Multi-Objective Optimization Based on Unsteady Analysis Considering Impeller Radial Force and Efficiency of a Single-Channel Pump for Wastewater Treatment

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Long Abstract

Introduction

In general, submerged pumps used for wastewater treatment require unique design features that can prevent performance reduction, failures and damage due to clogging, unlike general submerged pumps. Two types of submerged pumps for wastewater treatment that incorporate these characteristics are the crushing and the flow passage securing types.

The single-channel pump shown in Fig. 1 is a representative type of the flowpath-securing pump. Its impeller has a free passage with no blade, and thus is pressurized only by the centrifugal force generated from the rotating impeller. Therefore, the single-channel pump impeller has completely different design features than those of general pumps that are pressurized by blades, and moreover is very resilient against failures and damage caused by clogging. Thereby, the demand for single-channel pumps is growing rapidly for use in domestic and industrial sewerage systems.

However, few studies on the design concepts of single-channel pumps have been reported till now [1]. To the best of the authors' knowledge, the lack of studies in this area is due to the difficulties in establishing systematic design, manufacturing, and balancing methods for single-channel pumps, in comparison with general blade pumps. Moreover, the vibration generated from the rotor-stator interaction between the single-channel pump impeller and volute is main problem. Although axial force of a single-channel pump is theoretically balanced, the influence of radial force on vibration cannot be ignored. The extreme unsteady radial force can result in fatigue failure of pump shaft and low hydrodynamic efficiency.

This work presents an optimization procedure for a single-channel pump volute based on a hybrid multi-objective evolutionary algorithm (MOEA) coupled with three-dimensional unsteady Reynolds-averaged Navier-Stokes (RANS) analysis. The multi-objective optimization was conducted to simultaneously improve the efficiency and reduce the peak radial force of the rotating impeller outlet, with two design variables related to the internal flow cross-sectional area of the volute designed from Stepanoff theory.

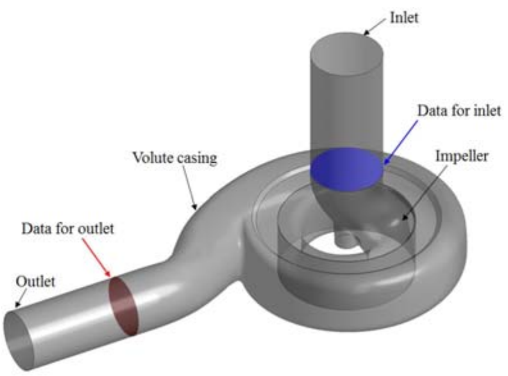

Figure 1. Single-channel pump for wastewater treatment

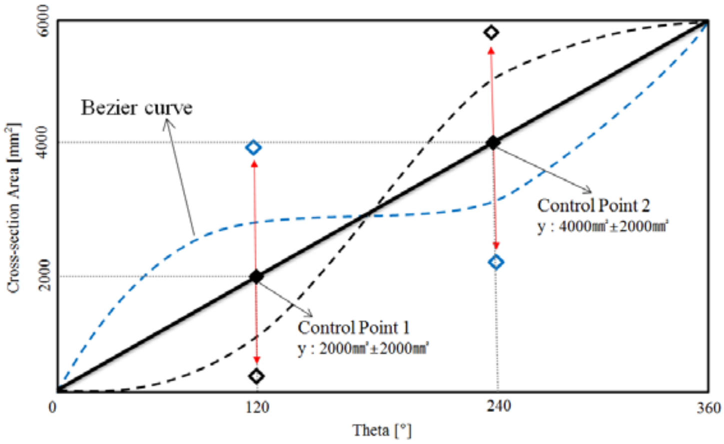

Figure 2. Area distribution with the theta angle of the volue

1. Methods

The flow field in the computational domain shown in Fig. 1 was analysed by solving three-dimensional steady and unsteady incompressible RANS equations through a finite volume solver, the commercial code ANSYS CFX 13.0 [3]. The discretizing method was a high resolution method with second-order accuracy. A k-ω based shear stress transport (SST) model was employed to account for the transport of turbulent shear stress and to produce highly accurate results for flow separation under an adverse pressure gradient.

Based on the results of steady RANS analysis, unsteady RANS analysis was conducted to obtain the radial force values of the rotating impeller outlet over time to analyze the unsteady flow phenomena of the single-channel pump.

The single-channel impeller optimized from the previous work [2] was used for the volute design in this work. An initial single-channel pump volute for wastewater treatment was designed based on the Stepanoff theory. Thus, the initial model has the constantly increased area distribution with the theta angle of the volute, as shown in Fig. 2. The internal flow cross-sectional area for the section of 0~360° theta was designed so that it can be controlled through the Bezier curve, and the position on the y axis of the two control points that determine the shape of the Bezier curve were chosen as design variables.

The objective functions (i,e,m the efficiency and peak radial force) were evaluated at the twelve design points, sampled by Latin hypercube sampling in the design space. These objective functions were numerically accessed through the steady and unsteady analyses. For the multi-objective optimization, the response surface approximation surrogate models were constructed to approximate the objective functions based on the values calculated at twelve design points. A fast nondominated sorting genetic algorithm for the local search coupled with the surrogate models was applied to determine the global Pareto-optimal solutions. The tradeoff between the two objectives was determined and finally is described with respect to the Pareto-optimal solutions.

References

[1] B. F. Hansen and P. J. Henning. Waste water pump. U.S. Patent Application.13(886): 479, 2013.

[2] B. M. Cho, J. H. Kim, Y. S. Choi, J. W. Kim, Y. S. Kim, K. Y. Kim, T. S. Ahn and J. H. Kim. Surrogate Based Optimization of a Single-Channel Pump Impeller," *7th International Conference on Pumps and Fans 2015*, October 18-21, Hangzhou, Zhejiang Province, China, ICPF-121, in process.