PUMP APPLICATION AS HYDRAULIC TURBINE – PUMP AS TURBINE (PaT)

SŪKŅA DARBĪBA HIDRAULISKĀS TURBĪNAS REŽĪMĀ

D. Rusovs

Key words: centrifugal pump, hydropower potential, hydraulic turbines, Francis and Kaplan turbine.

The paper considers pump operation as hydraulic turbine with purpose to produce mechanical power from liquid flow. The Francis hydraulic turbine was selected for comparison with centrifugal pump in reverse operation. Turbine and centrifugal pump velocity triangles were considered with purpose to evaluate PaT efficiency. Shape of impeller blades for turbine and pumps was analysed. Specific speed calculation is carried out with purpose to obtain similarity in pump and turbine description. For lower head of liquid flow (10 meters and less) was considered axial pump comparison with Kaplan turbine. The practical application of KSB AG pumps as turbine was used to demonstrate operation range of various pumps type.

Introduction

When centrifugal pump rotate in correct direction, the impeller converting mechanical power of engine to potential and kinetic power of liquid flow through the pump. If pumped medium begin to flow backwards – from the discharge pipe to the suction pipe, then impeller start rotating in opposite direction as well.

Such operation could happen for number of reasons: broken non-return valve if several pumps are working in parallel in one network, broken shaft between pump and motor, sudden loss of power etc. For normal pumps operation such situation should be avoided as system risk.

However if “return” flow had sufficient head to overcome the breakaway of the impeller and shaft, then such flow can be used to generate power. Such operation called “pump as turbine” (PAT) and the only difference from a “real” hydraulic turbine is that (PAT) cannot be expected to operate as efficient as turbine like *Francis* or *Kaplan* types.

Latvia had significant hydropower potential of small rivers. However often volume of flow and head is too small to prove purchase and installation of “real” hydraulic turbine. High investment and expensive maintenance cost of “real” hydraulic turbine make to search alternative way of hydropower potential utilization. In this situation, reverse-rotating centrifugal pumps could be acceptable choice. Due to industrial scale of pumps production, cost of pumps is low enough to cover less efficient operation in comparison with “real” hydraulic turbine.

Another application of reverse-rotating centrifugal pumps for power generation could be in following operational point: bypass or throttling elements, tank management system, power accumulation system. Pump operation as turbine had to be properly engineered and selected according relevant operation condition. If PaT is properly designed and installed the payback time for pump and generator is short.

The basic concepts of pump as turbine operation

The centrifugal pump had usually backward curved blades impeller so angle $\beta_2 = 15\text{-}50^0$. Velocity triangles in impeller are used for the pump theoretical consideration. In fig.1 represented section of impeller for the pump: the flow enter in small diameter and leave impeller at bigger diameter.

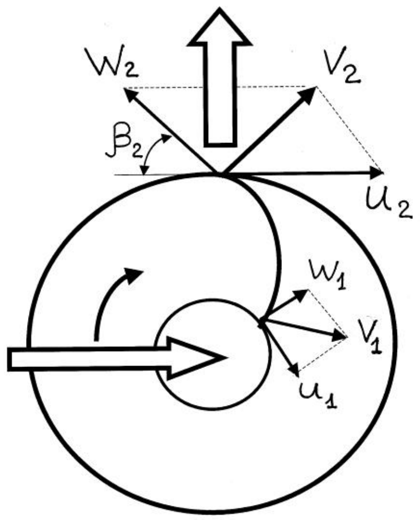

Fig.1 Velocity diagrams at the inlet and outlet of centrifugal pump
1.att. Ātruma diagramma centrbēdzes sūkņa ieejā un izejā

Fig 1.contain vectorial representation of following velocity: U – circumferential (rotational – or blade speed), W – relative and V – absolute. Index 1 is for inlet and 2 for outlet of impeller.

Absolute velocity V turns in direction of blade motion. Blades pushes and turns the fluids in direction of blade motion, doing work on the fluid adding power to it. Also velocity V_2 is bigger then V_1 that represent flow kinetic energy increase as result of impeller rotation.

If flow direction is reversed as in fig.2 this impeller works as radial-flow turbine.

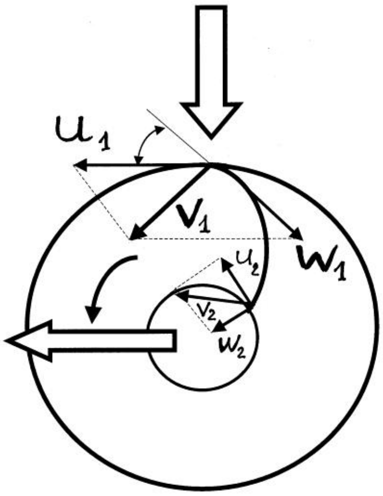

Fig.2 Velocity diagrams at the inlet and outlet of impeller under reverse flow operation condition.
2. att. Ātruma diagramma lāpstiņriteņa ieejā un izejā pretējas plūsmas ekspluatācijas režīmā.

If in fig.1. impeller rotation direction is clock wise, then for reversed rotation change direction to anti clock wise. The flow enter in larger radii and left impeller in smaller radii. Blades angle remain as for pump operation – but for turbine operation - anti clock rotation it become forward curved blades. The blade must push against the fluid in the direction opposite the motion of the blade to cause it. Hence the fluid pushes against the blade in direction of blade motion or doing work on the blade. The absolute velocity V_2 less than V_1 as result flow lost it energy for impeller rotation.
The transfer of work from the flow to the impeller mean turbine operation.

In "real" hydraulic turbine stationary vanes around the perimeter of impeller provide flow enter in impeller along blades. In PaT operation stationary blades are not used and correct direction of enter should be provided by impeller machining for proper profilating of the leading edge. Therefore it is important to check efficiency of power transfer from flow to shaft in real pump devices.

Pump as turbine performance experimental data

A series of experiments were carried out in order to get performance curve for PaT operation of two single stage centrifugal pumps: Etanorm 150-315 with impeller diameter 334 mm and Etanorm-R 300-340 with impeller diameter 320 mm. Both pumps were tested in PaT operation in KSB AG factory (Germany). The purpose of tests was evaluate operational range of centrifugal pump where PaT become able with sufficient efficiency to convert flow power in mechanical energy. Pump Etanorm 150-315 had inlet in PaT operation DN200 and outlet DN250, but pump Etanorm R 300-340 had inlet DN350 and outlet DN300. The most often way to use mechanical power is to couple a PaT onto electrical generator.

Practical application of generated electrical power requests frequency of generator according grid standard.

Therefore to avoid any gearbox or frequency converter application – due capital cost and losses impeller should rotate with certain angular speed.

PaT operation was tested for three rotational speeds 1520 rpm (with four pole generator), 1020 rpm (six pole generator) and 760 rpm (eight pole generator).

Rotational speed variation make possible to investigate PaT operation with various head and flowrate. That is important as Latvia had mainly hydropower potential of small rivers with limited head up to 10-15 m.

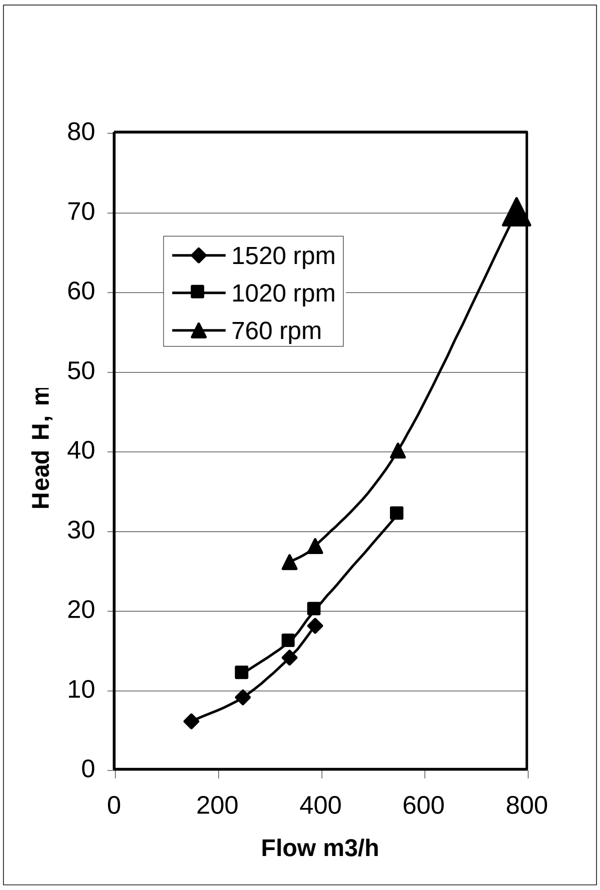

Fig.3 Pump 150-315 operation as turbine
3. att. Sūkņa 150-315 darbināšana turbīnas režīmā

From fig.3 it become that PaT could be in wide range of head from 5 m to 70 m. Maximum efficiency for PaT operation of Etanorm 150-315 is 80% for flow 600 m^3/h at 1520 rpm, 400 m^3/h at 1020 rpm and 300 m^3/h at 760 rpm. PaT operation with small head of 11,5 m for speed 760 rpm at flow 300 m^3/h will generate 7,5 kW power on impeller shaft.

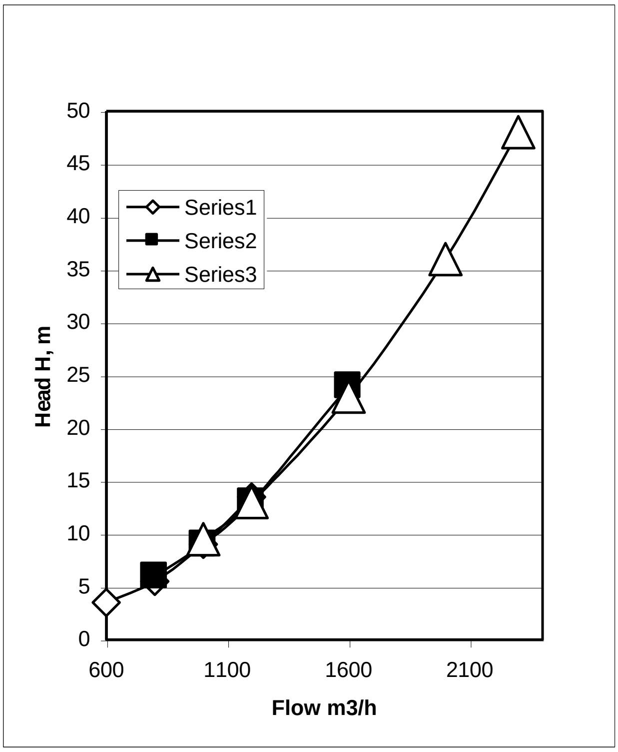

Fig.4 Pump 300-340 operation as turbine
4. att. Sūkņa 300-340 darbināšana turbīnas režīmā

Test of pump 300-340 was done with impeller of diameter 320 mm, which is less than for pump 150-315 diameter 334 mm. But impeller of 30-340 had mixed flow and with bigger possible flowrate up to 2400 m^3/h. Performance point at various frequency actually fit on one line, that demonstrate stability of PaT in various operating condition.

Maximum efficiency for PaT operation of 300-340 is 78% for flow 1800 m^3/h at 1520 rpm, 1200 m^3/h at 1020 rpm and 900 m^3/h at 760 rpm.

Pump as turbine specific speed calculation

Turbomachinery devices often described by n_s specific speed which is calculated as according [1]

$$n_s = n\,(N/\rho)^{0.5} / \left((gH)^{5/4} \right) \quad (1)$$

where

n is rotation speed in rad/sec, H – head in m, and N is power in W, ρ density in kg/m^3, g=9,8 m/c^2.

Then specific speed calculation for PaT with pump 150-315 give n_s = 0,6 for all frequency and for 300-340 n_s = 1,4. Thus specific speed value for PAT in considered experiments perfect feet with value of n_s = 0,4-2,2 for *Francis* turbine [1]. Hence we can consider investigated PaT as Francis turbine.

Francis turbine performance based guide vane ring with adjustable blading impinges on runner's curved blades.Normally, the flow come in through volute casing, and so-called draft pipe is placed downstream of the runner.

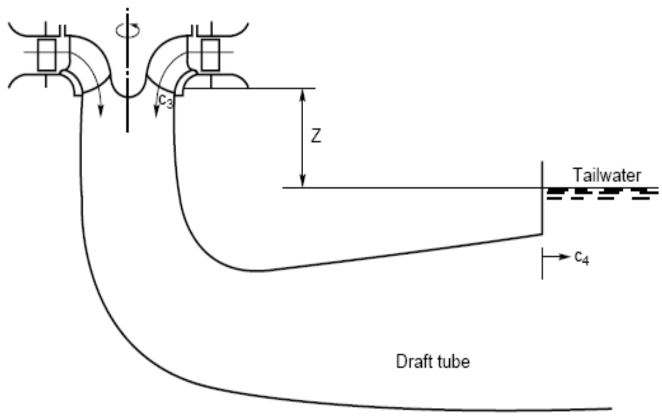

Fig.5 *Francis* turbine [1]
5. att. *Francis* turbīna [1].

Efficiency of Francis turbine is between 90-95%, as far as PaT in our investigation had no stationary blades and no draft tube, then it is clear reason for smaller efficiency of PaT.

Kaplan turbine had bigger specific speed n_s = 1,8-5,5 and it application related to smaller head and bigger flow. Kaplan had runner with adjustable blades, like a boat propeller and water flow come in axial direction (as runner axis). Axial pump also could be tested as PaT like Kaplan turbine, however axial pumps less attractive price wise in comparison with centrifugal pump. Another disadvantage of axial pump in PaT operation is generator design – it should be encapsulated with runner or connected by long shaft. Both decision create extra cost and longer payback time.

Pump as turbine reference application

There are reported several successful PaT application. One of them is Zweckverband Landeswasserversorgung in Stuttgart (Germany). Eight KSB Etanorm M 150-315 was installed to operate with flow in range from 175 l/sec at H max = 52 m till 1100 l/sec at H min = 35 m. The advantage of KSB pump is reverse running option, and proven, time-tested solution.

Conclusions

The experimental results prove PaT application with reasonable efficiency of 78-80% for wide range of flow between 300 till 2400 m3/h for head of 5 till 60 m.
Based on specific speed calculation was done comparison of *Francis* turbine and centrifugal pump as turbine in PaT operation.

References

1. Dixon S. L. Fluid Mechanics, Thermodynamics of Turbomachinery. - Liverpool: Pergamon Press, 1998, 353 p.
2. KSB AG – http://www.ksb.com - A pump becomes a turbine.
3.Radziņš Z., Zars V. Hidrauliskās mašīnas un mehānismi. - LV izdevniecība, Rīga, 1964, 514 lpp.

Dmitrijs Rusovs Dr.Sc.Ing. born in Riga, 1959.Graduated Moscow Engineering Physical Institute (nuclear power plants) in 1983. Doctor`s course of Riga Technical University 1985-1988. Interests: heat transfer in liquid boiling, hydraulics, flow mechanics. Dr.sc.ing. since 1992.

At present: Rīga Technical University in Heat and Power Engineering dept. Ezermala street 6, LV-1006, Riga, Latvia. Phone + 37167089796, dmirijs.rusovs@rtu.lv

D. Rusovs. Sūkņa darbība hidrauliskās turbīnas režīmā.
Darbā aprakstīta sūkņu izmantošana darbam hidrauliskās turbīnas režīmā ar mērķi iegūt mehānisko enerģiju no šķidruma plūsmas enerģētiskā potenciāla. Centrbēdzes sūkņa reversīvās darbības analīzei un salīdzināšanai ar tiešā pielietojuma hidroturbīnām tika izvēlēta *Francis* tipa hidrauliskā turbīna. Enerģijas pārveidošanas efektivitātes novērtēšanai turbīnā un sūknī tika izmantotas ātruma trīsstūru diagrammas. Veikta turbīnas un sūkņa lāpstiņu ģeometriskās formas analīze. Analoģiju pamatojumam aprēķināti raksturīgie ātrumi. Plūsmām ar nelielu augstuma kritumu (līdz 10 metriem) dots aksiālā sūkņa un *Kaplana* turbīnas salīdzinājums. Ar praktisko KSB AG firmas sūkņu darbību turbīnas režīmā pamatots dažādu tipa sūkņu darba režīma parametru apgabals.

Д. Русовс. Работа насоса в режиме гидравлической турбины.
В статье описано применение насосов, как гидравлических турбин для получения механической энергии из потока жидкости. Турбина типа *Франциса* была выбрана для сравнения с работой центробежного насоса при обратном потоке. Треугольники скоростей в турбине и насосе были рассмотрены для оценки влияния на эффективность преобразования энергии. Проанализирована форма лопаток турбины и насоса. Проведен расчет характерной скорости для выявления аналогий в описании турбины и насоса. Для использования потоков с небольшим перепадом высоты (до 10 метров) дано сравнение осевых насосов и турбины *Каплана*. На примере насосов KSB AG в турбинном режиме показана область использования различных типов насосов.