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Analytical study of the endface friction of the revolving vane mechanism

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ABSTRACT

The effects of the fluid friction acting on the endfaces of the revolving vane (RV) machine, where the cylinder rotates together with the rotor, are investigated analytically with closed form solutions. It was found that the endface losses of the RV machine are generally affected by both the relative velocity and the eccentricity between the rotor and the cylinder. The endface loss of an RV machine with the simply supported bearing arrangement is found to be always lower than that with the cantilever arrangement.

When compared to a similar rotary machine but with a stationary cylinder, the RV machine used in this study exhibits a 95% decrease in the endface loss, while in the wider practical dimensions range, an RV machine consistently shows at least a 50% lower in endface loss.

These findings supply more proof to the claim of the suitability of the employment of the RV mechanism in high-speed and high-pressure applications.

Etude analytique du frottement sur la surface de contact, d'une machine rotative à cylindre tournant

Mots clés : Désorption ; Miniaturisation ; Transfert de masse ; Microcanal ; Pompe à chaleur

1. Introduction

Reciprocating compressors are known to have vibration and noise problems. To overcome these issues, various new types of rotary compressor have been invented. They include the screw, scroll, rotary vane and rolling piston compressors, among others. Screw compressors are commonly used in high cooling capacity range (Wu et al., 2004, 2007; Wang et al., 2009;

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Nomenclature

A	area [m^2]
S	ratio between the shaft and the rotor radii [–]
H	ratio between the cylinder shaft hole and the rotor radii [–]
e	eccentricity – the gap between the rotor and the cylinder centers [m]
F	force [N]
l	length [m]
L	loss ratio [–]
P	power [W]
r	radius [m]
R	radius ratio [–]
t	time [s]
T	torque [N m]
V	velocity [m s^{-1}]
x	distance [m]
δ	endface gap [m]
Δ	difference [–]
φ	operating angle [rad]
μ	fluid viscosity [Pa s]
θ	angle [rad]
ρ	density [kg m^{-3}]
τ	shear stress [N m^{-2}]
ω	angular velocity [rad s^{-1}]

Subscripts

0	stationary cylinder; 0-angle
1	configuration 1
2	configuration 2
A	case A
B	case B
c	cylinder
h	cylinder shaft hole
r	rotor
s	shaft
v	vane

Stosic et al., 2003; Kovacevic et al., 2006) and scroll compressors are used in medium capacity ranges (Duprez et al., 2007, 2010). There leaves the rotary vane, which is commonly used in low cooling capacity range of less than 10 kW.

As compared to the reciprocating counterpart, rotary sliding vane and rolling piston compressors exhibit better vibration and noise characteristics. In addition, they are usually more compact and simpler in their overall construction. However, these machines suffer from high frictional losses caused by high relative velocities between the sliding components. This, in turn, reduces the mechanical efficiencies of the machines. In addition, these frictions also cause wear and tear which will eventually give rise to reliability issues. In the early applications of rotary compressors, Kruse (1982), and Badr et al. (1985) reported that large frictional losses occur at the sliding contacts between the vane tips and the stationary cylinder in rotary sliding vane compressors, resulting in the poor compressor performance and has limited the use of rotary sliding vane compressors in some practical applications. Pandeya and Soedel (1978), Ozu and Itami (1981), Yanagisawa and Shimizu (1985) and Ooi (2005) showed that even in the more popular rolling piston compressors, significant friction loss is present between the eccentric and the roller. This high friction occurring at the rubbing surfaces has limited the development of high-speed rotary compressors.

The friction issue also limits the efficient use of rotary compressors for high-pressure applications, such as those in the carbon-dioxide refrigeration systems. This is because it is necessary to reduce the clearance gaps in order to reduce leakage in such applications (Süβ and Kruse, 1998; Collings et al., 2002), since leakage is a significant problem in such applications and it can reduce COP by as much as 16% (Ooi, 2008). However, reducing the clearance gaps will increase the frictional losses of the compressor even further.

The Revolving Vane (RV) mechanism design (Teh and Ooi, 2006) was invented to circumvent these high friction issues of rotary machines. In this design, the cylinder rotates together with the rotor, resulting in significant reductions in relative velocities between the rubbing components. Preliminary studies have shown that the RV mechanism exhibits an almost 20% reduction in the overall frictional loss over a rolling piston (RP) compressor (Teh and Ooi, 2009b). The volumetric efficiency is also expected to be better than an RP compressor (Teh and Ooi, 2009c). In addition, the unique situation experienced by the discharge valve of the RV compressor was also found to bring additional benefits to the performance of the valve when appropriately designed (Teh et al., 2009). The RV concept has been shown to work for compressor applications experimentally (Teh and Ooi, 2009a). The same design concept has also been used in expander (Subiantoro and Ooi, 2009, 2010). More in-depth discussions on the RV mechanism design concept will be presented in Section 2.

In their study, Teh and Ooi (2009b) have shown that the frictional losses of the RV mechanism are effectively reduced to those at the vane side and the bearings while the losses at other places, including the endfaces, are either eliminated or reduced. Specifically, the frictions at the endfaces are significantly reduced as the relative velocity between the rotor and the cylinder endfaces is much lower, caused by the fact that the two components rotate together. This is significant to the improvement of the mechanical efficiency since the endface losses contribute around 25% of the total friction loss in a rolling piston compressor (Pandeya and Soedel, 1978; Ooi, 2005). However, it can be seen that due to the eccentric nature of the rotations of the rotor and the cylinder, the relative velocity cannot be completely eliminated; leaving a possibility that the friction losses may become significant if the mechanism is inappropriately designed. As an illustration, Teh and Ooi (2009b) reported a power loss of only around 4% of the total friction loss of their RV compressor. However, if the same compressor is shortened by enlarging cylinder radius by 20%, the contribution of the endface friction power loss will increase to more than 8%.

In the interest of designing an RV machine for high-speed and high-pressure applications, friction losses must be