international journal of refrigeration 35 (2012) 1734–1743

Available online at www.sciencedirect.com
SciVerse ScienceDirect
journal homepage: www.elsevier.com/locate/ijrefrig

Analysis of the revolving vane (RV-0) expander, Part 1: Experimental investigations

Alison Subiantoro, Kim Tiow Ooi*[1]

Thermal and Fluids Engineering Division, School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore

A R T I C L E I N F O

Article history:
Received 15 October 2011
Received in revised form
26 March 2012
Accepted 19 April 2012
Available online 26 April 2012

Keywords:
Experimentation
Rotary compressor
Expansion
Compressed air
Efficiency
Energy

A B S T R A C T

A revolving vane expander prototype based on the RV-0 mechanism design has been fabricated and tested. The range of operational conditions studied is of suction pressures of up to 6 bar (abs) with a constant discharge pressure of 1 bar (abs) and operational speeds of up to 900 rpm. The machine has been shown to work without any significant operational problem in the range of operational conditions tested. The analysis includes the effects of various operational pressures and speeds to the flow rate, leakage and mechanical performances of the expander. The findings show that the prototype machine has the volumetric efficiency of up to 55% with the major leakage paths due to the lip seal and at the radial clearances, contributing to around 50% and 40% of the total leakage, respectively. The isentropic efficiency was found to be up to 17.5% with the frictional losses caused mainly by the journal bearings.

Analyse du détendeur rotatif à palettes (RV-0), Partie 1 : étude expérimentale

Mots clés : Expérimentation ; Compresseur rotatif ; Détente ; Air comprimé ; Efficacité ; Énergie

1. Introduction

With the banning of the environmentally damaging synthetic refrigerants, natural refrigerants, especially CO_2, have been studied and proposed as an alternative in the recent years (Lorentzen, 1994, 1995). However, the efficiency of the system is not as competitive as the conventional systems. This is largely due to the large throttling loss suffered by the system. Recovering the expansion work with expanders has been proposed as one of the methods to overcome this problem

* *Corresponding author*. Tel.: +65 6790 4674; fax: +65 6792 4062.
E-mail addresses: alis0004@ntu.edu.sg (A. Subiantoro), mktooi@ntu.edu.sg (K.T. Ooi).
[1] Tel.: +65 6790 5511; fax: +65 6792 4062.
0140-7007/$ – see front matter © 2012 Elsevier Ltd and IIR. All rights reserved.
doi:10.1016/j.ijrefrig.2012.04.015

Nomenclature

h	specific enthalpy [J kg^{-1}]
l	length [m]
m	mass [kg]
P	power [W]
p	pressure [Pa]
r	radius [m]
R	gas constant [J kg^{-1} K]
T	temperature [K]
Greek letters	
γ	adiabatic index [–]
η	efficiency [–]
ω	angular velocity [rad s^{-1}]
Subscripts	
atm	atmospheric
c	cylinder
disc	discharge condition
exp	expander
r	rotor
suct	suction condition
tot	total
th	theoretical
v	volumetric

(Lorentzen, 1994). The early studies have suggested that expanders can increase the COP of the CO_2 system by up to 40% (Robinson and Groll, 1998).

Since then, various types of expanders have been studied. Baek et al. (2005a,b) studied the piston-cylinder expansion device. They also pointed out the challenge to control the expander inlet flows. Yang et al. (2009b) and Jia et al. (2009) investigated the rotary vane expander and discussed the internal leakage issues. Fukuta et al. (2009) also developed a rotary vane expander and studied the CO_2 expansion process involved. Li et al. (2009) and Matsui et al. (2009) studied the rolling piston expander. Other mechanisms like screw (Kovacevic et al., 2006), scroll (Kim et al., 2008) and swing piston (Guan et al., 2006) have also been investigated. In another paper, Huff and Radermacher (2003) compared the rotary vane, rolling piston, screw and scroll expanders. They concluded that the screw expander is preferable due to its high efficiency and simple flow controls.

Teh and Ooi (2006) introduced a new rotary machine design called the revolving vane (RV) mechanism. Unlike the conventional rotary machines where the cylinders are stationary, the cylinder is allowed to rotate together with the rotor and the vane, resulting in smaller relative velocities at the rubbing parts. This, in turn, reduces the friction loss of the mechanism (Subiantoro and Ooi, 2011; Teh and Ooi, 2009b). The volumetric efficiency (Teh and Ooi, 2009c) is also expected to be better than other conventional machines. The working cycle of the mechanism when used as an expander is shown in Fig. 1. In the subsequent developments, an improved model of the RV mechanism has been proposed, whereby the vane is rigidly fixed to the driving component (Ooi and Teh, 2008). To easily differentiate the two RV mechanisms in the subsequent discussions, the original design will be called the RV-0 design, while the improved design will be called the RV-i design.

Since then, an RV-0 compressor prototype has been built and tested to confirm the mechanism functionality (Teh and Ooi, 2009a). However, the mechanism has never been tested for expander applications. Recently, a novel RV-0 expander prototype was built to prove the working concept and to carry out a preliminary study on the characteristics of the mechanism. The results will be presented and discussed in this paper. The experimental data will then be used to verify the mathematical models developed. This is presented in the second part of this paper series.

2. Experiments

2.1. *The prototype*

The RV-0 expander prototype is built by modifying the RV-0 compressor built by Teh (2009) and Teh and Ooi (2009a). The schematic drawing of the prototype is shown in Fig. 2. The main dimensions of the prototype are listed in Table 1. The original suction and discharge holes are now blocked. New discharge and suction holes are constructed at the rotor body and at the cylinder and the rotor endfaces, respectively, as shown in Figs. 2 and 3. Due to the eccentric nature of the RV-0 mechanism, when the suction hole at the cylinder begins to uncover at the beginning of a cycle, high-pressure gas flows in through the hole, into the suction port at the rotor and eventually into the suction chamber. As the expander rotates further, the high-pressure gas flows into the working chamber directly through the cylinder suction hole, while the rotor suction port is now covered by the cylinder inner endface wall.

The control of the inlet flow is carried out with a stationary blocker that will cover the suction port, which is located at the endface of the cylinder, during a predetermined range of the operational angles. This prevents the high-pressure gas to flow into the working chamber during the expansion process, causing the gas inside to expand. As the expander rotates further, the suction port is exposed and high-pressure gas flows into the expander, resulting in the suction process. The design concept and the suction hole blockers are illustrated in Fig. 4.

Four suction hole blockers are designed with opening angles of 156.7°, 183.7°, 198.8° and 209.1° for suction pressures of 2–5 bar (abs.), respectively. These blocker sizes are obtained by assuming that the gas will expand isentropically in the expander. The blockers are made of PTFE material to minimize friction. They are secured to the upper bearing with two pins. Compression springs are installed between the upper bearing and the blocker surfaces to press the blockers toward the cylinder endface to ensure proper covering of the suction holes during the expansion process (see Fig. 5).