Optimal design of machine tool bed based on Ansys and orthogonal design

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Received 1 March 2014, www.cmnt.lv

Abstract

This paper attempts to use a simple and practical method based on the finite element theory and orthogonal design for the optimal structural parameters of machine tool bed. Dynamics finite element model of MCH63 machine tool bed has been established with the finite element analytic technique in order to improve the dynamic characteristics. The thickness of the ribs are looked as the design variables, the orthogonal design is used to optimize the natural frequency and the total mass. The simulation result indicates that the method is simple, effective and feasible.

Keywords: machine tool bed, optimal design, modal analysis, orthogonal design

1 Introduction

Machine tool bed is the major component of CNC machine tool, and its structural deformation affects machine tool's machining precision and dynamic characteristics greatly. With the ever-increasing demand in higher machine precision, the requirement for bed's stiffness is also increasing. At the same time, lightweight design is also being pursued for bed structure, which is important for a lower cost of material. However, it is difficult to obtain such a successful design due to the intricacy involved, including the diversity of layout pattern, the complexity of structural features as well as the variability of design parameters [1]. Recently, some researchers and scholars have done some work on machine tool bed [1-7]. However, there is much work to be done on CNC machine tool and its components in order to improve its stiffness, strength and dynamic characteristics.

As we know, the orthogonal design method is one of the experimental design methods. It samples some level combinations, which are orthogonal with each other, to represent the whole solution space. The selected combinations distribute uniformly in the solution space and more or less present some properties of their neighbours. The number of combinations to test is much smaller than the total number in solution space, and the combinations are representative and the results are convincing, so the experiments can be finished in a shorter time [8].This method can provide an effective way to find the near optimal solution combination of levels for the experiments, and it has been widely successfully applied in different areas [8, 9]. Therefore, it is more suitable for structural parameters of machine tool bed in order to obtain a better performance in this paper.

The remainder of this paper is organized as follows. Section 2 describes the model and modal analysis of the machine tool bed. The optimizing structural parameters based on orthogonal design are given in section 3. Concluding remarks are presented in section 4.

2 Modelling and modal analysis of the machine tool bed

The work space of MCH63 machine was designed to be $3768\times2080\times482mm^3$. Bed material is HT300, and its density is $7350kg/m^3$. The Poisson's ratio and elastic modulus are 0.27 and 1.3E11Pa respectively. A "well" structural layout for bed structure is formed in order to improve the stiffness, strength and dynamic characteristics. As a result, the simplified machine tool bed can be modelled, as shown in Figure 1. The finite element method (FEM) is popular and widely used in industrial area. Several studies have been carried out, modelling machine components with the FEM [10, 11]. Furthermore, the FEM is useful in the design process because many FEM software packages have useful interfaces to 3D CAD systems. Therefore, we also use FEM to process modal analysis for machine tool bed in this paper, and the finite element mesh is shown in Figure 2. By adding the boundary conditions to the finite element mesh model, the modes from the first order to the fourth order can be obtained, as shown in Figure 3-Figure 6. The natural frequencies from the first order to the fourth order are shown in Figure 7.

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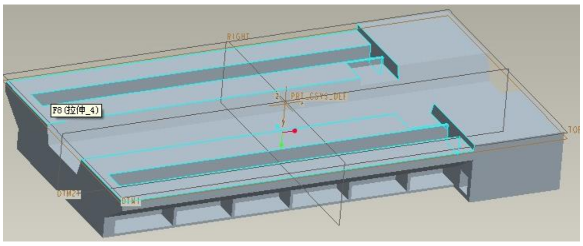

FIGURE 1 The simplified 3D model

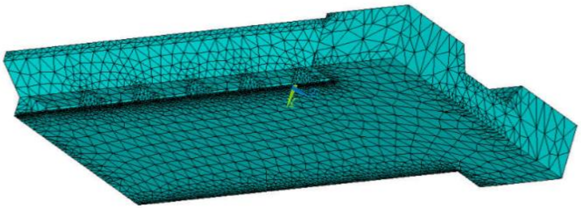

FIGURE 2 The finite element mesh

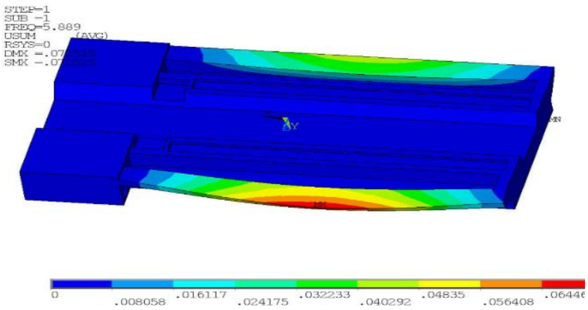

FIGURE 3 The first order mode of the bed

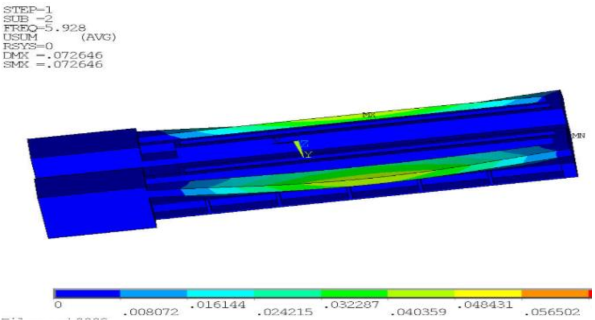

FIGURE 4 The second order mode of the bed

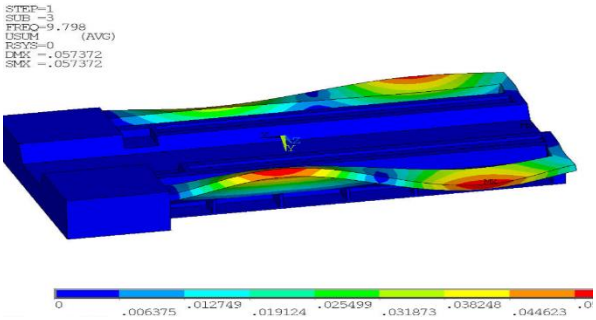

FIGURE 5 The third order mode of the bed

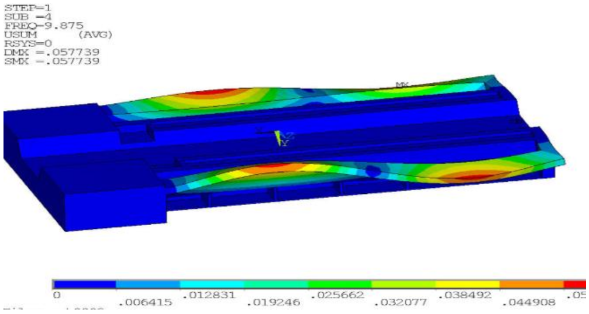

FIGURE 6 The fourth order mode of the bed

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***** INDEX OF DATA SETS ON RESULTS FILE *****

 SET   TIME/FREQ     LOAD STEP   SUBSTEP  CUMULATIVE
   1  5.8888            1           1         1
   File: prt0002

   2  5.9276            1           2         2
   File: prt0002

   3  9.7975            1           3         3
   File: prt0002

   4  9.8753            1           4         4
   File: prt0002

   5  14.310            1           5         5
   File: prt0002
```

FIGURE 7 Natural frequencies for each order mode

3 Optimal design based on orthogonal design

In this section, optimal selection of structural design parameters using orthogonal design for machine tool bed is given.

3.1 L25 (5^6) ORTHOGONAL ARRAY EXPERIMENTS

The three five-level parameters, i.e. the thickness of the rib in the x direction (t_1), the thickness of the rib in the z direction (t_2) and the thickness of the rib on both sides (t_3) are considered. The optimal parameters and their selected levels are presented in Table 1. For three parameters at five levels each, the traditional full factorial design would require 5^6 experiments. However, in the current design (L25 (5^6) orthogonal array) the required experiments are only 25.

TABLE 1 Parameters and their respective levels in the present experimental design

Parameters	Level 1	Level 2	Level 3	Level 4	Level 5
t_1(mm)	22	24	25	26	28
t_2(mm)	26	28	29	30	32
t_3(mm)	22	24	25	26	28

The experimental lay out for genetic parameters using L25 (5^6) orthogonal array and the frequencies (f/Hz) and mass (M/Kg) are shown in Table 2. This design involves 25 separate experiments with specified levels and particular combination of parameters. However, the sequence in which the experiments were carried out was randomized to avoid any kind of personal or subjective bias, which may be conscious or unconscious. This procedure ensures greater validity of test results [9].

3.2 EXPERIMENTAL RESULT AND ANALYSIS

As mentioned above, we use the natural frequency f and mass M as the evaluation indexes. As far as f is concerned, it for bigger-the-better characteristics is considered. The extreme difference analysis is carried out from Table 2, it can be obtained that the processing condition for attaining optimal f are t_1 at level 4, t_2 at level 2 and t_3 at level 2 (optimal scheme 1). In addition, we use the mass M as the evaluation index. As far as M is concerned, it for smaller-the-better characteristics is considered. The extreme difference analysis is carried out from Table 2, it can be obtained that the processing condition for attaining optimal f are t_1 at level 1, t_2 at level 1 and t_3 at level 1 (optimal scheme 2). The results are shown in Table 3. From the comparison results of these two kinds of optimal combination of parameters in Table 3, although the total mass M is a little bigger in optimal scheme 1 than that in optimal scheme 2, yet the natural frequency is improved in the optimal scheme 1. Therefore, we select the optimal scheme 1 as the final result.

TABLE 3 Summarized results of frequency f and mass M

Scheme	Index	
	f/Hz	M/Kg
optimal scheme 1(t_1=26，t_2=28, t_3=24)	6.031	183.750
optimal scheme 2(t_1=22，t_2=26, t_3=22)	5.720	167.727

Finally, the 3D model for the machine bed tool by using the optimal combination parameters is shown in Figure 8.

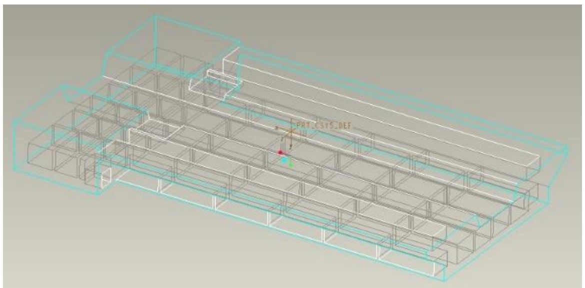

FIGURE 8 The optimal 3D model of the machine tool bed

TABLE 2 L25 (5^6) orthogonal array design and results

Experiments	Parameters			Index	
	t_1(mm)	t_2(mm)	t_3(mm)	f (Hz)	M(kg)
1	1(22)	1 (26)	1(22)	5.725	167.727
2	1(22)	2 (28)	2(24)	5.713	178.458
3	1(22)	3 (29)	3(25)	5.658	183.823
4	1(22)	4 (30)	4(26)	5.632	189.189
5	1(22)	5 (32)	5(28)	5.587	199.920
6	2(24)	1 (26)	2(24)	5.773	170.814
7	2(24)	2 (28)	3(25)	5.752	181.325
8	2(24)	3 (29)	4(26)	5.735	186.690
9	2(24)	4 (30)	5(28)	5.704	192.276
10	2(24)	5 (32)	1(22)	5.683	201.243
11	3(25)	1 (26)	3(25)	5.794	172.358
12	3(25)	2 (28)	4(26)	5.783	182.868
13	3(25)	3 (29)	5(28)	5.780	188.454
14	3(25)	4 (30)	1(22)	5.803	192.276
15	3(25)	5 (32)	2(24)	5.872	203.007
16	4(26)	1 (26)	4(26)	6.012	173.901
17	4(26)	2 (28)	5(28)	5.994	184.632
18	4(26)	3 (29)	1(22)	6.003	188.454
19	4(26)	4 (30)	2(24)	5.889	194.040
20	4(26)	5 (32)	3(25)	5.793	204.550
21	5(28)	1 (26)	5(28)	6.014	176.988
22	5(28)	2 (28)	1(22)	6.032	185.955
23	5(28)	3 (29)	2(24)	5.904	191.541
24	5(28)	4 (30)	3(25)	5.897	196.907
25	5(28)	5 (32)	4(26)	5.789	207.417

4 Conclusions

This paper attempts to develop a simple and practical method based on the finite element method and orthogonal design for the optimal structural design of machine tool bed in order to meet increasingly stiffness, strength and dynamic characteristics requirement. The proposed approach involves a two-phase procedure. Firstly, a simplified 3D model for machine tool bed is established. With this model, the finite element method can be easily and economically employed to process modal analysis of the bed structure under actual operation conditions. Then, the thickness of the ribs are looked as the design variables, the orthogonal design is used to optimize the natural frequency and the total mass. Optimization results are finally elaborated to demonstrate the effectiveness of the proposed method.

Acknowledgments

This paper is supported by the National Natural Science Foundation of China (Grant No. 51305001), Natural Science Foundation of Anhui Province (Grant No. 1208085QE94, 1308085ME78), Universities Natural Science Research Project of Anhui Province (Grant No. KJ2013B033), the Youth Foundation of Anhui Polytechnic University (Grant No. 2012YQ29), and the National Training Programs of Innovation and Entrepreneurship for Undergraduates (No.201210363139). The authors would like to thank the referees, the editors and the anonymous reviewers for their helpful comments and constructive suggestions.

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Publications: more than 20 papers.