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Identification and digital control of a household refrigeration system with a variable speed compressor

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ABSTRACT

This paper presents an autoregressive–moving-average model with exogenous inputs (ARMAX model) and a digital controller for a household refrigeration system that uses a variable speed compressor. The ARMAX model takes as inputs the RPM of the compressor and environmental variables, such as temperature and relative humidity. Additionally, the output variables were defined as the temperatures of the freezer, the evaporator plate, and the compartment air and the compartment air relative humidity. The results of the experimental tests showed that the ARMAX model reproduces with high accuracy the dynamic behavior of the refrigeration system with less than 7% error. Tests of energy consumption and food storage were performed according to the NTC 2078 standard, which applies to household refrigeration systems manufactured or sold in Colombia. These tests indicated that the refrigeration system with a variable speed compressor consumes 15% less energy than an equivalent conventional refrigeration system and that the temperature profiles inside the compartment are more stable.

Identification et régulation numérique d'un système frigorifique domestique avec compresseur à vitesse variable

Mots clés : Identification du système ; Système frigorifique ; Compresseur à vitesse variable ; Régulation numérique

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Nomenclature

$\bar{e}$	Mean percentage relative error
n	Total data points
k	Current data point
y	Output variable
$y(k)$	k data point of output variable y
y_{ARMAX}	Output variable of the ARMAX model
$y_{ARMAX}(k)$	k data point of output variable of the ARMAX model
$y(t)$	Outputs of the system
$u(t)$	Inputs of the system that are being taken into account in the model
$e(t)$	Represents all the unknowns in the model (e.i. disturbances not being measured)
$A(q)$, $B(q)$, $C(q)$	Polynomials in the discrete variable q, whose parameters have to be found using input–output data from the system.
$G(z)$	Transfer function in the discrete operator z
T_s	Sample time of the transfer function
$T_{Freezer}$	Freezer temperature
RPM	Revolutions per minute
T_{room}	Room temperature
RH_{room}	Room relative humidity
$T_{Evaplate}$	Evaporator plate temperature
$T_{compartment}$	Compartment air temperature

1. Introduction

Household and commercial refrigeration systems are essentially composed of two heat exchangers (evaporator and condenser), an expansion valve (capillary tube), a compressor, and a device for control of the system (thermostat). The temperature in the compartment is maintained in an acceptable range due to the constant on/off switching of the compressor. Currently, commercial and household refrigeration systems are designed with consideration for extreme operating conditions, such as $T_{room} = 43\ ^\circ C$ and $RH_{room} = 60\%$. These conditions are defined in the Colombian standard NTC 2078 (ICONTEC, 2006) and result in a maximum heat load in the compartment, which the refrigeration system should be able to remove. In the daily use of these systems, these extreme conditions are usually not encountered; therefore, the refrigeration systems are oversized for the conditions in which they normally function. According to Schwarz (2001), this is the reason why the conventional refrigeration system consumes more energy than necessary, generates noise and why the temperature variation in the compartment is considerable.

In recent years, consumer interest has increased for refrigeration systems that consume less energy, have better performance, and offer greater functionality compared with standard products. Replacing a conventional compressor with a variable speed compressor in which the cooling capacity can be adjusted to the current thermal load of the system allows a considerable reduction in energy consumption and noise and more stable temperature profiles in the compartment (Schwarz, 2001). However, the replacement of the conventional compressor with a variable speed compressor changes the control paradigm for refrigeration systems, because the classic on/off control used in these systems does not permit the modulation of the cooling capacity in a variable speed compressor. To obtain lower power consumption and more stable temperature profiles, it is necessary for the refrigeration system to be supervised by a control system that modulates the cooling capacity of the variable speed compressor based on the current thermal load of the refrigeration system. Obtaining a robust model of the refrigeration system is of great importance to the design of the control system because this model would allow the evaluation of different control policies and the overall behavior of the system before they are implemented in an operational model.

Prior investigations have studied the thermal behavior of refrigeration systems using energy and mass balances (Koury et al., 2001; Lei and Zaheeruddin, 2005; Morini and Piva, 2007). In general, these models reproduced the dynamic behavior of the refrigeration system, but their design purposes and evaluations of control systems were limited due to system complexity and high order.

Li et al. (2008) defined an empirical model to determine the temperature variation within the compartment and the

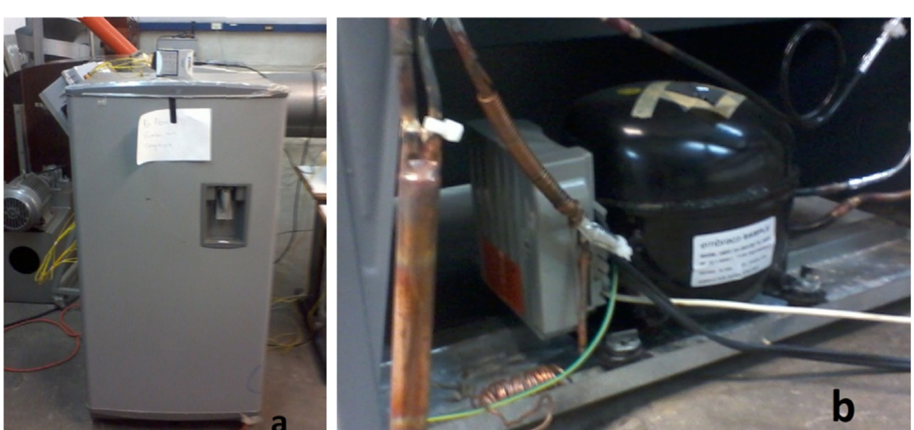

Fig. 1 – Refrigeration system: a) Refrigerator and b) variable speed compressor.