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Modal Optimization Design of Supporting Structure Based on the Improved Particle Swarm Algorithm

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ABSTRACT

To cope with the strong vibration of a supporting structure excited by external loads under operating conditions, and in order to achieve the purpose of vibration reduction by structural optimization through modal modification, a modal modification method was proposed, through structural vibration theory. Subsequently, the search performance of an improved particle swarm optimization method was analyzed before conducting a case study on the structural optimization. Finally, aiming at the problem of strong vibration of gun mount at the time of firing, a finite element model of the gun mount was constructed and the type and natural frequency of the gun vibration in a free state was analyzed. Meanwhile, taking the thickness, height and width of the stiffening structure of the bracket as the design variables, combined with the improved particle swarm algorithm, an optimized mathematical model was developed with the first-order natural frequency of the gun mount as the objective function. The secondary development of Abaqus finite element software by using Python is used as a tool to calculate the optimization model. By virtue of optimation, thickness, width and height of the stiffening structure are 156.4mm, 453.7mm and 238.9mm at the range of [100,600]mm, [100,700]mm, [100,700]mm, respectively, and the base frequency of the gun mount has been increased by 11.3%. The effect is remarkable.

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1. INTRODUCTION

Vibration is a phenomenon that occurs when a structure or system repeats a reciprocating motion at a balanced position under the input excitation of dynamic loads. The vibration of a structure or system is known as a dynamic response output [1-3]. In the vibration of a system, the dynamic loads will cause resonance when the excitation frequency falls near the natural frequency of the system. Resonance is harmful to most mechanical systems because it may generate a strong vibration and noise while causing severe structural damage. Under actual operating conditions, a structure which supports a whole system is the position that has the strongest vibration in the entire system and is most vulnerable to resonance. Usually, the excitation of external loads is normally certain. Therefore, in the mechanical industry, many researchers have presently focused on how to make a modal modification to such a supporting structure, which can keep its natural frequency away from the excitation frequency of loads with the goal of preventing resonance.

Liu et al. [4] conducted a research on the horizontal vibration problem of a building that noticeably exceeded the limit.The natural frequency of the building structure was solved by considering its mechanical characteristics, and then the natural frequency was employed to identify the source of excitation. By adding an inverter on the source of excitation, the frequency of excitation is kept away from the natural frequency of the building, so as to achieve the purpose of vibration reduction. This method is applicable to a system with known but mutable source of vibration. However, most mechanical vibration systems has vibration source with complex structure and composition, which make it very difficult to change the frequency of external loads on them.

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Ma et al. [5] attached some ultralight locally resonant plate-type units onto the vibration structure as dampers. The structural vibration in the pre-defined band gap range is localized and consumed by the dampers, which realized the purpose of a vibration damping. In this method, much additional structure is added, and the application other structures has limitations practically. Shi and Li [6] adopted the anti-resonance method to reduce the vibration of a girder structure excited by the engine of a warship. By taking the first-order excitation frequency of the engine as the anti-resonance frequency, the mass and stiffness of the hull girder structure were modified, respectively; which changed the natural frequency of the hull, which achieved remarkable vibration optimization. This method is applicable when excitation frequency, excitation points, and response points are known. It is mainly used in the initial structural design of a system. However, the application in the structural improvement of a complex system should be further explored.

Modal modification means to modify the dynamic properties of the structure for a vibration system based on the modal data after the modal analysis of the vibration system provides its modal parameters. To some extent, modal modification may achieve this type of natural frequency as desired by a designer, so as to avoid the excitation frequency of the external load and reduce vibration and noise.Therefore, it is presently a commonly used method for structural optimization in the engineering field [7-15].

In the low-frequency structural vibration optimization of steering wheel of a passenger vehicle, Ye et al. [16] measured the vibration response of the steering wheel using the experimental apparatus and analysis procedures in performing the TPA. According to the results of the modal analysis, the mounting structure of the exhaust system was modified by the finite element method to reduce the vibration of the steering wheel. Li et al. [17] adopted modal prediction and sensitive parameter identification in the dynamic performance optimization of machine tools, and employed Simcenter Test.lab software to implement modal modification, which enhanced the natural frequency of machine tools and reduced the amplitude of vibration.

In order to solve the problem that the mechanical properties of CFRP structures are difficult to grasp comprehensively and accurately, Zhang et al. [18] proposed a finite element model correction method of CFRP laminated structures based on correlation analysis and established an approximate model. The approximate model was updated based on the multi-island genetic algorithm (MIGA) to modify the finite element model of the CFRP laminated structure model. Although Zhang paid attention to building a dynamic model for a system, but the proposed method for modifying modal parameters is also applicable to the modal modification of any known structure.

The present study focused on the vibration of a supporting structure impacted by heavy loads under practical operating conditions, and presented a case study on the modal modification for a naval gun mount. First, in section 2, according to the structural vibration theory, a method to modify the mode shape and natural frequency of the structure by modifying the parameters of the boundary conditions of the supporting structure was proposed. In the third section, for the parameter optimization method, the improved particle swarm algorithm is determined and its performance is analyzed. In the fourth section, the optimization of a certain type of naval gun mount was taken as an example. First, a finite element model was built using the actual structure of the gun mount. Secondly, a structural optimization method was put forward, and design parameters were selected. Lastly, an improved particle swarm optimization algorithm was adopted to conduct the modal modification of the gun mount, which takes the maximum natural frequency of the specified order as the optimization goal. In conclusion, the research results and managerial insight are summarized, and the next research direction is proposed.

The comparison between related research and the research in this paper is shown in Table 1.

Aiming at the problem that the support structure will produce strong vibration under external excitation, a modal modification method is proposed to improve the natural frequency of the structure in order to avoid the excitation frequency. Taking the naval gun mount as an optimization case, taking the maximum fundamental frequency as the optimization objective, and combining

TABLE 1. Comparison between related research and this paper

Research content	This paper	Related research
Method of vibration reduction	Change the structure of the forced system	Change the excitation frequency of the source
Method of structural modification	Increase the stiffening structure under the condition that the main structure remains unchanged	Change the main structure
Engineering application stage	After the main structure is determined or the main structure cannot be greatly changed	Structural initial design
Scope of application	A type of structure	A specific structure

with the PSO algorithm, the shape parameters of the optimal reinforcement structure are obtained. The optimization method in this paper is aimed at a class of structures, rather than a single structure. In addition, the optimization method proposed in this paper can be usednot only in the initial design of the structure, but also in the improvement of the existing structure under working conditions, so as to achieve the purpose of completing the structure optimization without disassembling the structure, which is more suitable for actual engineering needs.

2. STRUCTURAL VIBRATION THEORY

When the structure is subject to an external excitation, the frequency domain form of its response can be obtained by performing Fourier transform on the differential equation of motion, as shown in Equation (1):

$$[K]-\omega^2[M]+j\omega[C]=\{f\} \tag{1}$$

Damping is normally low for engineering structure, and may be regarded as proportional damping to solve the natural frequency ω_i of the structural system as well as the corresponding mode of vibration ϕ_i. Equation (1) can be used to obtain the displacement response of the system as follows:

$$[X(\omega)]=\sum_{i=1}^{n}\frac{\{\phi_i\}\{\phi_i\}^T\{f\}}{k_i-m_i\omega^2+jc_i\omega} \tag{2}$$

In Equation (2), $k_i=\{\phi_i\}^{\mathrm{T}}[K]\{\phi_i\}$, $m_i=\{\phi_i\}^{\mathrm{T}}[M]\{\phi_i\}$, $c_i=\{\phi_i\}^{\mathrm{T}}[C]\{\phi_i\}$.

Displacement response is one of the quantity characterizing the vibration of structure [19]. In most cases, the motion response of structure can be characterized by displacement response. From Equation (2), it is learned that, under the same external load, the mode of vibration and natural frequency should be identical so that the designed boundary condition domain and the original domain has the same displacement response when their finite element models are similar.

In the modal modification, it is very difficult to ensure the consistence of the required frequencies at several orders and the similar mode of vibration at these orders. It is also unnecessary in engineering. In the practical engineering, the response of structure is highly affected by the mode at low orders, but slightly affected by the mode at high orders. While modifying the dynamic boundary conditions of structure, the natural frequency at the front orders is taken as the design index and the low-order modes is similar in the process of optimization. With this strategy, the dynamic response of the modified structure is nearly consistent with that of the original structure [20].

Following the strategy of modifying lower-order modes by modifying boundary conditions, the modification method is established as follow. The characteristic equation of structural system is state as follows:

$$[K][\phi]=[M][\phi][\Lambda] \tag{3}$$

In Equation (3), $[\phi]$ is the mode of vibration matrix after orthonormalization; $[\Lambda]$ is the natural frequency matrix.

Considering only the dynamic characteristics at low orders, the following relationship is obtained by the dynamic substructure method as follows:

$$\left([K_A^0]+[K_B^0]\right)\left[\phi^0\right]=\left([\mathrm{M}_A^0]+[M_B^0]\right)\left[\phi^0\right]\left[\Lambda^0\right] \tag{4}$$

$$\begin{cases}\left[\phi_r^0\right]^{\mathrm{T}}\left([K_A^0]+[K_B^0]\right)\left[\phi_r^0\right]=\left[\Lambda_r^0\right]\\ \left[\phi_r^0\right]^{\mathrm{T}}\left([\mathrm{M}_A^0]+[M_B^0]\right)\left[\phi_r^0\right]=\left[I_r\right]\end{cases} \tag{5}$$

In Equations (4) and (5), $[M_B^0]$ and $[K_B^0]$ are the mass and stiffness matrices of boundary conditions; $[M_A^0]$ and $[K_A^0]$ are the mass and stiffness matrices in structure excluding boundary conditions; $[\phi^0]$ and $[\Lambda^0]$ are the natural frequency matrix and mode of vibration matrix of the designed structure.

The mass matrix and stiffness matrix of boundary conditions consist of the structural boundary condition parameters. In other words, the mass matrix and stiffness matrix of boundary conditions are the function of boundary structural parameters, and represented by $[M_B^0](b)$ and $[K_B^0](b)$ respectively. In the process of modal modification, $[M_B^0](b)$ and $[K_B^0](b)$ can be changed by modifying the parameters of the boundary conditions, so that the mode shape and natural frequency of the system after the modification of the boundary conditions can meet the requirements of the measured data.

3. BASIC PRINCIPLES OF IMPROVED PARTICLE SWARM ALGORITHM

Particle swarm algorithm is an intelligence algorithm to simulate the bird flock foraging. Each particle is characterized as a possible solution vector [21-24]. The quality of particles is judged by the value of fitness function. Moreover, the position and velocity of particles are constantly updated by learning from the global and individual optimal solutions to eventually fulfill the purpose of global optimization [25]Error! Reference source not found.. The position and velocity of particles are denoted by $X_i=\left(x_{i1},x_{i2},x_{i3},...,x_{in}\right)$ and ,$V_i=\left(v_{i1},v_{i2},v_{i3},...,v_{in}\right)$, respectively; and updated by Equations (6) and (7):

$$V_{id}^{t+1}=V_i^t+c_1r_1\left(p_i^t-X_i^t\right)+c_2r_2\left(p_g^t-X_g^t\right) \tag{6}$$

$$X_i^{t+1}=X_i^t+V_i^{t+1} \tag{7}$$

In Equations (6) and (7), p_i^t and p_g^t stand for the individual optimal solution and global optimal solution of particles when the iterations equal t; r_1 and r_2 are the random numbers in the range (0,1); c_1 and c_2 are learning factors.

In the particle swarm algorithm, parameters exert a very high effect on the search capability of the algorithm. The role of parameters and the criteria for selecting them are briefly described in the following sections.

(1) Swarm size p_s

Undoubtedly, the larger swarm, the more particles under mutual effect, and more easily the advantage of the particle swarm algorithm in is demonstrated. If the swarm size is too small, the calculation result will easily fail into local convergence, failing to achieve the goal of global optimum. If the swarm is too large, the efficiency of calculation will decrease dramatically, which increases the time cost. In the meanwhile, an increase in swarm size will make little contribution to the improvement of search capability after a certain level. For this reason, it is very important to choose a proper swarm size according to the complexity of the problem

(2) Learning factors c_1、c_2

In the particle swarm algorithm, learning factors c_1 and c_2 are two factors that regulate the degree of individual and group experience learning. In the iterative process, the learning factor is used to control the particle to seek a balance between the local search and the global search. That is, when the particle approaches the optimal solution, the learning factor plays the role of inertial weight. The smaller the value is, the better the global search performance of the algorithm is. Normally, the value of c_1 and c_2 is between 0 and 4.

(3) Maximum velocity $V_{\max}$

The maximum distance of particles in iterations depends on the maximum velocity $V_{\max}$. Its increase can improve the capability of global search, but makes it easy to overlook a better solution. When it goes down, the capability of local search is enhanced, but easily leading to local convergence. In this paper, the maximum speed is set as the value range of the initial variable, which remains unchanged during the search process.

In the original particle swarm algorithm, if the velocity of particles V_i^t is low, particles are very easy to converge on the same position, and trapped in the local search. Therefore, the solution depends too much on the setting of initial swarm. Increasing the particle velocity V_i^t can effectively improve the global search performance, but when solving optimization problems, both global search and local search need to be considered. How to seek a balance between them is therefore crucial to improving the performance of particle swarm algorithm. Reference [25] introduced inertia weight w into Equation (6) in particle swarm algorithm. Equation (6) that introduces the inner weight is shown in Equation (8):

$$V_{id}^{t+1}=wV_i^t+c_1r_1\left(p_i^t-X_i^t\right)+c_2r_2\left(p_{gd}^t-X_g^t\right) \tag{8}$$

Inertia weight w plays a role in coordinating global search and local search. When the inertia weight is (0.9, 1.2), the performance of algorithm is better. The decreasing strategy of inertia weight points out that as the iteration progresses, the value of inertia weight needs to be decreased linearly.This strategy can not only update the search area in a wide range, so that ensure the global search performance of the algorithm in the early stage of iteration, but also has strong local search ability in the later stage of iteration, which can speed up the convergence speed and ensure that the algorithm searches finely near the possible optimal solution. Equation (2) is combined with Equation (3) to generate the most widely recognized standard particle swarm algorithm. The particle swarm algorithm mentioned in the subsequent sections of this paper refers to this standard particle swarm algorithm. The linear decreasing strategy of inertia weight is shown in Equation (9). Shi [26], Shi and Eberhart [27] pointed out that the optimization tends to be better when the weight varies linearly between 0.4 and 1.4.

$$w=w_{\max}-\frac{t}{T}\left(w_{\max}-w_{\min}\right) \tag{9}$$

The basic procedure of particle swarm algorithm is as follows:

1. Initialize: Initialize the particle swarm including random velocity and position;

2. Evaluate particles: Calculate the fitness of each particle in the problem space;

3. Update the optimal position: Compare the current position and optimal experienced position p_i for all particles:

If the former is better, the optimal experienced position is replaced by the current position of the particle. In the comparison of the optimal experienced position p_i and the global optimal position p_g, if the former is better, the global optimal position is replaced by the optimal experienced position;

4. Update particles: Update the particles based on their velocity and position using Equations (6) and (7);

5. If stop conditions are met, the search is stopped. If not, move back to step 2 for iteration.

4. EXAMPLE: MODAL OPTIMIZATION DESIGN of GUN MOUNT BASED on MODIFICATION of STRUCTURAL PARAMETERS

Gun vibration is a movement phenomenon accompanying the process of firing. As an inherent property of gun, it is a major factor affecting the firing accuracy and reliability of the gun [28]. The mount bears the recoil impact and the transmission torque of the following rotation during the firing process of the naval gun. Moreover, the inertia moment caused by the naval gun when the warship rocks, absorbed by the mount. The mount enables the gun to keep a certain direction at the time of firing. Therefore, the performance of the mount directly determines the operational stability and firing accuracy of the gun.

In the structural optimization design of the naval gun mount, static optimization design is often employed to improve the existing structure [29]. In the modal analysis and structural optimization of the gun mount, the dynamic design of structure is studied with the swarm intelligence algorithm, i.e. determining the modification of physical parameters under the constraints of modal parameters. For this reason, efforts should be further made to explore the measures against the low-frequency vibration of the mount under the impact, and find the general method for the dynamic design of the naval gun structure [30, 31].

4. 1. Finite Element Model for Mount Structure

A model for the structure of a naval gun mount is presented in Figure 1.

The gun mount is made of around 100 parts by virtue of welding, including many solid structures such as shell, stiffening beam, and so on. In the finite element model, it must be properly simplified to lower the complexity of modeling, reduce the number and improve mass of grid elements, etc. The simplification ignores the holes, protrusions, chamfers, cambers, and other matters that have little influence on the response of structure. The mount structure is mostly made of plates and stiffeners. So the plates are meshed using shell elements, and shell or solid elements are chosen for stiffeners based on the ratio of length and thickness.

The finite element model is consistent with the actual model in the experiment. During the modal test, the state of structure may not be completely consistent with the given three-dimensional model. Thus, the finite element model should be adjusted to the actual state of structure at the test site. During the modal test in this paper, some structures are installed inside the bracket including sensor mount and stop. Additionally, the base of the gun mount rests on the mounting seat, which is made of steel structure and cement, and the seat ring is suspended as shown in Figure 2.

In the modal test, the bracket and other components have not been installed on the gun mount, and the mount is placed on the steel plate and cement seat on the ground. There is a good test environment. In this case, the gun mount can be regarded as a constrained structure with specific boundary conditions.

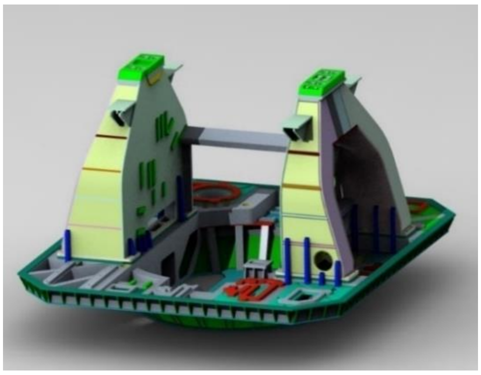
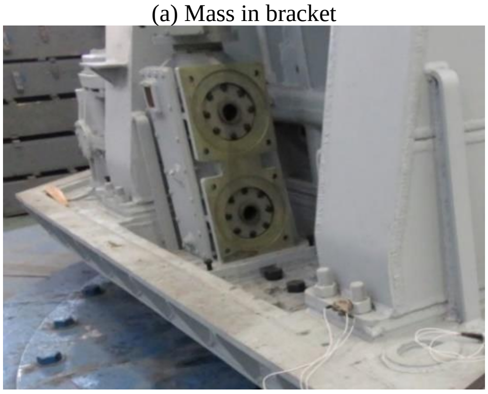


Figure 1. Model for a naval gun mount

(a) Mass in bracket



(b) Bottom connection

Figure 2. Test state of a naval gun mount

Structure domain in this paper is described by the equilibrium equation of continuum motion, which takes into account small deformation but ignores the volume force and damping of the structure. The equilibrium equation of the structure is given below:

$$\nabla\cdot\boldsymbol{\sigma}+\nabla\cdot\boldsymbol{\tau}-\rho_s\ddot{\boldsymbol{u}}_s=\mathbf{0} \tag{10}$$

In Equation (10), $\boldsymbol{\sigma}$ is the stress of the structure; $\boldsymbol{u}_s$ is the displacement of the structure; ρ_s is the density of the structure. The boundary conditions are fixed supporting and force boundary conditions. The mathematical model for such two boundaries is stated as follows:

1) Fixed supporting wall

$$\boldsymbol{u}=\mathbf{0} \tag{11}$$

2) Force boundary conditions

$$\nabla\cdot\boldsymbol{\sigma}\boldsymbol{n}_s+\nabla\cdot\boldsymbol{\tau}\boldsymbol{n}_s=\boldsymbol{f}_s \tag{12}$$

In Equation (12), $\boldsymbol{n}_s$ is the vertical vector of the coupling plane in the structure domain. Equations (10)-(12) are the classical fundamental equations for the vibration of structure. Following the principles of virtual work, it is very easy to solve the vibration of structure in the form of finite element,

$$\mathbf{M}_s\ddot{\boldsymbol{u}}_s+\mathbf{K}_s\boldsymbol{u}_s=\boldsymbol{f}_s \tag{13}$$

In Equation (13), the mass matrix $\mathbf{M}_s$, stiffness matrix $\mathbf{K}_s$, and coupling force matrix $\boldsymbol{f}_s$ are

$$\begin{cases}\mathbf{M}_s=\rho_s\int_{Ss}\boldsymbol{N}_s^{\mathrm{T}}\boldsymbol{N}_s ds\\ \mathbf{K}_s=\int_{Ss}\left(\nabla\cdot\boldsymbol{N}_s\right)^{\mathrm{T}}\boldsymbol{D}_s\nabla\cdot\boldsymbol{N}_s ds\end{cases} \tag{14}$$

Equation (14), is the shape function of structure element; $\boldsymbol{D}_s$ is the elastic coefficient matrix. When the structure has the free vibration without damping, the solution of the equation is obtained in the following form

$$\boldsymbol{u}_t=\hat{\boldsymbol{u}}e^{i\omega t} \tag{15}$$

Equation (15) is the form of harmonic vibration, which is a constant, and substituted into Equation (13). The term of external load is overlooked to obtain

$$\left(\mathbf{K}_s-\omega^2\mathbf{M}_s\right)\hat{\boldsymbol{u}}_s=\mathbf{0} \tag{16}$$

This is the characteristic equation of structure.

Based on Equations (15) and (16), boundary conditions have a great impact on the dynamics of the system. Comparing Equations (10) and (13), it can be seen that the change of boundary conditions can directly change the mode shape of the structure. So, compared with the internal parameters of the structure, the structural dynamics of the system is more sensitive to the changes of boundary condition parameters. Therefore, the dynamic characteristics of the structure can be modified to a certain extent by modifying the boundary conditions [32]. The number of boundary condition parameters is generally less than that of the internal parameters of the system structure. And in actual projects, due to working conditions and performance limitations, the internal structure cannot be changed significantly. Therefore, dynamic modification of boundary conditions to meet the overall dynamic characteristics of the system structure is an effective method. In addition, the main structural parameters of the gun mount should not be modified too much during the modal modification, so as to avoid the subsequent optimization design of the gun mount structure being difficult to apply to the actual structure.

In the modal test, the mount is placed on the steel plate and cement seat on the ground, but not connected, so that it is deemed to be in the free state. A finite element model is built in the commercial finite element software ABAQUS [33]. The trunnion seat and bracket are simplified into a whole. The trunnion seat is solid in the model. The finite element model is presented in Figure 3. The mount is made of gun steel and aluminum alloy by welding. The material parameters are shown in Table 2.

Based on the design of a naval gun, the stiffeners at both sides of the bracket have a great influence on the mode of the gun mount. Therefore, this paper focuses on how the gun mount is affected by the arrangement and geometry of stiffeners.

4. 2. Modal Modification of Gun Mount The natural frequency and mode of vibration in a free state before optimization are shown in Figure 4. The indices are compared on this basis after optimization.

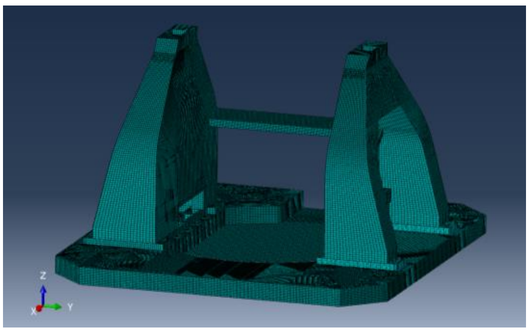
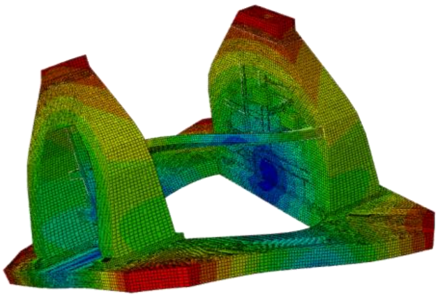


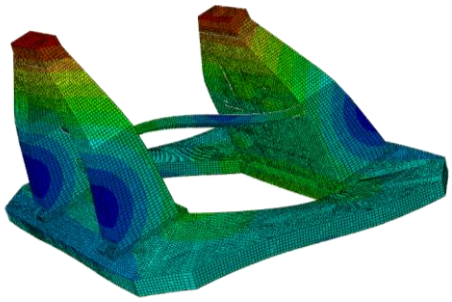
Figure 3. A finite element model for a naval gun mount

TABLE 2. Material parameters of gun mount

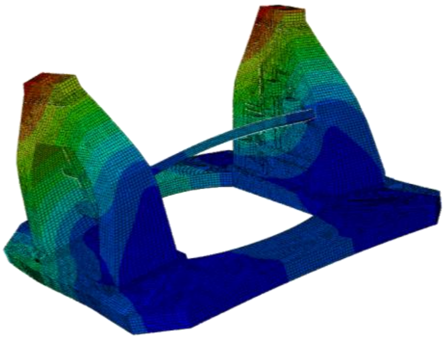
Material parameters	Density (kg/m^3)	Elastic modulus (Gpa)	Poisson's ratio
Gun steel	7.8×10^3	210	0.3
Aluminum alloy	3.8×10^3	68	0.35



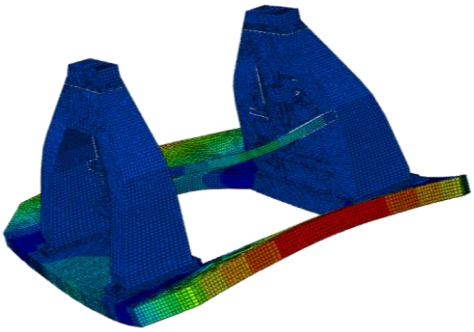
The 1st order: 23.991 Hz



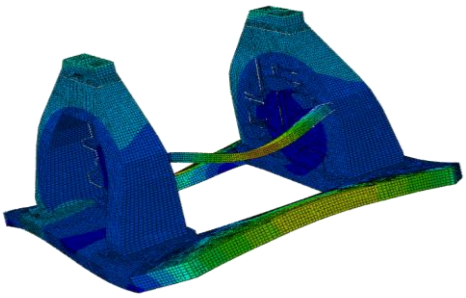
The 2nd order: 33.603 Hz



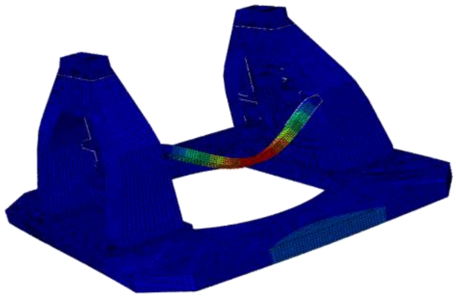
The 3rd order: 41.778 Hz



The 4th order: 68.204 Hz



The 5th order: 81.358 Hz



The 6th order: 93.224 Hz

Figure 4. Parameters at the initial free mode of structure for a gun mount

In the modal modification design process of the gun mount structure, the design level should first be determined according to the design variables, and the finite element model should be established according to the relevant structural domain. The constructed finite element model is then utilized to carry out numerical calculation, and obtain the response variables. At the end, the analysis model and objective function are employed in the parameters optimization of gun mount with the particle swarm algorithm. The optimization result is input into the finite element model for verification.

As shown in Figure 5, the stretched thickness, height and width of the stiffening structure at both sides of the bracket are taken as the design variables in the optimization calculation. To guarantee the symmetry of the gun mount, the stiffening structure of the left and right brackets has exactly the same structural size and material properties. Therefore, there are only three design variables regardless of two stiffening structures. The mount assembly model and finite element grid of the stiffening structure domain are presented in Figure 6.

Table 3. presents the setting of parameters for particle swarm algorithm, and the range of design variables. Among them, the maximum iterations are 400 times; the range of stretched thickness is [100,600]mm; the range of stiffening structure height is [100,700]mm; and the range of structure width is [100,700]mm. The fundamental frequency of structure has a great influence on the

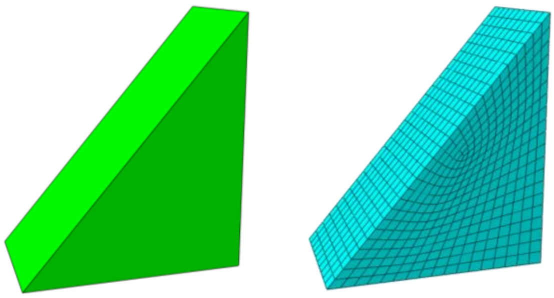


Figure 5. Structure model and finite element grid of stiffeners at both sides of the bracket

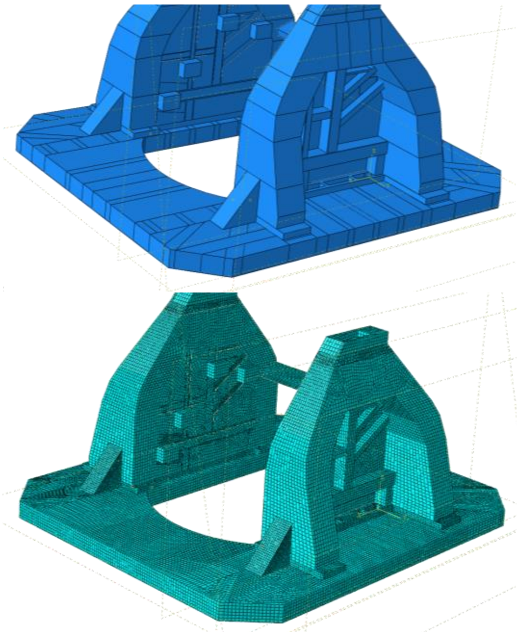


Figure 6. Assembly model and finite element grid of a gun mount

TABLE 3. Parameters of particle swarm optimization algorithm

Parameter	Value
Number of particles	3
Initial velocity	0
Stretched thickness W_{min}	100mm
Stretched thickness W_{max}	600mm
Height W_{min}	100mm
Height W_{max}	700mm
Width W_{min}	100mm
Width W_{max}	700mm
Acceleration constant	2.05
Maximum iterations	400

response to vibration. Especially under the heavy impact load, the high impact energy may trigger the fluctuation of fundamental frequency, and significantly affect the firing stability and mechanical reliability. Therefore, this paper takes the maximization of the fundamental frequency, that is, the first-order natural frequency, as the objective function, and performs iterative calculation within a given range to obtain the optimized iterative curve and the optimized stiffening structure size as shown in Figure 7 and Table 4.

Through building a mathematical model with the improved particle swarm optimization algorithm and using such design variables as the stretched thickness,

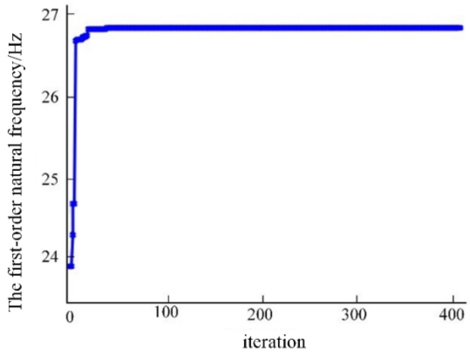


Figure 7. Optimization by iteration with PSO algorithm

TABLE 4. Optimal results after particle swarm optimization

Parameter	Value
Stretched thickness	156.4mm
Width	453.7mm
Height	238.9mm
Frequency after optimization	26.7Hz

width and height of the stiffening structure, after iterations, the optimal solution of the stiffening structure under the constraints is obtained. As shown in Table 4, the optimal solutions for stretched thickness, width, and height are 156.4mm, 453.7mm, and 238.9mm, respectively. It is found that the optimization algorithm increases the first-order natural frequency to 26.7Hz. The natural frequency at the designated order is improved by 11.3%. Therefore, the optimization is significantly effective.

5. CONCLUSION

In the present study, structural vibration equations were deduced under the effect of external excitation. A strategy was proposed to modify the low-order modes, and used together with the mathematical model based on the improved particle swarm optimization algorithm, so as to present an optimized design scheme for the supporting structure based on structural parameters. In a case study on the optimization of the gun mount, a solid finite element model was constructed for the gun mount. Taking the optimization of the gun mount as an example, by establishing the solid finite element model of the gun mount and combining with the finite element calculation, the mode shape and natural frequency of the gun mount in the free state are obtained. The stretch thickness, width and height of the stiffening structure on both sides of the gun mount were taken as the design variables to obtain the optimal solutions of the stiffening structure under constraints by virtue of iteration. The results revealed that:

(1) Modal modification was proposed in this paper to increase the natural frequency of a supporting structure to avoid the excitation frequency of external loads for the purpose of reducing the vibration of the structure;

(2) Taking the modal modification of a naval gun mount as an example, an improved particle swarm optimization algorithm was used to optimize the gun mount, which increased the natural frequency of the designated order by 11.3%. Therefore, optimization was remarkably effective.

(3) As revealed in a case study on computing, the proposed modal optimization method based on structural parameters in this paper could effectively optimize the supporting structure to avoid the external excitation frequency in a way that lowered vibration. The proposed method can be extended to a large number of supporting structures with different shapes and working conditions in engineering practice.

(4) In engineering practice, there are many structures whose main structure should not be changed too much due to material and manufacturing process limitations. The research results of this article showed that an appropriate stiffening structure might be added, e.g. adding a supporting structure in the supporting structure, to effectively improve the dynamic performance of the supporting structure. The method proposed in this paper solves the problem of small-scale structural optimization in engineering practice to a certain extent, and can achieve the purpose of improving the required optimized structure without disassembling the main structure by welding the external structure to save costs.

(5) This article is aimed at the optimization of supporting structure, and the application of the proposed optimization method to other structures needs further study. In addition, the type of stiffening structure used in structural optimization is also an issue that needs to be considered in the future study.

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Persian Abstract

چکیده

با توجه به مشکل ارتعاش قوی سازه نگهدارنده تحت تحریک بار خارجی، به منظور دستیابی به هدف بهینه سازی سازه از طریق اصلاح مودال برای دستیابی به هدف کاهش ارتعاش، ابتدا روشی برای اصلاح مودال از طریق تئوری ارتعاش سازه پیشنهاد شده است .ثانیاً، عملکرد جستجوی الگوریتم ازدحام ذرات بهبودیافته تحلیل می شود؛ در نهایت، با در نظر گرفتن بهینه سازی ساختاری پایه تفنگ به عنوان مورد، ساختار پایه تفنگ دریایی برای مشکل نوع خاصی از پایه تفنگ دریایی که ارتعاش می کند بهینه سازی شده است .در حین شلیک یک مدل فیزیکی اجزای محدود پایه تفنگ برای تجزیه و تحلیل شکل ارتعاش و فرکانس طبیعی پایه تفنگ در حالت آزاد ایجاد شد؛ در همان زمان، با توجه به الگوریتم ازدحام ذرات بهبود یافته، پارامترهای اندازه ساختار تقویت کننده در هر دو مورد از کناره های براکت به عنوان متغیرهای طراحی استفاده شد و فرکانس ذاتی مرتبه اول پایه تفنگ فرکانس تابع هدف برای ایجاد یک مدل ریاضی بهینه است و نرم افزار اجزای محدود Abaqus برای توسعه ثانویه استفاده می شود .پس از بهینه سازی و تکرار ، فرکانس اساسی افزایش یافته است و اثر قابل توجه است.