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AUTOMOBILE STRUCTURE CRASHWORTHINESS DESIGN AND OPTIMIZATION

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Abstract: The collision safety of automobiles is one of the issues that the automobile industry has always focused on. The crashworthiness design of automobile structures has become an important means to improve vehicle collision safety. This article reviews and summarizes the research results on the crashworthiness design and optimization of automobile structures at home and abroad. In view of the strong nonlinearity of the collision process and the mutual coupling of many design criteria, the article focuses on the approximate multi-objective crashworthiness optimization method and its application. review and analyze existing problems and directions for further in-depth research.
Keywords: Automobile structure; Crashworthiness design; Multi-objective optimization; Surrogate model

1 INTRODUCTION

Car collision safety has become one of the most difficult public health issues in today's society. Countries have successively formulated vehicle safety regulations and proposed new car evaluation procedures to constrain and evaluate the passive safety of cars. The crashworthiness design of automobile structures has been proven to be an effective means to improve the passive safety of vehicles. By carrying out structural crashworthiness design, the fatality rate in collision accidents can be reduced by at least 43%. Therefore, the exploration of crashworthiness and related product development has attracted the attention of experts and scholars.
Comparing different structural design solutions and obtaining solutions that meet structural performance requirements based on optimization theory are two methods commonly used in the field of crashworthiness design. The former evaluates the collision safety characteristics of the entire vehicle or components by simulating the collision process of the automobile structure, and compares various solutions to assist in the improved design of the automobile structure [1]. Should The method is suitable for qualitative analysis, and it is difficult to provide the best design solution. The latter has theoretical support, and mathematical methods can be used to maximize the potential for improving structural performance [2]. In structural crashworthiness optimization research, the optimization process requires repeated iterative evaluation of design indicators. Since a single collision simulation is expensive, directly calling the simulation model is inefficient and delays the development of new products. In addition, the existing crashworthiness design guidelines are not only numerous in number and equally important, but also many conflict with each other. If a single-objective optimization method is used, it can only provide an optimal solution, and designers cannot analyze it in depth based on actual needs. Therefore, it is the focus of research on structural crashworthiness design to construct a surrogate model to approximate the functional relationship between design variables and criteria, instead of time-consuming simulation models, and to use multi-objective optimization solving strategies to obtain a series of optimization solutions. This article summarizes the current research on crashworthiness design and optimization of automobile structures, and analyzes existing problems and future development directions.

2 ANALYSIS AND DESIGN OF AUTOMOBILE STRUCTURE CRASHWORTHINESS BASED ON CAE

CAE has become a mainstream method for passive safety analysis in the automotive industry. In the current research, safety response and energy absorption response are the two types of structural collision mechanical responses that designers are mainly concerned about, and their instantaneous extreme values or cumulative positive values during the collision process are important in the structural crashworthiness evaluation and design criteria. occupies a large proportion of them. Based on these criteria, designers have conducted a lot of research on the crashworthiness analysis and design of simple thin-walled structures, components and body structures [3,4].
CAE-based simulation comparison is more suitable for the initial stage of crashworthiness research. It may qualitatively evaluate existing design solutions to select the best one from several alternatives, or it may provide guidance to designers based on qualitative comparison results. Provide preliminary ideas for structural improvement. However, this type of method relies more on experience, and there is still a lot of room for improvement in the crashworthiness of automobile structures.

3 CRASHWORTHINESS DESIGN OF AUTOMOBILE STRUCTURE BASED ON OPTIMIZATION METHOD

Introducing crashworthiness design criteria into the design goals and constraints of structural optimization is called crashworthiness optimization. When defining the optimization problem, it is necessary to clarify the mapping relationship between the design variables and the design objectives and constraints. Based on the method used to establish the mapping relationship, the automobile structure crashworthiness optimization method can be divided into the following three categories.

3.1 Analytical Equation Method

This method has been widely used in early research, and it is committed to establishing a theoretical model in which design variables are independent variables and crashworthiness design criteria are dependent variables. Because there are many assumptions set when deriving the theoretical model, or the theoretical model is a semi-empirical formula for a specific structure under specific working conditions, its reliability and applicability are limited.

3.2 Directly Coupled CAE

This method directly couples CAE with the optimization algorithm, and during the optimization process, the crashworthiness response under different design variable combinations is obtained by calling the simulation model. However, this type of method has several bottlenecks: 1) It requires multiple calls to finite element analysis, resulting in a huge amount of calculation that makes the optimal design lose its practical significance; 2) Based on CAE The optimization can easily make the optimization process difficult to converge or cause the design target to fall into local peaks caused by numerical noise, and the final results are difficult to be directly used to guide structural design.

3.3 Agent Model Technology

The surrogate model technology can fit or interpolate unknown high-complexity relationships between design variables, design goals, and constraints by fitting or interpolating a small number of sample points with certain rules, and then constructing a low-complexity explicit function for approximate expression. The time required to build the model is much less than that of the original simulation model. Therefore, on the premise that the prediction accuracy of the surrogate model is guaranteed, approximate optimization based on it can greatly save computing resources. At present, surrogate model technology has been widely used in the field of engineering structure optimization. Extracting sample points based on experimental design methods and selecting appropriate data fitting methods to construct models are the basic contents of this technology, which include:

3.3.1 Experimental Design Methods

The experimental design method determines the basic characteristics of sampling, which in turn determines the accuracy of constructing the surrogate model and the feasibility and accuracy of subsequent optimization. Experimental design methods can be divided into direct methods and intelligent methods. The direct method samples at the boundary of the design domain or within the entire design domain at one time. Methods for sampling at the boundary of the design domain include: central composite design, factorial design, and D-optimal design, etc.; methods for sampling within the entire design domain include: Orthogonal design, uniform design and Latin hypercube design, etc. On the basis of one-time sampling, the intelligent method introduces optimization algorithms, interpolation methods and calculation criteria to adaptively supplement sample points in the local design domain. Typical intelligent methods include minimizing statistical lower bound methods, maximizing improved probability methods, and boundary and best neighborhood search methods [5].

3.3.2 Agent Model Construction Method

Commonly used surrogate models in the field of structural optimization include polynomial response surface models, Kriging models, radial basis function models, artificial neural network models, support vector machine models, and combined surrogate models [6]. Different proxy models have different characteristics. It is still unclear which proxy model is more suitable for crashworthiness design. It needs to be comprehensively analyzed based on factors such as specific structures, specific working conditions, and specific design criteria. The above surrogate models have been effectively used in single-objective optimization of crashworthiness [7]. Considering that there are many design criteria for passive safety, it is more common to use multi-objective optimization methods for crashworthiness design. It can provide a series of alternative design solutions, and designers can weigh each solution according to the actual situation and choose from them. Suitable for the scheme.

4 MULTI -OBJECTIVE CRASHWORTHINESS OPTIMIZATION OF AUTOMOBILE STRUCTURE BASED ON SURROGATE MODEL

4.1 Multi-Objective Optimization Method

Usually the result of a multi-objective optimization problem is not a unique solution but a set of solutions, and the surface mapped on the space is called Pareto. Frontier(POF). Two representative methods have been developed to obtain POF, one of which is the intelligent optimization method and the other is the weighted multi-objective optimization method (WS).

Intelligent optimization methods are generally global random search algorithms based on biological intelligence or physical phenomena. Since they do not require prior knowledge of preference information for each target, they can effectively handle discontinuous, non-differentiable, non-convex, highly nonlinear and other characteristics. problem, and also has strong adaptability to the uncertainty of data in calculations. However, the current computational efficiency of this type of method is low and often cannot ensure the optimality of the solution. Commonly used intelligent optimization methods in multi-objective crashworthiness optimization include multi-objective particle swarm optimization algorithm and non-dominated sorting genetic algorithm - II, etc.

WS It is an extension of the direct method based on preference information. It changes the weights between different design objectives in a parametric way, transforms the multi-objective optimization problem into a series of single-objective optimization problems, and uses the gradient information optimization algorithm to perform the single-objective optimization set. Solve to get POF. WS is computationally efficient due to its gradient information-based solver. However, the traditional WS has two main defects: first, it is easy to cause uneven distribution of points on the POF; second, it is difficult to obtain solutions located in the non-convex region of the POF. In view of this, Kim et al. proposed an adaptive weighted multi-objective optimization method (AWS) [8]. After research, AWS It has great engineering application potential.

4.2 Approximate Multi-Objective CrashWorthiness Optimization of Automobile Structure

Based on the existing crashworthiness design criteria, the multi-objective optimization method is used for automobile structural design, and the surrogate model is called during the optimization process. This is a mainstream method in the current industry. With the increase in crashworthiness optimization design goals, the complexity of the design problem has also been greatly enhanced. How to obtain an approximate POF with an accuracy that meets the requirements by improving the accuracy of the surrogate model in approximate multi-objective optimization? It is the key to crashworthiness optimization.

Currently, there are two commonly used methods to solve this type of problem, namely, one-step construction of agent model and sequential update of agent model. The former constructs a proxy model whose accuracy meets the requirements for each design criterion before optimization. Because of its direct idea and simple process, it has been embedded in commercial finite element software. However, it is difficult to control the number of sample points, and it is difficult for this type of method to balance calculation accuracy and optimization efficiency. The latter uses the approximate POF obtained after each iteration optimization The relevant information is supplemented by sample points to update the surrogate model, and continuously approaches the real POF until convergence. This method can better balance calculation accuracy and efficiency. However, the generation criteria of supplementary sample points are relatively complex and require in-depth study. Both of the above two methods have been widely used in practical engineering [9].

5 DEVELOPMENT DIRECTIONS OF AUTOMOBILE STRUCTURAL CRASHWORTHINESS DESIGN AND OPTIMIZATION

Based on CAE Simulation comparison is suitable for qualitative research on the crashworthiness of automobile structures in the early stages of design. Combining optimization methods to guide crashworthiness design is an effective means to improve passive safety in the detailed design stage. Approximate multi-objective crashworthiness optimization is a key research object in the industry, and fruitful research results have been achieved in this field. Despite this, there are still several problems and shortcomings, which can be studied in depth in the following two aspects in the future.

5.1 In Terms of Agent Model Sequence Update Strategy

In current related research, intelligent optimization algorithms combined with empirical criteria are often used to generate supplementary sample points. This type of method is difficult to control the number of new sample points, and it is easy to increase the number of iterations of the optimization solution. At the same time, the optimization efficiency of a single iteration is low, and the optimization results are highly random. Therefore, it is necessary to study targeted surrogate model sequence update strategies to further improve the performance of the approximate multi-objective crashworthiness optimization method.

5.2 In Terms of Definition of Crashworthiness Design Criteria for Complex Automobile Structures

The existing crashworthiness design criteria are difficult to describe the typical characteristics of the mechanical response of the entire structure during the entire collision time history. As the complexity of the structure increases, the approximate multi-objective crashworthiness optimization based on it cannot guarantee the optimal result. Effect.

Therefore, it is necessary to define more applicable crashworthiness design criteria based on the characteristics of each collision mechanical response, so as to effectively guide the multi-objective crashworthiness optimization of complex automobile structures.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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