Component layout optimization design based on genetic algorithm

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Abstract. When working, electronic equipment is often subjected to a mechanical environment dominated by vibration. The printed circuit board (PCB) in the equipment is prone to deformation and transmits vibration to the components on the board. As the weakest link, the component corner position has a large acceleration, which is one of the important reasons for the failure of components and the entire electronic equipment. Based on the finite element modeling of PCB, the interaction between the finite element analysis software NASTRAN and the programming software MATLAB is realized, and the application of genetic algorithm in component layout optimization becomes possible. The optimization results show that the method adopted in this paper can effectively reduce the acceleration value at the component corner and optimize the mechanical environment when the electronic equipment works.

1. Introduction

Electronic equipment generally contains many sophisticated electronic components. To meet special requirements, it needs to be installed on a special platform. When the electronic equipment is subjected to mechanical environment such as vibration input from the platform, the PCB undergoes large dynamic bending deformation, which is an important reason for the failure of the electronic equipment. If we can estimate the acceleration of the PCB under the vibration in the design, optimize the component layout and reduce the acceleration value of the component corners, the mechanical environment of the printed circuit board and the reliability of the product can be improved.

The traditional means of dynamic analysis through vibration test not only cost and time, but also difficult to grasp the structural characteristics of the internal components of electronic systems. But finite element simulation can effectively make up for the above defects. Therefore, verification is often performed through finite element simulation in the optimization. Zhu [1] analyzed the calculation formula of natural frequencies to obtain the conclusion that large and heavy components should be placed as close to the constraint as possible. Zhu introduced inertial forces into the proposed integrated layout optimization method designing the multi-component systems. A consistent material interpolation scheme between element stiffness and inertial load was presented to avoid the singularity of localized deformation, which was due to the presence of design dependent inertial loading when the element stiffness and the involved inertial load were weakened with the element material removal. The tested numerical example show the proposed methods extended the actual concept of topology optimization and were efficient to generate reasonable design patterns [2].

Due to the large number of components on the board and adjustable locations, the traversal optimization cannot be performed under normal circumstances. It is often done by calculating the results of models under a number of typical locations to compare and analyze, and then put forward suggestions
for the optimization of its layout. However, due to the limited selection of typical locations, the optimization results are often not optimal. In recent years, intelligent optimization algorithms have gained attention, which can overcome the limitations of traditional optimization algorithms and achieve global optimization [3-5]. Krishna [6] presented a fixture layout optimization technique that used the genetic algorithm to find the fixture layout. The technique minimized the deformation of the machined surface due to clamping and machining forces over the entire tool path. Particle swarm optimization (PSO) intelligent algorithm was adopted to perform optimization, and obtained the optimal solution in the multidisciplinary optimization design for the section layout of umbilicals [7].

In this paper, based on the genetic algorithm and the finite element simulation, the component layout is optimized. In the solution of the optimization model, an improved genetic algorithm is proposed and the idea of parametric modeling is used to realize the interactive optimization of MATLAB and NASTRAN to achieve the purpose of optimizing the component layout and improving the mechanical environment.

2. Finite element simulation of printed circuit board

This paper takes the circuit board in an electronic device as the research object, and uses finite element software PATRAN to model it. The finite element model is shown in figure 1.

![Figure 1. Finite element model.](image)

There are 8 components on the board, and each component has been numbered in figure 1. Considering the limited installation space near the location of the component, this paper focuses on component No. 6 and improves its mechanical environment by optimizing its layout.

When constructing the finite element model, the PCB is constructed by surface, and the quadrilateral element (Quad4) is used to divide the mesh. The surface is cut according to the position of the components on the board, ensuring that the corner and the node on the board are coincident, and the shell element is stretched to modeling the components. At the end, common node processing is performed to achieve the unity of the cutting surfaces and the constraints between the components and the board. The total finite element model includes 65597 Hex elements, 13274 Quad4 elements and 78871 nodes.

The circuit board is mounted on the platform by bolts at the edges. Bolt connections limit the X, Y, Z movement in three directions. So the constraint is applied to the node on the model at the bolts position. According to actual working conditions, the load on the circuit board comes from the vibration of the platform. So, the acceleration in the Z direction is applied at the model by 1 g, where g is about 9.81 m/s². In the calculation process, the linear elastic constitutive equation model is adopted for the board.
and the components. The material parameters used in each part are shown in Table 1.

| Material       | Elastic Modulus/Pa | Poisson ratio | Density/kg/m³ |
|----------------|--------------------|---------------|---------------|
| PCB            | 1.40e10            | 0.12          | 1800          |
| Component NO. 1| 17.65e10           | 0.32          | 7500          |
| Component NO. 2| 27.65e10           | 0.32          | 7500          |
| Component NO. 3| 37.65e10           | 0.32          | 7500          |
| Component NO. 4| 47.65e10           | 0.32          | 7500          |
| Component NO. 5| 52.06e11           | 0.30          | 7800          |
| Component NO. 6| 61.86e11           | 0.32          | 16600         |
| Component NO. 7| 77.00e10           | 0.34          | 2700          |
| Component NO. 8| 82.06e11           | 0.30          | 7800          |

First, the modal analysis of the board model is performed. The results are shown in Table 2 below.

| Modal Order | 1 | 2 | 3 | 4 | 5 |
|-------------|---|---|---|---|---|
| Frequency/Hz| 485.16 | 1174.6 | 2315.0 | 2715.8 | 3233.4 |

According to modal analysis, the natural frequency of the circuit board model is 485.16 Hz. The sinusoidal frequency excitation of acceleration is applied to the circuit board and the interval is 20~2000 Hz. Initially set the modal damping ratio to 0.01. We get the frequency response curve of the average acceleration of component No. 6 in the current position, as shown in Figure 2.

Figure 2. Frequency response curve of average acceleration (Z direction).

The average value of the acceleration at the component corners peaks at 1180 Hz with a peak value of 24.01 m/s². The average acceleration frequency response curve of the component has obvious resonance characteristics. The resonance frequency is close to the modal frequency of each order, and the response is the most obvious at the second-order modal frequency.

3. Genetic algorithm and improvement
3.1. Genetic algorithm
The generation of Genetic Algorithm (GA) was attributed to the pioneering work of Professor Holland of the University of Michigan in the United States in the 1960s and early 1970s [8]. Later, after further research by Jong and Goldberg, the genetic algorithm was more perfect [9]. It has been widely used to solve complex combinatorial optimization problems. It can be said that genetic algorithm is the most widely used and most successful modern optimization method.

Genetic algorithm mimics the evolutionary processes of living things. In the process of evolution, children maintain the characteristics of their parents to a certain extent, which is hereditary. At the same time, variations may occur during the generation of offspring. Both heredity and variation occur on the chromosome, reflecting changes in the gene on the chromosome. The entire evolutionary process is controlled by the competition mechanism of “survival of the fittest, survival of the fittest”, which makes the most viable chromosomes survive with the greatest possibility, thus allowing the organism to evolve and develop.

The strategy of roulette is used to mimic the survival mechanism. The probability that each individual will survive is

$$p_i = \frac{F_i}{\sum_{j=1}^{N} F_j}$$

(1)

where $F$ is the objective function value, $N$ is the number of the individuals in the population. The purpose of the formula (1) is to allow individuals with higher objective function value to obtain higher survival chances, and to eliminate inferior solutions during the evolution process and optimize the objective function values of the population. Considering that the objective function value in this paper is as small as possible, the above formula is rewritten as

$$p_i = \frac{\sum_{j=1}^{N} F_j - F_i}{(N-1) \times \sum_{j=1}^{N} F_j}$$

(2)

Taking into account the above characteristics and advantages of the simulated annealing algorithm, this paper optimizes the component layout on the printed circuit board based on the simulated annealing algorithm. The optimization parameters of simulated annealing algorithm are shown in table 3.

Through the selection, crossover and mutation operations in the algorithm, the genetic algorithm can finally obtain a good solution with low objective function.

Considering the above characteristics and superiority of genetic algorithm, this paper optimizes the layout of components on the printed circuit board based on genetic algorithm. The optimization parameters of the genetic algorithm used are shown in table 3.

| Name               | Value |
|--------------------|-------|
| Cross rate         | 0.75  |
| Mutation rate      | 0.05  |
| Population size    | 10    |
| Genetic algebra    | 200   |

Table 3. Optimization parameters of genetic algorithm.

3.2. Adaptability improvement
In order to make the genetic algorithm more suitable for the layout optimization of components, it has been improved adaptively in the programming, mainly in the following aspects.

- Considering that the program calls NASTRAN to perform the calculation for a long time, each
calculation result is stored to avoid repeated calculations for the same state, and the iteration time can be shortened;

- Since each current state has a limited neighborhood, the searched neighborhoods are recorded during the optimization process, avoiding repeated searches to the same neighborhood, which can increase the convergence speed.

4. Optimization Design of Component Layout

The acceleration value at the component corners is an important indicator of the mechanical environment of the printed circuit board. When the material properties meet the requirements, the reduction of the acceleration value means the increase of the life of the components, which is particularly important for the reliability of the circuit board and even the entire electronic equipment.

The most effective way to reduce the acceleration at the component corners is to adjust the component layout. Layout optimization is the design and redo of the circuit board model. In order to automate modeling, the idea of parametric modeling is used to update the model by updating the relevant data of nodes, units, etc. in the model file. And on this basis, interacting with the finite element calculation software NASTRAN to obtain the calculation results of the new model, so as to judge whether the acceleration value under the new layout has decreased.

4.1. Objective Function

The output file of finite element calculation contains the real and imaginary values of the accelerations in three directions. Calculate the modulus length of accelerations of each of the three directions, and then calculate the total acceleration. The formula is as follows

\[ a = \left( a_{11}^2 + a_{12}^2 + a_{21}^2 + a_{22}^2 + a_{31}^2 + a_{32}^2 \right)^{1/2} \]  

where \( a_{1i} \) is the real value of the \( i \)-direction acceleration and \( a_{2i} \) is the imaginary value of the \( i \)-direction acceleration.

4.2. Restrictions

There are two restrictions as follows.

- The distance from other components is not less than 8mm to facilitate the installation of components.
- The distance from the circuit board boundary is not less than 3mm, to facilitate the connection between the circuit board and the platform.

4.3. Interaction Methods between MATLAB and NASTRAN

In this paper, the joint programming of NASTRAN and MATLAB can not only use the program to realize the powerful search ability of the algorithm, but also realize the finite element calculation of the current state. The software interaction process is shown in figure 3.

The establishment of the optimization model and the reading of the calculation results are all implemented using MATLAB programming. At the same time, the finite element calculation is performed using NASTRAN and the calculation results are output. MATLAB programmatically controls the input parameters calculated by NASTRAN and reads the result of the calculation. Then the component position parameters of the next iteration are generated and output. Through the above loop iteration process, the optimization problem is ultimately solved.
4.4. Optimization results

With the current mesh density, there are 840 adjustable positions for the target components. If traversing the search, the time required is 98h. The optimal solution obtained by traversal search is 13.08 m/s².

The optimization result of the objective function is shown in figure 3. The abscissa is the time of iterations, and the ordinate is the acceleration value. The red line represents the optimal solution found during the optimization process and the black line represents the average of the accelerations of all individuals in the population under the current iteration. As the number of iterations increases, the average acceleration value of the population decreases and the optimal solution is reduced to a minimum of 13.08 m/s².

To verify the stability of the program, repeat the operation 5 times, record the time and results of each run, as shown in table 4.

| Num | Time/min | Result/m/s² |
|-----|----------|-------------|
| 1   | 815      | 13.08       |
| 2   | 772      | 13.08       |
| 3   | 742      | 13.08       |
| 4   | 703      | 13.08       |
| 5   | 863      | 13.08       |

The average program running time is 779 minutes. The length of the run time is related to the initial solution, which is the randomly selected initial positions of the component.

It can be seen that using the improved genetic algorithm for search optimization, the average time required is 779 min. Compared with the ergodic search, the time is shortened to less than 2/15 of the original, and the searched results are all global optimal solutions.

The finite element model of the components before and after optimization is shown in figure 4. The distance between the optimized position and other components is greater than 8 mm, and the circuit board boundary is greater than 3 mm, which meets the restrictions.

The average frequency response curve of acceleration at the component corners after optimization is shown in figure 5. Compared with the pre-optimization, the curve trend is constant and the frequency at which the average value of the acceleration peaks is basically constant, which is because the optimized components have light weight and little influence on the overall natural frequency.
Figure 4. Model of printed-circuit board. (a) Before optimization and (b) after optimization.

Figure 5. The mean acceleration response curve after optimization (Z direction).

5. Conclusion

Based on the finite element modeling analysis, this article uses the idea of parametric modeling to realize the interaction between MATLAB and NASTRAN, and realizes the application of the improved genetic algorithm on the component layout through programming. The acceleration value at the corners has been reduced, which improves the mechanical environment of the circuit board, prolongs the service life of the electronic device, and improves the overall reliability. The optimization results show that the component layout optimization method adopted is reasonable and feasible, and has practical value and promotion significance.

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