The Role of Lightweight Design Method in Flexible Fixture Design

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Abstract. To reduce the processing cycle and cost of sheet metal parts, a flexible fixture is designed by light weight method. First, the finite element analysis techniques adopted are summarized. Second, the static and modal analysis of the flexible fixture unit is carried out to obtain the design structure that meets the strength and rigidity requirements. Third, the lightweight design of the base of the positioning clamping unit is carried out after the analysis of the design structure of the positioning clamping unit. The modal analysis results of the positioning clamping unit show that at the operating frequency of 50Hz, the positioning clamping unit designed in this research would not resonate. Lightweight design results obtain the optimal section design parameters, achieve the purpose of reducing the weight of the flexible fixture base structure, and save the cost. Therefore, the results of this study provide a good idea for flexible fixture to adapt to the diversity of mechanical products.

Keyword: Lightweight design; Flexible fixture; Finite element design; Strength; Stiffness.

1. Introduction
With the increasing application of sheet metal parts, in recent years, the proportion of sheet metal parts in mechanical products has increased, so its use value in product design is increasing, and the current processing technology of sheet metal parts has also been continuously improved and standardized. At present, many mechanical products are designed to use sheet metal parts [1]. Because sheet metal parts not only save the production cost of mechanical products, but also effectively improve the production efficiency of parts. With the continuous improvement of people's living standard, more and more kinds of products are used in daily life. In order to adapt to different products, various sheet metal parts come into being. If these sheet metal parts are to be processed, it is necessary to design the appropriate fixture for processing and manufacturing. Therefore, the research on flexible fixture is of great significance [2].

At present, sheet metal parts are made by rigid tool processing, so its processing and manufacturing costs are high. For some small batch sheet metal parts, special fixtures and stamping models must be made according to the structure and shape of the parts, so the processing and manufacturing costs of these parts are very high [3]. As the speed of updating sheet metal parts accelerates, and the shape of sheet metal parts constantly changes, the fixtures used to process and manufacture sheet metal parts also need to change accordingly. If all sheet metal parts are made with special fixtures and fixtures, the price...
of sheet metal parts that can be produced will be very high. Especially, for sheet metal parts with complicated curved surfaces, the production of clamps and fixtures will also become relatively complicated, directly resulting in high costs [4]. Therefore, it is urgent to develop a kind of fixture that can meet the processing and manufacturing requirements of sheet metal parts of different sizes and shapes by quickly adjusting the position and clamping point of the fixture in the sheet metal bending processing and manufacturing. This kind of flexible fixture can be used to process sheet metal parts of different shapes by adjusting the position of fixed point and clamping point, which can effectively adapt to the current rapidly developing market demand. In order to further optimize the flexible fixture, its structure needs to be optimized.

To sum up, in this research, to improve the adaptability and work efficiency of the flexible fixture, the lightweight design method is adopted to optimize the base of the positioning clamping unit of the flexible fixture. Firstly, the finite element analysis technology is introduced in this research, and then the statics and modes of the positioning clamping unit of the flexible fixture are analyzed, and the optimization design is carried out according to the analysis results. Finally, the modal and lightweight results of the positioning clamping unit are discussed and analyzed. It is hoped that the results of this research can provide a good idea for optimizing the design of flexible tooling fixtures.

2. Methodology

2.1. An overview of finite element analysis techniques

At present, finite element analysis is widely used in the engineering field. Finite element analysis is a kind of numerical analysis method, which mainly simulates mechanical structure forces by means of computer technology. Generally, before designing a mechanical structure, a computer can be used to design the mechanical structure, which can not only reduce the design cost and cycle, but also greatly improve the design efficiency and quality of mechanical products.

The basic idea of finite element calculation is to discretization continuous geometric elements into finite element points, and set finite nodes in each element point, so as to assume the analysis results as finite element nodes in the process of finite element analysis, and analyze the whole mechanical structure. The exploration of the mechanical structure can be completed by analyzing each element node [5].

In this research, ANSYS Workbench software is used to design the parts of each flexible fixture. When adopting ANSYS Workbench software for analysis, pre-processing, load solving, and post-processing are required. The specific mechanical design process is as follows. Firstly, the sheet metal part material is studied, the cell type and mesh are divided. Then, the constraint conditions (such as load) are applied, and finally the stress cloud diagram and total deformation diagram of the part are solved. In this research, in order to ensure the strength and stiffness of the positioning clamping unit, the weight of the infrastructure should be reduced as much as possible, and the flexible fixture structure should be optimized by ANSYS Workbench software.

2.2. Static analysis of positioning clamping unit

The most important mechanism in the flexible fixture is the positioning clamping unit. The positioning clamping unit can adjust the position of the positioning mechanism and the clamping mechanism quickly and conveniently. During the work, the base will bear the working load, so the dimensional parameters need to be determined during the design of the base structure of the positioning and clamping unit.

During the working process, the positioning clamping unit of the flexible fixture mainly bears the load imposed by the positioning mechanism or the clamping mechanism, and also bears the load imposed by the bottom plate in the base. In order to analyze the strength and stiffness of the clamping element base, the static analysis of the structure is required. During the static analysis of the position of the clamping element, it should be meshed.
2.3. Modal analysis of locating clamping unit

The natural frequency and mode of vibration of mechanical structure can be obtained by modal analysis of clamping unit. For the traditional mechanical mechanism design method, static design is generally adopted, not dynamic design. For the design of flexible fixtures, it is not only necessary to improve the strength coefficient, reliability, and service life, but also to reduce weight, reduce vibration and noise. In the design process of mechanical structures, it is generally considered that sufficient strength and stiffness can meet the requirements, but many mechanical structures will appear cracks and other damage phenomena in the process of repeated use. Therefore, it is necessary to use modern design methods to study and analyze the dynamic characteristics of parts or products [6].

In this research, in order to improve the working performance of the flexible fixture clamping unit, ANSYS Workbench software is used for modal analysis. In the process of modal analysis, the fixture structure is considered as a whole, and the fixture material used is Q235. A vertical constraint is applied to the bottom during the analysis. Then, grid division is adopted, which is imported into the three-dimensional structure model and analyzed according to the modal analysis steps reminded by ANSYS Workbench software. Because in a mechanical structure, the modal system is the natural frequency and has nothing to do with the external load, there is no need to set the load boundary conditions. After the establishment of the modal model of the positioning clamping unit, the input modal number is 20, and finally the modal analysis begins.

2.4. Optimized design of the base of the positioning clamping unit

Since the base of the clamping unit adopted in this research is a semi-cut structure, the section size should be designed when optimizing the base structure of the positioning clamping unit. In the design of semi-cut section size adopted in this research, \( x_1 \) represents the length of groove in the middle of the base; \( x_2 \) represents the width of the guide rail in the base structure; \( x_3 \) represents the base structure; \( x_4 \) represents the height of the guide rail in the base; \( x_5 \) represents the groove thickness in the middle of the base; and \( x_6 \) represents the height of the guide rail in the base.

![Figure 1. Schematic diagram of base size](image)

According to the initial design structure of the flexible fixture, \( x_1 \sim x_6 \) are fixed value. In the process of design, the design process and size of these variables need to be improved. Table 1 shows the initial value and value range.

| Variable | \( x_1 \) | \( x_2 \) | \( x_3 \) | \( x_4 \) | \( x_5 \) | \( x_6 \) |
|----------|----------|----------|----------|----------|----------|----------|
| Initial value | 85 | 23 | 125 | 42 | 19 | 13 |
| Constraint function | \( 65 < x_1 < 95 \) | \( 20 < x_2 < 30 \) | \( 95 < x_3 < 125 \) | \( 30 < x_4 < 50 \) | \( 10 < x_5 < 25 \) | \( 15 < x_6 < 25 \) |
In the process of optimizing the base of the positioning and clamping unit of the flexible fixture, the strength and stiffness are required to meet the requirements for each optimization. The deformation amount of the parts can’t be added at will. The foundation structure design of the positioning unit of the flexible fixture should be taken as the basis for deformation. According to the basic structure designed in this research, during the whole working process, the deformation quantity shall not be greater than 0.5mm.

According to the structure design of the flexible fixture, the base material is made of aluminum alloy. Since the yield strength limit of aluminum is 66.7 Mpa, the stress limit can’t exceed the yield strength of aluminum during the stress design process [7]. Therefore, according to the principle, the yield limit of the fixture positioning device should meet equation (1):

$$
\sigma_{\text{stress}} \leq [\sigma] = \frac{\sigma_y}{n}
$$

(1)

Among them, $[\sigma]$ represents the allowable stress of materials in the design process of fixture unit base; $\sigma_y$ represents the yield strength of the aluminum material; and $n$ represents the safety factor. Therefore, it can be calculated from equation (1) that the allowable stress of the material designed in this research should be 66.8 Mpa.

In the design of flexible fixture, lightweight design should be required to reduce the weight of the fixture as far as possible, making it as light as possible. In the optimal design of the foundation-base structure, the weight of the clamping unit is chosen as the objective function. The base of the positioning clamping unit is cast from aluminum, so the density of the entire structural material remains constant. In the process of optimizing the foundation structure, it is necessary to calculate the base structure and analyze its quality. The density of the material is determined, so its volume can be used as an objective function of the optimal design of the entire infrastructure. The objective function can be expressed as follows.

$$
\min f(X) = \rho \cdot L \cdot a
$$

(2)

Where, $\rho$ represents the material density of the base structure; $a$ represents the size of the section area of the base structure; and $L$ represents the length of the base structure. According to the interface dimension $x_1 \sim x_6$ of the base designed above, its section area can be calculated with equation (3).

$$
a = 2 \cdot x_1 \cdot x_6 + (x_3 - x_2) x_4 + x_1 \cdot x_5
$$

(3)

Through the structural design of the base in the flexible fixture, the length and size of the base can be obtained to be 44mm. The objective function can be obtained according to the optimized design of the structure of the whole base, as shown in equation (4).

$$
\min f(x) = \rho \cdot L \cdot (2 \cdot x_1 \cdot x_6 + (x_3 - x_2) x_4 + x_1 \cdot x_5)
$$

(4)

3. Results and discussion

3.1. Analysis of modal results of positioning clamping unit

In this research, a modal analysis is performed on the positioning and clamping unit, and the modal analysis results are obtained. Since the vibration of the mechanical structure is mainly a linear combination of the modes of the natural modes of each order, the influence of the low-order natural modes on the structure is greater than that of the high-order natural modes on the positioning and clamping unit. Figure 2 shows the histogram of natural frequencies of the first 10 free modes of the positioning clamping unit. As can be observed from the figure, the bending deformation and torsion deformation of the positioning clamping unit are concentrated in 8-10 orders.
3.2. Analysis of the result of the lightweight of the base of the positioning clamping unit

In this research, by adopting Workbench software to design the base of the flexible fixture clamping mechanism, the optimal structural parameters are calculated. The initial weight of the clamping mechanism is 3.25 kg, and the optimized weight is reduced to 2.72 kg. According to the calculation results, the weight of the clamping mechanism is reduced by 16.5%. After lightweight design, the base weight of the positioning clamping unit is reduced, but its maximum equal effect is higher, which is much less than the allowable stress of the material. Figure 3 is the total deformation cloud diagram of the optimized base structure.

After the optimized design of the positioning and clamping unit of the flexible fixture, the corresponding interface size has also changed to some extent. Figure 4 is the comparison diagram of the change of the cross-section size variable. As can be observed from the figure, the size of the section decreases with the exception of $x_6$ in a certain range of constrained changes.

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**Figure 2.** Histogram of natural frequency of the first 10 free modes of the positioning clamping unit

**Figure 3.** Total deformation cloud diagram of the optimized base mechanism

**Figure 4.** Comparison chart of section size variables before and after optimization
In this research, Workbench software is used to design the positioning clamping unit of the flexible fixture in a lightweight way. Through the lightweight design results, it is found that the flexible fixture is able to reduce the weight under the condition of meeting the stiffness and strength, thereby saving the cost of materials.

4. Conclusion
In this research, in order to improve the adaptability of flexible fixture in the production process of diversified sheet metal parts, a lightweight method is adopted to design flexible fixture. First, the finite element technical analysis is summarized in this research, and the ANSYS Workbench software in the finite element is used to design the positioning clamping position of the flexible fixture. Second, the static and modal analysis of the positioning clamping unit is carried out. Third, the parameters of the base structure section of the positioning clamping unit are analyzed to design the base section parameters under the condition that the strength and stiffness requirements are met. Fourth, the relevant constraint function and objective function are established to reduce the initial weight of the clamping base mechanism from 3.25 kg to 2.72 kg, reducing the weight by 16.5% and realizing the lightweight design of the clamping unit base structure.

In a word, this research is of great significance to the lightweight design of flexible fixture. However, there are still certain limitations. The flexible fixture designed in this research has not been manufactured at the actual price, so the corresponding parameters have not been verified. It is hoped that the next research can be expanded and deepened.

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