WAY TO IMPROVE THE EFFICIENCY OF THE PROPELLER TURBINE IN THE HEAD PIPELINE

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ABSTRACT Is considered the new way to improve the efficiency of the propeller turbine, located in the head pipeline, without a guide vane apparatus. It is proposed to method for calculating the efficiency of propeller turbines. Provides the results of the experimental verification of the calculation method.

KEYWORDS *micro low head hydro-power plant, pipeline, propeller turbine, power efficiency, guide vane apparatus, way to improve the efficiency, method for calculating.*

Introduction

It is known that defining role of the flow part geometry choice of small hydraulic power plants power equipment plays a hydraulic turbine impeller. The inicial geometric parameters assignment of the flow part is carried out according to its characteristics. In this connection, it is necessary take into consideration some impeller engineering features. Axial type (Kaplan) impellers in particular, because these properties directly influence on the working part energy efficiency of hydraulic turbine. Presently, a set of parameters that allow to describe the shape of a blade system more fully is allocated. However, the power equipment design procedure of small capacity and scale hydraulic power plants are not worked out as well as for large-scale power plants. In materials of this article the authors are presented the analysis of the phenomenon which certainly must be considered when designing.

1 Hypothesis of the flow velocity vector circulation increase

The working process of hydraulic turbines in accordance with its basic equation (the Leonhard Euler equation) implies the need for a difference between the flow velocity vector circulations at the inlet to the impeller and at the output of it:

$$H_{theor}^{ht} = \frac{\omega}{2\pi g}(\Gamma_1 - \Gamma_2) \qquad (1)$$

here $H_{theor}^{ht} = H_{hpp}\eta_{hydr}$ − theoretical head of hydraulic turbine;

$\Gamma_1 = 2\pi r_1 v_{u1}$ − circulation at the inlet to the impeller;

$\Gamma_2 = 2\pi r_2 v_{u2}$ − circulation at the output of the impeller.

Furthermore, at the present not only acknowledged, but also confirmed experimentally [1] that at the outlet of the impeller blade system *positive* flow velocity vector circulation must be provided. This condition directly affects on the hydraulic turbines efficiency and its cavitation performance improving. It is also known that the flow velocity vector circulation sign at the outlet of blade system

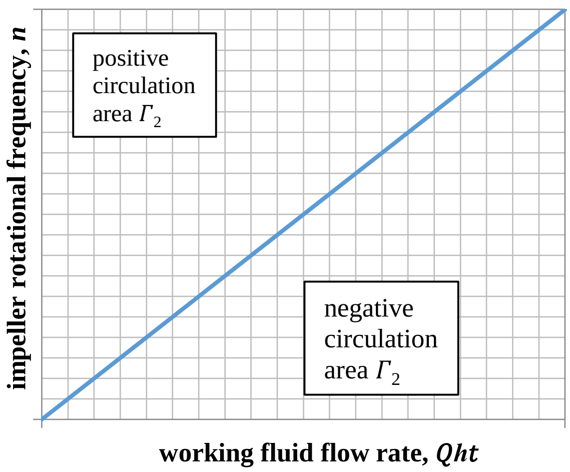


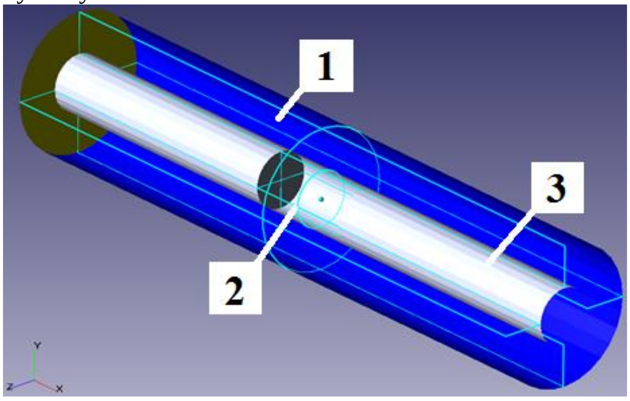
Fig. 1 Graphical relationship $\Gamma_2 = f(n, Q_{ht})$ showing the change of circulation in depending of the argument variable parameters

depends of the impeller rotational speed n and the value of working fluid flow rate Q_{ht} through the hydraulic turbine. This relationship is described by the function $\Gamma_2 = f(n, Q_{ht})$ shown in Fig. 1.

In accordance with the above, previously conducted research [2] shows that for low-power hydraulic machines the flow velocity circulation must be accepted differently when they designed. Therefore, it is need to disengage from classic methods of creating hydraulic power plant construction schemes to improve energy efficiency. Thus, the authors consider that blade system of small hydraulic power plants turbines without guiding devices at the inlet (construction discussed in [3], for example) must be designed in conditions of so-called "normal inlet". That is, lack of circulation flow velocity at the inlet of a blade system (Fig. 8). At the axial-type impeller construction detailed design for hydraulic power plants of this arrangement the authors were able to put forward a hypothesis about the impeller cowl positive influence. The cowl rotates with a frequency equal to the blade system rotational frequency that is rigidly connected with the rotor. The essence of the phenomenon is the following: at the hydraulic turbine steady operation under the action of viscous forces the cowl surface rotation causes deviation of the flow velocity vector before further passing through a blade system. Thus is realized the negative flow velocity vector circulation accretion at the inlet to the blade system. This fact in accordance with equation (1) leads to an increase the difference circulations value $(\Gamma_1 - \Gamma_2)$ at the hydraulic turbine impeller and, as a consequence, to increase the flow head.

2 Modelling of the hypothesis

For experimental verification of the proposed hypothesis, it was decided to hold virtual computational experiments described below. The first computing researches consisted in creation of 3D-model of the pressure pipeline flow part (Fig. 2) and conducting its hydrodynamic calculation.



1 – pressure pipeline, *2* – fixed shaft, *3* – rotating sleeve

Fig. 2 3D-model of the pressure pipeline flow part

Creating the model was carried out in the "*SolidWorks*" software package workspace with Russian "*Flow Vision*" applications package intended for modeling three-dimensional flows of liquids and gases in natural and technical objects. 3D-model consists of a coaxial-placed fixed shaft in the flow part. The shaft includes a rotating sleeve with an outside diameter equal to the diameter of the shaft and simulating impeller cowl. The model has the following overall dimensions:

shaft / sleeve diameter, mm ……………………… 37,5
pipeline length, mm ………………...…………... 160
hydraulic diameter of the pipeline, $D_г$, mm…….. 80
sleeve length, mm ...…………………………….. 75

At preparation to the calculations has been used incompressible fluid model which provides a possibility of flow velocity and turbulence calculating. It is provided by the introduction of additional components in the Navier-Stokes equations, describing the turbulent viscosity and turbulent thermal conductivity. Accepted boundary conditions are given in Table 1. The flow space and fixed shaft surface are made by appropriate cylindrical sections with the type of border is "wall" and the sleeve which imitates the impeller cowl with the type of border is "rotational rotor surface". In the modeling experiment was used k-ε turbulence model with the logarithmic law of flow velocity gradient distribution in the boundary layer. Estimated grid created for a virtual experiment is 1,152,000 cells.

Tab. 1 3D-model boundary conditions

Specific cross section	**Type of border**	**The boundary condition**
Inlet in the pipeline	"Inlet"	"Normal flow velocity "
Outlet from the pipeline	"Free outlet"	"Zero pressure"

Simulation allowed to obtain the distribution diagrams of peripheral flow velocity in the flow part cross section. View of the flow velocity vector field in the longitudinal plane of the pipeline allowed to obtain the distribution which shows the flow velocity vectors deviation under the influence of the rotating sleeve. In addition, working fluid flow in the flow part of the pipeline is visualized. This is obtained by using the tool of "*Flow Vision*" software package, so-called "velocity flashes" that simulate the actions (the paths) of studied working fluid particles. The result of calculation also showed the deviation of the path of working fluid particles in the direction of the sleeve rotation after its passage. Pictures of flow velocity distribution, its vector field and the paths of working fluid particles in the 3D-model flow part shown in Fig. 3, 4.

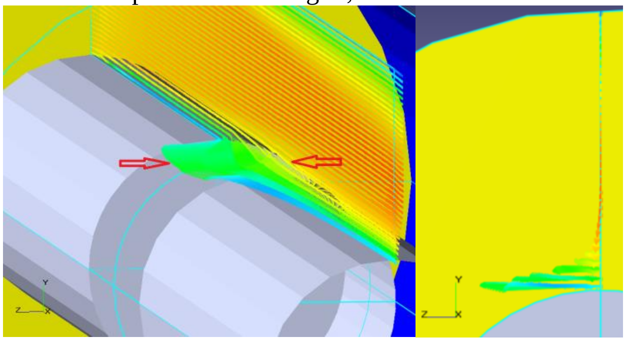


Fig. 3 The acquisition a peripheral flow velocity by the flow around the rotating sleeve

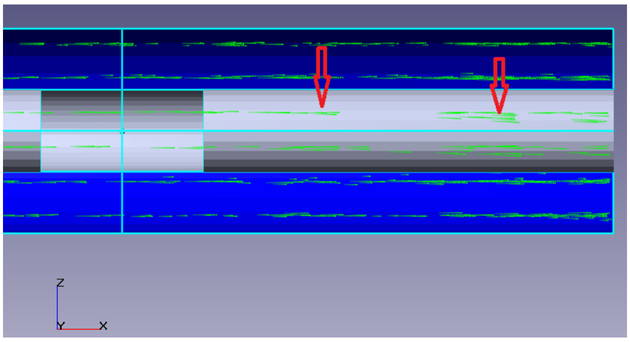


Fig. 4 The deviation of working fluid particles at a flow around the rotating sleeve

The second series of computational experiments consisted in carrying out similar researches which include installing an impeller in a previously created 3D-model and obtaining similar characteristics and flow velocity vector diagrams.

In accordance with Fig. 5, the model has undergone a following changes: the shaft fixed part at the inlet to pressure pipeline is replaced by the equivalent of a rotating sleeve at the end of which is located the impeller vane system. It is consists of eight blades having a profile of a flat plate. Elongated sleeve with a blade system are form a single unit, and rotate with a frequency n. The shaft behind the impeller is stationary.

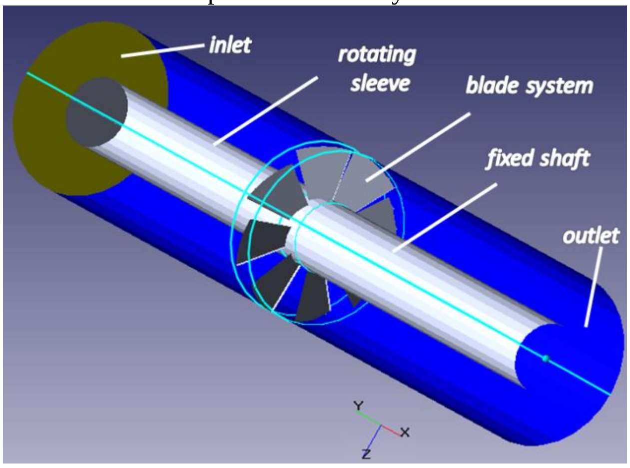


Fig. 5 3D-model of the pressure pipeline flow part with the hydraulic turbine impeller.

Similar to previous researches, imaging of the flow velocities vector field (Fig. 7) shows the deviation of the velocity vectors under the influence of the rotating sleeve surface over the whole area of the pipeline flow part. For the most complete understanding about the studied influence a diagram distribution of peripheral velocity projection on the cross-section near the front edge of the blade of impeller was obtained (Fig. 6, *a*). Its three-dimensional sketch (Fig. 6, *b*) is presented which correlated not only with the classical theory of gas and fluid mechanics [4], but also taking into account the pre-creation of the flow velocity circulation.

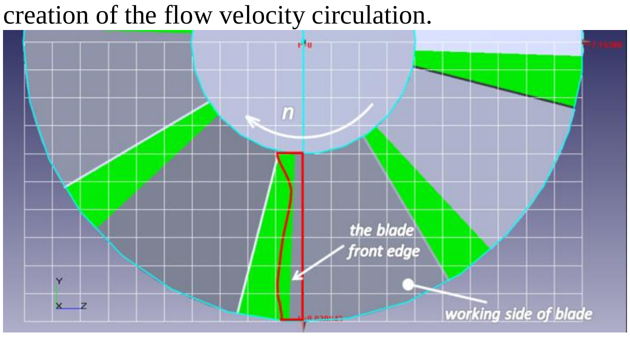


Fig. 6 (*a*) The diagram distribution of peripheral velocity projection at the inlet of blade system

It is important to note that in Fig. 6, *b* theoretical diagram is white marked in accordance with the slip boundary condition at the walls of the impeller sleeve and is red - the calculated real curve in view of apparent influence of the impeller sleeve rotating surface on the peripheral velocity projection diagram.

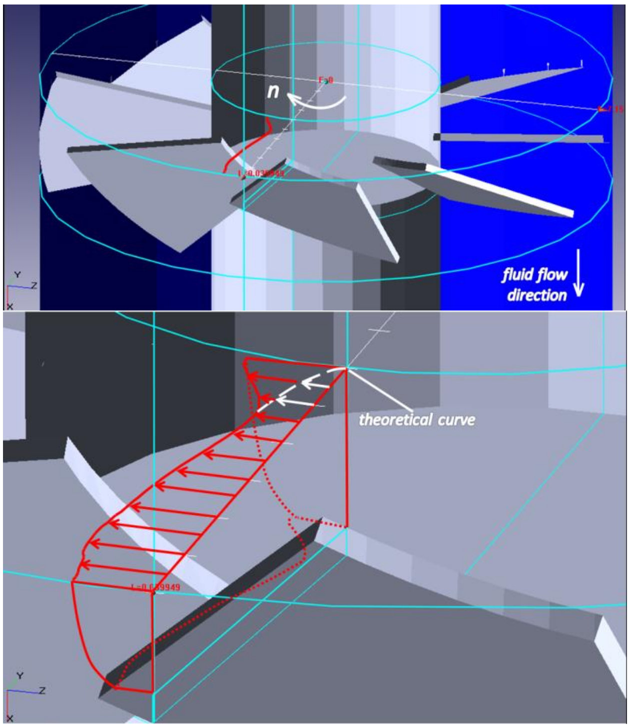


Fig. 6 (*b*) The diagram distribution of peripheral velocity projection at the inlet of blade system (enlarged)

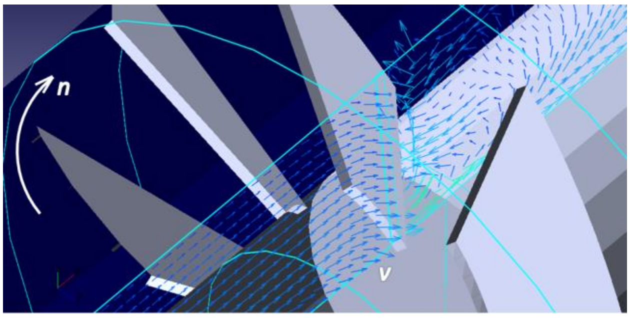


Fig. 7 The vector field of peripheral velocity projection at the inlet of blade system

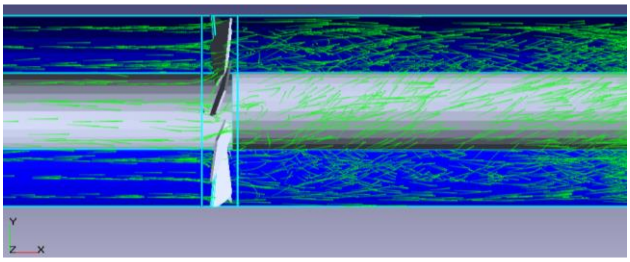


Fig. 8 The blade system designed from the condition of "normal inlet"

The results of calculations can determine a positive influence of energy equipment rotating construction elements on the formation of the flow velocity vector negative circulation and appropriately produce accounting changes of this working fluid flow parameter at blade impeller system profiling. These aspects are planned to be discussed in the next publications.

3 Experimental approbation of the hypothesis

As an evidence of the hypothesis, experimental researches of the hydraulic unit energy characteristics (Fig. 9, *a*) have been conducted based on NRU "MPEI" educational and research stand (Fig. 9, *b*). It is integrated in the pressure pipeline DN 250 and is designed on the power of 1500 W. Measurements made in the course of the experiment showed that the hydraulic unit output power was 1606 W on the rated operation (n = 1000 rpm). It gives great reason to suppose about development prospects of the observed effect.

Fig. 9 (*a*) The hydraulic unit with propeller axial-type impeller

Fig. 9 (*b*) NRU "MPEI" educational and research stand with hydraulic unit

This phenomenon deserves accounting at the small hydropower plants hydraulic equipment designing, because its positive influence is already at this stage of the research is estimated to increase in the energy efficiency of 5-7%. Even at explaining the effect in terms of adhesion condition (unlike to the slip condition) slippage of liquid particles is minimal due to the large value of the velocity gradient. It is clearly illustrated in Fig. 6, *b* and indicates the high importance of this study for small and micro-objects of hydraulic power generation.

4 Application of the effect

The effect of the rotating cowl influence on the flow velocity vector deviation from the "normal inlet" in impeller blade system with a certain analogy is also used to prevent the formation of vortex rope mostly radial-axial hydraulic turbines (Francis type). The vortex rope has a negative effect on the energy characteristics and reliability of the hydraulic equipment. There are studies and technical solutions proposal in this area are known and developed by Sc.D., professor Gennady M. Morgunov (NRU "MPEI", Russian Federation) [5] as well as the staff of the Kharkov turbine plant named Sergey M. Kirov (mod. PJSC "Turboatom", Ukraine) [6].

Research problems of solid surfaces interaction with a liquid at different times have different popularity. However, attention to this subject is increasing significantly in recent years. The main interest here is paid to the study of the liquid sticking effect to the working equipment surfaces.

In this case, at a flow the rotating cylindrical body (sleeve) by a viscous liquid axially it carries away the working fluid adjacent layers. This occurs as a result of the viscous friction forces [7]. So the layers having linear motion in the axial direction (Fig. 4,8) receive rotational motion on the side and moving around the sleeve and the fixed shaft. It is leads to the velocity flow negative circulation appearance at the blade system inlet.

It is interesting to pay attention to some of hydraulic power plants turbines specific designs which schemes are applicable to small hydraulic power generation. Among those should consider capsular hydraulic units (Fig. 10). In its design from the standpoint of structural elements flow around a blade impeller system can be distinguished only.

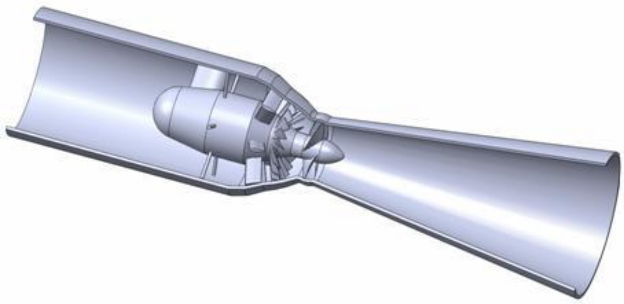


Fig. 10 The design of capsular hydraulic unit.

As a result, practically the entire construction of this type hydraulic turbines can be regarded fixed and intractable to influence of said effect. However, the implementation of a rigid connection impeller blade system and cowl in this case, could make a positive influence in the formation of the flow velocity vector circulations difference at the impeller.

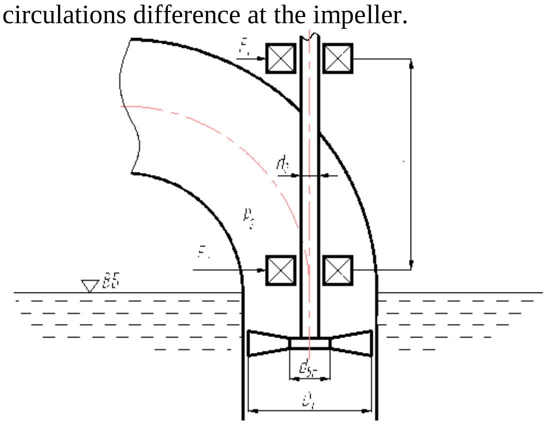


Fig. 11 The double-seat support of hydraulic turbine shaft

It creates a great reason for the modernization of the main working part in order to increase energy efficiency, besides allowing to simplify the impeller design and therefore reduce the investments in the this type power equipment production.

These conclusions are relevant with a high degree of compliance as for double-seat constructive solutions of hydraulic turbines (Fig. 11). In this scheme the hydraulic turbine shaft is supported by bearings in accordance with the "thrust in" type circuits, "in the stretching" and "free support".

Important to note that on the analyzed effect also affects the quality of the cowl surface that is a function which depends on the surface roughness. In this case rougher cowl mechanical processing and consequently higher values of the relative surface roughness comply with increase the described effect.

5 Conclusion

This and the previously stated facts are the fundamental basis for research and represent a promising foundation for the development of new solutions to improve energy efficiency of small hydraulic power plants equipment.

Acknowledgement

This work was financially supported by the Russian Federation Ministry of Education and Science. Grant agreement №14.574.21.0076 from June, 27 2014 (RFMEFI57414X0076 unique identification number).

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