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Experimental study of fixed-vane revolving vane compressor

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HIGHLIGHTS

- A novel fixed-vane revolving vane compressor has been designed and tested.
- The compressor has been tested using air as working fluid from 2350 rev/min to 3800 rev/min from pressure ratios 1.5 to 2.4.
- The discrepancy between the predicted and the measured mechanical power is below 10.0%.

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ABSTRACT

A new compressor mechanism, called fixed-vane revolving vane compressor, has been designed, fabricated, instrumented and tested. The compressor design eliminates the pressure differential dependency of the vane side friction. A compressor prototype has been tested using air as the working fluid and operated at 2350–3800 rev/min with pressure ratios of up to 2.4, starts from the discharge pressure of 1.5 bar with an increment of 0.3 bar, while keeping the suction pressure constant at the atmospheric pressure. Over the range of the pressure ratios tested, the discrepancy between the predicted and the measured mechanical power is well below 10.0%. The measured air flow rate is found to be greater than the prediction when the discharge pressure is lower than 1.8 bar and the reverse is true for higher discharge pressures.

1. Introduction

In an attempt to introduce a new highly energy efficient compressor mechanism, the revolving vane compressor was introduced in 2006 and a few studies in the areas of friction [7], leakages [9], valve performance [8], journal bearing design [4], in-chamber heat transfer [5] and the experimental study [12] have been carried out. The revolving vane compressor has been further improved by physically fixing the vane onto the driving component. This design improvement eliminates the dependency of the vane side frictional loss on the pressure difference across the vane. The mechanical efficiency of this fixed-vane revolving vane compressor is predictably increased by 2.5% as compared to the original revolving vane compressor design [6].

Fig. 1 shows the schematic view of the fixed-vane revolving vane compressor. In its basic form, the compressor consists of four parts, namely a cylinder, a rotor, a vane and a split bush. The vane is rigidly fixed to the driving component, which is the cylinder in this case. The centers of the cylinder and the rotor are offset such that the outer rotor circumference and the inner cylinder wall surface form a line contact and together with the vane, it divides the working chamber into two: a suction and a compression chambers. The split bush is accommodated inside the slot on the rotor. During the operation, the rotor and the cylinder remain to rotate at their respective centers. The cylinder assembly which consists of the cylinder and the vane rotates the rotor through the contacts at the split bush. The split bush provides the angular adjustment of the vane during the operation due to the eccentricity between the rotor and the cylinder.

A fixed-vane revolving vane compressor with volumetric displacement of 1.7 cc has been designed, instrumented and tested. This paper introduces its design and the experimental setup. In addition, the measured mechanical power and the discharged mass flow rate are shown and used to validate the mathematical models for this unique compressor design.

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Nomenclatures

e	distance between rotor and cylinder centers [m]
F_x	resultant force along x direction [N]
F_y	resultant force along y direction [N]
I	current [A]
I_0	no-load current [A]
I_r	rotational inertia of rotor [kg m^2]
k	torque constant [Nm A^{-1}]
L_{Br}	length of bearing [m]
$P_{ef,lower}$	lower end face friction [W]
$P_{ef,upper}$	upper end face friction [W]
$P_{f,Br}$	bearing friction [W]
$P_{f,ls}$	lip seal friction [W]
P_{ind}	indicated power [W]
$P_{ind,max}$	maximum indicated power [W]
$P_{ind,min}$	minimum indicated power [W]
P_{vs}	vane side friction [W]
R	winding resistance [Ω]
R_{Br}	radius of bearing [m]
R_{cc}	radius of cylinder cover [m]
R_r	radius of rotor [m]
R_s	radius of shaft [m]
V	supply voltage [V]
V_v	vane side velocity [m s^{-1}]
α_r	angular acceleration of rotor [rad s^{-2}]
δ_{Br}	clearance at the bearing [m]
δ_{ef}	clearance at the end face [m]
ε	eccentricity between journal and bearing centers [m]
η_{mech}	mechanical efficiency [%]
$\eta_{mech,max}$	maximum mechanical efficiency [%]
η_{vs}	vane side friction coefficient [−]
μ	lubricant viscosity [Pa s]
ω	operating shaft speed [rad s^{-1}]
ω_c	cylinder rotational velocity [rad s^{-1}]
ω_J	journal rotational velocity [rad s^{-1}]
ω_r	rotor rotational velocity [rad s^{-1}]
ϕ	attitude angle [rad]
ϕ_c	angular position of cylinder [rad]
ϕ_r	angular position of rotor [rad]

2. Prototype design

The fixed-vane revolving vane compressor prototype consists of nine components and these are the cylinder and its cover, the rotor, the vane, the split bush, the discharge valve reed, the valve plate and the journal bearings. The compressor prototype can be grouped into three assemblies, namely cylinder assembly, rotor assembly and the journal bearing assembly.

2.1. Cylinder assembly

The cylinder assembly consists of a cylinder, a vane, a cover, a discharge valve and the valve stop, as illustrated in Fig. 2. The cylinder assembly is the driving component. The cylinder shaft is directly coupled to the motor shaft. The discharge port is located at the outer circumference of the cylinder. The discharge port is covered by a discharge valve. The deflection amplitude of the discharge valve is constrained by the valve stop. The cylinder is covered by a cover. A groove on the cover is used for O ring to prevent the possible leakage through the axial clearance between the cylinder and the cover.

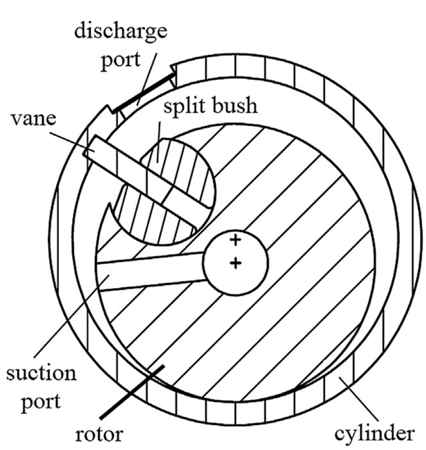

Fig. 1. Schematics of the fixed-vane revolving vane compressor.

2.2. Rotor assembly

The rotor assembly shown in Fig. 3 consists of a rotor and a split bush. The rotor assembly is the driven component. The rotor is driven by the vane through the split bush during the operation. The split bush is inside the vane slot and it swivels during the operation to accommodate the angular difference caused by the offset of the cylinder and the rotor centers. The working fluid travels from the intake hole, which is at the end of the rotor shaft, to the suction port, which is located on the rotor circumference.

2.3. Bearing assembly

The cylinder and the rotor assemblies constitute the major fixed-vane revolving vane compressor mechanism. The centers of these two assemblies are offset and to maintain this offset, the rotor and the cylinder assemblies are supported by journal bearings. In this prototype design, the cylinder is supported in a simply supported manner by two journal bearings, one on each side and the rotor is supported by a single journal bearing in a cantilevered manner, as shown in Fig. 4.

The clearance at the protruded shafts of the rotor and the cylinder are sealed by two lip seals, one at each end. The prototype design is also equipped with a predictably working lubrication network to channel the required amount of lubricating oil to all rubbing parts to lubricate and seal. The rotating components are theoretically balanced dynamically before the fabrication of the prototype begins.

3. Experiment setup and procedures

The fixed-vane revolving vane compressor prototype has been designed and fabricated. A test rig has been instrumented to conduct measurement on this unique compressor design.

3.1. Experimental setup

The schematic for the experimental test bed is shown in Fig. 5. The measured parameters are the voltage (V) and the current (I) supplied to the electric motor, the discharge pressure (P_{dis}), the