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The influences of the operating characteristics of an Electronic Expansion Valve (EEV) on the operational stability of an EEV controlled direct expansion air conditioning system

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ABSTRACT

This paper reports on a study on the influences of the operating characteristics of a proportional–integral (PI) controlled Electronic Expansion Valve (EEV) on the operational stability of a direct expansion (DX) air conditioning (A/C) system. Using the classical control theory, EEV's PI settings and time constant of EEV's temperature sensor were analyzed. The theoretical analysis results using the classical control theory were further verified experimentally using an experimental DX A/C system. The study results showed that a larger proportional or integral gain would lead to a high chance for the EEV–evaporator control loop to become unstable, while slowing down the rate of degree of superheat (DS) signal transfer by increasing EEV's time constants may help mitigate system's operational instability. The results confirmed that the operating characteristics of an expansion valve in a refrigeration system could impact its operational stability.

Les influences des caractéristiques de fonctionnement d'un détendeur électronique (EEV) sur la stabilité opérationnelle d'un système de conditionnement d'air à détente directe contrôlé par un EEV

Mots clés : Stabilité opérationnelle ; Dynamique du capteur ; Détendeur électronique ; Théorie du contrôle classique ; Système de Conditionnement d'air (A/C) à détente directe (DX) ; Paramètres PI

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Nomenclature

T	temperature [°C]
M_{re}	mass flow rate [kg h^{-1}]
K_p	proportional gain [—]
K_i	integral gain [—]
T_i	integral time [s]
R	thermal resistance [K kW^{-1}]
C_p	specific heat [kJ kg^{-1} K^{-1}]
V	volume [m^3]
e	relative error [—]
u_e	EEV control signal [—]
r_s	reference setting [—]
DS	degree of refrigerant superheat [°C]
t	time [s]

Greek letters

ρ	density [kg m^{-3}]
θ	time delay [s]
τ	time constant [s]
ϕ_0	offset adjustment parameter for a particular EEV [—]

Subscripts

a	air side
m	measured by the temperature sensor
e	evaporator
v	valve
re	refrigerant side
se	sensor

1. Introduction

Instability in a refrigeration system, conventionally known as hunting, is the phenomena of the oscillation of certain system operational parameters such as the degree of refrigerant superheat (DS), refrigerant mass flow rate and evaporating pressure. Hunting has been noticed not only in the refrigeration systems controlled by thermostatic expansion valves (TEVs) (Eames et al., 2014; Huang et al., 2014; Wedekind, 1971; Wedekind and Stoecker, 1968; Yasuda et al., 1983), but also those controlled by electronic expansion valves (EEVs) (Chen et al., 2008; Fallahsohi et al., 2010; Li et al., 2004; Qi et al., 2010). Hunting leads to a lower operational safety and a higher energy consumption (Liang et al., 2010), and therefore, should be avoided as far as possible for the safe and energy efficient operation of a refrigeration system.

There have been two different views on the causes of unstable system operation. The first concentrated on the inherent characteristics of an evaporator. Random fluctuation in a refrigerant mixture–vapor transition point was first described by Zahn (1964). Wedekind and Stoecker (1968, Wedekind, 1971) further indicated that the random oscillation of a transition point in an evaporator was due to the nature of two phase flow, which appeared to be related to the same mechanism causing the density wave instabilities. The theory of minimal-stable-signal (MSS), defined as a critical minimal DS at which a refrigeration system could exhibit unstable operation as a mixture–vapor transition point moving toward evaporator exit, was proposed by Huelle (1967). Huelle (1972) later introduced conceptually a so-called MSS line which is a monotone conic curve starting from the original point on a DS (X-axis) – cooling capacity (Y-axis) chart, for predicting the conditions of hunting, and considered the MSS line for a refrigeration system as one of the inherent characteristics of an evaporator itself. Chen et al. (2002) confirmed the existence of an MSS of ~ 4 °C at a specific cooling capacity for a TEV controlled refrigeration system, and attributed the primary reason of hunting to the flow type and nonlinear variation of heat transfer coefficient in an evaporator. However, the second view tried to explain the cause of hunting based on the influence of the operating characteristics of an expansion valve on system stability, as it would take some time for the DS signal to propagate through the expansion valve to adjust the refrigerant mass flow required, which was considered as the fundamental reason for hunting. A number of related modeling studies suggested that either increasing or decreasing the time constant of the TEV sensing bulb for measuring the DS at the exit of an evaporator would help reduce the hunting (Broersen and Vanderjagt, 1980; Ibrahim, 1998; Mithraratne et al., 2000). For TEV controlled evaporators, decreasing valve gain and increasing static superheat setting would also be beneficial to system operational stability (Mithraratne and Wijeysundera, 2001, 2002; Mithraratne et al., 2000).

Among these reported stability studies, only limited numbers of studies on the influences of the operating characteristics of an Electronic Expansion Valve (EEV) on system operational stability have been carried out. In an EEV-controlled refrigeration system, proportional and integral (PI) and proportional, integral and derivative (PID) control algorithms are extensively used for its EEV to regulate the EEV's opening for controlling refrigerant mass flow rate in response to DS at evaporator exit (Jolly et al., 2000; Qi et al., 2010). In practice, a PI controller is adequately capable to provide an acceptable control performance, without the need to consider the problems associated with the derivative actions, namely the need of properly filtering out the measurement noise (Visioli, 2006). In addition, in an EEV-controlled refrigeration system, a temperature sensor is used to measure the temperature of refrigerant at evaporator exit, so that the actual operating DS may be evaluated and sent to the EEV for control action. The temperature sensor acts in a similar manner to a TEV's sensing bulb in a TEV-controlled refrigeration system. On the other hand, it was previously shown that in a TEV-controlled system, the TEV's valve gain and the time constant of the TEV's sensing bulb (Mithraratne and Wijeysundera, 2001, 2002; Mithraratne et al., 2000) did impact the system operational stability, because the former directly affected the value of opening and thus the refrigerant mass flow rate, and the latter the time for the DS signal to propagate through the TEV to adjust the refrigerant mass flow rate. This suggested that the operating characteristics of a PI controlled EEV in terms of PI settings and the time constant of its temperature sensor may also similarly impact on the operational stability of an EEV-controlled system. However, no previous investigations on the influences of EEV's PI settings and the time constants of EEV's temperature sensor on the operational stability in an EEV-controlled refrigeration system may