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Extension of a virtual refrigerant charge sensor

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ABSTRACT

The primary goal of the work described in this paper was to evaluate and extend a virtual refrigerant charge sensor (VRC) for determining refrigerant charge for equipment having variable-speed compressors and fans. Based on the evaluations, the original VRC sensor (termed model I) was found to work well in estimating the refrigerant charge level for systems with a variable-speed compressor. However, for extreme test conditions such as low compressor speed, the model I needed to be improved. To overcome the limitations, the model was modified to include a term involving the inlet quality to the evaporator (termed model II). The model II gave better performance for systems with a variable-speed compressor. When the superheat of the compressor was zero, neither model II could accurately predict charge level. Therefore, a third approach (Model III) was developed that includes the discharge superheat of the compressor.

Extension d'un capteur virtuel de charge de frigorigène

Mots clés : Système de détection et diagnostic d'anomalies ; Charge en frigorigène ; Capteur virtuel ; Compresseur à vitesse variable ; Pompe à chaleur ; Conditionneur d'air

1. Introduction

There have been laboratory studies that have documented the impact of refrigerant charge on the performance of air conditioning equipment, including work by Rice (1987), Moshen (1990), Breuker and Braun (1998), and Goswami (2002). Recently, Kim and Braun (2012) found that a refrigerant charge reduction of 25% led to an average energy efficiency reduction of about 15% and capacity degradation of about 20% when considering a range of different equipment. These studies showed that improper refrigerant charge could significantly decrease energy efficiency and capacity and lead to operating conditions that decrease equipment lifespan. Furthermore, refrigerant charge leakage can contribute to global warming in the long term. The leakage of refrigerant released to the atmosphere contributes to the greenhouse effect. The other long-term impact is caused by the extra carbon dioxide emissions from fossil fuel power plants due to lower energy efficiency.

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Nomenclature

EEV	Electronic expansion valve (–)
FXO	Fixed orifice (–)
$K_{dsh/sc}$	Constant characteristic of a given system related to discharge superheat of compressor (–)
K_{ch}	Empirical constant (–)
K_{sc}	Constant related to condenser subcooling and depending on the condenser geometry (–)
K_{sh}	Constant related to evaporator superheat and depending on the evaporator geometry (–)
$K_{sh/sc}$	Empirical constant (–)
$K_{x/sc}$	Constant characteristic of a given system related to inlet quality of evaporator (–)
K_x	Constant characteristic of a given system (–)
m	Refrigerant charge (–)
m_{total}	Total refrigerant charge (kg)
$m_{total,rated}$	Total refrigerant charge at rated condition (kg)
RMS	Root Mean Square (–)
P	Pressure (kPa)
P_{cond}	Condensing saturation pressure (kPa)
P_{evap}	Evaporating saturation pressure (kPa)
Q_{cond}	Condenser capacity (kW)
Q_{evap}	Evaporator capacity (kW)
T	Temperature (C)
T_{cond}	Condensing saturation temperature (C)
T_{evap}	Evaporating saturation temperature (C)
T_{sc}	Liquid line subcooling (C)
$T_{sc,rated}$	Liquid line subcooling at rated condition (C)
T_{sh}	Evaporator superheat (C)
$T_{sh,rated}$	Evaporator superheat at rated condition (C)
TXV	Thermostatic expansion valve (C)
$X_{hs,rated}$	Ratio of high side charge to the total refrigerant charge at rating conditions (–)
x	Refrigerant quality (–)
VRC	Virtual Refrigerant Charge (–)
W	Compressor input power (W)

Subscripts

dsh	Discharge superheat of compressor
dsh, rated	Discharge superheat of compressor at rated condition
evap, in	Inlet of evaporator
evap, in, rated	Inlet of evaporator for rated condition
hs	High side
hs, o	High side for zero-subcooling
hs, rated	High side for rated condition
ls	Low side
ls,o	Low side for zero-superheat
ls, rated	Low side for rated condition
rated	Rated operating conditions
sc	Subcooling
sc, o	Zero subcooling
sc, rated	Rated subcooling
sh	Superheat
sh, rated	Rated superheat
total	Total
total, o	Total for zero-subcooling and zero-superheat
total, rated	Total for rated condition

Greek

α_0	Fraction of refrigerant charge amount necessary to have saturated refrigerant liquid existing at the condenser outlet to the rated refrigerant charge mount at rating conditions.

Packaged air conditioners are widely used in 46% of all commercial buildings, serving over 60% of the commercial building floor space in the U.S. (EIA, 2003). The survey data indicates that annual cooling energy consumption related to packaged air conditioner is about 160 trillion Btus. Therefore, small improvements in packaged air conditioner performance can lead to significant reductions in overall energy use and environmental impact. Based on a survey and analysis of 215 rooftop units on 75 buildings in California (Jacob. et al., 2003), it has been shown that 46% of the units were not properly charged, which resulted in reductions in capacity and energy efficiency. The average energy impact of refrigerant charge problems was about 5% of the annual cooling capacity. Based on research of more than 4000 residential cooling systems in California, only 38% were found to have correct charge (Downey and Proctor, 2002) and the data from Blasnik et al. (1996) have indicated that an undercharge of 15% is common.

A survey and analysis of 215 rooftop units on 75 buildings in California (NBI, 2003) found that 46% of the units were not properly charged, which resulted in reductions in capacity and energy efficiency. The average energy impact of refrigerant charge problems was about 5%. A study by ADM (2009) evaluated 109 units at 75 buildings in California. This study found that 89 of the 109 units had fault conditions and 45% of the units were not properly charged. The survey data indicated that faults or non-optimal control caused performance degradation of about 20%.

The typical approach used to verify refrigerant charge for systems having variable-speed compressors was reviewed. Despite the fact that there are slight differences between manufacturers, the basic methods are based on using measured pressure at the service valve determined with a manifold gauge, when the system is operating at fixed-speed in a test mode set by a remote controller. A technician decides to add or remove refrigerant based on the difference between a pressure measurement and a target pressure specified by technical data provided by the manufacturer. These approaches can only determine whether the charge is high or low, not the level of charge. They also require pressure gauges or transducers be installed at the service valve. The installation of these gauges or transducers can lead to refrigerant leakage. Because of these limitations, the current protocols for checking refrigerant charge may be doing more harm than good in many situations.

The original VRC sensor (Li and Braun, 2009) uses a correlation in terms of superheat and subcooling that are determined using low-cost surface mounted temperature sensors. Parameters of the method can be estimated using