Aspects of the Operation of the Blade Pumps Used in Agricultural Irrigation Applications

Assistant professor **Fănel Dorel ȘCHEAUA**[1]

[1] "Dunărea de Jos" University of Galați, fanel.scheaua@ugal.ro

Abstract: *The population increase rate represents a factor of progress registered as a result of the people living standard improvement. This increase must be sustained worldwide through improved agricultural practices that allow to obtain optimum yields on cultivated lands that guarantee the well-being of human communities first and foremost in terms of providing food and related economic activities. The agricultural productions have had remarkable increases on the units of cultivated areas in the last years, which denotes the use of agricultural techniques that give good results regarding the quality of the seeds used, the land quality but also of the water resources that allow the irrigation of the cultivated surfaces so that optimum results are obtained from agriculture. In this paper are presented constructive and functional aspects of the primary component of the irrigation plant of the cultivated areas of agricultural land represented by the pump. This is a constructive version of a blade pump that is used for the water supply in a pumping plant intended for agricultural irrigation.*

Keywords: *Agriculture irrigation, water flow, blade pump, three-dimensional modelling, CFD*

1. Introduction

The sustained development in the field of agriculture of the last period was possible due to the specific techniques applied strictly regarding the scheduling of the necessary works for the cultivation of agricultural lands.The scientific principles underlying agricultural engineering have been pursued and applied in order to obtain optimal results that are better compared to previous decades in terms of obtaining crops from cultivated land for the benefit of human communities.
Emphasis is placed on agronomic engineering in order to obtain the best possible harvests with much smaller water resources through efficient water use, thus avoiding high values of water and energy consumption. This is because many areas around the world are increasingly facing the lack of water as a natural resource and irrigation systems contribute to a specific consumption that determines an impact on the natural system. It is necessary that the irrigation systems be properly sized, continuously monitored and the operation be directed not only to the benefit of the user but also of the whole community.
The efficiency of the irrigation system of agricultural lands is a function of several factors such as water losses along the length of the irrigation column or the water transport channels through infiltration, the type of water distribution systems and the type of pumping solution adopted to be used in water conveyance from the main supply basin. [1]
The model of a blade pump used within an pumping installation adopted for the conveyance of water for irrigation of agricultural land is presented in this paper. The constructive and functional model of the blade pump determines the water circulation on the hydrodynamic principle with the mass flow rate and water flow velocity components, which transforms the mechanical energy taken at the pump rotor axis from the energy source into kinetic energy of the water.
The blade pump model from a constructive and functional point of view is analyzed in this paper, presenting the kinematic structure of the water currents formed during operation.

2. Blade pump principal characteristics

The model of pumping system is presented which has the main component represented by a blade pump.
The main parameters that define the operation of the pumping system are the pumping height, static or geodesic height and the power at the pump axis.

The pumping height, (H_P) represents the difference between the specific energies of the water in the discharge basin and the suction basins of the pump, where the total local and distributed load losses, (h_r) are considered along the suction and discharge water pathlines within the supply basin. [2][3][4]

$$H_p = H_{st} + h_r \tag{1}$$

$$h_r = h_{ra} + h_{rr} \tag{2}$$

The pressure values determination at the connection with the discharge pipe is made by installing a manometer and at the suction connection a vacuummeter for the case where the pump operates without back pressure and the pressure on the suction pipe is below atmospheric pressure value. Thus, two pressure values will be read on the devices mounted on the pressure gauge in terms of the pumped water column (p_M) and on the vacuum gauge in terms of the suction water column (p_V) and the relation for the pumping height is of the form:[3][5]

$$H_P = p_M - p_V + (z_M - z_V) + \frac{v_2^2 - v_1^2}{2g} \tag{3}$$

Because for the pumping installations the term $\left(\frac{v_2^2 - v_1^2}{2g}\right)$ has a reduced value, the relation for the pumping height of simplified form can be considered as: [3][5]

$$H_P = p_M - p_V + (z_M - z_V) \tag{4}$$

The static or geodesic height represents the difference between the water level in the discharge basin positioned in the upper position and the suction basin positioned in the lower position, being calculated with the relation: [3][5]

$$H_S = z_{Br} - z_{Ba} \tag{5}$$

For the case where the installation works under the conditions where the pressure values on the free water surface in the suction region (p_{Ba}) and discharge basin (p_{Br}) are different the relation of static height (H_s) becomes: [3][5]

$$H_S = z_{Br} - z_{Ba} + \frac{p_{Br} - p_{Ba}}{\gamma_a} \tag{6}$$

The determination of the power values at the pump shaft is made taking into account the specific water weight (γ_a), the pump flow rate (Q_P), the pumping height (H_P) and the total efficiency of the pump (η_P) using the relation: [3][5]

$$N_P = \frac{\gamma_a Q_P H_P}{100\eta_P} \tag{7}$$

The kinematic structure of currents for the case of centrifugal pumps is shown in Figure 1.

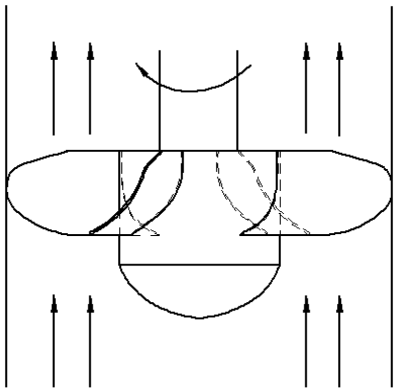


Fig. 1. Operational principle of blade pump

For the inlet section area the water velocity values are close to the radial direction. The velocity parallelogram of water circulation is constructed if the water velocity (v_1) is decomposed on components represented by the transport velocity (u_1) and the relative velocity (ω_1). On the output edge of the rotor blades the absolute velocity (v_2) is determined by constructing the parallelogram with the relative velocity (ω_2) and the transport speed (u_2).

$$u_1 = \frac{\pi D_1 n}{60};\ u_2 = \frac{\pi D_2 n}{60} \quad (8)$$

The velocity parallelogram at the rotor blade contour is shown in figure 2

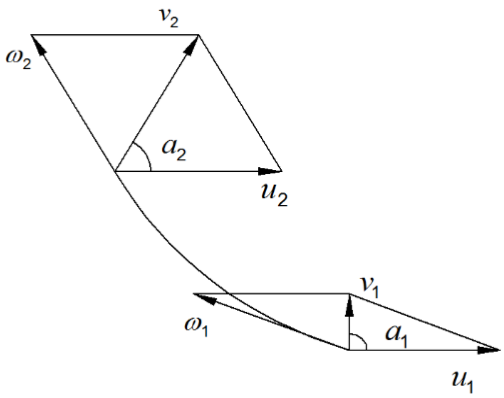


Fig. 2. Velocity parallelogram

The fluid is entrained into the enclosure by the rotor blades in rotational motion and at the entrance to the rotor area the velocity (v_1) is directed parallel to the axis and at the rotor exit the velocity (v_2) is inclined at an angle relative to the rotor axis which means that the fluid is driven in rotational motion with respect to the axis but also with advance movement in relation to the axis. In order to eliminate the rotational movement of the fluid stream, an auxiliary device is usually installed which has the role of stopping the rotational movement and driving the fluid parallel to the rotor axis.
The Euler equation describes the connection between the transmitted energy to convey a fluid at a certain pumping height value (H_P) and the velocity parallelograms:[3][5]

$$H_P = \eta_h \left(\frac{u_2 v_2 \cos a_2 - u_1 v_1 \cos a_1}{g} \right) \tag{9}$$

where η_h is hydraulic efficiency of the pump unit.

Considering the value of the velocity circulation (Υ) with the components $(\Upsilon_1),(\Upsilon_2)$ representing the velocity circulation of the fluid on a contour before and after entering the rotor having the angular velocity (ω) it can be considered: [3][5]

$$H_P = \eta_h \left[\frac{\omega}{2\pi g} (\Upsilon_2 - \Upsilon_1) \right] \tag{10}$$

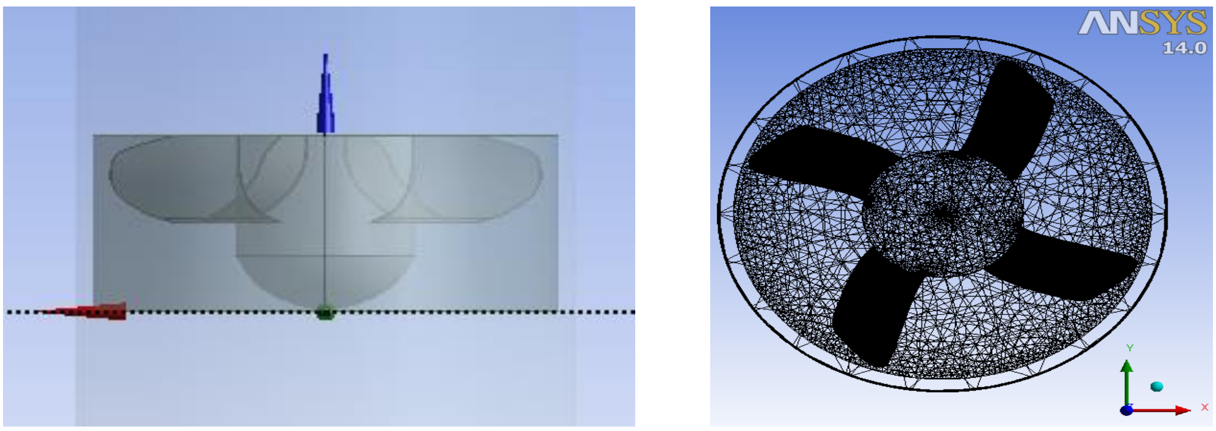
Because at the inlet of the pump rotor the fluid velocity circulation is considered to be null value $(\Upsilon_1 \cong 0)$, it can be written: [3][5]

$$H_P = \eta_h \frac{\omega}{2\pi g} \Upsilon_2 \tag{11}$$

The optimum operating conditions for the pump are established for the situation where the fluid is admitted into the rotor enclosure without shocks. Therefore, the relative velocity direction must coincide with the tangent direction at the blade contour at the level of the rotor enclosure inlet region.

4. Fluid flow aspects within lobe pump virtual model

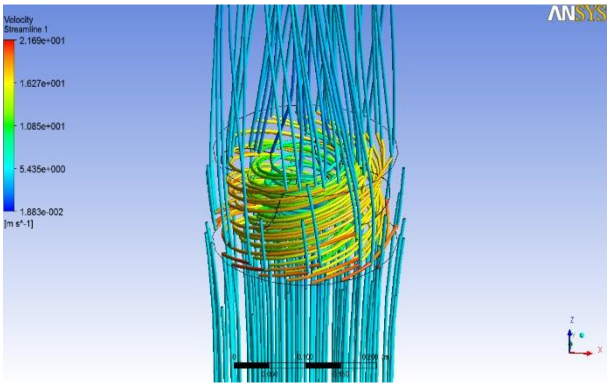
Aspects of fluid flow through the blade pump enclosure related to the operation of these volumetric units are highlighted through a CFD analysis on the overall virtual model of the blade pump rotor.
The overall 3D virtual model was developed and introduced in the analysis with the Ansys CFX analysis program.
Figure 3 shows the overall rotor model and the mesh network with a number of 495875 nodes and 2261255 elements of triangular form.



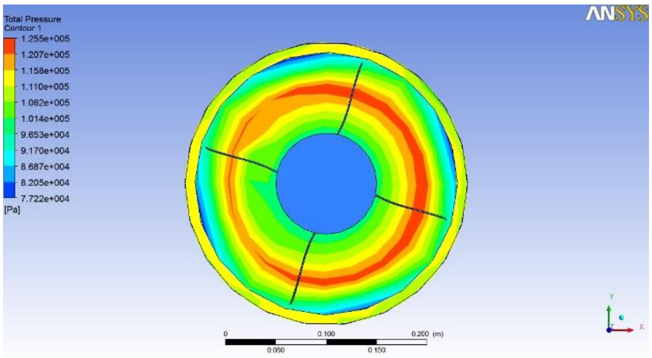
a) imported model b) mesh network of triangular elements

Fig. 3. Assembly model for water flow analysis

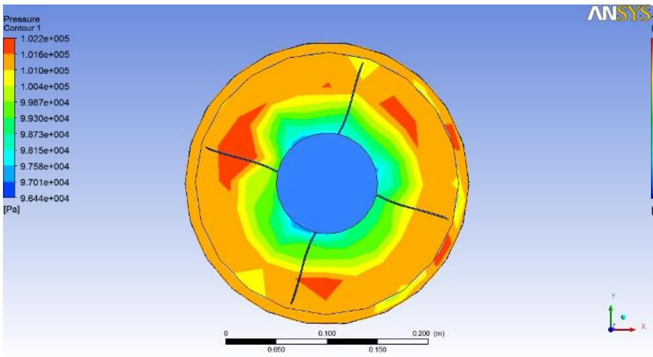
The operating principle for this volumetric unit is based on the rotational motion which engage the fluid in motion along the casing wall. The pressure at the inlet is considered as atmospheric pressure, while the rotational velocity is declared at 1500 rot/min.
The flow rate values of liquid circulation is according with the volumetric capacity at a single rotation of pump shaft.
The analysis main domains are represented by fluid region declared as water, and the immersed solid represented by the rotor, material steel.
The analyzed fluid model has an inlet port for the working fluid (water) and one outlet port while the enclosure cylinder is declared as wall.



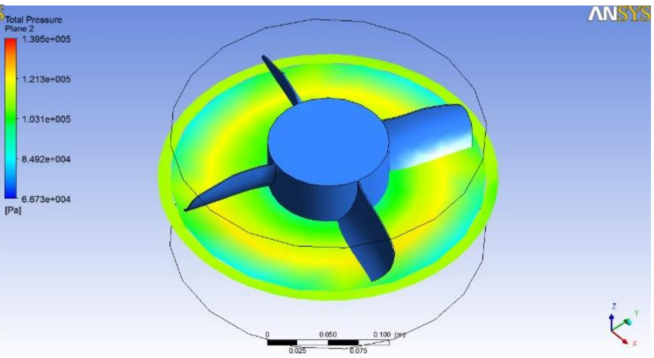
a) water velocity on streamlines



b) total pressure on rotor fluid contour



c) pressure values on rotor fluid contour



d) total pressure on XY cutting plane

Fig. 4. Water flow analysis result values

The results are presented in terms of total pressure and water velocity and pressure values as shown in figure 4. The fluid stream path lines created as a result of the rotor movement that draws the water according to the blades shape in rotary motion are highlighted. The pressure values are not very high, the analyzed fluid region considers the water entrainment and exit to the discharge duct.
The operation of the blade pump model presented is based on the rotor speed which has the possibility to vehiculate water due to the specific geometry of the rotor blades, the unit operating on the hydrodynamic principle that ensures the kinetic energy of the fluid conveyed in the form of mass flow rate and flow velocity.
The mass flow rate of water at the rotor outlet enclosure is calculated at 213.5 kg/s and water entrainment velocity of up to 2.5 m/s.

5. Conclusions

Theoretical aspects related to the constructive and functional particularities for the model of a blade pump were presented in this paper.
The blade pump model is the primary component of a water pump unit for irrigation in agriculture. On the basis of a three-dimensional virtual model, an analysis of the water flow inside the pump rotor blades enclosure was performed, with specific results of the flow velocity and water pressure recorded. Are emphasized the flow pathlines at the rotor level, formed due to rotational motion declared at the rotor shaft.
Based on the results obtained from water flow analysis on the virtual model of the blade pump are created the premises of optimizing the constructive shape of the blade contour in order to allow uniformity of the relative velocity during rotor motion ensuring in this manner the optimization of pump operation, thus improving the values for the operating efficiency for the blade pump assembly.

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