Lightweight Design of Automobile Structure Topology Based on Sparse Grid Technology

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Abstract: As an effective means of energy saving and environmental protection, lightweight automobile structure is a core basic technology for both traditional automobile and new energy automobile. However, in the lightweight design of automobile, due to the differences of process conditions, material heterogeneity and anisotropy, the reaction of automobile structure will fluctuate to a certain extent, and even the structural function will fail. In view of this, the traditional structural topology method for vehicle lightweight design and development has limitations. Based on the above background, this paper proposes to construct a design optimization process based on sparse grid technology with sparse network technology as the carrier. On this basis, the lightweight design of automobile structure topology can reduce the quality of automobile and realize the reliability and robustness of automobile lightweight design.

1. Introduction

With the improvement of social civilization and the increasing scarcity of renewable energy, coupled with the rising oil prices in recent years, the automotive industry is facing unprecedented pressure. How to minimize the amount of materials and control of exhaust pollution is a car[1]. An extremely important challenge facing the industry. Focusing on long-term sustainable development, saving resources and reducing environmental pollution have become two major problems for the world's automotive industry[3]. The light weight of automobiles is the most effective way to reduce fuel consumption and reduce emissions. The research data show that if the vehicle quality is reduced by 10%, the fuel efficiency can be increased by 6% to 8%, the fuel consumption will be reduced by 10%, and the emission will be reduced by 5% to 6%. In addition, as the essence of the automobile industry, the production cost of the automobile body accounts for 60% of the investment cost of the automobile company. And because of the mass production of automobiles, most of the body parts are stamping parts, the quality of which is about 30% to 40% of the total quality of the automobile, and about 70% of the fuel consumption is consumed in the body quality under under no-load conditions[4]. Therefore, how to reduce the weight of vehicles, reduce fuel consumption and emissions has become a core issue facing the development of the current automotive industry.

Topology optimization combines the weight reduction design of the automobile structure with the optimization design of the automobile structure, which can achieve a lighter structural form in the case of meeting the comprehensive performance requirements of the automobile, guiding the designer's later design, and innovative design and reduction of the structural form. Redesigning has important help. Traditional factors such as process conditions, material non-uniformity and anisotropy lead to a certain range of fluctuations in the reaction of the automobile structure, and even structural failure[7].

Based on the sparse grid technology, this paper optimizes the topology of the car. The design optimization process based on sparse grid technology is constructed, and the lightweight structure of automobile structure topology is designed based on this, which reduces the quality of the automobile and realizes the reliability and robustness of the lightweight design of the automobile. The result proves the accuracy and efficiency of the method in fitting high-dimensional problems and its applicability in high-dimensional optimization design, and achieves the purpose of lightweight design of automobile structure[2].

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2. Lightweight design of structure topology based on sparse grid technology

2.1 Sparse grid technology

In recent years, the sparse grid method based on the Smolyak algorithm has been widely used in the fields of partial differential equation solving, numerical integration and interpolation, image processing and data compression. The basic idea is to construct a multi-dimensional discrete sample space by using a tensor product operation of one-dimensional integration points to perform a special linear combination[6]. It has been proved to be a special numerical discrete technique suiTable for dealing with high-dimensional problems. It guarantees numerical accuracy while minimizing the exponential dependence of the number of sample points on the dimension, avoiding the occurrence of “dimensionality disaster”.

Assuming that the objective function is smooth enough, for the d-dimensional problem at L level, the full-factor mesh method based on direct tensor product requires the number of sample nodes is -$O(l^d)$, The error in the sense of l^2 norm is $O((l)^{-2})$; the sparse grid method only needs $O(l(\log l)^{d-1})$ and its error is $O(l^{-2}(\log l)^{d-1})$. This paper extends sparse grid technology into uncertainty analysis. One-dimensional (d=l) smooth function shell. The one-dimensional (d=l)smooth function

$f(\xi)$performs the integral operation on the continuous interval $\xi \in \Omega:=[-1,1]^d$. Construct an approximate numerical integral formula with $l \in N$ algebraic accuracy[5].

$$Q_l^1(f)=\int_\Omega f(\xi)d\xi=\sum_{i=1}^{m_i} f(\xi_l^i)w_l^i \tag{1}$$

$$\Delta_k^1(f)=(Q_k^1-Q_{k-1}^1)(f), Q_0^1(f)=0 \tag{2}$$

For the function f of the d dimensional variable space, construct a Smolyak quadrature formula with l level ($l \geq 1$) precision:

$$Q_l^d(f)=\sum_{|k|\leq l+d}(\Delta_{k_l}^1\otimes\cdot\cdot\otimes\Delta_{k_d}^1)(f) \tag{3}$$

The corresponding sparse grid integration points are defined as:

$$U_l^d=\bigcup_{1\leq|k|\leq l+d}(U_{k_1}^1\otimes\cdots\otimes U_{k_d}^1) \tag{4}$$

According to Smolyak criterion, the weight ω_i corresponding to point ξ_i can be determined by the following formula:

$$w_i=(-1)^{l+d-|k|}\begin{pmatrix} d-1 \\ l+d \quad |k| \end{pmatrix}\left(w_{k_l}^{i_l}\otimes\cdot\cdot\otimes w_{k_d}^{l_d}\right) \tag{5}$$

The number of integration nodes in a sparse grid is:

$$n_l^d=\bigcup_{1\leq|k\leq l+d|}\left(m_{k_1}^1\otimes\cdot\cdot m_{k_d}^1\right) \tag{6}$$

Taking a sparse grid (d=2 households 2) as an example, the sample space construction process is shown in Figure 1. According to each pair of indexes, one-dimensional nodes and weights are calculated separately, and linear combination is used to construct a multi-dimensional discrete sample space, and the integration points with the same position are merged. Special attention is paid to only 13 integration points for sparse grids, while full factor grids require 25 integration points.

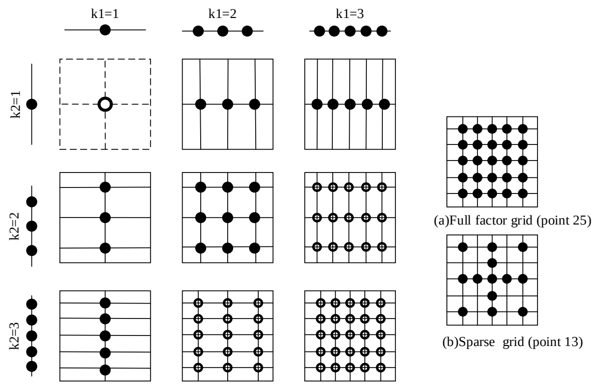

Fig.1. Sample point space of a sparse grid

2.2 Topology design flow using sparse grid technology

The approximate model based on sparse mesh is better than the other two approximation models in establishing high-precision approximate model and high-dimensional optimization problem[8]. This paper proposes a multidisciplinary design optimization process including sparse mesh approximation model[9]. The main steps include: research object finite element The establishment and verification of the model, based on the sparse grid theory, the approximation model of each discipline is established, the non-dominated sorting genetic algorithm is used to solve the optimal solution, and the four basic processes of multidisciplinary optimization scheme are determined according to the specific evaluation criteria. The detailed process is shown in Figure 2.

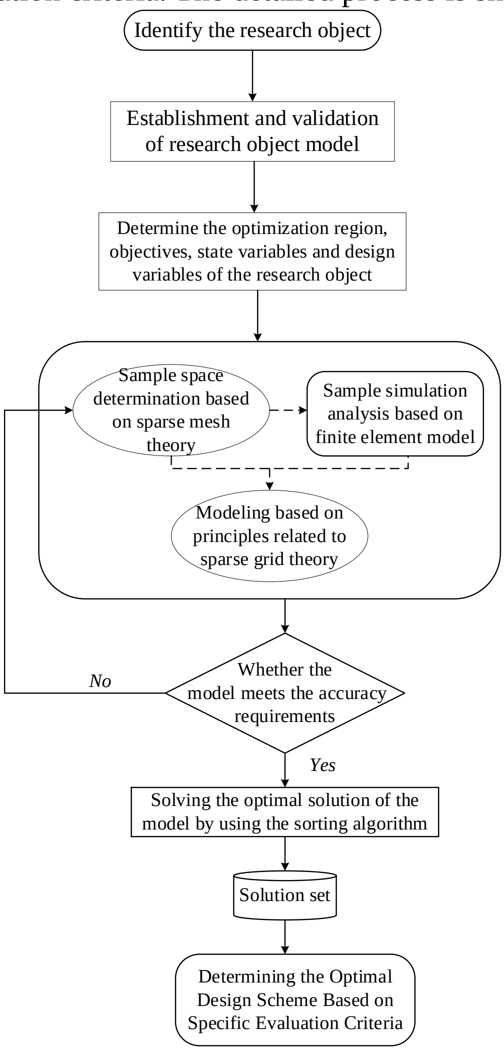

Fig.2. Structural topology design optimization process using sparse grid technology

3. Numerical example verification of structural topology based on sparse grid technology

Using test functions to verify the validity of the model based on sparse grid theory. The Haupt function is expressed as follows:

$$F_1(x) = x_1 \sin 4x_1 + 1.1x_2 \sin 2x_2 \tag{7}$$

Where $x_1, x_2 \in [0,4]$,its distribution in the design space is shown in Figure 3.

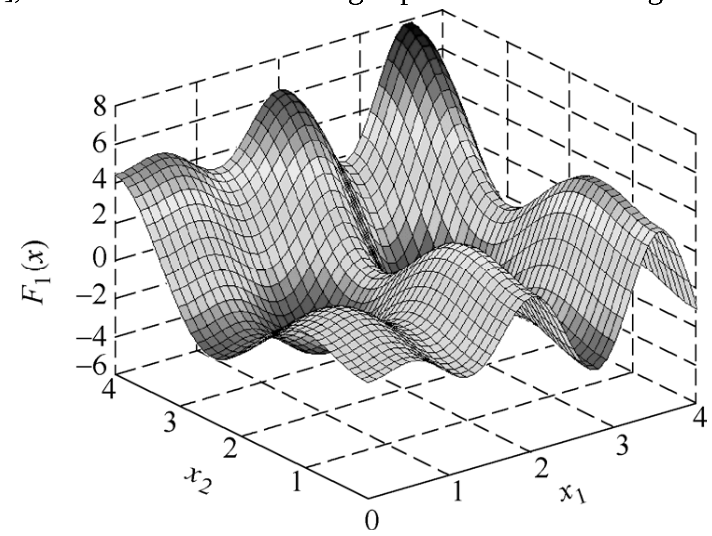

Fig.3. Schematic diagram of the Haupt function in the design space

The model of the test function is established by using the sparse grid method respectively, and the approximate effect is shown in Figure 4. By analyzing Figure 4, the sparse mesh method has good fitting precision for multi-extreme and nonlinear problems, but the Sparse Grid method establishes the approximate number of samples of the model 54, and the fitting accuracy errors of both are in Within 5%, it can be seen that the Sparse Grid method has good precision when fitting low-dimensional problems.

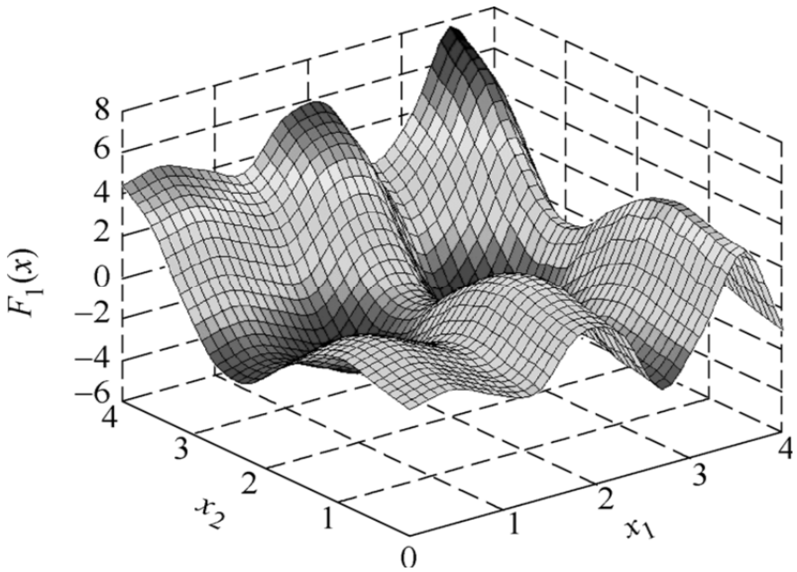

Fig.4. Fitting results of Sparse Grid model

4. Lightweight design of automobile structure topology

The lightweight design of automotive structural topology is a typical high-dimensional, nonlinear multidisciplinary optimization problem. The basic principle is to minimize the quality of the axle housing under the premise of satisfying static strength, fatigue strength and vibration constraints. According to the design optimization process, the application is sparse. Grid technology establishes an approximate model of four responsivenesses of mass, static strength, fatigue life and modality, based on which the lightweight design of the automotive structure is completed[3].

The approximate models of mass, first-order mode, static stress intensity and fatigue life generated by the sparse mesh method are shown in Figures 5-6. After testing, the accuracy of each approximation model is within 1.8%.

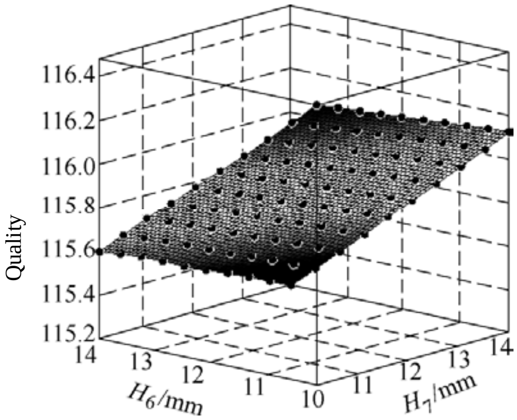

Fig.5. Mass response surface model

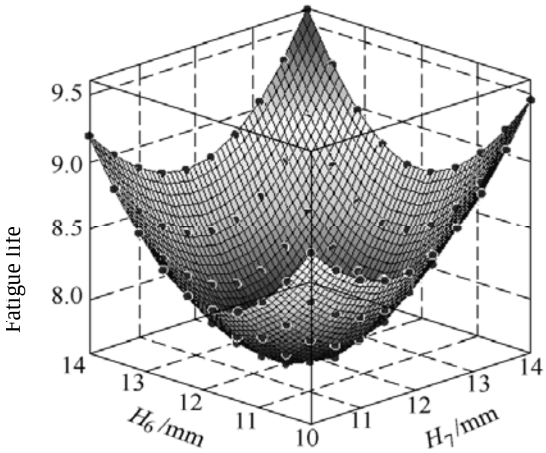

Fig.6. Mass response surface model

The corresponding modal frequencies change slightly, the fatigue life increases slightly, the maximum node stress decreases slightly, and the vehicle mass decreases to 121.35 kg, which is 3.14% lower than the original design. This optimization solution can provide some reference for lightweight vehicle structure.

5. Conclusion

This paper focuses on how to carry out the lightweight design of automotive structure topology, and uses sparse grid technology as the carrier to summarize the technical difficulties of traditional structural topology optimization design in automotive lightweight design. By introducing sparse grid theory based method, the sample points are alleviated. The index is dependent on the dimension and has the characteristics of a priori fitting accuracy. Using the sparse grid response method to solve the Haupt function prediction, when applying the approximate model of the sparse grid method to deal with high-dimensional design problems, it has advantages in fitting accuracy and modeling efficiency. The lightweight design process of automobile structure based on sparse grid is constructed, and the lightweight design is based on it. The optimized quality is lower than the original design and the first six modal frequencies do not change much. The static strength and fatigue life of the structure are small. It also meets the requirements and achieves better weight reduction. The approximate model based on sparse mesh has the advantage of dealing with high-dimensional problems, and enhances the practicability of topology in automotive lightweight design.

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References

[1] Zhao Q, Chen X, Ma Z D, et al. Reliability-based topology optimization using stochastic response surface method with sparse grid design[J]. Mathematical Problems in Engineering, 2015,(2015-9-16), 2015, 2015(3-4):1-13.

[2] Amir O. Revisiting Approximate Reanalysis In Topology Optimization: On The Advantages Of Recycled Preconditioning In A Minimum Weight Procedure[J]. Structural & Multidisciplinary Optimization, 2015, 51(1):41-57.

[3] Yang L, Wang J, Azevedo L, et al. An Efficient Topology-Based Algorithm for Transient Analysis of Power Grid[J]. Computer Science, 2015, 9225:649-660.

[4] Luo X, Ming Z, You Z, et al. Improving network topology-based protein interactome mapping via collaborative filtering[J]. Knowledge-Based Systems, 2015, 90(C):23-32.

[5] Liang C, Zhang X, Shahidehpour M, et al. Optimal Planning of Loop-Based Microgrid Topology[J]. IEEE Transactions on Smart Grid, 2016, PP(99):1-11.

[6] Kekatos V, Giannakis G B, Baldick R. Online Energy Price Matrix Factorization for Power Grid Topology Tracking[J]. IEEE Transactions on Smart Grid, 2014, 7(3):1239-1248.

[7] Babakmehr M, Simões M G, Wakin M B, et al. Compressive Sensing-Based Topology Identification for Smart Grids[J]. IEEE Transactions on Industrial Informatics, 2016, 12(2):532-543.

[8] Kai T, Wu S, Wang Y, et al. A Novel Two-Dimensional Sparse MIMO Array Topology for UWB Short-Range Imaging[J]. IEEE Antennas & Wireless Propagation Letters, 2016, 15:702-705.

[9] Liu G, Li H, Liu Y. A Topology Preserving Method of Evolving Contours Based on Sparsity Constraint for Object Segmentation[J]. IEEE Access, 2017, 5(99):19971-19982.