international journal of refrigeration 36 (2013) 786–794

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A sensitivity study of size parameters in a twin-type rolling piston compressor

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ARTICLE INFO

Article history:
Received 12 January 2011
Received in revised form
20 July 2012
Accepted 30 August 2012
Available online 7 September 2012

Keywords:
Rolling piston compressor
Dynamic analysis
Sensitivity study
Energy Efficiency Ratio
Optimization

ABSTRACT

In this paper, numerical studies on size parameters has been conducted to improve the performance of a twin-type rolling piston compressor, which has two cylinders called upper and lower cylinders with phase difference of 180°. In order to verify the computational reliability, the simulated results were compared with experimental ones. Sensitivity analysis of each parameter has been undertaken to investigate the influence of the parameters on compressor performance. Especially, size optimization has been studied to find an optimal combination of size parameters based on the sensitivity analysis of each parameter at the given operational condition and working volume. It was demonstrated that the maximum limits on the valve lift (y_{max}) and the suction port diameter (D_sp) showed the highest sensitivity to the compressor performance and optimum design condition, which corresponded to an Energy Efficiency Ratio (EER) that is 2.6% higher compared to the reference condition.

Etude sur la sensibilité des paramètres des dimensions menée sur un compresseur à deux pistons roulants

Mots clés : compresseur à piston roulant ; analyse dynamique ; étude sur la sensibilité ; efficacité énergétique ; optimisation

1. Introduction

The compressor is the core in a refrigeration and air-conditioning system, and consumes most of the energy in the system. Thus, focus is being put on the improvement of compressor performance in recent years. Furthermore, the replacement of anti-environmental refrigerants and energy-saving demand have recently caused changes in the components and operation of vapor compression plants; in particular, compressors have been experiencing upgrades and modifications.

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http://dx.doi.org/10.1016/j.ijrefrig.2012.08.027

Nomenclature

A	area (m^2)
b	vane thickness (m)
F	force (N)
F_p	gas force on the roller (N)
F_n	normal force on the vane tip (N)
F_{ec}	centrifugal force on the eccentric shaft (N)
F_h	resultant gas force on the side of vane (N)
F_d	discharge force on the vane (N)
F_k	Spring force on the vane (N)
F_m	friction force on the top and bottom surface (N)
F_{uw}	centrifugal force of upper balance block (N)
F_{dw}	centrifugal force of down balance block (N)
F_{mj}	force on the main bearing (N)
F_{sj}	force on the sub bearing (N)
F_{ec}	eccentric force of the roller (N)
k	spring constant ($N\ m^{-1}$)
M	mass accumulated in control volume (kg)
$\dot{m}$	mass flow rate ($kg\ s^{-1}$)
n	ratio of specific heats
P	pressure (Pa)
P_u	pressure of gas at the upstream (Pa)
P_r	ratio of pressure of gas at the upstream to pressure of gas at the downstream ($=P_u/P_d$)
R	gas constant ($kJ\ kg^{-1}\ K^{-1}$)
R_1	R_2 reaction force on the vane (N)
T_u	temperature of gas at the upstream
V	volume (m^3)
l_{vc}	contact length between the vane and cylinder (m)
r_v	radius at vane tip (m)
x	vane extension length (m)
y	valve displacement (m)
$\dot{y}$	valve velocity ($m\ s^{-1}$)
$\ddot{y}$	valve acceleration ($m\ s^{-2}$)

Greek letters

ρ	density of the refrigerant ($kg\ m^{-3}$)
α	angle from vane tip center to the roller center and cylinder center (degree)
θ	crank angle (degree)

Subscript

1	upper cylinder
2	lower cylinder
c	control volume
in	inlet direction
n	normal direction out outlet direction r radial direction
t,θ	tangential direction

The usage of rotary compressors has been increasing over the years through a good combination of the properties of a rotary compressor, such as quiet and smooth operation, simple and compact construction, and good reliability and efficiency (Al-Hawaj, 2009; Teh and Ooi, 2009). Various methods have been found to improve the performance of this kind of compressor. Examples include the inverter technique to match the load of a compressor for the purpose of saving energy, coating technology to reduce the noise and friction loss, lubricant and leakage loss studies to achieve higher cooling capacity, and so on. Apart from these methods, there is another effective method for improvement, which is called parametric study.

A literature survey shows that a relatively large amount of work has been done on parametric study for the optimization of compressor performance. Ooi (2005) proposed a mathematical model that was linked to an optimization algorithm to search a combination of six design dimensions and seven sets of constraints for optimum compressor performance with minimum mechanical losses. Yanagisawa and Shimizu (1985) found that a short length/diameter configuration of the cylinder was effective to decrease friction losses at the vane tip and sides and at the rolling piston bearing. Rong and Wen (2009) demonstrated a proper design of the key size parameters with a simplified model. Kim (1999) studied size optimization in a rolling piston-type compressor, in which the chamber configuration and determining displacement volume were considered.

Due to the complex structure of a compressor, each parameter may influence on the overall compressor performance, and the respective influences may interact with each other. For example, a bigger suction port yields a smaller suction loss, while resulting in an increase in the cylinder height, which leads to greater gas leakage. Previous works, however, have just studied the size parameters partially or separately.

In this paper, a numerical, interactional, size parametric study of a twin-type rolling piston compressor has been undertaken, and an optimum combination of the parameters has been found.

2. Related theories

2.1. Compressor structure

Fig. 1 showed the cross sectional view and plane view of a twin-type rolling piston compressor, respectively. During the operation, the roller rotates, and a working space is formed by the inner wall of the cylinder. The roller and the vane change in size, and hence result in compression and expansion of the working fluid, which forms a complete compressor working cycle. A typical cycle takes two motor revolutions to be completed.

2.2. Pressure calculation in a control volume

In order to calculate the pressures in the upper and lower cylinders, it is necessary to drive the related control volumes, as shown in Fig. 2a. For example, a suction pipe, a suction chamber, a compression chamber, a clearance volume, and a Helmholz resonator volume are generally considered with either the upper or lower cylinder.

As shown in Fig. 2a and c, the clearance volume consists of the volume in the cylinder caused by the cutter angle and the