Research on Mechatronic CAD / CAE Integration of Magnetic Levitation Precision Positioning Table

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Abstract. Modern manufacturing technology is moving towards high speed, precision and modularity, which is largely due to the continuous development of positioning platforms. Magnetic levitation technology can completely eliminate Coulomb friction, and has outstanding advantages such as high speed and no wear. This has broad application prospects in the field of high-speed, high-precision positioning platforms. In the product design process, CAE simulation analysis of parts / components is an important means to ensure its performance requirements and improve its design quality. The first step of CAE analysis is to establish an analysis model of parts / components. However, the current CAE software is characterized by powerful analysis functions and weak modeling functions, while the CAD software is characterized by very powerful modeling functions. Therefore, research on CAD / CAE integration of product parts / components has significant significance for improving its analysis efficiency and analysis accuracy. Based on this, this research used SolidWorks and ANSYS as software platforms, developed corresponding integrated systems. The mechanical and electrical performances of the magnetic levitation precision positioning table were also studied with examples.

Keywords: Magnetic Levitation; Precision Positioning Workbench; CAD / CAE Integrated System; Electromagnetic Simulation;
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1 INTRODUCTION

CAD and CAE are two important components of modern design and manufacturing technology and manufacturing informatization. CAD technology combines the computer's high-speed data processing and mass storage capabilities with people's logical judgment, comprehensive analysis, and creative thinking capabilities. This has played an important role in accelerating the development of new products, shortening the design and manufacturing cycle, improving product quality, saving costs, enhancing market competitiveness and corporate innovation capabilities. Nguyen and his coworkers [1] pointed out that CAD technology has become an indispensable design method in the modern manufacturing process, and the CAD data of the product runs through the entire product life cycle from design to manufacturing at present. The CAE tool is a comprehensive, knowledge-intensive information product formed by the combination of rapidly developing computational mechanics, computational mathematics, related engineering science, engineering management, and modern computer science. CAE is a rapidly developing information technology, which provides engineering software for calculation, analysis, simulation and optimization design of major engineering and industrial products. This is the most important tool and method to support engineering scientists in innovative research and engineers in innovative design.

The production of a product usually includes multiple links such as conception, design, analysis and improvement, process and manufacturing. This includes CAD, CAE, CAM and other technical fields. Before finalizing the design plan and entering the manufacturing stage, product data needs to be repeatedly transferred and modified between various links. In the traditional mechanical product design process, the design, analysis and manufacturing links are relatively independent. Perez-Diaz [2] considered that the product plan has to be repeated many times between various links, resulting in unnecessary waste of time. To improve the working efficiency of the whole process, it is of great significance to realize the system environment of CAD / CAE / CAM integration. Through system integration, in the product's integrated design process, the perfect combination of aesthetics, performance, exquisite manufacturing process and cost performance is achieved.

In the past, in the design stage of the magnetic levitation precision positioning table, it was usually carried out with reference to related parts that had been manufactured before, or compared with other people's related technologies. Sometimes, the method of testing the physical prototype performance of the already produced part product is also used to measure whether the designed product reaches the predetermined index. However, there are different degrees of disadvantages in the design phase of the product structure, such as high cost, long cycle, low accuracy, etc., which have become the bottlenecks that restrict the design of the magnetic levitation precision positioning table. This paper designs and implements the CAD / CAE integrated development technology, and analyzes the electromechanical (electromagnetic, mechanical) performance of the magnetic levitation precision positioning workbench.

2 DESIGN OF MAGNETIC LEVITATION PRECISION POSITIONING TABLE

2.1 Magnetic Levitation Technology

Magnetic levitation technology is an active isolation technology. It isolates the electromagnet from the suspended object with a magnetic field without mechanical contact, so that it avoids friction and wear. According to the electromagnetic theory, magnetic levitation can be divided into two types: suction magnetic levitation and repulsive magnetic levitation. Electromagnets and objects can be made to have opposite polarities. Chen et. al [3] said that suspension is achieved by relying on the attraction force exerted by the electromagnets to keep the gravity of the suspended objects in balance. The balance point is regarded as a floating reference point. The gap sensor measures the displacement δ of the suspended object from the reference point. As a microprocessor of the controller; The detected displacement is converted into a control signal, and then the power amplifier converts this control signal into a control current. The control current generates magnetic force in the execution magnet so that the suspended object maintains its floating position unchanged. The stiffness, damping and stability of the suspension system are determined by the control laws. The principle of magnetic levitation is shown in Figure 1. Among them, the suspended object can be a rotating part or a non-rotating part, and there are two types of installation methods with the electromagnet. If the suspended object is a rotating part, the solenoid coil will be wound along the periphery of the rotating part; If the suspended object is a non-rotating part, the electromagnet coil will be wound in a direction perpendicular to the direction of the suspended object [4].

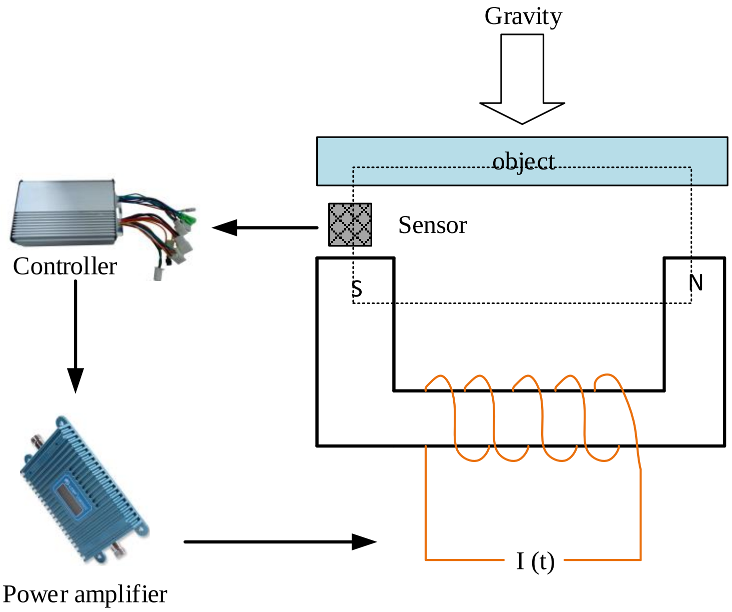


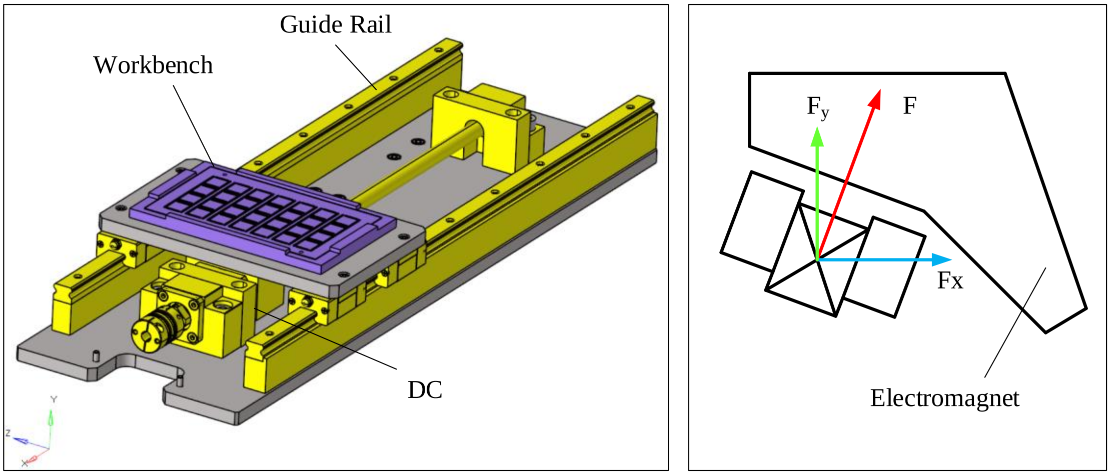
Figure 1: Schematic of magnetic levitation

2.2 Guide Design of Magnetic Levitation Positioning Platform

The main features of the magnetic levitation positioning platform: Under the interaction of the excitation magnetic field generated by the motor winding and the permanent magnetic field generated by the permanent magnet, the key components can both generate levitation force and provide electromagnetic driving force. The levitation force keeps the moving part in a non-contact levitation state relative to the supporting part. Ultra-precise positioning system with electromagnetic driving force for precise positioning of moving parts. In this way, the mechanical structure of the system becomes simple, and the number of parts requiring precision is greatly reduced. Therefore, the magnetic levitation positioning platform can realize multi-degree of freedom and large-scale ultra-precision motion. In addition, there is no contact between the relatively moving surfaces, which completely eliminates the phenomenon of crawling, and there is no problem of accuracy degradation and life caused by wear and contact fatigue. Of course, the maglev positioning platform can work in ultra-clean (such as vacuum) processing environments.

Valiente-Blanco and his group [5] pointed out that in the field of microelectronics manufacturing, the three-dimensional size of electronic components such as chips is very small, and the area of processing and manufacturing parts such as welding and photolithography is even smaller. Therefore, it is not only required that the positioning table can achieve precise and small positioning movement in the one-dimensional direction of movement, but also needs to ensure the accuracy in other two-dimensional directions. So, in the process of designing the positioning table, in addition to considering the main performance index that satisfies the positioning accuracy, it is also necessary to take into account errors such as up and down vibration and left and right deviation when positioning the mechanism. In this way, it can meet the three-dimensional dimensional accuracy requirements when manufacturing micro components. It can be said that the positioning table is a precision device with high 3D accuracy requirements.

Using magnetic levitation technology to change the guide rail pair of the positioning table from contact support to non-contact support, which is the novelty and key of the institution design. The guide rail pair thus eliminates friction and is conducive to improving the positioning accuracy of the mechanism. But for the traditional feed mechanism, due to the use of screw drive, friction between the screw pair still exists, making the mechanism still unable to meet the requirements of ultra-clean environment production. Considering this reason, this research designed a rail-type structure, combined with a moving iron-type DC linear motor, to achieve true contactless driving. As shown in Figure 2, the cross section of the guide rail is symmetrically distributed, the surfaces of the two sides of the guide rail are in the same horizontal plane, and the lower side of the guide rail is an inclined plane. The surfaces of the magnetic poles on the two sides of the electromagnet are parallel to the corresponding inclined surface of the guide rail, and the electromagnets are installed on the positioning table to provide electromagnetic force. From the magnetic force analysis, it can be seen that the electromagnetic force on the inclined plane provides both levitation force and linear motion traction force. The sensor detects the gap between the magnetic pole and a rail in real time [6]. When the positioning table has a horizontal deflection, the control system corrects the current or voltage of the coil in time to maintain the balanced state of the table.



Schematic | Electromagnetic force analysis

Figure 2: Structure and schematic diagram of the magnetic levitation positioning platform in this study.

The guide rail structure positioning work platform generates both levitation and traction forces by the same electromagnet, reducing the number of electromagnets and controllers, and simplifying the mechanical structure. However, it is precisely because the levitation and traction forces are generated by the same device, which causes them to merge with each other, which increases the control difficulty, and at the same time, the processing of the inclined surface of the guide rail is relatively difficult. It is also difficult to guarantee the accuracy of the electromagnet, and the positioning accuracy of the table is low.

3 KEY TECHNOLOGIES FOR CAD / CAE INTEGRATED DEVELOPMENT

3.1 Parametric CAD Modeling

Dimension-Driven is also called dimension drive. Zhu, H. et.al. [7] said it is one of the most important technologies in CAD application technology. As an important method of product modeling, it is well applied in serialized product design. Parametric design uses constraints to express the shape characteristics of the product model, a set of parameters to define the dimensional values of the geometric figure and to agree on the dimensional relationship, therefore, the product model can be changed or the similar product model can be created by changing the design parameters. In the dimensional parameters of the coupling parts in Figure 3, the dimensional parameters A, B, C, D, L can be variable parameters; Using DAA, DAB, DAC, DAD, DAE, and DAF as derived parameters, a constraint relationship formula is designed for the derived parameters, and the derived parameters are obtained indirectly through the constraint relationship formula. Designers only need to modify the variable parameters to constrain the dimensional values corresponding to the derived parameters, and then generate a new set of structural dimensions, finally quickly generate new parts.

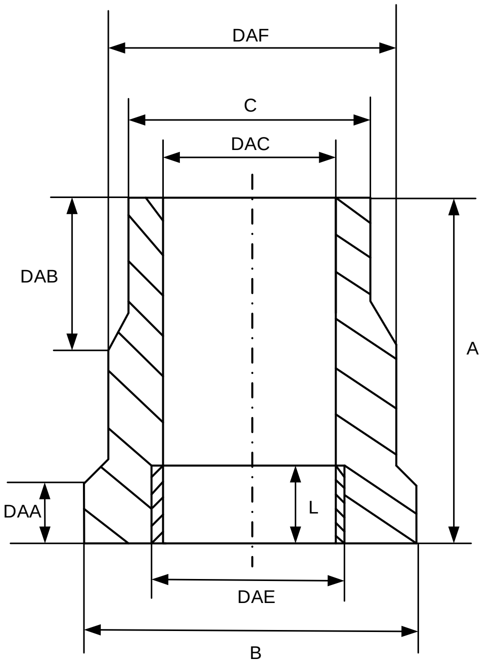


Figure 3: Parametric modeling.

3.2 Parameterized CAE Technology

CAE technology is an integrated process that includes product design, engineering analysis, data management, testing, simulation, and manufacturing. CAE technology can perform failure analysis on products and help designers better understand the structural performance of products [8]. It is an indispensable and important part of the design process.

In the design of mechanical products, CAE technology has become the main way to solve engineering analysis problems in recent years. The CAE technology is used to analyze and evaluate key structural performance and safety and reliability issues under various working conditions of the product, and handle design defects. Therefore, CAE technology provides new ideas for the study of variant design methods that meet engineering constraints. In practical applications, the analysis of serialized products is very repetitive, mainly reflected in the same basic operating steps. It is only different when selecting the parameters, that is, the process of "designing-modeling-analyzing-modifying the design-remodeling-reanalyzing" is repeated. This has caused a lot of repetitive work in finite element modeling and processing results, which affects the efficiency of design analysis, and the results was similar to Lahdo, M works [9]. Therefore, a parameter-based automatic analysis process template can be used to solve this repetitive engineering analysis problem. These parameters include model size parameters, material parameters, meshing parameters, load parameters, post-processing parameters, and so on.

The basic framework of parameterized CAE analysis: the idea of parameterization is integrated into the field of CAE. In this way, for products with different structure sizes, only the value of the corresponding parameterized object needs to be changed, and the final analysis target can be automatically and quickly obtained. It is not necessary to perform repetitive simple and tedious software operations in CAE software, which saves a lot of repetitive processes and improves the efficiency of design analysis. Through finite element analysis, the rationality of the product is verified, and the design quality of the product is improved.

3.3 CAD / CAE Integration Method

CAD / CAE integration is a trend in the development of CAD and CAE. There are currently three integration methods: the system integrates CAD and CAE through a third-party platform; CAD and CAE integration on the CAE platform; CAD and CAE integration on the CAD platform. This article is the third method to achieve CAD / CAE integration. In this method, the CAD system and the CAE system are independent systems, but combine the advantages of the two systems. In this way, both the powerful geometric modeling functions of CAD software and the professional analysis of CAE software are used.

Data are transferred between the finite element model based on the parametric CAE analysis process and the part variant design model of CAD parameters. This is the source of information for the entire integration process. The data transfer is a central database method. CAE finite element models can exchange data with CAD models through standard interfaces. In this method, three-dimensional modeling of product parts is performed, and parameter analysis is performed on the parameters. The relational expressions of the parameters are listed, and the modified design method of parameterization technology is used to generate new parts. Through the central database method, the model data can be directly transmitted to the CAE analysis software to generate the finite element model, and the CAD / CAE integrated data transmission can be realized, which can be agreed with Jeong et.al [10] works.

The parametric CAE technology method is used to parametrically mesh product parts, apply parametric loads and solve them, and display the results after parametric processing. Finally, analyze the results to determine whether the engineering constraints are met.

4 EXAMPLE OF INTEGRATED DEVELOPMENT OF MAGNETIC LEVITATION WORKBENCH

4.1 Simulation Analysis of Electromagnetism

Using the CAD \ CAE integrated development model established in the previous section, the magnetic induction strength at the air gap of the U-shaped electromagnet is approximately 0.625T by adjusting the design parameters, which is slightly smaller than the magnetic induction strength at the static operating point. The simulated value of electromagnetic force is 268N, and the calculated value is 300N. The simulated value is lower than the calculated value. When calculating the electromagnetic force, ignoring the core reluctance and magnetic leakage, the ideal working air gap length of this electromagnet is set to 5mm. Generally, the air gap length of the magnetic levitation platform is set to less than 5mm. The increase of the air gap length increases the magnetic leakage. Therefore, the large air gap length is an important reason for the simulation force to be lower than the calculated value.

Figure 4 is a graph of magnetic induction intensity at the air gap when the U-type electromagnet has different axial air gap lengths. It can be seen that as the axial air gap increases, the air gap magnetic induction intensity decreases. Similarly, the distance corresponding to the peak of curve

decreases, and the larger the axial air gap, the larger the magnetic leakage. Selecting a reasonable arrangement of magnetic poles and designing reasonable electromechanical parameters are conducive to reducing the closing effect between the magnetic poles, thereby improving the control accuracy of the response.

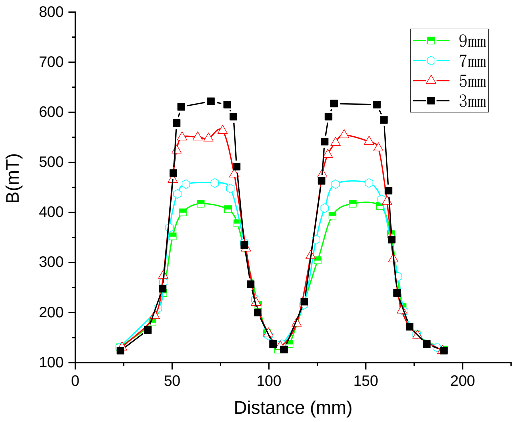


Figure 4: Graph of magnetic induction intensity at the air gap at different axial air gap lengths.

4.2 Finite Element Mechanical Analysis of Magnetic Levitation Table Structure

The finite element mechanical analysis of the magnetic levitation table structure mentioned in this article mainly includes static analysis and dynamic analysis. The static analysis of the structure mainly uses the finite element method to study the deformation and stress distribution of the mobile table under the suspension force support, in order to ensure the rigidity of the mobile table and improve the accuracy of the suspension. The dynamic characteristics of the magnetic levitation system mainly depend on the natural frequency of the suspended part of the table. The dynamic analysis of this part is mainly modal analysis. This chapter will use the finite element method to calculate and analyze the dynamic characteristics of the elastic vibrating body, which is mainly a magnetic levitation mobile platform. Including its eigenvalue, eigenform, natural frequency or natural mode, the dynamic characteristics of the floating state of the mobile platform, the support state of the guide rail and the free state are studied. Finding weak links and improving the dynamic stiffness of the structure have certain guiding effects on meeting system frequency response requirements, as well as control system design, control system hardware configuration, control method selection, and system debugging.

(1) Static analysis

Ansys software is used to build a finite element model based on the CAD model. The finite element model discretizes the solution area into a finite number of subdomains and a finite element by the number of elements. It is essentially equivalent to replacing a continuous system with unlimited degrees of freedom by a discrete system with limited degrees of freedom. In the discrete process, the type, size and number of elements must be selected and determined reasonably in order to describe the geometric and mechanical characteristics more accurately. The simplification of the mechanical model and the selection of the elements depend on the nature of the problem, the structural load situation, and the calculation accuracy requirements. On the key force transmission path, the meshing points should be denser. The non-critical part should follow the principle of energy conservation, and the analysis model and the actual structure should maintain the stiffness equivalent, mass equivalent and damping equivalent. The finite element model must ensure that the stiffness is not lost, and the mass distribution must be reasonable. The finite element model established in this study is shown in Figure 5, with 14384 elements and 16322 nodes.

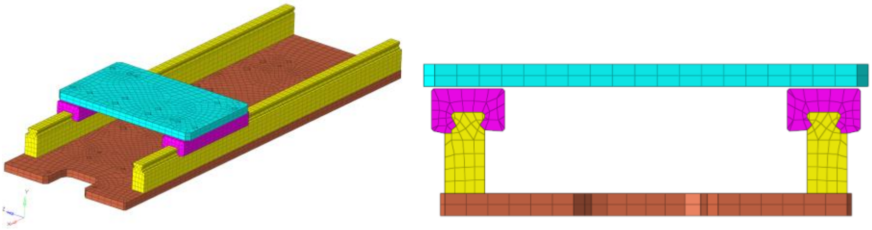


Figure 5: Finite element model used in this study.

The magnetic levitation workbench is subject to its own weight load, which causes bending deformation, which causes the electromagnet to tilt and the magnetic field to be uneven, which affects the mobile platform's stable levitation and mobile positioning accuracy. The static analysis of the structure mainly studies the deformation and stress distribution of the mobile workbench before the suspension, the mobile platform is located on the inverted guide rail and the magnetic support in the suspended state, which ensures the rigidity of the mobile workbench and minimizes its weight. Through finite element mechanical analysis, structural design can be guided. The boundary conditions are set as follows: When the mobile platform is located on the inverted rail, the self-weight load acts under the condition of full restraint on one side of the inverted rail. Using *Ansys* for analysis and calculation, the deformation cloud diagram and stress cloud diagram are shown in Figure 6: The maximum stress is 6.26 MPa, and the structure is in the elastic deformation zone. The result is ideal, and the maximum sinking amount is 0.03mm.

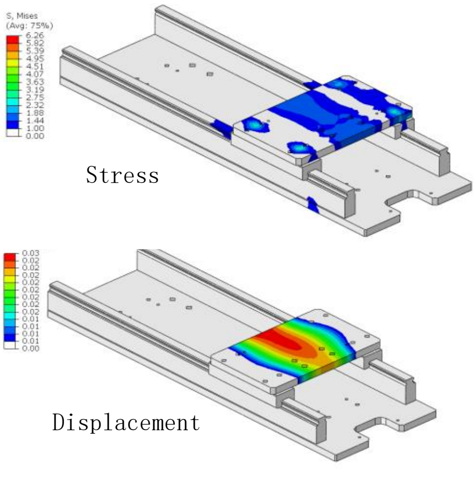


Figure 6: Stress results and deformation results.

(2) Dynamic modal analysis
Based on the finite element model, the modal analysis of the magnetic levitation workbench was performed. Modal analysis is used to study the dynamic characteristics of the magnetic levitation platform and further understand the noise and vibration problems of the structure. Modal analysis mainly examines the dynamic stiffness of the magnetic levitation table. In order to ensure the high positioning accuracy and reduce the vibration of the magnetic levitation worktable, it is required that the magnetic levitation worktable must have good dynamic stiffness, so that the magnetic levitation worktable does not generate large vibration under the external mechanical disturbance when it is floating. The dynamic stiffness of the magnetic levitation workbench structure is mainly determined by the dynamic characteristics of the structure, that is, it is mainly measured by the natural frequency and mode shape of the structure. The natural frequency of the structure of the magnetic levitation mobile platform, especially the larger the natural frequencies of the previous stages, the higher the dynamic stiffness of the structure and the higher the specific stiffness of the overall structure; When designing the structure of the magnetic levitation table, through modal analysis, find the weak link, improve the platform structure, and increase the natural frequency of the magnetic levitation table structure. The corresponding natural frequency of the magnetic levitation table structure is much larger than the external interference frequency. The calculated results are shown in Figure 7.

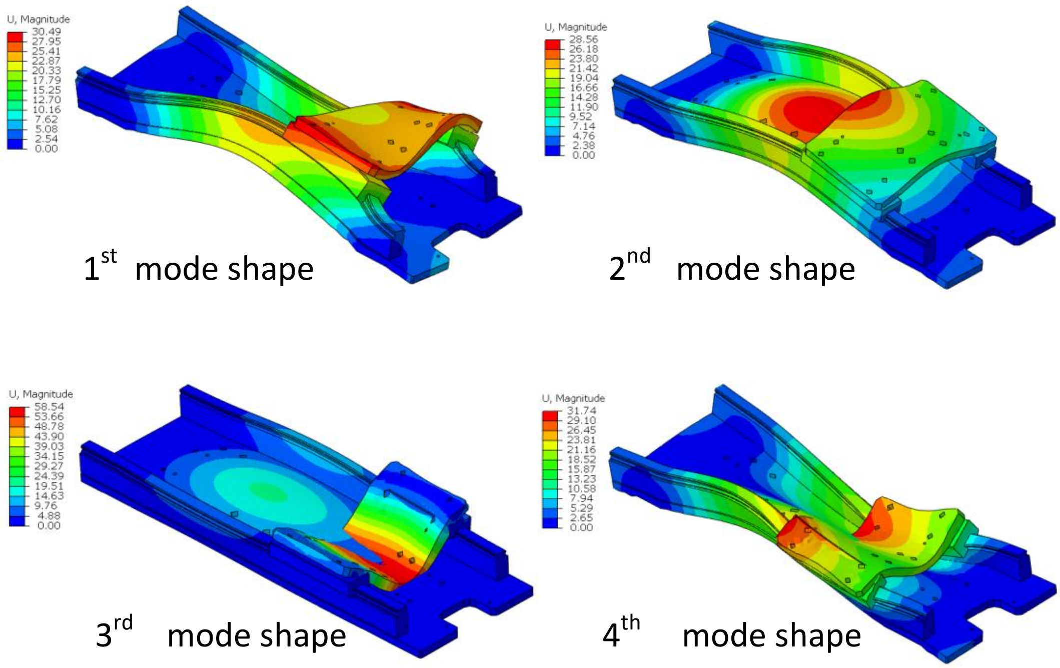


Figure 7: Modal results.

According to the finite element modal analysis of the above working conditions of the magnetic levitation worktable, it can be concluded that the first-order natural frequency of the magnetic levitation mobile platform is 787Hz when it is stably suspended. The excitation value far from the working environment is 200Hz, which meets the requirements. The natural frequency of the mobile table is mainly determined by the structural stiffness and mass of the platform and the boundary conditions. Among them, the structure size and material selection of the electromagnet core, the coupling stiffness of the electromagnet core, the magnetic steel and the platform, and the support stiffness and stability of the magnetic levitation system are the main factors affecting the natural frequency. The stiffness, damping and stability of the suspension system are mainly determined by the control laws. In the magnetic levitation workbench structure design, through modal analysis, weak links can be found, the workbench structure can be improved, and reasonable control design can be carried out. Increasing the rigidity, damping and stability of the magnetic levitation system, and making the platform reach stable suspension, can further increase the natural frequency of the magnetic levitation table, reduce dynamic response, and avoid resonance. Driven by a linear motor, the platform can be accurately positioned.

5 CONCLUSIONS

This article proposes a variant design method based on CAD / CAE integration for the problems of long design cycle and high cost of current parts products. By summarizing the characteristics of serialized product CAE, the basic process framework of parameterized CAE analysis is given. Based on the parametric variant design and parametric CAE analysis process, a design method based on CAD / CAE integration was established. Taking the magnetic levitation precision positioning table as an example, an electromechanical integration CAD / CAE integrated system was developed. The electromagnetic field analysis of the magnetic levitation table was performed using the finite element method, and the magnetic force calculation and structural mechanics were comprehensively calculated. This is effective for the analysis of the mechatronics design of the structure and control system of the magnetic levitation workbench.

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