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Volute Optimization Based on NSGA-Ⅱ Algorithm

Fannian MENG[a,1], Ziqi ZHANG[a], Liangwen WANG[a] and Yiyang LIU[b]
[a]*School of Mechanical and Electrical Engineering, Zhengzhou University of Light Industry, Zhengzhou 450002, China*
[b]*Zhengzhou College of Finance and Economics, Zhengzhou 450002, China*

Abstract. Optimizing the volute performance can effetely improve the efficiency of a centrifugal fan by changing the volute geometric parameter, so the Kriging model is used to optimize the volute geometric parameter. Firstly, Volute radius Rd, the radius of tongue r and outlet angle of the volute θ are selected as the optimization parameters of the volute, and Latin hypercube sampling is used to configure the initial sample points, the corresponding three-dimensional aerodynamic model under each sample point configuration is constructed. CFD software is used to simulate the efficiency value and total pressure of the centrifugal blower under each initial sample point configuration; Secondly, the Kriging surrogate model of initial sample point configuration parameters, efficiency value and total pressure of volute is constructed, the high-precision Kriging surrogate model is used as the fitness function of NSGA-II algorithm to get the optimal solution. The rationality of the above method is verified by optimizing the 9-19.4A type centrifugal fan volute. The efficiency of the optimized fan under working conditions is increased by 1%, and the total pressure under working conditions is not reduced.

Keywords. Volute, Optimization, Centrifugal fan, Kriging surrogate model, NSGA-II algorithm

1. Introduction

The function of the volute is to collect and guide the gas leaving the impeller, gradually reduce the airflow speed, and turn part of the kinetic energy into static pressure. At present, Shuiqing Zhou et al.[1] proposed a Latin hypercube sampling method combined with the surrogate model to parameterize the blade profile of centrifugal fan, and multi-objective optimization is carried out under NSGA-II algorithm. Selvaraj T et al.[2] treated the blade inlet angle, impeller diameter and width of centrifugal fan as optimized parameters using orthogonal experimental design method. Shuiqing Zhou et al.[3] studied a CST function to parameterize the blade, the surrogate model combined with the intelligent method are used in the research, which provides a new idea for fan energy saving. Honggang Fan et al. [4] researched a centrifugal fan optimization method. Abolfazl Khalkhali et al. [5] proposed neural network and CFD technology in the optimization processing. Xinfeng Li et al. [6] proposed a genetic algorithm to optimize the blade outlet installation angle and the number of blades. Finally, the

[1] Fannian Meng, School of Mechanical and Electrical Engineering, Zhengzhou University of Light Industry, Zhengzhou, 450002, China, Email: mengfannian123@163.com

compression ratio of the impeller at the design working point is increased by 3.57%, the isentropic efficiency is increased by 0.79%, and the overall condition of the impeller is improved. Konrad Bamberger et al. [7] used an evolutionary algorithm combined with surrogate model to quickly optimize the geometric parameters of centrifugal fan.

In this paper, the Latin hypercube sampling design method combined with the self-adaption Kriging surrogate model is used to optimize the centrifugal fan volute radius Rd, radius of tongue r and outlet angle of the volute θ. The response value is calculated by aerodynamics software CFX, and the NSGA-II algorithm is to find the Pareto optimal volute parameter; after optimization, the airflow distribution in the volute is smoother..

2. Volute Optimization problem description

The general mathematical model of the volute optimization problem can be described as:

$$\begin{aligned} & \text{find } \boldsymbol{x} = (x_1, x_2, \cdots, x_n) \\ & \min f(\boldsymbol{x}) \\ & \text{s.t. } g_j(\boldsymbol{x}) \le 0 \\ & \quad \boldsymbol{x}^{LB} \le \boldsymbol{x} \le \boldsymbol{x}^{UB} \\ & j = 1, 2, \cdots, m \end{aligned} \tag{1}$$

Where $\boldsymbol{x}$ is the n dimensions vector of design variable vector, $\boldsymbol{x}^{LB}$ and $\boldsymbol{x}^{UB}$ are upper and lower bounds value for design variable respectively, f is the objective function, g_j is the constraint condition, the analysis model for volute optimization can be described as a black-box model.

To cut down calculation cost to improve optimization efficiency, the surrogate model usually takes the place of the mathematical model. In this case, the optimization model is shown as follows:

$$\begin{aligned} & \text{find } \boldsymbol{x} = (x_1, x_2, \cdots, x_n) \\ & \min \widehat{f}(\boldsymbol{x}) \\ & \text{s.t. } \widehat{g}_j(\boldsymbol{x}) \le 0 \\ & \quad \boldsymbol{x}^{LB} \le \boldsymbol{x} \le \boldsymbol{x}^{UB} \\ & j = 1, 2, \cdots, m \end{aligned} \tag{2}$$

Where $\widehat{f}$ and $\widehat{g}_j$ are the surrogate model approximate response value, Kriging model, support vector machine (SVM) model, deep learning machine (DLM) model and so on usually used as a surrogate model.

In the volute optimization process, the mathematical relation equation between the volute shape and aerodynamic response value can't be directly constructed, fortunately; computational fluid dynamics (CFD) soft can be used to calculate the aerodynamic response value with geometric volute shape, but CFD calculation is time-consuming, so surrogate mode can be used to respect CFD calculation to save time, high precision surrogate model relies on adding sufficiency sample point, so the self-adaption sample point adding method is used to enhance the surrogate model accuracy. In the article, the self-adaption Kriging model is used to set as an objection function to optimize.

3. Volute Optimization problem description

3.1. Centrifugal fan structure

Collector, impeller, and volute are the main parts of the ventilation facility; the task of the volute is to guide the gas leaving the impeller to the outlet of the volute. The overall structure of the centrifugal fan and volute structure are drawn in Figure 1.

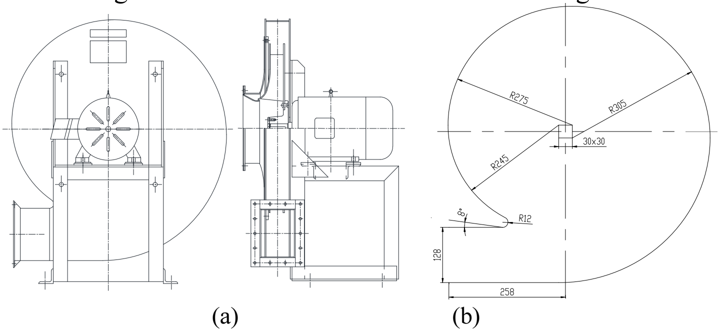


Figure 1. Centrifugal fan structure: (a) overall structure and (b) volute structure

3.2. CFD simulation analysis

In order to calculate the aerodynamic response parameters under a specific centrifugal fan model, CFD software needs to be used for numerical simulation calculation. Here, *. X_t model parameters are imported into ICEM software to divide the grid. The divided grid is shown in Figure 2.

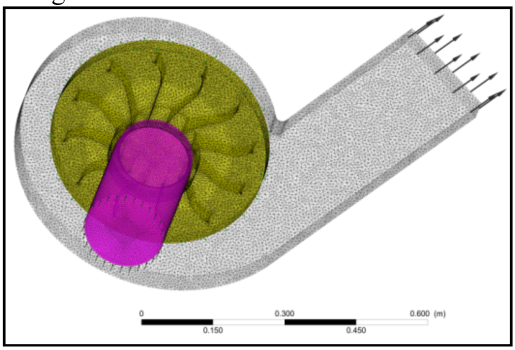


Figure 2. Grid mesh

3.3. Sample Point Design

First, volute radius R_d, radius of tongue r and outlet angle of the volute θ are selected are selected as optimization input parameters, Efficiency (*Eff*) and total pressure (*Tp*) are elected as optimization target parameters. The factors and levels are indicated in Table 1.

Table 1. Volute parameters and their levels

Factors	Parameters	Range
A	Volute radius R_d	235~255
B	Radius of tongue r	8~16
C	Outlet angle of the volute θ	0~10

The concrete optimization can be written in the below:

$$\begin{cases} \max \ Eff(R_d, r, \theta) \\ \max \ Tp(R_d, r, \theta) \end{cases} \quad \begin{cases} 235 \le Rd \le 255 \\ 8 \le r \le 16 \\ 0^{\circ} \le \theta \le 10^{\circ} \end{cases} \tag{3}$$

In the article, the LHS technology is adapted for parameter design; it is obvious that the distribution of sample points in each region of subspace is relatively uniform. The sample points also show a uniformly distributed full coverage state in the subspace formed by other factors.

3.4. NSGA- II Algorithm optimization

NSGA-II Algorithm is adapted in the article, and the parameters are set as; Maximum evolutionary algebra 300; Population size is equal to 100; Setting the crossover parameter value as 0.9; Variation probability is 0.1; Scaling factor 0.5; The distribution index of crossover and mutation algorithm is 20. The optimal combination of optimization parameters is calculated. After the combination of the parameters is rechecked by CFD, the total pressure evaluation parameter error is 0.5% and the efficiency fitting error of the fan is 0.1%, indicating that the response surface accuracy is high and the result is reliable. The fan efficiency is increased by 0.9%. The Pareto optimal front distribution is shown in Figure 3.

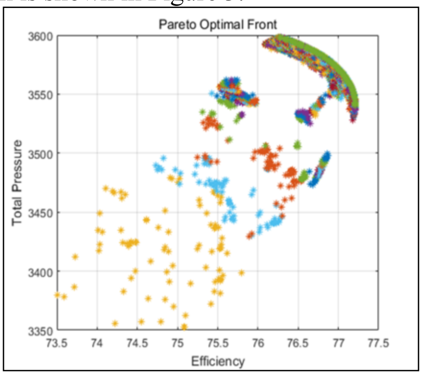


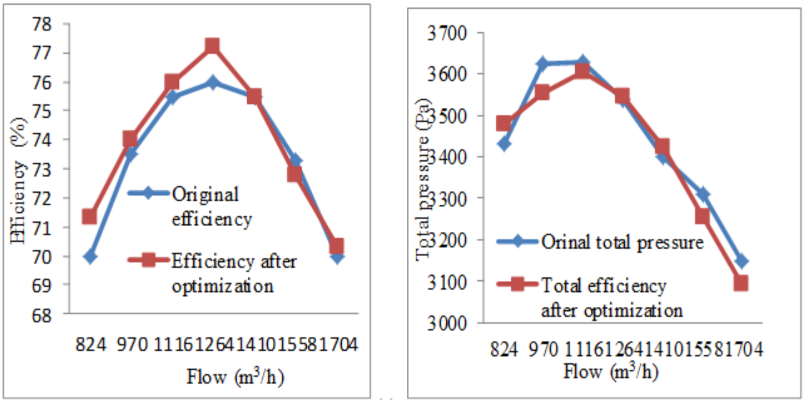
Figure 3. The Pareto optimal front distribution

Table 2 shows the Performance comparison of the centrifugal fan before and after optimization. It is known that at the design points, the total pressure value of the optimized centrifugal fan is raised from 3538Pa to 3545Pa, and the efficiency is increased from 76.3% to 77.2%. The efficiency of the optimized centrifugal fan is improved under the condition that the total pressure value is not lower than that of the original fan. The optimized centrifugal fan is more energy-saving and has better performance.

Table 2. Performance comparison of the centrifugal fan before and after optimization

Centrifugal fan	Total pressure at design point	The efficiency at design point
Before optimization	3538Pa	76.3%
After optimization	3545Pa	77.2%

Figure 4 are the centrifugal fan result curves before and after optimal design ((a) corresponds to the efficiency curve and (b) corresponds to the total pressure curve). It is known from this that under the design conditions after optimization, the total pressure of the optimized centrifugal fan is not less than of the original fan and its efficiency is increased by about 1%.

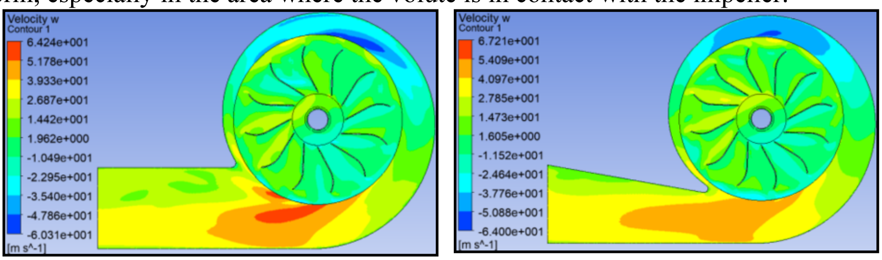


(a) (b)

Figure 4. Performance curve before and after optimization: (a) efficiency and (b) total pressure

3.5. *Volute internal flow performance comparison before and after optimization*

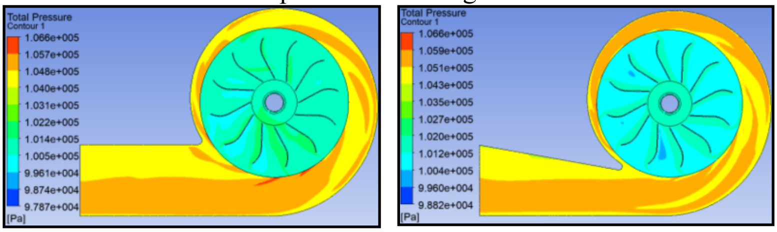
Figure 5 show the velocity distribution for the original fan and the optimized fan. It can be concluded that the velocity distribution in the volute after optimization is more uniform, especially in the area where the volute is in contact with the impeller.



(a) (b)

Figure 5. Velocity distribution: (a) before optimizaiton and (b) after optimization

Figure 6 show the total pressure distribution for the original centrifugal fan and the optimized centrifugal fan. It can be concluded from the figure 6 that the total pressure distribution in the volute for the optimized centrifugal fan is more uniform.



(a) **(b)**

Figure 6. Total pressure distribution: (a) before optimizaiton and (b) after optimization

4. Conclusion

In the article, the Kriging surrogate model is established, the EI adding points technology is used to raise the precision of the model, and the genetic method is used for optimization. The volute optimization design process considering the aerodynamic characteristic is proposed, and the centrifugal fan with better comprehensive performance is optimized.

- CFD method is complex and time-consuming to solve aerodynamic forces. The point-adding optimization method combining the Kriging model with EI point-adding optimization method can obtain a higher precision model with fewer sample points, which significantly improves the optimization efficiency.
- After optimizing the volute, the aerodynamic characteristic is improved, and the efficiency of the integral centrifugal fan is increased by 1%.

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