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Exploring the Optimization of Mechanical Structures: Theory, Trends, and Practice

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Abstract: *This article systematically studies the optimization of mechanical structures from the perspectives of theory, trends, and practice. In theory, it is clear that the core is to adjust the parameter balance performance and cost under a given constraint, and to sort out the principles, advantages, disadvantages, and scene adaptability of traditional methods (full stress method, mathematical programming method), modern intelligent algorithms (genetic algorithm, particle swarm optimization algorithm), and multidisciplinary optimization methods. On the trend, four directions are pointed out: artificial intelligence and machine learning driven optimization, multi physics coupling precise optimization, intelligent manufacturing fusion optimization, and sustainable green optimization. In practice, combining cases of aerospace (aircraft wings, satellite brackets), automotive manufacturing (vehicle lightweighting, engine cylinder blocks), and energy equipment (wind turbine blades, nuclear power plant pressure vessels), the effectiveness of optimization in weight reduction, quality improvement, cost reduction, and efficiency improvement is verified. At the same time, modeling difficulties, design manufacturing disconnect, and other issues are analyzed and corresponding strategies are proposed. Research has shown that mechanical structure optimization is a key path for upgrading mechanical engineering technology and can provide support for engineering practice.*

Keywords: *Mechanical Structure Optimization; Traditional Optimization Methods; Intelligent Optimization Algorithm; Smart Manufacturing*

1. Introduction

In the field of mechanical engineering, mechanical structure optimization always occupies a key position, playing a crucial role in improving product performance, reducing costs, effectively utilizing resources, and enhancing market competitiveness[1]. With the rapid development of technology and increasingly fierce market competition, higher requirements have been put forward for the performance, quality, and cost of mechanical products, and mechanical structure optimization has therefore become a focus of attention for both academia and industry.

Mechanical structure optimization can significantly improve product performance. By rational design and optimization of mechanical structures, key indicators such as load-bearing capacity, stiffness, accuracy, reliability, and dynamic performance of mechanical systems can be effectively improved[2]. In the aerospace field, structural optimization of aircraft can reduce weight, improve fuel efficiency, and thereby enhance flight performance and range; In the field of automobile manufacturing, optimizing the structural design of engines can improve combustion efficiency, reduce emissions, and enhance power performance.

Mechanical structure optimization helps to reduce costs. On the one hand, optimizing design can reduce the amount of materials used, thereby directly lowering material costs; On the other hand, the optimized structure can improve production efficiency, reduce energy consumption and labor hours in the manufacturing process, and lower manufacturing costs. Taking shipbuilding as an example, optimizing the design of the hull structure can not only reduce the amount of steel used, but also improve the navigation performance of the ship, reduce fuel consumption, and thus lower operating costs.

Mechanical structure optimization is also of great significance for the effective utilization of resources and environmental protection. In the context of increasingly scarce resources and strict environmental requirements, optimizing mechanical structures can achieve efficient utilization of resources, reduce waste generation, and minimize environmental impact. In the field of energy equipment, optimizing the structure of wind turbines can improve the conversion efficiency of wind energy, reduce dependence on traditional energy, and achieve sustainable development.

Mechanical structure optimization is a key factor in improving the market competitiveness of enterprises. In the fiercely competitive global market environment, enterprises can only occupy a place in the market by continuously optimizing the mechanical structure of their products, improving product performance and quality, and reducing costs.

2. Fundamental theory of mechanical structure optimization

2.1 Basic concepts of mechanical structure optimization

Mechanical structure optimization is the process of improving strength, stiffness, dynamic performance, or reducing weight, cost, vibration and noise by adjusting parameters such as shape, size, topology, or material distribution of the structure under established design space, load conditions, and constraints [3]. It requires the integration of knowledge from multiple disciplines such as mechanical engineering, materials science, mechanics, mathematics, and computer science. Essentially, it seeks the optimal balance between structural performance, cost, and reliability while meeting engineering requirements. For example, optimizing the cylinder body of an automobile engine requires consideration of shape design to ensure combustion and airflow, determining wall thickness to balance strength and material usage, and topology optimization to achieve strengthening of key areas and weight reduction of secondary areas; Bridge optimization can enhance load-bearing capacity, while optimization of high-speed rotating components can reduce vibration and extend lifespan. In terms of cost control, structural weight reduction in the aerospace industry can reduce energy consumption and overall costs, while topology optimization can simplify manufacturing processes and improve material utilization. As the core means of innovation and upgrading of mechanical products, mechanical structure optimization can not only help enterprises launch more competitive products, but also improve resource utilization efficiency, reduce material waste and energy consumption, conform to the concept of sustainable development, and promote high-quality development of the mechanical industry.

2.2 Main methods for optimizing mechanical structures

2.2.1 Traditional optimization methods

Traditional optimization methods rely on mathematical theory and mechanical principles, and are important means of optimizing mechanical structures. The full stress method is based on strength theory, calculates the stress of components through mechanical analysis, and iteratively adjusts the size to make the stress of each component approach the allowable stress. It can efficiently reduce weight in simple structural optimization such as trusses, but only considers strength and ignores stiffness and stability. When dealing with complex structures, it is inefficient and prone to local optima.

The mathematical programming method transforms optimization problems into mathematical models for solving, including linear, nonlinear, dynamic programming, etc. Linear programming is suitable for simple resource allocation and size optimization; Nonlinear programming is more widely applied due to its adaptation to the nonlinear relationship between structural performance and parameters; Dynamic programming can solve multi-stage decision-making problems. Its theory is solid and it can achieve precise solutions, but modeling complex structures is difficult, large-scale problems require a large amount of computation, and it is sensitive to initial values and prone to local optima.

2.2.2 Modern intelligent optimization algorithms

The development of computer technology and the demand for solving complex problems have driven the rise of modern intelligent optimization algorithms, providing a new path for mechanical structure optimization. Genetic algorithm is based on the principles of natural selection and genetic variation. It encodes the solution into chromosomes and iteratively searches through selection, crossover, and mutation operations. It has strong global search ability and does not require complex mathematical differentiation. It is suitable for nonlinear and multi peak problems and can optimize parameters such as structural topology and shape. However, it has the disadvantages of low computational efficiency and premature convergence.

The particle swarm optimization algorithm simulates the foraging behavior of a flock of birds, treating the solution as particles. By tracking its own and the group's historical optimal positions, it updates the speed and position according to a specific formula to achieve search. Its algorithm is concise, easy to implement, and converges quickly, widely used for optimizing mechanical structural parameters (such as gear transmission systems), but it is prone to getting stuck in local optima and has low search accuracy when dealing with complex multimodal problems.

2.2.3 Multidisciplinary optimization methods

Multidisciplinary optimization method is a comprehensive strategy that integrates the coupling effects of multiple disciplines in mechanical structures and collaboratively optimizes design parameters to achieve optimal overall performance. It can break through the overall performance shortcomings caused by traditional independent design of disciplines. Taking aircraft engine design as an example, it involves multiple disciplines such as aerodynamics, thermodynamics, structure, and materials, and the performance of each discipline affects each other. This method constructs a unified framework by integrating multidisciplinary analysis models and optimization algorithms, achieving information sharing and collaborative iteration among disciplines. For the optimization of aircraft engine turbine blades, it is necessary to first establish a multidisciplinary analysis model, determine design variables and objective functions, and then iteratively solve using adaptive optimization algorithms to ultimately verify the performance of the scheme. This method can fully consider the coupling relationship between disciplines and has broad application prospects in the design of complex mechanical systems. However, it faces challenges such as resource consumption in the construction and solution of multidisciplinary models, the need for improvement in interdisciplinary data collaboration mechanisms, and the need for professional control in the solution process.

3. Research Trends in Mechanical Structure Optimization

3.1 Optimization based on artificial intelligence and machine learning

Artificial intelligence technology is driving the transformation of mechanical structure optimization, with simulating human intelligent thinking and learning processes as its core, providing efficient solutions through data-driven and model learning. The neural network in deep learning consists of input layer, hidden layer, and output layer neurons. It is trained on a large amount of mechanical structural data (geometric parameters, material properties, load conditions, and performance indicators), adjusts the neuron connection weights, establishes a mapping relationship between input and performance (such as stress-strain), and can quickly predict new design performance, providing a basis for optimization.

The expert system is built based on domain expert knowledge, including a knowledge base (storing knowledge of mechanical structure design optimization) and an inference engine. It can reason based on input design requirements, such as determining the appropriate topology structure in topology optimization and avoiding unreasonable designs. Machine learning algorithms can improve optimization efficiency and accuracy. In parameter optimization, support vector machines (SVM) establish performance prediction models through training, quickly evaluate the impact of design parameters on performance, and reduce finite element analysis calculations; In multi-objective optimization, machine learning (such as neural networks) is combined with genetic algorithms. The neural network predicts the multi-objective values of the design scheme, and the genetic algorithm iteratively optimizes based on this to efficiently obtain the multi-objective optimal balance solution.

3.2 Structural optimization under multi physics coupling

The coupling of multiple physical fields (such as mechanical and electromagnetic fields) is widely present in modern mechanical systems, which has a profound impact on structural performance, such as the coupling of electromagnetic and thermal fields during motor operation. Its impact is reflected in multiple aspects: in terms of mechanical performance, thermal structural coupling causes thermal stress and deformation of aircraft engine turbine blades, and electromagnetic mechanical coupling causes vibration of transformer components; In terms of thermal performance, flow heat coupling affects the heat dissipation of automotive engines. Effective optimization strategies are needed to address this: establishing an accurate coupling model is the foundation, and numerical simulation methods such as finite element method (FEM) are widely used. Modeling needs to consider the physical field interaction mechanism and coupling relationship; The use of multidisciplinary optimization algorithms is also crucial, and optimization algorithms based on surrogate models have significant advantages. By simulating a response surface model with a small number of samples and combining optimization algorithms to search for the optimal solution and verify it, optimization efficiency can be improved while ensuring accuracy, making it suitable for coupling problems with high computational costs.

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3.3 Structural Optimization for Intelligent Manufacturing

The transformation of the manufacturing industry towards intelligent manufacturing promotes the deep integration of mechanical structure optimization, which brings about changes in the design and production of mechanical products and can meet the demands of intelligent manufacturing for high performance, high quality, and rapid response to the market. Intelligent manufacturing requires mechanical structures to adapt to intelligent production systems. For example, automated production lines in smart factories require high-precision and highly reliable mechanical components, and the structure needs to be able to flexibly adjust parameters to achieve personalized customization. This constitutes a new demand for structural optimization.

The integration of the two requires the support of advanced information technology, with digital design and simulation technology being key. By using CAD to establish a three-dimensional digital model and CAE simulation to analyze the multi working condition performance of the structure, taking into account the special factors of intelligent manufacturing (such as automated assembly stress and intelligent equipment thermal management), design problems can be detected in advance, reducing physical prototype testing, shortening the research and development cycle, and reducing costs.

In the operation of smart factories, the integration application has achieved significant results. In the field of automobile manufacturing, optimization algorithms and simulation technology are used to optimize the body structure, and topology optimization is used to achieve lightweighting while ensuring stiffness and strength. After optimizing the body of a certain vehicle model, key performance is guaranteed, weight is reduced, and fuel economy is improved; In terms of production equipment, industrial robot structure optimization (such as joint and arm optimization) improves stiffness and strength, reduces weight inertia, enhances motion accuracy and load capacity, reduces production errors, and improves assembly quality and efficiency through finite element analysis and size and shape optimization.

3.4 Green Structure Optimization Driven by Sustainable Development

In the context of global sustainable development, green structural optimization has become a focus in the field of mechanical engineering. Its core is to integrate sustainable concepts into structural design, coordinate performance, environmental impact, and resource efficiency from a full lifecycle perspective, achieve coordinated economic, environmental, and social development, emphasize meeting functional performance while reducing negative environmental impacts, reducing resource consumption, and improving energy efficiency. Its goals in sustainable development are clear: to reduce carbon emissions and pollution throughout the entire lifecycle of products at the environmental level, to reduce material consumption during the design phase, to improve energy efficiency during the use phase, and to promote recycling during the scrapping phase; At the resource level, it improve resource utilization efficiency and select renewable and recyclable materials. At the same time, it can promote the sustainable development of mechanical products, enhance market competitiveness, and assist the industry in green and low-carbon transformation. To achieve this optimization, efforts need to be made in multiple aspects: in terms of material selection, priority should be given to using renewable materials such as bamboo fiber composite materials and recyclable materials such as aluminum alloys; In design improvement, lightweight is achieved through topology and shape optimization to reduce energy consumption, and detachable design is optimized for easy recycling after scrapping, such as modular design of electronic devices.

4. Exploration of Mechanical Structure Optimization Practice

4.1 Case analysis in the aerospace field

In the aerospace field, the structural optimization of aircraft wings and satellite supports is crucial for equipment performance. The original design of a certain model of aircraft wing had problems such as heavy weight, low fuel efficiency, and insufficient strength and stiffness under some operating conditions. The research team used CAD/CAE technology to build accurate 3D and finite element models, and obtained stress-strain data under multiple flight states through finite element analysis; This study is based on multidisciplinary optimization theory, it aiming to improve force coefficient, reduce drag coefficient, reduce weight, enhance strength and stiffness. It determines design variables such as airfoil parameters. Genetic algorithm combined with response surface surrogate model is used for optimization and solution. After iteration, the wing weight is reduced, lift coefficient is increased, and drag coefficient is decreased,

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resulting in significant improvements in fuel efficiency, flight performance, and safety.

A certain satellite bracket needs to withstand complex loads, and topology optimization aims to reduce weight under mechanical constraints within a given design space. It uses finite element software to discretize the design space, define element properties, loads (launch acceleration, in orbit thermal load, etc.), and constraints (maximum stress, displacement, etc.), use variable density method, adjust the penalty factor to converge the element pseudo density to 0/1, optimize support to reduce weight, meet stress, deformation and other indicators, improve stiffness, enhance reliability and stability, and reduce satellite launch costs and energy consumption.

4.2 Case analysis in the field of automobile manufacturing

In the field of automobile manufacturing, environmental protection and energy conservation requirements have become important directions for promoting lightweight vehicle bodies and optimizing engine cylinder blocks. The original design weight of a certain car body is large, which affects fuel economy and overall performance. The design team first uses finite element analysis to build a three-dimensional model of the vehicle body, simulating bending, twisting, collision and other working conditions, and identifying key stress areas and weak links; Further topology optimization is carried out with stiffness and strength as constraints and weight minimization as the objective, while taking into account manufacturing and assembly requirements and removing redundant materials; High strength steel (key structural components), aluminum alloy (coverings), and carbon fiber composite materials (high-end models) are also selected to replace traditional steel, and combined with size and shape optimization (such as optimizing door reinforcement ribs). The final body weight is reduced, fuel consumption is lowered, power and handling performance are improved, and collision safety is enhanced.

The original design of a certain car engine cylinder block had problems such as large storage weight, poor heat dissipation, and insufficient strength and stiffness under high loads. It is optimized with the goal of reducing weight, improving heat dissipation, increasing strength and stiffness: in terms of structure, it uses finite element analysis to identify stress concentration areas and redundant materials, optimizes the topology of the cylinder, adjusts wall thickness and reinforcement layout; It optimizes the design of cooling water channels and uses aluminum alloy for heat dissipation; In terms of materials, high-strength aluminum alloy is used instead of cast iron, and surface treatment technology is applied to key parts. After optimization, the cylinder body is reduced in weight, the temperature under high load conditions is lowered, the stress deformation is reduced, the engine power and torque are both improved, and the overall performance is enhanced.

4.3 Case analysis in the field of energy equipment

In the field of power generation, a certain wind turbine blade was originally designed to capture wind energy with low efficiency, heavy weight, and short fatigue life under complex wind conditions. When it is optimized, it first uses computational fluid dynamics (CFD) software to simulate blade airflow under various wind conditions, analyze pressure distribution and boundary layer characteristics, optimize wing parameters to increase force coefficient, reduce drag coefficient, and improve aerodynamic performance; Structurally, finite element analysis is used to obtain stress-strain data under various loads, constrained by strength, stiffness, and fatigue life, with the goal of minimizing weight.Topology and size optimization are combined to optimize the main beam, skin, and reinforcement bars; The material selection is carbon fiber composite material (replacing glass fiber in key areas) and the layer design is improved. After optimization, the wind energy capture efficiency and power generation efficiency of the blades are improved, the weight is reduced, the moment of inertia is reduced, the starting and dynamic response capabilities are enhanced, the stress deformation is reduced, the fatigue life is extended, and the maintenance cost and downtime are reduced.

In the field of nuclear power plants, there is room for improvement in the original design of a pressure vessel in terms of structural rationality, material utilization, and extreme accident safety. During optimization, a three-dimensional model is constructed using finite element analysis to simulate stress, temperature, and radiation damage under normal and accident conditions. It is optimized at the head (spherical head to ensure uniform stress) and cylinder wall thickness (adjusted as needed); It uses low activation steel (reduced radiation after irradiation) as the material, strictly controls the manufacturing quality, and improves the heat treatment process; It adds protective structures such as insulation layers, optimizes sealing design, and upgrades monitoring systems. After optimization, the stress and temperature distribution of the container is more reasonable, the strength and sealing are enhanced, the leakage prevention ability under extreme accidents is improved, the material utilization rate is increased, the manufacturing cost is reduced, the service life is extended, and the safety and economy of the nuclear power plant are guaranteed.

5. Challenges and coping strategies in the practice of mechanical structure optimization

5.1 Difficulties in Modeling and Solving Complex Systems

5.1.1 Specific manifestations of difficulties

In the field of mechanical structure optimization, modeling and solving complex systems face multiple challenges that constrain the improvement of optimization efficiency, accuracy, and product performance. The primary challenge is the contradiction between model accuracy and computational efficiency: increasing the complexity of mechanical systems requires the construction of fine models (such as complex models with multiple physical field couplings in aircraft engine design), but model refinement leads to a surge in computational complexity, with some complex finite element models having millions of degrees of freedom, consuming a lot of resources and time. In engineering, it is difficult to balance the two. Secondly, the modeling of multi physics field coupling is complex: mechanical systems often involve multi field coupling such as mechanical and thermal fields (such as motor electromagnetic thermal structural coupling), and the coupling relationships between each field are complex. Modeling requires clear understanding of the physical field equations and coupling mechanisms, and current methods are difficult to build accurate and universal models, resulting in significant performance prediction errors. In addition, dealing with uncertain factors is difficult: material performance variability, manufacturing errors, and other factors affect structural performance. If ignored in modeling and solving, it can easily lead to optimization results deviating from reality. Existing probability analysis and other processing methods have limitations and need further improvement.

5.1.2 Exploration of coping strategies

To address the challenges of modeling and solving complex systems, comprehensive innovative strategies are needed to improve optimization efficiency and accuracy. Improving algorithms is the key path: for the problem of high computational complexity, parallel computing technology is used in finite element analysis, relying on high-performance computing clusters to allocate tasks to multiple nodes for parallel processing, which can increase computing speed by several times to tens of times; Simultaneously integrating the advantages of heuristic and intelligent algorithms to improve traditional algorithms, such as the hybrid algorithm combining genetic algorithm and simulated annealing algorithm, can balance global and local search capabilities and avoid falling into local optima. The proxy model technology has achieved significant results. Based on data fitting, response surface, kriging and other proxy models can be simulated numerically with a small number of sample points to build approximate models, replacing complex numerical analysis to quickly predict structural performance. After optimization algorithm optimization and verification correction, it can reduce computational costs while ensuring accuracy. Innovation and improvement are needed for multi physics field coupling modeling, and research on coupling mechanisms should be strengthened. A modeling method based on physical processes should be adopted to construct control equations and numerically solve them; Simultaneously utilizing multi-scale modeling techniques, such as balancing micro quantum effects with macro mechanical and electrical effects in the modeling of microelectromechanical systems (MEMS), can improve model accuracy and universality.

5.2 The disconnect between optimization results and actual manufacturing

5.2.1 Analysis of reasons for disconnection

The results of mechanical structure optimization are often disconnected from actual manufacturing, which restricts the application value of optimization technology. Manufacturing process limitations are an important factor: optimizing design pursues theoretical optimality, such as topology optimization, which may generate complex shapes, irregular holes, or thin-walled structures. However, traditional precision casting is difficult to ensure the accuracy and quality of complex castings, and mechanical processing of thin walls is prone to deformation and vibration, making it difficult to implement ideal solutions. Cost factors are becoming increasingly disconnected: optimizing or recommending high-performance materials (such as carbon fiber composite materials in the aerospace industry) and complex processes to improve performance, but such materials and processes are costly. In order to balance costs and competitiveness, companies may switch to low-cost alternative solutions (such as aluminum alloys), making it difficult to fully achieve optimization effects (such as weight reduction). Poor communication between design and manufacturing information is also a key issue: there is a lack of collaboration between the two departments in product development, designers have not fully considered manufacturing feasibility and cost, and manufacturing personnel have difficulty accurately understanding design intentions; Incomplete design documents can easily lead to manufacturing interpretation deviations, delayed or inaccurate transmission of design changes, and affect production process adjustments and product quality progress.

5.2.2 Measures to strengthen collaboration

To solve the problem of the disconnect between mechanical structure optimization and actual manufacturing, it is necessary to strengthen the coordination between design and manufacturing, and promote the implementation of optimized design through multiple measures. Forming a joint team is the core approach: the enterprise breaks down departmental barriers, forms a team consisting of design, manufacturing, and process personnel, collaborates and participates in the early stages of product development, fully absorbs the manufacturer's opinions on process feasibility and cost in the design stage, clarifies the design intention in advance, and avoids disconnection risks from the source. Digital manufacturing technology can improve collaborative efficiency: relying on CAD, CAPP, and CAM tools to achieve seamless transfer of design data, CAD optimization data is directly transmitted to the process planning generated by the CAPP, and then transmitted to the CAM to complete numerical control programming; It integrates full lifecycle data through PLM system, achieves information sharing, reduces human transmission errors, and improves collaboration accuracy. Conducting manufacturability analysis during the design phase is essential: using specialized software to evaluate the feasibility of optimized solutions and processes, and adjusting the design based on process limitations such as machining accuracy and material utilization; It simulates the casting process of castings, predicts defects, optimizes structure and process parameters, solves manufacturing problems in advance, and ensures that optimized designs are suitable for actual manufacturing.

5.3 Obstacles to Multidisciplinary Knowledge Fusion

5.3.1 Analysis of Fusion Obstacles

Multidisciplinary knowledge fusion is the key to achieving efficient design in mechanical structure optimization, but there are multiple obstacles in the fusion process that restrict the effectiveness and application scope of multidisciplinary optimization. Disciplinary differences are the primary obstacle: it involves multiple disciplines such as mechanical engineering and mechanics, with different theoretical systems, research methods, and professional terminology in each discipline. For example, mechanics focuses on the laws of deformation under stress, while materials science focuses on material properties. When interdisciplinary cooperation occurs, researchers may have difficulty accurately understanding knowledge from different disciplines, which can easily lead to communication misunderstandings and affect collaborative efficiency.

Poor communication exacerbates the difficulty of integration: Researchers from different disciplines have different communication styles, thinking patterns, and expression methods, and it is difficult to accurately convey intentions during discussions due to differences in terminology and focus (such as mechanical engineers' emphasis on mechanical performance and electronic engineers' emphasis on circuit principles); Moreover, some researchers lack interdisciplinary communication skills and are unable to convey their knowledge in a simplified manner, further hindering communication.

The unsuitability of organizational management models is also an important influencing factor: traditional organizations divide departments according to disciplines, restrict interdisciplinary communication, and lack interdisciplinary project resources; The traditional management model is difficult to coordinate multidisciplinary teams, lacks targeted assessment and incentive mechanisms, reduces researchers' participation enthusiasm, and leads to the impact of multidisciplinary project progress and optimization effects.

5.3.2 Methods to promote integration

To overcome the barriers to interdisciplinary knowledge integration in mechanical structure optimization, it is necessary to promote interdisciplinary exchange and cooperation through multidimensional measures. Interdisciplinary training is the fundamental path: Enterprises and research institutions regularly organize training, invite multidisciplinary experts to give lectures, and combine case analysis and practical activities to help researchers master the theories and skills of mechanics, materials science, and other related disciplines, enhance interdisciplinary thinking and problem-solving abilities, and lay the foundation for knowledge integration. Establishing a common language is key to communication: In a multidisciplinary team, we organize members to jointly develop a general terminology list applicable to the project, clarify terminology definitions, unify communication and document writing language, and avoid misunderstandings caused by differences in terminology; We also build a knowledge sharing platform to integrate and classify knowledge achievements from various disciplines, facilitate learning and acquisition, and promote knowledge exchange. We believe that optimizing organizational management models is an important guarantee: we build models suitable for interdisciplinary collaboration, establish interdisciplinary research centers or project teams, and provide resource support; We adopt project driven management, clarify goals, allocate resources reasonably, establish targeted assessment and incentive mechanisms, incorporate interdisciplinary cooperation contributions into assessments, reward outstanding teams and individuals, mobilize the enthusiasm of researchers, and promote effective integration of knowledge.

6. Conclusion

This article systematically studies the optimization of mechanical structures from the perspectives of theory, trends, and practice, and has achieved multiple results. In basic theory, its connotation is to adjust parameters under given conditions to achieve performance goals, in order to balance performance and cost; Sort out three types of methods: in traditional optimization, the full stress method is suitable for simple structures but neglects multi performance, while the mathematical programming method has a solid theoretical foundation but faces complex modeling and calculation challenges; In modern intelligent algorithms, genetic algorithms have strong global search but low efficiency and are prone to premature convergence, while particle swarm optimization algorithms are concise and fast convergence but difficult to break through multimodal local optima; Multidisciplinary optimization can collaborate with multiple disciplines to achieve overall optimization, but it faces challenges in modeling and data collaboration.

In terms of research trends, artificial intelligence and machine learning optimization have become important directions, with neural networks, support vector machines, and other technologies assisting in efficient optimization; Multi physics coupling optimization has attracted attention, and it is necessary to establish accurate models and improve efficiency through proxy models; The integration of intelligent manufacturing and structural optimization is inevitable, digital design simulation shortens the research and development cycle, and the application of intelligent factories has achieved significant results; Green structure optimization has emerged, reducing environmental impact and improving resource efficiency through material selection and design improvements.

In practice, wing and satellite support optimization in the aerospace field achieves weight reduction and quality improvement; Lightweight body and optimized engine cylinder block in the automotive industry to reduce costs and improve efficiency; Optimizing wind turbine blades and nuclear power plant pressure vessels in the field of energy equipment enhances performance and safety, fully verifying the value of optimization.

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