Bolt layout optimization design based on genetic algorithm

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Abstract. When working, electronic equipment is often subjected to mechanical environments such as vibration and shock. The reliability problem of components after experiencing vibration environment is one of the key research contents in the development of electronic equipment. The printed circuit board on which the component is mounted is deformed during vibration, and the vibration is transmitted to the component, so that the component corner has a large acceleration, which is one of the important reasons for the failure of the electronic device. Based on the finite element simulation of the circuit board, the application of genetic algorithm in bolt layout optimization is realized by MATLAB programming. By optimizing the bolt layout, the acceleration value at the component corners is greatly reduced, and the reliability of the electronic equipment is improved.

1. Introduction

When working, electronic equipment is often subjected to mechanical environments such as vibration and shock. The printed circuit board on which the component is mounted is deformed during vibration, and the vibration is transmitted to the component, so that the component pin has a large acceleration, which is one of the important reasons for the failure of the electronic device. Through the finite element simulation method, the acceleration of the board under vibration can be estimated in the design, and the layout of the bolt can be optimized to reduce the acceleration value of the component corner, so that the mechanical environment of the printed circuit board can be improved, and the reliability of the electronic equipment can be improved.

The bolts are typically mounted at the edge of the printed circuit board. Because of the need to determine the layout of each bolt, it is not possible to traverse all conditions. Previous scholars often proposed the bolt layout by calculating a number of typical bolt layout models[1, 2]. However, due to the limited number of typical models selected, the optimality of the optimization results is often not guaranteed. In recent years, intelligent optimization algorithms have been rapidly developed, which can overcome the limitations of traditional optimization algorithms and achieve global optimization[3, 4]. Krishnakumar[5] presents a fixture layout optimization technique that uses the genetic algorithm (GA) to find the fixture layout that minimizes the deformation of the machined surface due to clamping and machining forces over the entire tool path. Huanlin Liu[6] proposes a gene density genetic algorithm (GDGA) to optimize the LED layout. Gene density-based segmented crossover and gene mutation strategy is put forward. A weighted differences function is designed to select the right LED lamps' layout.

This paper improves the genetic algorithm and optimizes the layout of the bolt by finite element simulation. In the process of solving the optimization model, using the idea of parametric modeling, the interaction between MATLAB and NASTRAN is realized, and the purpose of optimizing bolt layout and improving the mechanical environment of components is achieved.
2. Finite element simulation of printed circuit board
In this paper, a simple circuit board is used as the research object, and the finite element software PATRAN is used for modeling. The shape of the board is regular and there is only one component on the board. The finite element model is shown in Figure 1.

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

The board is mounted on the platform with 8 bolts. The bolts are located at the four corners of the board and in the middle of four sides. According to the actual working conditions, the load on the board is from the vibration of the platform, so the unit acceleration in the Z direction is applied at the nodes at the bolts position by $1 \text{ m/s}^2$. The linear elastic constitutive equation model is used for the plates and components in the calculation process. The material parameters used in each part are shown in Table 1.

| Material | Length (mm) | Width (mm) | Height or Thickness (mm) | Elastic Modulus (GPa) | Poisson ratio | Density (kg/m³) |
|----------|-------------|------------|--------------------------|-----------------------|---------------|-----------------|
| PCB      | CCL         | 150        | 100                      | 2                     | 14            | 0.28            | 1800            |
| Component| Ceramics    | 30         | 30                       | 5                     | 310           | 0.22            | 3980            |

The modal analysis result of the board model is shown in Table 2 below.

| Modal Order | Frequency (Hz) |
|-------------|----------------|
| 1           | 557.6          |
| 2           | 749.7          |
| 3           | 1012.6         |
| 4           | 1088.8         |
| 5           | 1310.2         |

| Modal Order | Frequency (Hz) |
|-------------|----------------|
| 6           | 1577.6         |
| 7           | 1832.6         |
| 8           | 1987.3         |
| 9           | 2135.6         |
| 10          | 2271.9         |

Apply acceleration sinusoidal frequency excitation to the board, the interval is 20~2000Hz, and the initial modal damping ratio is 0.01. The acceleration or stress frequency response curve of the component corner position can be obtained. In this paper, the optimization is based on the sinusoidal sweep analysis results of the board.

3. Genetic algorithm and improvement

3.1. Genetic algorithm
In the 1960s, Professor John Holland of the University of Michigan in the United States creatively proposed to apply the genetic mechanism of biology to artificial adaptive systems to perform adaptive search in a group manner. In the 1970s, John Holland et al. proposed a more complete theory and method for genetic algorithms[7]. On the basis of this, Dr. De Jong conducted a large number of numerical function optimization experiments, established a framework of genetic algorithms, and the prototype of genetic algorithms was initially formed. To date, genetic algorithm has been widely used in combinatorial optimization, machine learning, adaptive control, planning and design, and artificial life.
Genetic algorithm is a process that simulates biological evolution during the optimization process. The trait of each individual depends on the genes on the chromosome. The process of biological evolution is also the process of chromosome crossing, genetic variation, and natural selection between individuals. Through the competition mechanism of “survival of the fittest, survival of the fittest”, individuals with poor viability are gradually eliminated, thereby improving the survival level of the whole population and realizing the evolution and development of biology. In the algorithm, the optimization variables represent the genes on the chromosome, and the objective function value represents the viability of the individual.

This paper adopts the roulette strategy to achieve the competition mechanism of "survival of the fittest, survival of the fittest". The probability that each individual will survive is

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

where $F$ is the objective function value, $N$ is 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. However, considering that the purpose of optimization in this paper is to reduce the objective function, the above formula is changed to

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

The goal of optimizing the objective function can be achieved by programming the selection, crossover and mutation operations in the genetic algorithm.

3.2. Adaptability improvement

In order to make the genetic algorithm used in this paper more suitable for bolt layout optimization, it has been adaptively improved during programming, mainly in the following two aspects[8].

- 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 neighbourhood, the searched neighbourhoods are recorded during the optimization process, avoiding repeated searches to the same neighbourhood, which can increase the convergence speed.

4. Optimization design of bolt layout

The acceleration value at the component corner is an important indicator to measure the mechanical environment of the component. In the case of material properties meeting the requirements, the reduction of the acceleration value means the improvement of the mechanical environment of the components, which is especially important for the reliability of the board and even the entire electronic equipment.

Changing the mounting position of the bolt can change the position at which the board receives the vibration of the platform, that is, the position of the load input. Each time the bolt position is changed, the board model needs to be redesigned. For rapid modeling, automation of modeling is required. Therefore, the idea of parametric modeling is introduced, and the related data such as nodes and units in the model file are changed by programming to realize the update of the model. On this basis, the program calls the finite element calculation software NASTRAN to calculate the changed model file, and obtains and reads the calculation result of the new model to determine whether the acceleration...
value is reduced under the new layout. The MATLAB version used in this paper is 2017a, and the
CPU is Intel(R) Core(TM) i5-6500 CPU@3.20GHz.

4.1. Objective function
The objective function can be selected in a variety of ways, such as acceleration or stress, and multiple
variables also can be coupled as an optimized objective function. In this paper, the average
acceleration value at the component corner is selected as the objective function of the optimization.
Acceleration can be obtained directly by NASTRAN calculation and MATLAB reading of the
calculation result file.

4.2. Restrictions
There are two restrictions as follows.
- The spacing of each bolt is not less than 20mm, which prevents the bolt from being too dense
to cause damage to the circuit board.
- The installation of the bolt adopts the principle of center symmetry, that is, if the bolt
mounting position of one side is determined, the installation position of the opposite bolt is
also determined.

4.3. Decision variables and bounds
The optimization object in this paper is the installation position of the bolts, so the decision variables
are the coordinates of the bolts. Under the premise of the restrictions in 4.2, only two bolts’ position
needs to be determined. So there are four decision variables, which are x1, y1, x2 and y2. Decision
variables satisfy the inequalities as follows.

\[
22 \leq x \leq 128 \quad (3)
\]
\[
22 \leq y \leq 78 \quad (4)
\]

Where x and y are even.

4.4. Optimization results
There are 8 bolts on the board in the model. Except for the bolts on the four corners, there is a bolt on
each side that needs to be optimized for layout. Due to the constraint of "central symmetry for the
installation of bolts", the number of variables in the optimization process is reduced to two. The
selected genetic algorithm optimization parameters are shown in Table 3.

| Name          | Value |
|---------------|-------|
| Cross rate    | 0.75  |
| Mutation rate | 0.15  |
| Population size | 20    |
| Genetic algebra | 300   |

In the current grid density, there are 1566 adjustable positions where the bolts on each side meet
the constraints. If the search is traversed, the results of all the positions need be analyzed and
calculated. The calculation time for each position is about 8 seconds, and the time of traversed search
required is about 3.5 hours. By traversing the search, the optimal solution is found to be 14.39 m/s².
The optimization process of the objective function is shown in Figure 2. The abscissa is the number of
iterations and the ordinate is the acceleration value. The line below represents the optimal solution
found during the optimization process, and the upper line represents the average of the accelerations of
all individuals in the population under the current number of iterations. With the increase of genetic algebra, the average value of the population's acceleration decreases and then fluctuates up and down, and the optimal solution is reduced to a minimum of 14.39m/s². Due to the large variation rate and the large population size in the parameters selected in this paper, the upper line always fluctuates above the line below, and the two lines do not intersect. Larger variability and population size can make more inferior solutions in each generation of populations, reducing the possibility of falling into local optimum during the optimization process, and this is also the main reason for the upper line being far from the line below.

In order to verify the stability of the program and observe the effect of the initial solution on the optimization of the algorithm, repeat the operation 5 times, record the time and result of each operation, as shown in Table 4.

| Num | Time(min) | Results(m/s²) |
|-----|-----------|---------------|
| 1   | 84.9      | 14.39         |
| 2   | 68.7      | 14.39         |
| 3   | 82.4      | 14.39         |
| 4   | 74.8      | 14.39         |
| 5   | 81.5      | 14.39         |

The average running time of the program is 78.46 minutes, about 1.3 hours. The length of the run time is related to the initial solution, that is, to the initial position of the randomly selected component, and the direction of the search during the optimization process is random. It can be seen that the average time required for the search optimization using the improved genetic algorithm is 78.46 minutes. Compared with the traversal search, the time is shortened to about one third, and the results of the five searches are global optimal solutions. It shows that using the genetic algorithm to optimize the bolt installation position can jump out of the local optimal solution and can be used to search the global optimal solution.

The schematic diagram of the bolt mounting position before and after optimization is shown in Figure 3 and Figure 4. The distances between the optimized position and other bolts are greater than 20mm, which meets the constraint requirements. Before the optimization, the bolts are equally spaced. After optimization, the bolts on the upper and lower sides are located near the third bisector, and the
bolts on the left and right sides are located near the bisector. It can be seen from the figure that the position of the bolt on the two sides closer to the component of the optimized circuit board is closer to the corner position of the component.

![Image](image1.png)  
**Figure 3.** Position before optimization.  

![Image](image2.png)  
**Figure 4.** Position after optimization.

The frequency response curve of the average acceleration at the component corners before and after optimization is shown in Figure 5. The peak value of the frequency response curve of the optimized acceleration average is reduced compared to before optimization. Under the bolt layout before optimization, the average value of the acceleration at the component corner is 43.9 m/s². After optimization, the average acceleration is only 14.4 m/s², and the reduction ratio is 67.2%. After optimization, the peaks in the curve are left-biased, indicating that the modal frequencies of the various stages are reduced after the bolts are not equally spaced.

![Image](image3.png)  
**Figure 5.** The mean acceleration response curve before and after optimization (Z direction).

The average stress at the component corners of the bolt layouts before and after optimization is calculated, as shown in Figure 6. The peak value of the frequency response curve of the optimized stress average is also reduced compared to before optimization. Under the bolt layout before optimization, the average stress at the component corners is 0.216 MPa. After optimization, the stress average is only 0.172 MPa, and the reduction ratio is 20.4%. The frequency at which each peak is reached is also reduced. The bolt layout position obtained by optimizing the acceleration value at corner also greatly reduces the stress value at corner.
**Figure 6.** The mean stress response curve before and after optimization (Z direction).

5. **Conclusion**

Based on the finite element simulation analysis, this paper introduces the idea of parametric modeling, realizes the interaction between MATLAB and NASTRAN, and realizes the application of the improved genetic algorithm in bolt layout through programming. The results of finite element simulation show that optimizing the layout of the bolt can reduce the acceleration value at the component corner and achieve the reduction of the stress value at the component corner, which can improve the overall reliability. The bolt layout optimization method adopted in this paper is reasonable and feasible, and has practical value and promotion significance.

6. **References**

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