Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ijrefrig

Indoor unit fault detector for a multi-split VRF system in heating mode

Younggy Shin[a,*], *Sarng Woo Karng*[b], *Seo Young Kim*[b]

[a] *Department of Mechanical Engineering, Sejong University, 98 Gunja-dong Gwangjin-gu, Seoul 143-747, Republic of Korea*

[b] *Center for Urban Energy System Research, Korea Institute of Science and Technology, 39-1 Wolgok-2dong, Seongbuk-gu, Seoul 136-791, Republic of Korea*

ARTICLE INFO

Article history:
Received 13 June 2013
Received in revised form
26 September 2013
Accepted 9 November 2013
Available online 19 November 2013

Keywords:
FDD (fault detection and diagnosis)
Heat exchanger fouling
State observer
Multi-split
VRF (variable refrigerant flow)
Heat pump

ABSTRACT

A multi-split VRF system operates unsteadily most of time due to the constantly varying refrigerant flow rates of associated indoor units. VRF systems require a different approach from conventional techniques to detect faults, which have developed based on steady-state operations. In this paper, two fault detection techniques are proposed. Their advantage is that they do not require the test data to be preprocessed to obtain steady-state data. The first technique is applied to detect heat exchanger fouling by a state observer, and the other technique is used to detect valve sticking by temperature variance. These techniques were not chosen haphazardly but were derived from physical reasoning. Their validity was confirmed by test data. The methodology developed in this study can be applied similarly to other HVAC equipment that operates mostly in transient states.

Détecteur des défaillances d'un système intérieur pour un système multi-split à écoulement variable en mode chauffage

Mots clés : Détection de défaut et diagnostic ; Encrassage des échangeurs de chaleur ; Observateur d'état ; Multi-split ; Débit variable de frigorigène ; Pompe à chaleur

* *Corresponding author*. Tel.: +82 2 3408 3284; fax: +82 2 3408 3333.
E-mail addresses: ygshin@sejong.edu, ygshin@sejong.ac.kr (Y. Shin).

http://dx.doi.org/10.1016/j.ijrefrig.2013.11.009

Nomenclature

$\mathbf{A}$	real system state parameter matrix
$\widehat{\mathbf{A}}$	dynamic model state parameter matrix
$\mathbf{B}$	real system input parameter matrix
$\widehat{\mathbf{B}}$	dynamic model input parameter matrix
$\mathbf{C}$	output parameter matrix
c_p	specific heat capacity [kJ kg^{-1} °C^{-1}]
d_p	diameter of valve port [m]
$\mathbf{e}$	error, deviation
$\mathbf{H}$	state observer feedback gain matrix
$h, \overline{h}$	enthalpy [kJ kg^{-1}]
$\dot{m}$	mass flow rate [kg s^{-1}]
MC	heat capacity of indoor unit (real system) [kJ °C^{-1}]
$\overline{MC}$	heat capacity of indoor unit (dynamic model) [kJ °C^{-1}]
p	pressure [kPa]
$\dot{Q}$	heat [kW]
S	error variance [°C^2]
T	temperature [°C]
t	time [s]
$\mathbf{u}$	input
UA	overall heat conductance of a real system [kW °C^{-1}]
$\overline{UA}$	overall heat conductance of a dynamic model [kW °C^{-1}]
$\dot{V}$	volumetric flow rate [m^3 s^{-1}]
$\mathbf{x}$	state variable vector
$\widehat{\mathbf{x}}$	state observer vector
$\mathbf{y}$	output vector

Greek symbols

θ	ratio of valve opening to its maximum [–]
ρ	density [kg m^{-3}]
τ	time constant [s]
ψ	non-dimensional function [–]

Subscripts

a	air
c	condenser
cl	closed loop
f	saturated liquid
i	in
o	out
ol	open loop
r	refrigerant

1. Introduction

Multi-split VRF (variable refrigerant flow) systems use one external unit that is connected to several indoor units. Multi-split systems are popular because they require less outdoor plant space than conventional central air conditioning systems, are less disruptive in fitting to existing buildings (particularly when occupied), and are able to cool and heat through common pipework. These systems all use refrigerant as the cooling/heating medium rather than chilled water/hot water, which is used in conventional hydraulic systems circulated by pumps. Because of their reduced space requirement and their flexible installation, multi-split systems can be quickly used to replace air conditioning systems in small- and medium-sized buildings.

As multi-split systems become one of the essential components in HVAC (heating, ventilating and air-conditioning) systems of buildings, it is necessary to develop an FDD (fault detection and diagnosis) algorithm of the system for automated building management. The market of automated building management is growing, and its success depends primarily on reliable FDD tools because they have a potential to serve in the information industry for energy savings and automated management.

The FDD algorithm should be able to monitor “soft faults” that do not require emergency stops so that timely remedial actions can prevent energy leaks and associated discomforts. Three general FDD approaches have been proposed (Li and Braun, 2007), namely model-based, data-driven and knowledge-based approaches (Chen and Lan, 2009; Cui and Wang, 2005; Zhao et al., 2012; Yang et al., 2013; Hou et al., 2006). Among them, model-based approaches have been most used because most HVAC systems are not heavily instrumented and can be manageably modeled (Piacentino and Talamo, 2013).

1.1. Model-based approach

A model is constructed on first principles, which are based on mass and energy conservation laws, and predicts performance at normal conditions. An essential advantage of using a model is that it does not require an exhaustively large amount of training data over the full spectrum of operation regions. However, the accuracy of model predictions is a critical issue that limits its usefulness. In general, steady-state models are used to impose the physical constraints of the FDD algorithm. For dynamic models, state observers and Kalman filters are used (Isermann, 2006; Navarro-Esbría et al., 2006).

1.2. Data-driven approach

Data-driven techniques assume that a system is a black box, where system characteristics are identified through associated sensor measurements. The number of sensors to be monitored can be reduced by applying first principles to the system. The most popular techniques are control chart (RamMaurya et al., 2010) and PCA (principal component analysis) (Wang and Xiao, 2004).

Control charts, also known as Shewhart charts or process-behavior charts, in statistical process control are tools used to determine if a manufacturing or business process is in a state of statistical control. PCA is a mathematical procedure that uses an orthogonal transformation to convert a set of observations