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Multi-criteria optimization of the flow of a centrifugal pump on energy and vibroacoustic characteristics

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Abstract

A method for optimizing the flow of a centrifugal pump stage according to several criteria, namely in the form of head characteristics, cavitation qualities and vibroacoustic properties is developed. Six geometrical parameters of impeller and guide vanes wet part are selected as optimization parameters. LP-tau method is selected as an optimization algorithm, which was well-proven in previous studies. Calculations of each model are based on computational fluid dynamics techniques using k-w SST turbulence model. 32 variants of wet parts with different values for each optimization criteria are obtained as a result of optimization. Deviation of head characteristics from desired is estimated by deviation of head value from defined at two points of characteristics, cavitation qualities are valued by integral of negative pressure on the surface of impeller, vibro-acoustic properties - by pressure pulsations amplitude on the inlet of guide vanes on the blade frequency. The resulting optimization technique, in contrast to the existing, allows one to carry out a comprehensive optimization of the flow of the pump according to several criteria quickly. Used methods were verified in previous works and showed good agreement when comparing computed head characteristics, cavitation qualities and pressure pulsations with experimental ones.

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Keywords: centrifugal pump, optimization, computational fluid dynamics, vibrations, acoustics, cavitation.

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1. Introduction

Hydraulic machines optimization with computational fluid dynamics methods is widely used in the process of new units designing and old designs improvement. Most commonly, the goal of optimization is pump efficiency increase. However, it is no less important to improve reliability of pumping units, improving their cavitation properties, and vibroacoustic characteristics. Excessive vibrations reduce the service life of pump parts and components and for some types of pumps specific requirements on vibroacoustic characteristics are imposed.

Pump optimization separately for energy efficiency criteria, cavitation or vibroacoustic characteristics was solved by various methods in a number of papers. Optimization is carried out as an intuitive method or using optimization algorithms. Examples of intuitive methods applications can be found in [1] and [2]. In [2] the influence of the impeller inlet parameters on cavitation characteristics is investigated and the number of calculation points and the settings are selected by the researcher's own reasons. In [1] the compressor's wet part is optimized for energy efficiency criterion and the choice of calculation points and optimization of parameters is carried out intuitively by researcher. This approach has significant drawbacks. Firstly, the quality of the result and the timing of its achievement are highly dependent on the researcher qualification and are poorly predictable. Secondly, such methods practically can not be applied to optimization by several criteria, especially if these criteria are in conflict with each other.

Some studies on optimization use sophisticated optimization algorithms. In [3] pump diverter is optimized for efficiency and hydrodynamic load with LP-tau algorithm. The authors of studies [4] and [5] used sophisticated genetic optimization algorithm to enhance the efficiency of the pump [4] and the turbine [5]. The article [6] - gradient optimization method. The use of formalized optimization algorithm can significantly reduce the human impact on the optimization results. However, all of these works consider the impact of several geometric parameters on one optimization criterion or an element of wet part is considered excluding the effect on analyzed criterion of other elements of a wet part. In study [5] a comprehensive optimization of the hydraulic turbine according to two criteria (efficiency and cavitation quality) is conducted using genetic algorithm, but its use requires a very large amount of calculation points (on the order of several thousand), which forces to use stationary methods for solving equations of hydrodynamics. When solving stationary equations it is impossible to assess vibroacoustic characteristics of the projected unit.

Wet part vibroacoustic characteristics are analyzed in [7], but the investigation is carried out without assessing the impact of other variable parameters on pump performance and is carried by intuitive method.

In our paper we propose a method of pump wet part designing, which allows to optimize several criteria at a time – discharge characteristics shape, vibroacoustic and cavitation properties. Such technique development is a particularly urgent problem in low-noise pump design. The proposed method can be supplemented by other optimization criteria, for example, load or efficiency. Introduction of other criteria or elimination does not affect the selected optimization techniques.

2. Optimization problem formulation

Application of the proposed method may be extended on blade machines of different purposes and types. In this paper, the use of optimization algorithm is shown on example of multi-stage pump with guide vanes.

Wet part of the pump is shown in the figure below (Fig. 1). It consists of impeller and guide vanes. As discussed above various characteristics of the pump can be considered as a criteria for optimization. In this example, they are the following.

1) Head characteristics of the pump – it must pass through two points with flow values of Q1 and Q2 and head values of H_1 and H_2, respectively.

2) Cavitation qualities – it is necessary to minimize the phenomenon of cavitation in the wet part. The emerging vapor cavity cannot show itself when evaluating energy characteristics of the pump but leads to a sharp deterioration of vibroacoustic qualities of pump. Therefore, the requirements for cavitation qualities for low noise pumps are higher than that of general industry.