angle was varied stability to maintain the superheat at 6[℃].

These experimental results present fairly good control performance of PI to control capacity and superheat when the chamber temperature reference was varied.

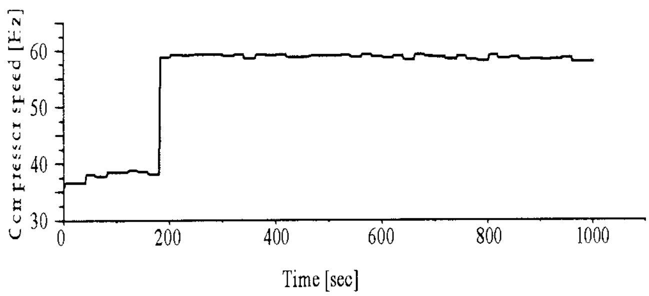
Fig. 5 presents the PI control response of chamber temperature and superheat when thermal load was stepwise varied from 1.75[㎾] to 1.55[㎾]. The control reference of chamber temperature is 0[℃] and the superheat control reference is 6[℃].

Fig. 5(a) and Fig. 5(b) shows the PI control response of chamber temperature and compressor frequency when thermal load was varied respectively. Fig. 5(a) indicates the chamber temperature decreased when the thermal load was decreased. It takes about 600[sec] from change thermal load to get close to the reference chamber temperature 0[℃]. From the Fig. 5(b), we can see that the compressor frequency decreased to maintain the chamber temperature at 0[℃]. Also, the compressor frequency was varied from 56[Hz] to 40[Hz] very stability.

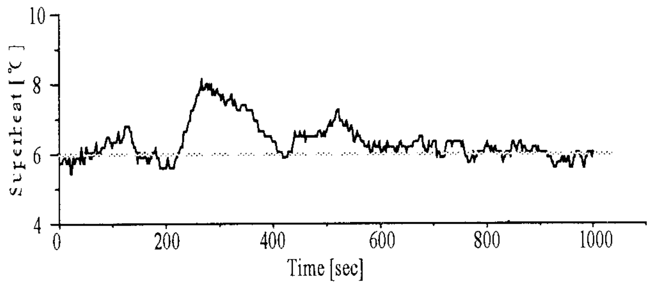
Fig. 5(c) presents the PI control response of superheat according to the thermal load. The superheat has been controlled as constant value of 6[℃] to obtain high COP. Fig. 5(d) shows the opening angle of EEV about the



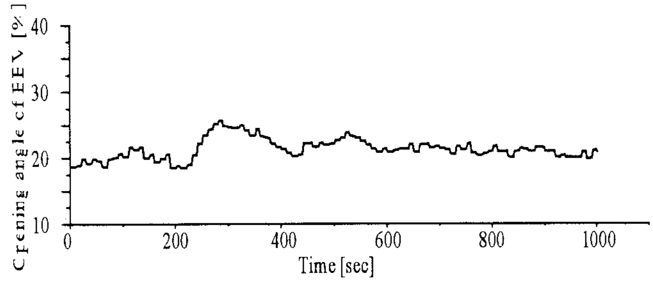
(a) The response of chamber temperature to follow T_a reference



(b) The compressor frequency to follow T_a reference



(c) The response of superheat to follow T_a reference



(d) The opening angle of EEV to follow T_a reference

Fig. 4 PI control response of chamber temperature and superheat when the chamber reference temperature was varied thermal load. The opening angle of EEV has been adjusted as some value depending on the superheat.

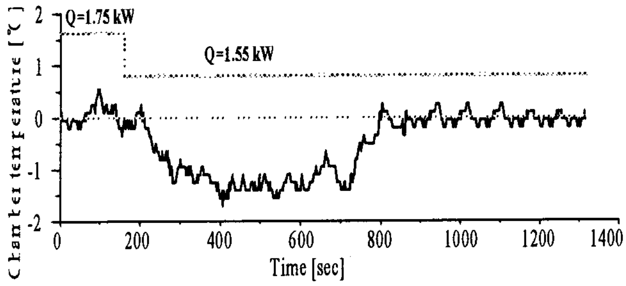
The PI control responses indicate good control performance of PI to control the capacity and superheat deal with the thermal load.

4. conclusion

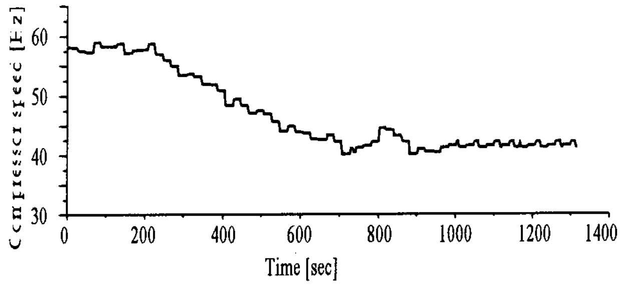
In this paper, we presented the high efficient control design with PI controller to control the capacity and superheat independently and simultaneously without interfering loops on the purpose of saving energy and progress of COP. The suggested decoupling model was obtained from several experiments under various operating conditions. Also, we designed PI controller based on the decoupling model. Some experiment results show that the designed PI controller is effective to control the variable speed refrigeration system. It is expected that the suggested decoupling control method can establish not only precise control but also high COP of the variable speed refrigeration system of ship.

References

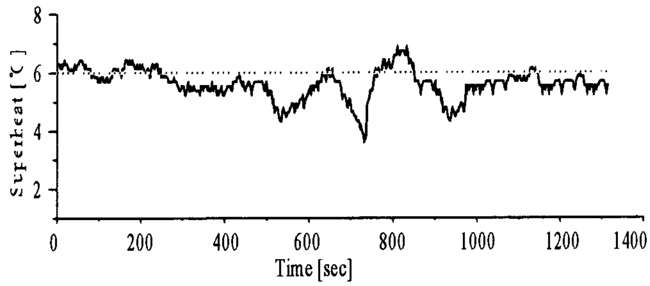
1. Jongmin Choi, Yongchan Kim and Jinho Ha, (2001), "Experimental study on superheat control of a variable speed heat pump", SAREK, Vol. 13, No. 4, pp. 233-241(in Korean).
2. A. Outtagarts, P. Haberschill, M. Lallemand, (1997), "The Transient Response of an Evaporator Fed Through an Electronic Expansion Valve", International Journal of Energy Research, Vol. 21, pp. 793-807.
3. Yoon, S. H. and Chang, H. W., (2001), "Empirical modeling and control performance simulation of an inverter heat pump system", Proceedings of the SAREK, pp. 725-730(in Korean).
4. LI HUA and S. K. Jeong, (2006), "An experimental model for decoupling control of a variable speed refrigeration system", KSPSE, Vol. 10, No. 3, pp. 81~87(in Korean).
5. Li Hua, Dong-woo Lee and Seok-kwon Jeong, (2005), "An experimental model for a variable speed heat pump system", Proceedings of ISAME, pp. 122-127.
6. Li Hua, Dong-woo Lee and Seok-kwon Jeong, (2005), "A decoupling model for superheat and capacity control of a variable speed refrigeration system",Proceedings of ISAE, pp. 132-140.



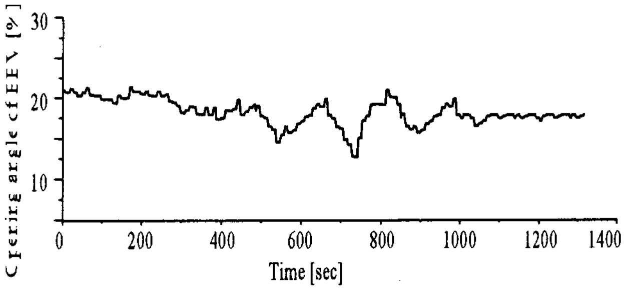
(a) The response of chamber temperature according to the thermal load



(b) The compressor frequency according to the thermal load



(c) The response of superheat according to the thermal load



(d) The opening angle of EEV according to the thermal load

Fig. 7 PI control response of chamber temperature and superheat when thermal load was varied