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Predictive functional control of an expansion valve for minimizing the superheat of an evaporator

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ABSTRACT

In a previous paper, a Predictive Functional Control (PFC) method was proposed to control the evaporator superheat with an electronic expansion valve. It has been shown that superheat may be more accurately controlled by PFC than the conventional Proportional-Integral-Derivative (PID) control. In this paper, the proposed methodology is extended to regulate the condensing pressure. In order to study the influence of this control method on the Coefficient of Performance (COP), experiments are conducted on a refrigerating machine by changing the cooling capacity from 120 to 30 kW. As PFC improves disturbance rejection compared to a PID control, it is possible to reduce the superheat setting value and to prevent any unevaporated refrigerant liquid from reaching the compressor. As a consequence the use of PFC leads to an increase of COP which depends on operating conditions.

Régulation prévisionnelle d'un détendeur utilisé pour réduire la surchauffe d'un évaporateur

Mots clés : système frigorifique ; détente directe ; régulation ; surchauffe ; évaporateur ; économie d'énergie

1. Introduction

The control of refrigerant flow is essential in any refrigerating system. Several physical parameters may be regulated such as temperature, pressure or liquid flow rate. On the one hand, the advanced control of evaporator superheat may be performed via an expansion valve which modulates the refrigerant flow, and the control of condensing pressure is carried out via the flow rate of the condenser cooling fluid. On the other hand, the methods of refrigerating capacity control include the following: (i) on-off cycling of compressors (ii) loading or unloading of cylinders for reciprocating compressors (iii)

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Nomenclature

BP	pressure at compressor suction line (bar)
C	setting value
cp	specific heat at constant pressure ($J\,kg^{-1}\,K^{-1}$)
Cyl^*N	compressor displacement ($m^3\,s^{-1}$)
D	diameter (m)
g	acceleration of gravity ($m\,s^{-2}$)
G	transfer function
h	enthalpy ($J\,kg^{-1}$)
HP	pressure at compressor discharge line (bar)
K	gain
L	tube length (m)
m	mass (kg)
$\dot{m}$	mass flow rate ($kg\,s^{-1}$)
Nu	Nusselt number
O_p	opening degree of the valve
Pr	Prandtl number
Q	heat flow (W)
Re	Reynolds number
S	exchange surface area (m^2)
T	temperature (K)
Td	time delay (s)
U	overall heat-transfer coefficient ($W\,m^{-2}\,K^{-1}$)
uc	control
W_{comp}	electrical power provided by the motor-compressor (W)
α	heat-transfer coefficient ($W\,m^{-2}\,K^{-1}$)
β	coefficient of the orifice equation
Δh	enthalpy difference ($J\,kg^{-1}$)
ΔT	superheat or temperature difference (K)
ΔTlm	log mean temperature difference (K)
η_i	isentropic efficiency
η_v	volumetric efficiency
λ	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
μ	dynamic viscosity (Pa s)
ρ	density ($kg\,m^{-3}$)
τ	time constant (s)

subscript

c	condenser
dp	two-phase flow
ext	external dimension
e	evaporator
int	internal dimension
is	isentropic transformation
li	saturated liquid (liquid phase)
m	model
r	refrigerant flow
sat	refrigerant saturation point
sp	single-phase flow
su	compressor's suction
sw	flow of water and antifreeze mixture
v	saturated vapour (vapour phase)
w	flow of water
wall	fluid property evaluated at wall temperature

superscript

in	inlet
o	outlet
∞	final operating condition
0	initial operating condition

compressor speed control. Several studies (Braun et al., 1989; Jakobsen and Rasmussen, 1998; Yao et al., 2004; Leducq et al., 2006) have demonstrated the potential savings associated with the use of optimal control. When a refrigerating plant has a number of actuators, it is possible to provide the cooling power for a desired temperature by various combinations of operating conditions. The purpose of these papers is to obtain an optimal control by considering the plant in its global nature. Another way consists to increase the Coefficient Of Performance (COP) by optimizing control on a single component of a refrigerating machine. As an example, the refrigerant at the evaporator outlet should be superheated to prevent any unevaporated liquid from reaching the compressor. A high value of superheat has an adverse effect on COP. In order to achieve energy savings, the superheat is regulated to a reasonably low setting, as investigated by Lin and Yeh (2007).

Several control methods are available for controlling the evaporator superheat via an Electrically driven Expansion Valve (EEV). Outtagarts et al. (1995a) presented a Proportional-Integral-Derivative (PID) control based on the plant characteristics obtained from the experiments. More recently, Lin and Yeh (2007) have developed new feedback control algorithms which incorporate a traditional Proportional Integral (PI) controller. The results of these studies show that the superheat may vary on a wide range in case of transient conditions and then the liquid refrigerant may enter the compressor. In order to keep the refrigerant superheat within a very restricted range with minimum oscillation, Zhu et al. (2000) have suggested combining PID laws with fuzzy parameters. Compared with the conventional PID, the time to reach the steady state is reduced, the control is better, but the superheat overshoot is not reduced. A dynamic neural network has also been used for evaporator control (Nanayakkara et al., 2002). This study shows that the superheat can be controlled within a desired limit although the learning process which requires a great amount of experimental data. To avoid such measurements, Changenet et al. (2008) have developed a method based on the physical modelling of the evaporator in order to use a Predictive Functional Controller (PFC). Some comparisons with a PID controller indicate that the PFC is a lot more robust from disturbances point of view and with a shorter response time. As a consequence, it seems possible to improve the energy efficiency of the refrigerating machine by using the PFC.

In addition to this previous study, one of the aims of this paper is to quantify the COP variation when PFC is used for controlling the evaporator superheat, instead of PID controller. Some experiments are conducted by changing the cooling capacity of a refrigerating machine which uses an EEV to modulate refrigerant flow from the condenser to the evaporator. In order to reduce possible disturbances at EEV inlet, the PFC is also implemented for regulating condensing pressure. Then investigations are performed on the minimum stable superheat setting value which can be used with