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Research on Topology Optimization Mathematical Model of Chemical Machinery Structure Based on Computer-aided Engineering Technology

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It is used to explore the topological optimization mathematical model of chemical machinery structure to build design plan. With computer-aided engineering technology, the mode shifting from grid data model to CAE model is studied to establish the reconstruction mode of optimization result model. The structural design of optimized model has significantly reduced the quality under the request of strength. Through research on topological optimization mathematic model, the weight of structure has been greatly reduced in the design plan to provide an important theoretical basis for future design.

1. Introduction

As the design process of the mechanical structure includes not only the basic concept design, but also the detailed design stage, the rapid development of computer-aided engineering technology has also greatly improved the level and efficiency of mechanical structure design. However, increasingly fierce market competition has also required higher design requirements. Therefore, how to design low-cost, high-precision products has become a design goal pursued by related companies. In fact, the design of mechanical structure is far more complicated than imagined, so computer-aided design (CAD) and computer-aided engineering (CAE) can play an important role.

Therefore, this paper aims to analyze the effect of the CAE system on structural analysis in order to find out the defects in the structure design and reduce the unreasonable part in the product structure design process, thus improving product quality. The formation and application of CAE software in China was started in the 1970s. In the past 40 years, as China has never ceased to strive to the CAE theoretical research and independent software development, some software systems with independent intellectual property have emerged. To improve the level of applicability of industrial design software and simulation analysis software, shorten the design cycle, improve product competitiveness and the company’s core competitiveness, the popularity of application of domestic CAE software in industrial enterprises has become an urgent task.

2. Literature review

The feature-based modelling technology in computer aided design has been widely studied, which greatly facilitates the manufacture of the design. We have incorporated the standard idea into topology optimization and developed a feature-based structure topology optimization method. The method applies a real valued function to implicitly represent complex material interfaces of a design structure and employs constructive solid geometry to describe the design structure based on a set of simple geometric primitives during the topological optimization process. Meanwhile, the topological derivative analysis is adopted to determine where a simple geometric primitive is inserted in the current structure, and the morphing technology is used to determine which is chosen among the given geometric primitives by combining with the sensitivity analysis. The fundamental developments that led to the creation of molecular connectivity chi indices are described along with extensions to different chi and delta chi formalisms. Continued thinking about structure in the topological sense led to the

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development of the only valence state electronegativity formalism based entirely on structure, Kier-Hall electronegativity. That creation further inspired the development of the electronegativity/topology-based atomic intrinsic state along with perturbation terms that together give electro topological state indices. Further creation led to atom and bond type E-State descriptors. All these developments are briefly illustrated with examples in QSAR, chemical similarity, and database searching (Hall, 2012).

A topological optimization algorithm based on the minimum potential energy is summarized according to the finite element analysis method. In the design process, the computer-aided design software UG is used to perform 3D modelling for design objects, and the computer-aided analysis software Hyper Mesh in Hyper Works is used to build a finite element model and view the displacement results of the topology optimization model whether the design structure meets the constraints through Opti Struct in Hyper Works for the topology optimization. In order to meet the functions of the energy absorption and anti-collision, a honeycomb-type energy absorbing structure is added on the side of topologically optimized helmet liner. In experiment, solid thinking Inspire software is used to verify the helmet liner with the honeycomb structure. The simulation shows that the maximum equivalent stresses of Von-Mises before and after topology optimization are similar. The experimental model is tested, and the load capacities of helmets before and after optimization are compared (Jiang et al., 2017).

We have been involved in research work in the field of finite element analysis integration with computer aided design for several years and have developed several concepts and tools that have aroused interest and shown efficiency. In the meantime, both the evolution of our research developments and the evolution of CAD systems and CAD kernels made us reconsider our database organization. This led to the design of an original development environment and database organization referred to as the Unified Topological Model. The main interests of this new CAD/FEA database organization is its ability to tackle multi-platform CAD/FEA integration, mixed-dimensional modelling and analysis (3D solid geometry mixed and integrated with surface geometry and curvilinear geometry) and topology optimization procedures (Jean-Christophe and Francois, 2014). The paper presents the structure of this new research development environment and the original concepts underlying it. The UTM environment is strongly designed around object-oriented computer programming concepts and it is focused towards generality, modularity and ability to evolve. The paper also briefly presents some of the most important features and algorithms that have been integrated, at this point, into the UTM environment.

This paper presents a new sophisticated platform for solving the topology optimization problems of various fields including structural, heat, other alternative physics and even coupled Multiphysics. Although several up-to-date commercial packages have been launched for solving topology optimization, all of them are limited to solving structural problems with specific constraints and objectives, such as volume, compliance, stress, eigen-frequencies and limited a few kinds of manufacturing constraints. This paper pays much attention to extend the power of the commercial software to solve the Multiphysics and multidisciplinary problems. For comparisons, the classical structural designs with different constraints are also discussed in this paper (Zhang et al., 2013).

There is significant interest today in integrating additive manufacturing and topology optimization. However, it often leads to designs that are not AM friendly. For example, topologically optimized designs may require significant amount of support structures before they can be additively manufactured, resulting in increased fabrication and clean-up costs. In this paper, we propose a methodology that will lead to designs requiring significantly reduced support structures. Towards this end, the concept of support structure topological sensitivity is introduced. This is combined with performance sensitivity to result in a framework that maximizes performance, subject to support structure constraints. The robustness and efficiency of the proposed method is demonstrated through numerical experiments, and validated through fused deposition modelling, a popular AM process (Mirzendehdel and Suresh, 2016).

Though many optimization methods are now available, their complete and efficient integration into the design process faces several problems. After introducing the basic steps involved in the whole process and identifying the challenges inherent to this integration, this paper presents our contribution in addressing these challenges (Francois and Drouet, 2014). There are numerous technologies that are using different kind of material. For each of these, there are at least two materials: the production material and the support one. Support material is, in most cases, cleaned and becomes a manufacturing residue. Improve the material volume and the global mass of the product is an essential aim surrounding the integration of simulation in additive manufacturing process. Moreover, the layer-by-layer technology of additive manufacturing allows the design of innovative objects and the use of topological optimization in this context can create a very interesting combination (Schneider, 2015). For each of these, there are at least two materials: the production material and the support one. Support material is, in most cases, cleaned and becomes a manufacturing residue. Improving the material volume and the global mass of the product is an essential aim surrounding the integration of simulation in additive manufacturing process. Moreover, the layer-by-layer technology of additive manufacturing allows the design of innovative objects, and the use of topological optimization in this context can create a very interesting combination (Gardan, 2014).

Comparing the static characteristics and dynamic characteristics of the base in the topological optimization after and before, the results of analysis shows that: the stiffness and nature frequency of the optimized base are all effectively improved, while reducing the quality with 10%, and these proves that the design with topological optimization has a good significance in theory for the productive practice.

3. Method

3.1 CAD/CAE rapid response design

Rapid design technology is an umbrella term for all design technologies based on modern design theories and methods and by applying modern science and technology such as information and management, in order to shorten product development cycle. The main theories and methods involved in the rapid response design include parametric design, modular design, network collaboration design, data management, and intelligent design. At present, concurrent design technology, rapid prototyping technology, serialized and modular technology, and virtual manufacturing technology have developed rapidly in rapid response design. The geometric model based on result of mechanical structure optimization is the basis for subsequent structural design and manufacturing. However, as current product design, analysis and optimization link are independent of each other, it is not possible to quickly apply the optimized design result to the actual project. The designer often manually performs the optimization result judgment to establish the geometric model of the optimization result, which is not only a waste of time, but also cannot guarantee the accuracy of the modeling, seriously hindering the development and pervasive application of the optimization design.
Before the analysis of the magazine drum structure by using CAE, CAD model needs to be simplified and deleted. After the model is imported into the CAE system, the missing data needs to be repaired. It may take a while to complete these pre-processing tasks. In addition, CAE analysis and feedback of optimization result also requires a lot of time and effort. Therefore, rapid design technology research on parametric design, database technology, and model transformation technology, etc. between CAD and CAE systems is required to be carried out. As parametric design and database technology are supporting technologies for rapid response of CAD/CAE, research and application technology in this aspect are relatively mature. The research on model transformation technology mainly involves data transmission between CAD and CAE through special geometric model data files. Therefore, two problems occur. One is that the model needs to be repaired due to lost product data. The other is that CAE information cannot be fed back to the CAD model, which needs human judgment and operation. Therefore, design accuracy cannot be guaranteed.
Topological optimization interpolation method and optimization algorithm
The commonly used topological optimization interpolation methods include homogenization method, edge thickness method, variable density method and evolutionary structural topological optimization method. Evolutionary structural topological optimization method (ESO) is one of the most commonly used methods for continuum structural topological optimization due to its good versatility and computational accuracy. During the topological optimization of important components of magazine drum using evolutionary structural topological optimization (ESO) method, it can be seen that the ESO method cannot be added after the restriction element of its optimization rule is rounded off. Based on it, the bidirectional evolutionary structure optimization (BESO) can be used to add the element, but whether added element is the correct one in the optimal solution cannot be guaranteed, and the final result may not the optimal solution of the structure, leading to infinite loop for algorithm as there are two operations of element deletion and addition, Therefore, this paper will explore an optimal solution of topological optimization that can be quickly and steadily converged to optimal solution.
In order not to affect the CAD geometric model, features including small hole, reinforcing rib, chamfer, etc. can be identified through search of feature tree in CAE geometric model, and then the CAD system's characteristics compression feature is used to remove these details, thus providing ideal geometric model for follow-up finite element grid partition. As shown in figure 1 and figure 2, fillet feature is recognized from the product feature tree to satisfy the compression condition, and after the feature is compressed, the idealized geometric model is obtained and meshed.
According to the role of parameters in the structure, parameters can be divided into two categories: geometric parameter and attribute parameter. The former describes the geometry of the structure, such as the length and width of the shape. There may be a certain dimensional chain relationship between such parameters, including variable parameter and deterministic parameter. The deterministic parameter is supplied by user or required by structure, which is not changed during the redesign process, and variable parameter is determined by mechanical calculation or finite element analysis to ensure the required strength and stiffness of the structure, such as the thickness of the board, etc.. When the design is modified, model is material properties of structure, processing and manufacturing characteristics, etc., which will be stored in the corresponding database in the establishment of the geometric model to provide a basis for subsequent analysis and optimization, as shown in Figure 3.

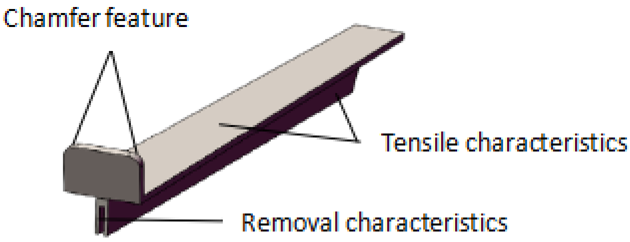

Figure 1: Feature model

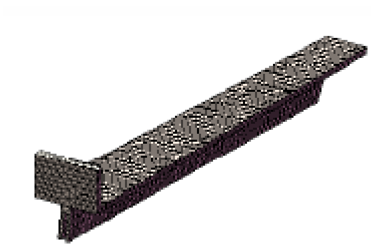

Figure 2: CAE Grid model

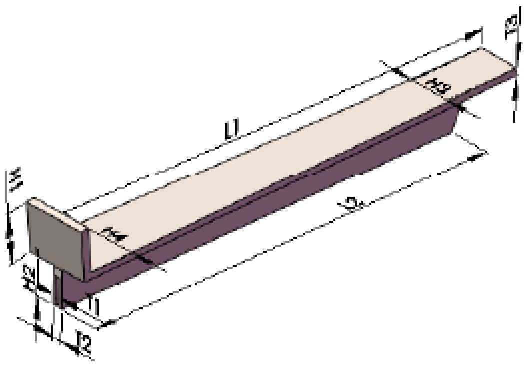

Figure 3: Schematic diagram of guide frame structure

3.2 CAD/CAE rapid response technology

The CAD model is mainly made of two parts, namely geometric feature and attribute feature. Geometric feature, also known as design feature, consists of geometrical shape, dimension parameter, positional parameter, and geometric constraint. Geometric shape means the boundary of feature and its corresponding basic element. The dimension parameter is mainly divided into initiative parameter and driven parameter. The initiative parameter is input by the designer, while the driven parameter is involved in the parameterization of other features or parametric relation. Positional parameter is a characteristic parameter that determines the specific location of feature, which can be described by a coordinate system, reference plane, reference line, reference axis, and reference point. Geometric constraint means the constraint of position, shape, and algebra of partial dimensions between features. Attribute feature, also called non-geometric information feature, mainly includes material information, inheritance rule, validation rule, and so on. Material information includes the type, strength, rigidity, ductility, material density, elasticity modulus, and Poisson’s ratio. Inheritance rule is the method of guiding the driven parameter. Validation rule refers to the condition that must be satisfied in order to ensure that feature has its specific engineering semantics. For example, slot guide model is shown in figure 4 and 5 below.

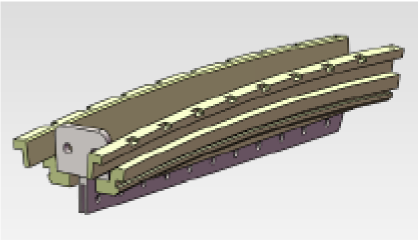

Figure 4: CAD Slot guide model

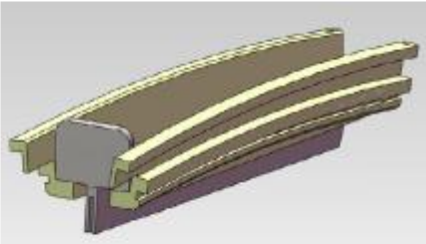

Figure 5: CAE Slot guide model

In CAE analysis, as finite element model after dimension reduction, simplification, and deletion of details is adopted, only grid data (such as model, node information and coordinates and arrangement of related nodes of each model) are needed. Compared with existing file interexchange format, this structural and normalized data is simple and pragmatic, having simple data management steps. It should be noted that since the grid element may be either tetrahedral or hexahedral, or even the higher-order element, it is necessary to pay attention to determining the element type when data is read and written, so as to ensure that the data is correct.

4. Results and discussion

According to the parametric modeling method described in this paper, parametric design of the important components of magazine drum, including definition of parametric modeling and properties, and parameter setting and storage of gear ring, center frame, guide frame, guide, partition, fixed ring, and projectile body, are carried out in following steps: firstly, parametric model of important components is established through three-dimensional software, then attributes such as material, data, constraint, etc., are added. Finally, constant main parameter and variable parameter are set, and these data information is stored into the database. In the parametric design, sketch of the part structure is drawn according to the design plan, and geometric and dimensional constraints are added; then features are generated successively based on three-dimensional modeling technology under certain principle, thus facilitating subsequent model simplification and variant design of parameters, and adding material properties based on actual requirements; Finally, parameters are classified, and important parameters such as the dimensions for height and thickness of guide and partition, and the density, Poisson's ratio, and elasticity modulus of the alloy steel are stored in the database for subsequent structural analysis and optimization invocation. When the constant acceleration is applied in the rotational motion, dynamic factor of the structural member is obviously different from that of the component under impact load.

Table 1 below shows the quasi-static analysis data before and after optimization. The dynamic factor for moving member with constant acceleration is

$$K = 1 + \frac{a}{g}$$

Table 1: Data before and after optimization

	Kilometers	Maximum stress	Displacement	Minimum safety factor
Before	190.55	5.080	0.304	10
After	165.00	7.649	0.395	10

5. Conclusion

With continuously increased complexity of mechanical structure design, structural design has become a major consideration in modern product design. As traditional design has obvious defects, the topology optimization design based on CAE and CAD technology has been used in the design of ammunition feeding system, giving important theoretical basis. In this paper, a structured parametric geometric model is constructed based on the rapid response design of mechanical structure, and commonly used structural topology optimization model is studied to design mathematical model and optimization plan, providing a manufacturing-oriented numerical solution. Therefore, the optimized model has been comprehensively studied, which has a significant effect on improving traditional technology.

The computing speed and optimization efficiency do not match in the traditional topological optimization design. Based on the in-depth study of the algorithm, different optimization methods are compared. The characteristics of the design and manufacturing are obtained to solve the difficulty issues in CAD model building, thus increasing the efficiency and quality of design modeling, and helping to promote the efficiency of topological optimization of mechanical products.

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