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A study on the operational stability of a refrigeration system having a variable speed compressor

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ABSTRACT

The increased use of variable speed compressors (VSC) in refrigeration systems can potentially lead to the unstable operation when compressor speed is varied from time to time for capacity control. The causes of unstable operation may be classified into two groups, one relating to control algorithms and the other to the inherent characteristics of systems. This paper reports on a study on the operational stability of a VSC refrigeration system due to its inherent characteristics. Based on experimental results, a new modified minimal stable superheat (MSS) line having a maximum MSS value and a minimal MSS value has been proposed. Using the modified MSS line, and supported by a series of purposely designed experiments, a detailed analysis on the operational stability of a VSC refrigeration system due to its inherent characteristics when its compressor speed is changed for capacity control has been carried out and presented.

Etude sur la stabilité lors du fonctionnement d'un système doté d'un compresseur à vitesse variable

Mots clés : Système frigorifique ; Système à compression ; Compresseur ; Vitesse variable ; Expérimentation ; Surchauffe

1. Introduction

In vapour compression refrigeration systems, there exists an expansion valve – evaporator control loop which regulates the refrigerant flow into the evaporator. The instability of such a control loop and the fluctuations of certain other operational parameters such as the degree of refrigerant superheat (DS), normally known as hunting, have been noted in several previous studies for thermostatic expansion valve (TEV) controlled evaporator refrigeration systems (Wedekind, 1971; Wedekind and Stoecker, 1966; Wedekind and Stoecker, 1968; Ibrahim, 2001; Mithraratne and Wijeysundera, 2002; Mithraratne et al., 2000).

Two groups of possible causes have been suggested in explaining the cause of hunting. The first concentrated on the influence of the control characteristics of an expansion valve on system stability (Dhar and Soedel, 1979; Brobesen, 1982; Higuchi and Hayano, 1982). Another, however, tried to

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explain the cause of hunting based on the inherent characteristics of an evaporator. Random fluctuations in the refrigerant mixture–vapour transition point due to the nature of two-phase evaporating flow were described (Wedekind, 1971; Wedekind and Stoecker, 1966; Wedekind and Stoecker, 1968). The concept of minimal stable superheat (MSS), which was defined as a critical minimal DS at which a refrigeration system could exhibit unstable operation, was first proposed by Huelle (1967). Huelle observed that hunting often occurred when a low DS was set in a refrigeration system even when its TEV was replaced by a manually operated expansion valve. Huelle (1972) later introduced conceptually a so-called minimal stable superheat signal line as shown in Fig. 1. The MSS signal line suggested by Huelle was a monotone conic curve starting from the original point. In addition, Huelle considered that the MSS in a refrigeration system was influenced by the inherent characteristics of its evaporator itself. Chen et al. (2002) experimentally confirmed the existence of such a MSS line, without further verifying whether the MSS line was actually a monotone conic curve as suggested by Huelle (1972).

When the concept of MSS line was introduced by Huelle (1972) based on his experiments, variable speed compressors had not been used. Hence, his MSS line was proposed based on a single speed compressor working with a narrow capacity modulating range. However, variable speed compressors are increasingly used nowadays because of their higher operating efficiency and wider capacity modulating ranges. Electronic expansion valves (EEV), on the other hand, have found more and more applications in refrigeration systems due to their quick response and the increased use of variable speed compressor (Lars, 1999). There have also been a number of reported studies on the hunting observed in EEV-controlled refrigeration systems (Outtagarts et al., 1997; Li et al., 2004; Aprea and Mastrubllo, 2002; Chen, 2005). Therefore, it became necessary to revisit the MSS line concept in the context of variable speed compressor refrigeration systems which have larger capacity modulating ranges.

This paper reports on a study on the operational stability for a VSC refrigeration system due to its inherent characteristics. Firstly, an experimental direct expansion (DX) air conditioning (A/C) plant, where all related experimental work was carried out, is briefly described. Secondly, the experimental work on qualitatively determining the relationship between MSS and the load imposed on a refrigeration system is presented, and a modified MSS line proposed. This is followed by reporting a detailed analysis on the operational stability of a VSC–EEV DX A/C system due to changes in compressor speed, using the modified MSS line and supported by a series of purposely designed experiments.

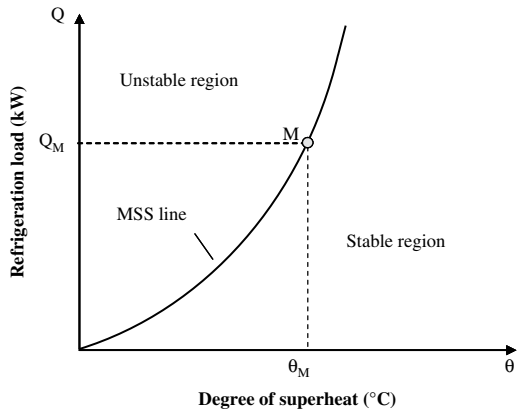

Fig. 1 – The MSS line as proposed by Huelle (1972).

2. Description of the experimental DX A/C plant

All the experimental work involved was carried out in the experimental DX A/C plant whose schematic diagram is shown in Fig. 2. The major components in the plant included a variable speed rotor compressor, a high-efficiency tube-louver-finned DX evaporator and an air-cooled tube-plate-finned condenser. The nominal output cooling capacity from the DX air conditioning plant was 9.9 kW (~2.8 RT), but its actual output cooling capacity can, however, be modulated from 15% to 110% of the nominal capacity through varying compressor speed.

The plant included a simulated air conditioned space, where load generating units (LGUs), having an adjustable heating capacity of up to 33.6 kW, were placed for simulating space cooling load.

The experimental DX A/C plant has been fully instrumented. All measurements were computerized, so that all the measured data can be recorded for subsequent analysis.

3. Experimentation on qualitatively determining the MSS line

3.1. *Experimental conditions*

Using the experimental DX A/C plant, a series of steady-state experiments were carried out to measure the MSS at different cooling loads, or equivalently the output cooling capacity of the DX A/C plant. Since the TEV and the EEV were installed in parallel, experiments were carried out in either a TEV- or an EEV-controlled DX A/C system.

Considering the inherent operational characteristics of a refrigeration system, at steady-state operation, a prescribed range of fluctuation of ±0.5 °C in DS was set. This range was used to assess whether hunting of DS occurred.

The procedures of experimentation were as follows. For both the TEV- and EEV-controlled systems, a fixed compressor speed corresponding to a fixed cooling load and a relatively high value of DS were firstly set. After the system reached a steady-state operation, the setting of DS was gradually lowered with an interval of ~0.1 °C, with the actually operating DS being monitored. When the actually operating DS could no longer be controlled within the ±0.5 °C of its setting, i.e., the prescribed fluctuation range, the last DS setting was then taken as the minimal stable superheat under that fixed system cooling load.

The corresponding load imposed on the experimental DX A/C system, at which the MSS was determined, was evaluated by

$$Q = m_a(h_{ai} - h_{ao}) \quad (1)$$

where m_a was the mass flow rate of air passing through the DX evaporator, at ~0.513 kg/s; h_{ai} the enthalpy of air at the