Available online at www.sciencedirect.com

ScienceDirect

Journal of Computational Design and Engineering 3 (2016) 179–190

www.elsevier.com/locate/jcde

Multi-objective robust optimization method for the modified epoxy resin sheet molding compounds of the impeller

Xiaozhang Qu[a,*], Guiping Liu[a], Shuyong Duan[a], Jichu Yang[b]

[a]State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha 410082, China
[b]Zhuzhou Lince Group Co., Ltd, Zhuzhou 412001, China

Received 6 November 2015; received in revised form 15 January 2016; accepted 15 January 2016
Available online 4 March 2016

Abstract

A kind of modified epoxy resin sheet molding compounds of the impeller has been designed. Through the test, the non-metal impeller has a better environmental aging performance, but must do the waterproof processing design. In order to improve the stability of the impeller vibration design, the influence of uncertainty factors is considered, and a multi-objective robust optimization method is proposed to reduce the weight of the impeller. Firstly, based on the fluid-structure interaction , the analysis model of the impeller vibration is constructed. Secondly, the optimal approximate model of the impeller is constructed by using the Latin hypercube and radial basis function, and the fitting and optimization accuracy of the approximate model is improved by increasing the sample points. Finally, the micro multi-objective genetic algorithm is applied to the robust optimization of approximate model, and the Monte Carlo simulation and Sobol sampling techniques are used for reliability analysis. By comparing the results of the deterministic, different sigma levels and different materials, the multi-objective optimization of the SMC molding impeller can meet the requirements of engineering stability and lightweight. And the effectiveness of the proposed multi-objective robust optimization method is verified by the error analysis. After the SMC molding and the robust optimization of the impeller, the optimized rate reached 42.5%, which greatly improved the economic benefit, and greatly reduce the vibration of the ventilation system.

Keywords: Multi-objective robust optimization; Impeller; SMC molding; Micro multi-objective genetic algorithm; Radial basis function; Fluid-structure interaction

1. Introduction

The cooling fan of the high speed trains is generally used for the axial flow, and the blade is the wing type. The impeller is one of the key parts of the cooling fan system, and its performance directly determines the quality of the whole machine. At present, most of the impeller is made of aluminum alloy or other metal cast. Application of aerofoil impeller made of the cast aluminum alloy in high speed trains has many problems. Because of the high density of metal material, the impeller has a large weight, which leads to the vibration and noise of the whole air blower in operation. The basic characteristics of the impeller is low load, light weight requirements, high output and cost sensitive, so we determine the short cut fiber molding plastic molding, that is, the modified epoxy resin sheet molding compound (SMC) for technical solution.

For the impeller of the composite material, the tensile strength can be in accordance with the requirements, and the lightweight design is mainly to meet the requirements of vibration. Easy to occur resonance of the impeller structure is determined by its own working conditions. When the impeller works, the blade is subjected to the periodic variation force, in addition to the mechanical vibration force, such as the impeller imbalance, rotor misalignment and installation, etc., as well as the aerodynamics , the random vibration and so on. Resonance occurs when the excitation frequency or frequency multiplication is equal or close to the natural frequency of the impeller. When the resonance occurs, the amplitude of the impeller will increase sharply, and the stress will also increase,

*Corresponding author.
E-mail address: quxiaozhang2001@163.com (X. Qu).

http://dx.doi.org/10.1016/j.jcde.2016.01.002

such as the long time work will be damaged due to the fatigue, and the aerodynamic performance and noise of the blade also has a great impact, thus affecting the normal operation of the high speed train ventilation system. At present, the unsteady fluid-structure interaction method is used to analyze the vibration of the impeller [1–10]. The impeller is one of the main vibration sources of ventilation system because of its high working speed. Therefore, the lightweight of the impeller is the main method to reduce the vibration of ventilation system. Vibration is one of the main parameters in the design of the impeller. The vibration of the impeller of high speed train ventilation system should not only meet the requirements of the resonance, but also meet the requirements of the random vibration of the track.

In the traditional optimization design, the optimal solution can be non-feasible due to the neglect of the fluctuation of the design variables and the noise factor, and the fluctuation of the objective function may exceed the permissible range of the prior regulations. In terms of safety coefficient instead of uncertainty factors easily lead to excessive design or unable to evaluate the uncertain factors and quantitative design of security [11–13]. Therefore, in the design stage of the impeller structure, we should consider the influence of the design parameters on the uncertainty factors. Reliability is used as the constraint condition, and the sensitivity of the target function to the uncertainty factor is reduced, and the robustness of the design scheme is improved.

Since the approximate model can greatly reduce the sample size and improve the working efficiency, it is widely used in engineering. At present, there are many approximate models, such as polynomial response surface, Kriging model, artificial neural network, support vector machine (SVM) model, moving least squares and radial basis function (RBF) and so on, but each model has its advantages and limitations. Jin et al. [14] studied the polynomial response surface, RBF and Kriging in detail, and the radial basis function has good compromise for accuracy. Mullur et al. [15] proposed an improved radial basis model with higher accuracy. Wang [16] proposed the dynamic approximate model of adaptive response surface method (ARSM) with good convergence and efficiency.

In this paper, the technical scheme of the SMC molding impeller is put forward, and the environmental aging and water resistance test are carried out. Based on the radial basis function and the robustness technology, a method of multi-objective uncertainty optimization for the impeller vibration is presented. The paper aims to solve the lightweight design of the impeller structure and meet the requirements of high reliability. By constructing the fluid analysis model of ventilation system and the fluid-structure coupling vibration model of the impeller, the optimization model of the impeller vibration is constructed. By increasing the sample point, the fitting accuracy of the radial basis function is improved, and the high precision approximation model is constructed. The reliability analysis method of the impeller vibration is used by Monte Carlo simulation and Sobol sampling technique. In order to improve the convergence of the optimization, the micro multi-objective genetic algorithm (μMOGA) developed by Liu et al. [17] is employed to solve the above problem, which has good efficiency, precision and convergence compared with the traditional genetic algorithm. The method obtains good results by engineering case analysis, and it can provide reference for the optimization of such related products.

2. Impeller molding process and material properties

2.1. Molding process

SMC molding method which can be near net size molding is characterized by high production efficiency, and the follow-up machining operation is almost No. The main core technology and process of SMC molding for the impeller are as follows:

(1) The short cut fiber, which is made of glass and cut into 5–10 mm, is used as the reinforcing material, and is mixed with the resin matrix.
(2) Polystyrene modified epoxy resin has good rigidity, good dimensional stability, low water absorption, anti creep and chemical corrosion resistance, etc. The epoxy resin is superior to phenol and polyester resin in the heat resistance, weather resistance and mechanical properties. It can fully meet the performance requirements of all aspects of the product.
(3) The curing temperature of the resin matrix is 140–160, with the use of SMC molding technology, and the curing time is 40 min.

Through the above technical requirements and forming process, the test sample of the impeller is made as shown in Fig. 1.

2.2. Characterization of material properties

In this study, the sheet molding compound (SMC) material is applied to the lightweight design of the impeller. The constitutive relations for the 3D bulk composite are expressed in the following form:

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{zx} \end{Bmatrix} = \begin{bmatrix} \frac{1}{E_x} & -\frac{\gamma_{yz}}{E_y} & -\frac{\gamma_{zx}}{E_z} & 0 & 0 & 0 \\ -\frac{\gamma_{xy}}{E_x} & \frac{1}{E_y} & -\frac{\gamma_{zy}}{E_z} & 0 & 0 & 0 \\ -\frac{\gamma_{xz}}{E_x} & -\frac{\gamma_{yz}}{E_y} & \frac{1}{E_z} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{xy}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{yz}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{zx}} \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{zx} \end{Bmatrix} \quad (1)$$

It can be expressed by a tensor form:

$$\varepsilon_{ij} = S_{ij}\sigma_{ij} \quad (2)$$

where ε_{ij} and σ_{ij} are the strain tensor and macroscopic stress, and S is named as flexibility matrix.

The thermal deformation temperature of the composite materials used in the impeller was tested by the method of the reference [18], and the thermal deformation temperature