Rotor Structure Optimal Design Based on Kriging Model and PSO

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Abstract. Rotor structure design technology often employed finite element analysis software (ANSYS), which are computational expense and highly time cost and need to employ approximation techniques. We herein studied a Kriging Model-based approximation technique, and applied it to optimize rotor structure. Firstly, we investigated the approximation models on rotor structure design. The mass of the rotor was the optimize goal, and the rotor statics, resonance frequency and geometry dimension were the constraint condition. We also employed particle swarm optimization (PSO) as model solution method. The computational results comparing to optimal results of ANSYS tested our proposed methods. The experimental results showed that the proposed method can increase the design efficiency and quality.

Introduction

Rotor natural frequency is one of the most important indicators in the design process. When the natural frequency of the rotor close to working frequency, the rotor vibrates intensified, or generates dynamic and static friction collision accidents. Especially when rotor dynamic balance is not checked well, vibration will be greater. In generally, we took minimum mass, good dynamic performance, reasonable distribution of the critical speed and so on as the optimal goal or constraint condition for rotor design, which meets the requirements of the rotor system.

In recent years, ANSYS is applied to carry on the statics analysis and modal analysis for rotor optimization design. B.C. Hang.et al[1] used sequential quadratic programming method to multidisciplinary design optimization for the flywheel rotor by ANSYS. J.Q. Tang.et al[2] adopted plane stress method to establish the stress model of the rotor, with the thickness of the composite rings and interference quantity between rings as optimization variables, and took stored energy as the optimization goal. Under the condition of strength constraint, they used sequential quadratic programming method for the rotor to optimize design. D.H. Wang.et al[3, 4] introduced genetic algorithms to rotor structure optimal design. W. Wang and Z.J. Niu[5, 6] combined response surface methodology and genetic algorithms to optimization design for rotor system.

This paper was organized as follows: firstly, we made a simple introduction about Kriging Model and PSO; secondly, we designed the application process of the approximation model in the rotor structure optimal design problems, and introduced the parameter settings of experimental study; thirdly, we optimized the rotor structure and compared to optimal results of ANSYS for testing our optimization methods, and analyzed the experimental results; we made a summary in the fourth part.

Kriging Model and PSO

Kriging method, also called the spatial local interpolation method, is based on variogram theory and structural analysis. It makes unbiased optimal estimations on regionalized variables in the limited area. We set x_0 as the point needed value, set $x_1, x_2, ..., x_N$ as observational points around x_0, set $y(x_1), y(x_2), ..., y(x_N)$ as observational values corresponding to $x_1, x_2, ..., x_N$ and set $\tilde{y}(x_0)$ as the valuation of x_0. Finally, we obtained $\tilde{y}(x_0)$ by using weighted summation of $y(x_1), y(x_2), ..., y(x_N)$:

$$\tilde{y}(x_0) = \sum_{i=1}^{N} \lambda_i y(x_i) \quad (1)$$

Particle Swarm Optimization (PSO), also called Particle Swarm algorithm, is an evolutionary computation technology developed by Kennedy and Eberhart.et al in 1995, and the original goal is in order to study the feeding behavior of birds. PSO algorithm uses the principle of evolutionary computation:

i) Initializing a set of random population;

ii) Searching optimal solution by updating the population generation;

iii)Evolving the group depending on the front of population.

PSO uses the particle swarm following the optimal particle to search the optimal solution in the solution space, and doesn't have the crossover and mutation operation of genetic algorithm. So compared with genetic algorithm, PSO is simple and easy to implement, and doesn't need to adjust many parameters.

Experimental Study

The optimization design of rotor structure is a constraint, nonlinear optimization problem. Firstly we established static model and dynamic model of the rotor by using ANSYS. The results of preliminary analysis of the initial parameters were calculated. Then we chose design variables, constraint conditions, and selected the optimization goal. We used optimal Latin hypercube as design of experiments. We sampled points in static model and dynamic model of the rotor and build the Kriging model. Cross-validation selected a subset of points from sampling data set, and removed each point to recalculation coefficients at a time. Then cross-validation compared exact and approximate output valuables at each removed point. We selected optimization algorithm (PSO) to solve rotor Kriging model, got a set of optimal design variables, and minimized the mass of the rotor. The geometry dimension of rotor structure was shown in Fig.1

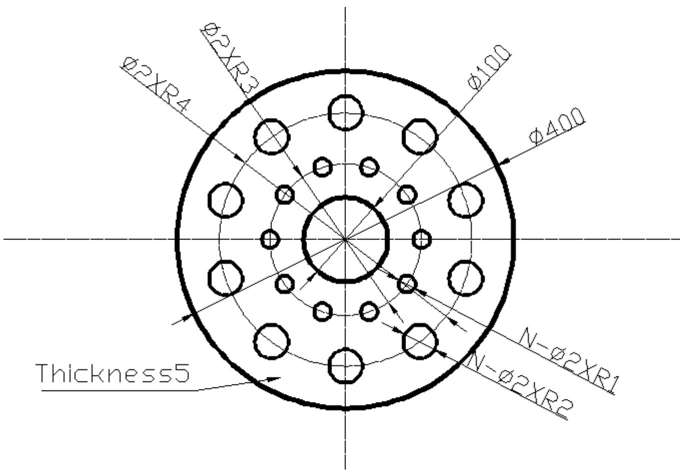

Fig.1: The geometry dimension of rotor structure

Considering all the factors, we applied PSO to solve the rotor optimal design problems. The mathematical description is as follows:

Optimization goal:	Minimize Mass= F(x)	(2)
Design variables:	x= (N, R1, R2, R3, R4)	(3)
Constraint condition:	MAX_EQV≤390MPa	(4)
	FREQ1≥156Hz	(5)

Where N is the quantity of round holes, R1, R2, R3, R4 is the round hole's radius respectively. Constraints on design variables: 6≤N≤16, 10mm≤R1≤20mm, 21mm≤R2≤34mm, 70mm≤R3≤110mm, 145mm≤R4≤165mm. MAX_EQV is the maximum stress in rotor statics analysis. FREQ1 is the 1st frequency in rotor dynamics analysis. The optimization flow chart of rotor design was shown in Fig.2.

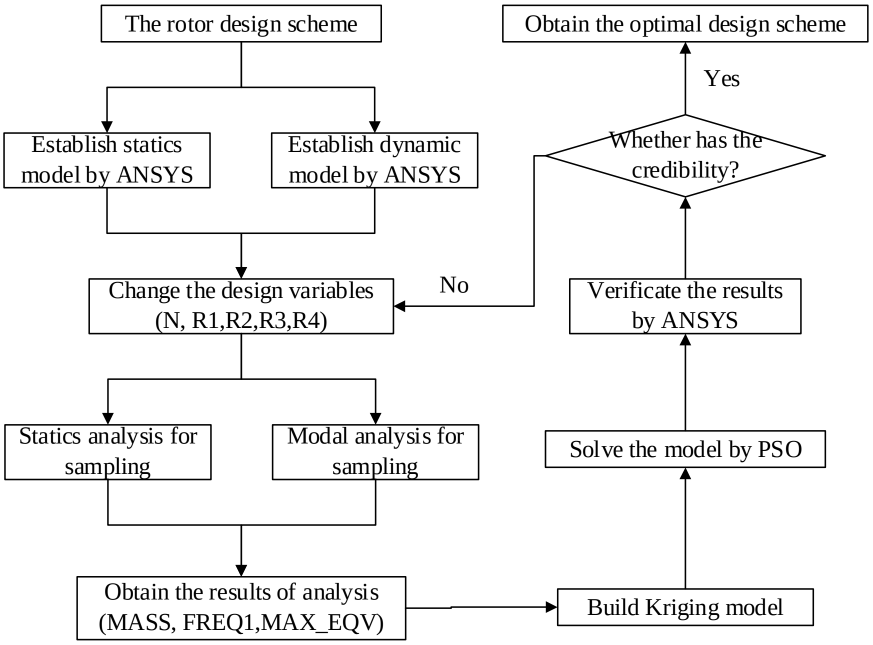

Fig.2: The optimization flow chart of rotor design

Experimental Results and Analysis

In this paper, the computational results comparing to optimal results of ANSYS tested our proposed methods. The optimization results of rotor design was shown in Table 1. The optimization curve of design variables was shown in Fig. 3. The optimization curve of optimization objective and constraint condition was shown in Fig. 4.

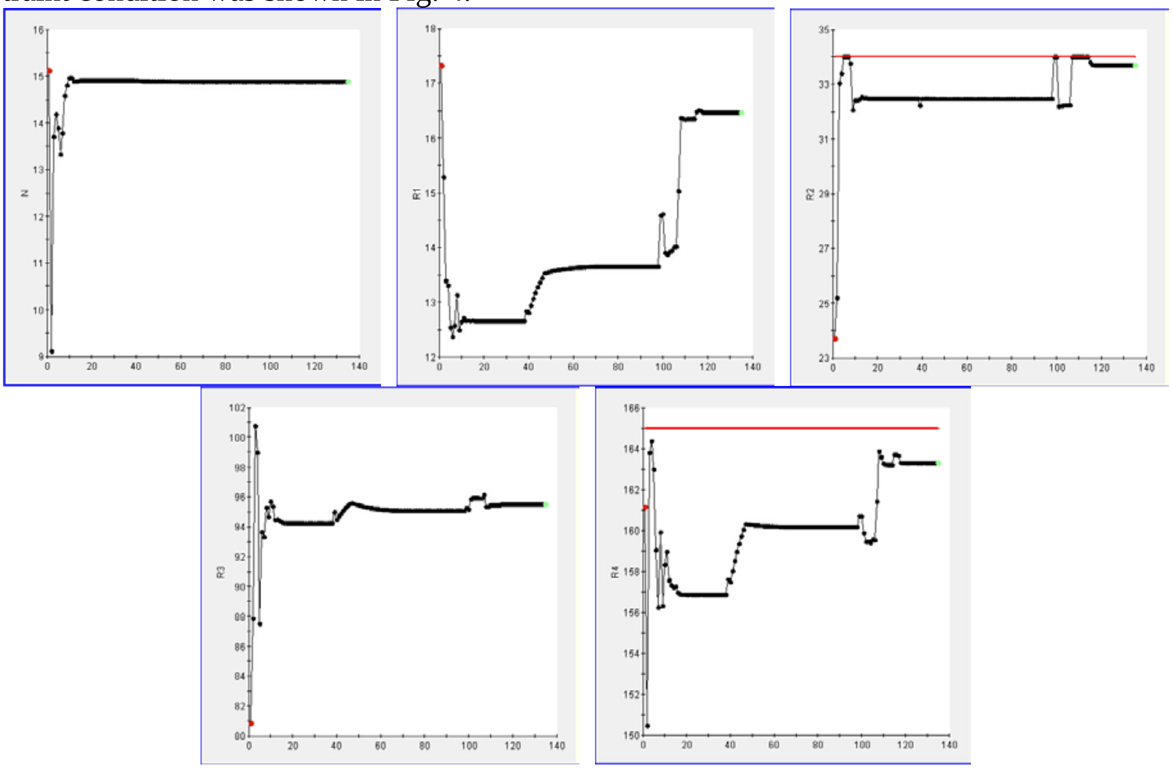
Fig.3: The optimization curve of design variables

Results can be seen from the second column in Table 1. Under the optimal design variables, maximum stress MAX_EQV of the rotor was 380.36MPa. The rotor material was 35CrMoVA, and tensile strength of the material was 780MPa. So the safety coefficient of the rotor was 2.05, which meets the strength constraint of the material. 1st frequency of the rotor nature frequency was 156.0Hz which is greater than the rotor working frequency (120Hz). Optimization design scheme of

ANSYS was shown in the third column of Table 1. Optimization minimize mass of the proposed method was better than ANSYS. The variables convergences quickly, which is shown in Fig. 3 and Fig. 4. The experimental results showed that the proposed method can increase the design efficiency and quality.

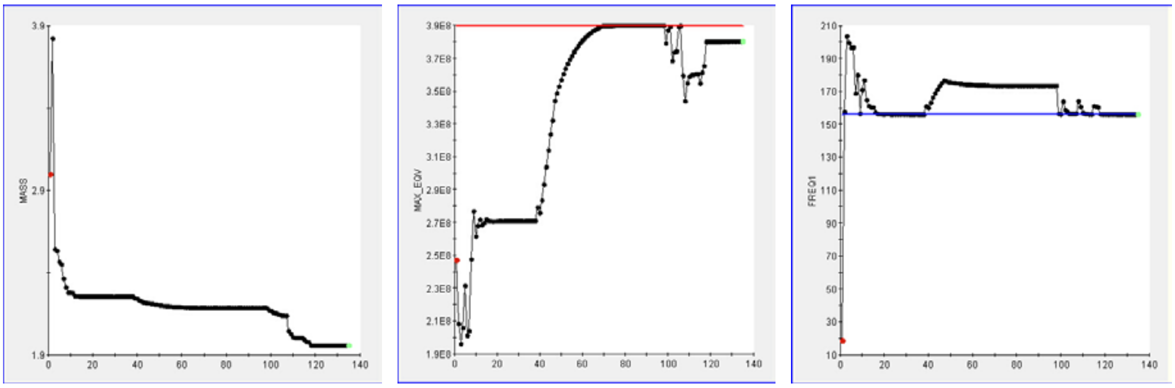

Fig.4: The optimization curve of optimization objective and constraint condition

Table 1: The optimization results of rotor design

Parameters	Optimization design scheme of the proposed method	Optimization design scheme of ANSYS
N	15	15
R1(mm)	16.464	15.275
R2(mm)	33.689	33
R3(mm)	95.518	102.45
R4(mm)	163.3	165
FREQ1(Hz)	156.0	203.85
MAX_EQV(Pa)	3.8036E8	3.0182E8
MASS(kg)	1.9557	2.1663

Conclusions

This article studied a Kriging Model-based approximation technique combined with PSO, and employed it for optimizing rotor structure design. We took the rotor as analysis object with the aim to optimize the minimum mass of the rotor, considered the strength constraint of the material, the first resonance frequency and structure requirements. We designed the application process of the Kriging model in the rotor structure optimal design problems, and used the optimal results of ANSYS to test our proposed methods. The results showed that the proposed methods can increase the design efficiency and quality for rotor structure design.

Acknowledgements

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