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APPLIED RESEARCH IN HARNESSING HYDROPOWER TO OBTAIN ELECTRICAL ENERGY

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Introduction

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Energy has ever been a hot issue for humanity. In the context of climate changes and environmental pollution by energy production or its conversion from fossil sources, one challenge is to get green, clean energy at an affordable price. Every year the classical energy sources show their limits and conventional oil and gas reserves will only be available for the next 40 -50 years or so. Gas accumulation in the air may have triggered irreversible processes such as the ozone layer play-out, global warming, etc. In this context, the use of alternative energy sources becomes increasingly important and neccessary for the functional configuration of the future world [1].

Energy from the sun, winds, rivers, oceans and seas, biological processes and geothermal heat can be captured by people using different procedures. Friction forces between air currents and water surface generate kinetic energy waves. This energy leads to the conversion of wave energy into electrical energy. The power of micro hydroelectric power plants on the rivers depends on several factors such as the geological conditions, the technical conception and the building materials, the hydrological cycles, and the type of equipment used. The types of turbines that have been used in hydroelectric power plants are as follows: Pelton turbines, Francis turbines, Kaplan turbines, transversal turbines, axial and helical turbines, a.s.o. On shorter rivers the following technical solutions [2, 3]:

- model with vertical axis, flow of water in cavity regime and external generator;
- intubated model with vertical or horizontal axis, axial turbine and external electric generator;
- built-in construction with submersible electric generator, inner bearing and gasket ringed line-shaft.

Types of electrical generators used in hydrotechnical constructions

In the case of synchronous generators, normal models for operating in the air, excitation is applied by using high energy permanent magnets made from earth metals and synthesized from NdFeB with six pairs of magnetic poles, rotation of up to 500 rot /min, at 50 Hz [4, 5, 6, 7, 8, 9].

The induced was built by using the package of steel sheets from an asynchronous motor of 7.5/1.500 rpm that has an aluminium casing and massive inductive yoke. It is a closed model, and several measures have been taken to prevent rain water from coming through (buried shields, differently sized axes, double insulated bearings).

The bearings are equipped with radial and axial double ball bearing situated at the opposite end of the traction and double and axially secured with the shield and on the shaft for a safe functioning when axially strained, there is also a normal radial medium heavy bearing, on the traction side.

The rotor is an empty cylinder, the magnetic yoke is radially dimensioned due to magnetic saturations and is consolidated on the shaft by side bearings. The rotor polar pieces are lopsided in order to keep the start coupling within safe values.

The number of both pole and phase slots is q = 1. The total number of slots is Z=36. The winding pitch is diametric. There is a two-layer winding. The total number of coils is 36 (Z = 36, two-layer winding). The number of phase coils is 12. The number of phase spires is $W_1 = 156$. The dimension of the entrefer is δ= 1mm. The outer diameter of the rotor is D_r = 131 mm. The average magnetic induction within the entrefer is B_δ=0,79 T. The actual phase voltage when idle is U_0=55 V at 300 rpm. The average nominal phase current is I_{fN}=11 A.

Tests have outlined a good behavior in the case of the generator when idle and loaded that presents the following features: [4, 5, and 6]:

- the rigid external characteristic of the voltage at terminals in accordance with the current that is delivered on the load, fig.1. (representation for the factual average values of the three phase voltages and current), at constant rotation values;
- the high value of the efficiency in accordance with the duty delivered to the load, fig.2, at constant rotation values.

Another type of generator used in hyfrotechnical constructions to convert water energy into electrical energy is the synchronous reversed built –up micro generator designed to operate in immersion.The electric generator is of synchronous, single phase, reversed built-up type and has its inner stator equipped with windings while its outer rotor (pot shaped) is equipped with permanent magnets on the inner side.

The inner stator is centrally fixed in the support on the right shield of the generator. It includes a central hub against which the package of FeSi plates and the insulating coil heads are pressed. The winding is accomplished by means of flat coils located on the package of no slot plates. The insulation of the entire construction is accomplished by means of an outer thermo contracted located over the windings as well as over the insulating bolsters and metal flange at the end. The outer rotor backed by the shaft is pot shaped (cylinder – magnetic yoke plus end flange), and is equipped with permanent magnets located inside in horizontal rows for each pole. The magnets are of Nd-Fe-B type and synthesized, and also present high magnetic parameters. The environmental protection is accomplished through a cylindrical foil on the active surface and through end elements made up of synthetic materials; the components are glued and the gaps are bridged by using a synthetic resin mixture compatible with the used materials.

The shaft crosses the left side shield of the generator by sliding and it is backed up (outside the shield) by the cogwheel of the rotation multiplier (it is thus moved by the hydraulic rotor). The second sliding of the (sliding) shaft takes place inside the stator hub.

The transversal marks of the construction (shields, flanges) are provided with holes to allow water to freely circulate within the entrefer.

The synchronous normal built-up generator equipped with claw shsped poles and designet to operate in immersion a variant of electric hydro generator that is directly operated from the hydraulic rotor. It is synchronous, normal built-up and three phased. It has been designed to be close and insulated, and provided with inner sliding and passing of the shaft and with ferrules. The inductor is the stator and the rotor is the inductor with cylindrical permanent and Nd-Fe-B synthesized magnets, and with claw shaped magnets.

The construction embeds three fixed coil subassemblies (with indentures), lined up within the encasing with intermediary spacing clamps and coiled together (the coils go through the three fixed coils), as well as the three rotatable subassemblies with claw poles sustained by the common shaft. The inductive excitation flux is achieved with permanent magnets (Nd-Fe-B, $B_r \approx 1T$, $\mu_r \approx 1$) of a cylindrical shape directed along an axial anisotropic line, interposed one by one among the claw poles slots of the three rotatable subassemblies (the number of pole pairs p=6) [1,2].The entrefer between the claw poles and the stator core teeth is relatively small, of about 0,5mm. On the frontal surface (towards the entrefer) of the claw poles of 0,5*25*25=312,5 mm^2 (each) and a dispersion between the claws along a winding trajectory having a length of (25+25)x6, average width of 4mm and of an entrefer height of about 5mm, resulting for an optimal speed, straight to the shaft of the hydraulic turbine of about 450 rot/min, the tension on the idle Y-voltage outlet terminals of about 24 V, an effective value experimentally confirmed (see the table below). For a winding pertaining to the fixed coil of a 0,6mm diameter we rely on an effective maximal power of approx. 80 W.

For the construction of the electric generator with a lubricated bearing coating form the river water, we have given up on the standard built-up, given the selected perfectly sealed frame – because of the serious consumption noticed for the sliding bearing coatings made of a special sintered brass. Thus, we have retorted to two classic bearings, these being tightly salad together with the stator coil with the help of three oil retainer ring set-up at the exit of the operating shaft from the carcass.

The optimization and design of the stator coil was achieved with the help of a special calculation program of the magnetic field generated by the rotor assembly.

On the lab model of the submersible electric generator we have performed idle and on-load measurements in order to raise its specific power depending on the rotation speed. The set of measurements was performed with INCDIE ICPE-CA. The generator sustained in a console was set in gear by means of an elastic hitch and operated with the help of a continuous current electric motor, of a variable rotation speed. We have taken into account the characteristic of the submersible electric generator both idle and on-load. (table 1)[3].The rotation speed was measured with an electronic revmetre type MSP 01.

We have measured the tension for each phase of the generator and for the driving motor as well.

The stator (induced) regroups three subassemblies: steel sheet package form the auto alternator, lined up with intermediary spacing clamps. The steel sheet presents 36 semi-closed indentures. The axial fastening is made with three tyrants between the traction shield and the spacing clamps on the one hand, and the opposite traction inner shield with the spacing clamp on the other hand.

Table 1: Tri-phased synchronous generator

n {rot/min}	***Tri-phased synchronous generator***						
	U_{line} [V]	U_{phase} [V]	I_{phase} Idle Measurements	$P_{phase\ 1}$ [W]	$P_{phase\ 2}$ [W]	$P_{phase\ 3}$ [W]	P_{tot} [W]
570	65.70	37.45					
495	56.00	32.3					
307	34.80	19.84					
158	17.70	10.09					
450	40.66	23.50	1.27	25.00	27.50	31.25	83.75
350	31.14	18.00	1.00	12.50	17.50	18.00	48.00
200	17.30	10.00	0.60			5.75	cca 15
100	8.65	5.00	0.25				
415	36.33	21.00	1.32	20.00	25.00	27.50	72.50
350	30.28	17.50	1.11	10.00	17.50	20.00	47.50
222	19.90	11.50	0.71			8.00	cca 21

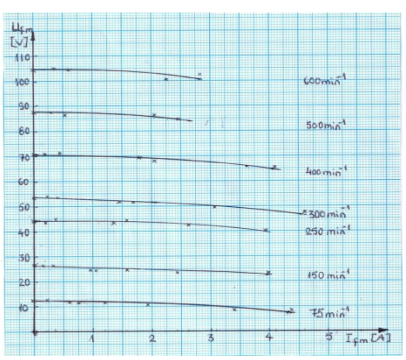

Fig. 1. Rigid external characteristic

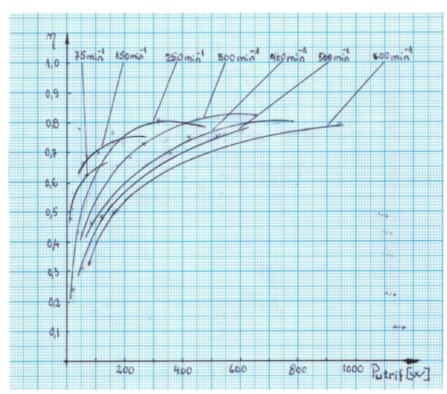

Fig. 2. High value of the efficiency

The rotor (inductor) regroups on the shaft three subassemblies of claw poles pairs (n_{sub}=3) in special construction, adapted for excitation with permanent magnets, of a cylindrical shape and are placed inside the claws (instead of the coil) with ferromagnetic spacing clamps. The centering and

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consolidation on the shaft is made with the help of interior non-ferromagnetic sockets. The axial centering is achieved with a bolt nut along a screwed section of the shaft. The traction bearing assures the position towards the stator. The end of the traction shaft goes through two tightening oil-retainer rings. The opposite traction shaft is axially free. The entire construction is tightly sealed with a glass shaped carcass with a tightening collar flange joint to a traction shield by bolts.

Dimensional and coiling elements:

- Interior diameter of the package of stator steel sheet: $D = 89mm$;
- The axial length of a steel sheet package (of the three): $l = 23mm$
- The size of the entrefer : $\delta = 0.5mm$;
- The useful surface of a claw pole: $S_p = 312mm^2$;
- The dispersion entrefer between claws : $\delta_\sigma = 5mm$;
- The average lateral surface of equivalent dispersion for a pair of poles: $S_\sigma = 300mm^2$;
- The exterior diameter of the magnet: $D_{em} = 70mm$;
- The interior diameter of the magnet: $D_{im} = 45mm$;
- The height of the magnet: $h_m = 7mm$;
- The number of stator indentures: $Z = 36$;
- The number of pole pairs: $p = 6$;
- The number of phases: $m = 3$;
- The number of indentures on pole and phase: $q = 1$
- The number of spires on phase : $w_1 = 216$, (12 coils with 18 spires) ;
- permanent sintered magnets NdFeB, with a remnant induction $Br \cong 1T$ (considered as coverage) and the relative reversible permeability: $\mu_r = 1$.

Calculus elements:

- The frontal surface of the magnet

$$S_m = \frac{\pi(D_{em}^2 - D_{im}^2)}{4} = 2258 \cdot 10^6 [m^2]; \quad (1)$$

The calculus of the electromotor tension (idle tension at the terminals) on phase voltage (effective value). As shown before, the construction incorporates three stator subassemblies of auto alternator (n_{sub}=3).

In order to establish the value of the electromotor tension we have taken into account a surface of the claw poles S_p=312mm^2 and a magnetic dispersion between poles along a winding trajectory between claws with an equivalent surface for a pair of poles $S_\sigma = 300mm^2$ and an average entrefer $\delta_\sigma = 5mm$. The reference rotation speed taken into account is n=150 rot/min, to which we relate a frequency of the phase electric tension;

$$f_1 = \frac{p \cdot n}{60} = \frac{6 \cdot 150}{60} = 15Hz ; \quad (2)$$

The shape and dimensions of the stator indentures imply an increment factor of the equivalent entrefer δ' (Carter factor) of $K = 1.18$, resulting $\delta' = \delta \cdot K = 0.59mm$.

Applying the calculus formula for magnetic circuits we obtain the following relations and values:

- average magnetic induction inside the magnet

$$B_m = \frac{B_r}{1 + \frac{1}{\mu_r} \cdot \frac{2\delta'}{h_m} \cdot \frac{S_m}{p(S_p + \frac{2\delta'}{\delta_\sigma} \cdot S_\sigma)}} = 0.959T ; \quad (3)$$

- Magnetic induction in the entrefer :

$$B_\delta = B_m \cdot \frac{S_m}{p\left(S_p + \frac{2\delta}{\delta_\sigma} \cdot S_\sigma\right)} = 0.943T ; \quad (4)$$

- Idle electric tension (effective value):

$$U_0 = 4 \cdot f_1 \cdot w_1 \cdot B_\delta \cdot S_p \cdot k_{w1} \cdot n_{sub} = 11.4V ; k_{w1} = 1$$

- winding factor). (5)

The hydropeneumatic micro power plant is assigned the generator module which consists of a one-way turbine and a small alternator while the turbine axis leans against two radial ball bearings and is elastically coupled to the generator axis [11]. The operating principle of the one-way, reciprocating blade turbine is based on the driving way of the air flow which leads to one way, lateral forces and causes the turbine to rotate in a single direction. The one-way turbine has 216 cm in diameter and consists of a central hub with 20 radial stainless steel axes on which we mounted 20 Dural blades with 2 polyamide bearings in the entering edge. To avoid radial movement the blades are attached to the turbine hub by a rivetted narrow Tombak bar. Unlike hydro pneumatic power plants that have oscillating casing, our plant allows for the waves to break in, avoiding the direction change of wave energy flow and catchment of both smaller and bigger waves. The turbine is turned on by bending the blades in a + or - 40° angle which ensures a rapid startup of the turbine at a very slow speed of the air flow. During operation, the bending angle of the turbine blades varies up to the nominal angle according to the air flow speed and the generator load. In order to protect the generator module against overloading there are two systems: a system based on turbine braking action when the frequency of the current produced by the generator is over 50 Hz, and the second system which is based on turbine braking action by bending the blades using a centrifugal device.

Turbine protection against overloading and overpression is achieved by the use of a centrifugal system. For a superior output, the generator module of the micro hydroelectric power plant is provided with a tri-phase generator whose excitation is done through permanent magnets and the rotation nominal speed of both the generator and the turbine reaches 3000 rot/min. The estimated output of the generator is 0.91 %, while the overall output of the micro hydroelectric power plant is 0.329 %.

EXPERIMENTAL SAMPLING OF THE GENERATOR MODULE

With a view to checking the constructive solution of the multi-blade turbine we have performed numerical simulations in a CFD environment (Computational Fluid Dynamics).

For the achievement of the 3D model of the turbine module we have used the documentation drawn-up by the coordinating partner INCDIE ICPE CA [12,13]-fig. 5,6.

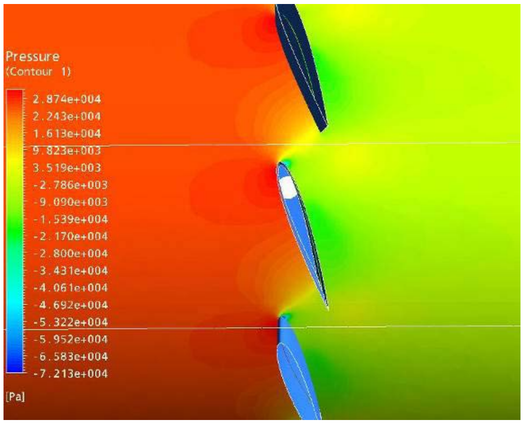

Fig.5 – Field of relative pressure values

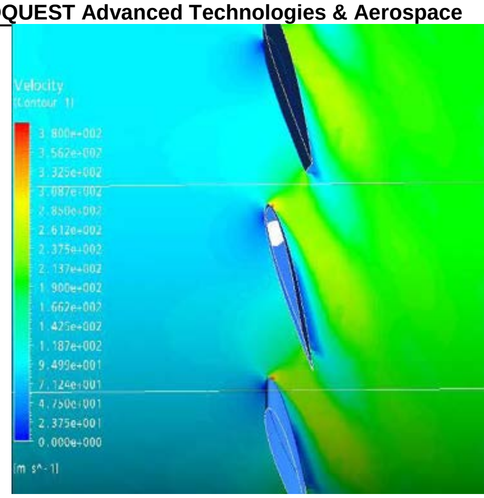

Fig.6 – Speed field

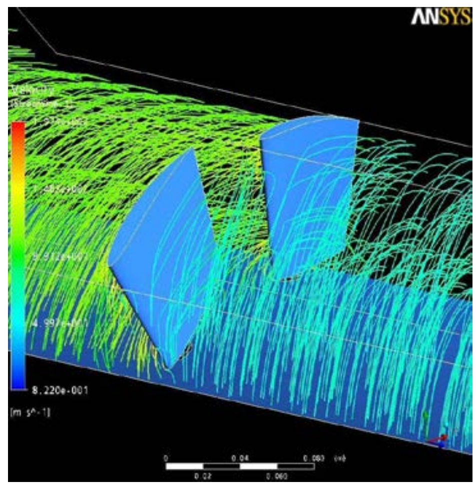

Fig.7 – Power lines

CONCLUSION

The design, model, and dimension of power plants used to convert water energy into electrical energy will be performed by taking into account the hydrodynamic, aerodynamic, mechanical and electrical loading parameters of the entire micro hydroelectrical power plant as well as the hydrological and meteorological conditions of inland waters and the Black Sea.

The research undertaken has enabled us to achieve the submersible generator and implement it after performing a testing on the Prut; we have also come up with an ecologic craft powered by the energy of the Danube.

We have built and experimented with a generator module for the conversion of wave energy into electrical energy. The constructive solution of the pneumatic turbine was achieved by means of numerical simulations in a CDF environment (Computational Fluid Dynamics) by INCD COMOTI. For the achievement of the 3D model of the turbine we have used the documentation drawn-up by the coordinating partner INCDIE ICPE CA providing representations of the relative pressure field and the speed field.

The proper experiments were performed for a single speed of air inside the turbine of 35m/s. The calculation for the useful power was made by means of measurements for electric power and the rotation speed for the shaft.

We have increased the power and shaft couple curves of the turbine for the air speed of 35m/s. At this speed we have noticed a compatibility of the turbine, extracting a maximal mechanical power of approx. 1.25kW. This observation leads to the conclusion that the pneumatic turbine will be able to reach a power ranging from 4.5 to 5kW at an air speed of 54 m/s.

REFERENCES

1. Nicolae,F. s.a. – ***„Tehnologii de valorificare a energiei din surse regenerabile"***,ISBN 978-973-692-331-9,5-8 pg, Constanţa,2012.

2. Cazacu, M.D.; Nicolaie, S. – ***„Micro-hydro turbine for run-of-river power station"***, A 2- Conferinţă a Hidroenergeticienilor din România, 24 – 25 mai 2002, Univ. Politehnica, Bucureşti, Vol.II, 443 – 448.

3. Gordon, J.L. – ***„Turbine selection for low-head hydro developments"***, Conference: Innovative small hydro technologies, organized by Natural resources Canada at Water-power Canada, New York, USA 2003.

4. Samoilescu, Gh. et alii. – ***„Sistem cu autonomie energetică destinat supravegherii paselor de trecere pe Dunăre"***, A 6-a Conferinţă Naţională „Profesorul Dorin Pavel – fondatorul hidroenergeticii româneşti", Sebeş, 2-3 iunie, 2006.

5. Samoilescu, Gh. ş.a. – ***„The analysis of the buoys used on the river for making a non-conventional energetic system"***, ICATE 2006 - 8th Intenational Conference on Applied and Theoretical Electricity, Băile Herculane, oct. 26-28, 2006.

6. * * *ICPE-CA - ***„Instalaţie de conversie neconvenţională de mică putere bazată pe integrarea unor materiale avansate şi soluţii tehnologice noi"***, proiect RELANSIN /2003.

7. * * *ICPE-CA - „Baliză fluvială autonomă din punct de vedere energetic, cu semnalizare luminoasă, utilizată pe Dunăre", proiect AMTRANS/2001.

8. * * *ICPE-CA (Mihăiescu, Gh.M.; Kappel, W.; Nicolae, S.; Seghianu, R.; Hondrea, M.), UPB (Cazacu, I.M.) şi BERIMPEX S.R.L. (Berar, C.) - ***„Hidrogeneratoare de mică putere", Atelierul „Actualităţi şi perspective în domeniul maşinilor eletrice"***, ICPE-ME-SA, 2004.

9. * * *ICPE-CA (Kappel, W.; Codescu, M.M.; Stancu, N.; Mihăiescu, Gh.M.; Nicolae, S.; Hondrea, M.; Seghianu, R.) - ***„Magneţi permanenţi pe baza de NdFeB pentru hidrogeneratoare de mică putere"***, Conferinţa Naţională de surse noi şi regenerabile, CNSNRE, Târgovişte, 2004.

10. Cazacu, M.D.; Nicolaie, S. – ***„Micro-hydroturbine for run-of-riwer power station",*** the 2-nd Conference of Romanian Hydro-energy specialists, 24 – 25 may 2002, Polytechnics University, Bucharest, Vol.II, 443 – 448;

11. *** Wavegen a world leader in marine renewable energy. httm://wwww. wavegen.co.uk

12. Demirbilek, Z., and Panchang, V., CGWAVE*: A coastal surface water wave model of the mild slope equation*, Technical Report CHL-98-26, U.S. Army Engineer Research and Development Center, Vicksburg, MS, 1998.

13. ***National Institute of Research-Development for Electric Engineering INCDIE ICPE-CA, as project manager**,** *„HYDROPNEUMATIC ELECTRIC WAVE-POWERED PLANT* " **CEHPV,** Contract nr: 21-001/2007;