MEANS AND METHODS FOR CONDUCTING EXPERIMENTAL TESTS ON HYDRAULIC TURBINE MODELS

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Abstract - The authors present an experimental stand dedicated to research laboratories for testing scale models of axial hydraulic turbine, and also the testing procedure suitable for this stand. The stand is one of the recent professional achievements of the two authors, being commissioned in 2015 at ICPE-CA Bucharest. It is characterized by high technical performance and reduced overall sizes. The aim of this material is to attract the attention of potential beneficiaries, educational and research units, who might be interested in procurement or development of such high performance stands.

Keywords – Experimental testing, SCADA, scale models, axial hydraulic turbines.

1. Introduction

In current practice in the field there are known constructive solutions for test stands with unique dedication, that is: either stands for experimental determination of the distribution of speeds around some fixed hydrodynamic profiles, placed inside water tunnels, or stands for experimental testing of axial hydraulic turbine scale models, placed inside water tunnels. The first category of stands is used to optimize the shape of hydrodynamic profiles based on an analysis of the spectrum of distribution of speeds obtained experimentally, while the second category is used for experimental determination of operating characteristics of hydraulic turbines.

The “classical” stands dedicated to both objectives above, are usually developed in constructive variants of relatively high overall sizes, either in the horizontal direction or vertical direction.

There are known few constructive variants of stands that can achieve both goals simultaneously, while constructive variants of stands with relatively small overall sizes [1] and at the same time dedicated to both goals above are even less known.

2. Stand structure and characteristics

2.1 Stand structure

In Figure 1 there is shown the functional block diagram which has underlain the development of the stand in Figure 2, in two steps: the step of achieving uniform flow of the water, at adjustable speeds, along the testing/viewing section, and the step of developing the devices for fastening-installing the axial hydraulic turbine models and the instrumentation for measuring parameters. In Figure 3 there is shown the fastening-installing of a model of vertical shaft axial turbine and the devices for measuring parameters.

The stand includes seven functional blocks, with parts represented in Figures 1, 2 and 3, namely:
1. Water tunnel with lids: Ti-input section; Tdd-decanting and distribution section; Tc-shrinkage section; Tvv-testing /viewing section; Te-output section.

2. Water tunnel support: Rap-pump suction tank; RG-discharge tap valve; SM-height adjustable metal frame; 3. Adjustable pumping unit: P1, P2, P3-3 pumps; M1, M2, M3-3 electric motors; CF1, CF2, CF3-3 frequency converters; CA-pumps suction collector; DR-distributor pump discharge, pipes and supports; DE-electrical case; ME-vibration damping electric sleeve; Ri-isolation tap valves; Car-check valves.

4. Items placed in the Ttv: Mtao-horizontal shaft axial turbine model; C-coupling, Lr-radial bearing; Lar-axial-radial bearing; Tpp-Pitot-Prandtl tube, Devices for displacement tunnel models and instrumentation.


The water tunnel forms a continuous, modular medium, composed of five removable and watertight flow sections, fitted with lids, as follows:

The input section, wherein discharge, through a stainless steel pipe with rated diameter Dn 200 mm, the pressure sides of the three vertical centrifugal pumps, mounted in parallel. Water access in this section is done through a plastic pipe fitted with perforations on its side surface. This section plays in flowing the role of a diffuser, because it continuously increases its flow section when transited by the water flow. In the last quarter of the length of this section, in order to reduce the harsh turbulences of the fluid flow, there has been installed, transversely against the direction of flow, a perforated stainless steel plate, with relatively large dimensions of holes.

The decanting and distribution section is a section for flow stilling, of constant sectional area, equal to the maximum sectional area of the input section, which is intended to equalize the lines of current. In this section there are installed perforated plates and screens, sieves and cellular honeycomb structures, whose sizes and distributions for holes will be finally set through experimental tests.

The shrinkage section represents a transition zone from the distribution section, with larger sectional area, to the testing one, with narrower sectional area, the ratio of shrinkage of the section being 1/6. The section is developed as having large connection radii and small slope, in order to minimize the size of swirls during forced flow.

The testing/viewing section, where the flow must be stabilized, due to the shape, dimensions, surface quality of all other three sections of water tunnel.

The output section, through which the water tunnel is linked with a flange to a pump suction tank, is part of the tank.

The first three sections of the water tunnel and the tank have been made out of polyester reinforced with glass fiber (PAFS), while the testing/viewing section out of resistant and transparent plastic.

The suction tank of the pumps has a prismatic shape, rectangular base, and inside, at the top, is fitted with a stainless steel sheet wall, which directs the flow of water to the pump suction area. At its upper side the tank shall be connected with the testing/viewing section, and at the bottom with the intake manifold of the pumping unit. Also at its bottom the tank shall be fitted with a drain tap valve.

The adjustable pumping group is made up of three vertical shaft centrifugal electro pumps, installed on a joint platform. It has a maximum flow rate of 3x120=360 m³/h, a power of 3x7.5=22.5 kW, and maximum speed of pumps is 2920 RPM. Flow adjustment, in the range 18-360 m³/h, is made by speed variation by using three frequency converters. The pumping group also includes an electric power supply panel, six tap valves for insulation of pumps, three reversing flaps and two collector pipes for suction and discharge. It is connected to the suction tank and the water tunnel through three anti vibration and elastic sleeves and a stainless steel discharge pipe, clamped with three briddles and three mounts.

The experimental stand works in closed circuit. After filling the stand with a volume of 3.5 m³ of water, up to the level of 0.3 m in the testing/viewing section, the pumping group sucks water out of the tank and discharges it into the water tunnel, which in turn spills-over the water in the same tank. The stand provides uniform and adjustable speed rate in the transparent section.

The stand is equipped with an experimental data acquisition system, which includes: a PC with dedicated software; an electrical enclosure with programmable automatic machine, electric power sources, numerical display for transducers; transducers for flow and speed of water subjected to forced circulation through the water tunnel; speed and moment (torque) transducers coupled to the shaft of the tested turbine model.

2.2 The main functional characteristics of the stand

Purpose of the stand: experimental determination of the distribution of speeds around hydrodynamic profiles and experimental determination of operating characteristics of scale models of axial hydraulic turbines with vertical or horizontal shaft. The stand works on clean water.

Sizes of the stand: length x width x height = 5.35 m x 2 m x 2 m. The stand has a modular design; each module can be inserted through a normal-size double door of 2.03 m x 1.06 m. The stand is equipped with a transparent testing/viewing section, free surface; sizes: length x width x height = 1.15 m x 0.300 m x 0.375 m. The water level in this section is 0.300 m. The hydrodynamic profiles or hydraulic turbine models placed inside the testing/viewing section must be framed in the water-full section of 0.300 m x 0.300 m.

Water speed and flow along the testing/viewing section: water speed is adjustable, in the range 0.05
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m/s...1 m/s; water flow is adjustable, in the range 0.005 m³/s...0.1 m³/s.

**Power of electric motors** of the pumping group is 3 x 7.5 kW = 22.5 kW

**Characteristics of water flow** along the testing/viewing section: flow must be stabilized, uniform, continuous and permanent; variations in speed must be less than 1% of the average speed.

**Characteristics of axial hydraulic turbine scale models:** maximum overall dimensions must not exceed the dimensions of the watered area of the testing/viewing section, which are 0.300 m x 0.300 m; maximum torque developed at the shaft of the axial turbine models tested is 1 Nm at a speed of 400 rpm.

3. Placing and installation of the stand

3.1 Placing

The modular stand is to be placed in a suitable area of research laboratories for Hydraulics which should provide: appropriate natural and artificial lighting, which gives a perfect visibility of all areas of the stand and its surrounding travel lane; natural or forced ventilation specific for an working environment dedicated to research laboratories; thermostated temperature of 20±1°C, throughout the year; a travel lane surrounding the stand of minimum width of 0.8 m. Area designated for stand location must be provided with the following utilities: filter fitted connection to the drinking water network of the beneficiary; hose fitted connection to the sewerage system of the beneficiary or floor drain; connected to the three-phase 380V network of the beneficiary; connection to grounding belt; chair and table for the PC, Internet connection, 220V electrical outlet.

3.2 Installation

In section 1 of the water tunnel there is mounted a cylinder made of PVC, perforated with holes of Ø32 mm, for water access into the tunnel and also a perforated stainless steel sheet screen, with PVC frame, for an initial calming of the turbulent water flow, Fig. 4.

In section 2 of the water tunnel there is mounted a plastic sieve and a honeycomb structure made of polycarbonate, to achieve a second area for calming the water flow, Fig. 5.

Figure 4: Mounting the perforated cylinder and perforated screen in section 1

Figure 5: Mounting the sieve and the honeycomb structure in section 2

In order to direct the flow of water from the tunnel to the outlet, eliminate the breaking of air bubbles absorbed by the water in the transparent section and mitigate the effects of bottom vortex in the suction area there are mounted on the cover of the pump suction tank a deflector, Fig. 6, a second plastic mesh, its frame stuck by ties and nuts, Fig. 7, and also a bend at 45° made of PVC, Fig. 8.

Figure 6: Mounting the deflector on the cover of the suction tank

Figure 7: Mounting the mesh with frame and ties on the cover of the suction tank

Figure 8: Mounting the PVC bend on the bottom of the suction tank

There is installed the metal support of the water tunnel, having 9 height-adjustable feet, then the common cover of sections 1 and 2, the cover of section 3 and sections 1, 2 and 3, with their respective covers, on the metal support, Fig. 9.
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There are set the suction tank, water tunnel and pumping group in their place, are height adjusted their support legs, the suction collector of the pumping group is connected to the suction flange of the tank by means of a flexible bellow coupling, the water tunnel along with the support is moved toward the tank, Fig. 10, action followed by mounting of the transparent Plexiglas section, Fig. 11, first the end near the tank, then the one near the tunnel.

There is installed the stainless steel discharge pipe, on props, between the flange of the discharge collector of the pumping group and the flange of section 1 of the water tunnel, separated from these flanges by two elastic bellow couplings, Fig. 12.

There are installed the electrical power panel and the SCADA electrical enclosure, by means of screws pinned on the metal support of the water tunnel, Fig. 13, then the three electric motors are connected to the electrical power panel, Fig. 14.

On the discharge pipe there is mounted the flow transducer, on the suction and discharge collectors of the pumping group there are mounted one gauge and a pressure transducer, and at the lower part of the suction tank - a drain tap valve.

4. Methodology for experimental testing of scale models of axial hydraulic turbines

This methodology contains a description of the main operations, in a chronological order, necessary for testing scale models of axial hydraulic turbines on the stand specialized and dedicated to this purpose, developed by the authors of this material.
4.1 Preparing the stand for testing the axial turbine models

Before installing the turbine model which is to be tested on the stand, there will be checked the functionality status of the stand and of the adjustable braking system.

**Horizontality of the stand water tunnel:**

Using a bubble level there is checked horizontality of the water tunnel, along its entire length. Any possible large deviation from horizontality will be reduced by adjusting the height of the nine feet of the tunnel support and of the four feet of the suction tank support, part of the pumping group.

After achieving a framing of horizontality of the water tunnel in the tolerances of the measuring instrument used, ensuring at the same time that tunnel support is created, on the floor of the laboratory, with all legs of the metal support, one can move on to the next step of performed checking.

**Checking the position of the shut off tap valves:**

It will be checked that all handles of the six tap valves for separation from pumps, Fig. 15, within the pumping group, are on the "OPEN" position.

**Checking the water level in the tunnel:**

It will be checked that the water level in transparent testing/viewing section is 300 mm from the bottom of the section, Fig. 16. Adjusting the water level is done by filling the section with clean water, from the network of the beneficiary, if the level is below 300 mm, respectively by discharging into the sewage network, if the level is above.

**Venting the pumps:**

By unscrewing and screwing successively the filler and vent cap, from each individual pump, Fig. 17, there will be ensured the purging of the air inside the pumps. Venting is complete when through the hole in the cap, at the position unscrewed, a continuous water jet is flowing without interruptions.

4.2 Turning the stand on

The three pumps of the stand are turned on sequentially at rated operating speed (2900 rpm). Turning the stand on is done by turning the general switch located on the cover of the electrical power panel.

**Checking the flow adjustability and water speed on the stand:**

By varying the drive speed of the pump, based on the frequency variation of the supply current of the electric motors by means of the three frequency converters, there is checked the achievement of the following water flow and speed rates in the transparent section: 18 m³/h, respectively 0.05 m/s; 360 m³/h, respectively 1 m/s; 20 flow rates between minimum and maximum flow (18...
360 m³/h), respectively 20 speed rates between minimum and maximum speed (0.05...1 m/s).
After checking the achievement of the mentioned flow and speed rates, the pumping group is switched to maximum flow (360 m³/h), then it is left to run for 15 minutes on this flow. While the group operates at maximum flow rate, there will be noticed possible water leaking out through: the separation planes between the sections of the tunnel water; between the sections and their covers; between the transparent section and the tank; between the flanges of the collectors of the pumping group, the flanges of the pumps, the flanges of the discharge pipe, the flanges of the three elastic couplings; between the couplings of the flow transducer, pressure gauges and pressure transducers, Fig. 19. This possible water leakage out will be removed by tightening the bolts and the couplings stronger in areas with leakage.

Checking the uniformity of water flow in the transparent section
Checking will be done under the most severe conditions for uniform flow, namely at maximum flow rate of the pumping group of 360 m³/h. There are chosen three parts along the testing/viewing section, located at the ends and in the middle of the section, where there will be immersed in the fluid flow, by means of the displacement device in three directions, the Pitot-Prandtl tube.
Within each part there will be carried out checks in 5 points located across the width of the section, and for each of these points there will be made checks in at least 5 points located throughout the depth of the section. The total number of measurements which will certify the framing of speed fluctuations in the allowed deviation will be 3x5x5 = 75 measurements. There is calculated the average water flow speed in the testing/viewing section, as the arithmetic mean of the 75 measured speeds. Each of the 75 measured speeds must be within the maximum deviation of 1% compared to the average speed.
In Fig. 20, Fig. 21, Fig. 22 there can be seen the shape of flow when the flow of stand is given by the pump P1 at maximum flow rate, the pumps P1 and P2 at maximum flow rates, the pumps P1, P2 and P3 at maximum flow rates.

5. Determining the stationary characteristics of axial hydraulic turbine models
The adjustable parameters of the stand can be monitored by reading the four indicators located on the cover of the electric data acquisition enclosure (SCADA enclosure), Fig. 23, namely:
Water flow, displayed in m$^3$/h (cubic meters per hour), is measured by means of the flow transducer, screwed into a drilled and threaded boss which is welded to the outer wall of the discharge pipe, before the first bend at 90º.

Dynamic pressure, measured as the difference between total pressure and static pressure, displayed in Pa (Pascal), is determined by means of the Pitot-Prandtl tube and differential pressure transducer, both fitted using clamping / movement devices, on the frame of the testing/viewing section.

Torque at the hydraulic turbine rotor shaft, displayed in Nm (Newton meter), is measured by means of the torque and speed transducer, located between hydraulic turbine shaft and the shaft of the magnetic particle brake.

Hydraulic turbine rotor speed, displayed in r.p.m. (revolutions per minute), is measured by means of the same torque and speed transducer.

Water speed in the testing/viewing section is determined indirectly using the ratio:

$$v = \sqrt{\frac{2\Delta p}{\rho}}$$

where: $v$ is water speed, in m/s; $\Delta p$ is differential pressure measured by means of the Pitot-Prandtl tube, displayed in Pa (1Pa=1 N/m$^2$); $\rho$ is the density of introduced water, in Kg/m$^3$. In this ratio the density of water is slightly corrected depending on the temperature.

Water density variation depending on temperature is given in Figure 24.

5.1 Adjusting the parameters of the stand

Water flow and speed rate in the testing/viewing section of the stand is adjusted by acting on the frequency converters of the three vertical electro pumps. The three converters are located inside the electrical power panel, and their operation is done either from the potentiometers placed on the outside of the panel cover, or from a virtual panel of the PC included in the control and data acquisition SCADA system.

The resistance torque at the shaft of the tested hydraulic turbine will be simulated by means of a magnetic particle brake. This brake produces a resistance torque adjustable in the range 0.04...2 Nm, dependent on the supply current, Fig. 25.

Power supply of the magnetic particle brake is done by means of a source located in the SCADA electrical enclosure, and power supply current adjustment is done from a potentiometer located on the virtual panel. The magnetic particle brake is mounted on the device supporting the rotor of the tested axial turbine.

5.2 Determining the stationary characteristics

For the experimental determination of stationary characteristics of axial hydraulic turbine models there will be mounted on dedicated devices, along with the torque/speed transducer, the magnetic particle brake and the small electric motor for mixing powders.

The devices, which are secured by means of a beam with four screws and nuts on the frame of the transparent section, are specific to each constructive and dimensional type of turbine.

Before testing the turbine, the brake will be actuated under no load for 10-15 minutes in order to homogenize the magnetic powders, and then the small electric motor will be removed from the device.

5.2.1 The characteristic torque dependent on flow at constant load $M=f(Q) / M_r=\text{const.}$:

After mixing the magnetic powder in the brake, removing the 24 VDC small electric motor, installing the turbine on the device and mounting the device on the frame of the transparent testing/viewing section the test is conducted in the following steps:

a) For the magnetic particle brake current unpowered:
- Start the first electric pump at a minimum flow rate corresponding to the frequency of the converter adjusted at the value of 20Hz;
- Gradually increase the frequency of the first converter, from the rotary potentiometer, up to 50Hz, respectively increase the flow rate of the first pump up to maximum flow, observing the flow value at which the turbine starts rotating;
- If the turbine does not rotate when the first pump has reached the maximum flow rate, then the flow adjustment of the second electric pump overlaps the maximum flow rate of the first pump, by actuating slowly the potentiometer of the second converter;
- If the turbine does not rotate when the first two pumps have reached the maximum flow rate, then the flow adjustment of the third electric pump overlaps the flow rates of the former pumps, by actuating slowly the potentiometer of the third converter.
- If the turbine does not rotate not even at the maximum flow rate of the stand which is 360 m³/h, respectively a water speed of about 1.1 m/s, this means that the turbine cannot develop a torque higher than 0.1Nm and its construction must be reconsidered in view of testing it on this stand.
- Flow rate value at which the turbine rotates at a minimum imposed rotational speed, for instance 100 rev/min, represents the flow rate at which the turbine develops a torque of 0.1 Nm (resistance torque of unpowered brake and of the device bearings), denoted \( Q_{\text{m}} \).

**Note:** The stationary characteristic \( M=f(Q)/M_{r}=\text{const.} \) determined on the stand is the more precise the lower is the flow rate value at which the turbine starts to rotate.

b) For the magnetic particle brake current powered:

After determining the minimum flow at which the turbine rotates at 100 rev/min, under the conditions of not current powering the brake, the test will continue with flow rate adjustment from this minimum value to the maximum value, along with adjusting the current powering the magnetic particle brake, namely:
- There will be determined the turbine shaft torque for maximum flow of the stand and rotational speed of 100 rpm. To this end the three pumps will be coupled at maximum flow rate, the current powering the brake will be gradually increased till the rotational speed decreases to 100 rpm. After determining the torque value at maximum flow rate, \( C_{\text{OMAX}} \), the test will continue as follows:
  - There will be adjusted gradually, upwards, the resistance torque of the adjustable brake system, with equal pitch, for 10 values in the range 0.1... \( C_{\text{OMAX}} \) Nm;
  - For each of the ten current values of the adjusted load the flow rate will be gradually increased, from the value corresponding to the previous load up to the value corresponding to the rotational speed of 100 rpm of the tested model;
  - There will be acquired the 10 values of flow rate corresponding to load increasing and obtaining a rotational speed of 100 rpm for the tested model;
  - The test is repeated idem also for decreasing of the load, from \( C_{\text{OMAX}}...0.1\text{Nm} \);

- There will be acquired other 10 values of flow rate corresponding to load decreasing and obtaining a rotational speed of 100 rpm for the tested model;
- With the 20 pairs of values (flow, torque) there can be drawn the characteristic \( M=f(Q)/M_{r}=\text{const.} \).

**Note:** Accuracy of stationary characteristic \( M=f(Q)/M_{r}=\text{const.} \) is satisfactory, at maximum flow rate, \( C_{\text{OMAX}} \), for torque values of minimum 1 Nm and values of flow \( Q_{\text{m}} \) of maximum 180 m³/h.

5.2.2 The characteristic rotational speed dependent on flow at constant load \( n=f(Q)/M_{r}=\text{const.} \):

The test is conducted in the following steps:
- Determine the minimum flow at which the turbine develops a torque of 0.1 Nm, \( Q_{\text{m}} \), idem as in paragraph 5.2.1 a and turbine torque at maximum flow rate, \( C_{\text{OMAX}} \), idem as in paragraph 5.2.1 b;
- The adjustable brake will be set to a value of resistance torque within the range 0.1... \( C_{\text{OMAX}} \) Nm, which will be maintained constant;
- For that value of load, the flow decanting the testing/viewing section is varied upwards, from \( Q_{\text{m}}...360 \text{ m}^3/\text{h} \) and downwards, from 360m³/h... \( Q_{\text{m}} \);
- For each flow rate value of the stand there is acquired the rotational speed value of the tested turbine model;
- There can be drawn up a family of stationary characteristics, rotational speed dependent on flow at constant load, where every characteristic of the family belongs to a constant load value in the range 0.1... \( C_{\text{OMAX}} \) Nm.

**Note:** Accuracy of stationary characteristic \( n=f(Q)/M_{r}=\text{const.} \) is satisfactory, at maximum flow rate, \( C_{\text{OMAX}} \), for torque values of minimum 1 Nm and values of flow \( Q_{\text{m}} \) of maximum 180 m³/h.

5.2.3 The characteristic rotational speed dependent on load at constant flow \( n=f(M)/Q=\text{const.} \):

The test is conducted in the following steps:
- Determine the minimum flow at which the turbine develops a torque of 0.1 Nm, \( Q_{\text{m}} \), idem as in paragraph 5.2.1 a and turbine torque at maximum flow rate, \( C_{\text{OMAX}} \), idem as in paragraph 5.2.1 b;
- Set a value of water circulation flow in the range \( Q_{\text{m}}...360 \text{ m}^3/\text{h} \);
- For that flow rate value, the resistance torque of the adjustable brake system, within the range 0.1... \( C_{\text{OMAX}} \) Nm, is varied, upwards and downwards, with constant pitch;
- For each value of resistance torque there is acquired the rotational speed value of the tested turbine model;
- There can be drawn up a family of stationary characteristics, rotational speed dependent on load at constant flow, where every characteristic of the family belongs to a constant flow value in the range \( Q_{\text{m}}...360 \text{ m}^3/\text{h} \).

**Note:** Accuracy of stationary characteristic \( n=f(M)/Q=\text{const.} \) is satisfactory, at maximum flow rate, \( C_{\text{OMAX}} \), for torque values of minimum 1 Nm and values of flow \( Q_{\text{m}} \) of maximum 180 m³/h.
5.3 Parameters monitoring and remote control of the stand

In addition to monitoring and control of frequency of the current supplying the three frequency converters, respectively startup and adjustment of the pumping group flow rate, performed locally from the cover of the electrical power panel, and to monitoring the flow rate, differential pressure (dynamic pressure), torque and speed, performed locally from the cover of the SCADA electrical enclosure, the stand is also equipped with a remote monitoring/control system.

The stand operator has at his/her disposal a software application, installed on a PC connected to the programmable controller of the SCADA system. The panel of the operator, Fig. 26, offers the following facilities:

- Monitoring of the following parameters: flow (m³/h); speed (m/s); torque (Nm); rotational speed (rpm); dynamic pressure (Pa); power (W);
- Calibration of the Pitot-Prandtl tube at no flow (determining the zero in Pa);
- Control of the magnetic particle brake (% of the maximum supply current);
- Control of the 24 VDC electric motor to mix the powder (% of the maximum supply voltage);
- Drive of the three frequency converters.

6. Conclusions

When commissioning the stand, in the research laboratory of ICPE-CA Bucharest, there have been noticed the following issues:
- adjustability of water flow in the transparent section with fine pitch, in the range 48...360 m³/h;
- adjustability of water speed in the transparent section with fine pitch, in the range 0.154...1.087 m/s;
- achieving stability in water flow in the transparent section after 15...20 s from setting the testing flow;
- uniformity of flow in the transparent section is characterized by water speed deviations of 0.4823%...0.1147% from the average speed;
- the possibility to test scale models of axial turbines, with sizes compatible with the ones of the transparent testing/viewing section, Fig. 27, Fig. 28.

7. References