A two-dimensional design method for the hydraulic turbine runner and its preliminary validation on the basis of laboratory tests

Long Abstract

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Introduction

A turbomachinery blading is usually designed, except classical one-dimensional theory, by analyzing the flow in an iterative way by means of the *CFD* programs i.e., the flow parameters are calculated for a given “a priori” geometry of the blade (the so-called direct problem). Practically, finding the optimum geometry is based on a comparative multiple analysis of the *CFD* results. During the analysis, arbitrary and intuitively the blade geometry of the designed machine is modified. An advantage of this approach is the use of full three-dimensional flow field parameters analysis. In contrast, a disadvantage of this approach is the time-consuming geometry preparation, mesh generation and performing same calculation. That is why effective design methods that can fast and properly solve the so-called inverse problem have been strongly developed, in which the blading of the turbomachine (geometry of the guide vanes and runner) is directly and quickly computed.

It is obvious that theoretical model used to solve the inverse problem is usually more simplified so that it can be solved than in the case of direct problem (analysis problem). The simplifications may be e.g.: omitting the boundary layer or taking it into account with the use of empirical formulas. Therefore, it is important to confirm the reliability of the inverse problem results by means of an experimental research.

The paper presents the approach to solve the inverse problem by means of a two-dimensional (*2D*) axisymmetric flow model [1][2] on a basis of runner blade of the Kaplan vertical model hydraulic turbine (characteristic diameter = 265 mm). In order to solve it authors’ own algorithm and code were prepared. The initial validation of the prepared algorithm has been based on the results of model Kaplan turbine design (obtained by means of other method) and its experimental results [3] carried out in the laboratory at the Gdansk University of Technology (Poland). A comparison of the tested runner blade with the runner blade generated by means of the presented design method indicates its large utility and applicability.

The fundamentals of the used design method

A *2D* model used to calculate the geometry of the Kaplan hydraulic turbine runner is based on a curvilinear coordinate system, in which any point in *3D* space is described by three coordinates ($x^{(1)}$ – a coordinate associated with a streamline, $x^{(2)}$ – an angular coordinate, $x^{(3)}$ – an axial coordinate). Therefore, the Cartesian conservation equations were transformed into this system in order to obtain easier to solve form of these equations. The system adapts to the meridional shape of blade through a predetermined streamline function $f(x^{(1)}, x^{(3)})$ dependent on the coordinates $x^{(1)}$ and $x^{(3)}$. A meridional shape of runner was based on an existing model runner, as mentioned, to ensure maximum validation fidelity between the experimentally tested runner and runner designed with the use of the developed theoretical *2D* algorithm. The streamline function in the algorithm has been computed using the Vortex Lattice Method. After that the streamline equation *f* has been found by means of the least squares method.

The object of test

The flow domain of the model Kaplan turbine is presented in Figure 1. The main part of the flow system consists of five-bladed bent channel (driving the flow from radial to axial direction), six axial stationary guide vanes, twelve adjustable guide vanes, six adjustable blades of runner and the axisymmetric draft tube. The shaft generator is provided vertically upwards. This turbine has been tested in a wide load range on a laboratory test stand at the Mechanical Faculty of the Gdansk University of Technology. Using the geometry of the model turbine and achieved optimal parameters the reliability of the design method has been positively verified.

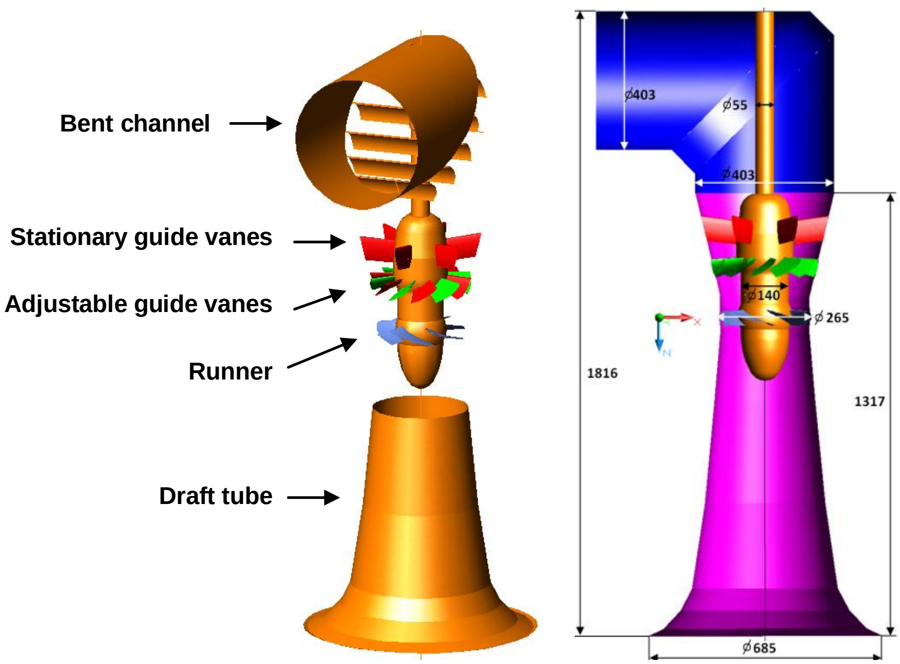

Figure 1. A vertical model Kaplan turbine – the object of the experimental tests.

Conclusions

Computational design method of hydraulic turbine blade system based on a *2D* flow model has been developed. This method has been positively verified on the basis of an earlier designed runner blade of the Kaplan model hydraulic turbine and test results of this machine carried out in a wide range of flow parameters changes. Large applicability of a *2D* model and a design method based on this model for the hydraulic runner blade design has been stated.

References

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