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ScienceDirect
Energy Procedia 82 (2015) 201 – 208
Energy Procedia

ATI 2015 - 70th Conference of the ATI Engineering Association

Study of a Pump as Turbine For a Hydraulic Urban Network Using a Tridimensional CFD Modeling Methodology

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Abstract

Nowadays, the application of a PAT (Pump as Turbine) has been developed in several applications as pressure dropping valve. Generally, pump manufacturers do not provide the characteristic curves of their pump working as turbine and researchers have the objective of build a model to predict the turbine operation of pumps for energy recovery schemes. This paper shows a methodology based on a mathematical model of a centrifugal pump used as a PAT in an urban hydraulic network, to solve this kind of problem.
The model was built up, starting from the real geometry, with a commercial tridimensional code, which is particularly suitable to simulate pumps and valves.The aim of this paper isthe investigation on the possibility to use a simulation methodologyto obtain the inverse characteristic of a commercial centrifugal pump.First, the model results were compared with the data declared by the pump manufacturer and after it was used to obtain the inverse characteristic (PAT mode).
Furthermore, an experimental test bench was used to obtain the reverse mode pump characteristic, in terms of flow-rate/head.In both cases, the simulation model showed good accuracy, there is a low difference between simulated results and manufacturer/experimental data.The model results, which represents the first step of this activity, revealed that it is possibleto obtain the pump characteristic in reverse mode, which is not declared in the commercial pump datasheet.

Peer-review under responsibility of the Scientific Committee of ATI 2015

Keywords: Pump As Turbine, Best Efficiency Point, Hydraulic Network

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Peer-review under responsibility of the Scientific Committee of ATI 2015
doi:10.1016/j.egypro.2015.12.020

1. Introduction

Pressure reducing valves (RPV) are dissipative organs that must be used in a hydraulic urban network to reduce pressure in order to prevent breakage and failures and to adapt the water pressure to the necessary level of the users. As well known, the application of a PRV is a simple and cheap method but not efficient by an energetic point of view. It would be possible to use a hydraulic turbine to recovery the dissipated energy in a hydraulic network; but this solution is generally expansive and not easy applicable in an already existing urban network. Other solution is the application of a pump in a water network[1-3] and to run it as a turbine:this application is commonly called PAT (Pump As Turbine). Pumps are reasonably simple machines, inexpensive (if compared to a hydraulic turbine), readily available worldwide and the capital payback period could be less than few years, even if the efficiency in reverse mode in not so high. The choice of a commercial pump [4] in a water network is not always a simple task, because the pump manufacturers do not supply the operating conditions in reverse mode. Therefore, the current research on PAT is focused on the development of prediction model for the reverse operation of a centrifugal pump [5-7]. These methods are based generally on geometrical, theoretical and experimental analysis [8]. In this paper authors shows a methodology to obtain the pump reverse characteristic using a 3D CFD model. Data of an experimental activity on a PAT in a hydraulic network are shown. These data has be used to validate the CDF model.

Nomenclature

PAT	Pump As Turbine
CFD	Computational Fluid Dynamic
PRV	Pressure Reducing Valve
H	Head
Q	Flow rate
P	Power
η	Efficiency
BEP	Best Efficiency Point
φ	Specific Capacity
N_s	Specific speed
ψ	Specific Head

2. Experimental test

With the aim of validate the pump's CFD model in reverse mode, an experimental campaign was performed on a test bench. This bench is able to test pumps running in reverse mode. The test bench consists of 4 nodes and reproduces partly of afull-scale hydraulic network. An external pump increases the water pressure to simulate the behavior of a real urban network, while an air chamber stabilizes the flow-rate. The tested pump was installed in one node where two pressure-reducing valves PRV allow the regulation of water-flow rate and pressure at inlet and outlet of the pump.

The pump electric motor is connectedto an inverter. The produced electrical power is jointed to the urban power grid. In the node two pressure transducers (Burkert model 8314), a flow meter Q (Siemens mag 500) were installed. All test bench data were acquired by a home-made acquisition system. A 360 teethes encoder was installed on the electrical motor to acquire the shaft speed. The test were performed only in steady state conditions, varying the pump's water flow-rate and inlet pressure, for different shaft speed. In particular, the flow-rate was varied between (8 – 21) l/s while the shaft speed between (300 – 2200) rpm. During the test, the inlet and outlet pump's pressure were acquired at a sample frequency of 1 Hz.

2.1. Pump characteristic

The tests were performed on a centrifugal pump connected with an electrical motor of 22 kW (400 V, 50 Hz, 2 poles). The nominal diameters of the delivery outlet is 80 mm while the impeller diameter is 190mm. In figure 1, the pump's (Q – H)characteristic is reported. These data are declared by the pump's manufacturer.

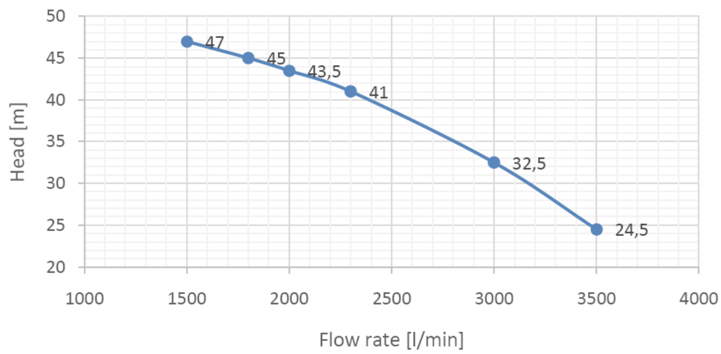

Fig 1:Q-H pump characteristic

Furthermore, the manufacturer declares data at the best efficiency point showed by following:

- H_{BEP}=39 m
- Q_{BEP}=148 m^3/h
- P_{BEP}=20 kW
- η_{BEP}=78.7 %
- N_s = 37.6

2.2. Experimental results

As already said, the test were made in steady state conditions, running the pump in reverse mode. Flow rate, pressure at inlet and outlet of the pump and shaft rpm were measured. In figure 2, the results of the whole experimental campaign are shown. To examine the PAT performance, the total head [bar] versus shaft rpm is reported varying water flow rate for all the examined conditions. The results confirmed what is known by literature: the PAT head increases with the rpm and with the flow rate. For the tested conditions, the head varies between 0,1 and 1,8 bar.

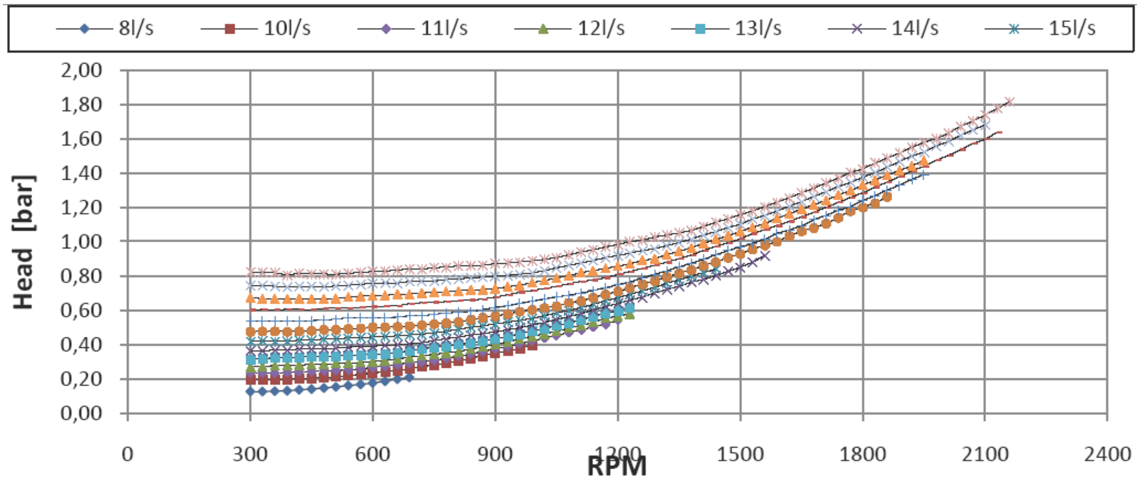

Fig.2: Experimental results of the PAT

3. CFD results

The simulation model was built up with Pumplinx®, a CFD code developed by Simerics Inc®. It solves numerically the fundamental conservation equations of mass, momentum and energy; it includes physical models for turbulence and cavitation. Pumplinx® has a its own grid generator and uses a body-fitted binary tree approach, and treats simultaneously moving and stationary fluid volumes and each volume connects to the other via an implicit interface.

Starting from the 3D CAD geometry of the pump, the fluid volume (figure 3a) was extracted and meshed (figure 3b).The obtained CFD model presents 851.000 total cells and 3.300.000 faces number. A grid sensitivity analysis was made to verify the grid-independence of results. By the end of this analysis, the selected model presented the best accuracy with the lowest required computational time.

Fig.3: (a) CFD model fluid volume, (b) CFD model mesh

In a first phase, several simulations were made in the pump mode and the results were compared with the data declared by manufacturer. This first validation phase was useful to validate the simulation model. The simulation and the boundary conditions was all in accordance to ISO 9906 (annex a) [15].In figure 4, results in terms of total head versus volumetric flow-rate are shown. At low flow rate the model overestimate the manufacturer data with an maximum error of 4,7% while at high flow rate it underestimates the manufacturer data with a maximum error of 3,4%. Therefore the error, in all examined conditions, is lower than 5%.The model accuracy is verified.

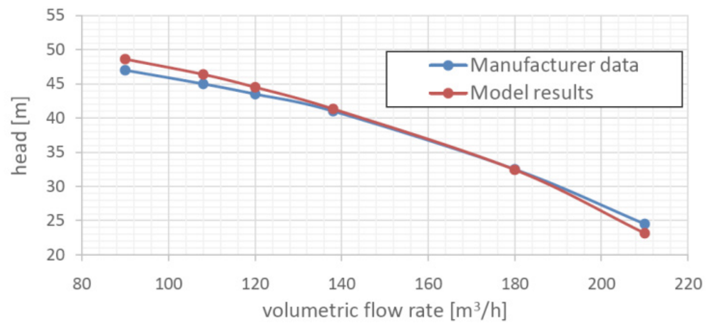

Fig. 4: Model validation pump mode

Using the validate model the reverse mode was analyzed. The boundary conditions were changed in order to running the pump as a turbine and were:

- Intake pressure
- Shaft speed
- Outlet volumetric flow rate.

For these simulations the output experimental pressure was used as validation parameter.

Simulations were done for all tested conditions and the validation graphs is reported in figure 5.The model showed a good accuracy. At low flow rate the difference between experimental and model results are less than 1% while at high flow rate (more than 18 l/s) the error is always under 4%.

Therefore, the simulation model confirm a good accuracy in both mode.

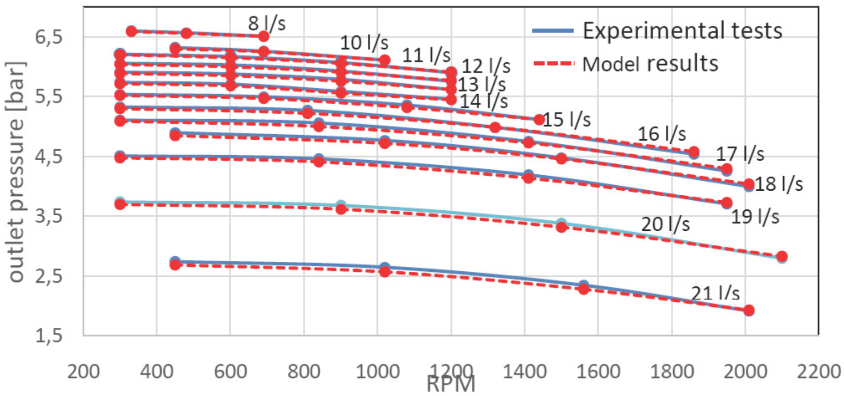

Fig. 5: Model validation PAT mode

3.1. Model application: PAT efficiency at 2900 rpm

The validated model was used to predict the efficiency curve at 2900 rpmin absence of experimental data. The aim was to obtain the pump's inverse characteristic and then to evaluate the PAT efficiency. These data are useful to choose the pump for each urban network.Moreover, the Best Efficiency Point, at

2900 rpm, was found in reverse conditions.There are several methodsavailable in literature which allows to predict the best efficiency point of a PAT [5-10]. These models take into account all the phenomena of a pump in reverse condition such as power losses in the volute and impeller, power losses due to gland packing and bearing cases, disc friction losses in gaps between rotor and stator, volumetric losses due to leakage from clearances between rotor and stator. In this section, a method to predict the efficiency of a PAT is presented, starting from the CFD model results. In the following figure Specific Capacity (φ), Efficiency(η), Specific Head (ψ)and Specific speed (Ns)are shown, each variable was evaluate from the following equations:

$$\varphi = \frac{Q}{nD^3} \qquad \text{Specific Capacity} \qquad (1)$$

$$\eta = \frac{P}{\rho Q H} \qquad \text{Efficiency} \qquad (2)$$

$$\psi = \frac{gH}{n^2 D^2} \qquad \text{Specific Head} \qquad (3)$$

$$Ns = \frac{333 * n\sqrt{Q}}{(gH)^{3/4}} \qquad \text{Specific speed} \qquad (4)$$

where Q is the volumetric flow rate, n the shaft speed, D the diameter of the impeller, H the total head, P the power. Parameters can be evaluated in both mode. With the CFD model results, the data to evaluate this parameterswere obtained. The boundary conditions settled in simulations are:

- Outlet pressure = 1.9 bar
- Inlet volumetric flow = outlet volumetric flow in pump mode
- Fluid = water
- T_in=20°C=293.15 K
- P_sat=2886 Pa

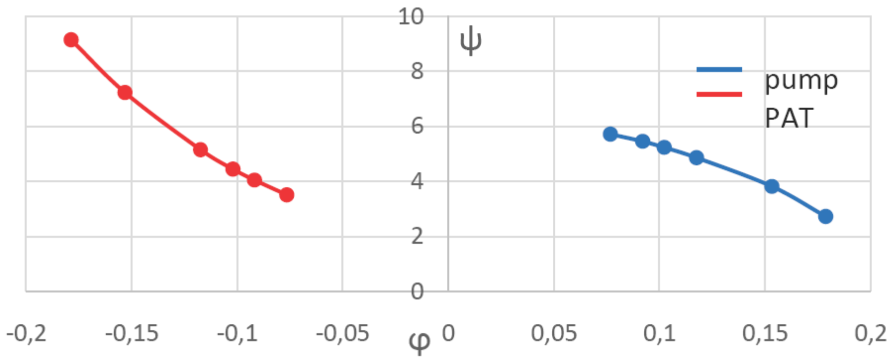

Fig. 6 Specific Head

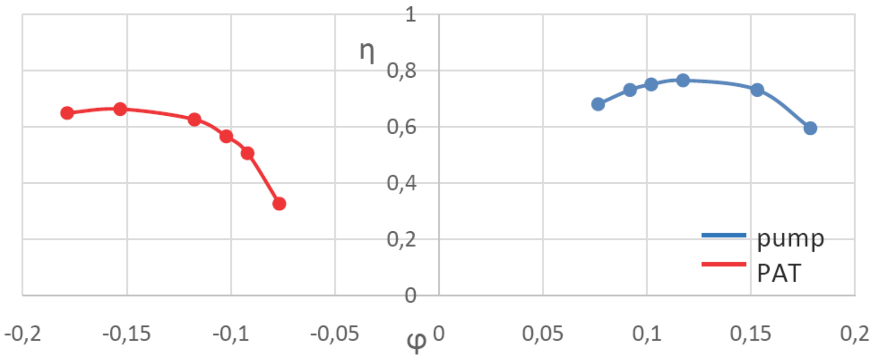

Fig 7: Efficiency

In figure 6 the Specific Head behavior versus Specific Capacity is shown for the PAT and pump mode. The specific capacity and the efficiency were than evaluated (see figure 7).From figure 7 is possible to see that, in the direct mode, the efficiency versus capacity has a typical bell shape curve. In reverse mode the efficiency has a behavior very similar to a Francis turbine.

Analyzing graph in figure 7, it is possible to observe that the BEP in reverse mode is achieved for higher flow-rate and the efficiency curve arises from the lower flow-rate, and after its maximum, keeps a high value, while in direct mode the efficiency rapidly decreases after BEP value. Furthermore, this figures highlights that the BEP value in reverse mode is 0.663.

This methodology can be a valid tool to predict the PAT efficiency and then it can help designers to rapidly and efficiently choose the pump for each hydraulic network. To better understand to working conditions in both mode, table 1 summarized all the obtained results.

Table 1. Direct and reverse mode comparison

	Direct mode	Reverse mode
Head [m]	39	61
Capacity [m^3/s]	0.041	0.05
Power [kW]	20.5	19.98
Efficiency	0.787	0.663

4. Conclusions

In this paper a methodology to analyze a Pump As Turbine was illustrated. It consists on building up a tridimensional CFD model of a pump and to obtain the reverse mode characteristics, running the model as a turbine. The simulation model was validated both in direct and reverse mode. In direct mode, the model was validated using the pump manufacturer data, available in the pump data-sheet, while in reverse mode the data of a dedicated experimental campaign were used. The experimental tests were performed in a full-scalehydraulic network, where the PAT was fully characterized. The validation procedure highlights that it is possible to validate a PAT fluid-dynamic model using the data available in the pump manufacturer data-sheet.Then the model results were used to build up the efficiency curve in reverse mode and to evaluate the BEP.

This methodology could be very useful during the PAT choice in a hydraulic urban network, permitting to analyze the running parameters of a PAT and to evaluate its Best Efficiency Point in reverse mode.

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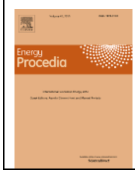

Biography

Dario Buono took its PhD degree in 2007 at the Industrial Engineering Department of the University of Naples in Italy. Now he is working at researcher. His major research fields are Biofuels and Hydraulic systems.