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Experimental study of a novel hinged vane rotary turbine – part I: The effect of different vane thickness and vane weight on turbine performance

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ABSTRACT

The structure of newly designed turbo rotary Pars turbine shows similarities with the structure of commercially available vane compressors. The vane is embedded within the turbine mainframe whereas the other end is hinged to the rotor liner. Friction loads and pressure leaks occur in the vane side surface during the operation of the turbine. Therefore, design studies that reduce the friction losses and pressure leaks of the vane which improves turbine performance. In this study, the effects of friction and pressure leakages on the performance of the turbine have been investigated. Vane thickness size has been changed. Three different sizes (thick, standard and thin vanes) have been experimentally investigated. The experiments are also repeated by reducing the vane weights without making any changes on the outer geometry of the thick and standard vane. As a result of the experiments, 75% more power of the turbine has been obtained for the thin vane.

Etude expérimentale d'une nouvelle turbine rotative à aubes articulées – 1ère partie : Effet des diverses épaisseurs de palettes sur la performance de la turbine

Mots clés : Compresseur rotatif ; Moteurs rotatifs ; Épaisseur des palettes ; Poids des palettes

1. Introduction

The gas turbines and piston engines operate on Brayton, Otto and Diesel thermodynamic cycles respectively and have the largest share in the world market. Although there is continued improvement of piston engines they still have some inherent disadvantages such as reversing moment of inertia and associated rocking motion. In this regard, new engines with new structures are being designed as an alternative to piston engines. The rotary engines, which date back to the 1500s, have an important place among these engines developed.

Today, the structure of vane compressors used in the refrigeration industry is consistent with the structure of the

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Nomenclature

P_{ef}	friction at vane end faces [W]
μ	dynamic viscosity of the lubrication [Pa-s]
V_v	vane velocity [m s^{-1}]
A	vane end faces area [m^2]
δ_{ef}	vane end face clearance [m]
P_{vs}	friction at vane side [W]
η_{vs}	friction coefficient at vane side [–]
F_1	vane side contact force on high pressure side [N]
F_2	vane side contact force on low pressure side [N]
F_3	vane top contact force along radial direction [N]
F_4	vane top contact force along tangential direction [N]
F_{hp}	force on vane due to high pressure [N]
F_{lp}	force on vane due to low pressure [N]
F_c	coriolis force on vane [N]
P_{vt}	friction at vane top [W]
γ	difference between rotational angle of rotor and vane top [rad]
$\lvert\dot{\gamma}\rvert$	difference in rate of change between rotational angle of rotor and vane top[rads^{-1}]
η_{vt}	friction coefficient at vane top [–]
R_{vt}	vane top radius [m]
q_{mve}	leakage mass flow rate at vane end face [kg s^{-1}]
R_{gv}	body radius [m]
R_{ro}	rotor radius [m]
$\delta_{ve\ up}$	vane up clearance [m]
$\delta_{ve\ lo}$	vane low clearance [m]
V_e	volume at leakage channel exit [m^3]
P_e	pressure at leakage channel exit [Pa]
R_g	gas constant [J kg^{-1} K^{-1}]
T_e	temperature at leakage channel exit [K]
Tk.	thick vane
S.	standard vane
Tn.	thin vane
Tk. L.	thick vane less heavier
S. L.	standard vane less heavier

compressor and turbines of some rotary engines and particularly with that of the Pars Engine (Akmandor and Erzöz, 2008; Akmandor, 2013).

In the literature, there are several studies conducted to improve the performance of the vane compressors and most of these improvements are related to the changes made on vanes and their housing. In particular, the reduction of friction and pressure leakages between the vanes and housing has been an important topic for designers and scientists (Okur and Akmandor, 2011).

Bagepalli (1990) has aimed to reduce the vibration on the vanes, caused by the movement of the vane, by removing some material from the vane.

Da Costa (1991) has proposed different solutions in the geometry of the vane to reduce the effect of hydrodynamic forces that occur between the vane and housing due to the unbalanced loads during the up-down movement of the vane.

Adams (1987) has conducted a study that aimed to reduce the effect of friction on the vane by creating a leakage via a duct when the vane comes to the lowest point and reducing the load on the vane.

Rinehart (1974) has carried out some studies in order to minimize the unbalanced load distribution, caused by pressurized and unpressurized area, by opening small ducts and creating a load distribution between the vane and housing to reduce the effect of the friction.

There are other designs that aim to reduce the friction and pressure leakages in the vane housing (The et al., 2009a,b; Yang et al., 2011; Tan et al., 2011a,b; Lee and Oh, 2003, Ooi, 2005; Huang and Yang, 2008).

In the present study, thickness and weight changes of vanes on the turbine output powers have been investigated. The dimensions of the turbine are given in Table 1. The thickness of the vane was increased in order to reduce the pressure leakages across the vanes and flanges. However, the friction on the side walls of the vanes has increased as a result of increasing thickness and the power of the turbines reduced. The highest power of the turbine has been obtained with the thin vane which exceeds the power associated with the thick vane by 75%.

2. Material and method

The Pars Engine is a new design and consists of three parts, namely a compressor, a combustion chamber and a turbine. The structural concepts of the compressor and turbine are similar to each other and are composed of the body, eccentric shaft, rotor and vane (Fig. 1).

The vane separates pressurized and unpressurized working chambers. Increasing the thickness of flanges and sealing work aim to reduce the pressure leakages but by the same token, the friction losses also increase. This negatively affects the shaft powers produced by the turbine and an optimum point has to be found. The friction forces of the Pars Turbine are shown in Fig. 2.

1. Friction at end faces of vane

The friction force between the side surfaces of the vane and flanges are associated with the thickness of the vane and friction coefficient is given by Eq. (1).

$$P_{ef} = \frac{\mu.\mathbf{A}.\mathbf{V}_v^2}{\delta_{ef}} \quad (1)$$

2. Friction at vane side

The vane rubs against its housing within the body. This friction is calculated by Eq. (2)

Table 1 – Dimensions of the turbine.

Body radius (mm)	53.5
Rotor radius (mm)	44.7
Rotor length (mm)	24
Vane thickness (mm)	4.7