MICRO-HYDROPOWER STATIONS FOR CONVERSION OF KINETIC ENERGY OF RIVER WATER WITHOUT BUILDING BARRAGES

Bostan I.,PhD, Dr.Sc, Dulgheru V., PhD, Dr.Sc, Bostan V., PhD, Ciobanu O., PhD student
Technical University of Moldova

1. INTRODUCTION

To avoid the construction of dams, the kinetic energy of rivers can be utilised by means of exploiting water stream turbines. This type of turbines is easily mounted, is simple in operation and maintenance cost is suitable. The 1m/s current velocity represents an energetic density of 500W/m^2 of the crossing section, but only a part of this energy can be drawn off and converted into useful electrical or mechanical energy. This fact depends on the type of rotor and blades. Velocity is especially important as a double increase in the water velocity can result in an eight times rising of energetic density. Prut river has a section equivalent to 60 m^2 and an average velocity in explorable zones of (1 – 1,3) m/s, which is equivalent to an approximate theoretical energy of (30 – 65) kW. Taking into account the fact that the turbine can occupy only a portion of the river bed the generated energy might be much smaller. There are various conceptual solutions, but the issue of increasing the conversion efficiency of water kinetic energy is in the view of researchers. The analysis of constructive versions of floatable micro-hydro power stations previously examined did not satisfy at all from the point of view of conversion efficiency of water kinetic energy. In a classical hydraulic wheel horizontal axle (fig. 1) the maximum depth at which one of blades is sunk makes approximately 2/3 of the blade height *h*.

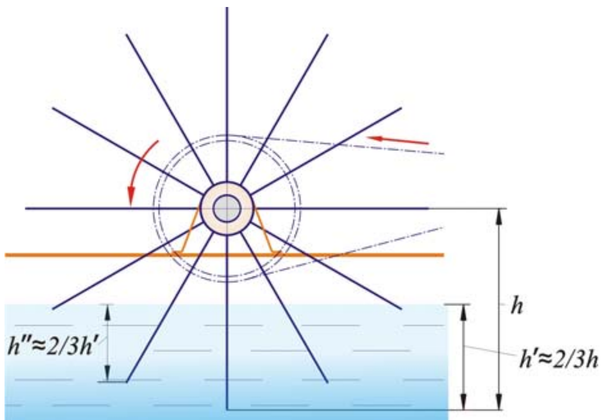

Figure 1. Conceptual diagram of the water wheel with rectilinear profile of blades.

Namely, only this area participates in the transformation of water kinetic energy into mechanical one. As well, the prior blade covers approximately *2/3* of the blade surface sunk utmost in the water *(h''≈ 2/3h')*. This fact reduces significantly the water stream pressure on the blade. The blade that comes next to the blade that sunk maximally into water is covered completely by it and practically does not participate in the conversion of water kinetic energy. Therefore, the efficiency of such hydraulic wheels is small.

The insistent searches of authors lead to the elaboration and patenting of some advanced technical solutions for floatable micro-hydro power stations, based on the hydrodynamic effect, generated by the hydrodynamic profile of blades, and their orientation at optimum positions concerning the water streams with account of energy conversion in each phase of the turbine rotor rotation (fig. 2) [1]. Therefore it was necessary to perform a large volume of multi-criteria theoretical research concerning the selection of optimum hydrodynamic profile of the blades and the design of the orientation mechanism towards the water streams.

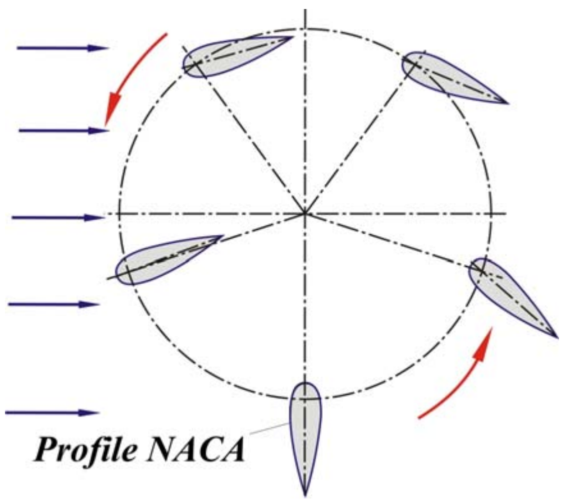

Figure 2. Conceptual diagram of the rotor with hydrodynamic profile of adjustable blades concerning the water streams.

The basic advantages of these types of micro-hydro power stations are as follows:

- Small impact on the environment;

- It is not necessary to carry out civil constructions;
- The river does not change its natural course;
- The possibility to utilise local knowledge in order to produce floatable turbines.

Another important advantage consists in the fact that along the river course it is possible to mount a series of micro-hydro stations at small distances (approximately 30-50 m) because the influence of turbulence provoked by the adjacent installations can be excluded.

The results of the carried out research by the authors concerning the water flow rate in the location selected for the micro-hydro power stations mounting, the geological prospecting of the river banks in the place of anchoring foundation mounting, the energetic needs of the consuming potential, represent initial data for the conceptual design of the micro-hydro power stations and its working element.

Conceptual design of the micro-hydro power station constructions with hydrodynamic profile of blades was carried out on the basis of three conceptual schemes:

- micro-hydro power station with pintle and blades mounted on vertical axles anchored by the metallic structure;
- floatable micro-hydro power stations with pintle and blades mounted on vertical axles;
- floatable micro-hydro power stations with horizontal spindle and blades mounted on horizontal axles.

Aiming at an increase of the conversion coefficient of the water kinetic energy (Betz coefficient), a number of structural diagrams of floatable micro-hydro power plants have been designed and patented [1-4]. They comprise a rotor with pintle and vertical blades, and hydrodynamic profile in normal section. The blades are interconnected by an orientation mechanism towards the direction of the water streams. The motion of rotation of the rotor with pintle is multiplied by a mechanical transmission system and is transmitted to an electrical generator or to a hydraulic pump. The mentioned knots are fixed on a platform, mounted on floatable bodies. The platform is linked to the bank by a hinged metallic truss and by straining cables.

A very important aspect in the functional optimization of micro-hydro power plants is the selection of optimum hydrodynamic profile of the blades which allows increasing the conversion coefficient (Betz coefficient). Due to the hydrodynamic upward forces the increase in the conversion level is reached by means of ensuring the optimum position of the blade towards the water streams in various phases of rotor rotation by utilizing blades orientation mechanism. Thus, practically all blades (even those which move opposite the water streams) participate simultaneously in the generation of summary torque moment. The blades which move along the water streams utilize both hydrodynamic forces and water pressure exercised on blade surfaces for the generation of the torque moment. The blades which move opposite the water streams utilize only hydrodynamic upward forces for the generation of the torque moment. Due to the fact that the relative velocity of the blades toward water streams at their motion opposite water streams is practically twice bigger, the hydrodynamic upward force is relatively big and the generated torque moment is measurable to the one generated by the water pressure. This effect forms the basis of all patented technical solutions.

In the process of designing industrial prototypes of micro-hydro power plants for the conversion of river water kinetic energy, the following criteria and requirements have been taken into consideration:

- the elimination of dam constructions and implicitly, of the negative impact on the environment;
- minimal costs;
- construction simplicity and operation;
- high reliability at dynamic overstressing caused by operating conditions;
- utilization of resistant composite materials including increased humidity conditions;
- automatic control of micro-hydro power plant platform position at water level variation;

The adopted technical solutions have resulted in an ample theoretical and experimental research carried out at the Centre for Renewable Energy Conversion Systems Design, Department of the Theory of Mechanisms and Machine Parts. To justify the constructive and functional parameters, supplementary digital modelling and simulation have been carried out by utilizing ANSYS CFX5.7 software. Subprograms developed by authors for the MathCAD, AutoDesk MotionInventor, etc. software, have been utilized, namely simulation of the interaction „*flow-blade*” of the floatable steadiness and also the optimization of blades hydrodynamic profile, with the purpose to increase the river water kinetic energy conversion efficiency for different velocities by using 3, 4 and 5 blade rotors. In the process of micro-hydro power plants design, the experience gained at research-design-manufacturing of the pilot plant was utilized.

The efficiency of micro-hydro power plant operation by private consumers for special purposes depend on the right selection of micro-hydro power plant constructive configuration and of the functional characteristics of the component aggregates participating in the process of flowing water kinetic energy conversion into useful energy.

In order to satisfy the objectives and consumers demand for micro-hydro power plants, and also for the increase in the flowing water kinetic potential conversion efficiency in the certain zone of the river, the authors have designed the following constructive and functional concepts based on modular assembling:

1. micro-hydro power plant with hydrodynamic rotor for river water kinetic energy conversion into mechanical energy – for water pumping (MHCF D4x1,5 M);

2. micro-hydro power plant with hydrodynamic rotor for river water kinetic energy conversion into electrical and mechanical energy (MHCF D4x1,5 ME);

3. micro-hydro power plant with hydrodynamic rotor for river water kinetic energy conversion into mechanical energy at small rotations (MHCF D4x1,5 ME);

4. micro-hydro power plant with hydrodynamic rotor for river water kinetic energy conversion into electrical energy (MHCFD4x1,5 E).

The mentioned micro-hydro power plants, conceived as modular ones, allow the modification of destination and functional characteristics by replacing certain aggregates with other (generator, pump, blades with different hydrodynamic profile, 3-5 blades rotor).

Micro-hydro power plants have similar resistance structure as constructions calculated from the point of view of resistance and rigidity at dynamic demands. Floatability and maintenance of the perpendicularity of micro-hydro power plant rotor spindle for a variable river water level are ensured by technical solutions protected by patents [1-4]. The instant orientation mechanism of blades for a constant entering angle concerning the direction of the water flow represents Know-How and it is not described. The main working element on which the quantity of kinetic energy converted into useful energy depends is the blade with the hydro-dynamic profile NACA 0016, developed on the basis of the performed digital modelling. Two types of rotors with 3 and 5 blades have been designed for the mentioned micro-hydro power plants. The installed capacity of micro-hydro power plants with diameter $D = 4\ m$, water-submersed blade height $h = 1{,}4\ m$ and the length of the blade cord $l = 1{,}3\ m$ for water flowing velocity $V = 1...2\ m/s$ can be within $P = 2...19\ kW$.

2. MICRO-HYDRO POWER PLANT WITH HYDRODYNAMIC ROTOR FOR RIVER WATER KINETIC ENERGY CONVERSION

The micro-hydro power plant with constructive configuration MHCF D4x1,5 ME for river water kinetic energy conversion into electrical and mechanical energy (fig. 3) is poli-functional and can be utilized for street illumination, heating, water pumping for irrigation by weeping, for drainage of agricultural areas adjacent to rivers.

The assembling of blades 1 with NACA 0016 profile in hydrodynamic rotor 2 and its mounting on the inlet shaft of the multiplier 3 are done in the same manner as for micro-hydro-power plant. The kinematics and constructive peculiarities of micro-hydro plant are the following: rotation motion of hydrodynamic rotor 2 with angular speed ω_I, by

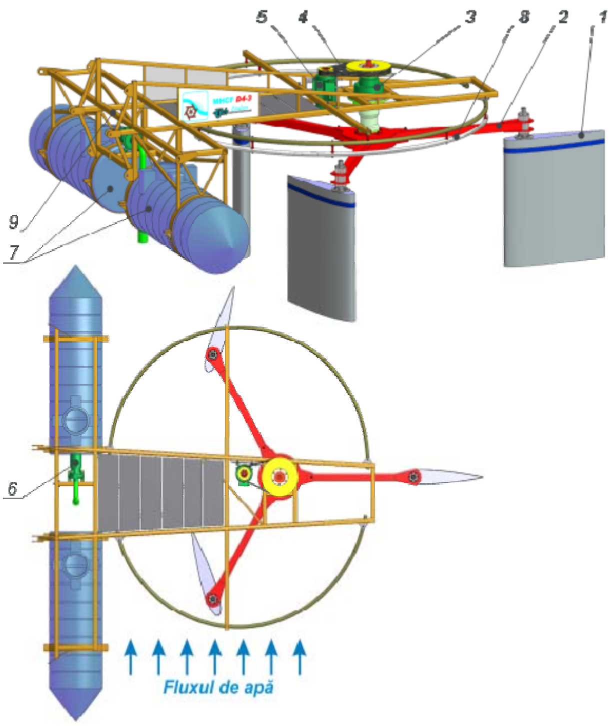

Figure 3. Micro-hydro power plant with hydrodynamic rotor river water kinetic energy conversion into electrical and mechanical energy (rotor diameter $D = 4m$, water-submersed blade height $h = 1{,}4m$, length of the blade cord $l = 1{,}3\ m$) (MHCF D4x1,5 ME): *1. hydrodinamic NACA 0016 profile blades; 2 – 3-blade rotor; 3 – planetary multiplier with multiplication coefficient i = 112; 4 – belt drive with multiplying coefficient i = 1,9; 5 – generator with permanent magnets (characteristics – p. 5.4); 6 – impeller pump CH – 400 (characteristics – pumping flow rate Q = (20-40) m^3/h la at pumping height 15...32m); 7 – plastic mass pontoons, 8 – guide path, 9 – space case.*

means of multiplier 3 and of belt drive 4 having an effective multiplying coefficient $i = 212,8$, is being multiplied up to angular working speed of the generator with permanent magnets with small rotations 5:

$$\omega_3 = \omega_1 \cdot i_1 \cdot (s^{-1}).$$

Torque moment T_3, applied to rotor 5, is:

$$T_3 = \frac{T_1 \cdot \eta_1 \cdot \eta_2 \eta_r}{i}, (Nm),$$

where: η_1 is the mechanical efficiency of the multiplier ($\eta_1 = 0,9$);

η_2 - mechanical efficiency of the belt drive ($\eta_1 = 0,95$);

η_r - mechanical efficiency of the hydrodynamic rotor bearings ($\eta_1 = 0,99$).

i – effective multiplication coefficient equal to the composition of multiplying ratios of the planetary multiplier and of the belt drive. Diagrams of the summary torque moment T_1 at the hydrodynamic rotor shaft with blades for different water flow velocities is shown in fig. 4.

The electric energy produced by the generator with permanent magnets 5 (fig. 4) can be utilized

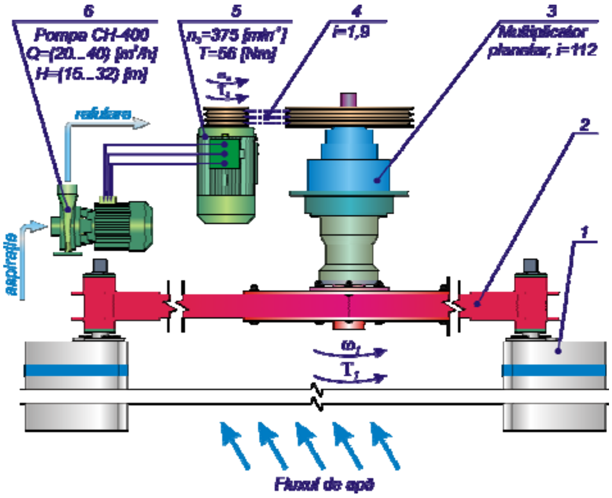

Figure 4. Micro-hydro power plant MHCF D4x1,5 ME kinematics.

both for private consumer needs of power and for supplying electricity to impeller pump 6 (CH 400), for water pumping into irrigation systems by means of weeping or drainage of agricultural areas adjacent to the rivers (by relocation of the impeller pump 6). In the fig. 5 the dependence of the torque moment T_1 at hydrodinamic rotor shaft at one rotation is presented. In the case of electric energy production, the energy utilization efficiency with account of mechanical losses in the kinematics chain of the micro-hydro power plant and in the generator with permanent magnets makes up (at generator terminal):

$$\eta_\Sigma = \eta_1 \eta_2 \eta_r \eta_g = 0,9 \cdot 0,95 \cdot 0,99 \cdot 0,87 = 0,736,$$

and in case of water pumping (at the shaft of the pump):

$$\eta_\Sigma = \eta_1 \eta_2 \eta_r \eta_g \eta_{me} = 0,9 \cdot 0,95 \cdot 0,99 \cdot 0,87 \cdot 0,91 = 0,67,$$

where: η_g is generator efficiency; η_{me} – efficiency of the hydraulic pump of the electric motor.

On the basis of the conceptual diagram designed above, technical documentation was developed and industrial prototype of micro-hydro power plant for river water kinetic energy conversion into electrical and mechanical energy was manufactured (fig. 5). Thus, micro-hydro power plant MHCF D4x1,5 ME provides

Figure 5. Industrial prototype of micro-hydro power plant river water kinetic energy conversion.

conversion of up to 73,6% and 67% of useful energy for electricity production and for water pumping from the energy potential of flowing water entrapped by the hydrodynamic rotor.

Bibliography

1. ***Bostan I., Dulgheru V., Sobor I., Bostan V., Sochirean A.*** *Renovable Energies Conversion Systems: solare, eoliene, hydraulic. Tehnica Info, Chişinău, 595 p. ISBN 978-995-63-076-4.*

2. ***Bostan I., Dulgheru V., Bostan V., Ciupercă R.*** *Anthology of inventions: renovable energies conversion systems. Bons Offices" SRL, Chişinău, 458 p. ISBN 978-9975-80-283-3.*

3. ***Bostan I., Dulgheru V., Bostan V., Ciobanu O., Sochireanu A.*** *Patent nr. 2991(MD).Hydro-electric plant / U.T.M. Publ. BOPI, 2006.- Nr.2.*

4. ***Bostan I., Dulgheru V., Bostan V. Sochireanu A., Ciobanu O., Ciobanu R. Dicusară I.*** *Hydro-electric plant. Patent nr. 3104 (MD). BOPI nr. 7/2006.*

Recommended for publication: 16.09.2010.