Multi-objective optimization of centrifugal pump impeller based on kriging model and multi-island genetic algorithm

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Abstract: Low-specific-speed pumps are extensively used in various fields, but the efficiency is low, consuming huge energy. An optimization approach is proposed based on numerical simulation, design of experiment, approximation model and genetic algorithm. The low-specific-speed centrifugal pump IS50-32-160 is determined as the research subject, three parameters containing blade outlet width b_2, blade outlet angle β_2, and blade warp angle φ are selected as the design variables, and then 20 impellers are designed by optimal Latin hypercube sampling method. The ANSYS CFX 14.5 is applied to conduct the steady numerical simulation to obtain the head and the efficiency, which are the optimal objectives. Approximation model is built between the objectives and the design variables based on the Kriging model. Finally, the best combination of impeller parameters is figured out by solving the approximation model with multi-island genetic algorithm. The results of original pump show that the performance curves obtained by experiments and simulations have a good agreement and the head deviation is 3.1%. The optimization method improves the hydraulic efficiency by 3.3%. The internal flow in the optimal impeller are steadier and the pressure fluctuation intensity is decreased. The optimization method presented can provide references to the optimization of non-over-load design of low-specific-speed centrifugal pumps.

Keywords: low-specific-speed centrifugal pump, multi-objective optimization, kriging model, multi-island genetic algorithm, numerical simulation

1. Introduction

The low-specific-speed centrifugal pump, whose specific speed is between 8 and 22, is widely used in the agricultural irrigations, power plants and chemical productions etc. According to the traditional design method, the impeller passage is very narrow and long in order to meet the requirements of low flow rate and high head. However, the low efficiency of low-specific-speed centrifugal pumps is urgent to increase.

The present optimization on efficiency and head for low-specific-speed centrifugal pump mainly focuses on the empirical formulas and experiments, but it is difficult for the designers to select the coefficients of empirical formulas and time-consuming to conduct experiments. The optimization techniques on improvements of performance of pump are well-developed. Kim et al[1,2] applied factorial design to optimize the impeller of pump and analyzed the effects of impeller's parameters on efficiency with response surface method. A multi-objective optimization of required net positive suction head ($NPSH_r$) and the efficiency of pump under design flow rate was presented by using metamodels and optimization algorithm[3-5].

In this study, a multi-objective optimization procedure of low-specific-speed centrifugal pump is proposed to improve the efficiency under design flow rate. The optimization combines Optimal Latin Hypercube Sampling (OLHS), Kriging model, multi-island genetic algorithm with numerical simulation. Finally, the inner flow is deeply analyzed to illustrate the improvement of performance of low-specific-speed centrifugal pump.

2. Methods

2.1 Model pump

The single-stage low-specific-speed centrifugal pump is a typical IS centrifugal pump used in agricultural irrigation. The pump consists of the impeller equipped with six straight blades and a spiral volute with rectangle section, as shown in Fig.1. The volute with long inlet pipe is made of PMMA for PIV measurements of the inner unsteady flow. The designed flow rate Q and head H are 6.3 m^3/h and 8m, and the rotating speed is 1450r/min. The main geometrical parameters of the pump are shown in table 1.

2.2 Numerical simulaiton and optimization method

The structured mesh is generated by ICEM CFD and ANSYS CFX 14.5 is applied to the calculation. The optimization process is illustrated in Fig.2. First, the design variables that have great influence on the pump's performance are determined. Secondly, Optimal Latin Hypercube Sampling (OLHS) is used to generate different schemes of impeller. The impellers are built according to the design space. Then the mesh generation and steady simulation are executed. The databeses are formed by the design variables and the objectives that contain hydraulic efficiencies and head. Then the surrogate model is constructed and the best combination of parameters is obtained through solving the surrogate model based on multi-island genetic algorithm.

Table 1 Main geometrical parameters of pump

	Geometrical parameters	Symbols	value
impeller	Inlet diameter	D_j	50mm
	Outlet diameter	D_2	160mm
	Blade outlet width	b_2	6mm
	Blade inlet angel	β_1	24°
	Blade outlet angel	β_2	30°
	Blade wrap angle	φ	150°
volute	cutwater diameter	D_3	170mm
	Inlet width	b_3	18mm
	Cutwater angle	α_3	27°
	Outlet diameter	D_4	32mm

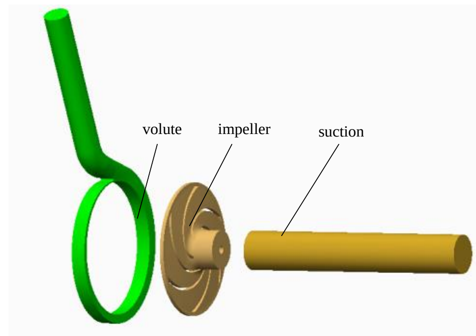


Fig. 1 Computational domains

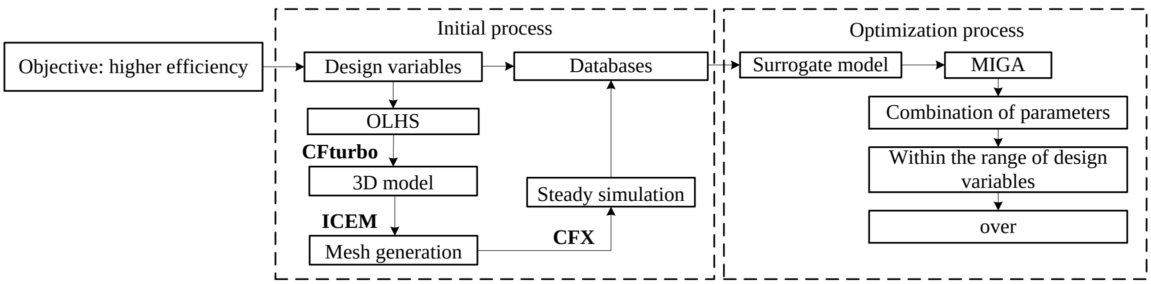


Fig. 2 Flow chart of optimization

2.3 experimental validation

The validation of the numerical results is essentially conducted by the experiments before the optimization process. The low-specific-speed pump is tested in the open test rig in the National Research Center of Pumps, Jiangsu University, as shown in Fig.3. The head of original impeller predicted by numerical simulation is compared with the experimental results, as shown in Fig.4. The trend of the head predicted is similar to the experimental performance. Therefore, it is proved that numerical simulation is reliable.

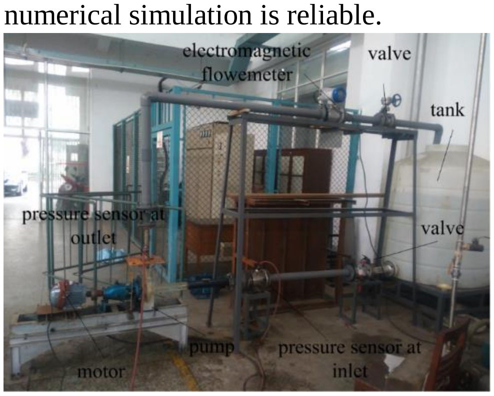


Fig. 3 Pump open test rig

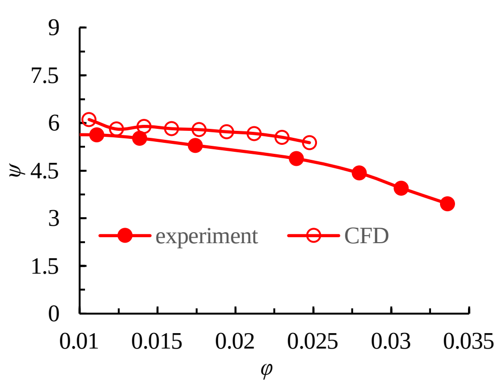
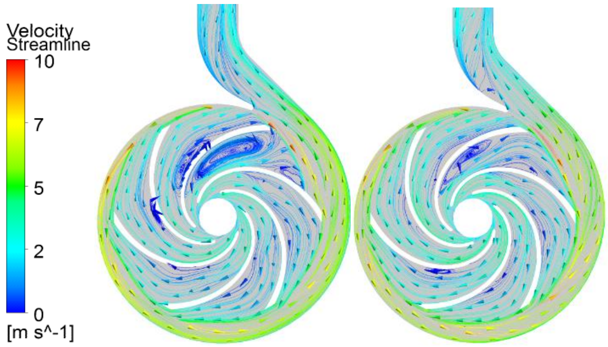


Fig. 4 Validation of head coefficient

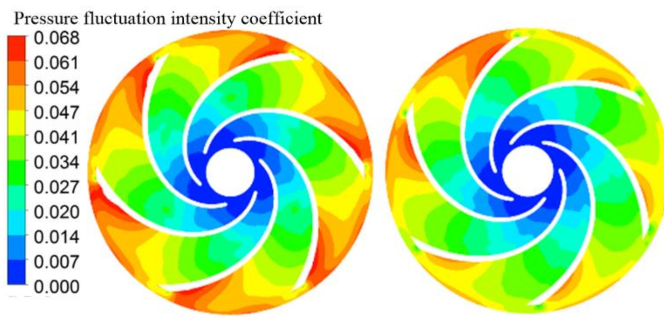
2.4 comparisons of steady and unsteady flow

To find reasonable factors for the improvement of performance in design flow rate, the inner flow characteristics of the original pump and optimal one have been compared. The vortex region in optimized impeller is smaller than that in original one and the flow is improved, so hydraulic performance is better, as shown in Fig.5. The pressure fluctuation intensity trends to be larger from inlet to outlet in the impeller, and the region of the maximum pressure fluctuation intensity is decreased after optimization, as shown in Fig.6.



(a) Origin impeller (b) Optimal impeller

Fig.5 Comparison of velocity distribution in the impeller under design condition



(a) Origin impeller (b) Optimal impeller

Fig.6 Pressure fluctuation intensity distribution in the impeller

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