MODELLING AND SIMULATION OF THE FLUID FLOW ACTION ON ROTOR BLADES OF THE MICRO-HYDROPOWER STATION

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Abstract. Micro-hydropower station provides kinetic energy conversion of river water into mechanical or electrical energy without building barrages. Increased efficiency is provided by blades aerodynamic profile and their optimum position for efficient conversion of water kinetic energy. Blades positioning provides water energy conversion on all blades simultaneously, in any position. Actually it is in phase of execution and will be installed on Prut river.

Key words: power, rotor, micro-hydro-power, blade with hydro-dynamic NACA profile.

Introduction

The decentralized systems for producing of mechanical and electrical energy from flowing water kinetic energy (micro-hydro-power stations) utilise turbines which do not require the construction of dams and barrages. The flowing water kinetic energy is an advisable source of energy, available *24 hours a day* and can be efficiently exploited by micro-hydro-power stations.

The usage of micro-hydro-power stations would allow partial assurance of consumers (especially from rural and riverside zones) with electrical and mechanical energy (for irrigation of lands), thermal energy (for heating of living spaces during the cold period of the year). This will assure partial reduction of the consumption of fuels used for producing of electrical energy, and, therefore of the emission of the exhaust fumes. Due to the simple construction and serving, the micro-hydro-power stations will allow the producing of electrical energy at low cost.

Elaboration of conceptual project of pilot-station of the micro-hydro-power plant

On the basis of the carried out research the conceptual pilot-station of the bi-functional micro-hydro-power plant (Fig. 1) has been elaborated. The pilot-station will serve as site for experimental research on more technical solutions and working elements in natural conditions, but, in particular, research on efficient blades with hydro-dynamic profile. The pilot-station will be anchored to the bank with adjustable cables on its length via communicating bridge.

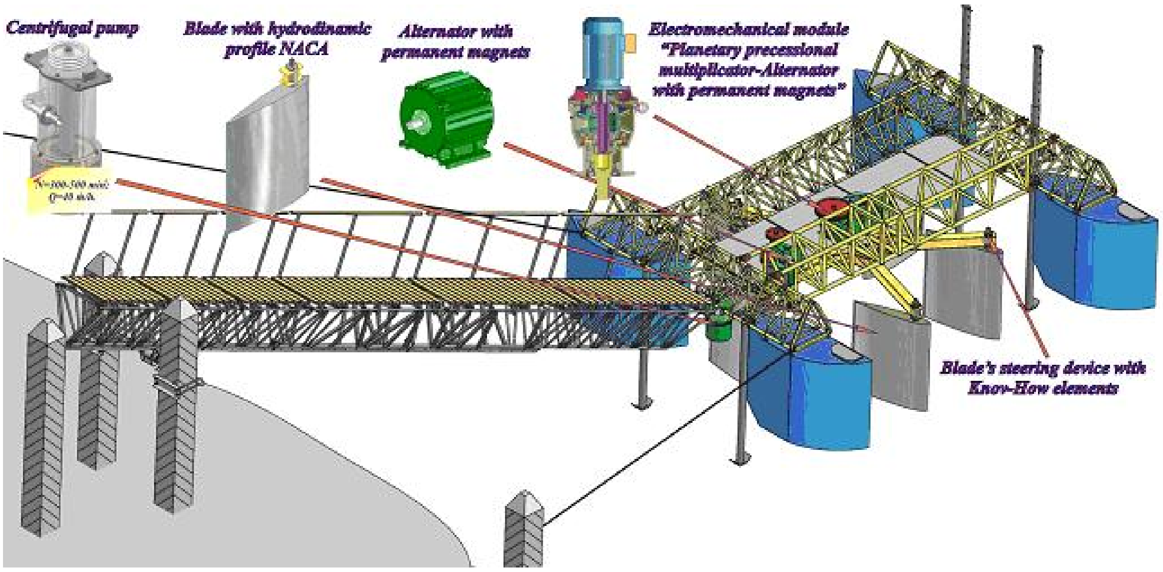

Fig. 1**. 3D overall view of the micro-hydro-power station**

The rotor with hydro-dynamic profile blades, precessional multiplier, centrifugal pump and electrical generator are fixed on the housing made from a metal framing. The framing, in their turn, are mounted on four landing pontoons. The communicating bridge and the mode of fixing to the bank by cables allow the pilot-station to float depending on the changing level of flowing water. The device for blades position control is not shown.

Numerical modelling of the hydrodynamic profile blades

Shape optimization of the blade's profile

In order to maximize the torsion moment developed by the micro-hydro power plant the shape optimization of the blade's profile was carried. The blade's profiles are chosen from the NACA 4 and 5 digits library with the shape expressed as a function of three parameters: maximum thickness, maximum camber and maximum camber location. As a shape parameter we consider only maximum thickness. Due to the use of symmetric profiles maximum camber shape parameter is taken to be zero, while the maximum camber location is arbitrary. The angle of attack is considered to be the second parameter. The goal of the shape optimization is to maximize the lift force, while keeping the pitching moment and drag coefficient not too large.

The following design optimization problem is considered:

$$\text{Maximize } C_L = C_L(\theta,\alpha) \text{ subject to bounds on } C_D \text{ and } C_M,$$

where θ – the maximum thickness and α is the angle of attack.

The values of the bounds are derived as follows: the maximum negative value for the pitching coefficient is chosen to correspond to the solution at zero angle of attack. The maximum value for the drag coefficient is chosen to correspond to the solution at angle of attack $\alpha = 18^{o}$.

We also add bounds on the parameters themselves, so that the optimization is performed in the space of reasonable profiles: $10\% \le \theta \le 20\%$ and $0^{o} \le \alpha \le 20^{o}$. In order to find the optimal values of a given function $f = f(x_1, \ldots, x_n)$ the variable metric iterative methods can be used:

```
While given precision is not attained do
    Solve $B_i S_i = -\nabla f(x_i)$
    $x_{i+1} = x_i + \alpha_i s_i$
End do
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where α_i – step multipliers and B_i are positive definite approximations to the Hessian of f.

The derivative of f with respect to the i^{th} component can be approximated by the central difference formula

$$\frac{\partial f}{\partial x_i}(x) = \frac{f(x+he_i) - f(x-he_i)}{2h},$$

where e_i – the i^{th} basis vector.

The shape optimization is performed within the Matlab optimization toolbox: a Sequential Quadratic Programming algorithm with a linesearch and a BFGS Hessian update. The quadratic subproblems are solved with a modified projection method. The gradients of $C_L = C_L(\theta,\alpha)$ are computed with central difference formulas with a constant stepsize *h = 1e-04*. As initial point for the optimization the symmetric NACA 0016 profile is used considered at angle of attack $\alpha = 18^{o}$. The initial and optimal profile shapes are shown in Fig. 2. About 30 iterations were needed in optimization subprogram to achieve the suitable convergence.

Numerical modelling of the fluid flow action on the rotor blades

In order to establish the optimal position of the blades we compare the torsion moment developed by one blade and the total torsion moment developed by all blades for different angle of attacks. The results are presented in Fig. 3 and 4. It can be seen that the optimal angle of attack is $17^{o} \le \alpha \le 18^{o}$, therefore the torsion moment is stable with respect to angle of attack. All computations were performed for the optimized profile NACA 0016M for the flow velocity 1 m/s.

Also we have analyzed the performance of the rotor with 3, 4 and 5 blades in order to choose the suitable rotor configuration. The total torsion moments developed by all blades for these configurations are presented in Fig. 5.

As future work we need to study the turbulence in the rotor area by carrying out a number of computer simulations in CFX 5.7 software. Thus the spatial interaction between the rotor and fluid will be investigated for various functional parameters in order to increase the efficiency of the turbine and decrease the energy loss.

Elaboration of the multi-blade rotor with hydro-dynamic profile blades

On the basis of preliminary research the construction of two rotors, with 5 and 3 blades with NACA profiles, has been elaborated. The blades are oriented at a setting angle α, which is variable concerning the action line of the flowing water speed vector (Fig. 6 a, c).

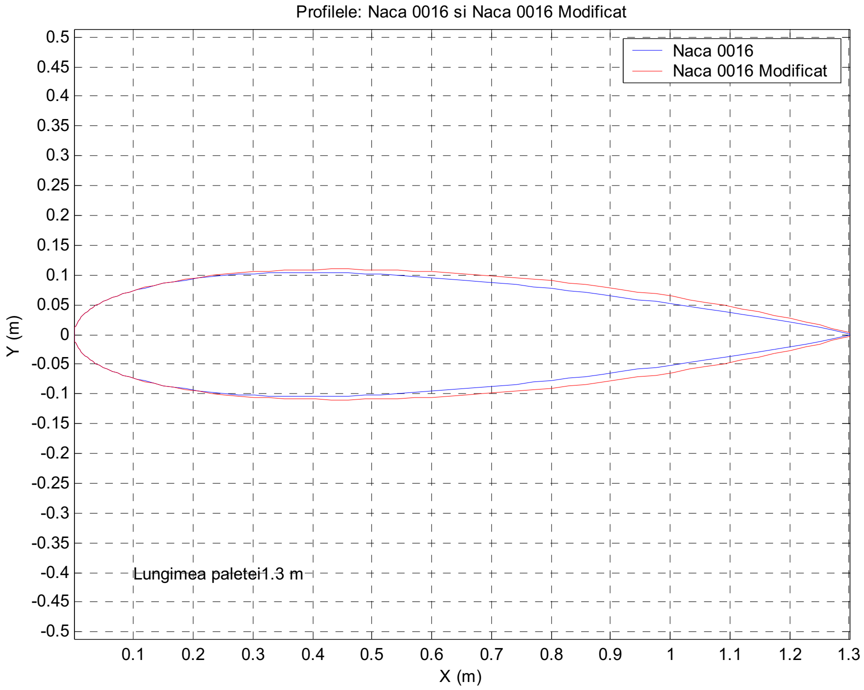


Fig. 2.

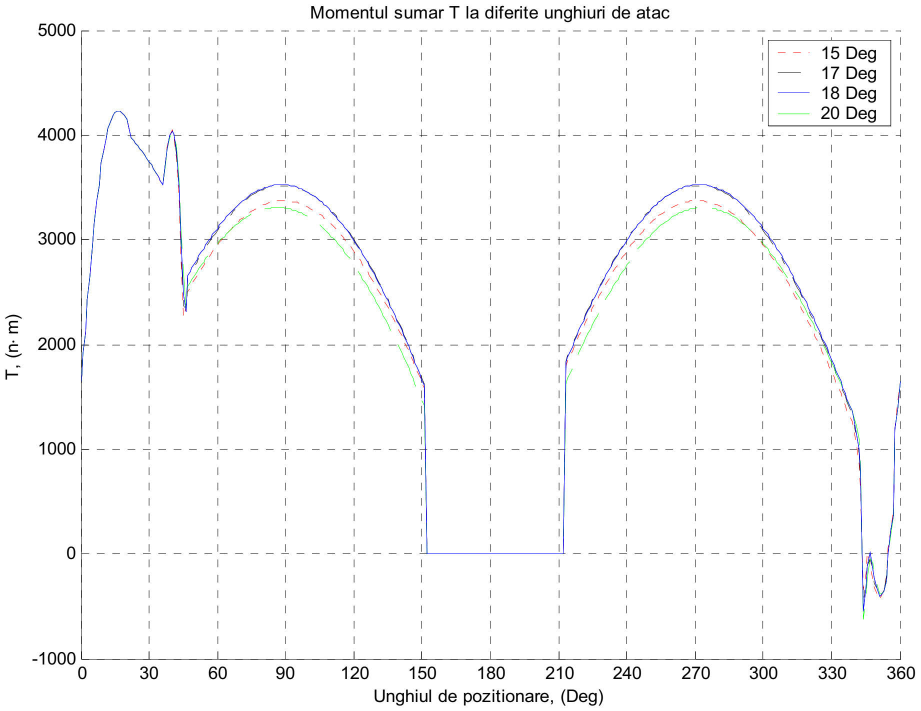


Fig. 3.

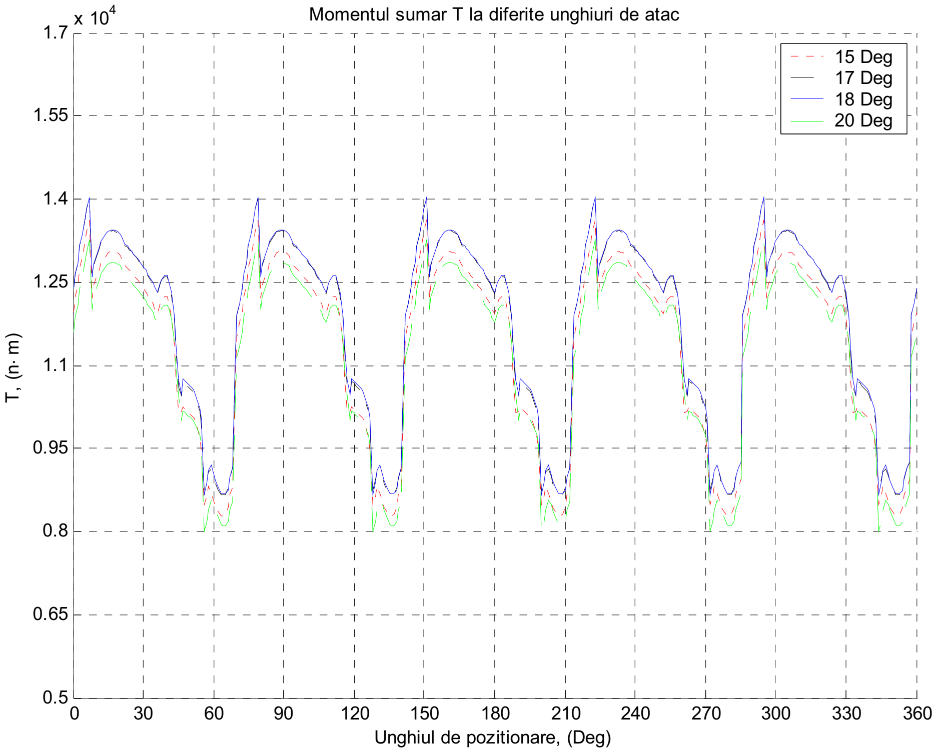


Fig. 4.

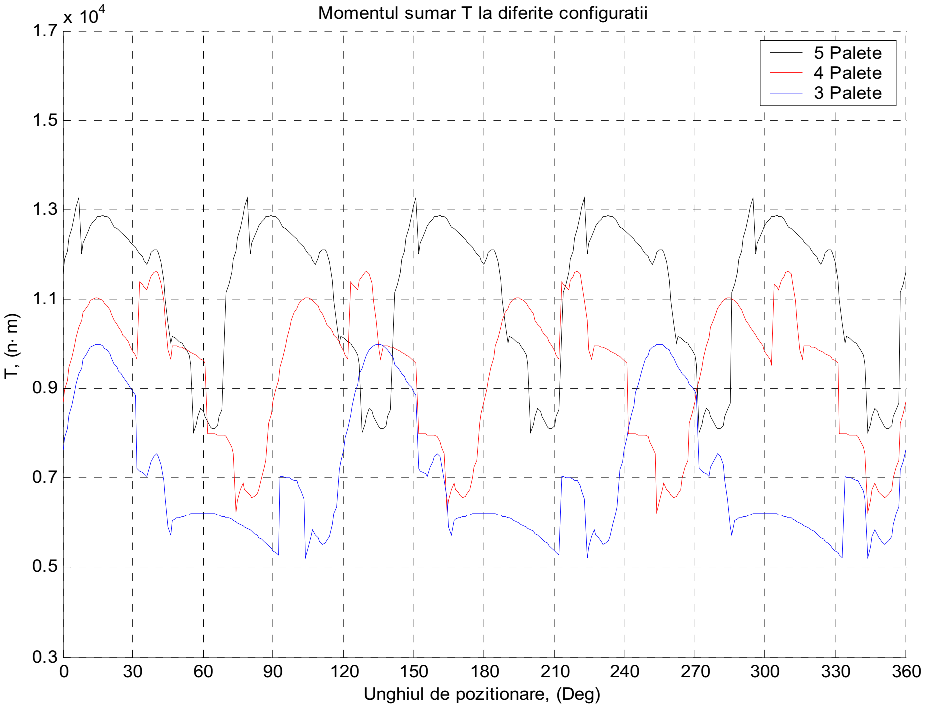


Fig. 5.

In Fig. 6 e and f the constructive diagrams of the rotor with 5 blades and of the hydrodynamic profile blade are shown. Theoretical research was reduced to the optimization of construction parameters of blades with various symmetrical NACA profiles (0012, 0014, 0016, 0018, 63012, 63015, 63018, 66015, 66018, 67015 – 32 profiles have been researched in total), with account of the maximal moment of torsion of the rotor shaft.

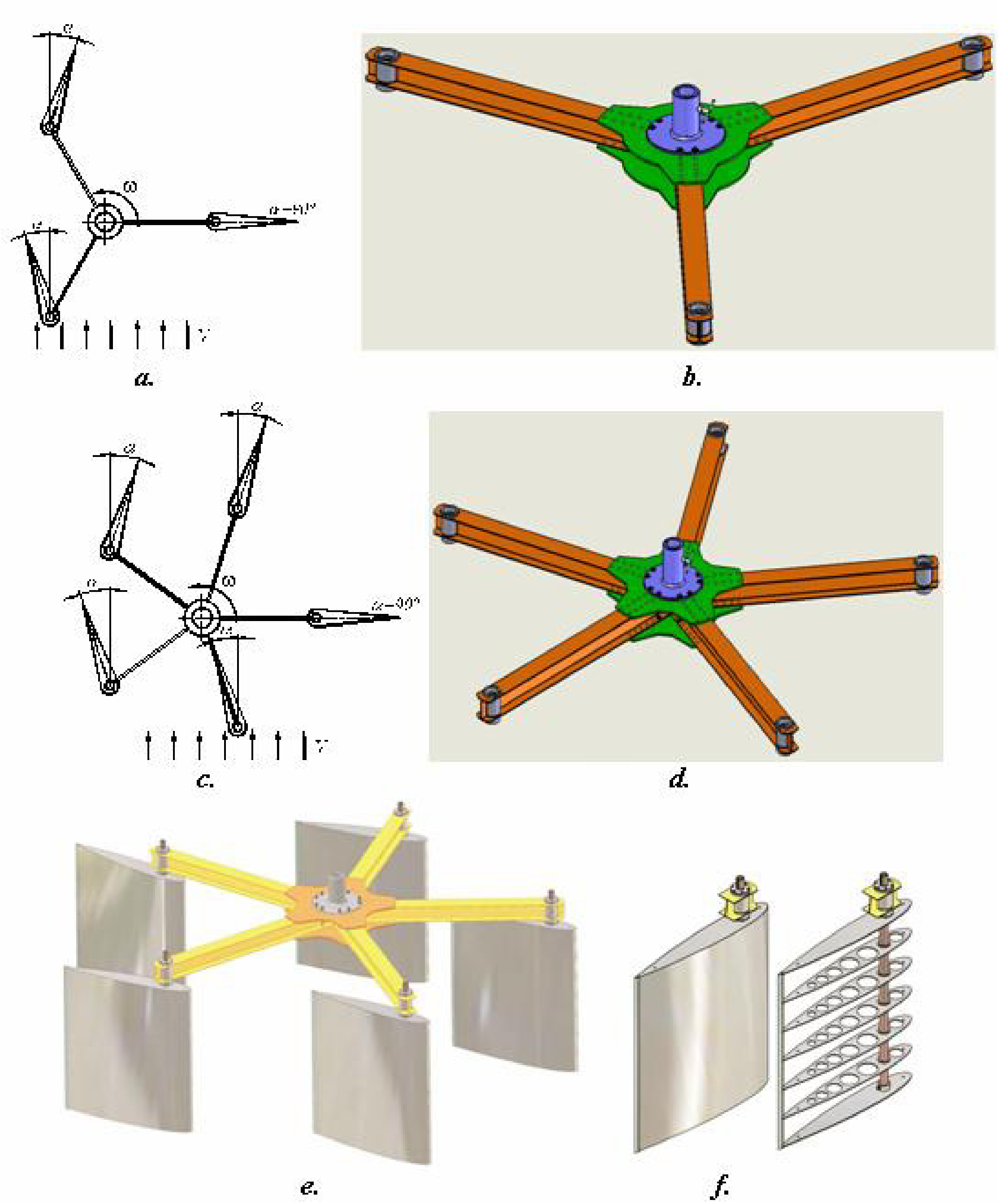
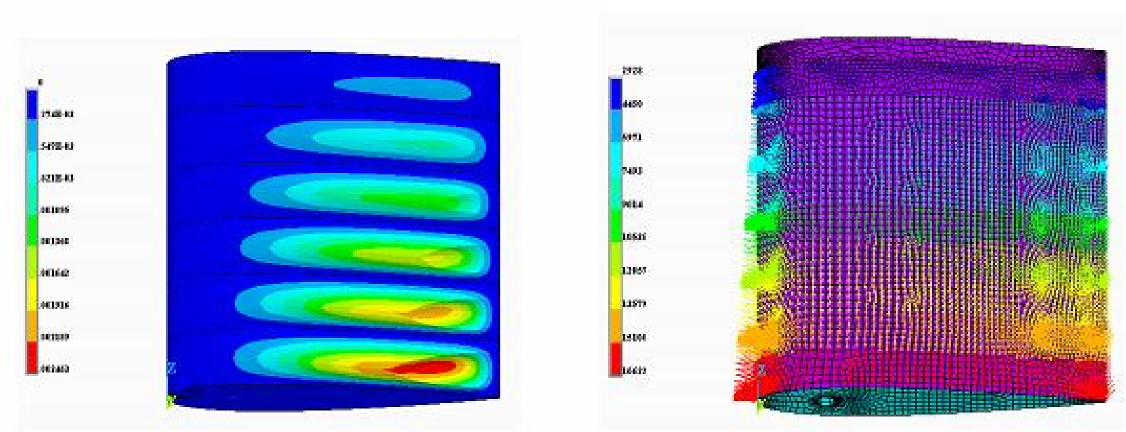


Fig. 6.

a), b) Construction of rotor with 3 NACA profile blades;
c), d) Construction of rotor with 5 NACA profile blades;
e), f) Constructive diagrams of rotor with 5 blades and of the hydrodynamic profile blade

In order to appreciate the straining state of the blade the finite element numerical modelling was carried out. This included the elaboration of the straining state model of the blade on its height and of the deformation state model of the blade on its height.

The qualitative appraisal of the straining and deformation state of the blade under the action of hydrodynamic forces has been carried out as result of the analysis of a large number of numerical calculus outcomes (Fig. 7 a b). There was established that the value of deformations is within the allowable limits, and the deviation of the blade position towards the water streams is minimum. This fact does not affect the conversion efficiency of the flowing water kinetic energy due to the position of blade towards the water streams.



a. b.

Fig. **7**.

a) Straining state model of the blade on its height;
b) Deformation state model of the blade on its height

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