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Alternative vane kinematics in Vane-In-Groove machines for power density increase

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ABSTRACT

The Vane-In-Groove hydromachines combine high volumetric and overall efficiency typical of piston machine with uniform flow typical of vane machine.

Currently used axial vane movement perfectly fits to variable displacement machines but does not provide the best power to volume ratio. The aim of the current development is to improve power density of the Vane-in-Groove hydromachine.

The paper presents new design of a vane drive mechanism for Vane-In-Groove machine and experimental results obtained for a prototype tested as a pump. Offered solution is an introduction of alternative vane kinematics provided by a rotary vane drive mechanism.

INTRODUCTION

Vane hydromachine with working chamber located in an annular groove that is made in one of rotor faces offers some advantages compare to a conventional vane machine. This type of vane machines was called (by the authors) Vane-In-Groove machine.

Working chamber of a Vane-In-Groove pump is formed by four surfaces: by cylindrical walls of the annular groove in radial direction, by the bottom of the annular groove and face cover plate of a pump housing in axial direction (see Figure 1).

Such working chamber allocation provides this pump with the following technical advantages:
- working chamber is basically sealed by a plane-to-plane clamping of a rotor face to a cover plate of the pump housing that is easy in manufacturing and has self-repair ability;
- since working fluid locked in the working chamber presses with the same force to the opposite walls of the annular groove, (which are the parts of the rotor), rotor is hydraulically balanced in radial direction.

Both technical features provide the pump with the following custom advantages:
- high output pressure (typical for piston pumps);
- uniform output flow with no kinematical ripple;
- high volumetric efficiency at wide range of rotation speed and operational pressure.

Vane-In-Groove (hereinafter VIG) pump can be made reversible, variable and can function as a motor.

When a machine is working as a motor the VIG architecture provides it with useful custom features such as:
- steady torque at a wide range of rotation speed;
- low rotation speed at still high volumetric efficiency.

VIG architecture assumes different types of vane kinematics. The most described in technical literature and is axial movement vane drive [1, 3]. This type of vane kinematics was implemented in series of prototypes, tested and shown good results [4, 5] in terms of pump efficiency.

However axial vane movement requires additional space in a rotor namely length of a rotor. This in it’s turn results in increase of a pump sizes and weight and thus in decrease of power density value. Thus deepening the annular groove does not lead to power density increase and therefore there is no sense to increase pump displacement this way with axial vane kinematics.

To increase power density of a VIG machine the alternative vane kinematics was introduced.

VANE-IN-GROOVE PUMP WITH A ROTARY VANE DRIVE MECHANISM

The idea of alternative vane kinematics is to use rotary vane movement instead of axial one.

Axial vane kinematics assumes that a vane performs back-and-forth motion out of and into a working chamber i.e the annular groove. The whole vane stroke in this case must be no shorter than the depth of the annular groove (see Figure 1). Rotary kinematics assumes that a vane turns around it’s axis in the annular groove locking and unlocking the groove. Turn angle of a vane in this case is close to 90 deg (see Figure 2).

The use of rotary kinematics allows to shorten a rotor by the value of 2 - 3 depths of the annular groove. Numerical evaluation of major advantages of rotary vane kinematics are given below.

POWER DENSITY CONSIDERATION

Precedent conditions

Since the implementation of alternative vane kinematics basically affects a rotor unit we focused on this unit from the power density point of view. That means we did not pay special attention to the problem of the whole machine optimization when building up a prototype for experimental verification of alternative vane kinematics implementation. Another reason for this simplification is that the methods for stator unit (casing, fittings, e.t.c) optimization are well known and widely used as a conventional design. A drive shaft is not included into consideration either as it is the part depending on machine application.

Power density comparison

To evaluate the effect of the use of rotary vane kinematics the 100 cm³ pump prototype was designed and manufactured. Existing prototype was taken for the reference. This is the 28 cm³ pump with axial vane kinematics that shown good experimental test results and can be considered as well optimized for power density in the rotor unit.
Figure 1 presents a simplified perspective view of the rotor of the reference prototype.
Figure 2 presents the same view of the rotor with rotary vane kinematics.

Power density comparison results for both prototypes are presented in Table 1.

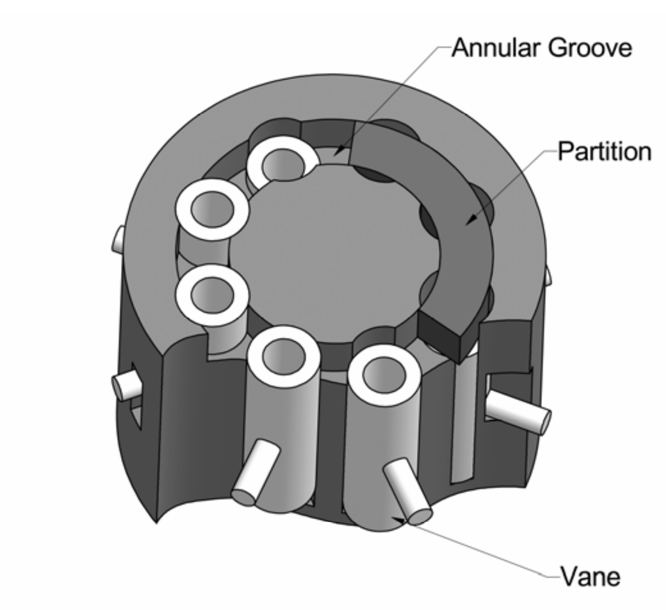

Figure 1: Vane-In-Groove pump with axial vane drive (simplified perspective view of the rotor)

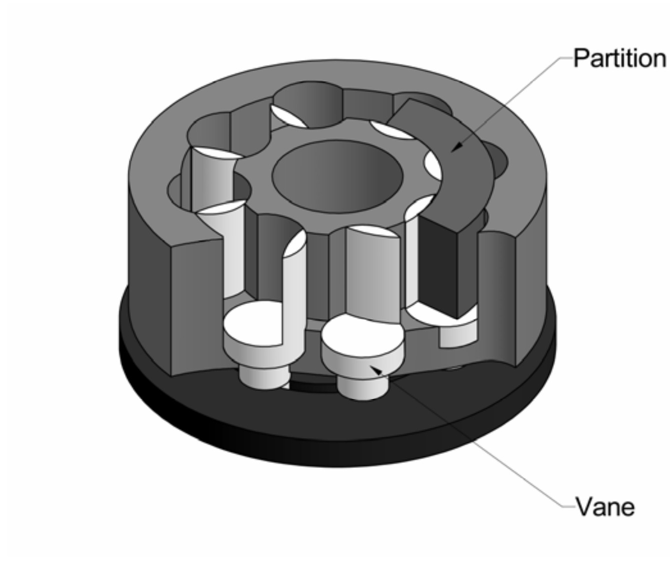

Figure 2: Vane-In-Groove pump with rotary vane drive (simplified perspective view of the rotor)

		assembly of the pump	
		pump without casing	rotor unit with vanes
Axial Vane Kinematics	displacement to weight ratio (cm^3/kg)	1,37	3,42
	power density at 35 MPa and 3000 RPM (kw/kg)	2,4	10,7
Rotary Vane Kinematics	displacement to weight ratio (cm^3/kg)	6,15	19,23
	power density at 35 MPa and 3000 RPM (kw/kg)	6,0	33,7
power density gain		150%	213%

Table 1: Pump displacement to weight ratio and power density for different assemblies of two pump prototypes (28 cm³ with axial vane kinematics and 100 cm³ with radial vane kinematics)

VOLUMETRIC EFFICIENCY INCREASE AS AN ADDITIONAL ADVANTAGE OF ROTARY VANE KINEMATICS

Rotary vane kinematics allows to make the annular groove deepper at the same diameter. This means that we can get a machine with bigger working chamber volume at the same perimeter of seals and thus the same external leakages. Since displacement of the machine is bigger at the same level of leakages it's volumetric efficiency is higher. This is additional important advantage of rotary vane kinematics.

EXPERIMENTAL VERIFICATION

The same 100 cm³ pump prototype was taken for experimental verification of rotary vane kinematics implementation. It was tested for volumetric efficiency as well as the same 28 cm³ reference prototype. The results of this comparison test are presented below.

Test installation and procedure

Figure 3 presents the scheme of the testing stand. Both prototypes were tested at our facilities using this stand. The test circuit is closed type without backup. Industrial oil similar to HLP 46 was used as a working fluid. The water cooling system working on counter-current flow principle kept up the fluid temperature within the limits of 30±5 °C. Adjustable orifice was used as a load. Maximal drive power provided by the electromotor was 55 kW. Outlet pressure, oil temperature, pump housing temperature at 2 points were recorded as well as outlet and drainage flow rates were measured by gravimetric method.

The test matrix for both prototypes was defined as follows:
- operating pressure: 0, 5, 10, 15, 20, 25 and 30 MPa
- rotation speed: 1500 RPM

Investigated parameters were measured for choosen rotation speed against the outlet pressure.

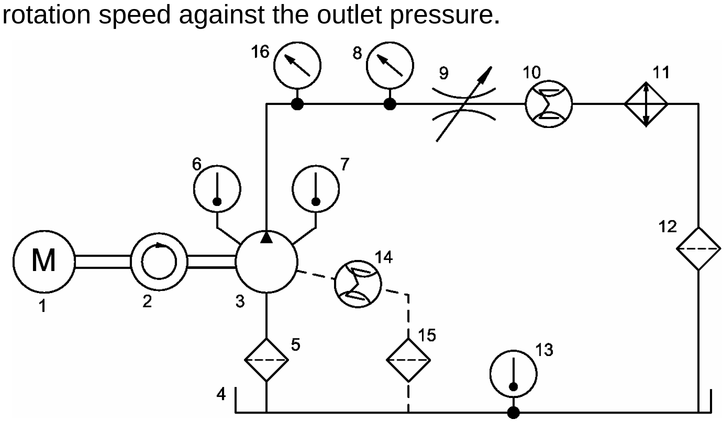

Figure 3: Scheme of the testing stand (auxiliary and safety equipment is not shown) 1– electromotor, 2 – tachometer, 3 – tested pump, 4 – tank, 5, 12, 15 – filters, 6, 7, 13 – thermometers, 8 – pressure sensor, 9 – adjustable load throttle, 10, 14 – flowmeter, 11 – counter-current flow cooler, 16 – pressure gauge

Test results

Volumetric efficiency was evaluated at stationary working points of the test matrix for two prototypes. The first prototype is 28 cm³ pump with axial vane drive. The second one is 100 cm³ pump with rotary vane drive. All findings for each prototype are presented as a curve, so that every curve represents volumetric efficiency of one prototype as a function of outlet pressure at constant rotation speed (1500 RPM).

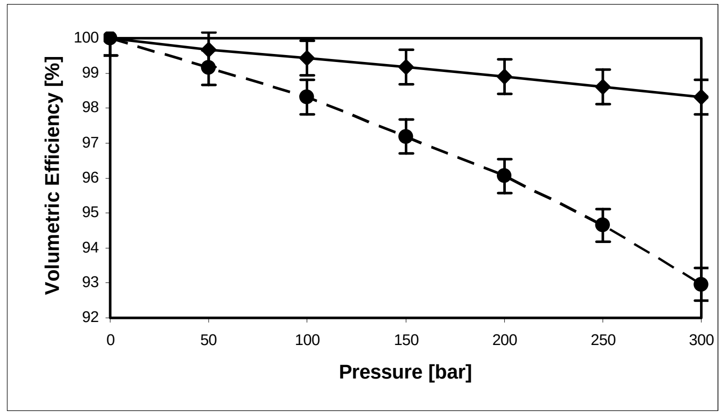

Figure 4: Evaluated volumetric efficiencies against outlet pressure at 1500 RPM for 100 cm³ (solid line) and 28 cm³ (dash line) pump prototypes.

CONCLUSION

Data presented above show that as applied to a VIG pump the use of rotary kinematics allowed to increase power density by 2,5 – 3,1 times compare to a pump with axial vane kinematics.

Experimental data also show high volumetric efficiency of a VIG pump with rotary vane kinematics at wide range of operational pressure suitable for most of common fluid power applications. Figure 4 demonstrates substantional (from 93% to 98% at 30 Mpa and 1500 RPM) volumetric efficiency increase when rotary vane kinematics is used.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

Vane-In-Groove pump: vane pump with working chamber located in an annular groove made in one of rotor faces