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Numerical shape optimization of a centrifugal pump impeller using artificial bee colony algorithm

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ABSTRACT

Centrifugal pumps consume huge amounts of energy in various industrial applications. Therefore for these pumps, the improvement of machine efficiency has become a major challenge. Since the hydraulic performance of a centrifugal pump strictly depends on its impeller shape, in the present work, an efficient and original approach has been developed and applied to the design of centrifugal pump impellers in order to achieve a higher efficiency. A global optimization method based on the Artificial Neural Networks (ANNs) and Artificial Bee Colony (ABC) algorithm has been used along with a validated 3D Navier–Stokes flow solver to redesign the impeller geometry and improve the performance of a Berkeh 32-160 pump as a case study. In the next step, to verify the optimization results, all the domains within the centrifugal pump were simulated using the CFD method. The complete numerical characteristic curves of the pump with the optimized impeller were compared to the validated (using the available experimental data) numerical characteristic curves of the initial pump. The numerical results show an efficiency improvement of 3.59% at only 6.89 m increase of total pressure difference for the Berkeh 32-160 centrifugal pump. The new impeller geometry presents much more changes in the meridional channel and blade profile. The results indicate a reasonable improvement in the optimal design of pump impeller and a higher performance using the ABC algorithm.

1. Introduction

Centrifugal pumps are huge consumers of energy in various industries. So, it is essential to improve the efficiency of such equipment through design optimization. The optimum configuration of a centrifugal pump is a compromise between reliability, manufacturing cost and efficiency [1]. The hydraulic performance of a centrifugal pump strictly depends on the shape of its impeller blades. Hydrodynamic shape optimization has become one of the most popular issues in hydrodynamic design process in recent decades. Gradient-based and evolutionary optimization algorithms have been widely used in pump impeller design to achieve higher performance [2–4]. Nowadays; the exponential increase of computation power has allowed the development of approaches based on the automation of the conventional design process by coupling the optimization method with computational fluid dynamics. These methods lead to a design process that relies more on a systematic methodology than on experience. They are less time-consuming than traditional approaches, which require a continuous refinement of component geometry.

The artificial bee colony algorithm has been proposed by Karaboga for the optimization of real parameters. This algorithm is based on the foraging behavior of a bee colony [5], and can be applied in multi-objective [6], combinatorial [7], unconstrained and constrained [8,9] optimization problems. Rao et al., Kang et al., Singh and Yildiz have expressed the ABC algorithm as a quite simple, flexible and robust method [10–13].

The core of the shape optimal design system in fluids mechanics is a database containing the results of all the computational fluids dynamics (CFDs) computations performed during the previous and present design processes. For each sample, the inputs are the geometrical parameters, fluid properties and the flow-field boundary conditions used by the 3D flow solver. The outputs are the efficiency and total pressure rise, which characterize the hydrodynamic performance.

In this design process, an iterative procedure is used. The first step is a "learning process" which is used to build an Artificial Neural Networks (ANNs) model based on the examples stored in the database. The learning process is accomplished by a generalized regression neural network. After this process, the ANN is able to predict the hydrodynamic performance of blade geometries under the boundary conditions not previously included in the database.

The next step consists of finding a new design using an optimization procedure presented by the ABC algorithm, which is based on the hydrodynamic performances provided by the trained ANN instead of the flow solver. The global impeller performance is

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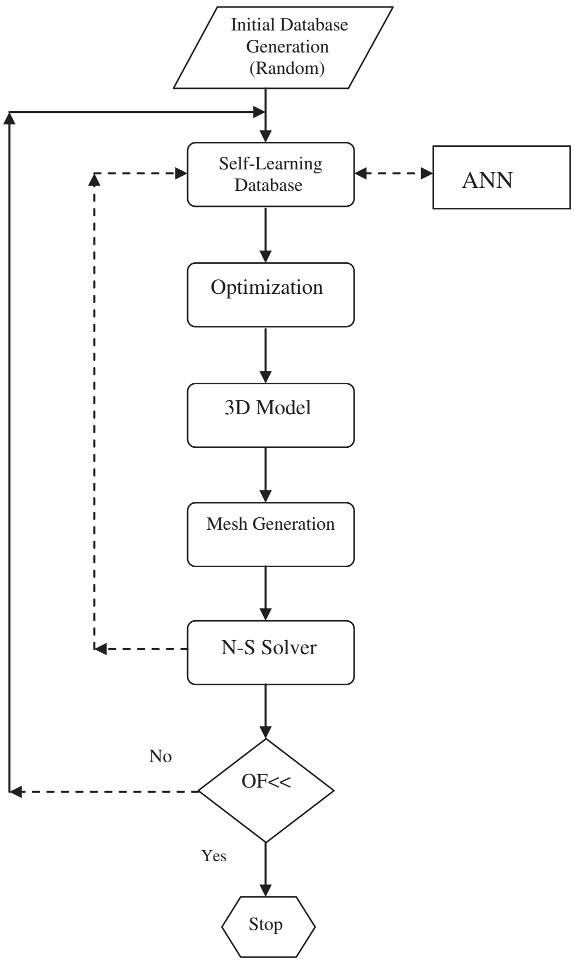

Fig. 1. Presented optimization technique.

determined through an objective function, which translates all the user-imposed constraints into a single number. The outcome of this optimization is a point in the design space, which is expected to be the optimum solution of the real problem. The new geometry provided by the optimization is then evaluated by the CFD solver. This new sample is also added to the database. By comparing the impeller performance obtained by CFD to the one predicted by ANN, the accuracy of the trained ANN can be evaluated. The obtained performance is also compared to the initial one. If the target performance has not been achieved, the next iteration is started, and the same process is repeated until the optimum blade is obtained (Fig. 1). Each design iteration starts with ANN training. As the optimization proceeds, the database grows, leading to the improvement of the approximate relation and therefore to a better localization of the real optimum.

In this research, a numerical optimal design package including the modules of parameterization, CFD, Artificial Neural Networks (ANNs) and Artificial Bee Colony (ABC) algorithm has been developed for the geometrical optimization of a centrifugal pump impeller. In advance, to validate the CFD code, the complete geometry of the initial pump including the inlet, impeller, chambers and the volute was simulated. The obtained characteristic curves were compared with the available experimental data. After the optimization process, the characteristic curves of the pump with new impeller were compared to the characteristic curves of the pump with initial impeller. Finally, all the results were compared and discussed.

2. Optimal design of centrifugal pump impeller

Fig. 1 shows the developed numerical optimal design package including the parameterization, CFD, ANN and ABC modules for the geometrical optimization of an initial centrifugal pump impeller. The details of the developed package are described in the following sections.

2.1. Design parameters

Arbitrary design parameters can be used as input data for an in-house pump design software program in order to generate the impeller geometry. The performance of an impeller depends on various parameters. However, the main parameters are [14]: Hub diameter (d_H), suction diameter (d_S), impeller diameter (d_2),

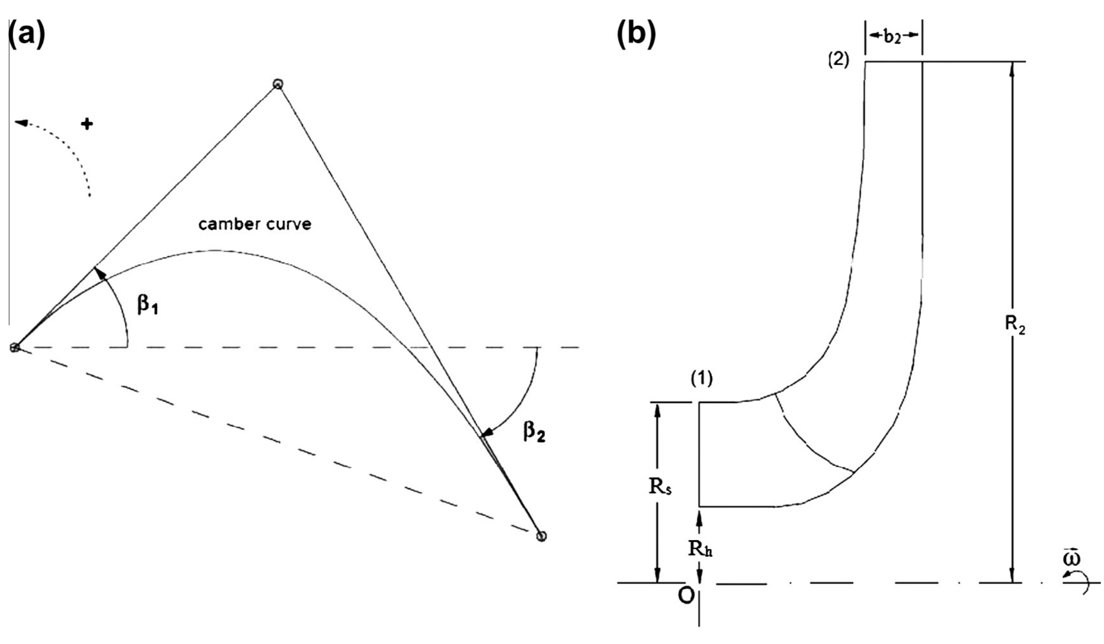

Fig. 2. Design parameters of impeller.