Aspects Concerning the Use of Plastics in Developing Test Stands for Experimental Models of Hydraulic Turbine Blades and Rotors

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This paper presents the development, operation and testing of a modular small sizes original stand, its main modules made of plastics, intended for tests on blades and rotors in the structure of experimental models of hydraulic turbines. The stand includes a water tunnel consisting of demountable and sealed sections of which the majority, of various shapes and sizes, are made of composite material type fiberglass reinforced polyester, FRP, and one of them, rectangular cross-section, is made of transparent and resilient Plexiglass. Through the shapes of sections, quality of interior surfaces and quality of plastics used, the water tunnel allows creating in its transparent section a forced, permanent and continuous circulation of water, of adjustable speed in the range 0.05...1.1m/s. The results of tests conducted on an experimental model of water turbine by use of this stand demonstrate the economic and technical advantages of using plastics in building these types of testing tools.

Keywords: composite material, transparent Plexiglass, water tunnel

Romania benefits from favorable conditions for the harnessing of the main types of renewable energy (wind, solar, hydro, biomass energy), and investments in the energy sector in the last decade, mainly, have enabled, on January 1, 2014, Romania to reach the target undertaken through the European Directive 2009/28 / EC (also known as Directive 20/20/20) [1]. At that time, the installed electric power was 4,349 MW, and in August the same year it reached 4,704 MW. Of this capacity, 2,800 MW is represented by wind farms, and 1,234 MW by photovoltaic panels' fields.

Hydro energy has a great potential in our country (36,000 GWh), higher than wind potential (23,000 GWh) and much higher than solar potential (1,200 GWh); however, the progress in increasing the harnessing capacity of hydraulic energy has been much slower. This type of energy exists in two forms: potential and kinetic energy.

Until recently potential hydraulic energy was the energy with the largest share. Currently in Romania the installed capacity exceeds 6 GW, and production is approx. 20 TWh per year. In accordance with European Directive for decentralization of energy resources, micro- (5-100 kW) and pico- (1-5 kW) hydropower plants become increasingly convenient. A shortcoming of macro-hydropower plants is generating environmental impact by construction of dams, flooding of large areas of farmland and decommissioning them.

Hydropower plants based on converting kinetic energy of flowing water currents are absolutely harmless from the ecological point of view. In this area there are requested technical solutions that would lead to increasing the efficiency of converting kinetic energy of water. Of particular interest in this respect are small hydropower plants with hydrodynamic rotors based on the combination of two effects: the effect of water pressuring on the blades (used so far) and the hydrodynamic drag effect, which occurs at the hydrodynamic profile blades optimal orientation relative to water currents [2].

Whatever type of hydropower plant and its size, such conversion systems must ensure conversion efficiency as high as possible and as close as possible to the Betz limit (0.59); currently, efficiency rates are within the range of values 0.2…0.35, from which it results that there is a vast field of research for improving performance. This improvement can be achieved by passing the experimental model of the product (the water turbine, in this case) through the stages of modeling, simulation and experimental validation under real conditions or as a scale model.

Therefore, it was considered appropriate to develop and promote test stands for renewable energy (especially hydraulic energy) conversion systems, within INOE 2000-IHP, Institute which has among its research directions also the functional optimization of renewable energy conversion systems; such a test stand was developed in 2015 and it was delivered to a beneficiary also involved in the area of renewable energy conversion.

System overview

Due to the development of renewable energy conversion sector, and also from the desire to reduce costs related to testing the models prior to being placed into production, worldwide there have been developed various solutions for stands that test water turbines, as a whole or parts of them (rotor or rotor blades) [3]. Besides advantages, current solutions also present some drawbacks:

-they have a limited destination, either solely for experimental determination of the distribution of speeds around some hydrodynamic profiles of rotor blades, fixed without possibility of moving in forced circulation water tunnels, in order to optimize their hydrodynamic profile, or solely for testing water turbine rotors, driven by the potential energy or kinetic energy of a volume of water pumped in a closed circuit;

-the stands for testing water turbine rotors have relatively high overall sizes, either in the horizontal direction, in the case of using the kinetic energy of a water volume pumped into an horizontal tunnel, constant cross-section, or in the vertical direction, in the case of using the potential energy of the same volume of water pumped up to a certain quota.

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Fig.1. Stand for testing experimental models of hydraulic turbine blades and rotors

Compared to water tunnels necessary for measurements and visualization of velocity field around some hydrodynamic profiles, and also compared to other known stands for testing hydraulic turbine rotors, the solution proposed by the authors [3,4] has the following advantages:

-it cumulates the two destinations, *optimization of the shape* of the rotor blades and *testing* the rotor assembly, in one means of testing;

-it offers the possibility of testing, on the same means of testing, both models of vertical axis hydraulic turbine rotors, and models of the horizontal axis ones;

-it has small overall sizes, both the stand and devices for testing turbine rotors that equip it, allowing installation and operation in tight areas;

-it reduces costs of experimental measurements of scale models of rotors and rotor blades in small dimensions and low weight hydraulic turbines.

To reduce dimensions of water tunnels, which is necessary for installation of stands containing them in tight areas, component sections are made of a laminated composite material [5,6], containing fiberglass reinforced plastic and a rigid core of balsa wood. This material easily takes over static and dynamic loading of the moving volume of water. Of great importance is the quality of interior surfaces of water tunnel sections, must be smooth and small roughness, and also the alignment of sectors when mounting the tunnel, which must form a continuous medium, without thresholds and discontinuities that could disrupt water flow.

The testing / viewing section of the tunnel, in which there is introduced the experimental model of rotor blade or hydraulic turbine rotor, is made of Plexiglas with high transparency and mechanical strength. The experimental models of rotor blades or hydraulic turbine rotors [8] can be manufactured out of plastics [7], by layer deposition, one layer on top of another, on a 3D printer.

Experimental part

The stand, shown in figure 1, forcibly circulates a volume of clean water in a closed circuit, by using an adjustable flow pumping unit *G.P.D.R.*, which contains three parallel connected pumps that absorb through the suction pipe *C.A.*, from a pump suction tank *R.A.P.* and discharge, through the discharge pipe *C.R.*, in a modular water tunnel, *T.A.M.*, composed of five horizontal sections, which are dismountable and watertight, provided with covers, of which the first three ones rest on an adjustable height metal frame *S.M.I.R.*, and the last one- on the pump suction tank *R.A.P.*, communicating with it, the closed water circuit being achieved on the route *R.A.P.*, *G.P.D.R.*, *T.A.M.*, *R.A.P.* The electric motors of the pumping unit are supplied from the power cabinet *D.E.*, comprising three frequency converters that adjust the drive speed of the pumps and thus the flow rate of the pumping unit.

The first three sections of the modular water tunnel *T.A.M.*, two of which have variable sectional area, contribute to a steady and uniform flow in the fourth section, wherein there are fitted the fixed rotor blades, to determine the distribution of speeds, respectively there is fitted the rotor of an axial flow horizontal shaft turbine *R.T.A.O.* or the rotor of an axial flow vertical shaft turbine R.T.A.V. which is to be tested. These models of hydraulic turbine rotors are coupled through a vertical or horizontal axis to an adjustable brake system *S.F.R.*, simulating load of the rotor immersed in the modular water tunnel, when it is powered by the kinetic energy of the water.

By means of a *supervisory, control and data acquisition* (SCADA) system, three transducers and a PC there are carried out the following: *control* of adjustable brake system and adjustment of pumping unit flow; *monitoring and acquisition* of adjustable parameters of the stand, namely flow *Q* and speed *v* of water in the fourth section of the tunnel, and of mechanical parameters of adjustable brake system, namely torque *M* and rotative speed *n*.

Figure 2 shows the functional diagram of the stand for testing models of hydraulic turbine blades and rotors, and figure 3 shows the fitting for testing a vertical shaft turbine rotor.

Notation in figure 2 and Figure 3 is as follows: G.P.D.R. = adjustable flow pumping unit; 1 = pumping unit suction / discharge collector; 2 = faucet valves for isolating the pumps; 3 = centrifugal pumps; 4 = electric motors driving the pumps; 5 = frequency converters; 6 = couplings; 7 = non-return valves; 8 = flow diffuser; T.A.M. = modular water

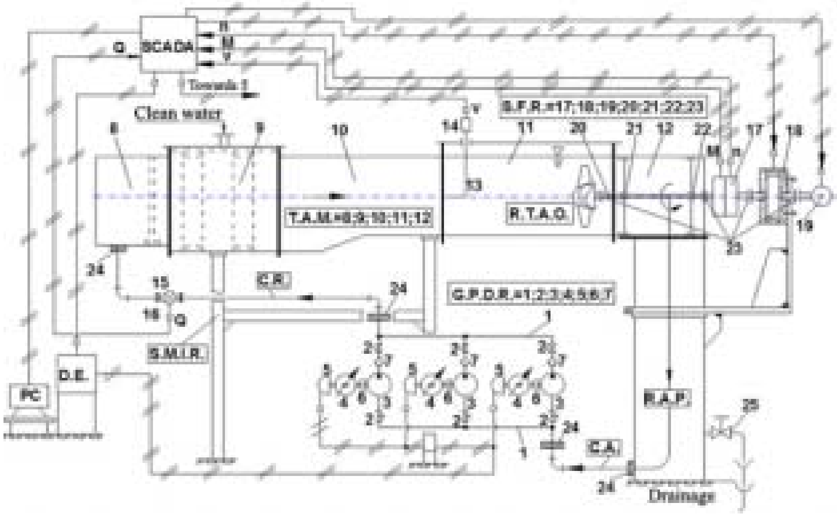
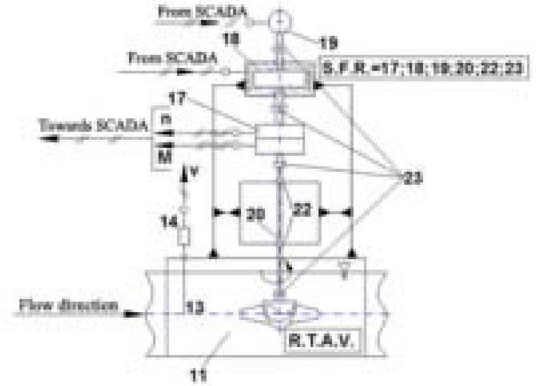


Fig.2. Functional diagram of the test stand



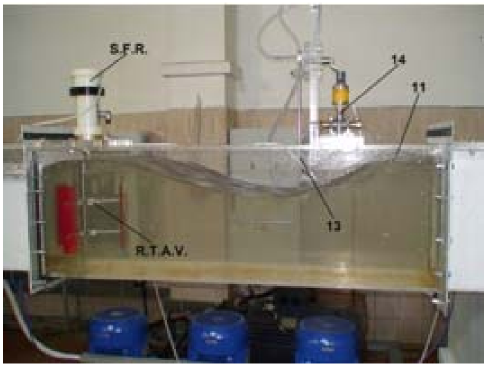


Fig.3. Testing a vertical shaft turbine rotor

Fig. 4. Water tunnel sections made of FRP

Fig. 5. Appearance of water flux in the transparent section at maximum flow rate of the stand

tunnel; 9 = flow stilling section; 10 = contraction section; 11 = transparent testing / viewing section; 12 = output section; R.A.P. = pump suction tank; C.A. = suction pipe; C.R. = discharge pipe; 13 = Pitot- Prandtl tube, movable in three orthogonal directions (length - x, width - y, depth - z); 14 = differential pressure transducer; 15 = electromagnetic flowmeter; 16 = flow transducer; R.T.A.O. = horizontal shaft turbine rotor; R.T.A.V. = vertical shaft turbine rotor; 17 = torque and speed transducer; 18 = magnetic particle brake; 19 = 24V DC electric motor to mix magnetic particles before using the brake; 20 = horizontal / vertical axis for rotor drive; 21 = radial bearing; 22 = axial-radial bearing; 23 = couplings; 24 = elastic sleeves; 25 = drain faucet valve; SCADA = supervisory, control and data acquisition system; D.E. = power cabinet, PC = computer.

The sections of the modular water tunnel *T.A.M.* and their covers are made of *fiberglass reinforced polyester, FRP*, except for the testing / viewing section and its cover, which are made of transparent and resilient Plexiglass. These sections are joined together, and also with the covers, by means of centring flanges made of FRP, stainless steel screws and nuts, being sealed by soft rubber gaskets, which are mounted in the housings that the fastening frames are fitted with, figure 4.

The sections made of FRP have metal bracing ribs on the outer surface of their bottom, and the first three ones are additionally provided with metal bosses fastening the adjustable height metal frame **S.M.I.R.** The pump suction tank is also made of FRP. All subassemblies and parts that come in contact with water, namely pumps, faucet valves and enclosures, pipes, fittings, marker parts inserted into the first and second sections of the modular water tunnel and pump suction tank are made of stainless steel, PVC, plastic, rubber.

Overall sizes of the stand are: length = 5.35 m; width = 2 m, height = 2 m. The testing / viewing section has a length = 1.15 m; width = 0.300 m, height = 0.375 m, and the section filled with water is 0.300 x 0.300 = 0.09 m^2.

The water speed and flow in the testing / viewing section are adjustable using the three frequency converters within the range 0.05...1.1 m/s, for the speed, respectively 0.005...0.1 m^3/s, for the flow.

Water flux in the testing / viewing section, (fig. 5) is stabilized, uniform, continuous and permanent, the deviations of fluctuation in speed being less than 1% of the average speed.

Power of electric motors of the pumping unit is 3 x 7.5 = 22.5 kW, and *maximum rpm* of the pumps is 2920 rev/min.

Resisting torque of magnetic particle brake (fig. 6) within the S.F.R., is adjustable in the range 0.04...2 Nm.

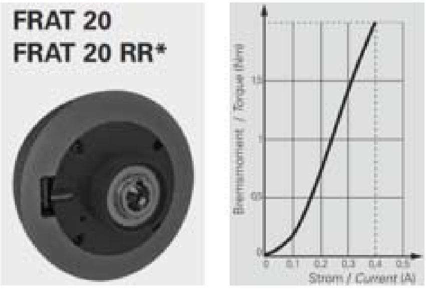


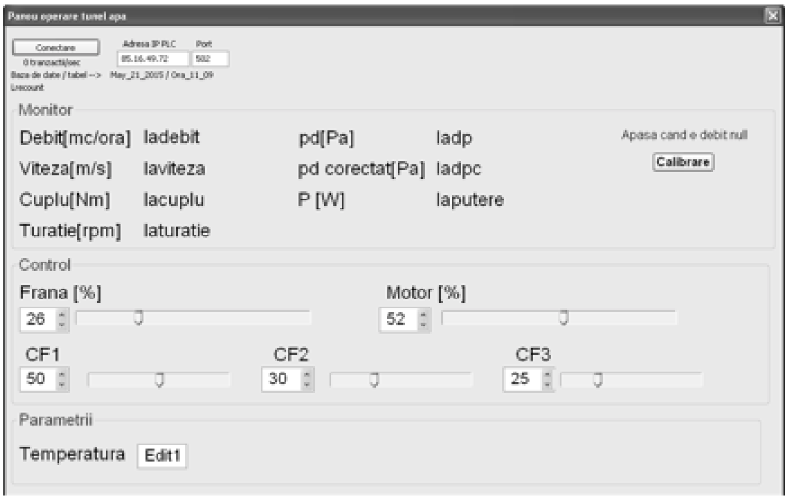
Fig. 6. Variation of resisting torque of the magnetic particle brake depending on the supply current

Minimum resisting torque of S.F.R (magnetic particle brake, bearings, couplings) is $M_{min} = 0.1$ *Nm.*

Operator panel (fig. 7) provides the following features: monitoring of the parameters flow - *Debit[mc/ora]*, speed - *Vitezã[m/s]*, torque - *Cuplu[Nm]*, rotative speed - *Turatie [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 V DC electric motor to mix the particles (% of the maximum supply voltage); drive of the three frequency converters.

Results and discussions

On this stand one can test rotors of axial flow horizontal or vertical shaft hydraulic turbines, of overall sizes that would



Panou operare tunel apa

0 tranzactii/sec

Adresa IP PLC: 85.16.49.72

Port: 502

Baza de date / tabel --> May_21_2015 / Ora_11_09

Lrecount

Monitor

Debit[mc/ora] ladebit

Viteza[m/s] laviteza

Cuplu[Nm] lacuplu

Turatie[rpm] laturatie

pd[Pa] ladp

pd corectat[Pa] ladpc

P [W] laputere

Apasa cand e debit null

Control

Frana [%] 26

Motor [%] 52

CF1 50

CF2 30

CF3 25

Parametrii

Temperatura Edit1

Fig. 7. Operator panel of the stand

Table 1
ADJUSTABILITY OF FLUX SPEED, ASCENDING AND DESCENDING, OF WATER FLOW

Item no.	Frequency P1 [Hz]	Frequency P2 [Hz]	Frequency P3 [Hz]	Q [mc/h]	$Q_{ascend.}$ v[m/s]	$Q_{descend.}$ v[m/s]	Deviation [m/s]
1	20 and a 30% closed valve	0	0	18	0.05		
2	20	0	0	48	0.154	0.157	0.003
3	25	0	0	60	0.194	0.197	0.003
4	30	0	0	72	0.235	0.237	0.002
5	35	0	0	84	0.274	0.275	0.001
6	40	0	0	96	0.313	0.313	0.000
7	45	0	0	108	0.348	0.348	0.000
8	50	0	0	120	0.380	0.381	0.001
9	50	20	0	168	0.514	0.514	0.001
10	50	25	0	180	0.555	0.557	0.002
11	50	30	0	192	0.596	0.596	0.000
12	50	35	0	204	0.635	0.636	0.001
13	50	40	0	216	0.672	0.674	0.002
14	50	45	0	228	0.710	0.712	0.002
15	50	50	0	240	0.744	0.748	0.004
16	50	50	20	288	0.843	0.845	0.002
17	50	50	25	300	0.888	0.894	0.006
18	50	50	30	312	0.934	0.938	0.004
19	50	50	35	324	0.977	0.980	0.003
20	50	50	40	336	1.012	1.016	0.004
21	50	50	45	348	1.050	1.052	0.002
22	50	50	50	360	1.087	1.092	0.005

Table 2
CHECKING FLOWING SPEED UNIFORMITY IN TWO POINTS IN AN HORIZONTAL PLANE OF THE TRANSPARENT SECTION

Item no.	Freq. P1 [Hz]	Freq. P2 [Hz]	Freq. P3 [Hz]	Q [mc/h]	(250,160,161) v[m/s]	(550,160,161) v[m/s]	Deviation [m/s]
1	20	0	0	48	0.156	0.156	0.000
2	30	0	0	72	0.237	0.236	0.001
3	50	0	0	120	0.382	0.381	0.001
4	50	20	0	168	0.518	0.514	0.004
5	50	30	0	192	0.603	0.596	0.007
6	50	50	0	240	0.763	0.746	0.017
7	50	50	20	288	0.851	0.844	0.007
8	50	50	30	312	0.951	0.936	0.015
9	50	50	50	360	1.119	1.090	0.029

Table 3
SPEED UNIFORMITY AT MAXIMUM FLOW IN TWO POINTS OF A VERTICAL PLANE OF THE TRANSPARENT SECTION

Item no.	Freq. P1 [Hz]	Freq. P2 [Hz]	Freq. P3 [Hz]	Q [mc/h]	(550,160,80) v[m/s]	(550,160,210) v[m/s]	Deviation [m/s]
1	50	50	50	360	1.120	1.117	0.003

allow installation in the transparent testing / viewing section, which develop mechanical torque in the range 0.1... 2 Nm, and rotative speed in the range 10...1000 rev/min.

Adjustability of water flow speed at a certain point of the testing / viewing section, with coordinates x = 250 mm, y = 160 mm and z = 161 mm, for values within the range 0.05...1.1 m/s, under ascending and descending flow rate values, is shown in table 1.

Table 2 shows measurement results for checking flux uniformity, at variable flow, in two points with different abscissas, but the same ordinates and quotas, with coordinates in millimeters of (250, 160, 161) and (550, 160, 161).

Table 3 shows measurements for checking speed uniformity, at maximum flow, in two points of a same vertical plane of the testing / viewing section.

Item no.	Point coordinates (x,y,z) in mm.	Q [mc/h]	v[m/s]	$v-v_{average}$ [m/s]
1	(550, 50,210)	360	1.125	0.00325
2	(550, 65,210)	360	1.120	-0.00175
3	(550, 150,210)	360	1.117	-0.00475
4	(550, 250,210)	360	1.125	0.00325

Table 4
FLOWING SPEED (V) UNIFORMITY IN FOUR POINTS OF DIFFERENT ORDINATES

Fig.8. SAVONIUS type turbine model

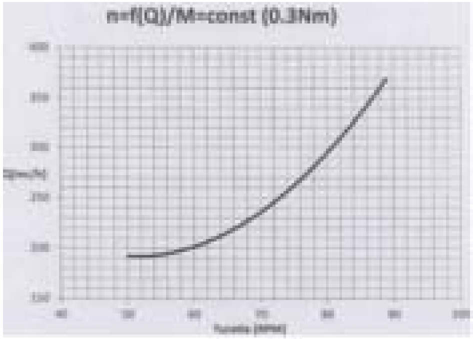


Fig.9.
The characteristic n=f(Q)/M=0.3Nm

Checking flowing speed uniformity, at maximum flow, in four points of different ordinates, but the same abscissa and quotas is shown in table 4.

Figure 8 presents a SAVONIUS type axial flow turbine which has been tested on this stand, and figure 9 – results of data acquired in graphic form, namely the functional characteristic: n=f(Q)/M=const.

Conclusions

Tests conducted on this stand have proven that that the water tunnel made of FRP resisted very well to the dynamic and static stress. No water leaks to the outside have been noted. The stand provides good adjustability and uniformity of flow that is adjustability and uniformity of water speed the testing / viewing section, and also adjustability and uniformity of load for the hydraulic turbine models which have been tested.

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 testing / viewing section, made of Plexiglass, proved to be resilient enough to the mechanical stress which it has undergone and also transparent enough to allow observation of water flux appearance, in order to compare it with the results obtained using professional modeling software.

The stand can test in comparison a wide range of models of rotor blades and hydraulic turbine rotors, and their manufacturing at minimal costs can be made out of plastics, by use of a 3D printer.

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