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Automotive electric scroll compressor: Testing and modeling

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ABSTRACT

The aim of this research is to characterize experimentally and by modeling an electrically driven automotive scroll compressor. The experimental characterization is carried out through 13 tests at compressor speeds varying between 3000 and 5000 rpm. The DC/AC converter used to supply the compressor was characterized through a calorimetric balance, obtaining an efficiency that depends only on the compressor speed, ranging from 92.5%, for a compressor speed of 1500 rpm, to 97.5%, for a compressor speed of 5000 rpm. The experimental results are used to identify the parameters of a semi-empirical compressor model, which is able to predict with an acceptable accuracy the main outputs of the mathematical model: confidence limits on the exhaust temperature of ±1.0 K, on the refrigerant flow rate of ±2 g s^{-1} and on the compressor power of ±60 W. This model is then used to determine the compressor cooling power at different compressor speeds and condensing pressures.

Compresseur automobile à spirale électrique à vitesse variable : essais et modélisation

Mots clés : Compresseur à spirale ; Vitesse variable ; Essai ; Modélisation ; Voiture ; Conditionnement d'air

1. Introduction

With the introduction of electrically driven vehicles, either supplied by batteries or fuel cells, the interest for electrically driven scroll compressors has increased enormously. These kinds of compressors are supplied by a DC/AC converter, which allows to work at any rotational speed by improving the overall air conditioning performance. These compressors also have lower risks of refrigerant leakages when compared to piston compressors, due to the fact that these are enclosed in a semi-hermetic housing. This is a very important point when considering the high Global Warming Potential of the refrigerants used in car air conditioning systems: around 1430 for R134a according to ASHRAE, 2009.

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Nomenclature

AU	heat transfer coefficient, W K^{-1}
c	specific heat, J kg^{-1} K^{-1}
$\dot{H}$	enthalpy flow rate, W
h	specific enthalpy, J kg^{-1}
K	lubricant or oil fraction
$\dot{M}$	mass flow rate, kg s^{-1}
N	rotational speed, s^{-1}
P	pressure, Pa or bar
$\dot{Q}$	heat flow rate, W
R	electrical resistance, Ω
$\dot{R}$	residuals, W
r	ratio
s	specific entropy, J kg^{-1} K^{-1}
t	temperature, °C
V	volume, m^3 or voltage, V
v	specific volume, m^3 kg^{-1}
w	specific work, J kg^{-1}
$\dot{W}$	power, W

Subscripts

0	constant values
a	air
amb	ambient
cal	calorimeter
cd	condenser
cor	Coriolis
cp	compressor
el	electrical
eq	equivalent
ev	evaporator
ex	exhaust
fan	fan
g	vapor
gw	glycol water mixture
in	internal
inv	DC/AC converter
l	liquid
lamps	lamps
loss	loss
lub	lubricant
m	motor
meas	measured
nom	nominal
oil	oil
r	refrigerant
ref	reference
s	isentropic or swept
sd	slip
sim	simulated
su	supply
v	volumetric, volume
w	water or wall

Greek symbols

Δ	difference or differential
α	power loss factor
ε	effectiveness, coefficient
$\bar{\varepsilon}$	error
Φ	error function
η	efficiency
ζ	solubility

These compressors normally work at high rotational speed which allows to reduce their swept volumes and thus their weights, by reducing with this the car electrical consumption. This combined with the use of a brushless motor and the main advantages of the scroll technology (low supply and exhaust pressure drop, no clearance volume effect) make the electric scroll compressor attractive against its competitors (fixed volume scroll and piston compressors, and wobble plate compressor).

This kind of compressor has been mainly studied in a whole automotive air conditioning system in some studies such as the ones proposed by Akabane et al. (1989) and by Yoshii and Tamura (1990). These studies do not give any detailed experimental characterization of the scroll compressors. An alternative hybrid scroll compressor (Yoshii and Tsuboi, 2004) has also been introduced, which can be driven mechanically or electrically. Mechanical drive is used when the vehicle is driven by the combustion engine and the electrical drive when is driven by the electrical motor.

The study presented here is mainly focused on the experimental characterization of an electrically driven scroll compressor and its modeling, and it is the continuation of a similar study carried previously out by Cardol et al. (2001). They characterized experimentally the DC/AC converter and the compressor, and developed a semi-empirical model for the compressor, which had a swept volume of the order of 20 cm^3.

The contribution developed in the present study allows providing additional information about the performance of this kind of compressor, which has still not been entirely characterized in the literature.

2. Test bench description

2.1. *Test bench overview*

The tests performed in this research study are mainly carried out to analyze the overall refrigeration system performance under different working conditions. Several tests were performed to characterize each component and to study the whole system behavior, but in this article only the test related to the compressor will be presented. The test bench used here is shown in Fig. 1. The main interest of this study is focused on the compressor and on the DC/AC converter.

The compressor tested here is an electrically driven automotive scroll compressor supplied by a DC/AC converter. This compressor is driven by a brushless motor. In this type of motor, the rotor is a permanent magnet and the stator is supplied with an AC excitation. The compressor is mounted horizontally and the refrigerant circulates first through the electric motor, to cool it, entering after to the compression