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Comparison between a crank-drive reciprocating compressor and a novel oil-free linear compressor

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ABSTRACT

Reciprocating compressors, driven by induction motors through a crank mechanism, have been commercially used over many years for refrigeration. An oil-free linear compressor driven by a moving magnet motor was designed, for a refrigeration system with a compact heat exchanger. Measurements using nitrogen are reported here to compare the motor performance and overall efficiencies of the two types of compressor with comparable design parameters. The experimental results show that the moving magnet linear motor has a much higher motor efficiency than the conventional induction motor, particularly at low power inputs. However, with a much smaller clearance volume (approaching zero), the crank-drive compressor demonstrates a higher volumetric efficiency based on the swept volume, that is approximately 20% higher than the linear compressor when operated at its maximum stroke (13 mm). It is anticipated that with a revised design, the overall performance of the linear compressor could be enhanced further.

Comparaison entre un compresseur à piston entraîné par vilebrequin et un compresseur linéaire sans huile

Mots-clés : Moteur linéaire ; Moteur à induction ; Entraînement par vilebrequin ; Compresseur linéaire sans huile ; Efficacités

1. Introduction

The piston in a conventional reciprocating compressor commonly used for refrigeration is driven by an induction motor through a crank mechanism, providing a reciprocating motion to compress the gas. The presence of the crank and bearings reduces the mechanical efficiency significantly. Furthermore, oil lubrication in crank-drive compressors narrows both the choice of refrigerants and their operating temperature range. Oil films inside the heat exchangers lower the heat transfer coefficients, especially in compact heat exchangers.

These problems can be mostly solved in a linear compressor, in which the piston is directly coupled to a linear oscillating motor. The spring suspension system ensures that the piston moves linearly, and there is a small radial clearance (~10 μm) between the piston and cylinder to provide a so-called ‘clearance seal’. So there is no physical seal, but there will be a leakage loss, and this is discussed later with Fig. 13.

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Nomenclature

A	area (mm^2)
BLDC	brushless direct-current
c	radical clearance (μm)
C	capacitance (F)
CL	clearance
CSIR	capacitor start induction run
DC	direct current
f	frequency (Hz)
F	force (N)
FE	finite element
FFT	fast Fourier transform
HDAQ	high-speed data acquisition
i	current (A)
k	stiffness (kN m^{-1})
L	inductance (H) or length (mm)
LDAQ	low-speed data acquisition
LVDT	linear variable differential transformer
m	moving mass (kg)
$\dot{m}$	mass flow rate (g s^{-1})
n	polytropic index
P	pressure (bar)
R	resistance (Ω) or specific gas constant (J kg^{-1} K^{-1})
RSIR	resistive start induction run
T	temperature (K)
TC	thermocouple
V	volume (mm^3) or voltage (V)
VF	vector field
$\dot{W}$	power (W)
x	displacement (mm)

Greek

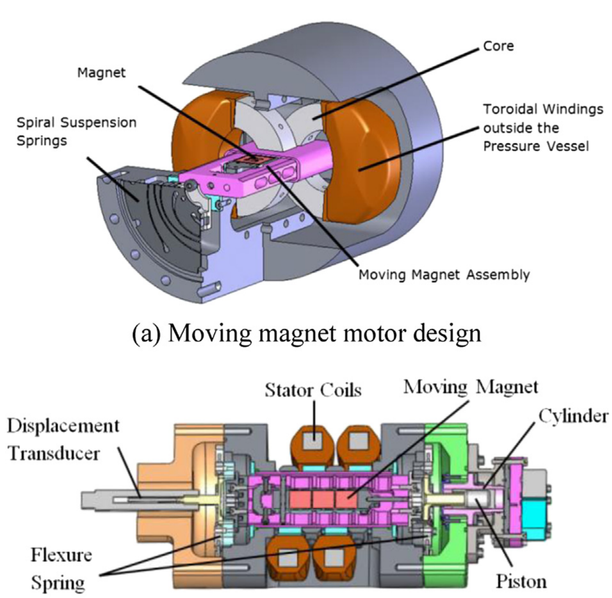
γ	heat capacity ratio
η	efficiency
β	damping coefficient

Subscripts

adb	adiabatic
b	body
c	cylinder
dis	discharge
e	experimental
EMF	electromotive force
g	gas
in	input
m	motor/mechanical
t	thermodynamic
o	overall
S	swept
suc	suction
V	volumetric

The elimination of the crank makes oil-free operation possible in linear compressors, which is one of the main advantages. Linear compressors operate at resonance in order to minimise the drive current, allowing higher motor efficiency and a reduction in the size of the motor as well. Bansal et al. (2011) reviewed the advantages of linear compressor technologies over traditional crank-drive reciprocating compressors for domestic applications and concluded that linear compressors offer higher efficiency and a more promising alternative to control the refrigeration capacity.

Since the 1970s, there have been some developments in this area. Bradshaw et al. (2011) have reported both the early and some more recent linear compressor developments. Bailey et al. (2010–2011) reviewed the three generations of moving coil linear compressors designed at the University of Oxford for space application (Bradshaw et al., 1986; Davey, 1990; Bailey et al., 2001). Liang et al. (2013) have reported on the recent development of a moving magnet linear compressor, other examples of which can be found in Beale and Scheck (1986), Yarr and Corey (1995), Nasar and Boldea (1997) and Lilie (2008).



(a) Moving magnet motor design

(b) Cross section of the linear compressor and motor

Fig. 1 – Design of the 100 W Oxford moving magnet compressor.

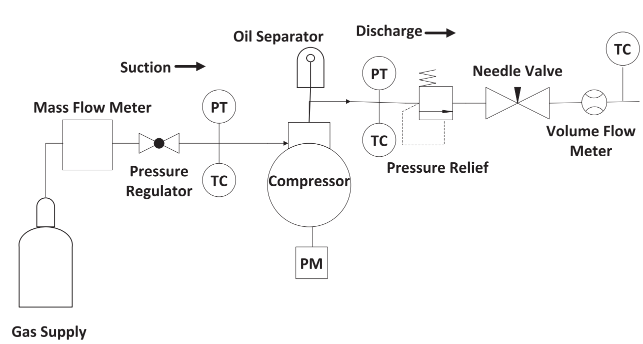


Fig. 2 – Crank-drive compressor test rig diagram using nitrogen (PT: Pressure Transducer, TC: Thermocouple, PM: Power Meter).