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A NEW INTEGRATED HYDRO-UNITS TEST RIG FOR EXPERIMENTAL INVESTIGATION

BY

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Abstract. As the society evolves and the population grows, the demand for energy increases. The hydro-based energy has the advantages of the lowest price/kWh, of being renewable, and the possibility of regulating the power system. In Romania, the hydro-based electricity represents 26% of the total electrical energy produced. A significant number of power plants and storage pumps were installed more than 20 years ago (38%), only 14% were installed in the last decade. Redesigning components (for example the impeller) increases the efficiency with a minimum investment. Since the power is in the range of hundreds of MW, any efficiency increase leads to significant increase in revenue. Working hand-in-hand with simulation, the experimental part helps investigate the improper operation regimes like cavitation.

Key words: hydro energy; centrifugal pumps; induction motors; data acquisition system.

1. Introduction

Today we witness an increase in demand of electricity. The reasons include the population growth, the economic development, etc. As a result, the society has to search for more energy resources. Due to the fact that only 18% of the hydro energy potential is employed today worldwide (26% in Romania),

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the hydro energy offers many opportunities. Also, it has a couple of advantages. It produces electricity with the lowest price/kWh. Hydro-power plants offer the advantage of regulating the power system. When there is a high energy demand, the turbines are used to produce electric energy (Popa *et al*., 2010). When the demand decreases (over the night for example) the electric energy is cheap. During this time centrifugal pumps may be used to pump the water back into the lakes. In this context the hydro-energy becomes "renewable". According to Badea (2010) the hydro-energy has the biggest potential. A major advantage is the absence of any form of pollution.

Many hydro-power plants were designed decades ago. Only 14% are installed in the last decade. Redesigning those using the latest technologies leads to an increase of operation efficiency. Since their power is in the range of hundreds of MW, any efficiency increase reflects in revenue (Barrio *et al*., 2010; Savar *et al*., 2009). Reducing or eliminating the conditions which generates cavitation (by using an inducer) has the effect of reducing the repairing and replacement periods and the maintenance cost (Anton *et al*., 2004, 2010).

The goal of this research is to improve hydro-units efficiency, their cavitational behavior as well as to reduce their operation and maintenance costs. An important step towards achieving this is the hydro-units experimental testing (Memardezfouli & Nourbakhsk, 2009). This paper presents an integrated experimental test rig (Fig. 1) for centrifugal pump test, its validation, discusses the obtained results (for constant speed) and points out future work. The paper is organized as follows: the rig and its components are described in section **2**. Section **3** presents the Data Acquisition System (DAQ). The software platform is presented in section **4**. The obtained results are discussed in the next section. The last section refers to the future work.

2. The Experimental Rig

A team effort result, the rig (Figs. 1 and 2), was built in the Pumps Laboratory at "Politehnica" University of Timişoara.

It is composed of a hydraulic circuit (*5*, *8*, *10…12*, *14*, *15* in Fig. 1), two reservoirs of 1 m^3 each (*1* in Fig. 1), vanes (*4*, *9*, and *16* in Fig. 1), a PCN 80-200 pump, an induction motor (Fig. 3), power electronics, sensors (pressure, temperature, flow and electrical power), and the data acquisition system. When the motor spins, the goal is to acquire the inlet and outlet pressure, the flow, the temperature, the speed, the mechanical and the electrical power data and determine the experimental characteristics for centrifugal pumps. The inlet pipe diameter is of 0.1 m and the outlet pipe diameter – 0.08 m.

An ASI 200 S48 22 kW induction motor (Fig. 3) is used to actuate the centrifugal pump. The motor has the following characteristics:

Nominal power: 22 Kw.

Voltage: Δ/Y, 220 V/380 V.

Current: Δ/Y, 77.5 A/41.8 A.

Speed: 2,970 rpm.

A 50 A thermal magnetic circuit breaker is used to protect the motor. Manufactured by Schneider electric, this component offers adjustable current value. To avoid mechanical and electrical shocks, the motor is started using a three-phase 22 kW/400 V ATS01N244Q soft-start system.

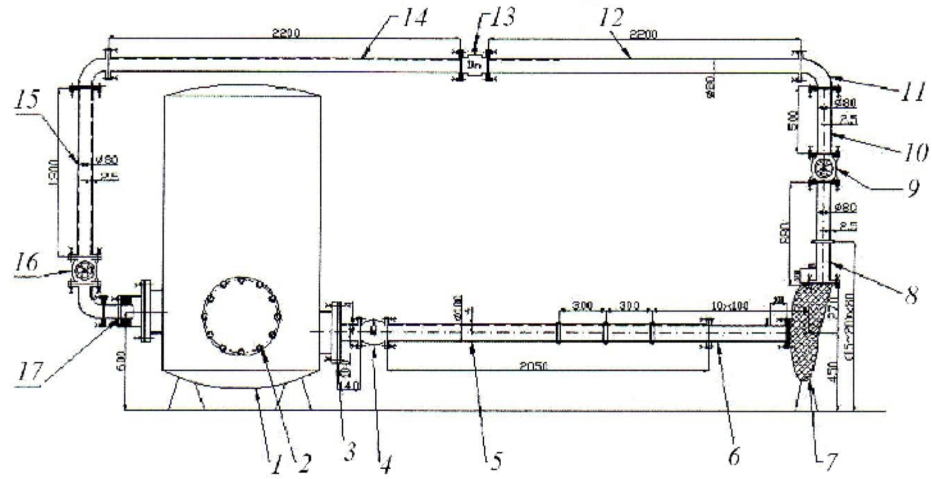


Fig. 1 – A schematic of the test rig.

Fig. 2 – The experimental test rig.

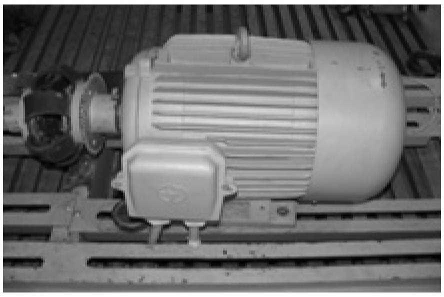


Fig. 3 – The ASI 200 S48 induction motor.

3. The SES-A1 Data Acquisition System

A data acquisition system was built to acquire data representing the inlet and outlet pressure, the speed, the flow, the mechanical and electrical power and the temperature. Built as a distinct module, this system has the following features:

a) PC communication through the serial interface.

b) 32 channels with voltage/current differential inputs.
c) 12 bits resolution.
d) Input range: ± 10 V/ ± 25 mA/4...20 mA.
e) 100 kb/s acquisition frequency.
f) 512 ksample memory.

A data acquisition system block diagram can be seen in Fig. 4. The electronic interface module is used to interface the system with the personal computer. The communication is realized *via* the serial port using the RS232 protocol. The data acquisition board SES-A1 ensures the proper sensors interface. The channel responsible for reading the speed sensor counts these pulses and computes the speed.

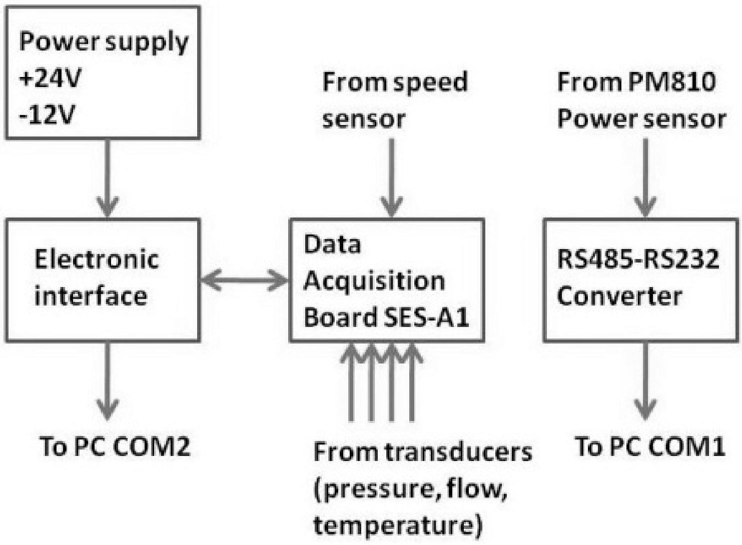


Fig. 4 –Data Acquisition System.

3.1. Sensors Used on the Rig

Several sensors are used to convert the electrical power, the pressure, the flow, and the temperature into an electric signal. They are directly interfaced with the data acquisition system. The electrical power is acquired using the Schneider Power Meter PM810. This device is a multifunction data acquisition and control device. PM810 is able to measure current, active and reactive power, voltage, etc. The device uses the RS485 communication standard (it needs a converter to interface with the PC).The COM1 serial port is used to interface with the PM810 power meter (Fig. 4).

The inlet pressure sensor uses stainless steel casing. The input pressure range is –1…2.5 bar while the output is a current in the range 4…20 mA. The accuracy reported by the manufacturer is ±0.25%. The sensor mounted on the rig can be seen in Fig. 5.

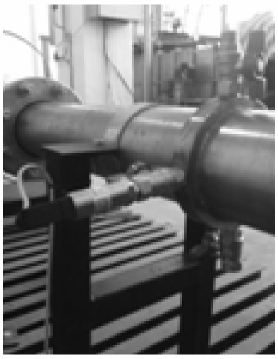


Fig. 5 – The pressure sensor mounted on the rig.

The outlet pressure sensor is of the same type as the inlet pressure. The pressure range is 0…6 bar while the output is a current situated in the range 4…20 mA. The accuracy reported by the manufacturer is ±0.25%. The sensor mounted on the rig can be seen in Fig. 6.

Fig. 6 – The outlet pressure sensor mounted on the rig.

Fig. 7 – The flowmeter mounted on the rig.

A Siemens SITRANS 5100 electromagnetic flowmeter is used to measure the flow. The flow domain is situated in the range 0…50 L/s and its accuracy is reported to be ±0.4%. The flowmeter was mounted in the middle of the top pipe (Fig. 7). For an accurate measurement the flowmeter has to be filled with water in every moment. SITRANS 5100 is connected to the SES-A1 data acquisition system.

4. The Software Platform

A software platform was designed to control the data acquisition. The software acquires automatically the motor speed, the temperature, the inlet and outlet pressures and the flow. The data gets stored into an Excel file. The platform has real-time plotting capability and possibility of performing calculations. The acquisition interval can be adjusted.

The platform was developed in Visual Studio 2008 in C#. The GUI can be seen in Fig. 8. Once the platform was ready the integration was performed. A series of experiments were performed to calibrate the data acquisition. Calibration was needed for the pressure sensors, the flow sensor, and the speed sensor. A set of experiments were performed using the pump's original impeller. The results were compared to the ones obtained in previous experiments.

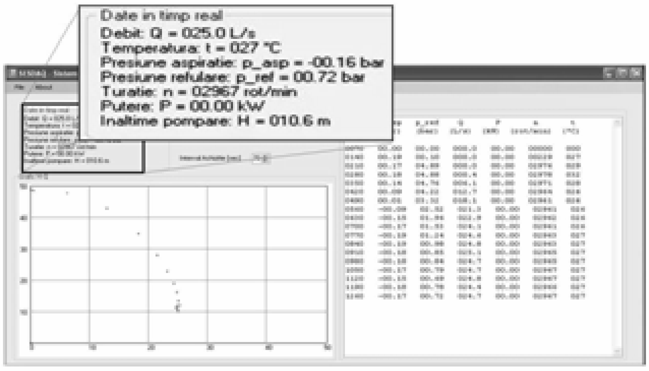
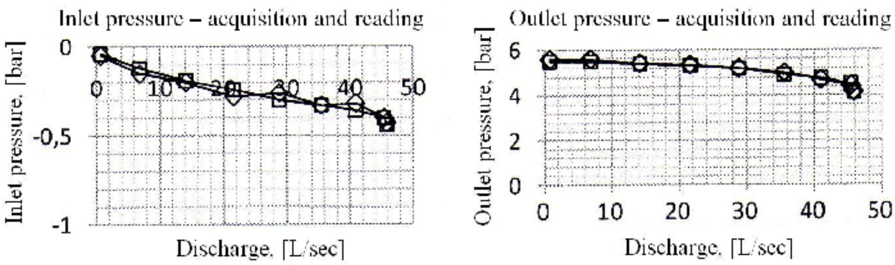


Fig. 8 – The software platform GUI.

4.1. Calibrating the Test Rig

Once the rig was installed and working, the first step was to calibrate it. To perform this task additional measuring devices were used. A Dwyer SS 316L pressure meter was installed. The device's pressure range is ±30 psi with 1% accuracy. A 0…10 bar manometer of 0.6% accuracy was used for the outlet pressure. Experiments were performed to compare the acquired results with the results indicated on these additional devices. The plots can be seen in Fig. 9 for



a *b*

Fig. 9 – The inlet (*a*) and the outlet (*b*) pressures. □ curve – reading and ◊ curve – acquisition.

both inlet and outlet pressures. To verify the flow with meter, the device was mounted on another test rig in the lab and the results were compared against a Krone flowmeter. The flow was measured using both with respect to the pump speed level. The plots for the two flowmeters can be seen in Fig. 10.

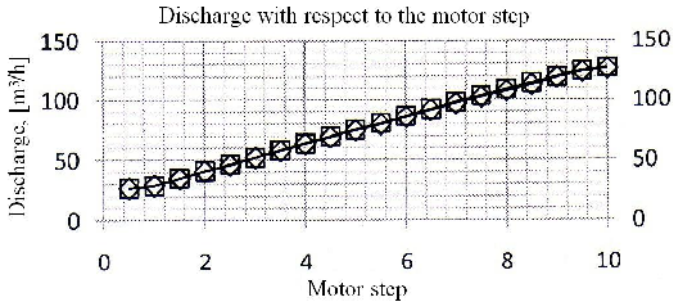


Fig. 10 – SITRANS and Krone flowmeters readings
(□ for – SITRANS and ◊ for – Krone).

5. Experiments and Results

Once the calibration was performed, the original impeller was installed and a series of experiments were performed. The target was to obtain data to plot the curves $H = f(Q)$, $P_{\text{abs}} = f(Q)$, and $\eta = f(Q)$. In the above relations, H is the head, Q – the flow, P_{abs} is the mechanical power delivered by the induction motor and η – the efficiency. The head, H, and the efficiency, η, are computed based on the following equations:

$$H = \frac{p_{\text{asp}} - p_{\text{ref}}}{\rho g} + \frac{v_{\text{asp}}^2 - v_{\text{ref}}^2}{\rho g} + Z_{\text{ref}} - Z_{\text{asp}}, \tag{1}$$

$$\eta = \frac{P_u}{P_{\text{abs}}} = \frac{\rho g Q H}{P_{\text{abs}}}, \tag{2}$$

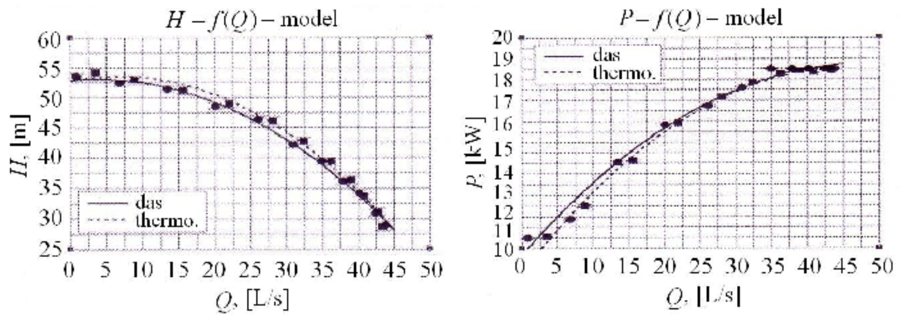
where: p_{asp} is the inlet pressure, p_{ref} – the outlet pressure, v_{asp} – the fluid inlet speed, v_{ref} – the fluid outlet speed, $\rho = 1{,}000\ \text{kg/m}^3$ – the water density and $g = 9.80665\ \text{m/s}^2$ – the gravitational acceleration.

The mechanical power transferred to the pump was approximated using the polynomial below

$$P_{\text{abs}} = aP_{\text{act}}^2 + bP_{\text{act}} + c, \tag{3}$$

with the coefficient values: $a = 0$, $b = 0.8887934$ and $c = -0.1697202$.

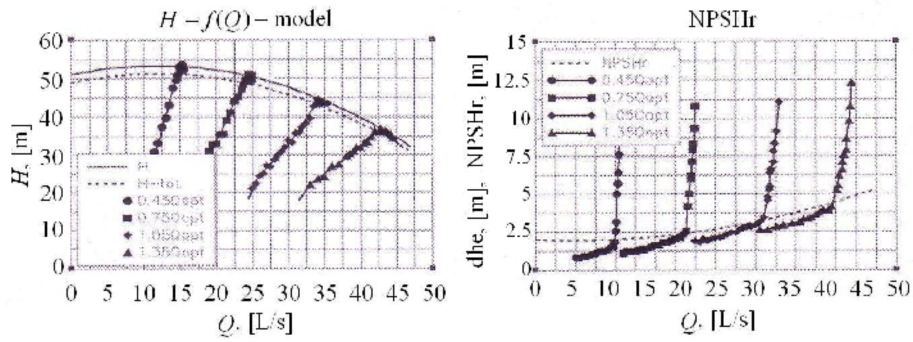
A scaled-down impeller (1:5.7) was manufactured based on the original one at Jidoaia. Energetic and cavitational experiments were performed with this impeller on the test rig. Data were also acquired using the thermodynamic method for comparison. The plots can be seen in Fig. 11. The second set of experiments was targeting the cavitation; the plots can be seen in Fig. 12.



a

b

Fig. 11 – The head (*a*) and the mechanical power (*b*) *vs*. flow rate; the square-marked curves are obtained using the thermodynamic method (in both figures); the circle-marked curves are obtained with the rig's data acquisition system.



a *b*

Fig. 12 – The head as a function of flow rate when functioning in cavitation (*a*) and the sensibility curve in cavitation (*b*).

6. Conclusions and Future Work

The results of an experimental test rig built to test centrifugal pumps were presented. Pressure, temperature, speed, flow and electrical power sensors are connected to the data acquisition system. The acquired data is stored on the PC in an Excel file. The rig is now validated and operational for a single speed value. This configuration is currently used for testing purposes to analyse new solutions for industry.

To be able to determine the maximum efficiency region, the future work targets experiments for different hydraulic regimes. A variable speed is then needed. An ABB 45 kW frequency converter was purchased for this matter. The converter can be remotely controlled from a PC. The software platform has to be able to modify the pump speed and acquire data. Another future work action targets the remote control (this may reduce the pumping station operation cost). The operating data can be easy centralized allowing for a better management.

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UN STAND INTEGRAT PENTRU INVESTIGAREA EXPERIMENTALĂ A UNITĂŢILOR HIDRO

(Rezumat)

Se prezintă părţile componente ale unui stand de încercări pentru unităţi hidro. Rod al efortului unei echipe de cercetare, acesta cuprinde un circuit hydraulic închis

constituit din două rezervoare de 1 m^3, țevi de inox, pompă PCN80-200 şi motorul de acționare. Pe parte electrică motorul este acționat printr-un sistem de soft-start ce asigură o pornire uşoară cu creşterea lină a turației. Un sistem de achiziții de date asigură conversia analog–numerică a datelor de interes de la senzori. Aceştia citesc presiunile de aspirație şi de refulare, debitul de fluid, temperatura, şi turația de acționare.

Sistemul de achziție de date asigură: comunicația serială cu calculatorul, 32 de canale diferențiale, rezoluție de 12 bit, domeniu de intrare de ±10 V / ±25 mA / 4...20 mA, frecvența de achiziție de 100 kb/sec, memorie pentru 512 kesantioane.

O platformă software integrată controlează sistemul de achiziție de date. Platforma asigură atât comunicația PC-ului cu sistemul de achiziție de date (pe magistrala serială) cât şi salvarea datelor obținute de la acesta în fişiere Excel. Ea permite şi afişarea rezultatelor într-un tabel în timp real şi trasarea curbei înălțimii de pompare calculate funcție de debitul măsurat.

Odată sistemul integrat, s-a trecut la experimente ce vizau calibrarea acestuia. În acest scop s-au amplasat aparate de măsură a presiunilor de aspirație şi refulare. În vederea verificării, s-au cules date atât manual cât şi cu sistemul de achiziție de date. Pentru verificarea debitmetrului, rezultatele acestuia au fost comparate cu rezultatele obținute cu un al doilea debitmetru.

Cu standul calibrat s-a trecut la măsurători la turație constantă, cu rotorul model la scara 1: 5.7 construit după rotorul stației de pompare Jidoaia. Curbele au fost ridicate atât din punct de vedere energetic cât şi din punct de vedere cavitațional.